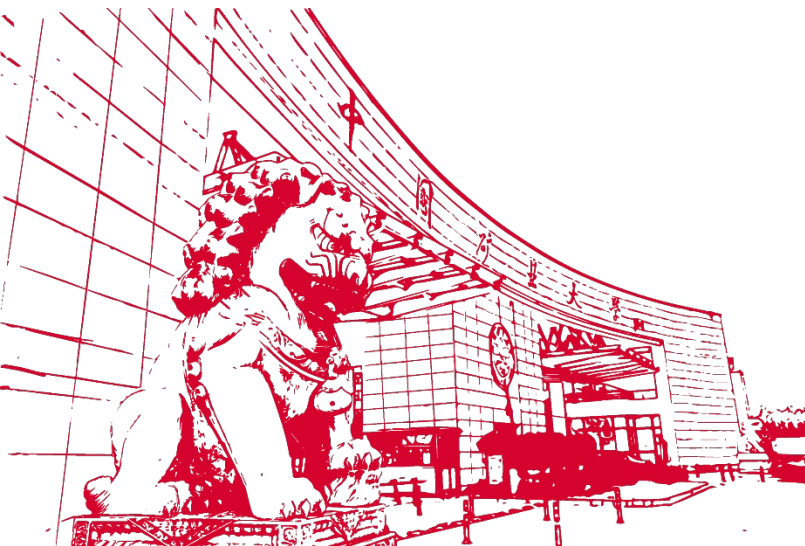


MISIS
UNIVERSITY
OF SCIENCE
AND TECHNOLOGY



Book of Abstracts

XVII International Symposium on Self-propagating High-temperature Synthesis

September 14-18, 2026, Xuzhou, China

Editors: Peizhong Feng, Baojing Zhang, Shiheng Li, Zunpeng Feng





SHS 2026
**XVII INTERNATIONAL SYMPOSIUM ON SELF-
PROPAGATING HIGH-TEMPERATURE SYNTHESIS**

September 14-18, 2026 Xuzhou · China

ORGANIZERS

China University of Mining and Technology

Henan Academy of Sciences

**Merzhanov Institute of Structural Macrokinetics and Materials Science,
Russian Academy of Sciences**

University of Science and Technology MISIS

CO-ORGANIZERS

Jiangsu Normal University

Xuzhou University of Technology

Changji University

GUIDING ORGANIZATION

**Department of Engineering and Materials Sciences, National Natural
Science Foundation of China; Russian Science Foundation**

SUPPORTING ORGANIZATION

Jiangsu Association for Science and Technology

SYMPOSIUM COMMITTEES

1. CHAIRMEN OF THE SYMPOSIUM

Mikhail Alymov (Russia)

Zhengyi Fu (China)

Peizhong Feng (China)

2. INTERNATIONAL ADVISORY BOARD

Chairs: E.A. Levashov (Russia), Peizhong Feng (China)

R.M. Agote (Spain)
S.M. Aldoshin (Russia)
A.P. Amosov (Russia)
T. Babul (Poland)
F. Baras (France)
F. Bernard (France)
V.M. Buznik (Russia)
G. Cao (Italy)
K. Chen (China)
B. Derin (Turkey)
E. Drezin (USA)
M.R. Filonov (Russia)
Z. Fu (China)
F.V. Grechnikov (Russia)
M. Gutierrez (Spain)
A.Ph. Ilyushchanka (Belarus)
V.K. Ivanov (Russia)
E.N. Kablov (Russia)
A. Kawasaki (Japan)
S.L. Kharatyan (Armenia)
J. Li (China)
J. Lis (Poland)
V.I. Lysak (Russia)
N.Z. Lyakhov (Russia)
Z.A. Mansurov (Kazakhstan)
K. Manukyan (USA)

K. Martirosyan (USA)
R. Mendez (Portugal)
Y. Miyamoto (Japan)
A.S. Mukasyan (USA)
Z. Munir (USA)
H. Nersisyan (Korea)
O. Odawara (Japan)
S.A. Oglezneva (Russia)
M. Ohyanagi (Japan)
R. Orru (Italy)
J. Puszynski (USA)
X. Ren (China)
R. Rosa (Italy)
M. Rodrigues (Spain)
A.S. Rogachev (Russia)
V.N. Sanin (Russia)
A.Yu. Tsivadze (Russia)
P. Vincenzini (Italy)
D. Vrel (France)
C.W. Won (Korea)
G.G. Xanthopoulou (Greece)
O. Yucel (Turkey)
V.I. Yukhvid (Russia)
S.A. Zelepugin (Russia)
Y. Zheng (China)

3. PROGRAM COMMITTEE

Peizhong Feng (China)
Jiangtao Li (China)
Xuanru Ren (China)
E.A. Levashov (Russia)
A.S. Rogachev (Russia)

A.S. Mukasyan (USA)
E.A. Sytshev (Russia)
P.M. Bazhin (Russia)
D. Vrel (France)
R. Orru (Italy)

4. LOCAL COMMITTEE (IN PINYIN ORDER)

Honorary Chairman: Changchun Ge

Chairmen: Peizhong Feng, Jiangtao Li, Ting'an Zhang

Members: Yuelei Bai, Kexin Chen, Chu Cheng, Xiaochuan Chong, Aimin Chu, Zhihe Dou, Donghai Ding, Ling Fu, Zhengyi Fu, Jing Guo, Shengyue Gu, Gang He, Fei Huang, Sijia Huo, Lin Han, Xiaoxuan Hou, Changlin He, Xiang Ji, Wei Ji, Yihan Jia, Baowen Jiang, Sihui Jiao, Qingyi Kong, Peiqing La, Yu Lei, Fatang Li, Liquan Li, Shiheng Li, Yanjun Li, Yuhua Li, Guanghua Liu, Dianguang Liu, Yong Liu, Qiong Lu, Chao Lv, Lihua Lyu, Feng Liang, Junyi Lv, Cheng Li, Xintao Mei, Yangfu Miao, Mingli Qin, Xuanru Ren, Xiaona Ren, Zhichao Shang, Shikao Shi, Zhongqi Shi, Weiping Shen, Xintai Su, Rongyue Sun, Shugang Sun, Yuping Tong, Jilin Wang, Xiaohong Wang, Zhilei Wei, Hongding Wang, Hao Wang, Zinian Wei, Dong Xiang, Yichen Xiang, Junpeng Xue, Li Yang, Shoulei Yang, Xuehua Yu, Yingjie Yu, Mingfang Yang, Guobin Zhan, Baojing Zhang, Deyin Zhang, Haijun Zhang, Shaofei Zhang, Xin Zheng, Yongting Zheng, Chengshang Zhou, Yu Zhou, Baixi Zhu, Chunyu Zhu, Yujuan Zhang, Yue Zhang, Xiaoqian Zhou, Yiming Zhang.

5. CONFERENCE SECRETARIES:

Anastasiia Bolotskaia (ISMAN, Russia), Zunpeng Feng, Qin Geng, Shiheng Li, Fangfang Liu, Zhichao Shang, Pengju Tang, Baojing Zhang.

Table of Contents

The 60th anniversary of the SHS	1
Study on Self-Propagating High-Temperature Synthesis Metallurgy and Its Applications	2
Overview of Recent Advances (2024-2026) in the Field of Combustion Synthesis	3
Progress in Combustion Synthesis of Silicon-based Ceramics in China: Theory, Technology and Applications	4
The SHS synthesis of zirconium silicides dedicated for reactive sintering of boride/carbide composites	5
Ceramic-metal composites by SHS: from “STIM”s to High Entropy Materials	6
Self-propagation High Temperature Synthesis of Refractory High Entropy Alloys and Carbides	7
Old Enemies, New Battles: Innovative Approaches to Combat Infection in the Era of Antimicrobial Resistance.....	8
Rapid Cooling Atomization Technology of Combustion Synthesized Melts: Synthesis and Micro-Nano Structural Evolution of Metastable Oxide Powders	9
Densification, Microstructure and Properties of Advanced Ceramics Sintered under High/Ultra-High Pressure	10
Self-propagating high-temperature synthesis of atomic-layered MAB-phases: features of combustion, structure formation and properties	11
Metallothermic Reduction Combustion Synthesis of h-BN Composite Powders and Its Application in Refractories ..	12
Fabrication of SHS-Derived TiC Powder for Al ₂ O ₃ -TiC Composite Lift Pins in Semiconductor Electrostatic Chuck Systems	13
Solution Combustion Synthesis of Advanced Powder Materials: Fundamentals and Applications	14
Ce-Doped (FeCoNiCrMn) ₃ O ₄ High-Entropy Oxide Nanoparticles Prepared by Rapid Low-Temperature Solution Combustion for High-Performance Oxygen Evolution	15
Influence of SHS conditions on the characteristics of AlN powders for microwave absorbers	16
Contribution of SHS to powder metallurgy of eutectic boride- carbide compositions	17
Combustion Synthesis of AlN with Controlled Morphologies: Powders, Whiskers, and Porous Ceramics	18
Ultrafast Laser Synthesis of Cr ₂ AlC MAX Phase for High-Performance Electromagnetic Wave Absorbers.....	19
Features of Metal Carbide Synthesis from Oxides via Calciothermic Reduction and Carburization.....	20
Rapid and energy-efficient synthesis of M- and W-Type Strontium Hexaferrite.....	21
Salt-assisted SHS synthesis technology for large-scale preparation of nano-ceramic powders	22
New Class of RHEAs/Oxide Fibers High-Temperature Composites: Synthesis and Characterization.....	23
Nickel nanopowder as a precursor for intermetallic rods produced by hot gas extrusion	24
Combustion Synthesis of Silicon-Based Ceramic Powders from Recycled Silicon Waste	25
Cold sintering assisted energy efficient sintering of ceramics.....	26
Self-propagating high-temperature synthesis of TiC/(Co+Cr+Ni) cermet	27
Comparative Evaluation of Cf/SiC and Cf/Si ₃ N ₄ Composites Processed by Spark Plasma Sintering for High-Temperature Brake Disc Applications	28
Dynamic sinter forging of yttria-stabilized zirconia ceramics with ultra-high flexural strength	29
Combustion Synthesis of Rare-Earth (RE) Sesquioxides and MgO-RE ₂ O ₃ Composite Powders for Transparent Ceramic Applications.....	30
Synthesis of low-defect-density high-κ gate dielectric materials assisted by molten metal halide salts	31
Preparation and characterization of columnar crystals reinforced Y ₂ O ₃ -MgO composite ceramics by combustion synthesis	32

Combustion Synthesis in the Thermal Explosion Mode and Gas-Solid Hydriding Synthesis of Mg-Based Hydrogen-Storage Materials	33
From Diffusion-Controlled Reactions to Thermal Explosion and SHS: Formation Mechanisms of Al-Based Intermetallics Under Combustion-Assisted Synthesis	34
Self-Propagating Combustion Growth of High-Entropy Spinel Electrodes on Ni Foam for Efficient and Durable Oxygen Evolution	35
Arc plasma-assisted combustion for the rapid synthesis of transition metal borides.....	36
Preparation of High-Activity Inorganic Functional Ceramic Powders by Reaction Coupling Self-propagating High-Temperature Synthesis Technology	37
Resistive Ti-Nb-B-C-N Thin Films for Microelectronics Obtained by Magnetron Sputtering With Heterophase SHS-Cathodes.....	38
Solution Combustion Synthesis of Medium-Entropy (FeCoNiZn)Al ₂ O ₄ Cocatalysts and Its Photocatalytic Hydrogen Production Coupled with Benzaldehyde Generation Performance.....	39
Zirconium-Modified TiAl(Nb,Mo)B Intermetallics Produced by Free SHS-Compression.....	40
Preparation of nanoparticles by carbon-containing droplet combustion-hydrocarbon synergistic reduction: Study on W-Cu composite powder	41
Investigation of Solid-State Reaction Kinetics in Thin Film Nanosystems Using Simultaneous Thermal Analysis and in situ Electron Diffraction	42
Solution Combustion Synthesis of Y ₂ Hf ₂ O ₇ /YAG Composites: Microstructural Evolution and Thermophysical Properties of Resulting Ceramics.....	43
Research on the Preparation of High-Alpha Phase Si ₃ N ₄ Powder by SHS	44
Metallothermic Reduction of Ores, Concentrates and Slags	45
Structural Regulation, Properties, and High-Entropy Engineering of Ultrafine Nanostructured Oxides via Solution Combustion Synthesis.....	46
Fuel-Dependent Solution Combustion Synthesis of Spinel and Rock-Salt High-Entropy Oxides.....	47
Rapid Oxidation of Hafnium Carbide: Microstructural and Phase Evolution of Hafnium Oxide	48
Combustion Synthesis of Composite Powders with Nanostructures and Their Effects on Thermal Shock Resistance of Refractories	49
Multi-Principal Element Carbides (Ta _{0.2} Ti _{0.2} Nb _{0.2} Zr _{0.2} Hf _{0.2})C: Advanced Ceramic Materials Fabricated via SHS and SPS	50
Thermal Explosion and Solution Combustion Synthesis of Porous Functional Materials: From Gas Filtration to Photocatalysis	51
Novel Process Design and Comprehensive System Evaluation of Chemical Looping Combustion and Post-Combustion Carbon Capture.....	52
Optimized Nickel-Based Catalysts for Production of Hydrogen and Carbon Nanomaterials via Methane Decomposition	53
Biomass Self-propagating Catalytic Humification Technology: From High-Temperature Combustion Synthesis to Kiloton-Scale Potassium Humate Commercialization.....	54
New Silicon Nitride Composite Ceramics for Gas-Insulated Ultra-High-Voltage Applications.....	55
Nd-Fe-B Magnets prepared by different approaches	56
Self-propagating high-temperature synthesis of AlON, MgAlON and MgAl ₂ O ₄ for transparent ceramics application.....	57
Use of Ball Milling for Mechanical Activation in the Preparation of Nanostructured SHS Materials.....	58
Combustion synthesis of several advanced ceramic materials.....	59

Self-propagating high-temperature synthesis of ternary intermetallic functional Heusler alloys.....	60
Microstructure and Properties of Self-Propagating High-Temperature Synthesized (Ti, W)C and Multi-component Carbides	61
Self-propagating High-Temperature Synthesis of HfB ₂ -HfSi ₂ -La ₂ O ₃ Composite Powders and Their Coating Formation and High Oxidation Resistance	62
Synthesis of Bi-based nanomaterials via ionic liquid self-combustion and their photocatalytic performance.....	63
Industrialization Status and Trend of Combustion-Synthesized Ceramic Materials in China.....	64
Research on Fabrication of STN-New Si ₃ N ₄ -based Ceramic Inserts via SHS of SiAlON Ceramic Powder from Coal Gangue Combined with Cold Pressing, Hot Pressing, Laser Cutting and Precision Grinding.....	65
Oxidation-driven glass evolution enabling self-sealing protection in HfB ₂ -based boride-silicide coatings at high temperatures.....	67
Machine learning screening the feasibility for self-propagating reactions with ab initio dataset of the MAX and MAB phases.....	68
Combustion synthesis of advanced functional materials and their performance in energy storage and conversion applications	69
Synthesis of Silicon Carbide by SHS Using Carbon Fibers as a Carbon Source.....	70
Fabrication of Unidirectional porous Si ₃ N ₄ Ceramics via the Combination of Freeze casting and Combustion Synthesis	71
Preparation and High-Temperature Corrosion Resistance of Al-Alloyed MoSi ₂ materials Fabricated by Self-Propagating High-Temperature Synthesis	72
Solution combustion synthesis of Ni-containing catalysts for methane decomposition: towards optimizing the yield of carbon nanomaterials	73
Study on the Fabrication of Transition-Metal-Based Porous Materials with Micro/Nano-Scale Pore Structures.....	74
Dual-Form Ru Species Induce Long-Range Electronic Modulation of Ni/NiO Electrocatalysts via Thermal Explosion Reaction and Dealloying.....	75
Rapid Fabrication and Performance Analysis of Si-Alloyed Porous TiAl ₃ Intermetallics	76
Phase- and Morphology-Controlled Synthesis of SiC Nanomaterials by Flash Joule Heating for Electromagnetic Wave Absorption.....	77
Recycling of SHS-Fabricated MoSi ₂ and SiC Heating Elements into Oxidation-Resistant Coatings on Molybdenum via Spark Plasma Sintering	78
Exploiting Thermal Expansion Mismatch for Gradient Self-Assembly in SHS-Derived Ultra-High Temperature Ceramic Coatings: A Strategy for Superior Oxidation Protection.....	79
A Modified Tubular Solid Oxide Electrolysis Cells Fuel Electrode Design for Efficient CO ₂ Electrolysis	80
Small-Size Atom-Driven Distortion Realizes High-Entropy Oxides with Simultaneous Chemical Stability and Activity Enhancement Enabling a Practical Cathode for Solid Oxide Fuel Cells	81
Enhancing the Stability of Direct Low-Concentration coalbed methane Tubular Solid Oxide Fuel Cells by Modifying the Catalyst Layer Using the B-site entropy engineering	82
Rapid Preparation of (MoW ₂ TaNbV)Si ₂ by Self-Propagating High-Temperature Synthesis Coupled with Spark Plasma Sintering and Its High-Temperature Oxidation Resistance.....	83
Preparation and Oxidation Resistance of (MoWNbTaCr)Si ₂ -SiC High-Entropy Silicide Coatings on Nb Substrate	84
Synergistically enhanced energy storage performance in BNT-based ceramics via phase engineering and local structure design	85
Machine-Learning-Assisted Optimization of SiAlON Ceramics Prepared from Coal Gangue via SHS: A Review and Research Framework.....	86

Effect of Heterogeneous Deformation-Induced Strengthening and Hardening on the Mechanical Properties of Laminated Aluminum Alloy	87
Combustion-Temperature-Mediated Carbon Regulation in WC Synthesis via the WO ₃ –Mg–C Self-Propagating Reaction System.....	88
Waste-derived MoSi ₂ as a self-reductant for carbon-free synergistic smelting of copper slag: Mechanistic insights into Fe–Mo alloy formation and element migration	89
Heterogeneous Polarization Configuration Regulated by Core-Multi-Shells Structure Enabled Superior Energy Storage in BNT-Based Ceramics	91
Combustion Synthesis, Microstructure and Electrocatalytic Performance of Porous Ni-Mg Intermetallic Compounds	93
Electric and Magnetic Fields Coupled Self-Propagating High-Temperature Synthesis of Highly Active and Defective CaB ₆ Micro-Nano Materials	94
Synthesis of Silicon Carbide by Magnesiothermic SHS Using Graphite Powders as a Carbon Source.....	95
Self-propagating Reduction Mechanism and Component Optimization of Copper-based Thermite Flux	96
Protective Ti-Al-C and Cr-Al-C Coatings Produced by Spark Plasma Sintering and High-Power Impulse Magnetron Sputtering Using SHS-Precursors Based on MAX-phases.....	97
Microstructure and Abrasive Wear Behaviour of (Ti,W)C–NiCu Composites Fabricated by Rapid Hot Pressing	98
Application of combined combustion synthesis with bidirectional metal disk rapid cooling for amorphous ceramic films production	99
Novel Route for the Synthesis of Nd ₂ Fe ₁₄ B Magnetic Material	100
Highly Efficient Catalysts from Material-Forming Combustion Processes.....	101
An interesting application-oriented investigation of hydrogen enriched natural gas-fueled solid oxide fuel cells supported by Ni-Cu co-doping CeO ₂ -δ catalyst-modified vertical-microchannel anode.....	102
Combustion synthesis of porous AlN frameworks and the composite phase change materials with high thermal conductivity.....	103
Solution Combustion Synthesis and Spark Plasma Sintering of (Y _x Yb _{1-x}) ₂ O ₃ Modified ZrB ₂ -SiC Ceramics for Oxidation at 1700 °C.....	104
Self-Combustion Synthesized Oxide Electrodes from Nanoporous Alloys: Applications in Energy Storage and Catalysis.....	105
Green Synthesis of Mg and Ca Co-doped ZnO Nanoparticles via Solution Combustion Method Using Lemon Extract for Photocatalytic Removal of R21 dye	106
Thermodynamic Evaluation of Self-propagating Aluminothermic Synthesis of TiFe, TiAl, CuCr, CuFe and FeNi Based Alloys	108
Research on the Preparation of High-Iron Copper Alloys via Aluminothermic Reduction and Induction Refining ...	109
Process Parameter Regulation and Product Characteristics of B ₄ C Powder via Self-propagating High-temperature Synthesis	110
Direct Preparation of Low-Inclusion W-Cu Composites by Coupling CaO Fluxing with Aluminothermic-Magnesiothermic Reduction	111
Direct Preparation of an As-Cast V–Cr–Nb–Mo Refractory Multi-Principal-Element Alloy by Self-Propagating High-Temperature Synthesis.....	112
As-Cast Fe-36Ni Invar Alloy Prepared by Self-Propagating High-Temperature Synthesis.....	113
Rapid Fabrication of High-Strength Porous Silicon Nitride Ceramics by Combustion Synthesis	114
UHTC Coatings Derived from Combustion-Synthesized Boride-Based Solid-Solution Powders	115

The 60th anniversary of the SHS

Mikhail Alymov

Merzhanov Institute of Structural Macrokinetics and Problems of Materials Science, Russian Academy of Sciences,
Chernogolovka, Moscow region, 142432 Russia

Email: alymov@ism.ac.ru

The phenomenon Self-propagating High-temperature Synthesis (SHS) that was later termed “combustion synthesis” was discovered in 1967 by A. Merzhanov, I. Borovinskaya and V. Shkiro in Russia [1, 2]. During this time, the following results were obtained:

- the theoretical and experimental research in the field of structural macrokinetics have been carried out;
- the new methods and technologies for production of new generations of structural, heat-resistant high-temperature materials based on refractory metals and their compounds, functional and high-purity materials were developed;
- the new methods for direct production of products from powders of refractory compounds, combining the processes of combustion and high-temperature shear deformation of synthesis products, bypassing the stage of synthesizing powders of the final product were developed;
- the new methods for experimental diagnostics of combustion processes: time-resolving radiography and high-temperature radiography to study the mechanisms of phase and structural transformations of materials were developed.

There were studied the effect of the oxide layer thickness on the oxygen content in AlN powders widely used in modern industry. The materials under study were aluminum nitride powders synthesized in the ISMAN pilot plant by SHS. The obtained powders were experimentally studied using X-ray diffractometry and scanning electron microscopy to determine particle size, phase composition, and morphology. The results allowed us to compare the calculated and experimental data on the oxygen content, demonstrating the effect of the oxide layer thickness and particle size on the total oxygen content in the AlN powder. The average oxygen content was calculated for aluminum powders with an average particle size of 1 – 7 μm , depending on the thickness of the oxide layer. The presented model and results can be used to optimize the processes of obtaining and processing AlN powders in order to minimize the impurity content and improve their performance characteristics.

This work was supported by the Russian Science Foundation, project no. 25-19-00530 (<https://rscf.ru/project/25-19-00530/>).

References

- [1] Merzhanov, A. G., Shkiro, V. M. and Borovinskaya, I. P. USSR Inventor's Certificate 255221, 1967; Bull. Izobr. no. 10.
- [2] Merzhanov, A. G. (1994). Solid Flames: Discoveries, Concepts, and Horizons of Cognition. Combustion Science and Technology, 98(4-6), 307-336. <https://doi.org/10.1080/00102209408935417>

Study on Self-Propagating High-Temperature Synthesis Metallurgy and Its Applications

Tingan Zhang^{1,2}

¹ School of Metallurgy, Northeastern University, Shenyang, 110819, China

² Key Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, 110819, China

Email: zta2000@163.net

Abstract: Self-propagating high-temperature synthesis (SHS) relies on the heat released by the reaction itself to achieve rapid high-temperature reactions and is one of the important technologies for materials preparation [1]. This study aims to extend SHS into the field of metallurgy and to establish a theoretical and technological system of self-propagating metallurgy centered on highly exothermic redox reactions and characterized by the synergistic coupling of external-field enhancement with metallurgical unit processes. Thermodynamic and kinetic research methods for self-propagating metallurgy were systematically established, and a series of new processes were proposed and developed, including self-propagating-hydrometallurgy, self-propagating-electromagnetic casting-induction refining, self-propagating-induction heating, and self-propagating-electrodeoxidation. These processes enabled the efficient short-process preparation of materials such as Cu-Cr, Cu-Fe, W-Cu, TiAl, Ti-Fe, and low-oxygen Ti powder, promoting the development of SHS from materials synthesis toward the integration of metallurgical materials preparation.

Keywords: Self-propagating high-temperature synthesis; Self-propagating metallurgy; External-field enhancement; Alloys and powders

References

[1] T.A. Zhang, Z.H. Dou, "Self-Propagating Metallurgy", Metallurgical Industry Press, Beijing, 2019.

Overview of Recent Advances (2024-2026) in the Field of Combustion Synthesis

Alexander S. Mukasyan

University of Notre Dame, IN, USA, 46556

Email: amoukasi@nd.edu

Combustion-based processes are a versatile class of thermally driven routes used for the rapid, scalable production of advanced materials. These techniques encompass combustion synthesis, solution combustion synthesis, flame aerosol synthesis, self-propagating high-temperature synthesis (SHS), and solid-state metallothermic and thermite reactions. Despite differences in implementation, these methods share several key characteristics: high localized temperatures, rapid reaction kinetics, and self-sustaining exothermic reactions. Together, these features enable energy-efficient material processing and facilitate the formation of metastable and non-equilibrium phases. This review summarizes recent (2024–2026) advancements in combustion-based methods for fabricating advanced materials and devices. It emphasizes reaction mechanisms, process–structure relationships, and the control of composition, defects, and microstructure. Furthermore, we discuss key material systems—including nanostructured oxides, catalysts, ultra-high-temperature ceramics, thermoelectrics, high-entropy materials, and MAX phases—along with emerging applications in thin films and device integration.

Progress in Combustion Synthesis of Silicon-based Ceramics in China: Theory, Technology and Applications

Jiangtao Li

Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China

Email: lijiaogtao@mail.ipc.ac.cn

This report reviews the research progress of combustion synthesis of silicon-based ceramics in China over the past 40 years in terms of theories, processes and applications. Its contents cover fundamental theoretical research, equipment development and scale-up, various gas-solid combustion synthesis processes for silicon-based materials, as well as the research and development of ceramic powders and porous ceramic products. Special emphasis is placed on pilot-scale research and development targeting engineering applications and the construction status of production lines for silicon-based ceramics in China.

With the aim of providing a comprehensive and clear introduction to China's related research and production activities, we hope to form a complementary cooperation with international counterparts, further promoting the development of combustion synthesis theory and application technologies, and helping this dynamic new technology to demonstrate greater advantages.

References

[1] G. Liu, K. Chen, and J. Li, "Emerging Technologies and Materials in Thermal Engineering: Combustion Synthesis, Processing and Materials", Ed: Hafiz Muhammad Ali, Elsevier, Amsterdam, 2025.

The SHS synthesis of zirconium silicides dedicated for reactive sintering of boride/carbide composites

A. Wilmański, P.O. Nwajei, D.Kozień, Z. Pędzich

AGH University of Krakow, Faculty of Materials Science and Ceramics, Department of Ceramics and Refractories, 30
Mickiewicza Av., 30-059 Krakow, Poland

Email: pedzich@agh.edu.pl

Magnesiothermic reduction was utilized for the synthesis of different stoichiometric zirconium silicides. Particular efforts were placed on obtaining materials with a high degree of purity and specific particle morphology, as the produced powders are intended for use as precursors in a reactive sintering process with boron carbide. This process yields dense composite sinters composed of titanium diboride and silicon carbide. To ensure adequate powder reactivity during sintering and the proper formation of the final composite microstructure, a key challenge lies in controlling the SHS process conditions to achieve a homogeneous distribution of intermetallic grains with minimal grain size.

Conducted syntheses included manufacturing of ZrSi_2 , ZrSi and Zr_5Si_3 powders from mixtures of zircon sand, zirconia or silica with magnesium. The main byproduct magnesia was leached by diluted HCl. The obtained zirconium silicides have a narrow and fine particle size distribution eligible for further boride/carbide composites fabrication.

Acknowledgement: Work was realized within project "Ceramic materials for specific application" financed by Ministry of Science and Higher Education subsidy for AGH; ID 18167.

Ceramic-metal composites by SHS: from “STIM”s to High Entropy Materials

Alexander Rogachev

Merzhanov Institute of Structural Macrokinetics and Problems of Materials Science, Russian Academy of Sciences,
Chernogolovka, Moscow region, 142432 Russia

Email: rogachev@ism.ac.ru

Ceramic-metal composites (cermets) are crucial to modern industry [1]. The production of these materials by the SHS method began in the 1980s, based on the principle of thermally coupled reactions [2]. They were named "synthetic hard tool materials" (Russian abbreviation STIM) and included cemented carbides, cemented borides and their combinations [3]. In the last decade, novel multi-component "high-entropy" SHS cermets have been rapidly developing. The high entropy cermets cover several types of materials, e.g., compositions of high-entropy ceramic phase with simple metal binder; simple carbides with Cantor alloys; both multi-principal component ceramic and binder phases. All these types of materials can be produced SHS. The review presents the development path of these materials - from STIMs to high-entropy cermets (Fig. 1). Thermodynamic and kinetic analyses, confirmed by experimental production of various cermets through SHS [4], show that exothermic reactions between the transition metals and carbon release amount of heat that is enough for melting up to 50 % of inert metals that forms the alloy binder. Mechanical, thermal and electrical activation can be used for further expanding the composition limits of the SHS cermets. New results of time-resolved X-ray and Synchrotron-ray diffraction study show that phase composition and crystal structure forms during a few seconds behind the combustion wave front. Consolidation of the SHS-cermets using SPS, vacuum sintering and hot pressing, allow production of bulk cermets with outstanding properties.

This work is supported by the Russian Science Foundation, project 25-13-00040.
(<https://rscf.ru/project/25-13-00040/>)

References

1. J. García, V.C. Ciprés, A. Blomqvist, B. Kaplan, Cemented carbide microstructures: a review. *International Journal of Refractory Metals & Hard Materials* 80 (2019) 40–68
2. A.G. Merzhanov, Thermally coupled processes of self-propagating high-temperature synthesis, *Dokl. Phys. Chem.*, 434(2) (2010) 159–162.
3. E.A. Levashov, A.S. Mukasyan, A.S. Rogachev, D.V. Shtansky, Self-propagating high-temperature synthesis of advanced materials and coatings. *Int. Mater. Rev.* 62(4) (2017) 203–239. DOI: 10.1080/09506608.2016.1243291
4. A.S. Rogachev, S.G. Vadchenko, et al., Combustion synthesis of TiC-based ceramic-metal composites with high entropy alloy binder, *J. Eur. Ceram. Soc.*, 40 (2020) 2527–2532. <https://doi.org/10.1016/j.jeurceramicsoc.2019.11.059>

Self-propagation High Temperature Synthesis of Refractory High Entropy Alloys and Carbides

Yong Liu, Yuankui Cao, Bin Liu, Chengshang Zhou

State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, P.R. China

Email: yonliu@csu.edu.cn

Refractory high entropy alloys and carbides have high melting points, high hardness, high-temperature resistance, and wear resistance, therefore with wide applications. The self-propagating high-temperature synthesis technology (SHS) can use the spontaneous exothermic maintenance reaction of combustion reaction continuously and has the advantages of less energy consumption, simple process, high crystallinity of products, and perfect crystallinity.

In this talk, a TiC-based ceramic composite with refractory high-entropy-alloy (HEA) binders was developed through SHS method. In the process, refractory carbide powders were reacted with Ti powder at high temperature, and in situ formation of Ti carbides and refractory HEA phases occurred. The results indicate that only body-centered-cubic HEA phases and TiC phases are formed after the reactive sintering. The microstructure of the composite is homogeneous, consisting of ultra-fine TiC particles with an average size of 0.85 μm and HEA grains with an average grain size of 1.8 μm . The TiC/HEA composite shows an ultra-high room-temperature compressive strength (> 3000 MPa). In another aspect, WC powder and coatings on diamond were successfully prepared by SHS technology, and the effects of process parameters on the phase structure, morphology, particle size and growth mechanisms of carbide powders were studied. It was found that the growth pattern of WC crystals depends on the compositions of the liquid phase at the crystallization front as well as the temperature gradient and the solidification rate in the crystallization direction.

Keywords: Refractory high entropy alloys, self-propagating high-temperature synthesis, tungsten carbide

References

- [1] B. Liu, J. Wang, J. Chen, Q. Fang, Y. Liu. Ultra-High Strength TiC/Refractory High-Entropy-Alloy Composite Prepared by Powder Metallurgy. JOM, 69(4), 1-6, (2017).
- [2] C. Zhou, Y. Gao, G. Chen, X. Tang, Y. Liu. Microstructure and properties of self-propagating high-temperature synthesized (Ti, W)C carbides, International Journal of Refractory Metals and Hard Materials, 128, 106994, (2025).

Old Enemies, New Battles: Innovative Approaches to Combat Infection in the Era of Antimicrobial Resistance

Dmitry Shtansky

National University of Science and Technology “MISIS”, Leninsky Pr. 4, Moscow 119049, Russia

Email: shtansky@shs.misis.ru

Despite significant progress in understanding bactericidal mechanisms and the development of new antimicrobial strategies, infection remain a major threat to humanity. Notably, mortality from infections caused by antibiotic-resistant bacteria currently ranks third globally, behind only stroke and coronary heart disease. Fungal infections pose a separate and increasingly serious problem, especially for hospitalized patients with immunodeficiency and those who have recovered from COVID-19. This report provides a holistic, systemic perspective on the fight against pathogenic microflora - from a historical overview and identification of current challenges for modern medical materials to an in-depth analysis of fundamental mechanisms and cutting-edge solutions. The analysis focuses on key strategies for suppressing bacterial and fungal infections, examined in detail in relation to metallic and polymeric biomaterials, inorganic nanoparticles, and heterogeneous platforms based on them for local therapy: (i) the effect of bactericidal components (antibiotics, antifungal drugs, bactericidal ions, or a combination of ions and drugs); (ii) the formation of reactive oxygen species (ROS); (iii) damage to the bacterial cell wall upon contact of bacteria with the implant surface due to mechanical damage or microgalvanic interaction; and (iv) prevention of bacterial adhesion by creating an anti-adhesive surface [1-9]. A new strategy for antibacterial protection is demonstrated, based on the generation of ROS by the implant surface in response to X-ray irradiation - including through the adipose tissue layer. Various methods for producing antibacterial surfaces and factors influencing the release of bactericidal ions (e.g., bactericidal component concentration, surface topography and roughness, the presence of various types of nanoparticles (cathodes and anodes), and surface oxidation) are discussed. It is demonstrated that, under optimal conditions, high antibacterial and antifungal effects can be achieved while maintaining biocompatibility, thereby ensuring the biological safety of medical devices. Examples of promising bactericidal materials are provided: coated implants [10], wound dressings [11], urethral catheters, bactericidal fabrics [12], and others.

This work was supported by the Russian Science Foundation (Agreement 25-19-00458).

References

- [1] A.N. Sheveyko, et al., *Surf. Coat. Technol.* 517 (2025) 132836.
- [2] A.D. Popova, et al., *ACS Appl. Bio Mater.* 7 (2024) 5579-5596.
- [2] V.A. Ponomarev, et al., *ACS Appl. Mater. Interfaces* 15 (2023) 50940–50952.
- [3] K.Y. Gudzh et al., *ACS Appl. Mater. Interfaces*, 20(13) (2021) 23452-23468.
- [4] E.S. Permyakova, et al., *Applied Surface Science*, 556 (2021) 149751.
- [5] E.S. Permyakova, et al., *Surf. Coat. Technol.* 405 (2021) 126538.
- [6] K.Y. Gudzh et al., *ACS Appl. Mater. Interfaces* 12 (2020) 42485-42498.
- [7] V.A. Ponomarev, et al., *Applied Surface Science* 516 (2020) 146068.
- [8] V.A. Ponomarev, et al., *ACS Appl. Mater. Interfaces* 11 (2019) 28699-28719.
- [9] V.A. Ponomarev, et al., *ACS Appl. Mater. Interfaces* 10 (2018) 24406-24420.
- [10] A.D. Popova, et al., *ACS Appl. Mater. Interfaces* 15 (2023) 37274–37289.
- [11] K.Y. Kotyakova, et al., *Chem. Eng. J.* 520 (2025) 166072.
- [12] E.S. Permyakova, et al., *ACS Appl. Bio Mater.* 5 (2022) 5595-5607.

Rapid Cooling Atomization Technology of Combustion Synthesized Melts: Synthesis and Micro-Nano Structural Evolution of Metastable Oxide Powders

Yongting Zheng

National Key Laboratory of Science and Technology on Advanced Composites in Special Environments, Center for Composite Materials and Structures, Harbin Institute of Technology, Harbin, 150080, PR China

Email: zhengyt@hit.edu.cn

Oxide ceramics are widely used in electronics, aerospace, and advanced manufacturing due to their high hardness, high melting point, and excellent chemical stability. This paper proposes a novel ultra-high-temperature combustion synthesis technique that utilizes reactions between metals and strong oxidizers (e.g., oxygen, nitrates) to produce high-quality oxide melts. The melts are then ejected into a cooling medium at high pressure, and rapidly solidified to obtain high-energy metastable oxide powders, including amorphous, supersaturated solid solutions, and nano-eutectics. During sintering, these metastable powders enable the controlled formation of high-density, multi-dimensional micro/nanostructures, including nanoparticles, submicron columnar and lamellar grains, thereby yielding oxide ceramics with excellent performance.

The microstructural evolution of ceramic melts under varying cooling rates was investigated by copper-plate rapid cooling combined with finite element analysis. $\text{Al}_2\text{O}_3\text{-ZrO}_2\text{-Y}_2\text{O}_3$ ternary amorphous thin films were prepared by bidirectional rapid cooling, and their crystallization behavior was studied. Submicron eutectic $\text{Al}_2\text{O}_3\text{-ZrO}_2$ ceramics, fabricated by centrifugal melt casting, exhibited a eutectic spacing of ~ 200 nm and a fracture toughness up to $10.2 \text{ MPa}\cdot\text{m}^{1/2}$. Nano-eutectic $\text{Al}_2\text{O}_3\text{-ZrO}_2$ powders with a eutectic spacing of ~ 70 nm were obtained by gas atomization, and the plasma-sprayed coatings showed a fracture toughness of $4.22 \text{ MPa}\cdot\text{m}^{1/2}$. Supersaturated $\text{Al}_2\text{O}_3\text{-ZrO}_2$ solid solution powders were produced by water atomization rapid cooling. During sintering, these powders in situ induced high-density nanoparticles, submicron columnar or lamellar grains, resulting in fracture toughness as high as 12.91, 15.59, and $10.76 \text{ MPa}\cdot\text{m}^{1/2}$, respectively. Furthermore, high-density columnar grains were also induced in the $\text{Al}_2\text{O}_3\text{-TiO}_2$ and $\text{Y}_2\text{O}_3\text{-MgO}$ systems. In summary, the ultra-high-temperature combustion synthesis technology represents a universal method for investigating novel nanostructured oxide ceramics. It provides a new technical pathway for the development and industrialization of high-performance ceramic products, such as ceramic bearings, artificial joints, and CNC ceramic cutting tools.

Densification, Microstructure and Properties of Advanced Ceramics Sintered under High/Ultra-High Pressure

Wei Ji, Zhengyi Fu

State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology,
Wuhan, China

Email: jiwei@whut.edu.cn

Advanced ceramics play a critical role in high-tech industries. Development of advanced ceramics faces two major challenges: contradiction between densification and grain growth during sintering leading to “mechanical strength ceiling”, contradiction between hardness and fracture toughness. We have proposed and developed the strategy of extreme condition sintering, which has provided valuable insights into addressing the challenges. This speech summarizes the recent advancements of the new techniques in the sintering of ceramics under extreme conditions, including ultra-fast heating, strong electric fields, high or ultra-high pressure, and multi-field coupling, and puts forward the proposal and perspective for future work.

References

- [1] H.Y. Xu, W. Ji, J.W. Jiang, H. Wang, F. Zhang, R.H. Yu, B.T. Tu, J.Y. Zhang, J. Zou, W.M. Wang, Z.Y. Fu. Nat. Commun. 2023, 14(1), 4889.
- [2] H.Y. Xu, W. Ji, W.M. Guo, Y.L. Li, J. Zou, W.M. Wang, Z.Y. Fu. Adv. Sci. 2022, 9, 2104532.
- [3] S. Fu, H.X. Liu, W. Ji. Interdiscip. Mater. 2026, 5, 243-251.

Self-propagating high-temperature synthesis of atomic-layered MAB-phases: features of combustion, structure formation and properties

Yu.S. Pogochev, A.Yu. Potanin, E.A. Bashkirov, E.I. Patsera

National University of Science and Technology “MISIS”, Leninsky Pr. 4, Moscow 119049, Russia

Email: yspogozhev@mail.ru

Recently, the research field related to the creation of a new class of materials based on atomically layered transition metal borides, known as MAB phases (where M is a transition metal, A is aluminum, B is boron), has seen rapid growth [1]. MAB phases are a relatively new family of borides, have attracted broad attention due to their unique structure, similar to that of MAX phases, and a combination of functional properties. Materials derived from them possess high electrical and thermal conductivity, a favorable combination of mechanical and tribological properties, as well as high thermal stability and oxidation resistance. They are promising for the fabrication of components subjected to severe tribocontact, high-temperature structural elements, solid-state coolers, and as precursor powders for the coatings deposition for various applications, as well as for the synthesis of two-dimensional layered borides (MBenes), which are of interest for the fabrication of composite photocatalysts. The most well-studied MAB phases are MoAlB and Fe₂AlB₂. The key advantage of MoAlB is oxidation resistance at elevated temperatures; in contrast, the Fe₂AlB₂ possesses a considerable magnetocaloric effect near ambient temperature.

New opportunities for the synthesis of MAB phases are offered by self-propagating high-temperature synthesis (SHS), an energy-efficient technology that enables the production of various heterophase materials based on refractory compounds, multicomponent solid solutions, intermetallics, and more, within a single technological cycle.

Materials based on multicomponent atomically layered MAB phases are of great scientific and practical interest, as they offer an enhanced combination of service properties owing to the solid-solution strengthening effect. The combustion kinetics and mechanisms of Mo-(W)-Al-B and Fe-(Mn)-Al-B reaction mixtures, as well as the stage-by-stage chemical transformations and structure formations in the combustion wave have been studied. Ceramics based on the ternary compounds MoAlB, Fe₂AlB₂, and the four-component solid solutions (Mo,W)AlB and (Fe,Mn)₂AlB₂ have been obtained. The established relationships between synthesis conditions, phase composition, and properties open the way to the controlled production of materials based on complexly alloyed MAB phases with tailored performance characteristics. The obtained results broaden the understanding of the SHS method capabilities for the synthesis of complexly alloyed atomically layered borides.

The work was carried out with the financial support of the Russian Science Foundation (project No. 26-13-00465).

References

[1] S. Kota, M. Sokol, M.W. Barsoum. Int. Mater. Rev. 65, 226 (2020)

Metallothermic Reduction Combustion Synthesis of h-BN Composite Powders and Its Application in Refractories

Xin Zheng, YanJun Li*, Donghai Ding, Guoqing Xiao*

College of Materials Science and Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China

Email: liyanjun@xauat.edu.cn

Carbon containing refractories, because of the carbon or the graphite, have excellent thermal shock resistance and slag corrosion resistance. High content of carbon would result in easy oxidation, high energy consumption and easy pollution of molten steel. However, the thermal shock and corrosion resistance of the refractories would be deteriorated if the carbon content is lowered directly. h-BN possesses similar crystalline structure to graphite and much better oxidation and corrosion resistance than the graphite. The properties and performances of the carbon containing refractories could be improved by replacing the graphite with the h-BN or introducing of h-BN, however, suffering high cost of the h-BN and difficulty in dispersion for industries application. Preparing composite powder for refractories is attractive for lowering the cost and promoting dispersion. In this work, h-BN composite powder was combustion synthesized and introduced into the alumina-carbon refractories. h-BN composite powder was synthesized by magnesiothermic combustion and thermite combustion reduction synthesis, respectively. The main components of the composite powder prepared by magnesiothermic combustion are h-BN, MgO and magnesium borate. Formation of the h-BN can be promoted with addition of the NH_4Cl . For thermit combustion synthesis, h-BN can hardly be formed without the addition of the diluent. With MgO was used as the diluent, h-BN can be formed and the main components of the composite powder prepared by thermit combustion are h-BN, spinel phase, aluminum nitride and 27R ($\text{Al}_2\text{O}_3 \cdot 7\text{AlN}$). The magnesiothermic combustion synthesized h-BN composite powder was introduced into low carbon alumina-carbon refractory, and the room/high temperature bending strength and residual strength retention rate after thermal shock of the refractory are improved, as well as the slag corrosion resistance was significantly improved. Preparing h-BN composite powder by combustion synthesis and introducing the composite powder into carbon-containing refractories is of great significance for lowering the carbon content of carbon-containing refractories.

Keywords: h-BN composite powder; combustion synthesis; alumina-carbon refractories; thermal-shock resistance; slag corrosion resistance

Corresponding author:

YanJun Li, E-mail: liyanjun@xauat.edu.cn, Tel: +86-29-82202600, Mobile phone: +86-15389407936, College of Materials Science and Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China

Fabrication of SHS-Derived TiC Powder for Al₂O₃–TiC Composite Lift Pins in Semiconductor Electrostatic Chuck Systems

C.G. Kim^{1,2}, Y.G. Lee^{1,3}, J.J. Sim^{*1}

¹Korea Institute of Industrial Technology (Korea National Institute of Rare Metals, Incheon, Republic of Korea)

²Inha University (Department of Materials Science and Engineering, Incheon, Republic of Korea)

³Korea University (Department of Materials Science and Engineering, Seoul, Republic of Korea)

Email: simjae@kitech.re.kr

Titanium carbide (TiC) is a promising conductive ceramic phase for Al₂O₃–TiC composite lift pins used in semiconductor electrostatic chuck systems, where high hardness, plasma resistance, and controlled electrical dissipation are simultaneously required. Conventional Al₂O₃ or SiC lift pins have limitations related to residual charge accumulation, wafer handling instability, and surface degradation under plasma exposure. Although TiC can provide an effective conductive pathway in ceramic composites, conventional TiC synthesis routes such as solid-state reaction, carbothermal reduction, mechanical alloying, and chemical vapor deposition often require high processing temperatures, long reaction times, or complex equipment.

In this study, TiC powder was synthesized by a self-propagating high-temperature synthesis (SHS) process using TiO₂ as the titanium source, Mg as the reducing agent, and carbon as the carbide-forming reactant. The Mg/TiO₂ ratio was controlled to promote TiO₂ reduction and subsequent TiC formation, and the reaction behavior was examined based on thermodynamic calculation and experimental verification. After combustion synthesis, acid leaching was applied to remove Mg-containing by-products and improve powder purity. The synthesized TiC powder was characterized by X-ray diffraction, scanning electron microscopy, particle size analysis, and ICP-OES.

The optimized 4Mg condition produced TiC powder with a purity of 99.48% and a particle size of 1.23 μm. ICP-OES analysis showed a total impurity level of 5,210 ppm, including Al 0.054%, Mg 0.277%, Ti 34.705%, and Zr 0.190%. The SHS-derived TiC powder was further applied to Al₂O₃–TiC composite fabrication by spark plasma sintering. Among the tested compositions, the Al₂O₃ = 50:50 wt% composite exhibited high mechanical and electrical performance, with hardness values up to 21.4 GPa and electrical conductivity of 7.69×10^4 S/m. These results indicate that Mg-assisted SHS is an effective route for producing high-purity TiC powder and that the resulting Al₂O₃–TiC composites have potential for semiconductor electrostatic chuck lift pin applications.

References

- [1] K. Ahmad, W. Pan, S.L. Shi, “Effect of Fabrication Method on Microstructure and Properties of Al₂O₃–TiC Composites”, *Mater. Trans.* 46, 2015 (2005).
- [2] S.N. Grigoriev, M.A. Volosova, P.Y. Peretyagin, et al., “The Effect of TiC Additive on Mechanical and Electrical Properties of Al₂O₃ Ceramic”, *Appl. Sci.* 8, 2385 (2018).

Solution Combustion Synthesis of Advanced Powder Materials: Fundamentals and Applications

Mingli Qin, Haoyang Wu, Baorui Jia, Deyin Zhang, Zhirui Zhang

Institute for Advanced Materials and Technology, University of Science and Technology Beijing, Beijing 100083, China

Email: qinml@mater.ustb.edu.cn

Solution combustion synthesis (SCS) is a versatile, energy-efficient, and scalable technique for producing advanced powder materials through highly exothermic redox reactions between metal precursors and organic fuels. Compared with conventional powder synthesis methods, SCS offers unique advantages including rapid reaction kinetics, low processing temperatures, excellent compositional homogeneity, and flexible control over particle size, morphology, crystallinity, and porosity. These characteristics make SCS an attractive approach for synthesizing a wide range of oxide, non-oxide, metallic, and carbon-based powders.

Over the past decade, our group has been dedicated to advancing the fundamental understanding of solution combustion synthesis and its application to the development of advanced powder materials. Our research has focused on elucidating the combustion mechanism and establishing effective strategies for controlling combustion behavior through precursor chemistry, fuel selection, fuel-to-oxidizer ratio, reaction atmosphere, and post-treatment processes. These studies have revealed the intrinsic relationships between combustion reactions, phase evolution, microstructure development, and powder properties, providing a scientific basis for the rational design of high-performance combustion-derived powders.

This presentation will summarize our recent progress in the synthesis of several representative material systems. Particular attention will be given to the combustion-assisted preparation of aluminum nitride powders, refractory metal and refractory compound powders, porous carbon adsorbents, and high-entropy oxide powders. The effects of combustion parameters on phase formation, particle morphology, pore evolution, and chemical homogeneity will be discussed, together with strategies for integrating solution combustion with carbothermal reduction, hydrogen reduction, and nitridation to fabricate high-quality non-oxide powders and refractory materials.

The advanced powders developed by solution combustion synthesis have been successfully applied to a variety of engineering fields, including high-thermal-conductivity aluminum nitride ceramics for electronic packaging and thermal management, refractory metals and alloys for aerospace and high-temperature applications, porous carbon adsorbents for environmental purification and low-volatility organic gas capture, and high-entropy oxide materials for catalysis. These representative applications demonstrate the versatility of solution combustion synthesis as an enabling technology for the design and manufacture of next-generation advanced powder materials.

Ce-Doped (FeCoNiCrMn)3O4 High-Entropy Oxide Nanoparticles Prepared by Rapid Low-Temperature Solution Combustion for High-Performance Oxygen Evolution

Yingjie Yu, Haijun Zhang*, and Wen Lei*

State Key Laboratory of Advanced Refractories, Wuhan University of Science and Technology, Wuhan 430081, China.

Email: leiwen@wust.edu.cn

High-entropy oxides provide tunable electronic structures and multimetallic synergy, but rapidly producing nanoscale, phase-uniform oxides remains challenging because segregation and particle growth can outpace entropy stabilization. Here, we report a rapid low-temperature solution-combustion strategy for growing spinel (FeCoNiCrMn)3O4 high-entropy oxide nanoparticles directly on different supports. Homogeneous mixing of the metal precursors at the ionic level triggers a brief combustion pulse below 230 °C that lasts about 2 s. This short event yields uniformly distributed nanoparticles smaller than 5 nm on carbon cloth and other substrates. The resulting Ce-doped spinel (FeCoNiCrMn)3O4 high-entropy oxide nanoparticles electrode reaches 100, 300, and 500 mA cm⁻² at overpotentials of 265, 277, and 286 mV, respectively. It remains stable for 7 days at both 300 and 500 mA cm⁻². Mechanistic analysis indicates that Ce tunes the Ni d-band centre and strengthens Ni-3d/O-2p hybridisation, which optimises oxygen-intermediate adsorption and lowers the barriers for *OH → *O and *O → *OOH. This combustion route offers a rapid, support-compatible strategy for preparing high-entropy oxide nanoelectrocatalysts for stable high-current OER.

Influence of SHS conditions on the characteristics of AlN powders for microwave absorbers

N.P. Cherezov, V.V. Zakorzhevsky, I.A. Shibakov, M.I. Alymov

Merzhanov Institute of Structural Macrokinetics and Problems of Materials Science, Russian Academy of Sciences,
Chernogolovka, Moscow region, 142432 Russia

Email: ncherezov@ism.ac.ru

Materials that absorb ultrahigh frequency (microwave) radiation based on the AlN–SiC system have higher characteristics than metal powder-based absorbers. However, their creation requires solving a number of tasks: obtaining AlN powders with a low content of oxygen impurities, selecting sintering additives, and establishing patterns of consolidation of materials. In addition, the defect in the AlN microstructure reduces the thermal conductivity of the material.

In this work, the synthesis of AlN powders was carried out in an industrial reactor SHS-30 (volume 30 liters) in the combustion mode. Charges of the following compositions were used: Al + AlN; Al + AlN + NH₄Cl; Al + AlN + NH₄F. The initial nitrogen pressure was 4–6 MPa. The aluminum content ranged from 18 to 40 wt.%, the content of gasifying additives from 1 to 10 wt.%. The mass of the charge in all experiments was 2 kg, mixing was carried out in a ball mill for 30 minutes.

During the experiments, it was found that with an increase in the proportion of Al in the charge from 18 to 40 wt.% combustion temperature increases from 1480 to 2290 °C. AlN particles obtained at minimum temperature have an average size of less than 2 microns. When the synthesis temperature increases to 2290 °C, the size of the crystallites increases to 10–15 microns. Next, the effect of gasifying additives was studied. It was found that with the introduction of NH₄Cl up to 5 wt.% AlN particles have an equiaxed shape. With an NH₄Cl content of 10 wt. When the temperature drops to 1500 °C, AlN particles form as filamentous crystals 10–20 microns long. Such a change in the morphology of AlN particles is associated with a change in the mechanism of nitriding. In the first case, nitriding occurs by the vapor–crystal mechanism. In the second case, a gas-phase mechanism is implemented, in which the decomposition products of ammonium chloride are involved. When NH₄F is introduced into the charge, mainly equiaxed particles are formed. An increase in the proportion of NH₄F from 1 to 4 wt.% (at 40 wt.% Al) reduces the size of crystallites from 5 to 0.5–1 microns. It was found that during the synthesis of AlN without gasifying additives, the oxygen impurity content in the product decreases with increasing synthesis temperature from 0.8 to 0.6 wt.%. When using NH₄Cl, the oxygen content was 0.8–1.0 wt.%. NH₄F additives reduced the oxygen impurity content in AlN to 0.5–0.6 wt.%.

This work was supported by the Russian Science Foundation, project no. 25-19-00530 (<https://rscf.ru/project/25-19-00530/>).

Contribution of SHS to powder metallurgy of eutectic boride- carbide compositions

E. A. Levashov, A.Yu. Potanin, V.V. Korolev, A.A. Zaitsev, Yu.S. Pogozhev, A.N. Astapov

National University of Science and Technology “MISIS”, Leninsky Pr. 4, Moscow 119049, Russia

Email: levashov@shs.misis.ru

The contribution of self-propagating high-temperature synthesis (SHS) to powder metallurgy of eutectic compositions based on boride, carbide and their solid solutions is quite significant. The stage-by-stage chemical transformations and structure formations in the combustion wave were investigated. The influence of the stoichiometry and morphology of heterophase SHS-powders on the mechanical and thermophysical properties of hot pressed ceramics are shown for near eutectic compositions in binary $\text{TiB}_2\text{-TiC}$, $\text{ZrB}_2\text{-ZrC}$, $\text{HfB}_2\text{-HfC}$, and multicomponent $(\text{Ti}_{1-x}\text{Zr}_x)\text{B}_2\text{-(Ti}_{1-x}\text{Zr}_x)\text{C}$, $(\text{Ti}_{1-x}\text{Nb}_x)\text{B}_2\text{-(Ti}_{1-x}\text{Nb}_x)\text{C}$, $(\text{Hf}_{1-x}\text{Zr}_x)\text{B}_2\text{-(Hf}_{1-x}\text{Zr}_x)\text{C}$, $(\text{Hf}_{1-x}\text{Ta}_x)\text{B}_2\text{-(Hf}_{1-x}\text{Ta}_x)\text{C}$ systems. SHS-powders exhibit excellent sinterability at hot pressing (HP) and SPS. In the absence of mutual solubility between carbides and borides, a coherent interphase boundary arises due to the superposition of the (111) MeC and (001) MeB₂ planes, while microplasticity is caused by the movement of dislocations from the bulk of the grains to the (110) interphase, and upon heating, facilitates the relaxation of thermal stresses. Compositions based on solid solutions of carbides and borides have advantages in properties compared to binary eutectics. In the studied eutectic compositions, a correlation is observed between the grain sizes of borides and carbides.

It has been established that during the hot pressing, diffusion redistribution of Me₄₊ and Me₅₊ cations occurs between the carbide and boride phases, which is accompanied by the formation of core-shell structures, which are observed in both phases, create additional barriers to dislocation motion and results in high values of hardness, fracture toughness, and flexural strength. By using B₄C as a reagent instead of boron and carbon black, it is possible to obtain an ultrafine grain structure of synthesis products and HP-ceramics.

The effects of Me (Ta₅₊, Zr₄₊) cations on the mechanism of oxidation and deformation of $[(\text{Hf}_x\text{Me}_{1-x})\text{B}_2\text{-(Hf}_x\text{Me}_{1-x})\text{C}]\text{-SiC}$ ceramics are discussed. Ta₅₊ in the boride and carbide phases has been shown to reduce stacking fault energy, facilitating dynamic recovery and polygonization at 1600 °C compression. For example, ceramics $[(\text{Hf}_x\text{Ta}_{1-x})\text{B}_2\text{-(Hf}_x\text{Ta}_{1-x})\text{C}]\text{-SiC}$ is capable of accumulating large plastic strains without fracture, whereas in $[\text{HfB}_2\text{-HfC}]\text{-SiC}$, defects cause rapid hardening and transition to brittle fracture at low strains. The oxidation resistance in air at 1650 °C was compared various ceramics: $\text{HfB}_2\text{-SiC}$, $(\text{HfB}_2\text{-HfC})\text{-SiC}$, $[(\text{Hf}_{0.8}\text{Ta}_{0.2})\text{B}_2\text{-(Hf}_{0.8}\text{Ta}_{0.2})\text{C}]\text{-SiC}$, $(\text{Hf}_{0.8}\text{Zr}_{0.1}\text{Ta}_{0.1})\text{B}_2\text{-SiC}$, $(\text{Hf}_{0.8}\text{Ta}_{0.2})\text{B}_2\text{-SiC}$, $[(\text{Hf}_{0.8}\text{Zr}_{0.2})\text{B}_2\text{-(Hf}_{0.8}\text{Zr}_{0.2})\text{C}]\text{-SiC}$, $(\text{Hf}_{0.8}\text{Ta}_{0.1}\text{Nb}_{0.1})\text{B}_2\text{-SiC}$, $(\text{Hf}_{0.6}\text{Zr}_{0.1}\text{Ta}_{0.1}\text{Nb}_{0.1}\text{V}_{0.1})\text{B}_2\text{-SiC}$. The oxidation mechanisms included the formation of a 3- or 4-layers structure of a protective oxide film.

The work was carried out with the financial support of the Russian Science Foundation (project No. 24-13-00085).

Combustion Synthesis of AlN with Controlled Morphologies: Powders, Whiskers, and Porous Ceramics

Zhongqi Shi, Zhilei Wei, Lei Zhao, Jiabin Hu

State Key Laboratory of Porous Metal Materials, Xi'an Jiaotong University, Xi'an 710049, China

Email: zhongqishi@xjtu.edu.cn

Combustion synthesis (CS) is an economical route for producing aluminum nitride (AlN) [1-2], yet the precise control of product morphology remains a prerequisite for its functional applications. In this work, we systematically investigate the CS of AlN with three distinct morphological categories, such as powders, whiskers, and porous ceramics, by tailoring processing parameters including dilution ratio, nitrogen pressure, cooling rate, and additive species (NH₄Cl and metallic catalysts) [3]. For powders, near-spherical equiaxed particles and hollow spheres are obtained via an in-situ nitriding route (shown in Figure). For one-dimensional products, quasi-aligned and ultra-long AlN nanowhiskers are synthesized, and their formation is interpreted by vapor–solid and vapor–liquid–solid growth mechanisms. For bulk porous architectures, honeycomb-like unidirectional porous scaffolds are fabricated by integrating CS with freeze-casting techniques, with their structural evolution analyzed. The resulting AlN nanowhiskers demonstrate enhanced thermal conductivity when used as fillers in polymer composites, while the honeycomb and unidirectional porous structures effectively improve heat dissipation in phase-change materials and epoxy composites. This study establishes a processing–morphology–property linkage for CS-derived AlN ceramics, providing practical guidelines for morphology-selective synthesis.

FIGURE Combustion synthesized AlN powders with different morphologies

References

- [1] A.G. Merzhanov, I.P. Borovinskaya, A new class of combustion processes, *Combust. Sci. Technol.* 195-201, 10 (1975).
- [2] A.G. Merzhanov, History and recent developments in SHS, *Ceram. Int.* 371-379, 21 (1995).
- [3] A.A. Gromov, L.N. Chukhlomina, "Nitride Ceramics: Combustion Synthesis, Properties, and Applications", Eds., Wiley-VCH: Weinheim, Germany, 2015.

Ultrafast Laser Synthesis of Cr₂AlC MAX Phase for High-Performance Electromagnetic Wave Absorbers

Junyi Lv, Tao Li, Haijun Zhang*

State Key Laboratory of Advanced Refractories, Wuhan University of Science and Technology, Wuhan 430081, China

Email: zhanghaijun@wust.edu.cn

As a representative MAX phase, Cr₂AlC combines metallic and ceramic characteristics, including good electrical conductivity and thermal stability. Conventional methods for synthesizing Cr₂AlC MAX phase powders often suffer from long processing times, limited purity, and poor scalability, which hinder their application in electromagnetic wave (EMW) absorption at high temperatures. In this work, high-purity Cr₂AlC MAX phase powders (96.3 wt%) were successfully synthesized via laser-induced self-propagating synthesis (LSS) using Cr₇C₃, Cr₃C₂ and Al powders as raw materials. Compared to conventional heating, this method greatly shortened the synthesis period by 10–240 times. The obtained Cr₂AlC powders showed excellent high-temperature EMW absorption performance. Even after oxidation at 973 K for 3 h, the absorber maintained strong absorption with a minimum reflection loss (RL_{min}) of –32.76 dB at 2.1 mm. This result also indicates favorable stability. These results demonstrate the promising potential of the as-prepared Cr₂AlC for high-performance high-temperature EMW absorption applications.

Features of Metal Carbide Synthesis from Oxides via Calciothermic Reduction and Carburization

S.S. Volodko, S.N. Yudin, D.O. Moskovskikh

National University of Science and Technology MISIS, Moscow, Russia

Email: volodko.ss@misis.ru

The calciothermic reduction of oxides of transitional metals with the addition of carbon was found to be a relatively simple method for obtaining ultrafine and nano carbide powders. Lately, it has been shown that this method allows for obtaining multicomponent carbide powders, also known as high-entropy ones. There are many features in this process that need to be studied, such as the effect of the carbon source, the preparation of raw materials, and the effect of a reducing agent on the process proceeding.

We found out that there is a strong relation between synthesis temperature, melting temperature of carbide, and particle size. This relation follows a power law and can be used to find a proper condition to obtain whether nano or submicron powders. Carbon source, being in our case CaC_2 and carbon black, significantly affects powder morphology and the synthesis kinetics, for the latter, giving more active synthesis, but irregular particle shape.

In turn, the amount of CaH_2 , particularly calcium melt, serves as a heat capacitor for high exothermic reactions of $\text{Me} + \text{C}$. At small CaH_2 amounts, the process has similarities with self-propagating high-temperature synthesis (SHS), demonstrating self-sustaining reactions at around 800-900 °C. At large CaH_2 amounts, the process proceeds smoothly. It is hypothesized that, at reduction of oxides by calcium, the exothermic effect heats up reduced metals and carbon up to combustion temperature, which causes SHS. Thermodynamic calculations show that, for instance, the reduction reaction of TiO_2 by CaH_2 can raise the temperature up to around 3000 °C under adiabatic conditions, which can be quite enough to launch a self-sustaining reaction of $\text{Ti} + \text{C}$ similar to the SHS process considering real non-adiabatic conditions. This aspect can be controlled by altering the CaH_2 amounts to suppress or ease this phenomenon.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (FSME-2026-0005).

Rapid and energy-efficient synthesis of M- and W-Type Strontium Hexaferrite

A. Sargsyan, H. Kirakosyan, S. Aydinyan

A.B. Nalbandyan Institute of Chemical Physics NAS RA, P. Sevak 5/2, 0014, Yerevan, Armenia

Email: hasmik.kirakosyan@ichph.sci.am

Hexaferrites are technologically important ferrimagnetic materials owing to their high chemical and thermal stability, corrosion resistance, relatively low cost, and tunable magnetic properties, making them attractive for permanent magnets, microwave devices, and high-frequency applications [1]. Among these materials, M- and W-type hexaferrites possess layered hexagonal structures composed of R and spinel-like S blocks. M-type $\text{SrFe}_{12}\text{O}_{19}$ is characterized by high magnetocrystalline anisotropy and coercivity, whereas W-type $\text{SrZn}_2\text{Fe}_{16}\text{O}_{27}$ exhibits a lower anisotropy field and tunable magnetic properties. These characteristics make both phases promising for a broad range of magnetic and microwave applications.

Various methods have been employed for the synthesis of hexaferrites, including solid-state reaction, sol-gel, co-precipitation, hydrothermal, and mechanochemical techniques. However, conventional methods generally require high temperatures and prolonged processing times, which can promote excessive grain growth and make precise control of phase composition and microstructure challenging. Combustion synthesis offers a rapid and energy-efficient alternative, enabling the formation of fine and relatively homogeneous powders within a short processing time.

In the present study, M- and W-type strontium hexaferrites were obtained through a two-stage synthesis route, in which intermediate products were first formed from the corresponding metal oxides via low-temperature combustion synthesis, followed by high-temperature calcination to obtain the target hexaferrite phases.

Ammonium nitrate was incorporated into the starting mixture to provide the required exothermicity for the combustion reaction. The effects of calcination temperature, holding time, and cooling rate on phase formation and microstructure were investigated. XRD analysis confirmed the formation of M- and W-type hexaferrite phases after calcination, with the resulting phase composition strongly dependent on the calcination conditions. Scanning electron microscopy (SEM) revealed distinct morphological features for the two phases: M-type $\text{SrFe}_{12}\text{O}_{19}$ predominantly consisted of fine, platelet-like particles, whereas W-type $\text{SrZn}_2\text{Fe}_{16}\text{O}_{27}$ exhibited larger, irregularly shaped particles. The W-type hexaferrite demonstrated a saturation magnetization above $70 \text{ emu}\cdot\text{g}^{-1}$. Overall, the results demonstrate that SHS followed by controlled calcination is an effective approach for tailoring the phase composition, microstructure, and magnetic properties of M- and W-type strontium hexaferrites.

References

[1] R.C. Pullar, Prog. Mater. Sci. 57, 1191 (2012).

Salt-assisted SHS synthesis technology for large-scale preparation of nano-ceramic powders

Peiqing La*, Faqi Zhan, Min Zhu

State Key Laboratory of Advanced Processing and Recycling of Non-ferrous Metals, Lanzhou University of Technology,
Lanzhou 730050, China

Email: pqla@lut.edu.cn

High-temperature ceramics possess excellent thermal chemical stability and physical properties, and are widely used in aerospace, defense technology and other fields. However, due to the strong covalent bond properties and low self-diffusion coefficients of ceramic compounds, it is difficult to achieve densification and deviceization, thus limiting their applications [1]. High-quality nano-ceramic powders are necessary prerequisites for preparing high-performance high-temperature structural ceramics and their composites. This study synthesized nano-ceramic powders (ZrC, TiC, SiC, ZrB₂, LaB₆, B₄C, etc.) with controllable particle size and high purity (99.9%) on a large scale using the salt-assisted combustion synthesis process [2-4]. A theoretical model for the SHS preparation of nano-ceramic powders was established, and the "dissolution-precipitation" mechanism of active species was proposed. The average particle size of the synthesized ZrC powder ranged from 100 to 35 nm; that of TiC powder ranged from 180 to 70 nm; that of SiC powder ranged from 200 to 30 nm; that of ZrB₂ powder ranged from 2 μ m to 90 nm; that of LaB₆ powder ranged from 400 to 20 nm; and that of B₄C powder ranged from 1 μ m to 90 nm. This technology enables the large-scale (kilogram-scale) preparation of nano-ceramic powders, laying the foundation for the high-end application of ceramic powders.

References

- [1] Faqi Zhan, Hua Zhang, Ke Xv, et al., J. Ceram. Process. Res. 23 (5), 694-708 (2022).
- [2] Faqi Zhan, Ru Bai, Xiao Liu, et al., J. Ceram. Process. Res. 25 (4), 490-498 (2024).
- [3] Ru Bai, Faqi Zhan, Hua Zhang, et al., J. Ceram. Process. Res. 26 (2), 219-230 (2025).
- [4] Faqi Zhan, Yinyan Du, Hua Zhang, et al., J. Ceram. Process. Res. 27 (1), 10-23 (2026).

New Class of RHEAs/Oxide Fibers High-Temperature Composites: Synthesis and Characterization

V. N. Sanin*¹, D. M. Ikornikov¹, D.Yu. Kovalev¹, S. B. Babkin^{1,2}, I. D. Petukhov^{1,2}, S. T. Mileiko^{1,2}

¹A. G. Merzhanov Institute of Structural Macrokinetics and Problems of Materials Science of RAS, Chernogolovka, Moscow region, st. Academician Osipyan 8, 142432, Russia.

²Yu. A. Osipyan Institute of Solid State Physics of the RAS, Chernogolovka, Moscow region, st. Academician Osipyan 2, 142432, Russia.

Email: svn@ism.ac.ru

This work aims to develop scientific principles and technical solutions for obtaining a new class of high-temperature oxide fiber/refractory high-entropy alloys (RHEAs) composites capable of long-term operation under high temperature (>1200 °C) and mechanical loads. For the first time a high-temperature composites Oxide fiber of the Al₂O₃-Al₅Y₃O₁₂ eutectic composition and RHEAs were produced and studied.

The study include two directions:

- i) The Development of a chemical engineering framework for producing liquid RHEAs based on refractory metals (Mo, Nb, Ta, Hf) alloyed with 3d and rare earth metals (Cr, V, Zr, Ti, Dy, Ce+La) using centrifugal SHS-metallurgy technique [1]. Study of the phase stability and oxide resisters for synthesized RHEAs and selection of promising compositions for forming oxide fiber/RHEAs composites.
- ii) The development of a new class of oxide fiber/RHEAs by powder metallurgy methods (hot pressing). Identification of optimal conditions for the composite formation, study of the compatibility of the oxide fiber the high-entropy matrix, and investigation of the properties for resulting composites under high temperatures (1300°C) and mechanical loads.

Cyclic oxidation tests at 1000 °C revealed that several compositions suffer from intense oxidation and scale spallation, particularly the Mo-rich reference alloy, which exhibited severe mass loss because of volatile MoO₃ formation. In contrast, the Cr-V- and especially Cr-Ti-containing alloys showed significantly improved oxidation resistance, with MoNbTa-Cr-Ti alloy exhibiting the lowest mass change and retaining its shape after long-term exposure [2].

High-temperature tests at 1300 °C revealed that with an increase in the volumetric fiber content in the composite composition, in the range of 0-25%, the strength increases by 4.5 times, reaching 163 MPa.

The work was supported by the Russian Science Foundation (project no. 24-13-00065). References

[1] V.N. Sanin et al. Gravity-Assisted SHS Metallurgy of Cast High-Entropy Mo-Nb-Ta-(Cr,V,Zr,Hf) Alloys. *Int. J. Self-Propag. High-Temp. Synth.* Vol. 33, No. 4, pp. 308–318. (2024).

[2] Sanin V.N. et al. Synthesis of refractory high-entropy alloys based on Mo-Nb-Ta-(Cr, V, Zr, Hf) using centrifugal SHS metallurgy and investigation of their oxidation resistance. *Powder Metallurgy and Functional Coatings.* 19(5):17–35 (2025).

Nickel nanopowder as a precursor for intermetallic rods produced by hot gas extrusion

F.F. Galiev, A.Yu. Malakhov, A.O. Kirillov

Merzhanov Institute of Structural Macrokinetics and Materials Science Russian Academy of Sciences, Academician Osipyan str.,
8 Chernogolovka Moscow Region, 142432, Russia

Email: galiev@ism.ac.ru

An alternative to traditional methods (rolling, drawing, etc.) for manufacturing intermetallic and ceramic rods in a metal shell is a technique that combines hot gas extrusion (HGE) and self-propagating high-temperature synthesis (SHS). For example, the HGE method allows the deformation and synthesis of Ni-Al intermetallics from a powder mixture in a steel shell in a single technological stage, achieving a maximum target product (NiAl phase) content of up to 78 wt.% [1]. It was found that the main limitation regarding synthesis completion is the low dissolution rate of nickel in the aluminum melt. As shown in [2], the dissolution of nickel can be accelerated by using fine powder as a precursor. Therefore, the aim of this study was to investigate the influence of nickel nanopowder on the completeness of synthesis in the Ni-Al system and on the microstructure of the intermetallic rod obtained by HGE.

Commercial Al (ASD-1) powder and Ni nanopowder, the latter obtained by chemical and metallurgical methods, were used in this study. The powder mixture was prepared by mixing the initial powders at a 1:1 ratio in a ball mill. For HGE, the powder mixture was loaded into a special steel cartridge. Extrusion was performed under a gas pressure of 200 MPa with simultaneous local heating in the deformation region up to 630 °C. The phase composition was determined by X-ray diffraction analysis, and the microstructure was examined using an electron microscope equipped with a microanalysis system.

Phase analysis of the rod core showed that the NiAl phase content along the main length is 51 wt.%. In the final part of the rod, where the extrusion rate dropped from 3 mm/s to 0.5 mm/s, the NiAl phase content reached 93 wt.%. This indicates that under HGE conditions, the completeness of SHS depends on the residence time of the powder mixture in the local heating region. The microstructural analysis revealed the presence of nickel particles with a diameter of up to 40 µm, indicating melting and coalescence. This can occur when the diffusion between Ni and Al slows down due to the formation of NiAl₃, Ni₂Al₃, and Ni₃Al intermetallic barriers. Therefore, to increase the completeness of SHS along the entire rod length, it is necessary to reduce the extrusion rate and apply mechanical activation of the Ni-Al mixture to inhibit the formation of a barrier layer.

This research was financially supported by the Russian Science Foundation, project no.25-29-00735 (<https://rscf.ru/project/25-29-00735/>)

[1] F.F. Galiev, I.V. Saikov, V.D. Berbentsev, et.al. Inorg. Mater.: Appl. Res. Vol.15, 772 (2024)

[2] L. Thiers, A.S. Mukasyan, A. Varma, Combust. and Flame Vol.1, 198 (2002).

Combustion Synthesis of Silicon-Based Ceramic Powders from Recycled Silicon Waste

Gang He

State Key Laboratory of Crystal Materials, Tianjin Key Laboratory of Functional Crystal Materials, Institute of Functional Crystal, Tianjin University of Technology, Tianjin 300384, China

Email: ipchg@mail.ipc.ac.cn

Silicon sludge, a byproduct generated during photovoltaic silicon wafer slicing, is a low-cost silicon resource with prominent application potential. To satisfy the urgent demand for high-thermal-conductivity nitride fillers in advanced semiconductor packaging, fine-grained photovoltaic silicon sludge with high oxygen content was utilized as the raw material to synthesize α - and β -phase Si_3N_4 powders via combustion synthesis. The influences of processing parameters including combustion temperature, gas pressure and catalyst on the phase composition and micromorphology of Si_3N_4 powders were systematically investigated. The as-synthesized α - Si_3N_4 powders were used as raw powder to fabricate Si_3N_4 ceramics through gas pressure-assisted ultra-fast high-temperature sintering. The effects of heating rate, nitrogen pressure and holding time on the microstructure and comprehensive properties of Si_3N_4 ceramics were explored. Moreover, the prepared β - Si_3N_4 powders were adopted as thermally conductive fillers to manufacture silicone resin composites. The correlations between the oxygen content and loading fraction of β - Si_3N_4 powders and the thermal conductivity, dielectric properties as well as mechanical performances of the composites were analyzed. The experimental results demonstrate that photovoltaic silicon sludge with an oxygen content of 4.0 wt.% can be converted into α/β - Si_3N_4 powders with low oxygen content (<1.0 wt.%) by optimizing the combustion synthesis procedure. Dense Si_3N_4 ceramics with a relative density of 94.17% can be fabricated within several minutes using low-oxygen α - Si_3N_4 powders under gas pressure-assisted ultra-fast high-temperature sintering conditions (sintering temperature: 1750 °C, nitrogen pressure: 0.2 MPa, heating rate: 50 °C/s, holding time: 180 s). In addition, low-oxygen β - Si_3N_4 fillers can drastically improve the thermal conductivity of silicone resin, achieving a thermal conductivity enhancement of more than 7 times at a filler loading of 80 wt.%. The Si_3N_4 powders fabricated from inexpensive photovoltaic silicon sludge through low-energy-consumption combustion synthesis possess bright prospects for engineering applications in advanced semiconductor packaging.

References

- [1] C. Li, L. Yang, G. He, et al. Journal of Alloys and Compounds, 1034, 181445 (2025).
- [2] C. Xu, L. Yang, G. He, et al. Ceramics International, 51, 30233-30238 (2025).
- [3] C. Li, L. Yang, G. He, et al. Ceramics International, 52, 6027-6034 (2026).

Cold sintering assisted energy efficient sintering of ceramics

Jing Guo

State Key Laboratory for Mechanical Behavior of Materials, School of Materials Science and Engineering, Xi'an Jiaotong University, Xi'an 710049, P.R. China

Email: jingguo19@xjtu.edu.cn

Developing high-efficiency sintering technologies with mild conditions is crucial for reducing the energy consumption and manipulating the performances of ceramics [1]. However, sintering ceramics at low temperatures with short times is challenging, due to their high melting points. Recently, cold sintering process (CSP) has been extensively investigated and has the advantages of ultralow sintering temperatures and rapid densification rates with the assist of transient liquid phase, leading to the development of new ceramic-based composites and even metastable materials [2, 3]. Based on CSP, we have further established a protocol for energy efficient sintering by combining CSP with other sintering technologies, such as microwave and spark plasma sintering [4]. Several typical ceramics including oxides, chlorides, phosphates, and molybdates with various applications are selected to demonstrate the feasibility of hybrid sintering in fabricating high-performance ceramics at reduced sintering temperatures, applied pressures or holding times. TEM and phase-field simulation have been employed to study the sintering mechanisms. These findings highlight the potential of cold sintering assisted hybrid sintering in efficiently fabricating high-performance ceramics, and offer inspirations on sintering combinations to develop low-temperature sintering technologies with high efficiencies.

References

- [1] D.G. Liu, G. Shao, X.Q. Tai, et al. J. Adv. Ceram. 15, 9221276 (2026).
- [2] J. Guo, H.Z. Guo, A.L. Baker, et al. Angew. Chem. Int. Ed., 55, 11457 (2016).
- [3] J. Guo, S.S. Berbano, H.Z. Guo, et al. Adv. Funct. Mater. 26, 7115 (2016).
- [4] X.M. Li, W.B. Liu, L. Li, et al. J. Adv. Ceram. 14, 9221186 (2025).

Self-propagating high-temperature synthesis of TiC/(Co+Cr+Ni) cermet

S.G. Vadchenko, D.Yu. Kovalev, A.O. Sivakova, A.M. Karpov, A.E. Sytshev, A.S. Rogachev

Merzhanov Institute of Structural Macrokinetics and Materials Science, Russian Academy of Sciences, Chernogolovka, 142432
Russia

Email: sivakovaalina@yandex.ru

In this work, 50CoCrNi-50TiC and 60CoCrNi-40TiC cermets [1] were produced from a mixture of elemental powders using self-propagating high-temperature synthesis with applied pressure. The synthesis process resulted in the formation of a cermet containing cubic phases -TiC (space group Fm-3m) and solid solution phases (space group Fm-3m). Determination of the volume fractions of the phases by Rietveld refinement gave the following results: titanium carbide - 77.1 vol.% (69.8 wt.%), chromium carbide-based compound - 18.0 vol.% (22.2 wt.%), metal binder 4.9 vol.% (8 wt.%). The presence of TiC particles in cermet increases its hardness. The average Vickers hardness of the CoCrNi alloy is 2025–2332 MPa, while that of 40CoCrNi-60TiC cermet is 16320 MPa, which is a direct result of the presence of dispersion-strengthening TiC particles. The calculation carried out using the Palmqvist toughness test yielded a crack resistance coefficient K_{Ic} equal to $8.12 \div 10.60 \text{ MPa} \cdot \text{m}^{1/2}$.

Fig.1. The dependence of specific electrical resistance vs temperature.

The dependence of specific electrical resistance on temperature (Fig.1) in the range from 300 to 1400 K was also measured. The synthesized cermets have a metallic conductivity. The values of specific electrical resistance increased uniformly within the entire measurement range and reached a maximum at a temperature of 1400 K. For the 60CoCrNi-40TiC sample, the maximum electrical resistance was $252 \mu\Omega/\text{cm}$, and for the 50CoCrNi-50TiC sample it was $507 \mu\Omega/\text{cm}$.

References

1. Rogachev A.S., Bobozhanov A.R., Kochetov N.A., Kovalev D.Yu., Vadchenko S.G., Boyarchenko O.D., Kochetkov R.A. Self-propagating high-temperature synthesis of TiC–CoCrNi cermet: Behavior and microstructure formation. Powder Metallurgy and Functional Coatings. 2025; 19(6):5–15. <https://doi.org/10.17073/1997-308X-2025-6-5-15>

Funding

This work was supported by the Russian Science Foundation (project no. 25-13-00040).

Comparative Evaluation of Cf/SiC and Cf/Si₃N₄ Composites Processed by Spark Plasma Sintering for High-Temperature Brake Disc Applications

Mohammad Reza Loghman Estarki*^{1,2}, Fatemeh Davar*^{1,3}, Ziliang Li¹

¹ School of Materials Science and Engineering, Liaocheng University, Liaocheng, 252000, PR China

² Department of Materials Engineering, Malek Ashtar University of Technology, Isfahan, Iran

³ Department of Chemistry, Isfahan University of Technology, Isfahan, Iran

Email: Loghman57@gmail.com

Advanced braking systems for aerospace and high-speed transportation demand materials with an exceptional balance of fracture toughness, thermal conductivity, friction stability, and lightweight characteristics. Carbon fiber-reinforced silicon carbide (Cf/SiC) composites currently represent the state-of-the-art for these applications; however, they suffer from moderate fracture toughness (5–7 MPa.m^{0.5}), sensitivity to thermal shock, and high manufacturing costs associated with chemical vapor infiltration (CVI) and liquid silicon infiltration (LSI) routes [1,2]. In response to these limitations, carbon fiber-reinforced silicon nitride (Cf/Si₃N₄) composites have emerged as a promising alternative due to the unique phase transformation behavior of Si₃N₄, which enables in-situ formation of self-reinforced microstructures without requiring external reinforcements [3].

This study aims to provide a systematic comparison of the microstructure, densification behavior, mechanical properties, thermal conductivity, and tribological performance of Cf/SiC and Cf/Si₃N₄ composites fabricated under identical spark plasma sintering (SPS, a rapid consolidation technique compatible with SHS-derived powders) conditions. By establishing clear phase-microstructure-property relationships, this work seeks to identify the optimal ceramic matrix system and processing strategy for next-generation brake disc applications.

The experimental results reveal that α -Si₃N₄-derived Cf/Si₃N₄ composites achieve the highest relative density (96.53%) with only 3.47% residual porosity, surpassing Cf/SiC composites (96.6%) and significantly exceeding LSI-processed materials (80–85%) [3,4]. The α -Si₃N₄-derived composite exhibits an exceptional fracture toughness of 10.87 MPa.m^{0.5}, which is nearly double that of the optimal Cf/SiC composite (5.72 MPa.m^{0.5}) [3,5]. This remarkable toughness is attributed to the in-situ formation of interlocking, needle-like β -Si₃N₄ grains (Fig.1) during the $\alpha \rightarrow \beta$ phase transformation, which promote crack deflection, crack bridging, and fiber pull-out mechanisms in synergy with carbon fibers [3]. Thermal conductivity of Cf/Si₃N₄ composites reaches 66 W/m.K, significantly higher than Cf/SiC (32 W/mK), due to reduced porosity and minimized phonon scattering [3,4]. The coefficient of friction for α -Si₃N₄-derived composites stabilizes at approximately 0.46 with minimal fluctuations, while wear rates remain on the order of 10⁻⁷ g/Nm, superior to Cf/SiC composites which exhibit wear rates of 10⁻⁶ g/Nm [3,5,6]. These findings demonstrate that controlling the initial Si₃N₄ phase provides an effective microstructural design strategy for developing high-performance Cf/Si₃N₄ composites as a viable alternative to SiC-based systems for advanced thermostructural applications.

References

- [1] S. Hoseinzadeh, M.R. Loghman Estarki, A. Ghasemi, et al. Sharifi, Sci. Rep. 16, 10739 (2026).
- [2] S. Zahabi, E.M. Sharifi, M.R. Dehnavi, et al., Ceram. Int. 47, 27553 (2021).
- [3] S. Hoseinzadeh, M.R. Loghman Estarki, A. Ghasemi, et al., Sci. Rep. 16, 10739 (2026).
- [4] A. Ghasemi, M. Ramazani, S.R. Bakhshi, et al., J. Korean Ceram. Soc. 60, 732 (2023).
- [5] S. Zahabi, E.M. Sharifi, M.R. Dehnavi, et al., Ceram. Int. 47, 27553 (2021).
- [6] S. Hoseinzadeh, et al., Arab. J. Chem. 17, 105378 (2024).

Dynamic sinter forging of yttria-stabilized zirconia ceramics with ultra-high flexural strength

Dianguang Liu

School of Integrated Circuits Science and Engineering, Southwest Jiaotong University, Chengdu, Sichuan 611756, China.

Email: dianguang@swjtu.edu.cn

This study presents a comprehensive investigation into the fabrication of high-performance zirconia ceramics via dynamic sinter forging (DSF). The effects of sintering temperature, dynamic pressure amplitude, and median pressure on the microstructure and mechanical properties were systematically examined. At a sintering temperature of 1550 °C, the DSF-processed samples achieved a flexural strength of 1950 MPa and a fracture toughness of 7.1 MPa·m^{1/2}. Under optimized pressure parameters (70 ± 5 MPa), the flexural strength further reached 1980 MPa. Notably, the flexural strength exhibited a non-monotonic dependence on both amplitude and median pressure: it first increased and then decreased with increasing amplitude, while it initially decreased and then increased with rising median pressure. Through the adjustment of dynamic pressure parameters, grain boundary energy could be effectively tailored; samples prepared under either the maximum median pressure (70 MPa) or the maximum amplitude (±25 MPa) showed significantly reduced grain boundary energy. At the optimal pressure of 70 ± 5 MPa, the samples exhibited thin, straight grain boundaries and a refined grain size. Microstructural analyses revealed that the DSF-derived ceramics featured exceptionally thin grain boundaries, high-density dislocations, and a pronounced phase-transformation capability under external loading—attributes likely arising from reciprocating grain-boundary sliding during sinter forging. The outstanding mechanical performance of the DSF-made zirconia ceramics is primarily attributed to the synergistic interplay of grain-boundary strengthening, strain hardening, and transformation toughening. These findings underscore the potential of DSF as a transformative pathway for the preparation of advanced high-performance ceramics.

Key words: Dynamic sinter forging; zirconia; mechanical property; grain-boundary sliding; dislocation

Combustion Synthesis of Rare-Earth (RE) Sesquioxides and MgO–RE₂O₃ Composite Powders for Transparent Ceramic Applications

D.A. Permin 1, L.A. Ketkova 1,2, S.V. Kurashkin 1,2, A.V. Belyaev, 2, Evstropov T.O. 2, Postnikova O.N.1, Naumova A.V. 2

1 N.I. Lobachevsky National Research University, 23 Gagarin Ave., 603022 Nizhny Novgorod, Russia

2 G.G. Devyatikh Institute of Chemistry of High-Purity Substances of the RAS, 49 Tropinin St., 603137 Nizhny Novgorod, Russia

Email: permin@chem.unn.ru

Rare-earth (RE) oxides serve as a crucial raw material for the fabrication of advanced optical and magnetic materials. Obtaining these oxides as highly dispersed, loosely agglomerated powders with precisely controlled impurity levels is of particular importance. The present report summarizes our studies on optimizing the parameters of solution combustion synthesis for rare-earth oxide powders and their composites with magnesium oxide.

The fuel type and its ratio to the oxidizer in the precursor most critically influence the powder properties. Among the fuels studied, glycine ensures the most vigorous interaction fully sustaining the SHS regime. The results suggest synthesis should target high adiabatic temperatures, which essentially define the energy reserve for a self-sustaining reaction. However, secondary factors like carbon contamination of the products must be considered. The morphology of SHS powders is characterized by loose, porous agglomerates formed due to intense gas evolution. Subsequent annealing at 900–1100°C yields uniformly distributed, equiaxed particles ~50 nm in size. The calculated mean equivalent diameter falls within 40–60 nm and is independent of the rare-earth oxide matrix.

Sintering these powders via hot pressing and vacuum techniques produced advanced laser and magneto-optical ceramics. Notably, Yb:Y₂O₃ achieved laser oscillation with >50% differential efficiency, while Tb₂O₃ demonstrated a record Verdet constant over 3.5 times that of terbium gallium garnet.

A separate set of studies was devoted to Y₂O₃–MgO composite ceramics. The selected approaches enabled sintering of ceramics with over 99.5% density, mean grain size of 100–150 nm, and transmission in the 2–8 μm range close to the theoretical limit.

The study was funded by the Russian Science Foundation (RSF) Project No. 22-73-10084(P)

Synthesis of low-defect-density high- κ gate dielectric materials assisted by molten metal halide salts

Yu Zhou

School of Physics, Central South University, Changsha, Hunan, China

Email: yu.zhou@csu.edu.cn

High- κ gate dielectric materials are highly important for post-Moore areas to enhance the electronic devices' performance, which could suppress the transistor leakage current and lower the device power consumptions. The device scaling needs high quality of low-defect-density high- κ gate dielectric materials, especially for the transistor's applications, which require the synthesis of dielectric materials with ultralow defect density for the bulk and interfacial surface, thus improving its electric breakdown strength and dielectric constants. However, high- κ niobium-based inorganic materials require high temperature to be synthesized (>1500 °C), still suffering the difficulty of forming the two-dimensional nanosheets and consisting of high defect density. Herein, we propose the molten metal halide salts to reduce the synthesis temperature for diverse high- κ gate dielectric materials, which also could be controlled to supply the ultralow concentration of niobium-based precursors for slow-kinetic reactions. The well-controlled reaction with single or double molten metal halide salts either in the liquid or gas state highly realize the 2D low-defect-density high- κ gate dielectric materials, which largely move forward the application of molten metal halide salts synthesis methods and solve the synthesis difficulty of nonlayered high- κ niobium-based materials.

References

- [1] Xiulian Fan, Anlian Pan*, Yu Zhou* et al., Nature Communications 16, 2585 (2025).
- [2] Chenyang Niu, Yu Zhou* et al., Physica Status Solidi (RRL)-Rapid Research Letters, 2400394 (2025).
- [3] Xuehao Guo, Zhaofeng Wu*, Yu Zhou*, et al., Applied Physics Letters 125, 084101 (2024).
- [4] Xiulian Fan, Yu Zhou*, et al., Advanced Functional Materials 24047504, (2024).
- [5] Bo Zhang, Yu Zhou*, et al., Phys. Status Solidi RRL-Rapid Research Letters 2400054, (2024).

Preparation and characterization of columnar crystals reinforced Y₂O₃-MgO composite ceramics by combustion synthesis

Canqing Fang, Jianyang Li, Yongting Zheng

National Key Laboratory of Science and Technology on Advanced Composites in Special Environments, Center for Composite Materials and Structures, Harbin Institute of Technology, Harbin, 150080, PR China

Email: zhengyt@hit.edu.cn

Y₂O₃-MgO composite ceramics, as a promising infrared-transparent material, exhibit superior optical transmittance, but still have limited mechanical strength, which restricts their application under demanding conditions requiring high mechanical strength and good thermal shock resistance[1].

Currently, the strengthening and toughening strategy of Y₂O₃-MgO ceramics is mainly grain refinement strengthening. However, Liu et al.[2] found that while grain size reduction significantly enhances ceramic hardness, its effect on fracture toughness is limited. Columnar crystal toughening, as a crucial toughening approach for advanced ceramics, can significantly enhance the toughness of ceramics through mechanisms such as fracture, pull-out, and bridging of the columnar crystals, as well as the crack deflection and branching. Therefore, introducing high-density columnar crystals into ceramics, has become a potential way to improve the toughness of Y₂O₃-MgO composite ceramics, but this approach has not yet been reported in the Y₂O₃ system.

In this work, metastable Y₂O₃-MgO solid solution powders were prepared by combustion synthesis combined with water atomization and rapid solidification. During subsequent heat treatment, the microstructure of metastable solid solution powders evolved. When the heat treatment temperature ranged from 1100 to 1300°C, high-density columnar crystals were induced in situ on the powder surface. The Y₂O₃-MgO ceramics were obtained by SPS at 1200°C, with the ceramic matrix consisting of submicron Y₂O₃ and MgO grains, and high-density columnar crystals distributed both intragranularly and intergranularly, as shown in the figure. After annealing at 1000 °C for 10 h, the ceramic exhibits a hardness of 11 GPa and a fracture toughness as high as 3.4 MPa·m^{1/2}, indicating that columnar crystals hold great potential for enhancing the fracture toughness of Y₂O₃-MgO ceramics.

References

- [1] Shen Z, Zhu Q, Feng T, et al. *Ceram. Int.* 47, 13007 (2021).
- [2] Liu L, Morita K, Suzuki T S, et al. *J. Eur. Ceram. Soc.* 41, 2096 (2021).

Combustion Synthesis in the Thermal Explosion Mode and Gas-Solid Hydriding Synthesis of Mg-Based Hydrogen-Storage Materials

Mengran Li, Yunfeng Zhu, Liquan Li

College of Materials Science and Engineering, Jiangsu Collaborative Innovation Centre for Advanced Inorganic Function Composites, Nanjing Tech University, Nanjing 211816, P.R. China

Email: yfzhu@njtech.edu.cn

Mg-based hydrides have merits of high hydrogen capacity, abundance and low cost, but their conventional synthesis typically requires high temperatures and hydrogen pressures over prolonged periods, with limited control over phase and micro-/nanostructure [1]. Here, various routes including Mg–Al combustion synthesis in the thermal explosion mode, hydriding combustion synthesis of Mg–Al-based hydrides and vapour-phase deposition–hydriding of Mg–Ni-based materials were developed to control phase evolution and structural dimensions.

Combustion synthesis in the thermal explosion mode yielded Mg₁₇Al₁₂ and Mg₂Al₃ with purities of 97.8 and 99.7 wt.%, respectively. The reactions proceeded through solid-state diffusion and intermediate-phase nucleation, followed by Mg/Mg₁₇Al₁₂ eutectic reactions and alloy melting that generated local secondary liquid phases, accelerating mass transport and target-phase formation via a random-nucleation-and-growth mechanism. Coupling Mg–Al alloying with low-temperature, low-pressure hydriding combustion synthesis (HCS) produced an Mg₉₀Al₁₀-based material containing 88.2 wt.% MgH₂ and releasing 6.02 wt.% H₂. During HCS, Mg₁₇Al₁₂ disrupted the Mg surface passivation layer, while lattice distortion and heterointerfaces facilitated hydrogen transport; its subsequent hydrogenation-induced disproportionation generated Al* in situ, promoting H₂ dissociation and MgH₂ nucleation [2].

A hydriding chemical vapour deposition (HCVD) route was developed to tailor particle size, morphology and interfaces. Coupling Mg vaporisation, vapour transport, heterogeneous deposition, Mg–Ni alloying and hydrogenation enabled the in situ formation of sub-100 nm Mg₂NiH₄ particles, Mg₂NiH₄ nanochains and confined composite hydrides [3, 4].

Overall, the integrated route enabled rapid alloying, sequential alloying–hydriding transformations and low-dimensional structuring, providing efficient access to high-purity, highly active Mg-based alloys and hydrides.

References

- [1] D.Q. Guan, B.W. Wang, J.G. Zhang, et al. *Energy Environ. Sci.* 16, 4926-4943 (2023).
- [2] M.R. Li, Q.H. Ji, J.Y. Zheng, et al. *J. Mater. Sci. Technol.* 278, 9-15 (2027).
- [3] J.G. Zhang, Y.F. Zhu, H.J. Lin, et al. *Adv. Mater.* 29, 1700760 (2017).
- [4] Y. Y. Zhao, Y. F. Zhu, L. Q. Li, *Mater. Rep.: Energy* 4, 100246 (2024).

From Diffusion-Controlled Reactions to Thermal Explosion and SHS: Formation Mechanisms of Al-Based Intermetallics Under Combustion-Assisted Synthesis

F. Akhtar¹, P. Z. Feng²

¹ Division of Materials Science, Luleå University of Technology, Luleå 97187, Sweden

² School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116 P.R.China

Email: farid.akhtar@ltu.se

Intermetallic compounds synthesized through combustion-assisted routes have attracted considerable attention owing to their rapid processing, low energy consumption, and ability to generate unique porous and reinforced microstructures. In the present work, the formation mechanisms of Al-based intermetallics were comparatively investigated under diffusion-controlled, thermal explosion (TE), and mechanically activated combustion conditions. Ti-Al, Cu-Al, and Ni-Al systems were selected as model materials to understand the transition from conventional reactive diffusion to combustion-driven intermetallic synthesis.

The thermal behavior, ignition characteristics, phase evolution, pore formation, and microstructure development were analyzed using temperature–time profiling, differential scanning calorimetry, X-ray diffraction, and electron microscopy. Results showed that low heating rates promoted solid-state diffusion and Kirkendall pore formation, whereas increasing heating rates caused significant heat accumulation leading to thermal explosion reactions. In Ti-Al systems, the compact temperature increased abruptly from approximately 670 °C to above 1100–1240 °C within seconds, demonstrating characteristic volume combustion behavior. The thermal explosion process produced highly porous TiAl- and TiAl₃-based intermetallics with interconnected pore structures and high open porosity. In Cu-Al systems, TE enabled rapid synthesis of porous CuAl intermetallics with bimodal pore structures and open cellular morphology. Furthermore, mechanically activated reactions in Ni-Al powders generated combustion-assisted oxidation and subsequent formation of nanoscale Al₂O₃-reinforced Ni₃Al composites after pulse current processing.

Our results demonstrate that the intermetallic formation pathway strongly depends on the balance between external heating, diffusion kinetics, stored mechanical energy, and exothermic heat release. A transition from diffusion-dominated reaction to thermal explosion and SHS-like behavior occurs with increasing activation conditions. The results provide an understanding of combustion-assisted intermetallic synthesis and offer guidance for tailoring porous and reinforced intermetallic materials through controlled reaction pathways.

Self-Propagating Combustion Growth of High-Entropy Spinel Electrodes on Ni Foam for Efficient and Durable Oxygen Evolution

Y. Zhang, J. Chen, Y. Pan

School of Materials Science and Engineering, Southeast University, Nanjing, China

Email: 230249771@seu.edu.cn

Solution combustion synthesis (SCS) offers a rapid and scalable route for preparing functional oxides, while high-entropy oxides (HEOs) provide compositionally flexible multication platforms for non-noble oxygen evolution reaction (OER) catalysts[1]. However, conventional powder-based synthesis followed by deposition onto conductive substrates is often inefficient and may lead to particle agglomeration and poor interfacial contact[2]. Here, we report a one-step SCS strategy for the in situ growth of (FeCoNiMnZnCu)O₈ HEO on Ni foam (SHEO@NF) as an efficient and durable OER electrode. A nitrate–glycine precursor gel was directly loaded onto NF and rapidly ignited, triggering a self-propagating combustion process that simultaneously enabled HEO formation and electrode fabrication. XRD, SEM, TEM/SAED, and elemental mapping confirmed a single spinel phase with a homogeneous multication distribution, while the combustion-derived coating consisted of loosely packed nanoparticles.

For OER, SHEO@NF exhibited high activity in 1 M KOH, requiring overpotentials of only 251, 297, and 358 mV to reach 20, 50, and 100 mA cm⁻², respectively, outperforming commercial RuO₂. SHEO@NF further demonstrated excellent durability in three separate 100-cycle current-switching chronopotentiometric tests (>120 h each) with target current densities of 20, 50, and 100 mA cm⁻², showing negligible potential variation throughout the repeated cycles. Notably, post-OER SEM/TEM revealed pronounced surface reconstruction into abundant wrinkled nanosheets and feather-like edges, increasing the electrochemically accessible surface area. XPS further showed that the oxygen-vacancy-related O 1s component increased from 24.1% to 49.8%, indicating the development of a defect-rich reconstructed surface.

References

- [1] A. Varma, A.S. Mukasyan, A.S. Rogachev, et al., Chem. Rev. 116, 14493 (2016).
- [2] K. Iwase, I. Honma, T. Tomai, ACS Catal. 16, 7395 (2026).

Arc plasma-assisted combustion for the rapid synthesis of transition metal borides

Junxi Li^{1,2,3}, Da Zhang^{1,2,3}, Feng Liang^{1,2,3}

¹ Key Laboratory for Nonferrous Vacuum Metallurgy of Yunnan Province, Kunming University of Science and Technology, Kunming, China

² National Engineering Research Center of Vacuum Metallurgy, Kunming University of Science and Technology, Kunming, China

³ School of Metallurgical and Energy Engineering, Kunming University of Science and Technology, Kunming, China

Email: liangfeng@kust.edu.cn

The combustion synthesis has been widely used to prepare transition metal borides (TMBs). However, the thermal explosion mode requires prolonged heating and holding, while the self-propagating high-temperature synthesis (SHS) mode typically relies on ignition enhancers. Here, a simple, universal, and mass production method for preparing TMBs in seconds via arc plasma-assisted combustion synthesis (APCS), which leverages the ultrahigh temperature and ultrafast heating rate characteristics of plasma. Depending on whether the adiabatic temperature (T_{ad}) exceeds 1800 K, the synthesis proceeds via either the SHS mode (APCS-SHS) or the thermal explosion mode (APCS-TE). A variety of TMBs, including FeB, CoB, NiB, VB₂, TiB₂, ZrB₂, and TaB₂, were successfully synthesized within 2–10 s. Notably, the APCS synthesis mode can be flexibly tailored according to the system's T_{ad} , rendering this approach extendable to other transition metal compounds such as carbides, nitrides, and oxides. This work offers a powerful and versatile technology for the production of metal compounds.

Preparation of High-Activity Inorganic Functional Ceramic Powders by Reaction Coupling Self-propagating High-Temperature Synthesis Technology

J.L. Wang, X.X. Hou, R.X. Li, F. Long

Guangxi Key Laboratory of Optical and Electronic Materials and Devices, Collaborative Innovation Center for Exploration of Nonferrous Metal Deposits and Efficient Utilization of Resources, School of Materials Science and Engineering, Guilin University of Technology, Guilin 541004, China

Email: jilinwang@glut.edu.cn

High quality powders are the indispensable prerequisite to prepare the high temperature structure ceramics and the corresponding composites with distinguished properties. Compared with the traditional bulk micron-sized particles, high purity nano-sized powders have a smaller particle size, higher chemical activity and better sintering ability, making it easier to fabricate the related ceramic materials. Self-propagating high temperature synthesis (SHS) technology has enormous development potential for low cost, high efficiency and large scale industrial production of nano-sized powders. However, the traditional SHS process is difficult to control given that the excessive exothermic energy in a much shorter time, resulting in high-temperature sintering agglomeration, exception grain growth, and/or many hardly completely removed impurities in the product. Therefore, how to effectively control the excessive high exothermic energy in the whole reaction system is a key problem for obtaining high quality ceramic nano-powders finally. In our opinion, it is worthy that exploring new approaches to fabricate high quality goal product through introducing the endothermic reaction into the exothermic reaction followed effectively controlled the heat, temperature and the grain growth condition of the whole reaction system. By applying this approach, our team conducted research about the controllable preparation of nano powders such as boron carbide, boron, zirconium carbide, and diboride titanium. The current results indicate that the reaction coupling SHS method has good universality, and the prepared ceramic powders present high activity. Therefore, this approach is expected to solve the problem of difficult energy control in the traditional self-propagating high-temperature synthesis process.

References

- [1] J.L. Wang, F. Long, W.M. Wang, et al., *Ceram. Int.* 42, 6969 (2016).
- [2] J.L. Wang, H.J. Liao, Y.C. Ji, et al., *Beilstein J. Nanotechnol.* 8, 2116 (2017).

Resistive Ti-Nb-B-C-N Thin Films for Microelectronics Obtained by Magnetron Sputtering With Heterophase SHS-Cathodes

Ph.V. Kiryukhantsev-Korneev, Yu.S. Pogozhev, A.Yu. Potanin, K.A. Goncharenko, E.V. Chernyshova,
D.A. Kiselev, E.A. Levashov

National University of Science and Technology "MISIS", Moscow, 119049 Russia

Email: kiruhantsev-korneev@yandex.ru

The Ti-B-C-based resistive films, due to their high hardness, wear- and oxidation resistance, and extremely high thermal stability, significantly outperform widely used two-component compounds (NiCr, TaN, etc.). Further improvements in properties can be achieved through complex alloying. The purpose of this study was to obtain films in Ti-Nb-B-C-N system by magnetron sputtering and to establish the relationship between deposition condition, composition, structure, and functional properties.

(TiNb)B_{2-x}(Ti,Nb)C ($x=20\div80\%$) targets were manufactured by self-propagating high-temperature synthesis (the force SHS-pressing or SHS+HP technologies). Magnetron sputtering was carried out at direct current and high-power impulse modes (DCMS and HIPIMS) with varying the working pressure, gas composition (Ar/N₂ ratio), average/peak power. The structure of coatings was studied by means of XRD, SEM, EDS, TEM, SAED, GDOES, and Raman spectroscopy. The mechanical properties were measured by nanoindentation and scratch-testing. The volt-ampere characteristics and current images of the surface were obtained by AFM. Specific electrical resistance and TCR were measured in broad temperature range by four-probe method. The thermal stability/oxidation resistance was assessed by annealing in a vacuum/air.

Non-reactive films had a nanocomposite structure with the general formula nc-(TiNb)B₂/a-B:C/a-C; when nitrogen was introduced into the composition, the proportion of the amorphous phase, characterized by N-B and N-Ti bonds, increased. The electrical resistivity raised from 102 to 107 $\mu\text{Om}\cdot\text{cm}$ when nitrogen content was enlarged from 0 to 58 at.%. Films obtained under optimal conditions had a hardness up to 45 GPa, elastic recovery up to 79 %, specific electrical resistance of 270 $\mu\text{Ohm}\cdot\text{cm}$ and TCR at the level of $-3\cdot10^{-5} \text{ 1/}^\circ\text{C}$ in temperature range $-200\text{--}400^\circ\text{C}$. Samples with a high volume of amorphous phase demonstrated oxidation resistance up to 800°C.

Work was supported by the Russian Science Foundation (project 24-13-00085).

References

- [1] E.A. Levashov, V.I. Kosayanin, L.M. Krukova et al. Surf. Coat. Technol. 92, 34 (1997)
- [2] Ph.V. Kiryukhantsev-Korneev, A.D. Chertova, E.A. Levashov et al. Phys. Atom. Nuclei. 87, 1591 (2024).
- [3] Ph.V. Kiryukhantsev-Korneev, K.A. Goncharenko, E.V. Chernyshova et al. Prot. Met. Phys. Chem. Surf., 62, 100 (2026)

Solution Combustion Synthesis of Medium-Entropy (FeCoNiZn)Al₂O₄ Cocatalysts and Its Photocatalytic Hydrogen Production Coupled with Benzaldehyde Generation Performance

Zhiqing Xu ^{a,b}, Aihua Yan ^c, Zigao Su ^b, Fei Huang ^{*,a,b}, Nan Li ^c, BoLei Hui ^c, Heng Wang ^c

^a Carbon Neutrality Institute, China University of Mining and Technology, Xuzhou 221008, China

^b School of Materials and Physics, China University of Mining and Technology, Xuzhou 221116, China

^c School of Low-Carbon Energy and Power Engineering, China University of Mining and Technology, Xuzhou 221116, China

Email: huangfei7804@163.com

Photocatalytic hydrogen production represents a promising route toward green energy, yet it is constrained by poor light utilization, rapid charge carrier recombination, and sluggish surface reaction kinetics [1,2]. Medium-entropy aluminate with abundant surface sites, excellent chemical stability, tunable electronic properties and fast charge transport is recognized as a kind of promising cocatalyst or charge-transfer mediator [3]. However, establishing intimate interfacial contact with semiconductor hosts remains a critical challenge. In this work, we synthesized a medium-entropy (FeCoNiZn)Al₂O₄ (FCNZA) cocatalyst via a solution combustion method and subsequently integrated it with ZnIn₂S₄ (ZIS) through a water-bath method to construct Schottky-type FCNZA/ZIS junctions. The aim was to exploit the synergistic benefits of medium-entropy effect and Schottky barrier. Characterization results confirmed that the optimized FCNZA/ZIS exhibited significantly improved photocatalytic activity for H₂ production and benzaldehyde generation, compared with pure ZIS. Photoelectrochemical measurements and band-structure analyses revealed that FCNZA broadened the light absorption range, promoted the charge separation, accelerated the interfacial charge migration, and effectively suppressed the carrier recombination. This work may open up a promising method for exploring highly-efficient bifunctional photocatalytic systems.

References

- [1] D. Liu, L. Dai, X. Lin, et al., Adv. Mater. 31, e1804863 (2019).
- [2] L. Zhang, X. Shi, A. Xu, et al., Nano Res. 17, 3693-3699 (2024).
- [3] C. Gomez-Solis, S.L. Peralta-Arriaga, L.M. Torres-Martinez, et al., Fuel 188, 197-204 (2017).

Zirconium-Modified TiAl(Nb,Mo)B Intermetallics Produced by Free SHS-Compression

I.A. Nazarko^{1,2}, P.M. Bazhin^{1,2}

¹ Merzhanov Institute of Structural Macrokinetics and Materials Science, Russian Academy of Sciences, Chernogolovka, 142432 Russia

² Peoples' Friendship University of Russia named after Patrice Lumumba, Moscow, 117198 Russia;

Email: nazarkovanya@yandex.ru

Titanium aluminide intermetallics are promising for high-temperature applications but are limited by low crack resistance at room temperature. In this work, the effect of zirconium alloying (1–3 at.%) on the synthesis, structure, and mechanical properties of TiAl(Nb,Mo)B-based materials produced by free SHS-compression [1] was investigated. It was established that Zr addition reduces the combustion temperature from 1550 to 1300 °C and increases the combustion velocity from 1 to 1.5 mm/s due to redistribution of the heat balance and the formation of refractory zirconium aluminide interlayers. X-ray diffraction confirmed the formation of a dispersed Al₂Zr phase, whose amount increases with Zr content, leading to significant structure refinement with Al₂Zr particles below 10 μm for the TNM-Zr3 composition, predominantly located at lamellar colony boundaries of γ- and α₂-phases. Mechanical testing by instrumented indentation and macroindentation at 100 N revealed an increase in Vickers hardness from 180 to 510 HV, microhardness from 3.7 to 6.8 GPa, elastic modulus from 140 to 220 GPa, and elastic recovery from 17.2 to 21.7%. For the TNM-Zr3 composition, no radial or lateral microcracks were observed around the indentation imprint, indicating high crack resistance at room temperature. The results demonstrate that zirconium alloying effectively improves the mechanical performance of TiAl(Nb,Mo)B-based intermetallics through combined strengthening by dispersed Al₂Zr precipitation, grain refinement, and matrix transformation.

References

[1] Bazhin P., Nazarko I., Bazhina A., Chizhikov A., Konstantinov A., Ivanov A., Antipov M., Stolin P., Agasieva S., Avdeeva V. Effect of High-Temperature Isothermal Annealing on the Structure and Properties of Multicomponent Compact Ti-Al(Nb,Mo,B)-Based Materials Fabricated via Free SHS-Compression. *Metals*. 2025; 15(10):1088. <https://doi.org/10.3390/met15101088>

Funding

This work was supported by the Russian Science Foundation project no. 22-19-00040-P

(https://rscf.ru/project/Eu4lcZCMCRUvJZDxa9QslFKsoBOTcEhnirsrHTMcItYVgxGlEU8npDA9_FmbCimJ_eJq5U14iwk~/).

Preparation of nanoparticles by carbon-containing droplet combustion-hydrocarbon synergistic reduction: Study on W-Cu composite powder

Aimin Chu¹, Xin Chen¹, Yuping Zhao²

¹ School of Materials Science and Engineering, Hunan University of Science and Technology, Xiangtan 411201, China

² School of Civil and Engineering, Hunan University of Science and Technology, Xiangtan 411201, China

Email: chuaiminme@163.com

Tungsten-copper (W-Cu) composite powders are important starting materials for manufacturing rocket nozzle throat liners, electromagnetic railgun rails, electronic heat dissipation components, and other advanced functional components, owing to their broad applications in aerospace, national defense, and electronics. When W-Cu composite powder are refined to the nanoscale, it can significantly increase the solid solubility between W and Cu, reduce the sintering temperature, and enhance densification, thereby enhancing the overall performance of W-Cu components. Therefore, development of effective preparation routes and the clarification of formation mechanisms for high-performance nanoscale W-Cu composite powders are of great significance. This study addresses the issues of abnormal W grain growth and W-Cu particle agglomeration during conventional hydrogen-reduction preparation of W-Cu composite powder by adopting a carbon-containing droplet combustion-hydrogen synergistic reduction method to produce nano W-Cu composite powder with micro-nano spherical structures. The stability of the components during carbon-containing droplet combustion, thermodynamic analysis of nano W-Cu composite powder preparation via hydrogen synergistic reduction, and related fabrication processes and reaction mechanisms were investigated. The main findings are as follows: (1) An ignition temperature above 600 °C and a hydrogen-assisted reduction temperature between 680 °C and 800 °C were suitable for preparing nanoscale W-Cu composite powders; (2) At an ignition temperature of 700 °C, combustion-derived powders collected using an electrostatic precipitator to collect combustion powder yields large hollow spherical precursors with high specific surface area and thin walls. After hydrogen-assisted reduction, uniform nanoscale W-Cu composite powder particles with an average particle size of 36 nm were obtained; (3) At a reduction temperature of 680 °C, the resulting nano W-Cu composite powder has a particle size of 21 nm and exhibited distinct micro-nano spherical structures; (4) The effective suppression mechanism of W for "volatilization-deposition" is as follows: On the one hand, carbon consumes the water vapor generated from tungsten oxide reduction, lowering the partial pressure of water vapor in the H₂ atmosphere and effectively inhibiting the formation of WO₂(OH)₂; on the other hand, highly reactive carbon-containing precursors and excess H₂ reduce the reduction temperature and holding time to 680 °C and 30 min, respectively, effectively preventing the volatilization of tungsten oxides at low temperatures and short durations.

Investigation of Solid-State Reaction Kinetics in Thin Film Nanosystems Using Simultaneous Thermal Analysis and in situ Electron Diffraction

E.T. Moiseenko¹, V.V. Yumashev^{1,2}, R.R. Altunin¹, S.M. Zharkov^{1,3}

¹ Siberian Federal University, Krasnoyarsk 660041, Russia

² Institute of Chemistry and Chemical Technology, Federal Research Center KSC SB RAS, Krasnoyarsk 660036, Russia

³ Kirensky Institute of Physics, Federal Research Center KSC SB RAS, Krasnoyarsk 660036, Russia

Email: e.t.moiseenko@ya.ru

The realization of controlled solid-state interactions between nanolayers in multilayer thin films is impossible without studying the kinetics of chemical reactions occurring in these films. The most informative way to study the kinetics of such reactions is the method of simultaneous thermal analysis combined with the structural methods. The kinetics of the solid-state reaction between nanolayers has been studied in Al/Pt [1], Al/Pt/Au, Al/Pt/Ag and Al/Pt/Cu thin-film nanosystems by the methods of in situ electron diffraction and simultaneous thermal analysis, as well as X-ray diffraction. The combination of the methods used allows us not only to specify both the reaction kinetic models and the kinetic parameters of all of the observed exothermic processes, but also to attribute them to the specific phases formed.

For example, in the case of the Al/Pt nanosystem it has been found that the process of solid-state reaction in the Al/Pt thin-film system under study is best described by a five-stage kinetic model:

The formation of the amorphous phase a-Al₂Pt has been found to be best described by the An type of reaction. The Al₃Pt₂ phase has been revealed to form in two sequential stages: Bna and R3 types of reaction. The formation of the Al₂₁Pt₈ and Al₄Pt phases can be best described by a kinetic model which consists of two parallel reactions: the An type of reaction for the Al₂₁Pt₈ phase and the Cn-X type of reaction for the Al₄Pt phase. The reaction types are described in detail in [2]. The kinetic parameters (apparent activation energies, pre-exponential factors etc.) of the phase formation for a-Al₂Pt, Al₃Pt₂, Al₂₁Pt₈ and Al₄Pt, have been determined, with those for Al₂₁Pt₈ and Al₄Pt found for the first time.

The work was supported by the Russian Science Foundation under grant #25-13-00351.

References

- [1] E.T. Moiseenko, V.V. Yumashev, R.R. Altunin, L.A. Solovyov, O.V. Belousov, S.M. Zharkov, J. Alloys Compd. 1047, 185110 (2025).
- [2] J. Opfermann, J. Therm. Anal. Calor. 60, 641 (2000).

Solution Combustion Synthesis of Y₂Hf₂O₇/YAG Composites: Microstructural Evolution and Thermophysical Properties of Resulting Ceramics

Shengyue Gu

Department of Materials Physics, School of Science, Xi'an University of Posts and Telecommunications, Xi'an 710121, China
Email: gushengyue@xupt.edu.cn

To address the demand for low thermal conductivity, sintering-resistant ceramic materials in high-temperature thermal protection applications, this study employed the solution combustion method using hafnium tetrachloride, yttrium nitrate, and aluminum nitrate as precursors to investigate the effects of distinct solutions on the synthesis of Y₂Hf₂O₇/Y₃Al₅O₁₂(YAG) composite powders. The reaction kinetics and the influence mechanism of YAG content on material properties were systematically analyzed. The results indicate that XRD confirmed the formation of Y₂Hf₂O₇/YAG dual-phase powders when urea was used as fuel, whereas other fuels predominantly yielded YAlO₃ and Y₂Hf₂O₇ phases. SEM/TEM characterization revealed porous morphologies across all systems; notably, the urea-derived powders exhibited uniform grain distribution and distinct grain boundaries, proving most suitable for controllable synthesis. Apparent activation energies for combustion (100.6–109.1 kJ·mol⁻¹) and crystallization (120.4–129.6 kJ·mol⁻¹) were determined via Kissinger, Augis–Bennett, and Mahadevan methods. The incorporation of the YAG phase increased interfacial density, effectively suppressing sintering while preserving high porosity and low bulk density. Thermal expansion and TG–DSC analyses verified excellent high-temperature stability. Furthermore, thermal conductivity exhibited a non-linear decrease with increasing YAG content, reaching a minimum value of 0.70–1.26 W·m⁻¹·K⁻¹ at a Y₂Hf₂O₇:YAG molar ratio of 1:0.25. In summary, the Y₂Hf₂O₇/YAG composite ceramics possess superior high-temperature stability, sintering resistance, and low thermal conductivity, showing promising potential for thermal and environmental barrier coating applications.

Research on the Preparation of High-Alpha Phase Si₃N₄ Powder by SHS

Weiping Shen, Changchun Ge

Institute of Powder Metallurgy and Advanced Ceramics, School of Materials Science and Technology, University of Science and Technology Beijing (USTB), China

Email: 3245761168@qq.com

Generally, the reaction will not be self-sustaining unless the adiabatic combustion temperature of the system $T_{ad} \geq 1800$ K in the center of the combustion wave. The temperature was higher than the melting point of Si (1685 K). Therefore, the β -phase content was significantly higher in the product core because the formation of the β -phase was favored by the presence of the liquid phase. In 1991, 95% α -phase Si₃N₄ powders were synthesized using self-propagating high-temperature synthesis (SHS) [1]. In 2000, 4 kg of 95% α -Si₃N₄ was synthesized using a 30 liters SHS reactor [2]. Consequently, the SHS of high- α -phase Si₃N₄ is challenging in a 60 liters SHS reactor.

In this study, a theoretical model of an open system was proposed in the high-temperature region of a propagating combustion wave in a large cake based on an analysis of the published research results of SHS Si₃N₄ and our research results on important reaction parameters in SHS Si₃N₄ and their mechanisms. The behavior of NH₄Cl, NH₄F, Ar, H₂, and NH₃ was analyzed using thermodynamics and reaction kinetics.

A cusp model was provided to illustrate the formation and transformation of α -Si₃N₄ and β -Si₃N₄. HF can react with β -Si₃N₄ or α -Si₃N₄ on the surface of inert diluent particles over a wide temperature range to form SiF₄. Then, α -Si₃N₄ could be re-synthesized through a decomposition and resynthesis mechanism, which explains why the α -Si₃N₄ content in our synthesized product was higher than that in the inert diluent. In the temperature region above the melting point of Si, liquid Si coated the surface of the Si₃N₄ particles that reacted with HF and HCl. In the temperature region below the melting point of Si, solid Si particles reacted with HF and HCl. The SHS Si₃N₄ cake of 110-120 mm in diameter and approximately 2250 mm long was characterized by high chemical purity, the highest content of the α -phase without β -Si₃N₄ and free silicon in the data file of XRD, and free silicon less than 0.8% in the chemical analysis, using a reactor of 60 liters into which a single load was 5 kg. The binding strength of hot-pressed ceramics using the SHS Si₃N₄ powder is equivalent to that of direct-nitrided Si₃N₄ powder.

References

- [1] Merzhanov A G, Borovinskaya I P, Popov L S, et al. Method of preparing silicon nitride with a high alpha-phase content. United States Patent, 5,032,370, 1991.
- [2] Zakorzhevskii V V, Borovinskaya I P. Some Regularities of α -Si₃N₄ Synthesis in a Commercial SHS Reactor. International Journal of Self-Propagating High-Temperature Synthesis, 9(2):171-191(2000).

Metallothermic Reduction of Ores, Concentrates and Slags

Onuralp YÜCEL¹, Ahmet TURAN², Kağan BENZEŞİK^{1,3}, Selçuk KAN¹, İbrahim YILDIRIM¹

¹ Metallurgical and Materials Engineering Department, Faculty of Chemical and Metallurgical Engineering, Istanbul Technical University, 34469, Maslak, Istanbul, Turkey

² Materials Science and Nanotechnology Engineering Department, Faculty of Engineering and Natural Sciences, Yeditepe University, 34755, Ataşehir, Istanbul, Turkey

³ Currently at; Max Planck Institute for Sustainable Materials, Düsseldorf, Germany

Email: yucel@itu.edu.tr

Solid waste generated by industry processes is a serious concern and the industry emphasizes the Reduce, Reuse and Recycle (3Rs) philosophy and effective waste management. This study aims to recover metals from raw materials such as solid ores, concentrates, and wastes like dolomite, chromite concentrates and electric arc furnace slag, through metallothermic reduction reactions using aluminum dross (Al_{Dross}), a waste of aluminum production, as a reducing agent.

According to the 2020 LCA conducted by the IMA, the production of 1 kg of magnesium using the Pidgeon process results in an average of 28 kg of CO₂ emissions when using ferrosilicon as the reductant which accounts for 12.5 kg of CO₂ per kg of Mg. Comparing reductants within thermal processes, aluminum offers the advantage of enabling magnesium production at temperatures below 900°C, although at a higher cost. Recycling aluminum from secondary sources offers significant energy savings, requiring approximately 5% of the energy needed for primary aluminum extraction. This study explores the potential use of aluminum smelting waste, which contains approximately 65 wt.% metallic aluminum (Al_{dross}), as a reductant in the vacuum aluminothermic production of magnesium.

In this study, the reducing smelting of chromite concentrates by EAF-assisted metallothermic method was also investigated. The effect of Al_{Powder} and Al_{Dross} addition amount, time, and the ratio of flux addition on the produced metal and slag compositions and metal recovery were investigated. It was seen that FeCr can be produced from fine-grained chromite concentrate by this method. As a result of EAF-assisted semi-pilot metallothermic smelting, the highest chromium content in produced alloys was 59.5 wt. %, while the highest chromium recovery to alloys was 76.7 wt. % in these experiments.

Slag is a byproduct of the steel industry that is created in large quantities because of increasing steel production. It is emphasized that 12–15% of the weight of the steel is generated as steel slag during the manufacturing of 1 ton of liquid steel in EAF. The aluminothermic reaction, in which aluminum was used as the reducing metal, was carried out in a muffle furnace within the scope of parameters such as %Al stoichiometry and Al_{Dross} addition in case EAF slag and mill scale were used as raw materials.

The results successfully demonstrated that the aluminothermic reduction reaction can effectively recover metals from dolime, chromite concentrate and solid industrial wastes such as EAF slag.

References

- [1] O. Yücel, U.A. Satılmış, M. Bugdayci, A. Turan, An Energy-Efficient and Environmentally Friendly Reductant in Magnesium Metal: Al_{Dross}, *Magnesium Technology 2025*, 51, TMS 2025 Annual Meeting & Exhibition, March 2025, Nevada, USA.
- [2] H. Güney, Ö. Güner, F.F. Boncuk, S. Kan, K. Benzeşik, O. Yücel, A Decarbonization Approach for FeCr Production, *Journal of Sustainable Metallurgy*, 2023, DOI: 10.1007/s40831-022-00632-7.
- [3] O. Yücel, A. Turan, K. Benzeşik, S. KAN, *et al.* “Combined Evaluation of EAF Steel and Aluminium Smelting Wastes, *Energy Technology 2025: Carbon Dioxide Management and Other Technologies*, 27, 2025, TMS 2025 Annual Meeting & Exhibition, March 2025, Nevada, USA,

Structural Regulation, Properties, and High-Entropy Engineering of Ultrafine Nanostructured Oxides via Solution Combustion Synthesis

Xiaohong Wang, Xintan Bai, Shaozhang Min, Zhichao Shang

School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, PR China

Email: wxhcumt@cumt.edu.cn

Solution combustion synthesis (SCS) offers a short-process, energy-efficient route to ultrafine oxides via self-sustained redox reactions between metal nitrates and fuels, and rapid heat release and gas evolution enable control of composition, defects, morphology, and phase structure. Here, SCS was extended from dopant-modified single oxides to high-entropy oxides to establish a progressive structure–property strategy. $\text{Ni}_{1-x}\text{Co}_x\text{O}$ nanopowders were first prepared by SCS and spray solution combustion synthesis (SSCS). SSCS produced NC91S with a hollow porous spherical architecture, a grain size of 15.1 nm, and $71.08 \text{ m}^2 \text{ g}^{-1}$ surface area. Co-incorporation induced lattice distortion and cation defects, enhanced visible-light absorption and charge separation, and increased methyl-orange degradation to 94.6% within 60 min, retaining 90.2% after five cycles. SCS was then extended to compositionally complex oxides. Single-phase rare-earth $(\text{Dy}_{0.2}\text{Ho}_{0.2}\text{Er}_{0.2}\text{Tm}_{0.2}\text{Yb}_{0.2})_2\text{O}_3$ was obtained at $\phi = 1$ and 700°C , with a particle size of 15.3 nm, homogeneous trivalent cation distribution, porous morphology, and high thermal stability. Further high-entropy engineering yielded a five-component spinel $(\text{MnFeCoNiMg})_3\text{O}_4$ via glycine-assisted SCS. Regulation of the fuel ratio and temperature yielded a single spinel phase with a controllable crystallite size; at $\phi = 1$ and 700°C , the crystallite size was about 19.4 nm. The powder exhibited a porous network morphology, while XPS revealed mixed +2/+3 valence states in Mn, Fe, Co, and Ni, along with Mg^{2+} , consistent with multivalent-cation occupation of the spinel lattice. SPS consolidation retained the spinel-dominated phase and produced a dense coating on SUS430 that remained bonded and suppressed Cr outward diffusion after oxidation at 800°C . These results demonstrate the evolution of SCS from single-oxide modification to high-entropy compositional engineering, integrating nanoscale structural regulation, defect/valence control, phase stabilization, and functional performance.

Fuel-Dependent Solution Combustion Synthesis of Spinel and Rock-Salt High-Entropy Oxides

U. Cinarli Yavas, A. Turan

Materials Science and Nanotechnology Engineering Department, Faculty of Engineering and Natural Sciences, Yeditepe University, 34755, Atasehir, Istanbul, Turkiye

Email: ahmet.turan@yeditepe.edu.tr

High-entropy oxides (HEOs) have emerged as a versatile class of materials due to their compositional complexity, entropy-driven phase stabilization, and multifunctional properties in energy, catalysis, and magnetic applications. The configurational entropy concept enables the stabilization of single-phase solid solutions in multi-cation systems, expanding the design space beyond conventional oxides [1,2]. Among these, spinel-structured (CoCrFeMnNi)₃O₄ and rock-salt (CoCuMgNiZn)O represent two HEO families with distinct structural characteristics.

In this study, both systems were synthesized via solution combustion synthesis (SCS) using glycine, urea, and citric acid fuels with varying fuel-to-oxidizer ratios. The effects of fuel chemistry and equivalence ratio (Φ_e) on combustion behavior, phase formation, and microstructure were investigated. Combustion characteristics strongly depend on fuel type and redox balance, directly influencing crystallinity and compositional homogeneity [3,4].

For the spinel system, glycine at the stoichiometric ratio (1.0x) provided optimal conditions, yielding homogeneous cation distribution and a well-defined Fd-3m phase after calcination at 900 °C. In contrast, non-stoichiometric conditions or alternative fuels resulted in incomplete combustion and reduced phase quality. For the rock-salt system, the optimal condition shifted to slightly fuel-rich compositions, where glycine at 1.5x produced the most homogeneous microstructure and a single-phase rock-salt structure. However, high-temperature calcination caused compositional instability due to Zn volatilization. To compensate for this, Mg and Zn contents were increased (+1.25x), resulting in near-equimolar cation distribution after calcination at 900 °C, as confirmed by normalized EDS (~20% oxide fractions).

Overall, the results indicated that fuel chemistry influenced combustion dynamics and consequently affected phase stability and microstructure in both systems. Glycine-based SCS appeared to be the most effective route, with optimal results obtained under stoichiometric or slightly fuel-rich conditions combined with calcination at 900 °C.

References

- [1] P. Kumar, T.N. Lam, P.K. Tripathi, et al., APL Mater. 10, 120701 (2022).
- [2] D. Ozkan, C. Karacaoglanli, ECJSE 8, 164 (2021).
- [3] E. Carlos, R. Martins, E. Fortunato, et al., Chem. Eur. J. 26, 9099 (2020).
- [4] N. Amirkhanyan, S. Kharatyan, K. Manukyan, et al., Combust. Flame 221, 110 (2020).

Rapid Oxidation of Hafnium Carbide: Microstructural and Phase Evolution of Hafnium Oxide

Tigran Ayvazyan, Viktoria Vardanyan, Marieta Zakaryan, Suren Kharatyan

Laboratory of Macrokinetics of Solid State Reactions, Institute of Chemical Physics NAS of Armenia, Yerevan 0014, Armenia

Hafnium carbide (HfC), as one of the most refractory ultra-high-temperature ceramics, holds great promise for applications in extreme environments. However, the reliable implementation of HfC requires a comprehensive understanding of its formation, processing pathways, and oxidation behavior under such conditions. In this work, we systematically investigate the synthesis, consolidation, and fast-heating oxidation mechanisms of dense HfC.

HfC nanopowder was successfully synthesized from HfO₂ via SHS by magnesiothermic reduction with subsequent carburization. Experimental results, supported by thermodynamic modeling, demonstrated that the combustion can be precisely controlled by optimizing the reactant stoichiometry. This optimization enabled the complete reduction of HfO₂ and the formation of HfC nanoparticles ranging from 20 to 100 nm in size. The synthesized powders were subsequently consolidated into compacts with >95% relative density using spark plasma sintering (SPS) technique under various temperature, pressure, and dwell-time conditions. Both the powders and the consolidated compacts were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), and transmission electron microscopy (TEM).

The HfC compacts were oxidized under rapid heating conditions using the High-Speed Temperature Scanning (HSTS) technique, which provided heating rates of up to 12,000 °C min⁻¹ followed by rapid quenching, thereby preserving intermediate oxidation stages. Oxidation experiments were performed in a controlled atmosphere (5% O₂ + 95% Ar) with up to maximum temperature of 1300 °C. High-resolution microstructural characterization provided detailed insight into the oxidation mechanism under these extreme conditions. In particular, fast heating promoted the stabilization of the metastable cubic phase of HfO₂ throughout a significant portion of the oxide scale, whereas slow heating resulted predominantly in the formation of the thermodynamically stable monoclinic phase. These findings demonstrate that rapid thermal processing significantly alters the oxidation pathway of HfC and provides new opportunities for tailoring the oxidation behavior of ultra-high-temperature ceramics.

Combustion Synthesis of Composite Powders with Nanostructures and Their Effects on Thermal Shock Resistance of Refractories

Donghai Ding, Xiaochuan Chong, Changkun Lei, Endong Jin, Chunzhuo Feng, Yanjun Li, Guoqing Xiao

College of Materials Science and Engineering, Xi'an University of Architecture and Technology

Email: dingdonghai@xauat.edu.cn

Both carbon/oxide composite powders and carbide/oxide composite powders can improve thermal shock resistance of refractories. The generation of nano carbon with special morphology (CNTs, CNFs or graphene) requires effective introduction of catalysts, while the growth of SiCnw is relatively easy, but the improvement of their amount and aspect ratio also requires effective introduction of catalysts and activators. Compared with powders by mechanical mixing, pre-synthesized composites powders have lower costs and significantly improve thermal shock resistance of low carbon refractories, primarily because composite powders enhance the specific fracture energy and Rst of matrix of low carbon refractories.

References

- [1] Cangshuo Wang, Changkun Lei, Donghai Ding, Guoqing Xiao et al. Enhancement of resistance to oxidation and low basicity slag corrosion of MgO-C refractories for steel refining ladles via addition of SiCnw/MgAl₂O₄ composite powders. Journal of the European Ceramic Society, Vol 46, 117936, (2026).
- [2] Chunzhuo Feng, Donghai Ding, Guoqing Xiao, et al. One-step synthesis of CNTs/MAw hybrids with excellent water wettability: The fate and role of Fe catalyst in growth of CNTs and MgAl₂O₄ whiskers. Carbon, Vol 234, 119984, (2025).
- [3] Chunzhuo Feng, Donghai Ding, Guoqing Xiao, et al. A review on enhancing properties of low carbon-containing refractories for advanced iron and steelmaking: from perspective of additives. Journal of Iron and Steel Research International, Vol 33, 32, (2026).

Multi-Principal Element Carbides ($\text{Ta}_{0.2}\text{Ti}_{0.2}\text{Nb}_{0.2}\text{Zr}_{0.2}\text{Hf}_{0.2}\text{C}$): Advanced Ceramic Materials Fabricated via SHS and SPS

D.O. Moskovskikh

National University of Science and Technology "MISIS", Moscow

Email: mos@nanoceram.ru

High-entropy or multi-principal element carbides (MPECs) represent a new class of ultra-high temperature ceramics with exceptional mechanical properties and thermal stability. In this work, a combined approach of high-energy ball milling (HEBM), self-propagating high-temperature synthesis (SHS) and spark plasma sintering (SPS) was applied to fabricate dense (TaTiNbZrHfC) ceramics. The SHS process demonstrated a stable combustion wave with maximum combustion temperature of 1740 °C. Phase composition analysis confirmed the formation of a single-phase face-centered cubic solid solution. The synthesized SHS powders were successfully consolidated by SPS at 2000 °C under 50 MPa for 10 minutes, resulting in nearly dense ceramics with relative density exceeding 97%. The obtained MPEC exhibits outstanding mechanical properties: Vickers hardness of 22.1 GPa, fracture toughness up to 5.8 MPa·m^{1/2}, and compressive strength of 2880 MPa. Detailed study of high-temperature creep behavior (1400–1600 °C) revealed extremely low steady-state creep rates of 10⁻⁸–10⁻⁹ s⁻¹, which is 1–2 orders of magnitude lower than those of binary carbides. The dominant deformation mechanism was identified as dislocation glide with a contribution up to 90%, and the active slip system $a/2\langle 0\bar{1}\bar{1} \rangle\{111\}$ was determined. Oxidation resistance tests at 1200 °C showed minimum mass gain of 17.5 mg/cm² due to the formation of a protective Ta₂Hf₆O₁₇ barrier layer. The developed material was also tested for helium ion irradiation and demonstrated superior structural stability compared to binary ZrC.

The proposed HEBM–SHS–SPS approach provides a reliable route for producing dense MPECs with excellent combination of hardness, creep resistance, oxidation resistance and radiation stability, making them promising candidates for aerospace and nuclear applications.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (FSME-2026-0005).

Thermal Explosion and Solution Combustion Synthesis of Porous Functional Materials: From Gas Filtration to Photocatalysis

Zhichao Shang^{a,b}, Peizhong Feng^a

^a Henan Key Laboratory of High Performance Carbon Fiber Reinforced Composites, Institute of Carbon Matrix Composites, Henan Academy of Sciences, Zhengzhou 450046, PR China

^b School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, PR China

Email: pz.feng@cumt.edu.cn

Combustion synthesis enables rapid phase formation and pore generation through exothermic reactions and gas release. Here, thermal explosion (TE) and solution combustion synthesis (SCS) were applied to porous CoAl-based IMCs for hot-gas filtration and ultrafine CeO₂-based photocatalysts. Preheating, space holders and low-energy self-exothermic regulation moderated the Co-Al reaction and produced interconnected porous monoliths. 3D X-ray microscopy linked pore topology with permeability and mechanical integrity. CoAl, Co-Al-Fe and Co-Al-Cr IMCs retained stable frameworks during high-temperature oxidation, while Fe and Cr promoted an Al₂O₃-rich protective layer. In parallel, template-assisted and spray SCS generated CeO₂-based materials with hierarchical porosity, ultrafine grains and oxygen-vacancy-rich surfaces. Spray-derived Ce_{0.95}Ni_{0.05}O₂ achieved 94.24 m² g⁻¹ and 94.90% xanthate degradation in 100 min, with •O₂⁻ as the dominant reactive species. These results show that controlling heat release and gas evolution provides a common route to integrate multiscale porosity with filtration durability and interfacial photocatalysis.

Novel Process Design and Comprehensive System Evaluation of Chemical Looping Combustion and Post-Combustion Carbon Capture

Dong Xiang

School of Chemistry and Chemical Engineering, Anhui University, Hefei, China

Email: xiangdong@ahu.edu.cn

Coal-fired power generation accounts for approximately 60% of China's installed capacity, and CO₂ emissions from the power sector contribute to over 40% of the nation's total emissions [1-2]. Driven by the “dual carbon” goals, energy-saving and emission-reduction retrofits of existing coal-fired units have become a critical task in the power generation sector. Current carbon emission reduction technologies for coal-fired power generation mainly include pre-combustion capture, oxy-fuel combustion, post-combustion capture, and chemical looping combustion [3]. Among these, pre-combustion capture is applicable to IGCC systems and can avoid issues such as large flue gas volumes and low CO₂ concentrations; however, it involves complex processes and high power generation costs. Oxy-fuel combustion uses high-purity oxygen instead of air to obtain high-concentration CO₂, but it incurs high energy consumption for air separation and requires substantial flue gas recirculation for temperature control. Post-combustion carbon capture offers good compatibility with existing power units and holds broad application prospects, yet its capture energy consumption and operating costs remain major bottlenecks to large-scale deployment. Chemical looping combustion, as an emerging carbon capture technology, utilizes oxygen carriers circulating between the fuel reactor and the air reactor to decouple the combustion process into two steps. This approach avoids direct contact between fuel and air, eliminates the need for air separation to produce pure oxygen, and enables the acquisition of high-purity CO₂ from the flue gas simply by condensation and water removal [4-5]. This study aims to conduct process innovation and techno-economic evaluation of chemical looping combustion and post-combustion carbon capture processes, with the goal of providing theoretical support for deep carbon reduction in coal-fired power generation and the integration of high shares of renewable energy.

References

- [1] Z. Shan, Q. Tan, H. Dong, et al. Optimization model of low-carbon technology adoption timing for coal power under decarbonization and flexibility demand: Empirical study in Beijing-Tianjin-Hebei region, China. *Appl. Energ.* 358, 122647 (2024).
- [2] X. Hou, X. Wang, S. Cheng, et al. High resolution CO₂ emissions inventory and investigation of driving factors for China using an advanced dynamic estimation model. *Resour. Conserv. Recy.* 215, 108109 (2025).
- [3] C. Wu, Y. Cai, L. Li, et al. Conceptual design, single-parameter and multi-objective optimization strategy for a low-power consumed and cost-effective CO₂ capture process from flue gas using [emim][NTf₂] as absorbent. *Chem. Eng. Sci.* 316, 121959 (2025).
- [4] N. Huang, A. Omosebi, X. Gao, et al. Water vapor effects on attrition and elemental migration of iron-based oxygen carrier in chemical looping combustion. *AIChE J.* 70, e18419 (2024).
- [5] L. Zhao, B. Ling, W. Xu, et al. A novel petroleum coke and biomass-to-olefins system by chemical looping gasification technology: Process design, efficiency assessment and cost assessment. *Energ. Convers. Manage.* 350, 120935 (2026).

Optimized Nickel-Based Catalysts for Production of Hydrogen and Carbon Nanomaterials via Methane Decomposition

T.S. Gudyma, P.B. Kurmashov, M.A. Danilenko, A.G. Bannov

Novosibirsk State Technical University, K. Marx. ave. 20, Novosibirsk, 630073, Russia

Email: gudymatan@mail.ru

The development of catalytic methods for the decomposition of light hydrocarbons (C1–C4) is an important direction in the processing of natural gas feedstocks. CO₂-free processes, such as the catalytic decomposition of methane, which yields “turquoise” hydrogen and carbon nanomaterials [1] are of particular interest:

The efficiency of this process depends strongly on the catalyst. Catalyst properties, in turn, are controlled by the synthesis method [2–3]. Solution combustion synthesis (SCS) is considered a promising approach for the synthesis of catalysts [4]. This method is a particular case of self-propagating high-temperature synthesis (SHS).

This work is devoted to the investigation of nickel-based catalysts (90%Ni-10%Cu/10%Al₂O₃) with high loading of active component prepared by SCS and compared with co-precipitated ones. Additionally, the feasibility of using multi-component mixtures for methane decomposition is assessed. Catalytic testing was carried out in a flow quartz reactor at 550–750 °C and atmospheric pressure under a methane atmosphere. The effluent gas composition was analyzed by gas chromatography, and the carbon yield was determined gravimetrically.

The SCS method using sucrose as a fuel produced bimetallic catalysts with high catalytic activity (carbon yield ~30 g/gcat. per 6 h time-on-stream) and a long lifetime (over 20 h). Co-precipitation, although more time-consuming than SCS, yielded catalysts with even higher activity, achieving carbon yields of up to 50 g/gcat. These results were obtained without preliminary reduction of the catalysts with hydrogen. Multicomponent catalysts (containing five or more metals, e.g. Ni, Cu, Co, Mo, Fe) also demonstrated activity in methane decomposition but required higher process temperatures and preliminary reduction. The novel approaches for optimization of yields of hydrogen and carbon nanofibers over SCS- and co-precipitation based catalysts were analyzed.

This work was carried out within the framework of a state assignment of the Ministry of Education and Science of Russia (project code FSUN-2026-0006).

References

- [1] M.A. Danilenko, P.B. Kurmashov, T.S. Gudyma, et al., *Fuel* 427, 140008 (2027)
- [2] Y. Li, C. Wang, C. Wang, et al., *Int. J. Hydrogen Energy* 230, 154829 (2026).
- [3] D. Yao, H. Yang, H. Chen et al., *Appl. Catal. B Environ.* 239, 565 (2018).
- [4] P.B. Kurmashov, A.V. Ukhina, A. Manakhov, A.V. et al., *Appl. Sci.* 13, 3962 (2023).

Biomass Self-propagating Catalytic Humification Technology: From High-Temperature Combustion Synthesis to Kiloton-Scale Potassium Humate Commercialization

Xintai Su, Changchun Ge, Xiaona Ren

South China University of Technology; University of Science and Technology Beijing

Email: ccge@mater.ustb.edu.cn

Self-propagating High-temperature Synthesis (SHS) technology, characterized by its rapid reaction kinetics, low energy consumption, and high product purity, has long been confined to the fabrication of advanced structural ceramics and cemented carbides. Breaking disciplinary boundaries, Academician Changchun Ge's team has pioneered the cross-domain application of SHS principles to biomass conversion, originally proposing the "Biomass Self-propagating Catalytic Humification Technology." This technology harnesses the inherent calorific value of agricultural and forestry residues to trigger a self-sustaining exothermic reaction under catalytic activation, enabling the rapid and directional conversion of biomass into artificial humic acid without external continuous heating. The research team systematically elucidated the catalytic mechanisms of iron-based catalysts, industrial solid wastes (e.g., fly ash, carbide slag, wood ash), and potassium hydroxide on the humification process, establishing clear structure-performance relationships between catalyst types and the resulting humic acid content as well as active functional group distribution. In November 2025, the world's first 1000-ton/year pilot demonstration production line for biomass self-propagating catalytic humification was commissioned at Fubang Fertilizer Co., Ltd. in Xiyang County, Jinzhong City, Shanxi Province. The produced potassium humate met the Grade I specifications for fertilizer-grade potassium humate as defined in GB/T 33804-2017. Field trials on maize demonstrated a significant yield increase of 16% when applying merely 3 kg/acre of the product alongside conventional compound fertilizer, compared to plots receiving compound fertilizer alone. Building on the stable operational data from the 1000-ton pilot line, two 10,000-ton/year commercial production facilities are scheduled for completion in Xinjiang and Guangdong in 2027, marking the technology's transition to full-scale industrial deployment. This presentation will detail the reaction mechanisms, solid-waste synergistic catalysis strategies, and key scale-up engineering techniques underlying this innovation, with particular emphasis on its adaptability for high-value agricultural recycling of biomass residues and saline-alkali soil remediation—providing critical technical support for a circular agriculture model featuring "solid waste reduction—humic acid valorization—soil quality enhancement."

Keywords: Self-propagating High-temperature Synthesis (SHS); Biomass humification; Artificial humic acid; Potassium humate; Solid waste synergy; Yield enhancement

New Silicon Nitride Composite Ceramics for Gas-Insulated Ultra-High-Voltage Applications

Yiming Zhang^{1,2}, Qiang He^{1,2}, Jingkai Nie^{1,2}, Hui Liu^{1,2}, Dong Hou^{1,2}, Yu Han^{1,2}

¹ Institute of New Electrical Material, China Electric Power Research Institute, Beijing 100192, China.

² State Key Laboratory of Advanced Power Transmission Technology, Beijing 102209, China.

Email: zhangyiming_ustb@163.com

Currently, the post insulators used in ultra-high voltage DC wall-penetrating bushings are all made of epoxy composite materials. With the rapid growth in electricity demand, the electrical and thermal conditions inside the equipment have become increasingly severe, making the reliability of the surface insulation performance of epoxy composite post insulators increasingly prominent. Ceramic materials, known for their high insulation and mechanical strength, hold potential for application in high-voltage DC electrical equipment. We explored a novel ultra-high voltage gas-insulated material, silicon nitride composite ceramics. Detailed investigations were conducted on the densification behavior and growth kinetics of silicon nitride powder under different rare earth additive systems. Through a stepwise sintering process, silicon nitride composite ceramics with a volume resistivity of $7.33 \times 10^{14} \Omega \cdot \text{m}$ at room temperature and low electric field were obtained, exhibiting superior mechanical and acid resistance properties. The research findings provide a new approach for the design of ultra-high voltage gas-insulated materials.

References

- [1] Y. Zhang, D. Hou, J. Nie, et al., J. Asian Ceram. Soc. 14, 105-113 (2026).
- [2] D. Hou, Y. Han, J. Nie, et al., Appl. Sci. 14, 1125 (2024).

Nd-Fe-B Magnets prepared by different approaches

A. Zurnachyan¹, Kh. Nazaretyan¹, S. Kharatyan¹, S. Aydinyan^{1,2}

¹A.B. Nalbandyan Institute of Chemical Physics, NAS RA, 5/2 P. Sevak St, 0014, Yerevan, Armenia

²Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia

Email: alina.zurnachyan@gmail.com

Nd-Fe-B magnets have indispensable components in a wide range of technologies, including electroacoustic devices, electric transportation systems, wind power generators, and household appliances [1,2]. However, the growing demand for neodymium (Nd) and other critical rare-earth (RE) elements has raised significant concerns regarding their cost, supply stability, and environmental impact [2]. Owing to the outstanding magnetic properties, continuous efforts are being devoted to developing efficient, sustainable, and cost-effective processing routes for the fabrication of Nd-Fe-B magnets.

This work investigates the preparation and characterization of Nd-Fe-B-type permanent magnets produced by different approaches, including conventional high-temperature furnace processing, self-propagating high-temperature synthesis (SHS), and spark plasma sintering (SPS). Particular attention was paid to the use of different precursor sources, including metallic and oxide forms of neodymium and iron, in order to evaluate their influence on phase formation and material properties. Experimental studies enabled the identification of processing conditions that promote the formation of the desired magnetic phases and facilitate solid-solution formation in the investigated systems.

It was shown that the desired products can be obtained by one stage process: a) in furnace, from mixtures 2Nd-14Fe-1B and Nd₂O₃-14Fe-CaH₂-1B and, b) by SHS process from mixtures (Nd)Nd₂O₃-Fe-Fe₂O₃-B-CaH₂ by variation of Fe/Fe₂O₃ ratio, as well as applied pressure, and sample dimensions.

Phase and microstructural analyses confirmed that the synthesized materials consist predominantly of the tetragonal Nd₂Fe₁₄B phase, with a phase fraction exceeding 95 wt.%. Microscopy observations revealed a homogeneous microstructure and uniform phase distribution. SPS consolidation of the synthesized powders resulted in highly dense magnets with refined microstructures and strong interparticle bonding. The fabricated magnets exhibited competitive magnetic and physical properties, together with enhanced thermal stability, as confirmed by thermal analysis. The results highlight the potential of combining different approaches with metallic and oxide precursor sources as versatile and energy-efficient routes for the production of high-performance Nd-Fe-B permanent magnets.

This work was supported by the Horizon Europe Project BEETHOVEN, which received funding from the European Union's Horizon Europe research and innovation program under GA No 101129912.

References

- [1] L. Liu, Q. Li, Z. Qu, et al. J. Magnet. Mag. Mat. 655, 174301 (2026).
- [2] C.W. Km, Y.H. Km, H.G. Cha & Y.S Kang, Physica Scripta 2007 (T129), 321 (2007).

Self-propagating high-temperature synthesis of AlON, MgAlON and MgAl₂O₄ for transparent ceramics application

T.G. Akopdzhanyan

Merzhanov Institute of Structural Macrokinetics and Materials Science RAS, 8 Academician Osipyan str., Chernogolovka,
Moscow Region, 142432, Russia

Email: tigj@yandex.ru

Transparent ceramics based on the AlN-Al₂O₃-MgO system (AlON, MgAlON, and MgAl₂O₄ spinel) are promising for applications in infrared windows and laser ceramics, as well as the automotive and aerospace industries [1,2,3]. However, their widespread use is limited by energy-intensive, multi-step powder synthesis routes. This work presents a novel, energy-efficient self-propagating high-temperature synthesis (SHS) approach for producing single-phase AlON, MgAlON with tunable compositions (M25, M50 and M75), and MgAl₂O₄ (MAS) powders, using perchlorates (Mg(ClO₄)₂ and KClO₄) as an internal oxidizers.

The key innovation is the use of solid oxidizer to provide internal oxygen, enabling self-sustaining combustion without external furnace heating. The influence of key processing parameters on combustion macrokinetics and phase composition was systematically investigated, including the amount of oxidizer, the composition of the gas atmosphere (N₂ for oxynitrides, air and argon for MAS), and the initial gas pressure (from 0.1 to 80 MPa). The as-synthesized powders are fine-grained with a high specific surface area after milling (up to 24.6 m²/g for MAS), demonstrating excellent sinterability.

The SHS-derived powders were consolidated by pressureless sintering (1830–1930°C) with various sintering aids. The resulting transparent ceramics showed composition-dependent properties: AlON exhibited the highest Vickers hardness (16.8 GPa) and fracture toughness, while MgAl₂O₄ demonstrated the highest thermal conductivity and the broadest IR transmittance (Figure). MgAlON ceramics provided intermediate properties, tunable by the AlON/MAS ratio. The optimal sintering temperature decreased with increasing MAS content, from 1930°C for AlON to 1830°C for MgAl₂O₄. This systematic investigation demonstrates that the SHS method offers a fast (synthesis time <120 s), scalable, and low-energy route for producing high-quality AlON, MgAlON, and MgAl₂O₄ powders, and the resulting ceramics exhibit a combination of optical, thermal, and mechanical properties suitable for various applications.

References

- [1] A.M. Tsabit, D.H. Yoon, J. Korean Ceram. Soc. 59, (2022).
- [2] J. McCauley, P. Patel, M. Chen, et al., J. Eur. Ceram. Soc. 29, (2009).
- [3] I. Ganesh, Int. Mater. Rev. 58, (2013).

Use of Ball Milling for Mechanical Activation in the Preparation of Nanostructured SHS Materials

Lj. Balanovic¹, V. Cosovic², I. Markovic¹, K. Bozinovic¹

¹ University of Belgrade, Technical Faculty in Bor, VJ 12, Bor, 19210, Serbia

² University of Belgrade, Institute of Chemistry, Technology and Metallurgy, Njegoseva 12, Belgrade, Serbia

Email: ljbalanovic@tfbor.bg.ac.rs

High-energy ball milling followed by self-propagating high-temperature synthesis (SHS) offers a versatile route for producing fine-grained, chemically homogeneous ceramics, intermetallics, refractory compounds, coatings, and functional materials. Milling modifies the precursor powder through repeated fracture, cold welding, plastic deformation, and remixing, thereby increasing specific surface area, refining particles and crystallites, introducing lattice defects and residual strain, removing or disrupting surface oxide layers, and creating fresh contacts that affect SHS ignition, wave propagation, and phase formation [1]. Two principal processing routes can be distinguished as mechanically induced self-propagating reaction (MSR), in which milling and reaction occur during milling in the same vessel, and mechanically activated SHS (MASHS), in which milling is intentionally stopped before significant reaction and the activated precursor is subsequently ignited in a separate step [2,3]. This contribution examines the development of the field from the foundations of SHS and mechanochemistry to contemporary studies of layered nanocomposites, nanoscale interfacial phases, discrete reaction waves, and time-resolved combustion dynamics. Particular attention is given to how milling dose affects thermodynamics, phase equilibria, microstructure, and kinetics. Thermal analysis, X-ray diffraction, and microscopy relate precursor activation to phase composition, porosity, and grain scale, while time-resolved methods address heterogeneous reaction waves [4]. Emerging directions are discussed, including standardized descriptions of milling intensity, quantitative precursor characterization, real-time diagnostics, refractory boride and silicide synthesis, high-entropy materials, and integration with advanced manufacturing methods.

Keywords: SHS; mechanical activation; ball milling.

Acknowledgment: Supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-34/2026-03/20013 and 451-03-33/2026-03/200026).

References

- [1] P. Baláž, M. Achimovičová, M. Baláž, et al., *Chem. Soc. Rev.* **42**, 7571 (2013).
- [2] L. Takacs, *Prog. Mater. Sci.* **47**, 355 (2002).
- [3] A. S. Mukasyan, A. S. Rogachev, S. T. Aruna, *Adv. Powder Technol.* **26**, 954 (2015).
- [4] A. S. Mukasyan, A. S. Rogachev, *Prog. Energy Combust. Sci.* **34**, 377 (2008).

Combustion synthesis of several advanced ceramic materials

G.H. Liu¹, K.X. Chen², J.T. Li³

¹ State Key Laboratory of New Ceramic Materials, School of Materials Science and Engineering, Tsinghua University, Beijing 100084, China

² State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing 100083, China

³ Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China

Email: liuguanghua@mail.tsinghua.edu.cn

Combustion synthesis is an effective method to produce a large diversity of inorganic materials with various chemical compositions and in different forms like powders, coatings, porous and dense bulks. In this work, we report some results on combustion synthesis of dense bulk inorganic materials.

We have employed two ways of High-Gravity Combustion Synthesis (HGCS) and Gas-Pressure Combustion Synthesis (GPCS) for preparing dense bulk inorganic materials including ceramics, metals, cermets, and functional materials. By these two ways, dense bulk samples are directly synthesized from the reactive mixture, where both the synthesis and the densification are finished in one step. In comparison with the conventional powder sintering, combustion synthesis may provide a furnace-free and faster approach to the fabrication of dense bulk inorganic materials. At the same time, the special reaction conditions in combustion synthesis offer more opportunities to tailor the microstructure of samples, thus opening new possibilities for the optimization of mechanical and physical properties.

References

- [1] G.H. Liu, K.X. Chen, J.T. Li, "Combustion Synthesis: Processing and Materials", Elsevier, 2024.
- [2] G.H. Liu, K.X. Chen, J.T. Li, Scripta Mater. 157, 167 (2018).
- [3] G.H. Liu, J.T. Li, K.X. Chen, Int. J. Refract. Met. Hard Mater. 39, 90 (2013).

Self-propagating high-temperature synthesis of ternary intermetallic functional Heusler alloys

M. Busurina¹, A. Sytshev, P. Lazarev

¹ Merzhanov Institute of Structural Macrokinetics and Materials Science, Russian Academy of Sciences, Chernogolovka,
Moscow region, 142432 Russia

Email: busurina@ism.ac.ru

Intermetallic alloys are essential for high-temperature structural components, thermoelectric converters, and spintronic applications. However, conventional synthesis methods such as arc melting and hot isostatic pressing are energy-demanding, slow, and, unlike SHS, require complex equipment (water-cooled copper crucibles, high-power power supplies), and are difficult to scale for producing porous or gradient structures. This work demonstrates that self-propagating high-temperature synthesis (SHS) and its modifications – SHS-metallurgy, SHS-pressing, and selective laser melting (SLM) of SHS-produced powders – enable rapid, single-step routes to dense, functional intermetallic alloys.

We investigated the synthesis of Co-based Heusler alloys Co_2TiAl (thermoelectric Heusler), Co_2MnSi (half-metallic ferromagnet) and $\text{Ti}_{20}\text{Si}_3\text{Al}_9$ (structural composite). For Co_2TiAl , SHS-metallurgy from $(\text{Co}_3\text{O}_4+\text{TiO}_2+\text{Al})$ yielded pure L_{21} phase. The Seebeck coefficient reached $-36.5 \mu\text{V/K}$ at 800 K, with a thermoelectric power factor of $1230 \mu\text{W/m}\cdot\text{K}^2$ at room temperature. For Co_2MnSi , thermal explosion of $(2\text{Co}+\text{Mn}+\text{Si})$ produced single-phase L_{21} structure ($a=0.565 \text{ nm}$) in 1–2 seconds. Saturation magnetization reached 130 emu/g (theoretical maximum), Curie temperature was 960 K, and the Seebeck coefficient was $-17.9 \mu\text{V/K}$ at 300 K. The maximum power factor was $1170 \mu\text{W/m}\cdot\text{K}^2$ at 470 K.

For the $\text{Ti}_{20}\text{Si}_3\text{Al}_9$ system, SLM of SHS powder produced fully fused claddings on Ti substrates with strong interfacial bonding. The phase composition of the remelted alloy after SLM is completely inherited from the original SHS-produced powder: the $\text{Ti}_{20}\text{Al}_3\text{Si}_9$ intermetallic phase remains unchanged.

Our future research will center on defect engineering in ternary intermetallic Heusler alloys to achieve a superior thermoelectric figure of merit. The underlying principle is that by optimizing defects, we can concurrently improve the materials electrical and thermal transport properties, leading to a synergistic enhancement of its thermoelectric performance.

References

- [1] M. Busurina, A. Karpov, Y. Morozov, et al, Metall Mater Trans A. 56, 5405 (2025)
- [2] P. Lazarev, A. Raznoschikov, M. Busurina, et al, Int.J. of SHS, 33, 287 (2024)

Microstructure and Properties of Self-Propagating High-Temperature Synthesized (Ti, W)C and Multi-component Carbides

Chengshang Zhou,¹, * Yuyang Gao, ¹ Tongwen Huang, ¹ Yunan Fan, ¹ Wanglin Li, ¹ Gang Chen, ² Xiaotian Tang, ² Yong Liu¹, *

¹, State Key Laboratory of Powder Metallurgy, Central South University, Changsha, Hunan 410083, China

², School of Materials Science and Engineering, Hunan University, Changsha, Hunan, 410082, China

Email: chengshang.zhou@csu.edu.cn

Refractory metal carbides play a critical role in numerous applications due to their exceptional hardness, excellent wear resistance and high-temperature stability. This study successfully synthesizes (Ti, W)C powders by using the self-propagating high-temperature synthesis (SHS) method. The results indicate that the phase structure, morphology, microstructure of (Ti, W)C carbides differ significantly from those of WC carbide synthesized using the similar technique. The (Ti, W)C carbides exhibit angular grain morphology with refined grain sizes due to the addition of Ti. The effect of the Ti/W ratio on the nanohardness of (Ti, W)C was examined, with the (Ti_{0.6}, W_{0.4})C sample achieving the highest hardness of 35.7 GPa±2.8 GPa. In addition, multi-component carbides can be synthesized using the SHS method. We further explore the synthesis route utilizing recycled WC-Co as a raw material.

Self-propagating High-Temperature Synthesis of HfB₂-HfSi₂-La₂O₃ Composite Powders and Their Coating Formation and High Oxidation Resistance

Chenzhe Zhu¹, Ph.V. Kiryukhantsev-Korneev³, Evgeny A. Levashov³, Xuanru Ren², Peizhong Feng¹,
Xiang Ji²

¹ School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, China

² Henan Key Laboratory of High Performance Carbon Fiber Reinforced Composites, Institute of Carbon Matrix Composites,
Henan Academy of Sciences, Zhengzhou 450046, China

³ National University of Science and Technology "MISIS", Leninsky prospect, 4, Moscow 119049, Russia

Email: pzfeng@cumt.edu.cn

The HfB₂-SiC based coating system is a classic ultra-high-temperature anti-oxidation coating,[1] relying on the protective passivation of self-formed glassy phases to prevent oxidation.[2] In this study, to further improve the high-temperature stability of the self-formed glassy phase, La₂O₃ was added to create a high-melting-point multi-phase glass layer, [3] enhancing the coating's high-temperature anti-oxidation protection.

This study used elemental powders of Hf, B, Si, and La₂O₃ as raw materials to prepare HfB₂-HfSi₂-La₂O₃ composite powders through self-propagating high-temperature synthesis (SHS), and then prepared (HfB₂-HfSi₂-La₂O₃)SHS-SiC coatings on carbon substrates via spark plasma sintering (SPS), systematically investigating their isothermal oxidation behavior at 1700°C and oxygen barrier mechanism. The results show that La₂O₃ is uniformly dispersed in the composite powders and forms good metallurgical bonding with HfB₂ and HfSi₂; the coating doped with 0.5 vol.% La₂O₃ (HHSL0.5) exhibited the lowest oxidation weight gain of 0.910×10^{-2} g·cm⁻², a 26.84% reduction compared to the undoped coating, with a cumulative carbon loss rate reduced to 6.999×10^{-6} g·cm⁻²·s⁻¹ and oxygen permeability as low as 0.636%. After oxidation, La³⁺ incorporates into SiO₂ to form La-Si-O complex glass,[4] which, together with Hf oxides, cooperatively constructs an Hf-La-Si-O multi-phase oxygen barrier layer, while the formation of high-melting La₂Si₂O₇ enhances the high-temperature durability of the glass phase; excessive La₂O₃ leads to coral-like aggregation of La₂Si₂O₇ and pore formation, weakening the oxygen barrier performance. This study provides an effective modification approach for improving the high-temperature oxidation stability of Hf-based coatings.

References

- [1] Shi D, Ji X, Wu B, et al., *Ceramics International*. 49.22, 36679 (2023).
- [2] Wu B, Wang P, Ren X, et al., *Ceramics International*. 48.15, 22039 (2022).
- [3] Qian D, Chen Y, Ren X, et al., *Journal of the American Ceramic Society*. 06.3, 2155 (2023).
- [4] Xie W, Fu Q, Cheng C, et al., *Ceramics International*. 47.8, 11560 (2021).

Synthesis of Bi-based nanomaterials via ionic liquid self-combustion and their photocatalytic performance

Fa-tang Li, Ying Liu

Hebei Key Laboratory of Photoelectric Control on Surface and Interface, College of Science, Hebei University of Science and Technology, Shijiazhuang 050018, China

Email: lifatang@126.com

Ionic liquid self combustion is a concept proposed by our research group. This work introduces the origin of our use of ionic liquid self combustion method and its application in synthetic materials. Using this method, for the sake of atomic economy, we synthesized a series of BiOX materials and proposed the idea of ion adsorption reverse induction to regulate crystal planes, achieving in-situ control of crystal planes and flipping of primary and secondary crystal planes in bismuth based materials. The in-situ generation of oxygen vacancies was achieved by constructing a reducing atmosphere, adjusting the band position of the catalyst and improving its activity. The one-step synthesis of heterojunctions utilizing the uniform mixing of ions has improved the separation rate of charge carriers. The relationship between surface properties and photocatalytic activity of bismuth based materials was studied, and for the first time, the side effects of hydroxyl radicals and oxygen vacancies in toluene mineralization were proposed, which broadened the application of combustion synthesis materials.

References

- [1] Q. Li, J. Ren, Y.J. Hao, Y.L. Li, X.J. Wang, Y. Liu, R. Su, F.T. Li, Appl. Catal. B, 317, 121761 (2022).
- [2] Q. Li, Y.L. Li, B. Li, Y.J. Hao, X.J. Wang, R.H. Liu, Y. Ling, X.Y. Liu, F.T. Li, Appl. Catal. B, 289, 120041 (2021).
- [3] L.Y. Li, Y.G. Ma, Q. Li, Y.L. Li, Y.J. Hao, X.J. Wang, R.H. Liu, F.T. Li, Chem. Commun., 57, 9676-9679 (2021).
- [4] F.T. Li, Q. Wang, J.R. Ran, Y.J. Hao, X.J. Wang, D.S. Zhao, S.Z. Qiao, Nanoscale, 7, 1116-1126 (2015).

Industrialization Status and Trend of Combustion-Synthesized Ceramic Materials in China

G.B.Zhan, Y.F.Miao, L.Fu

Shanghai GTC Semiconductor Material Co., Ltd

Combustion-Synthesis technology has emerged as a vital technical approach for the manufacturing of advanced ceramics. Based on China's industrial development status, this report systematically sorts out the industrialization status and bottlenecks of two types of ceramic materials, i.e., mature commercialized products and products for strategic emerging industries, and puts forward suggestions for future development directions.

There are three representative products for the former category: Al_2O_3 ceramic-lined composite steel pipes, molybdenum disilicide (MoSi_2), and ferrovanadium nitride (FeVN). Among them, Al_2O_3 ceramic-lined composite steel pipes are produced in China via the SHS centrifugal-casting process, with considerable production capacity and leading enterprises in this sector. For MoSi_2 powder production, the SHS process has become the dominant manufacturing technology in China, and its products are mainly applied to high-temperature heating elements and high-temperature protective coatings. As a micro-alloying additive for steel-making, ferrovanadium nitride is produced by existing ten-thousand-ton-scale annual-output production lines, which can fully satisfy both domestic and international market demands. As typical examples, these products have played a vital role in industrial applications over the past nearly 30 years.

The latter mainly covers high-end ceramic powders such as silicon nitride, aluminum nitride and silicon carbide prepared by combustion synthesis. Their new application scenarios support the development of high-end industries including photovoltaics, new-energy vehicles and semiconductor packaging. However, the industrialization of such ceramic products for emerging industries is constrained by multiple technical bottlenecks, mainly involving the design and fabrication of special-purpose equipment, process control for scaled-up production, harmless treatment of exhaust gas, as well as supporting post-treatment equipment and processes for combustion-synthesized powders.

This report appeals to researchers from academia and industry to strengthen applied research and fundamental theoretical research in above-mentioned fields. Priorities should be given to the R&D of dedicated equipment and on-line monitoring technologies, the construction of industrial-chain databases, and the promotion of data sharing as well as industry-university-research cooperation, so as to accelerate the industrialization of combustion-synthesized ceramic materials.

Research on Fabrication of STN-New Si_3N_4 -based Ceramic Inserts via SHS of SiAlON Ceramic Powder from Coal Gangue Combined with Cold Pressing, Hot Pressing, Laser Cutting and Precision Grinding

Changchun Ge, Xiaona Ren, Lin Han, Fengyu Lv

Institute of Powder Metallurgy and Advanced Ceramics, School of Materials Science and Technology, University of Science and Technology Beijing (USTB)

Email: ccge@mater.ustb.edu.cn

China has a massive stockpile of coal gangue. Conventional disposal methods tend to trigger water, soil and air pollution while resulting in low resource utilization efficiency. Nevertheless, coal gangue contains 50%–95% of SiO_2 and Al_2O_3 , making it a low-cost raw material for synthesizing Sialon ceramic powder. It can replace high-purity chemical feedstocks to substantially cut the production costs of ceramic inserts. STN-New Si_3N_4 -based Ceramic Inserts feature high wear resistance, hot hardness, excellent thermal shock resistance and chemical stability, good toughness and impact resistance. They are suitable for rough and interrupt machining of those materials which are very difficult or even impossible to be machined with cemented carbide inserts, such as wear resistant alloyed cast irons, chilled irons, quenched steels etc.. They can also be used for high-rate machining of grey irons, heat-treated steels etc., showing good versatility. They are widely adopted in high-end cutting processes in automotive, mold manufacturing, military and aerospace industries, with broad market demands.

We have established an integrated technological route consisting of "Coal Gangue pretreatment – carbonitriding self-propagating high-temperature synthesis of powder – cold pressing – hot-pressing and gas-pressure sintering – laser cutting – precision grinding". Relying on the coupled technology of carbothermal reduction nitridation and self-propagating high-temperature synthesis (SHS), Sialon ceramic powder is fabricated under a nitrogen atmosphere. After granulation with our first self-developed non-toxic, non-oxide sintering additives, the powder is formed into 150 mm circular green bodies via uniaxial bidirectional cold pressing. Two sintering routes are adopted separately: hot pressing sintering at 1850 °C and gas pressure sintering at 1950 °C. The sintered blanks are precisely cut by laser-cutting machine, then finish-machined with disc grinding, peripheral grinding and chamfer grinding to obtain finished cutting inserts with surface roughness grade 6. The pilot-production line is equipped with special manufacturing equipments including high-temperature nitriding furnaces, SHS autoclaves, attrition ball-mills, planetary ball mills, cold-pressing machine, hot-pressing furnaces, gas-pressure sintering furnaces, laser cutters and CNC grinding machines etc. Meanwhile, a full set of chemical analysis instruments, X-ray diffractometers, X-ray fluorescence spectrometer, universal testing machines, scanning electron microscopes, SEMs, EDSs, TEM are used for research and for full-process quality control covering raw materials, semi-finished products and finished products.

The pilot-production line boasts an annual output of 300,000 inserts. Bag dust collectors and high-voltage static-electricity collectors are used throughout the pilot-production process. The project can consume large quantities of coal gangue solid waste, which aligns with the policy direction of green manufacturing.

Overall, compared with the traditional synthesis route using high-purity chemical raw materials, this study innovatively adopts coal gangue solid waste to prepare Sialon ceramic powder, which drastically reduces the raw material cost of powder production can continuously consume tens of thousands of tons of coal gangue solid waste, fully complying with the strategic policies of circular economy, industrial solid waste resource utilization and the "Dual Carbon" goals. We have first developed non-toxic, non-oxide sintering additives to produce high-performance STN-New Si_3N_4 -based Ceramic Inserts, the performance of which reaches the internationally advanced level. Featuring remarkable environmental benefits and

steady economic returns, this pilot- production line is consistant with new circular-economy policy. It is worthy of extensive promotion.

Oxidation-driven glass evolution enabling self-sealing protection in HfB₂-based boride-silicide coatings at high temperatures

Yuexing Chen^{1,2}, Xiang Ji^{1,3}, Xuanru Ren^{1,3*}

¹ Henan Academy of Sciences, No. 228 Chongshi Lane, Zhengzhou City, Henan Province Zhengzhou 450046, China

² National Key Laboratory of Science and Technology on Advanced Composites in Special Environments, Harbin Institute of Technology, Harbin 150080, China

³ School of Materials Science and Physics, China University of Mining and Technology, No.1 Daxue road, Xuzhou, China, 221116

Email: XuanruRen@163.com

At high temperatures, oxidation is generally regarded as an unavoidable degradation process for ceramic protective coatings. Here, oxidation is shown to drive dynamic glass evolution and form a robust self-sealing barrier under extreme thermal conditions. An in situ alloyed boride-silicide composite coating is constructed, and the controlled incorporation of HfSi₂ is found to change oxide-scale development by providing additional Hf and Si sources during oxidation and promoting the early formation and continuous reconstruction of a highly sealing Hf-Si-O glassy layer. The optimized coating exhibits exceptional oxidation resistance at 1700 °C, with the oxygen permeability and carbon loss rate reduced by 61.67% and 75.26%, respectively, corresponding to an average protection efficiency of 99.94%. Mechanistically, oxidation-driven glass evolution seals pores and microcracks and slows inward oxygen diffusion, whereas appropriate HfSi₂ incorporation helps compact and stabilize the glassy layer, while excessive glass stiffening reduces high-temperature fluidity and weakens scale integrity. These findings provide a general design method for improving self-sealing oxidation protection at high temperatures.

Machine learning screening the feasibility for self-propagating reactions with ab initio dataset of the MAX and MAB phases

Yuelel Bai, Hang Yin, Xiaodong He

National Key Laboratory of Science and Technology on Advanced Composites in Special Environments and Center for Composite Materials and Structure, Harbin Institute of Technology, Harbin 150080, PR China

Email: baiyl@hit.edu.cn

As a rapid, scalable, and eco-friendly synthesis method, the self-propagating high-temperature synthesis (SHS) is widely applied for ceramics, however, whose development is always limited by high experimental costs. To address this challenge, a full ab initio computational procedure based on density functional theory (DFT) is proposed for screening the SHS feasibility of the MAX and MAB phases. After screening 34 MAB and 72 MAX phases, 19 MAB and 60 MAX phases have been determined to be synthesized via direct-ignition SHS under ideal adiabatic assumptions. The T_{ad} and ΔH_f are found to serve as almost identical criteria, while the T_{ad} of ternary compounds is independent of the corresponding binaries. The successful synthesis of Nb₂SC, V₂PC, Nb₂SB, Mn₅SiB₂ and V₅SiB₂ by direct-ignition SHS supports the usefulness of this prediction procedure. Using the calculated T_{ad} by DFT simulations as input data, the machine learning (ML) with Random Forest Regression (RFR) reveals that the elemental properties, such as atomic radius, valence electron concentration, and Pauling electronegativity, play a decisive role in determining the T_{ad} . The T_{ad} values generally increase when M elements are positioned toward the left of period 5 and A elements occupy the upper-right region of the periodic table. In addition, the SISSO algorithm brings a more interpretable forecast model that greatly reduces computational expense. With the aid of the well-trained ML models to quickly calculate T_{ad} , a new 512-type MAB phase V₅PB₂ is synthesized by SHS. This demonstrates the potential of the established ML models for identifying promising candidates, which indicates that they are anticipated to be of significant importance in screening for the feasibility of SHS reactions and optimizing process conditions.

Combustion synthesis of advanced functional materials and their performance in energy storage and conversion applications

Chunyu Zhu, Nan Sheng

School of Low carbon energy and power engineering, China University of Mining and Technology, Xuzhou, Jiangsu Province, China

Email: zcyls@cumt.edu.cn

Combustion synthesis is a very useful and widely studied method in synthesizing various functional materials for applications in energy storage and conversion. In our group, we have used solution combustion synthesis (SCS) process to fabricate oxide and porous carbon materials for use in electrode materials and electrocatalysts, which have shown good tailored performance. In addition, self-propagating high-temperature synthesis (SHS) process was also adopted to fabricate high-temperature functional ceramics, such as AlN and Si₃N₄, which were used as thermal conductive fillers with high thermal conductivity. The authors will share our recent researches about using combustion synthesis to produce functional materials for applications in energy storage and conversion.

The examples of the use of combustion synthesis in fabricating functional materials by our group.

References

- [1] Li Yunfei, Feng Peizhong, Zhu Chunyu et al. Applied Thermal Engineering, 2025, 279: 127535.
- [2] Zhao Bo, Sheng Nan, Zhu Chunyu, et al. Journal of Energy Storage, 2021, 42, 103028.
- [3] Sheng Nan, Zhu Chunyu, Rao Zhonghao. Journal of Alloys and Compounds, 2021, 871: 159458.
- [4] Zhu Chunyu, Takata Manami, Aoki Yoshitaka et al. Chemical Engineering Journal, 2018, 350: 278-89.
- [5] Zhu Chunyu, Saito Genki, Akiyama Tomohiro. Journal of Alloys and Compounds, 2015, 633(0): 424-9.
- [6] Zhu Chunyu, Akiyama Tomohiro. Electrochimica Acta, 2014, 127(0): 290-8.

Synthesis of Silicon Carbide by SHS Using Carbon Fibers as a Carbon Source

I.A. Shibakov¹, V. V. Zakorzhevsky¹, M. I. Alymov¹, N. S. Shibakova¹

¹ Merzhanov Institute of Structural Macrokinetics and Materials Science Russian Academy of Sciences (ISMAN), Academician
Osipyan str., 8, Chernogolovka, Moscow Region, Russia

Email: shibakov@ism.ac.ru

Silicon carbide (SiC) has high strength, hardness, thermal conductivity, resistance to oxidation, and low density and thermal expansion coefficient, making it a promising material for abrasives and high-temperature ceramics. One effective method for producing SiC powders is through self-propagating high-temperature synthesis (SHS), but the Si + C reaction has a low heat of formation and requires energy intensification [1]. To enhance the energy efficiency of the process, the synthesis was carried out in a nitrogen atmosphere. Carbon fibers were used as the source of carbon. The aim of the study is to investigate the possibility of obtaining silicon carbide fibers or whiskers by silicizing carbon fibers in a combustion mode.

In the experiment, carbon fibers (fiber length ~6 mm, diameter 6–7 μm , density 1.8 g/cm³), silicon powder (d₅₀ $\approx$ 2.0 μm), and technical nitrogen (O₂ content $\leq$ 0.4 % vol.) were used. The mixture was mixed in a vessel with tungsten carbide balls for 6 hours, and the fibers were crushed to a size of <50 μm . The mixture was placed in a graphite boat with fiberglass insulation, and the synthesis was carried out in a reactor at a nitrogen pressure of 4 MPa, initiated by a tungsten spiral.

As a result of the study, it was found that the SHS synthesis of silicon carbide using carbon fibers in a nitrogen atmosphere proceeds stably due to the additional heat generation during the interaction of silicon with nitrogen, which ensures the achievement of a combustion temperature of approximately 2000 °C and the realization of the main reaction for the formation of SiC. The resulting product consists of cubic silicon carbide and silicon nitride with a content of (~10 wt.%). The morphology of the synthesized product consists of conglomerates consisting of prismatic crystals, as well as polycrystalline hollow microtubes that retain the shape of the original carbon fibers. It was found that the formation of different types of structures is associated with the heterogeneity of the mixture and the implementation of two silicization mechanisms: the interaction of the fibers with liquid silicon and the reaction with silicon vapor in closed pores. The obtained results demonstrate the potential of using carbon fibers for the directed formation of SiC fibrous and tubular structures using the SHS method.

This work was supported by the Russian Science Foundation, project no. 25-19-00530 (<https://rscf.ru/project/25-19-00530/>).

References

[1] Izhevskiy V.A., Genova L.A., Bressiani J.C., Review article: Silicon carbide. Structure, properties and processing, *Ceramica* 46, 4-13 (2000)

Fabrication of Unidirectional porous Si₃N₄ Ceramics via the Combination of Freeze casting and Combustion Synthesis

Zhilei Wei¹, Wenqi Xie², Zhongqi Shi^{1,*}

¹ State Key Laboratory of Porous Metal Materials, Xi'an Jiaotong University, Xi'an 710049, China

² School of Materials Science and Engineering, Xi'an University of Technology, Xi'an, 710048, China

Email: weizhilei@xjtu.edu.cn

Unidirectional porous (UP) Si₃N₄ ceramics have attracted great attention for their wide applications in catalyst supports, filters and composite reinforcements. However, current strategies exhibit the drawbacks of high energy consumption, prolonged production cycle and challenges to control the anisotropic pore structures. Herein, a novel route of freeze casting combined with combustion synthesis was proposed to prepare the UP Si₃N₄ ceramics using Si powder and Si₃N₄ diluent as raw materials. The effects of diluent content and solid loading on the phase composition, microstructure and permeable/mechanical/filtration properties were investigated systematically. The results showed that the porosity and structure wavelength of UP Si₃N₄ ceramics can be tailored in a wide range of 50.8–86.0 % and 21.7–45.6 μm, respectively. In addition, the corresponding products possessed anisotropic thermal conductivity, compressive strength as well as good permeable and filtration properties. This work provides a novel insight into the fabrication of UP Si₃N₄ ceramics with the advantages of low cost, energy-saving and high efficiency.

References

- [1] Z. Wei, W. Xie, B. Zhang, et al. Compos. Sci. Technol. 267, 111199, (2025).
- [2] Z. Wei, W. Xie, J. Hu, et al. J. Alloys Compd. 1004, 175917, (2024).
- [3] Z. Wei, W. Xie, T. Li, et al. J. Am. Ceram. Soc. 109, e70552, (2026).

Preparation and High-Temperature Corrosion Resistance of Al-Alloyed MoSi₂ materials Fabricated by Self-Propagating High-Temperature Synthesis

Dewu Qin¹, Nana Zhu¹, Lu Zhu¹, Ph.V. Kiryukhantsev-Korneev², Evgeny A. Levashov², Peizhong Feng¹

¹School of Materials and Physics, China University of Mining and Technology, Xuzhou 221116, Jiangsu, P R. China

²National University of Science and Technology "MISIS", Leninsky prospect, 4, Moscow 119049, Russia

Email: pzfeng@cumt.edu.cn

MoSi₂-based ceramics are attractive candidates for high-temperature structural applications owing to their intrinsic oxidation resistance; yet molten Na₂SO₄ corrosion often degrades their durability. Although Al alloying has been explored to enhance the stability of the SiO₂ scale, the evolution of the protective scale under prolonged molten-salt attack and its interplay with pre-oxidation remain unclear. This study elucidates the evolution and degradation mechanisms of the surface scale and evaluates the potential synergy between Al alloying and pre-oxidation for improving the hot-corrosion resistance of MoSi₂-based ceramics. The results show that under direct molten-salt exposure, unalloyed MoSi₂ develops a porous reaction layer composed mainly of Na₂Si₂O₅ and Na₂MoO₄, causing progressive scale degradation and loss of surface integrity. In contrast, Al alloying induces a dense Al–Si–O composite oxide accompanied by protective NaAlSi₃O₈, which substantially enhances the stability and integrity of the reaction layer during prolonged corrosion. Pre-oxidation further establishes a continuous surface oxide scale prior to molten-salt exposure. While the pre-formed SiO₂ scale on MoSi₂ gradually deteriorates through alkaline fluxing, the Al-containing composite oxide remains dense and adherent throughout prolonged exposure, effectively suppressing molten-salt-induced scale degradation. These results demonstrate that the combined Al-alloying and pre-oxidation strategy can stabilize the surface scale and alter the corrosion evolution pathway, providing an effective approach for achieving durable protection of MoSi₂-based ceramics in aggressive molten-salt environments.

Solution combustion synthesis of Ni-containing catalysts for methane decomposition: towards optimizing the yield of carbon nanomaterials

A. G. Bannov, T.S. Gudyma, P.B. Kurmashov

Novosibirsk State Technical University, Novosibirsk, K. Marx 20, 630073 Russia

Email: Bannov_a@mail.ru

The catalytic decomposition of methane (CDM) is a novel CO_x-free method for the production of hydrogen [1]. The second product of the reaction is carbon nanomaterials. The search for a catalyst for the CDM process is an important task, since the catalyst determines the yield of products and the conversion of methane, as well as the process conditions. Solution combustion synthesis (SCS) is a promising technique for the synthesis of a wide range of catalysts for CDM. Ni-based systems possess the highest yields of hydrogen and carbon produced from methane and C₁–C₄ hydrocarbons. SCS makes it possible to carry out the synthesis in one stage and very quickly compared to well-known sol–gel, mechanical activation, impregnation, and other techniques.

This work is dedicated to the optimization of SCS of Ni-containing catalysts (Ni/Al₂O₃). There are many optimization approaches to enhance catalytic activity, and they are mainly based on the selection of synthesis regimes using conventional furnace heating. The ANOVA approach was used to optimize the heating rate, temperature, and fuel-to-oxidizer ratio when synthesizing the catalyst. The influence of various fuels (oxalic acid, hexamethylenetetramine, citric acid, sucrose, starch, urea, etc.) has been determined. Regression analysis has shown that the yields of carbon and hydrogen are most strongly influenced by temperature compared to other synthesis parameters. The additional application of correlation analysis, principal component analysis, and the random forest approach made it possible to determine the interconnections between product yields and textural properties of the catalyst (surface area, average pore size, etc.). Machine learning models could enhance the activity and lifetime of the catalysts before deactivation. This could make the catalysts useful not only for research but also for industry, allowing the optimization of not only materials for CDM but also other chemical engineering processes.

The work was carried out within a scope of State Task of Ministry of Science and Higher Education of Russian Federation (FSUN-2026-0006).

References

[1] S. Karimi, F. Meshkani, M. Rezaei, et al., Fuel 284, 118866 (2021).

Study on the Fabrication of Transition-Metal-Based Porous Materials with Micro/Nano-Scale Pore Structures

H. Wang^{1,2,3}, C.Y. Xu¹, W.B. Gao¹, Z.C. Shang¹, W.J. Guo^{1,2}, J.Z. Wang³, P.Z. Feng¹

¹ School of Materials Science and Physics: China University of Mining and Technology, Xuzhou 221116, PR China

² School of Chemical Engineering and Technology: China University of Mining and Technology, Xuzhou 221116, PR China

³ State Laboratory of Porous Metal Materials: Northwest Institute for Non-ferrous Metal Research, Xi'an 710016, PR China

Email: wanghz1012@163.com

Transition-metal-based porous materials possess unique pore structures that endow them with a broader range of functional properties than conventional materials. As a representative transition-metal-based porous material, porous Ni–Al materials exhibit considerable application potential. Owing to their distinctive porous structures and lightweight characteristics, they can be used as filtration or catalytic materials in high-temperature oxidative environments and acidic or alkaline corrosive conditions.

In this study, a fabrication strategy for porous Ni–Al materials with micro/nano-scale pore structures was investigated. Unlike conventional porous Ni–Al materials typically fabricated by self-propagating high-temperature synthesis, a combined powder diffusion sintering and dealloying approach was employed to construct porous Ni–Al materials with hierarchical pores spanning the microscale and nanoscale ranges. First, Ni–Al powders containing a sintering aid were compacted and subsequently sintered to generate the primary pore structure. Al was then partially removed through selective dissolution during dealloying. During this process, uniformly distributed nanopores were formed in situ, ultimately producing porous Ni–Al materials with a bimodal pore-size distribution.

The resulting material exhibited micrometer-scale pores ranging from 1 to 100 μ m and nanopores smaller than 5.0nm. Its specific surface area reached approximately 50m²/g while maintaining a relatively high overall porosity. The porous Ni–Al material fabricated using this method therefore combines high porosity with a large specific surface area and shows promising potential for applications in filtration and separation, fine chemical processing, catalysis, and related fields.

Keywords: micro–nano scale; transition metal; porous materials; fabrication technology

Dual-Form Ru Species Induce Long-Range Electronic Modulation of Ni/NiO Electrocatalysts via Thermal Explosion Reaction and Dealloying

W.J. Guo^{1,2}, P.Z. Feng¹

¹ School of Materials Science and Physics, China University of Mining and Technology, Xuzhou, 221116, P.R. China

² School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou, 221116, P.R. China

Email: wj.guo@cumt.edu.cn

Rationally modulating the electronic structure of catalysts and interfacial water structure is of great significance for achieving efficient water electrolysis[1-3]. Herein, a thermally explosive-synthesized Ni-Al intermetallic compound was selected as the dealloying precursor, and a hierarchically porous Ru-Ni/NiO catalyst modified by dual-form Ru species was fabricated via a thermal explosion-dealloying-electrodeposition strategy. In this catalyst, Ru exists in the coexisting form of single atoms and nanoscale clusters, distributed on the surface and within the pores of the substrate microstructure. Single-atom Ru effectively tunes the local electronic structure of Ni/NiO and facilitates interfacial charge redistribution via electronic coupling. Ru preferentially binds to surface oxygen of the NiO substrate, generating local Ru-O-Ni configurations to realize bridge oxygen-mediated electronic coupling. Meanwhile, Ru nanoclusters serve as primary active sites to optimize the adsorption and conversion behaviors of key reaction intermediates. Furthermore, the introduction of dual-form Ru promotes the formation of hydrogen-bond networks of interfacial water, thereby accelerating the Volmer step during the hydrogen evolution reaction (HER). Benefiting from the synergistic mechanism integrating dual-dispersed Ru species, electronic structure modulation and optimized interfacial water behavior, the Ru-Ni/NiO catalyst with a Ru loading of 1.05 wt.% exhibits outstanding bifunctional electrocatalytic activity toward HER and oxygen evolution reaction (OER), as well as excellent overall water splitting performance. This work establishes a dual-form metal modulation strategy that enables both the substrate and the decorated species to function cooperatively, providing new insights into the rational design of high-performance bifunctional electrocatalysts.

References

- [1] T. Liu, L.Q. Wang, B. Chen, et al. *Angew. Chem. Int. Ed.* 64, e202421869 (2025).
- [2] A.H. Al-Naggar, N.M. Shinde, J.S. Kim, et al. *Coordination Chemistry Reviews* 474, 214864 (2023).
- [3] Z.Y. Yu, Y. Duan, X.Y. Feng, et al. *Adv. Mater.* 33, 2007100 (2021).

Rapid Fabrication and Performance Analysis of Si-Alloyed Porous TiAl_3 Intermetallics

Yu Zhang

China University of Mining and Technology, Xuzhou 221116, China

Email: 774749768@qq.com

Porous TiAl_3 intermetallic compounds can be applied to high-temperature flue gas filtration and solid-liquid separation of titanium tetrachloride suspensions. However, monolithic pure TiAl_3 suffers from poor pore channel uniformity and insufficient high-temperature oxidation resistance. In this work, Ti and Al powders were used as raw materials with Si incorporated as an alloying element, and Si-modified porous TiAl_3 was rapidly fabricated via thermal explosion reaction. The effects of Si doping content on the exothermic behavior, phase composition, three-dimensional pore structure, permeability, and high-temperature oxidation resistance at 700–900 °C of the as-prepared materials were systematically investigated. The results reveal that the addition of Si alters the exothermic behavior of the Ti–Al system, transforming the original solid-liquid reaction pathway into a reaction route involving solid Ti, liquid Al–Si eutectic, and solid-liquid co-reaction. Si atoms dissolve into the intermetallic phase to form $\text{Ti}(\text{Al},\text{Si})_3$ solid solution, which to a certain extent hinders the direct contact between Al and Ti and weakens the intensity of the exothermic reaction. Both Ti and Al elements are homogeneously distributed, and Si is also uniformly dispersed throughout the skeleton of TiAl_3 products. Three-dimensional X-ray tomography characterization verifies that introducing Si into the Ti–Al system yields porous Ti–Al intermetallics with more complete reaction and more uniform pore structure. At identical oxidation temperatures, Si-free samples exhibit higher susceptibility to oxidation compared with specimens doped with 5 wt.% Si. At 700 °C, the oxidation kinetics follow a logarithmic growth law, indicative of mild oxidation or an ultrathin oxide scale. When the oxidation temperature rises to 800 °C and 900 °C, oxide film growth complies with the parabolic rate law. A dense and stable oxide scale exclusively forms on the skeleton surface, which inhibits further inward diffusion of oxygen and prevents substantial microstructural degradation, endowing the porous material with outstanding high-temperature oxidation resistance. Accordingly, the Si alloying strategy enables simultaneous optimization of the pore structure and high-temperature oxidation resistance of porous TiAl_3 , offering a novel fabrication route for high-temperature industrial filter materials.

Keywords: Porous TiAl_3 ; Thermal explosion reaction; Si alloying; Pore structure regulation; High-temperature oxidation resistance

Phase- and Morphology-Controlled Synthesis of SiC Nanomaterials by Flash Joule Heating for Electromagnetic Wave Absorption

Yong Gao, Rongtao Zhu

School of Chemical Engineering, China University of Mining and Technology, Xuzhou 221116, China

Email: rtzhu2010@cumt.edu.cn

Silicon carbide (SiC) is a promising ceramic and wide-bandgap semiconductor for high-temperature and electromagnetic-wave absorption applications, but conventional production often requires long thermal treatment, high energy consumption, and gas- or reagent-involved processes [1]. Here, a rapid field-assisted route for phase- and morphology-controlled SiC nanomaterials was developed using Flash Joule Heating (FJH) [2], which generates transient high-temperature conditions within seconds.

A variable-frequency FJH system with a main circuit, control module, reaction chamber, and data acquisition unit was constructed. HSC thermodynamic analysis indicated that a SiO₂/C molar ratio of 1:3 was favorable. Using SiO₂ and carbon black, complete conversion to 3C-SiC was achieved at 120 V after 15 flashes, followed by carbon removal at 850 °C for 1 h. Increasing the input voltage from 120 to 150 V tuned the peak temperature from approximately 1600 to 2800 °C and promoted the transformation from 3C-SiC to 6H-SiC. High-purity 3C and 6H-SiC nanoparticles with a purity of 99.9% were selectively obtained. Product morphology was regulated by raw-material particle size: smaller SiO₂ particles improved reaction completeness, whereas larger carbon black particles favored one-dimensional growth. SiC nanowires with aspect ratios of 7-35 were obtained from 10 μm carbon black, mainly through a vapor-vapor pathway.

Electromagnetic measurements showed that the SiC nanowires exhibited a minimum reflection loss of -16.31 dB at 6.4 GHz and 3.6 mm, with an effective absorption bandwidth of 4.65 GHz (4.08-8.73 GHz). The SiC/C-25 composite delivered a minimum reflection loss of -38.04 dB at 3.66 GHz and 3.6 mm, with an effective absorption bandwidth of 1.66 GHz (3.01-4.67 GHz). These results demonstrate that FJH offers a rapid, low-cost, and scalable route for preparing SiC-based functional materials and provides a promising field-assisted strategy for ceramic absorbers.

References

- [1] Chen, H., Jiang, J. & Zhao, H. Synthesis of highly dispersed silicon carbide powders by a solvothermal-assisted sol-gel process. *Appl. Phys. A* 124, 470 (2018).
- [2] Luong, D.X., Bets, K.V., Algozeeb, W.A. et al. Gram-scale bottom-up flash graphene synthesis. *Nature* 577, 647–651 (2020).

Recycling of SHS-Fabricated MoSi₂ and SiC Heating Elements into Oxidation-Resistant Coatings on Molybdenum via Spark Plasma Sintering

Lei Cheng¹, Ph.V. Kiryukhantsev-Korneev³, Evgeny A. Levashov³, Lu Zhu², *, Peizhong Feng¹, *

1. School of Materials and Physics, China University of Mining and Technology, Xuzhou 221116, Jiangsu, P R. China

2. Department of Industrial and Materials Science, Chalmers University of Technology, SE-41296, Gothenburg, Sweden

3. National University of Science and Technology "MISIS", Leninsky prospect, 4, Moscow 119049, Russia

Email: pzfeng@cumt.edu.cn

A sustainable approach to fabricating oxidation-resistant coatings on molybdenum is developed by reusing retired MoSi₂ and SiC heating elements, both of which are industrially produced through self-propagating high-temperature synthesis (SHS). The spent components were crushed and milled into powders, and four coating compositions were designed: pure MoSi₂, 85MoSi₂–15SiC, 75MoSi₂–25SiC, and 50MoSi₂–50SiC (wt.%). These mixtures were consolidated onto Mo substrates via spark plasma sintering (SPS) at 1500 °C. Microstructural observations revealed that the pure MoSi₂ coating contained cracks, while the SiC-containing coatings exhibited improved structural integrity. Oxidation tests indicated that the addition of SiC enhanced the oxidation resistance compared to pure MoSi₂; however, the optimal composition has not yet been determined and further evaluation is ongoing. Based on the current results, the most promising SiC-containing formulation will be selected as the matrix for the subsequent incorporation of recycled glass powder, aiming to improve self-healing capability and thermal cycling performance. This work demonstrates an environmentally friendly strategy that bridges SHS-derived starting materials and SPS coating technology for refractory metal protection.

References

- [1] L. Zhu, S.P. Zhang, F. Ye, X.R. Ren, P.Z. Feng, Recycling of MoSi₂-based industrial solid wastes for the fabrication and high-temperature oxidation behavior of MoSi₂-ZrSi₂-SiC composite coating, *Composites Part B-Engineering*, 274 (2024).
- [2] L. Zhu, P. Chen, Z.M. Cai, P.Z. Feng, X.Q. Kang, F. Akhtar, X.H. Wang, Fabrication of MoSi₂ coatings on molybdenum and its high-temperature anti-oxidation properties, *Transactions of Nonferrous Metals Society of China*, 32 (2022) 935–946.

Exploiting Thermal Expansion Mismatch for Gradient Self-Assembly in SHS-Derived Ultra-High Temperature Ceramic Coatings: A Strategy for Superior Oxidation Protection

Jun Zhao^{1,2}, Xiang Ji², Leihua Xu¹, Peizhong Feng¹, Xuanru Ren²

¹ School of Materials Science and Physics, China University of Mining and Technology, No.1 Daxue road, Xuzhou, China, 221116

² Henan Academy of Sciences, No. 228 Chongshi Lane, Zhengzhou City, Henan Province Zhengzhou, 450046, China
Email: ts24180057a31@cumt.edu.cn

Corresponding author Email: jixiang_manuscript@163.com

This work addresses the intrinsic porosity and oxidation susceptibility of Self-propagating High-temperature Synthesis (SHS)-produced ultra-high temperature ceramics. A borosilicate glass (BSG)-modified ZrB₂-MoSi₂ gradient composite coating is fabricated via SHS, utilizing thermal expansion mismatch to induce an in-situ self-assembled gradient structure. Systematic investigation of densification temperature effects reveals that a self-assembled oxygen-blocking microstructure forms above 1300 °C. Optimal interfacial bonding strength reaches 84.6 N, with minimum oxidation weight gain of 0.24×10^{-2} g·cm⁻² after 100 min at 1700 °C. The coating exhibits an oxygen transmission rate of 0.04 % and cumulative protection efficiency of 99.95 %.

To overcome oxide scale volatility and self-depletion in the base system, a Hf-based borosilicate glass modification is introduced. Optimal HfO₂ content enables in-situ formation of a continuous, highly viscous Zr-Hf-Si-O multi-phase glass layer during oxidation, significantly suppressing oxygen inward diffusion. This modification reduces oxidation weight gain and average oxidation rate while improving hardness retention. The enhanced stability and continuity of the oxide scale align with the gradient self-assembly principle observed in the primary coating.

A Modified Tubular Solid Oxide Electrolysis Cells Fuel Electrode Design for Efficient CO₂ Electrolysis

Yaqiong Guo, Ao Shen, Fangjun Jin*, Yihan Ling*

School of Materials Science and Physics, China University of Mining and Technology, No.1 Daxue road, Xuzhou, China, 221116

Email: lyhyy@cumt.edu.cn

High-temperature CO₂ electrolysis using solid oxide electrolysis cells (SOECs) represents an important technical route for large-scale renewable energy storage and CO₂ resource utilization. However, the catalytic activity of Ni toward CO₂ in conventional Ni-YSZ fuel electrodes is limited, which restricts the electrolysis performance and long-term operational stability. To address this issue, this study employed La_{0.1}Ce_{0.9}O_{2-δ} (LDC) nanoparticle infiltration to modify the Ni-YSZ fuel electrodes of tubular SOECs, aiming to improve their catalytic activity and stability for CO₂ electrolysis. Electrochemical measurements showed that under a fuel atmosphere of 50%H₂-25%CO₂-25%N₂, the LDC-modified cell delivered a current density of 1794.35 mA/cm² at 800 °C and 1.5 V, significantly higher than the un-infiltrated cell. Meanwhile, the LDC-infiltrated cell exhibited outstanding stability over 120 h with negligible microstructural degradation, whereas the un-infiltrated cell showed obvious performance decay after 60 h of operation. DFT calculations confirmed that LDC possesses a higher oxygen vacancy concentration and stronger CO₂ adsorption and activation capability, which can effectively accelerate interfacial reactions and CO₂ adsorption. This work provides an effective strategy for the modification of Ni-YSZ fuel electrodes.

Small-Size Atom-Driven Distortion Realizes High-Entropy Oxides with Simultaneous Chemical Stability and Activity Enhancement Enabling a Practical Cathode for Solid Oxide Fuel Cells

Wenjing Zhang, Yihan Ling*

School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, PR China

Email: lyhyy@cumt.edu.cn

Both high activity for oxygen reduction reaction and excellent chemical stability against contaminants in the surrounding atmosphere under operating conditions are required for a viable cathode of solid oxide fuel cells. However, traditional Ba_{0.8}Sr_{0.2}Co_{0.2}Fe_{0.8}O_{3-δ} (BSCF) crystal structures suffer from instability under both high-temperature, high-reduction conditions and low-temperature, high-oxidation environments, making them prone to poisoning and significantly compromising their long-term operational stability. In this study, we engineered lattice distortion in BSCF by incorporating small-sized atoms at the A-site, resulting in a novel Ba_{0.2}Sr_{0.2}La_{0.2}Pr_{0.2}Sm_{0.2}Co_{0.2}Fe_{0.8}O_{3-δ} (H-BSCF) high-entropy perovskite oxide, which shows significantly improved resistance to CO₂ and Cr vapor poisoning without impairing catalytic activity. Both experimental and results show the high-entropy strategy introduces lattice distortion, enhancing structural stability to prevent phase transitions and segregation. This distortion induces a spin state transition in Co³⁺ ions that increases the density of unpaired electrons and significantly enhances Co 3d-O 2p orbital hybridization, which also prevent structural collapse, thereby markedly improving chemical stability without sacrificing catalytic activity. Density functional theory calculations demonstrate that H-BSCF possesses favorable oxygen migration energy and high segregation energy. The combined superior catalytic activity and stability make H-BSCF promising for industrial application.

References

- [1] S. S. Sohn, A. Kwiatkowski da Silva, Y. Ikeda, et al., Adv. Mater. Vol., 31st 1807142, (2018).
- [2] X. Han, Y Ling, Y. Yang, et al., Adv. Funct. Mater. Vol., 33st 2304728, (2023).

Enhancing the Stability of Direct Low-Concentration coalbed methane Tubular Solid Oxide Fuel Cells by Modifying the Catalyst Layer Using the B-site entropy engineering

Tian Li, Yihan Ling*

School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, P.R. China

Email: lyhyy@cumt.edu.cn

Low-concentration coalbed methane (LCCBM), has long faced utilization challenges due to the high costs and safety hazards associated with traditional methods. Coupling LCCBM with tubular solid oxide fuel cells (T-SOFC) offers a viable pathway for achieving efficient energy conversion. However, this process is prone to carbon deposition and oxidation of Ni-based anode, resulting in diminished cell stability. Therefore, based on the classical $\text{La}_{0.75}\text{Sr}_{0.75}\text{Cr}_{0.5}\text{Mn}_{0.5}\text{O}_{3-\delta}$ (LSCrM) perovskite, a high-entropy catalyst ($\text{La}_{0.75}\text{Sr}_{0.25}\text{Cr}_{0.5}\text{Fe}_{0.1}\text{Ni}_{0.1}\text{Co}_{0.1}\text{Zn}_{0.1}\text{Mn}_{0.1}\text{O}_{3-\delta}$, HE-LSCrM) is proposed. After hydrogen reduction, a configuration of a high-entropy perovskite matrix with Ni nanoparticles (HE-LSCrM-R) is in-situ formed, significantly enhancing methane partial oxidation activity and carbon tolerance. When employed as anode reforming layer of T-SOFC, the decorated cell achieves a maximum power density of 728.293 mW/cm² at 750 °C with LCCBM fuel. More importantly, the cell remains a stably operation for 100 h with no carbon deposition observed on the anode surface. Density functional theory calculations (DFT) further reveals that high-entropy material exhibits strong adsorption capacity for both CH₄ and O₂, promoting the formation of CH₂O and CHO intermediates, thereby effectively suppressing carbon deposition. Concurrently, the high-entropy perovskite material demonstrates exceptional adsorption and hydration capabilities for water generated during the anode reaction, further enhancing the reforming efficiency of methane gas.

References

- [1] Y. Yang, T. Li, P. Feng, et al, Appl. Energy, 328 428-437 (2022).
- [2] Y. Yang, Y. Liu, Z. Chen, et al, Sep. Purif. Technol. 288 120134 (2022).

Rapid Preparation of (MoWTaNbV)Si₂ by Self-Propagating High-Temperature Synthesis Coupled with Spark Plasma Sintering and Its High-Temperature Oxidation Resistance

Dewu Qin¹, Lu Zhu², Xiaohong Wang^{1,3,4,*}, Peizhong Feng^{1,3,4,*}

¹School of Materials and Physics, China University of Mining and Technology, Xuzhou 221116, Jiangsu, P R. China

²Department of Industrial and Materials Science, Chalmers University of Technology, SE-41296, Gothenburg, Sweden

³Jiangsu Key Laboratory for Clean Utilization of Carbon Resources, Xuzhou, 221116, P R. China

⁴International Joint Laboratory of Minerals Efficient Processing and Utilization Ministry of

Email: pzfeng@cumt.edu.cn

Refractory metal disilicides are promising for ultra-high temperature applications but suffer from catastrophic oxidation and brittle SiO₂ scales that spall under thermal cycling [1, 2]. High entropy silicides (HES) have shown improved intermediate temperature behaviour, yet their oxidation performance above 1500 °C remains unexplored, especially for the C40-type (MoWTaNbV)Si₂ system. Furthermore, the role of compositional tailoring—specifically Mo content—on phase stability, oxidescale evolution, and longterm protection at 1500 °C is unclear [3]. This work aims to clarify how reducing Mo content influences the phase constitution, microstructural development, and oxidation kinetics of sparkplasma-sintered (MoWTaNbV)Si₂ ceramics during 50 h exposure in air at 1500 °C. Powders of Nb, Mo, Ta, W, V, and Si were used as raw materials. (MoWTaNbV)Si₂ powders with varying Mo molar ratios were first synthesized by self-propagating high temperature synthesis (SHS), then consolidated into dense bulk ceramics by spark plasma sintering (SPS) at temperatures 200–300 °C lower than conventional hot pressing, with short holding times. The sintered specimens were subjected to isothermal oxidation tests at 1500 °C for up to 50 h in static air. Phase constitution was characterized by XRD, microstructure and oxidescale morphology by SEM/EDS.

All sintered compacts achieved high densification. Decreasing Mo content drove a phase transformation from binary MoSi₂ towards a single-phase high entropy solid solution, accompanied by a reduction in free SiO₂. During the initial oxidation stage, low-Mo compositions (Mo₂₀) formed a dense, multiphase oxide scale consisting of amorphous silicate and SiO₂, whereas Mo-rich samples produced loose and nonuniform scales. After 50 h at 1500 °C, the mass gain for Mo₈₀ was only 0.143×10^{-2} g·cm⁻², markedly lower than that of Mo₁₀₀ (0.553×10^{-2} g·cm⁻²). The oxide scale on Mo₈₀ remained dense and adherent throughout the test. Rational reduction of Mo content effectively suppresses the formation of volatile MoO₃ and promotes a continuous, crack-free silicate/SiO₂ protective layer, significantly enhancing the ultra-high temperature oxidation resistance of (MoWTaNbV)Si₂ high entropy disilicides. The C40-type phase, favoured at lower Mo levels, appears to contribute to scale stability. These findings provide a clear compositional strategy for designing oxidation-resistant HES ceramics for demanding ultra-high temperature environments, and open further questions on the interplay between valence electron concentration, phase structure, and longterm oxidation mechanisms.

Keywords: High-entropy silicides; SHS-SPS route; MoSi₂ ceramics; high-temperature oxidation

References

- [1] S. Ye, J. Zhu, H. Wang, M. Li, Z. Huang, J. He, Phase evolution and thermal stability of novel high-entropy (Mo_{0.2}Nb_{0.2}Ta_{0.2}V_{0.2}W_{0.2})Si₂ ceramics, *J. Eur. Ceram. Soc.*, 42 (2022) 5314–5322.
- [2] A. Salian, P. Sengupta, I. Vishalakshi Aswath, A. Gowda, S. Mandal, A review on high entropy silicides and silicates: Fundamental aspects, synthesis, properties, *International Journal of Applied Ceramic Technology*, 20 (2023) 2635–2660.
- [3] Z. Zhang, H. Yi, M. Liang, L. Xie, B. Wang, J. Gao, T. Ma, B. Yin, Y. Yang, Revealing the oxidation and self-healing properties of the in-situ synthesised high-entropy silicide composite ceramics, *Ceramics International*, 51 (2025) 21340–21353.

Preparation and Oxidation Resistance of (MoWNbTaCr)Si₂-SiC High-Entropy Silicide Coatings on Nb Substrate

Hongfeng Chai, Lu Zhu, Peizhong Feng

1 School of Materials Science and Physics, China University of Mining and Technology, Xuzhou, 221116, P. R. China

2 Department of Industrial and Materials Science, Chalmers University of Technology, SE-41296, Gothenburg, Sweden

Email: chf00814@gmail.com

Nb alloys are attractive for ultra-high-temperature applications, but their poor oxidation resistance restricts service in aerobic environments. This work aimed to fabricate a (MoWNbTaCr)Si₂-based coating on Nb and clarify the role of SiC in crack suppression and oxidation resistance. Mo, W, Nb, Ta, Cr and Si elemental powders were ball-milled for 6 h and reacted by SHS to obtain a high-entropy silicide precursor. The product was crushed/ball-milled, mixed with 5 or 10 wt.% SiC, and consolidated on Nb by SPS at 1450 °C. XRD confirmed a C40-type (MoWNbTaCr)Si₂ phase. The bulk silicide was dense and crack-free, and after short oxidation it was covered by an almost continuous SiO₂ film. In contrast, the SiC-free coating showed through-thickness cracks, attributed to thermal-expansion mismatch between the coating ($9.8 \times 10^{-6} \text{ K}^{-1}$) and Nb ($7.2 \times 10^{-6} \text{ K}^{-1}$). Adding SiC reduced this mismatch: 5 and 10 wt.% SiC eliminated visible surface cracks and produced dense coatings.

After oxidation at 1500 °C for up to 50 h, all coatings showed low mass gain. The SiC-free coating exhibited higher initial mass gain because cracks acted as oxygen diffusion paths, while SiO₂ formation gradually sealed the cracks. After 50 h, the surface consisted mainly of a thin ($\sim 7 \mu\text{m}$) SiO₂-Cr₂O₃ scale with CrTaO₄ particles, and cross sections revealed a $\sim 230 \mu\text{m}$ diffusion layer composed of a Si-depleted region, NbSi₂/Nb₅Si₃ layer and Cr-rich zone. These results demonstrate that SHS-assisted SPS can fabricate oxidation-resistant (MoWNbTaCr)Si₂-SiC coatings on Nb, and that SiC mainly improves reliability by suppressing thermal-stress-induced cracking.

Synergistically enhanced energy storage performance in BNT-based ceramics via phase engineering and local structure design

Lanqing Liang¹, Chaoqiong Zhu^{2,3}, Ziming Cai^{2,3}, Peizhong Feng^{1,2,3,4}

¹ School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou, China.

² School of Materials Science and Physics, China University of Mining and Technology, Xuzhou, China

³ Jiangsu Key Laboratory for Clean Utilization of Carbon Resources, Xuzhou, China.

⁴ International Joint Laboratory of Minerals Efficient Processing and Utilization Ministry of Education, Xuzhou, China.

Email: pzfeng@cumt.edu.cn

Bismuth sodium titanate (BNT)-based ceramics are promising lead-free candidates for advanced pulsed-power capacitors; however, their energy-storage performance is severely restricted by intrinsically strong long-range ferroelectric domains. In this work, a multiscale regulation strategy integrating phase engineering, local lattice distortion, and defect-structure construction is proposed to induce relaxor ferroelectric behavior in $(1-x)(0.65\text{Bi}0.5\text{Na}0.5\text{TiO}_3-0.35\text{BaZr}0.2\text{Ti}0.8\text{O}_3)-x\text{Sr}(\text{Mg}1/3\text{Nb}2/3)\text{O}_3$ $(1-x)\text{BNTBZT}-x\text{SMN}$ ceramics. The introduction of $\text{Sr}(\text{Mg}1/3\text{Nb}2/3)\text{O}_3$ effectively promotes the coexistence of rhombohedral R3c and tetragonal P4bm phases, induces pronounced lattice distortions and dislocation structures, and disrupts the long-range ferroelectric order of the BNTBZT matrix, thereby enhancing the relaxor behavior. The synergistic effects of grain refinement, band-gap widening, and reduced oxygen-vacancy concentration significantly improve the breakdown strength. As a result, the 0.85BNTBZT-0.15SMN ceramic achieves a recoverable energy storage density of 4.63 J/cm³ with an energy storage efficiency of 90.3%. By further employing the tape-casting technique, the energy-storage performance of the tape-cast 0.85BNTBZT-0.15SMN ceramic is further enhanced, delivering a recoverable energy storage density of 9.1 J/cm³ and an energy storage efficiency of 90.1%. Moreover, this ceramic exhibits good frequency stability over the range of 1-100 Hz and also demonstrates favorable temperature stability within the investigated temperature range of 25-120 °C. This work demonstrates an effective strategy for developing high-performance BNT-based dielectric ceramics.

Machine-Learning-Assisted Optimization of SiAlON Ceramics Prepared from Coal Gangue via SHS: A Review and Research Framework

Yujuan Zhang, Yichen Xiang, Changchun Ge

Institute of Powder Metallurgy and Advanced Ceramics, School of Materials Science and Technology, University of Science and Technology Beijing (USTB)

Email: zhangyujuan@ustb.edu.cn

Coal gangue is an abundant aluminosilicate solid waste containing SiO_2 , Al_2O_3 , carbon and minor oxides, and has been demonstrated as a low-cost precursor for β -SiAlON synthesis [1,2]. Self-propagating high-temperature synthesis (SHS) offers rapid reaction and low external energy consumption; however, the coupling among feedstock variability, reductant and nitrogen-source contents, compact density, nitrogen pressure, ignition conditions and combustion-wave behavior makes trial-and-error optimization inefficient. This review examines progress in coal-gangue-derived SiAlON, combustion synthesis of SiAlON and machine-learning-assisted ceramic processing. Support vector regression has been used to model SiAlON properties from limited datasets [3], while recent work has shown that machine learning combined with thermodynamic descriptors can screen SHS feasibility and guide experimental synthesis [4]. Three major data gaps are identified: insufficient standardized reporting of coal-gangue composition, scarce in-situ measurements of combustion temperature and propagation velocity, and limited linkage between processing parameters, phase assemblage, microstructure and properties. A prospective data-driven framework is therefore proposed. Chemical and mineralogical composition, particle size, Al/C/Si₃N₄ additions, green density, nitrogen pressure and ignition parameters are used as inputs; adiabatic temperature, combustion stability, wave velocity, β -SiAlON content, porosity and mechanical properties are defined as outputs. Interpretable models, uncertainty quantification and Bayesian active learning are recommended to establish composition-process-combustion-phase-property relationships and sequentially select informative SHS experiments. This framework provides a practical route for reducing experimental cost and accelerating the sustainable conversion of coal gangue into high-value SiAlON ceramics.

References

- [1] X. Luo, J. Sun, C. Deng, Y. Hong, J. Mater. Sci. Technol. 19, 93 (2003).
- [2] H. Wang, Z. Chen, Z. Meng, et al., Ceram. Int. 49, 11275 (2023).
- [3] X. Liu, W.C. Lu, S.L. Jin, et al., Chemom. Intell. Lab. Syst. 82, 8 (2006).
- [4] H. Yin, W. Yu, Y. Yu, et al., npj Comput. Mater., DOI: 10.1038/s41524-026-02216-5 (2026).

Effect of Heterogeneous Deformation-Induced Strengthening and Hardening on the Mechanical Properties of Laminated Aluminum Alloy

Sicheng Qian¹, Peizhong Feng^{1*}, He Yiqiang²

¹ School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, Jiangsu, China

² School of Mechanical Engineering, Shanghai University, Shanghai 200444, China

Email: pzfeng@cumt.edu.cn

Heterogeneous laminated metals develop GNDs and HDI stress because hard and soft domains deform incompatibly, and the interface-affected zone (IAZ) strongly influences the strength-ductility balance [1]. Here, AlFeCoCrNi-reinforced 5086Al/Al laminated metal composites were fabricated by multi-pass ECAP to clarify how pass number and HEA-5086Al/Al lamellar thickness ratio regulate the IAZ and mechanical response. Tensile tests, microhardness mapping, EBSD/KAM, TEM and finite-element analysis were combined with a dislocation pile-up model.

Strength and hardness increased with ECAP pass number, whereas three passes provided the best overall balance before the ductility/toughness loss at four passes. The 2:1 laminate showed the most favorable response; after three passes, UTS and elongation reached 265.5 ± 3.3 MPa and $15.5 \pm 1.2\%$, respectively. An interlayer inclination of $\sim 30^\circ$ reduced crack initiation and improved load transfer. Fig. 1 shows that the 2:1 laminate also developed a comparatively smooth interfacial hardness gradient.

The experimental IAZ width was ~ 5 μm , close to the 4.16 μm value predicted by the single-sided pile-up model. The model predicted a strength of 272.95 MPa, only 7.45 MPa above experiment; the difference is attributed to intrinsic defects and the interdiffusion layer. These results show that ECAP pass number, lamellar thickness ratio, interface inclination and IAZ gradient can be jointly tuned to optimize HDI strengthening and hardening.

References

[1] C.X. Huang, Y.F. Wang, X.L. Ma, et al., Mater. Today 21, 713 (2018).

Combustion-Temperature-Mediated Carbon Regulation in WC Synthesis via the WO_3 –Mg–C Self-Propagating Reaction System

Yongkwan Lee^{1, 2}, Chan Gyu Kim^{1, 3}, Jaejin Sim^{1*}

¹ Korea National Institute of Rare Metals, Korea Institute of Industrial Technology, Incheon, South Korea

² Department of materials science and engineering, Korea University, Seoul, South Korea

³ Department of Materials Science and Engineering, Inha University, Incheon, 22212, South Korea

Email: simjae@kitech.re.kr

Tungsten carbide (WC) powders were synthesized through a self-propagating high-temperature synthesis (SHS) process based on the highly exothermic WO_3 –Mg–C reaction system. Although excess carbon is generally required to promote complete carburization and suppress the formation of W_2C and metallic W, uncontrolled residual free carbon can deteriorate the quality of WC-based powders. In this study, the carbon consumption behavior in the WO_3 –Mg–C system was systematically investigated through thermodynamic analysis and experimental verification. The results indicate that carbon loss occurs mainly under high-combustion-temperature conditions, where side reactions such as the carbothermal reduction of MgO and the direct reaction between WO_3 and carbon can consume carbon and disturb the stoichiometric balance required for WC formation. Without a diluent, significant carbon loss was observed, resulting in the formation of W_2C and W unless a sufficient amount of excess carbon was introduced.

To suppress carbon loss and improve WC formation, the combustion temperature was controlled by introducing NaCl as a diluent and excess Mg as both a reductant compensator and thermal moderator. The combined use of NaCl and excess Mg effectively reduced carbon loss by lowering the combustion temperature and compensating for Mg evaporation during the SHS reaction. In particular, the $\text{WO}_3 + 4\text{Mg} + 1.6\text{C} + 2\text{NaCl}$ system minimized carbon loss while maintaining WC as the dominant phase. In addition, NaCl contributed to particle refinement by forming a molten phase during combustion, which suppressed particle growth and sintering. These findings provide a practical strategy for controlling carbon balance, phase formation, and powder morphology in WC synthesis via the WO_3 –Mg–C SHS system.

Keywords: Self-propagating High-temperature Synthesis (SHS), Tungsten carbide, Carbon, Tungsten trioxide, Magnesium

Waste-derived MoSi₂ as a self-reductant for carbon-free synergistic smelting of copper slag: Mechanistic insights into Fe–Mo alloy formation and element migration

Zhi Liu¹, Baojing Zhang^{1,2}, Peizhong Feng^{1,2,3}

¹ School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, P R. China.

² Jiangsu Key Laboratory for Clean Utilization of Carbon Resources, Xuzhou, 221116, P R. China

³ International Joint Laboratory of Minerals Efficient Processing and Utilization Ministry of Education, Xuzhou, 221116, P R. China

Email: zhangbj@cumt.edu.cn; pzfeng@cumt.edu.cn

Self-propagating high-temperature synthesis (SHS), as an advanced materials processing technique, utilizes highly exothermic reactions to produce materials with high purity. Owing to its advantages of low energy consumption, short processing time, versatile microstructures and functionalities of final products, and relatively simple processing procedures, SHS has been widely applied for the synthesis of intermetallic compounds and ceramic powders[1]. Molybdenum disilicide (MoSi₂), a typical refractory metal silicide, represents an important application system of SHS and is extensively used as a high-temperature heating element. With the development of modern industries, a large quantity of these components are gradually retired after long-term service, forming a secondary resource enriched in molybdenum (Mo content >60%)[2]. Meanwhile, the dominant phase of these wastes remains MoSi₂, which possesses considerable potential as a reductant. Copper slag, a major industrial solid waste generated during copper smelting, is a high-oxygen-potential iron-bearing slag. Its total iron content (TFe >38%) is significantly higher than the industrial grade of iron ores in China, indicating substantial potential for resource recovery[3].

In this study, based on the resource utilization of spent MoSi₂ heating elements, a “waste-to-treat-waste” strategy was proposed, in which retired MoSi₂ was simultaneously utilized as a molybdenum source and reductant, while copper slag served as an oxidant, iron source, and reaction medium. Through a synergistic smelting process, selective enrichment and recovery of molybdenum and iron were achieved, providing a promising pathway toward sustainable development and carbon emission reduction.

Firstly, systematic process mineralogical characterization of copper slag and spent MoSi₂ heating elements was conducted. Combined with thermodynamic calculations and high-temperature smelting experiments, the reaction pathways between MoSi₂ and the major phases in copper slag were elucidated. The results revealed that iron in copper slag mainly existed as fayalite (Fe₂SiO₄) and magnetite (Fe₃O₄), whereas the spent MoSi₂ heating elements were primarily composed of MoSi₂, accompanied by minor amounts of Mo₅Si₃ and bentonite binder phases. Silicon in MoSi₂ acted as a reductant to reduce Fe₃O₄ and Fe₂SiO₄ into metallic Fe, while Mo was simultaneously incorporated into the metallic phase to form Fe–Mo alloy in situ. During the reaction, Mo and Si underwent decoupled diffusion, with the decomposition of Mo₅Si₃ identified as the rate-limiting step. Both Fe₃O₄ and Fe₂SiO₄ exhibited synergistic catalytic effects on the decomposition of MoSi₂ by reducing the Gibbs free energy of the overall reaction system.

Based on these findings, a carbon-free MoSi₂-driven reduction smelting process for copper slag was proposed to fully exploit the reductive capability of Si in MoSi₂ and minimize the consumption of carbonaceous reductants. The phase transformation behavior, MoSi₂ decomposition mechanism, and elemental migration characteristics during synergistic smelting were systematically investigated, and the effects of process parameters on the recovery of valuable Mo and Fe were evaluated. Non-isothermal thermal treatment experiments were performed to reveal the pyrolysis behavior and phase reconstruction mechanism of MoSi₂. The apparent activation energy of the primary reaction was calculated to be 113.47 kJ mol⁻¹ using the Kissinger method, confirming the feasibility of MoSi₂-driven reduction of copper slag

from a kinetic perspective. Furthermore, liquid–solid reaction interface experiments were conducted to clarify the decomposition behavior of MoSi₂ and the migration mechanisms of Mo and Fe. The results demonstrated that Si diffused toward the reaction interface driven by the chemical potential gradient and reduced FeO, while the generated SiO₂ continuously dissolved into the slag phase. Meanwhile, Mo and Fe reacted in situ to form ferromolybdenum alloy, accompanied by the formation of an interfacial transition layer. The decoupled diffusion of Mo and Si was identified as the key mechanism governing MoSi₂ decomposition.

The effects of MoSi₂ addition amount and CaO/SiO₂ mass ratio on the smelting performance were systematically investigated, revealing the intrinsic relationships among slag composition, melt properties, and metal recovery efficiency. Under optimized conditions with 13 g of spent MoSi₂ addition, a CaO/SiO₂ mass ratio of 1.2, and a smelting temperature of 1550 °C, the recovery efficiencies of Mo and Fe reached 99.97% and 96.29%, respectively. The obtained ferromolybdenum alloy exhibited a Mo grade of 33.43% and a Si content of 1.14%. Moreover, the secondary slag contained low concentrations of heavy metal elements and could be further utilized as a raw material for cement production after harmless treatment.

This study establishes a novel synergistic smelting system for the recovery of ferromolybdenum alloy from copper slag and spent MoSi₂ heating elements. The reaction mechanism involving the reduction of iron oxides by MoSi₂ and the in situ formation of Fe–Mo alloy, together with the interfacial diffusion behavior, was systematically elucidated. The intrinsic correlations among slag composition, melt properties, and metal recovery efficiency were clarified. These findings provide new theoretical insights and technological strategies for the high-value synergistic utilization of copper smelting waste and retired MoSi₂ heating elements.

References

- [1] Zhu, N., Zhu, L., Zhang, B., Feng, P., Li, S., Kiryukhantsev-Korneev, P. V., Levashov, E. A., Ren, X., & Wang, X. Microstructural evolution and 1500° C oxidation resistance of Mo(Al, Si)₂ fabricated via an innovative two-step SHS-SPS technique. *Materials & Design*, 247, 113397 (2024).
- [2] Zhu, L., Zhang, S., Ye, F., Ren, X., & Feng, P. Recycling of MoSi₂-based industrial solid wastes for the fabrication and high-temperature oxidation behavior of MoSi₂–ZrSi₂–SiC composite coating. *Composites Part B: Engineering*, 274, 111281 (2024).
- [3] Zhang, B., Liu, Z., Cheng, J., Yu, L., Zhang, Z., Li, J., Li, S., & Feng, P. In situ synthesis of Fe-Mo alloys via synergistic smelting of copper slag and spent MoSi₂ rods: Phase transformation and decomposition mechanism of MoSi₂. *Journal of Materials Research and Technology*, 39, 1053-1066 (2025).

Heterogeneous Polarization Configuration Regulated by Core-Multi-Shells Structure Enabled Superior Energy Storage in BNT-Based Ceramics

Zixuan Wang^{1,2} Chaoqiong Zhu^{1,2} Lanqing Liang^{1,2} Shiheng Li^{1,2} Zunpeng Feng^{1,2} Yihan Ling^{1,2}
Peizhong Feng^{1,2} Ziming Cai^{1,2}

¹ School of Materials Science and Physics, China University of Mining and Technology, Xuzhou, Jiangsu, China

² Jiangsu Key Laboratory For Clean Utilization of Carbon Resources, Xuzhou, Jiangsu, China

Email: 18232638492@163.com

Nowadays, developing and the effective storage of green and renewable energy has become a key research focus to address the environmental impacts of traditional energy [1]. Among the mainstream energy storage devices, dielectric capacitors have demonstrated unique competitiveness in fields of power electronics and pulse power systems due to their high power density and ultra-fast charging and discharging rates [2]. However, the low energy storage density of dielectric capacitors remains a bottleneck for their wider application [3], thus making its enhancement a top research priority.

Bi_{0.5}Na_{0.5}TiO₃(BNT)-based ceramic dielectrics have been extensively studied owing to their high spontaneous polarization, rich and adjustable phase structures, and excellent temperature stability. However, the energy storage capacity of BNT-based ceramics is fundamentally limited by the polarization hysteresis and early saturation. These issues are compounded by high leakage currents under electric fields and a low breakdown strength, collectively hindering the material development [4].

To address this issue, BNT-based ceramics are usually modified into relaxor ferroelectric ceramics. By incorporating linear or relaxor components, the ferroelectric domain structure can be engineered from long-range to short-range order. This transformation facilitates faster polarization switching with reduced hysteresis, leading to improved energy storage efficiency and higher energy storage density. However, there is a problem with this method, as excessive disruption of long-range polarization to enhance relaxation behavior significantly reduces polarization strength, and the improvement in breakdown field strength is limited [5], which is also detrimental to energy storage performance. Consequently, researchers have begun to adopt some structural designs to co-optimize both polarization and breakdown strength. An effective strategy in this regard is the core-shell structure, a structural design engineered to integrate the functionalities of two dissimilar materials.

The core-shell structure, despite its potential, faces a fundamental challenge in current studies: it is difficult for the binary combination of heterostructures to optimize polarization, breakdown strength, and efficiency concurrently. For example, if the core is tasked with high polarization and the shell with high breakdown strength, the critical question of how to achieve high efficiency remains. This highlights the need to pursue a more sophisticated functional design within heterostructures to seek triple synergy. In this work, a novel core-multi-shells structure, coupling the anti-ferroelectrics core, relaxor ferroelectrics inner shell, and linear dielectrics outer shell together, is constructed.

This design employs a grain as the structural unit. The antiferroelectric (AFE) core provides high polarization while minimizing residual polarization. The inner relaxor ferroelectric (FE) shell ensures a rapid response to the electric field, maintaining high efficiency and optimizing polarization nonlinearity. The outer linear dielectric shell effectively homogenizes the electric field distribution to mitigate local concentration, thereby enhancing overall reliability while further tuning polarization behavior. Additionally, the strain distortion present at the interfaces between these phases is expected to favorably modify the polarization-electric field response, potentially leading to superior energy storage performance.

Inspiringly, by utilizing a chemical coating method and leveraging differential elemental diffusion during sintering, ceramics with core-multi-shells structures were successfully fabricated, exhibiting superior energy storage performance with a remarkable W_{dis} of 11.05 J/cm³ at 790 kV/cm. The materials also exhibited good temperature and frequency stability, with the variation of W_{dis} among the temperature range from 25°C to 150°C, keeping in 7.6% and η always surpassing 86%. Especially, (BNBST-0.3NN)@SiO₂ ceramic film has a high η of 88.7% at a high temperature of 150°C, indicating the great inhibitory effect of heterogeneous structure on high-temperature dielectric loss and demonstrating its application prospects in high-temperature energy storage. Meanwhile, the (BNBST-0.3NN)@SiO₂ ceramic film also shows a good frequency stability in the energy storage performance, with no significant change in polarization and a slight decrease in η as the frequency increases. The variation of W_{dis} is within 4.6% over the frequency range of 0.6-200 Hz.

References

- [1] S. Pattipaka, Y. Lim, Y. H. Son, et al., Ceramic-Based Dielectric Materials for Energy Storage Capacitor Applications, *Materials*.10, 2277 (2024).
- [2] L. B. Qiao, X. H. Zhang, X. Z. Sun, et al., Advances in Battery Supercapacitor Hybrid Energy Storage System, *Energy Storage Science and Technology*. 1 98-106 (2022).
- [3] S. Pattipaka, L. Yeseul, H. S. Yong, et al., Ceramic-Based Dielectric Materials for Energy Storage Capacitor Applications, *Materials* .10 2277 (2024).
- [4] P. Shi, X. Zhu, X. Lou, et al., Bi_{0.5}Na_{0.5}TiO₃-Based Lead-Free Ceramics With Superior Energy Storage Properties at High Temperatures, *Composites Part B: Engineering*. 215 108815 (2021).
- [5] Z. Dai, J. Xie, W. Liu, et al., Effective Strategy to Achieve Excellent Energy Storage Properties in Lead-Free BaTiO₃-Based Bulk Ceramics, *ACS Applied Materials & Interfaces*. 27 30289-30296 (2020).

Combustion Synthesis, Microstructure and Electrocatalytic Performance of Porous Ni-Mg Intermetallic Compounds

Chaoqun Xie¹, Xiaohong Wang¹, Peizhong Feng^{1,2,3}

¹ School of Materials Science and Physics, China University of Mining and Technology, Xuzhou, 221116, PR China

² Jiangsu Key Laboratory for Clean Utilization of Carbon Resources, Xuzhou, 221116, P R. China

³ International Joint Laboratory of Minerals Efficient Processing and Utilization Ministry of Education, Xuzhou, 221116, P R. China

Email: 2788357928@qq.com

Developing non-noble metal electrocatalysts with high activity and stability is critical for cost-effective alkaline water electrolysis [1]. Ni-Mg metal materials have emerged as highly promising candidates due to their tunable electronic structure and the potential synergistic catalytic effects between the nickel and magnesium components [2]. Thermal explosion (TE), a mode of combustion synthesis, enables rapid in-situ synthesis with suppressed volatile loss and controllable pore structure, providing an efficient route for high-performance Ni-Mg based catalysts [3]. This study seeks to develop porous Ni-Mg intermetallics with tailored porosity and surface reactivity via TE combined with oxide surface engineering and NH₄HCO₃ sacrificial templating, thereby boosting the bifunctional hydrogen evolution reaction and oxygen evolution reaction performance. Original results show that TE reaction completes within 8 s with a peak temperature of 910 °C, forming a bicontinuous skeleton-pore structure derived from green body gaps, Kirkendall effect and reaction-generated pores. The 700 °C/0.5 h sample delivers a low HER overpotential of 70 mV at 10 mA·cm⁻² and maintains activity for 48 h, attributed to the synergistic effect of MgNi₂-Ni dual phases and porous structure. For OER, the oxide-loaded composites NM/FeO exhibits superior performance with an overpotential of 284.8 mV at 10 mA·cm⁻², where lattice oxygen mechanism contributes significantly to the activity enhancement. By introducing 50 vol.% NH₄HCO₃, the open porosity increases linearly from 32.15% to 52.5%, and the optimized 50 vol.%-1 h sample presents an OER overpotential of 359.8 mV at 50 mA·cm⁻², with stable current increase during 48 h operation due to surface active species reconstruction. This study provides a feasible strategy for fabricating high-performance porous intermetallic electrocatalysts via combustion synthesis.

Keywords: Ni-Mg intermetallics; thermal explosion reaction; electrocatalysis; pore

References

- [1] Wu L, Li L, Wang H, et al. Porous Ni₃Si intermetallics as electrocatalysts for hydrogen evolution reaction. *International Journal of Hydrogen Energy*, 2024, 51: 806-818.
- [2] LIANG H, ZHANG H, ZONG Y, et al. Studies of Ni-Mg-catalyst for stable high efficiency hydrogen storage[J]. *Journal of Alloys and Compounds*, 2022, 905: 164279.
- [3] Yu Y, Cai X P, Cao Z J, et al. Effect of the heating rate on the thermal explosion behavior and oxidation resistance of 3D-structure porous NiAl intermetallic. *Materials Characterization*, 2022, 190: 112062.

Electric and Magnetic Fields Coupled Self-Propagating High-Temperature Synthesis of Highly Active and Defective CaB₆ Micro-Nano Materials

X.X. Hou, J.L. Wang*, R.X. Li, F. Long

Guilin University of Technology, PR China

Email: jilinwang@glut.edu.cn

Guangxi Key Laboratory of Optical and Electronic Materials and Devices, Collaborative Innovation Center for Exploration of Nonferrous Metal Deposits and Efficient Utilization of Resources, School of Materials Science and Engineering, Guilin University of Technology, Guilin 541004, China.

jilinwang@glut.edu.cn

Calcium hexaboride (CaB₆), an ultra-high temperature ceramic, exhibits high melting point, hardness, low density, and excellent neutron absorption, making it a promising candidate for nuclear radiation shielding and advanced composites. However, the conventional self-propagating high-temperature synthesis (SHS) process for CaB₆ faces significant challenges in controlling product morphology. Recent studies have shown that external electric or magnetic fields can significantly affect reaction kinetics and grain growth during SHS; nevertheless, their synergistic effect in the SHS system remains unexplored. Therefore, an in-depth investigation of the coupled electric and magnetic fields on the SHS synthesis of CaB₆ is urgently needed to enable precise morphology control and effectively suppress particle agglomeration. It was found that the samples synthesized without external fields were predominantly composed of irregular cubic particles with sizes ranging from 0.15 to 0.6 μm, and exhibited poor crystallinity. The application of a magnetic field promoted crystallization and grain refinement, with the most pronounced effect observed at 1.257 mT, where the average grain size decreased to approximately 0.16 μm. In contrast, an applied electric field significantly increased the grain size, reaching a maximum of about 0.4 μm at 40 V/mm, and concurrently raised the proportion of elongated or rectangular parallelepiped particles. When the electric and magnetic fields were coupled, the abnormal grain growth and sintering-induced agglomeration caused by the electric field alone were effectively suppressed. Under the combined condition of 10 V/mm + 0.314 mT, the samples exhibited a distinct hollow cubic structure, with particle sizes mainly in the range of 0.2–0.65 μm and shell wall thicknesses of approximately 15–30 nm.

References

- Y.Y. Wang, H. Jin, *Advanced Materials Research*, 284-286, 2106 (2011).
- E.A. Levashov, A.S. Mukasyan, A.S. Rogachev, et al. *International Materials Reviews*, 62, 203 (2017).
- O. Guillon, C. Elsässer, O. Gutfleisch, et al. *Materials Today*, 21, 527 (2018).

Synthesis of Silicon Carbide by Magnesiothermic SHS Using Graphite Powders as a Carbon Source

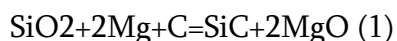
N. S. Shibakova, V. V. Zakorzhevsky, M. I. Alymov

Merzhanov Institute of Structural Macrokinetics and Problems of Materials Science, Russian Academy of Sciences,
Chernogolovka, Moscow region, 142432 Russia

Email: nshibakova@ism.ac.ru

Silicon carbide (SiC)-based materials are widely used in mechanical engineering, chemical and nuclear industries due to their high hardness, thermal stability, and chemical resistance. However, traditional methods for producing fine SiC are characterized by high energy consumption and equipment complexity. A promising alternative is self-propagating high-temperature synthesis (SHS), which utilizes the thermal effect of the reaction. In this work, the production of SiC by magnesiothermic reduction of silicon dioxide in SHS mode using graphite powders of various dispersity as a carbon source was investigated.

The following commercial carbon powders were used in the work: artificial graphite grade A (GII) with an average particle size $d_{50} = 16, 38$, and up to $500 \mu\text{m}$ ($\rho = 2.23 \text{ g/cm}^3$), as well as colloidal graphite preparation V-1 ($d_{50} \approx 6.8 \mu\text{m}$) after preliminary drying. Silicon dioxide ($d_{50} \approx 3.6 \mu\text{m}$) was used as the silicon-containing component, and magnesium grade MPF-2 was used as the reducing agent. Silicon carbide was synthesized by magnesiothermic reduction according to reaction (1):



The process was carried out in gaseous media: an argon atmosphere and air. The components were mixed in a ball mill. The batch weight of the mixture was 1 kg. The ratio of the charge components SiO_2 ; Mg; C was 50, 40, and 10%, respectively. The sintered product after synthesis was subjected to mechanical grinding followed by acid leaching in a 10% HCl solution to remove by-products. The purified silicon carbide powder was separated on a vacuum filter, thoroughly washed with distilled water, and dried.

The study revealed that both the type of carbon and its degree of dispersity significantly affect the completeness of the magnesiothermic reaction in an air environment. The use of a highly dispersed colloidal graphite preparation promotes a more complete process of silicon carbide formation, which is confirmed by the absence of silicon reflections in the synthesis products; however, it is accompanied by the presence of residual carbon. At the same time, the use of graphite with a large particle size (about $500 \mu\text{m}$) limits the reaction rate, leading to the retention of unreacted silicon in the final product. The results show that the average particle size of the synthesized SiC is weakly dependent on the initial dispersity of the carbon component. The product particle size (about $2.6\text{--}2.9 \mu\text{m}$) is significantly smaller than the initial graphite size, and the particle size distribution of the final powder is determined to a greater extent by the synthesis conditions and subsequent grinding than by the characteristics of the initial carbon raw material. The obtained data indicate that the use of the highly dispersed colloidal graphite preparation V-1 leads to the formation of a finer product with a pronounced nanostructure, which is consistent with the X-ray diffraction results indicating a more complete reduction reaction.

The research was carried out at the expense of a grant from the Russian Science Foundation No. 25-19-00530, <https://rscf.ru/project/25-19-00530/>»

Self-propagating Reduction Mechanism and Component Optimization of Copper-based Thermite Flux

Chuancai Du, Peizhong Feng, Baojing Zhang

School of Materials Science and Physics, China University of Mining and Technology, Xuzhou, 221116, P.R. China

Email: zhangbj@cumt.edu.cn

Flux-based hot-metal welding agents are widely used in welding steel-clad grounding conductors, but long-standing issues such as copper-steel interface cracking, zinc layer erosion, and difficulty in flux removal persist. This study is based on the $\text{Cu}_2\text{O}/\text{Al}$ system and investigates three substrates: copper-clad steel, zinc-clad steel, and stainless steel-clad steel. The effects of the aluminum/copper oxide equivalent ratio and additives such as CaF_2 , Si, C, B, Fe-B, and Na_3AlF_6 on reaction extent, weld morphology, porosity, crack tendency, and flux removal were examined.

The experiments revealed a high-temperature antagonism between boron and CaF_2 : CaF_2 reacts with B to produce BF_3 gas, causing both the grain-refining effect of boron and the viscosity-reducing effect of CaF_2 to fail simultaneously. Replacing boron powder with Fe-B alleviates this effect and suppresses cracking. For the first time, a negative interaction between silicon and boron was observed—coexistence of the two leads to product adhesion to the mold, and simultaneous addition of Si, B, and CaF_2 results in crack recurrence and increased adhesion. The mechanisms and appropriate quantities of each additive were clarified: silicon reduces slag surface tension to improve slag-metal separation; graphite powder forms a gas cushion at the slag-metal interface to aid flux removal; CaF_2 dissolves Al_2O_3 slag and lowers viscosity. For zinc-clad steel, using copper powder as a diluent combined with phosphor copper to regulate the molten pool temperature and wettability significantly reduces zinc layer burning and joint porosity. The identification of these antagonistic and synergistic effects provides a systematic experimental basis for the rational formulation design of flux-based hot-metal welding agents.

Keywords: thermite welding; thermite welding agent; steel-clad substrate.

References

- [1] C.H. Luo, M.P. Liu, Y. Mao, T. Hu, *Adv. Mater. Res.* 560-561, 100 (2012).
- [2] J.Y. Xu, W. Shi, X.W. Wang, et al., *Combust. Flame* 246, 112460 (2022).
- [3] S. Yi, X.L. Liu, Q. Li, Z. Zhang, *Eng. Fail. Anal.* 130, 105774 (2021).
- [4] M.M. Song, B. Song, M. Cao, et al., *Chin. J. Eng.* 37(4), 436 (2015).
- [5] L. Liu, Master's Thesis, Chongqing University of Science and Technology (2023).

Protective Ti-Al-C and Cr-Al-C Coatings Produced by Spark Plasma Sintering and High-Power Impulse Magnetron Sputtering Using SHS-Precursors Based on MAX-phases

Ph.V. Kiryukhantsev-Korneev¹, A.Yu. Zachinyaev¹, S.I. Rupasov¹, P. Feng², X. Ren³, E.A. Levashov¹

¹ National University of Science and Technology "MISIS", Moscow, 119049 Russia

² China University of Mining and Technology, Xuzhou, 221116 China

³ Henan Academy of Sciences, Zhengzhou, 450046 China

Email: kiruhantsev-korneev@yandex.ru

To improve the wear and oxidation resistance of critical components made from heat-resistant alloys, Ti-Al-C and Cr-Al-C coatings were produced by spark plasma sintering (SPS) and high-power impulse magnetron sputtering (HIPIMS) [1]. Heterophase powders produced by the SHS method were used as precursors for the SPS. Cathodes for sputtering by the HIPIMS method were produced from the elemental powders using force SHS-compacting [2]. The coatings were examined using SEM, EDS, GDOES, XRD, SAED, and TEM techniques. Nanoindentation and pin-on-disk testing were used for estimation of mechanical and tribological properties. Oxidation resistance and thermal stability were assessed by heating in air and vacuum, respectively.

SPS-coatings, 1.6 mm thick, had a dense structure and contained phases, wt.%: 43 Ti₂AlC, 41 Ti₃AlC₂, 16 TiC and 94 Cr₂AlC, 6 Cr₇C₃. The hardness of SPS-coatings was 13-17 GPa, elastic modulus was 202-283 GPa. The Cr-Al-C demonstrated minimal wear rate 3.14×10^{-7} mm³N⁻¹m⁻¹ and friction coefficient of 0.17. The deposition of Ti-Al-C and Cr-Al-C SPS-coatings increased oxidation resistance of heat-resistant alloys by 2.5 times.

HIPIMS-coatings, 2-6 μm thick, were based on the TiC and Cr₃C₂ phases, while Cr-Al-C contained also Cr₂AlC MAX-phase. The hardness of coatings was 23-31 GPa, elastic modulus was 207-294 GPa, and the elastic recovery was 54-64 %. The Ti-Al-C showed best tribological properties: wear rate of 5.1×10^{-6} mm³N⁻¹m⁻¹ and friction coefficient of 0.2. HIPIMS coatings exhibited the high oxidation resistance at 1000°C, due to the formation of Al₂O₃ and Cr₂O₃-based surface films. When heated to 1000°C in a vacuum, nanocrystallites of the MAX phases Ti₂AlC and Cr₂AlC (9-20%) precipitated in the coatings in addition to the main carbide phases. HIPIMS coatings have significantly increased the wear- and oxidation resistance of substrates.

Work was supported by the Russian Science Foundation (project 23-49-00141). P. Feng and X. Ren would like to acknowledge the financial support of NSFC (project 52261135546).

References

- [1] Ph.V. Kiryukhantsev-Korneev, A.D. Chertova, P. Feng, et al. Prot. Met. Phys. Chem. Surf. 61, 597 (2025).
- [2] E.A. Levashov, Y.S. Pogochev, D.V. Shtansky, et al. Russ. J. Non-ferrous Metals. 50, 151 (2009)

Microstructure and Abrasive Wear Behaviour of (Ti,W)C–NiCu Composites Fabricated by Rapid Hot Pressing

Yong Liu, Yunan Fan, Chengshang Zhou

State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, P.R. China

Email: yonliu@csu.edu.cn

Carbide-reinforced Ni-based composites combine the high hardness of ceramic reinforcements with the toughness of metallic matrices, making them promising wear-resistant materials. This study examined how the (Ti,W)C content affects the microstructure and abrasive wear behaviour of (Ti,W)C–NiCu composites. Composites containing 50, 60, and 70 wt.% (Ti,W)C were fabricated through ball-milling-assisted powder blending and rapid hot pressing at 900 °C under 50 MPa. Scanning electron microscopy (SEM) showed that the (Ti,W)C phase was distributed within the NiCu matrix. Optimisation of the powder-blending process helped reduce carbide agglomeration and local matrix enrichment, although some porosity remained in samples with high carbide contents. The composite containing 70 wt.% (Ti,W)C had a bulk density of 7.62 g·cm⁻³ and a macrohardness of approximately 70.4 HRA. Abrasive wear tests demonstrated that these composites exhibited good wear resistance, with an improvement over conventional material. Their wear behavior was jointly governed by the carbide content, phase distribution, and degree of densification. Accordingly, these composites show potential for application in wear-resistant engineering components.

Keywords: (Ti,W)C–NiCu composites; microstructure; rapid hot pressing; abrasive wear

Application of combined combustion synthesis with bidirectional metal disk rapid cooling for amorphous ceramic films production

Viacheslav I. Kvashnin, Zhenwei Miao, Canqing Fang, Ce Chen, Yuelel Bai, Xiaodong He, Yongting Zheng

National Key Laboratory of Science and Technology on Advanced Composites in Special Environments, Center for Composite Materials and Structures, Harbin Institute of Technology, Harbin, 150080, PR China

Email: slava.kvashnin@mail.ru

Alumina-based composite materials have been attracting considerable attention in recent years owing to its strength, hardness and wear resistance. However, its application as structural materials is strongly restricted by inherent brittleness. Among the known toughening methods of alumina-based ceramics an in-situ approach to form toughening objects is considered one of the most helpful. The growth of strengthening objects such as fine precipitates, columnar grains or whiskers and thin platelets during sintering, synthesis or heat treatment result in more homogeneous distribution of these objects, denser phase/grain boundaries and higher relative density values, leading to enhanced mechanical properties of the final materials [1, 2]. Controllable crystallization of amorphous materials is one example of the in-situ microstructure formation allowing researchers to obtain fine-grained ceramics. Production of amorphous ceramic precursors, however, is not a simple task and requires appropriate technology. Therefore, the aim of the present work is to produce amorphous $\text{Al}_2\text{O}_3\text{-ZrO}_2\text{-Y}_2\text{O}_3$ ceramic films of the eutectic composition by applying

a novel method combining Al-O₂ combustion synthesis to produce ceramic melts of high temperature and subsequent rotating metal disk roller assisted rapid cooling of the melt.

As a result of the experiments about 200 μm thick ceramic films have been obtained. According to XRD results the films are predominantly amorphous with little quantities of crystallized t-ZrO₂ (see figure, a). Cross section of the films is represented by three zones – two external ones of $\sim 30\text{-}40\ \mu\text{m}$ (5 and 1 in figure, b, d) and internal zone (3 in figure, b, d). The external zones are characterized by almost complete absence of crystalline inclusions showing high degree of amorphization whereas internal zone contains some distinct zirconia inclusions (figure, c). With the help of heat conduction simulations cooling rates of external and internal regions have been calculated to be ~ 107 and $106\ \text{K/s}$ respectively.

FIGURE – XRD spectra (a) and cross-sectional BSE image (b) of the as-received film, cross section EDS (c), calculated cooling rates for regiones, marked in b (d)

References

- [1] Y. Yu, Y. Zheng, X. Liu et al. Small 18, 2105367 (2022)
- [2] W. Yu, Y. Zheng, Y. Yu et al. J. Eur. Ceram. Soc. 39, 4313 (2019)

Novel Route for the Synthesis of Nd₂Fe₁₄B Magnetic Material

Kh. Nazaretyan¹, A. Zurnachyan¹, S. Aydinyan¹

¹ A.B. Nalbandyan Institute of Chemical Physics NAS RA, P. Sevak 5/2, 0014, Yerevan, Armenia

Email: khachik.nazaretyan@ichph.sci.am

Nd₂Fe₁₄B is a technologically important permanent-magnet material owing to its outstanding magnetic properties, including high magnetocrystalline anisotropy, coercivity, and saturation magnetization [1,2]. These properties make Nd₂Fe₁₄B-based materials attractive for a wide range of advanced applications, including renewable energy systems, robotics, aerospace technologies, healthcare, and consumer electronics. Nd₂Fe₁₄B is conventionally synthesized using powder-metallurgical and melt-based routes, which generally require prolonged high-temperature treatment. Slow heating and extended holding can promote grain growth, secondary-phase formation, and higher energy consumption, while limiting control over phase-formation kinetics. Rapid non-isothermal heating offers an opportunity to overcome these limitations by shortening the thermal treatment and providing better control over phase formation.

In this study, Nd₂Fe₁₄B was synthesized under high-heating-rate conditions using a High-Speed Temperature Scanner (HSTS-3) [3]. This technique enables the synthesis of target materials under controlled non-isothermal conditions at predefined heating and cooling rates. The heating process can be automatically terminated at a specified temperature or time, followed by rapid quenching at rates of up to 30.000 °C·min⁻¹, thereby effectively suppressing further reactions and phase transformations.

The target Nd₂Fe₁₄B phase was synthesized from an initial powder mixture of NdH₂, Fe, and B in an argon atmosphere. The mixture was heated at a rate of 1200 °C·min⁻¹ to 1030 °C and held for 3 min, resulting in the formation of Nd₂Fe₁₄B as the major phase in the final product. In addition, the synthesis of Nd₂Fe₁₄B was investigated using Nd₂O₃ and Fe₂O₃ precursors via a calciothermic reduction route. The effects of precursor particle size, reducer content (CaH₂), and mechanical activation conditions on phase formation were systematically examined. Optimization of these parameters resulted in the formation of a product containing up to 60 wt.% Nd₂Fe₁₄B after a holding time of 3 min. Magnetic measurements confirmed the ferromagnetic behavior of the synthesized product, with a saturation magnetization of 140 emu·g⁻¹ and a coercivity of 500 Oe at an applied field of 13 Oe.

These results demonstrate the potential of high-speed heating and non-isothermal synthesis for the efficient preparation of Nd₂Fe₁₄B-based magnetic materials.

References

- [1] D. Brown, B.M. MA, et al J. Magn. Magn. Mater. 248, 432 (2002).
- [2] J.Wu, O. Korman, et al, IEEE Access 12, 138921 (2024).
- [3] Kh. Nazaretyan, S. Aydinyan, et al, J. Alloys Compd. 931, 167589 (2023).

Highly Efficient Catalysts from Material-Forming Combustion Processes

V. N. Borshch, S. Ya. Zhuk, E. V. Pugacheva, I. M. Bystrova, D. E. Andreev, V. N. Sanin, V. I. Yukhvid

Merzhanov Institute of Structural Macrokinetics and Materials Science, Chernogolovka, Russia

Email: borsch@ism.ac.ru

Various variants of material-forming combustion processes, including classical solid-phase SHS, liquid-phase processes (SHS metallurgy, solution combustion), low-temperature combustion in porous media, and others, represent a powerful tool for the inorganic synthesis of a wide range of catalytically active materials and their precursors of virtually unlimited composition. Distinguishing features of this approach include relative ease of implementation, high reaction rates, and low energy consumption. Heterogeneous catalysts, both monolithic and supported, produced after minimal chemical treatment of these materials exhibited high activity and selectivity across a wide range of processes, both oxidative and reductive.

A number of significant achievements obtained at ISMAN in this area are noteworthy. A new class of polymetallic catalysts based on complex multicomponent intermetallics, obtained through centrifugal SHS-metallurgy, has demonstrated excellent performance in diverse processes such as deep oxidation, Fischer-Tropsch synthesis, hydrodesulfurization of diesel fractions [1], and hydrogenation of CO₂ to heavy hydrocarbons [2]. Research is underway to develop supported catalysts obtained through the low-temperature combustion of a metal-containing oxidant – organic fuel composition on a wide range of supports. These catalysts have exhibited high activity in the processes of deep oxidation and CO₂ methanation [3]. For the first time, we have succeeded in implementing the idea of a one-step synthesis of ceramic-metal composites as precursors for supported catalysts for deep oxidation and hydrogenation of CO₂ [4]. The results mentioned provide strong grounds for further expansion of work in this area with the aim of discovering, developing, and applying new classes of catalysts.

References

- [1] V. N. Borshch, V. N. Sanin, E. V. Pugacheva, S. Ya. Zhuk, D. E. Andreev, V. I. Yukhvid, In: “Technological Combustion”, Eds: S.M.Aldoshin, M.I.Alymov, Moscow, RAS, (2018), 395-428, (In Russ.).
- [2] Vyacheslav N. Borshch, Svetlana Ya. Zhuk, Elena V. Pugacheva, Tshepo Duncan Dipheko, Dmitrii E. Andreev, Yurii A. Agafonov, and Oleg L. Eliseev. *Mendelev Commun.* 33, 55–57 (2023)
- [3] V. N. Borshch, I. M. Dement'eva, and N. Yu. Khomenko. *Int. J. SHS.* 28. 45–49 (2019).
- [4] Pugacheva E.V., Zhuk S. Ya., Bystrova I.M., Kochetkov R.A., Abzalov N.I., Golosova O.A., Seplyarskii B.S., Borshch V.N. *Mater. Chem. Phys.* 326. 129828 (2024).

An interesting application-oriented investigation of hydrogen enriched natural gas-fueled solid oxide fuel cells supported by Ni-Cu co-doping CeO₂- δ catalyst-modified vertical-microchannel anode

Xiaoyu Li, Yihan Ling*

School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, P.R. China

Email: lyhyy@cumt.edu.cn

Hydrogen blending in natural gas pipelines is one of the key technologies to realize the long-distance hydrogen transmission, which facilitates the large-scale hydrogen utilization. Solid oxide fuel cells can directly use hydrogen enriched natural gas (HENG, with 20% H₂) to generate electricity without separating and purifying the hydrogen, which enables the efficient conversion of hydrogen energy. In this work, finger-like pore anodes and Ni_{0.05}Cu_{0.05}Ce_{0.9}O₂- δ (NCCO) catalyst were prepared to address the need for anode performance and stability with hydrogen-doped natural gas fuels. The results show that NiCu@CeO₂ precipitates NiCu nano-alloys on the surface after reduction treatment, which is beneficial for the anode activity. With NCCO catalyst, the maximum power density of the single cells was 970 mW cm⁻² and 700 mW cm⁻² at 750 °C under wet H₂ and HENG fuel atmospheres, respectively. At 750°C, the methane conversion is as high as 46%. More importantly, the single cell ran smoothly for 150h, with the constant voltage (0.8 V) discharge and HENG as fuel gas. Our results confirm that the synthesized NCCO catalysts have excellent ability to catalyze CH₄ and carbon resistance.

References

- [1] Y. Yang, T. Li, P. Feng, et al, Appl. Energy, 328 428-437 (2022).
- [2] Y. Yang, Y. Liu, Z. Chen, et al, Sep. Purif. Technol. 288 120134 (2022).

Combustion synthesis of porous AlN frameworks and the composite phase change materials with high thermal conductivity

Yunfei Li, Zhuo Liu, Nan Sheng, Chunyu Zhu

School of Low-carbon Energy and Power Engineering, China University of Mining and Technology, Xuzhou, 221116, China
Email: snym@cumt.edu.cn

Phase change materials (PCMs) exhibit broad application prospects in electronic thermal management due to their high latent heat storage density and thermal stability. However, their inherent defects of low intrinsic thermal conductivity and easy leakage during phase transition severely limit their practical applications[1]. Herein, we propose a facile, rapid, and low-energy-consumption fabrication strategy by coupling radial freeze-casting with self-propagating high-temperature synthesis (SHS). Porous AlN skeletons with radially aligned layered structure were successfully fabricated, and bi-directionally thermally conductive composite phase change materials were obtained by vacuum impregnation with paraffin wax. The chemical characteristics, microscopic morphology, thermal conductivity and phase change characteristics of the samples were systematically characterized[2].

Adding AlN diluent effectively reduces the peak combustion temperature from 1908°C to 1384°C, avoiding the melting and agglomeration of Al powder and skeleton shrinkage deformation. The radial structure induced by the ice template is well preserved during the rapid propagation of the combustion wave, and AlN particles and whiskers interlock via sintering necks to form a continuous three-dimensional thermal conduction network with bidirectional anisotropy. The optimal composite achieves a horizontal thermal conductivity of 15.63 W·m⁻¹·K⁻¹ (78.2 times of paraffin) and an axial thermal conductivity of 11.72 W·m⁻¹·K⁻¹ (58.6 times of paraffin). The composite also has excellent thermal storage capacity (melting enthalpy of 82.3 J·g⁻¹ and solidification enthalpy of 84.1 J·g⁻¹), outstanding shape stability and leakage resistance and excellent thermal cycle stability. The composite can reduce the temperature of a 70°C heat source to 35.3°C within 20s in simulated electronic chip thermal tests, showing remarkable heat dissipation performance. The entire SHS process only requires 3–10s of instantaneous ignition power without subsequent high-temperature sintering[3]. This work provides a novel and scalable strategy for the low-energy and large-scale preparation of oriented porous high-thermal-conductivity ceramics, holding great promise for applications in high-density electronic device thermal management, industrial waste heat recovery and other fields.

References

- [1] JIE L, ZHANG J, FAN Y, et al. Journal of Energy Storage, 2025, 112: 115579.
- [2] LI Y, DENG M, CHEN F, et al. Applied Thermal Engineering, 2025, 279: 127535.
- [3] HAN Y, XIE Z, LI S, et al. Ceramics International, 2018, 44(6): 6949-6952.

Solution Combustion Synthesis and Spark Plasma Sintering of $(Y_xYb_{1-x})_2O_3$ Modified ZrB₂-SiC Ceramics for Oxidation at 1700 °C

Changlin He^{1,2}, Zhichao Shang¹, Xiang Ji¹, Peizhong Feng³, Xuanru Ren¹

¹ Henan Key Laboratory of High Performance Carbon Fiber Reinforced Composites, Institute of Carbon Matrix Composites, Henan Academy of Sciences, Zhengzhou 450046, PR China

² School of Materials and Science Engineering, Henan University of Science and Technology, Luoyang, 471023, P.R. China

³ School of Materials Science and Physics, China University of Mining and Technology, Xuzhou, 221116, P.R. China

Email: XuanruRen@163.com

To address the problems of ZrO₂ phase transformation-induced cracking, SiO₂ glass protection failure, and the resulting degradation of mechanical properties in ZrB₂-SiC ultra-high-temperature ceramics under oxidation at 1700 °C, this study prepared $(Y_xYb_{1-x})_2O_3$ -ZrB₂-SiC composite ceramics by solution combustion synthesis followed by spark plasma sintering, and investigated the synergistic effect of Y³⁺ and Yb³⁺ on the isothermal oxidation behavior at 1700 °C and the residual mechanical properties after oxidation. The $(Y_xYb_{1-x})_2O_3$ powders produced by solution combustion synthesis possess particle sizes in the range of 30-50 nm, which can assist the ZrB₂-SiC ceramics to achieve synergistic effects of ZrO₂ phase stabilization, SiO₂ glass phase modification, and interface strengthening at high temperatures, thereby improving the oxidation resistance. Among the samples, the ZrB₂-SiC-(Y_{0.9}Yb_{0.1})₂O₃ sample exhibited reductions of 44.79 %, 69.16 %, and 43.47 % in mass gain per unit area, oxide scale thickness, and surface roughness, respectively, compared with the unmodified ZrB₂-SiC sample. Furthermore, all samples modified with $(Y_xYb_{1-x})_2O_3$ showed hardness retention greater than 94 % and flexural strength retention greater than 78 % after oxidation at 1700 °C. These improvements are attributed to the co-dissolution of Y³⁺ and Yb³⁺ into the t-ZrO₂ lattice, which effectively suppresses the t→m phase transformation, eliminates the volume effect of the ZrO₂ transformation, and reduces the sources of microcracks. Simultaneously, Yb³⁺ can incorporate into the SiO₂ glass network, improving the high-temperature fluidity of the glass, and forming a continuous and dense Zr-Y-Yb-Si-O composite oxygen-barrier layer, which enhances the oxygen barrier performance and self-healing capability. This work provides new insights into the development of dual rare-earth synergistic strategies for improving the protective capability of ultra-high-temperature ceramics.

Self-Combustion Synthesized Oxide Electrodes from Nanoporous Alloys: Applications in Energy Storage and Catalysis

Shaofei Zhang

School of Materials Science and Engineering, Hebei University of Science and Technology

Email: zhang_sf@hebust.edu.cn

Nanoporous alloys derived from dealloying possess high specific surface energy, offering a unique platform for constructing advanced core-shell architectures. In this work, we exploit this advantage to synthesize high-loading alloy@oxide core-shell structures via a self-combustion process. The influence of alloy composition on the phase evolution of the oxide shell is systematically investigated, revealing that combustion oxidation promotes the formation of complex multiphase oxide heterojunctions. Subsequent reduction treatment further introduces a Cu-doped conductive network, significantly enhancing charge transfer kinetics. Benefiting from the synergistic effects of the heterojunction interfaces and the conductive scaffold, the resultant materials exhibit excellent electrochemical performance in both supercapacitors and oxygen evolution reaction (OER) catalysis. This work provides a facile and effective strategy for designing multifunctional oxide-based electrodes with tailored phase compositions and electronic structures for energy storage and conversion applications.:

References

- [1] Wang T, Sun Q, Wei Z, et al. Fast synthesis of hierarchical porous high entropy spinel oxide with rich grain boundaries for efficient oxygen evolution reaction[J]. Chemical Engineering Journal, 2025: 172081.
- [2] Zhang, S., Du, B., Li, T., et al. Self-combustion induced hierarchical nanoporous alloy transition toward high area property electrode for supercapacitor[J]. Journal of Alloys and Compounds, 2022: 900, 163443.

Green Synthesis of Mg and Ca Co-doped ZnO Nanoparticles via Solution Combustion Method Using Lemon Extract for Photocatalytic Removal of R21 dye

Fatemeh Davar^{1,2*}, Ziliang Li^{1,2}, Mohammad Reza Loghman Estarki^{*1}, Ali Majedi²

¹ School of Materials Science and Engineering, Liaocheng University, Liaocheng, 252000, PR China

² Department of Chemistry, Isfahan University of Technology, Isfahan, Iran

Email: Davar@iut.ac.ir

The rapid industrialization and widespread use of synthetic dyes in textile, pharmaceutical, and food industries have led to severe water pollution, posing significant threats to aquatic ecosystems and human health [1]. Conventional wastewater treatment methods such as adsorption, coagulation, and membrane filtration often suffer from high operational costs, slow kinetics, and low degradation efficiency [2]. Semiconductor photocatalysis has emerged as a promising and sustainable alternative for the complete mineralization of organic pollutants. Zinc oxide (ZnO), with its wide band gap (~3.37 eV), high electron mobility, non-toxicity, and low cost, is one of the most extensively studied photocatalysts [3]. However, its practical application is limited by rapid recombination of photogenerated electron-hole pairs and restricted light absorption to the ultraviolet region. Doping with metal ions such as magnesium (Mg²⁺) and calcium (Ca²⁺) has been shown to introduce defect states, modify the band structure, and enhance charge separation efficiency [4].

In this study, Mg and Ca co-doped ZnO nanoparticles were synthesized via a green solution combustion method using lemon juice extract and sucrose as both a chelating and gel agent, as well as a natural source of Mg and Ca dopants. Zinc nitrate was used as the precursor, and the citrate (from lemon juice extract)-nitrate combustion reaction was self propagated at 300 °C. The synthesized nanoparticles were characterized by X-ray diffraction (XRD), field-emission scanning electron microscopy (FE-SEM), energy-dispersive X-ray spectroscopy (EDX), Fourier transform infrared (FTIR) spectroscopy, UV-Vis diffuse reflectance spectroscopy, and photoluminescence (PL) analysis. XRD patterns confirmed the formation of a hexagonal wurtzite structure with an average crystallite size of ~20 nm, with no secondary phases detected, indicating successful incorporation of Mg and Ca ions into the ZnO lattice. EDX analysis revealed characteristic peaks for Zn, O, Mg, and Ca, confirming the presence of dopants derived from the lemon extract. FTIR spectra showed the characteristic Zn-O stretching vibration band at ~666 cm⁻¹, along with bands corresponding to residual organic functional groups. UV-Vis absorption spectra exhibited a blue shift in the absorption edge compared to bulk ZnO, attributed to the quantum confinement effect. PL spectra displayed a broad emission band in the visible region (400–600 nm), indicative of surface defects, particularly oxygen vacancies, which are known to promote the separation of photogenerated charge carriers.

The photocatalytic performance of the synthesized nanoparticles was evaluated through the degradation of methyl orange (MO), methyl red (MR), methylene blue (MB), and reactive blue 21 (RB21) under UV irradiation. The results demonstrated excellent photocatalytic activity, with degradation efficiencies exceeding 90% for all tested dyes within 120 minutes. Notably, the sample prepared with 30 mL lemon juice and 0.0012 mol sucrose exhibited the highest activity, which is attributed to its smaller particle size (~21.5 nm), uniform morphology, and the synergistic effect of Mg and Ca doping. The enhanced photocatalytic performance can be explained by the increased surface area, improved light absorption, and efficient separation of electron-hole pairs facilitated by the dopant-induced defect states. Furthermore, the nanoparticles showed remarkable degradation of RB21, a phthalocyanine textile dye, achieving nearly complete degradation within 270 minutes. This study demonstrates that green solution combustion synthesis using lemon extract is a cost-effective, eco-friendly, and scalable approach for

producing high-performance Mg/Ca co-doped ZnO photocatalysts for environmental remediation applications.

References

- [1] F. Davar, A. Majedi, A. Mirzaei, J. Am. Ceram. Soc. 98, 1739 (2015).
- [2] K. Gayathri Devi, A. Clara Dhanemozhi, L. Sathya Priya, Mater. Today Proc. (2023) in press. Doi: 10.1016/j.matpr.2023.03.576.
- [3] G. Kaliyur Nanjundaiah, S. Hanumanthappa, S. Rudrappa, Int. J. Mater. Res. 117, 36 (2025).
- [4] Roy, S., Foysal, R.S., Ali, et al., Eco-friendly synthesis of ZnO and Cu-doped ZnO nanoparticles via lemon juice: morphological, antibacterial, and photocatalytic performance evaluation, Discover Catalysis 2, 19 (2025).

Thermodynamic Evaluation of Self-propagating Aluminothermic Synthesis of TiFe, TiAl, CuCr, CuFe and FeNi Based Alloys

Wei Xie^{1,2}, Zhihe Dou^{1,2}, Bingqi Li^{1,2}, Shuai Fang^{1,2}, Tingan Zhang^{1,2}

¹ School of Metallurgy, Northeastern University, Shenyang, 110819, China

² Key Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, 110819, China

Email: douzh@smm.neu.edu.cn

Abstract: The thermodynamic characteristics of self-propagating synthesis provide a fundamental basis for reaction-system design and process control. In this study, a systematic thermodynamic analysis was conducted for the self-propagating synthesis of TiFe [1], TiAl [2], CuCr [3], CuFe [4], and FeNi [5] based alloys. Key parameters, including the adiabatic temperature, heat released by the reaction, and melting temperatures of the alloy and slag, were calculated for each reaction system. The selection of slag-forming, heating, and cooling agents and their roles in controlling the reaction were also comprehensively evaluated. The thermodynamic calculations showed that the adiabatic temperatures of the aluminothermic reduction systems decreased in the following order: CuO > NiO > Fe₂O₃ > Cr₂O₃ > TiO₂. For reaction systems with excessively high adiabatic temperatures, an appropriate amount of cooling agent can be added to moderate the reaction intensity. Conversely, for systems with excessively low adiabatic temperatures, a heating agent can be introduced to increase the adiabatic temperature and thereby maintain stable self-propagation. Based on these results, a thermodynamic evaluation model for self-propagating reactions was developed using the adiabatic reaction temperature and its relationship to the melting temperatures of the alloy and slag as the principal criteria. This model provides a theoretical basis for assessing reaction feasibility and regulating the thermal conditions of different alloy systems.

References

- [1] Z. Dou, T. Zhang, H. Zhang, et al., J. Cent. South Univ. (Sci. Technol.) 43, 2108 (2012).
- [2] Y. Song, Z. Dou, T. Zhang, et al., J. Alloys Comd. 789, 266–275 (2019).
- [3] W. An, Z. Dou, T. Zhang, et al., Mater. Charact. 217, 114400 (2024).
- [4] S. Fang, Z. Dou, B. Li, et al., J. Alloys Comd. 1065, 188032 (2026).
- [5] B. Li, Z. Dou, S. Fang, et al., J. Alloys Comd. 1052, 186057(2026).

Research on the Preparation of High-Iron Copper Alloys via Aluminothermic Reduction and Induction Refining

Shuai Fang^{1,2}, Zhihe Dou^{1,2}, Tingan Zhang^{1,2}

¹ School of Metallurgy, Northeastern University, Shenyang, 110819, China

² Key Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, 110819, China

Email: douzh@smm.neu.edu.cn

Abstract: Conventional preparation methods for Cu–Fe alloys, such as melting and casting and powder metallurgy, are prone to Fe segregation and generally involve relatively complicated processing procedures [1-3]. To address these issues, a novel route combining aluminothermic reduction and induction refining was proposed for the preparation of Cu–Fe alloys. Based on thermodynamic design using the mass action concentration model, the evolution of equilibrium phases during the self-propagating reduction process was theoretically predicted. Guided by the mass action concentration model, CuFe₁₀, CuFe₃₀, and CuFe₅₀ alloys were successfully prepared, and the evolution of their microstructures with increasing Fe content was systematically investigated. In addition, considering that Cu–Fe alloys prepared by aluminothermic reduction are susceptible to inclusions and porosity, the effects of refining on the microstructures and properties of CuFe₁₀, CuFe₃₀, and CuFe₅₀ alloys were further studied. After refining, the hardness of the Fe-rich phase increased from 119–222 HV to 143–346 HV, while the electrical conductivities of the CuFe₁₀, CuFe₃₀, and CuFe₅₀ alloys were 47.7% IACS, 25.1% IACS, and 11.8% IACS, respectively. The proposed process provides a new route for the low-cost and high-efficiency preparation of Cu–Fe immiscible alloys and demonstrates promising potential for industrial application.

References

- [1] B.Q. Li, Z.H. Dou, S. Fang, et al., J. Alloys Compd. 1052, 186057 (2026).
- [2] W. Xie, Z.H. Dou, S. Fang, et al., Rare Met. Mater. Eng. 55, 2421 (2026).
- [3] W. An, Z.H. Dou, J.R. Han, et al., J. Alloys Compd. 960, 170797 (2023).

Process Parameter Regulation and Product Characteristics of B₄C Powder via Self-propagating High-temperature Synthesis

Ceng Wang^{1,2}, Zhi-he Dou^{1,2}, Ting-an Zhang^{1,2}

¹ School of Metallurgy, Northeastern University, Shenyang, 110819, China

² Key Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, 110819, China

Email: douzh@smm.neu.edu.cn

Abstract: To address the issues of high temperature and large energy consumption in the traditional preparation of B₄C, this study adopted self-propagating high-temperature synthesis (SHS) to fabricate B₄C powder [1-3]. The effects of carbon stoichiometry, Ar atmosphere pressure, compaction pressure and sample loading mass on SHS combustion behavior and product performance were investigated. The influencing mechanisms of key process parameters on reaction thermal behavior and product characteristics were revealed, providing theoretical and experimental support for process regulation and optimization of SHS-prepared B₄C. The results show that each process parameter modulates the sufficiency of the SHS reaction by regulating heat accumulation, reactant contact conditions, and heat-mass transfer processes of the system, thereby altering the phase composition, free carbon content and particle size of B₄C. Appropriate carbon stoichiometry favors B₄C formation and reduces residual free carbon. Moderate Ar atmosphere pressure and compaction pressure improve reaction stability. Increasing the sample loading mass enhances system heat accumulation and promotes complete reaction. Considering both free carbon content and particle size, the optimal process parameters were determined as carbon stoichiometry of 1.0 mol, Ar atmosphere pressure of 1 atm, compaction pressure of 30 MPa, and sample loading mass of 60 g. This work offers experimental references for low-energy-cost fabrication of B₄C powder via SHS and its process optimization.

References

- [1] H. Shi, Z.H. Dou, T.A Zhang. *Ceram. Int.* 48, 33400-33411 (2022).
- [2] H. Shi, Z.H. Dou, T.A Zhang. *J. Cent. South Univ.* 30, 735-748 (2023).
- [3] C. Wang, Z.H. Dou, T.A Zhang. *Ceram. Int.* 51, 65856-65870 (2025).

Direct Preparation of Low-Inclusion W-Cu Composites by Coupling CaO Fluxing with Aluminothermic-Magnesiothermic Reduction

Xinyu Wang^{1,2}, Zhihe Dou^{1,2}, Tingan Zhang^{1,2}

¹ School of Metallurgy, Northeastern University, Shenyang, 110819, China

² Key Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, 110819, China

Email: douzh@smm.neu.edu.cn

Abstract: W-Cu composites fabricated by conventional powder metallurgy are limited by poor W-Cu wettability and inadequate densification, which often result in pores, microcracks, and weak interfacial bonding, thereby restricting their use in advanced applications [1,2]. In previous studies, an innovative route based on coupled aluminothermic-magnesiothermic reduction was proposed for preparing W-Cu composites containing micro- and nanoscale W particles [3]. This method effectively refines the W particles and improves microstructural homogeneity [4]. However, the formation of high-melting-point slag phases and residual oxide inclusions adversely affects slag-metal separation. To enhance slag-metal separation and reduce the inclusion content in the W-Cu composites, the influence of CaO, used as a fluxing agent, on the slag-metal separation behavior of the reaction system was systematically investigated. The effects of CaO addition on slag properties and inclusion removal were therefore investigated. CaO modified the slag phase constitution, reduced its melting point and density, and increased its liquid-phase fraction and fluidity, thereby promoting inclusion migration, coalescence, and flotation. With increasing CaO addition, the slag-density range decreased from 3.60-3.65 to 3.41-3.62 g/cm³, while the liquid-phase fraction increased from 26.54% to 53.68%. Meanwhile, the inclusion phase fraction decreased from 17.21% to 3.76%, and the average inclusion size decreased from 5.40 to 0.85 μm . These results demonstrate that CaO fluxing effectively enhances slag-metal separation, providing an effective route for directly preparing dense, homogeneous W-Cu composites with low inclusion contents.

References

- [1] W. An, Z.H. Dou, J.R. Han, et al. *J. Alloys Compd.* 960, 170797 (2023).
- [2] J.R. Han, Z.H. Dou, T.A. Zhang, et al. *J. Mater. Res. Technol.* 25, 1585-1598 (2023).
- [3] C. Cheng, X.Y. Wang, T.A. Zhang, et al. *Rare Met.* 43, 6113-6121 (2024).
- [4] X.Y. Wang, C. Cheng, Y.S. Feng, et al. *J. Mater. Res. Technol.* 34, 2684-2697 (2025).

Direct Preparation of an As-Cast V–Cr–Nb–Mo Refractory Multi-Principal-Element Alloy by Self-Propagating High-Temperature Synthesis

Xu Miao^{1,2}, Tingan Zhang^{1,2}

¹ School of Metallurgy, Northeastern University, Shenyang, 110819, China

² Key Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, 110819, China

Email: zta2000@163.net

Abstract: V–Cr–Nb–Mo refractory multi-principal-element alloys possess high melting points, excellent high-temperature strength, and good thermal stability, demonstrating considerable potential for aerospace and high-temperature structural applications [1–4]. However, their conventional preparation is generally associated with high melting temperatures, substantial energy consumption, and difficulties in controlling compositional homogeneity. In this study, a self-propagating high-temperature synthesis (SHS) route is proposed for the direct preparation of an as-cast V–Cr–Nb–Mo refractory multi-principal-element alloy [3]. Based on thermodynamic calculations of the aluminothermic reduction reactions, the proportions of the V, Cr, Nb, and Mo containing oxide feedstocks were designed. The effects of feedstock composition on the reaction process, alloy composition, and slag–metal separation were subsequently investigated. The results demonstrate that the heat released by the self-propagating reaction is sufficient to drive the reduction of the metal oxides, melting of the reduced metals, and multicomponent alloying, thereby producing a V–Cr–Nb–Mo alloy ingot. Similar thermochemical synthesis routes have also demonstrated their feasibility for the preparation of refractory multicomponent alloys. Characterized by a high reaction temperature, a short processing route, and low external energy consumption, the proposed method provides a feasible approach for the cost-effective production of refractory multi-principal-element alloys.

References

- [1] O. N. Senkov, G. B. Wilks, D. B. Miracle, et al. *Intermetallics* 18, 1758 (2010).
- [2] Y. Tian, W. Zhou, Q. Tan, et al. *Trans. Nonferrous Met. Soc. China* 32, 3487 (2022).
- [3] W. An, Z. Dou, T. Zhang, et al. *Mater. Charact.* 217, 114400 (2024).
- [4] M. Moser, S. Dine, D. Vrel, et al. *Materials* 15, 5416 (2022).

As-Cast Fe-36Ni Invar Alloy Prepared by Self-Propagating High-Temperature Synthesis

Bingqi Li^{1,2}, Zhihe Dou^{1,2}, Tingan Zhang^{1,2}

¹ School of Metallurgy, Northeastern University, Shenyang, 110819, China

² Key Laboratory of Ecological Metallurgy of Multi-metal Intergrown Ores of Ministry of Education, Shenyang, 110819, China

Email: douzh@smm.neu.edu.cn

Abstract: Fe–36Ni Invar alloy is widely used in precision instruments, aerospace, and other fields due to its low thermal expansion; however, conventional preparation processes are complex and costly [1–3]. In this study, a novel approach for the direct preparation of as-cast Fe–36Ni Invar alloy by self-propagating high-temperature synthesis is proposed. Based on the thermodynamic design of the metallurgical reduction process, a mass action concentration model for the Fe–Ni–Mn–Al–O system was established to theoretically predict the evolution of equilibrium components during the SHS reaction. Guided by the thermodynamic predictions, the effects of the NiO and Fe₂O₃ feed ratios and CaO slagging on the alloy composition and slag–metal separation were investigated. The results show that the thermodynamic model can effectively guide the optimization of the raw-material proportions. The Fe, Ni, Mn, and Al contents of the obtained alloy were 63.52%, 35.25%, 0.22%, and 0.65%, respectively, with deviations of less than 1.5% from the theoretical calculations. When $n(\text{CaO}/\text{Al}_2\text{O}_3) = 0.4$, good slag–metal separation was achieved, enabling the continuous and controllable preparation of Fe–36Ni Invar alloy.

References

- [1] B.Q. Li, Z.H. Dou, T.A. Zhang, et al. J. Alloys Compd. 1052, 186057 (2026).
- [2] S. Fang, Z.H. Dou, T.A. Zhang, et al. J. Alloys Compd. 1065, 188032 (2026).
- [3] B.Q. Li, Z.H. Dou, T.A. Zhang, et al. J. Sustain. Metall. (2026).

Rapid Fabrication of High-Strength Porous Silicon Nitride Ceramics by Combustion Synthesis

S.L. Chen, J.T. Li

Technical Institute of Physics and Chemistry, Chinese Academy of Science

Porous silicon nitride ceramics, featuring low density, high strength, excellent dielectric properties, and favorable thermophysical performance, are promising candidates for structural components operating under extreme and complex service conditions. However, as a strongly covalent compound, silicon nitride is difficult to densify by sintering. Moreover, liquid-phase sintering is accompanied by the α -to- β phase transformation. The growth of β -Si₃N₄ grains often causes non-uniform shrinkage of the porous structure, posing major challenges to microstructural homogeneity and mechanical strength and thus limiting practical applications.

In this work, a new self-solidification–combustion route is proposed for fabricating porous silicon nitride ceramics with a uniform microstructure and high strength. A Si–Si₃N₄–Y₂O₃ multiphase particulate system was, for the first time, successfully self-solidified in an Isobam-based aqueous gel system through a mechanochemical approach. Subsequently, a rapid combustion reaction was employed to construct an in situ intergrown and interlocking β -Si₃N₄ grain structure. This architecture mitigates the densification effect of the high-temperature liquid phase on the porous framework while significantly improving the strength of the porous silicon nitride ceramics. This approach provides an efficient, cost-effective, and environmentally friendly manufacturing strategy for high-performance structural porous ceramics based on complex multiphase gel systems.

UHTC Coatings Derived from Combustion-Synthesized Boride-Based Solid-Solution Powders

Xiang Ji^{1,2}, Ph.V. Kiryukhantsev-Korneev³, Evgeny A. Levashov³, Xuanru Ren^{1,2}, Peizhong Feng²

¹ Henan Key Laboratory of High Performance Carbon Fiber Reinforced Composites, Institute of Carbon Matrix Composites, Henan Academy of Sciences, Zhengzhou 450046, China

² School of Materials Science and Physics, China University of Mining and Technology, Xuzhou 221116, China

³ National University of Science and Technology "MISIS", Leninsky prospect, 4, Moscow 119049, Russia

Email: jixiang_manuscript@163.com

To address the sluggish formation of protective glassy oxide layers caused by compositional heterogeneity in mechanically mixed powders, (Zr,Ta)B₂-SiC and (Hf,Ta)B₂-MoSi₂ composite coatings were fabricated via spark plasma sintering using solid-solution powders synthesized by self-propagating high-temperature synthesis. Compared with mechanically blended coatings, SHS-derived solid solutions exhibited enhanced densification and reduced oxidation reactivity, thereby improving the integrity of the oxygen barrier during high-temperature oxidation. In the (Zr,Ta)B₂-SiC system, adding 4 mol.% Ta to ZrB₂ promoted in-situ Ta-O bonding, stabilizing t-ZrO₂ and forming a Zr-Ta-Si-O composite glass layer. The 4TZS coating had an oxygen permeability of only 0.47 % and carbon loss of 0.78×10⁻² g·cm⁻², while structural and inerting factors decreased by 69.27 % and 37.45 % versus pristine ZrB₂-SiC. For (Hf,Ta)B₂-MoSi₂ system, the (Ta_{0.1}Hf_{0.9})B₂-MoSi₂ coating demonstrated the best oxidation resistance, with a weight gain of 0.25×10⁻² g·cm⁻² after oxidation at 1700 °C for 100 min, representing a 28.85 % reduction compared with HfB₂-MoSi₂. The uniform elemental distribution in SHS-derived solid solutions facilitated rapid oxide redistribution and homogeneous incorporation of Hf/Ta oxides into the SiO₂ glass phase, generating stable oxide frameworks that suppressed oxygen inward diffusion and SiO₂ volatilization. These results demonstrate that SHS-derived boride solid solutions can regulate multi-component oxidation behavior through homogeneous elemental design, providing a promising strategy for constructing durable oxygen-barrier coatings under extreme environments.