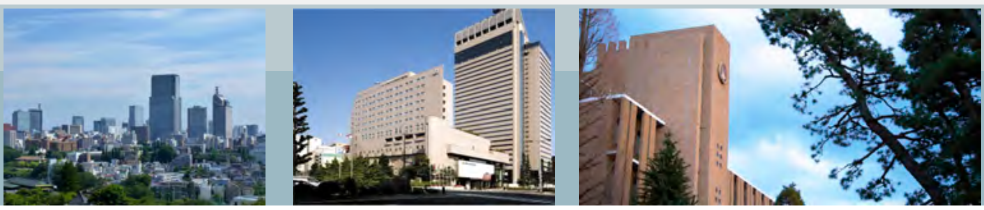
5th ISNMAC

5th International Symposium on Nanoporous Materials by Alloy Corrosion

October 6-8, 2025, Sendai, Japan



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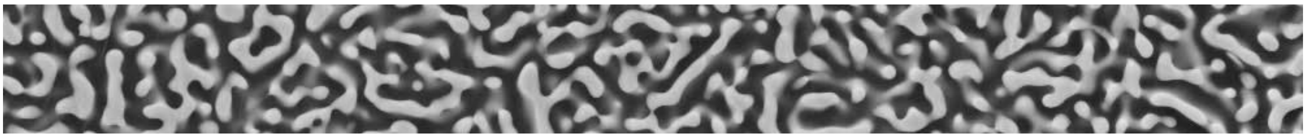
Program Book



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International Symposium on Nanoporous Materials by Alloy Corrosion

October 6-8, 2025, Sendai, Japan

Congress President

Prof. Hidemi KATO
Institute for Materials Research, Tohoku University, Japan

Conference Organizers

Prof. Takeshi WADA,
Institute for Materials Research, Tohoku University, Japan

Dr.-Ing. Ilya Okulov,
Leibniz Institute for Materials Engineering — IWT Bremen, Germany

Prof. Yu-chen Karen Chen-Wiegart
Department of Materials Science and Chemical Engineering, Stony Brook University, USA & National Synchrotron Light Source II, Brookhaven National Laboratory, USA

Sponsor

Global Institute for Materials Research Tohoku (GIMRT)

Table of Contents

Welcome Message

On behalf of the organizing committee, it is our great pleasure to welcome you to the **5th International Symposium on Nanoporous Materials by Alloy Corrosion (ISNMAC)**, held on October **6–8, 2025, at the Sendai Kokusai Hotel, Sendai, Japan.**

Since its inception, ISNMAC has served as a unique forum for the international community to share cutting-edge research and build collaborations in the field of nanoporous and nanocomposite materials. These advanced materials, fabricated through dealloying, continue to expand possibilities in catalysis, energy conversion and storage, sensing, and other functional applications.

This year's program features:

- Keynote Lectures delivered by distinguished leaders in the field, setting the stage for lively discussions.
- A rich selection of Invited and Contributed Talks, covering the latest developments across fundamental science, new techniques, and applications.
- A Poster Session with a newly introduced Poster Slam, where presenters deliver short, dynamic highlights of their work—offering both visibility and engagement for early-career researchers.
- A Conference Dinner, providing an opportunity to strengthen connections in a relaxed and collegial atmosphere.

We are delighted to host ISNMAC 2025 in Sendai, a city that combines innovation and tradition, with a welcoming spirit and rich cultural heritage. We encourage you to take this opportunity not only to exchange scientific ideas but also to enjoy the beauty and hospitality of the region.

We warmly thank all speakers, poster presenters, participants, sponsors, and supporting institutions for making this symposium possible.

We look forward to stimulating presentations, vibrant discussions, and lasting collaborations.

Welcome to ISNMAC 2025!

The ISNMAC 2025 Congress President
Hidemi KATO

Organizing Committee
Takeshi WADA
Ilya OKULOV
Yu-chen Karen CHEN-WIEGART

Key Information

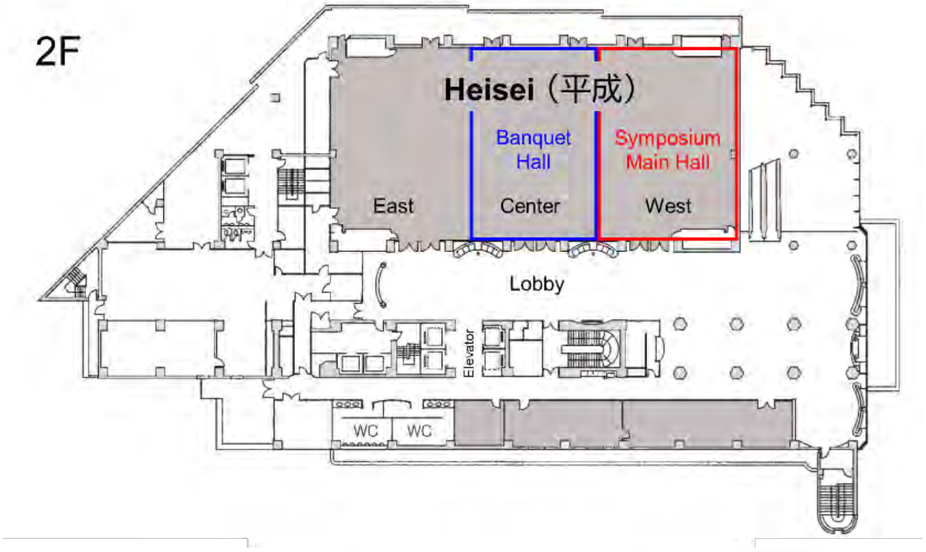
Conference Venue

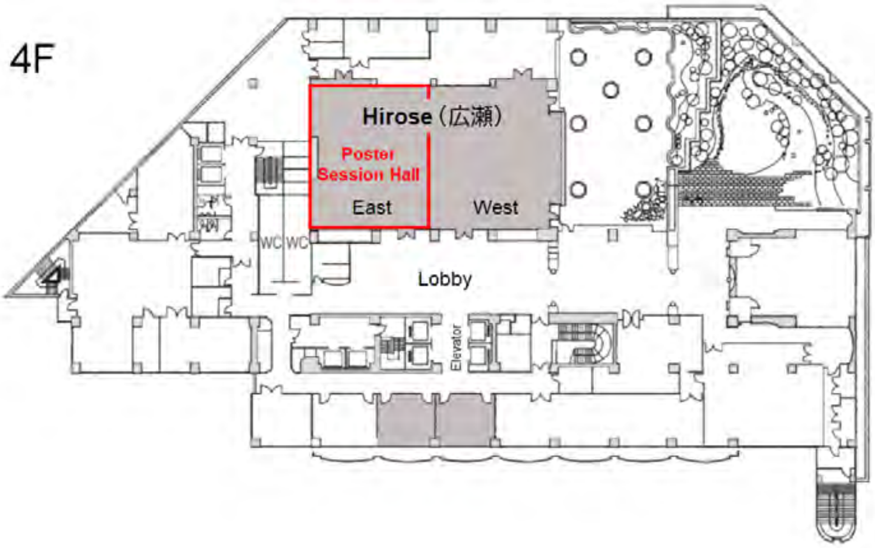
Sendai Kokusai Hotel
4-6-1, Chuo, Aoba-ku, Sendai, Japan

Tel：+81-22-268-1111

Free WiFi is available in Sendai Kokusai Hotel

Meeting Rooms and Banquet Hall Location





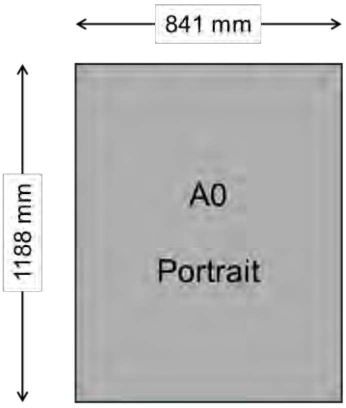
Conference Food and Beverages

- Coffee and light snacks will be served during the coffee breaks.
- Japanese-style bento boxes will be provided during the lunch breaks.
- The Conference Dinner will take place on Day 2 in the banquet room of the conference venue (see Meeting Program for details).

Poster Session

Poster Size and Format

The maximum poster size is **A0 (portrait orientation)**, as shown in the image below (**1188 mm × 841 mm,** or **33.11 in x 46.81 in**). Posters must be designed to fit within these dimensions. Portrait orientation means the poster is taller than it is wide.



Poster Slam Presentation

- In addition to the poster, each **presenter** will participate in a **Poster Slam**, a rapid-fire oral presentation designed to highlight their work. Please note:
- **Duration**: Each presenter will have **two minutes** to speak—concise delivery focusing on the key message is essential.
- **Slide**: Each presenter should prepare **one slide** using the **PowerPoint template** provided and save it as a **PDF**.
- **Submission**: The PDF slide must be sent to *isnmac5.imr@grp.tohoku.ac.jp* by **October 3rd**. All slides will be compiled on a single computer to ensure smooth transitions.
- **Schedule**: The Poster Slam will take place on **Day 1 in the afternoon**, immediately before the poster session. Presenters will be grouped in sets of five, with short breaks between groups.

Poster Display

After the Poster Slam, presenters should bring their posters to the **Poster Session Hall (Hirose Eest, 4th Floor)** and display them on the boards corresponding to their assigned poster numbers.

Program Overview

	Day 1 (2025.10.06. Monday)	Day 2 (2025.10.07. Tuesday)	Day 3 (2025.10.08. Wednesday)	
9:00	Welcome Remark **Hidemi Kato** (9:00)	Session Chair: **Nadiia Mameka**	Session Chair: **Soo-Hyun Joo**	9:00
	Session Chair: **Ilya Okulov**	O-11 Keynote Talk (9:00-9:40) **Mingwei Chen**	O-23 Keynote Talk (9:00-9:40) **Hidemi Kato**	
	O-01 Keynote Talk (9:10-9:50) **Patrick Huber**			
		O-12 Invited Talk (9:40-10:10) **Haijun Jin**	O-24 Invited Talk (9:40-10:10) **Jörg Weissmüller**	
10:00	O-02 Invited Talk (9:50-10:20) **Norbert Huber**			10:00
		O-13 Contributed Talk (10:10-10:30) **Ruirui Song**	O-25 Contributed Talk (10:10-10:30) **Fei Chen**	
	O-03 Contributed Talk (10:20-10:40) **Carlos J. Ruestes**	Coffee break (10:30-11:00)	Coffee break (10:30~11:00)	
	Coffee break (10:40-11:10)	Session Chair: **Haijun Jin**	Session Chair: **Karen Chen-Wiegart**	
11:00		O-14 Invited Talk (11:00-11:30) **Jiuhui Han**	O-26 Invited Talk (11:00-11:30) **Takeshi Fujita**	11:00
	Session Chair: **Takeshi Wada**			
	O-04 Invited Talk (11:10-11:40) **Erkin Şeker**			
		O-15 Contributed Talk (11:30-11:50) **JaeHyuk Lee**	O-27 Contributed Talk (11:30-11:50) **Jo Kubota**	
	O-05 Invited Talk (11:40-12:10) **I-Chung Cheng**	O-16 Contributed Talk (11:50-12:10) **Michihisa Fukumoto**	Closing Remark **Takeshi Wada 11:50**	
12:00			**Lunch** (12:00-13:00) Bento Box Provided	12:00
	Conference Photo (12:10)	**Lunch** (12:10-13:30) Bento Box Provided		
13:00	**Lunch** (12:20-13:40) Bento Box Provided			
		Session Chair: **Ian McCue**		
	Session Chair: **Shan Shi**	O-17 Invited Talk (13:30-14:00) **Pierre-Antoine Geslin**		
	O-06 Invited Talk (13:40-14:10) **Ian McCue**			
14:00		O-18 Invited Talk (14:00-14:30) **Soo-Hyun Joo**		
	O-07 Contributed Talk (14:10-14:30) **Yu-chen Karen Chen-Wiegart**			
	O-08 Contributed Talk (14:30-14:50) **Lijie Zou**	O-19 Contributed Talk (14:30-14:50) **Nathan Bieberdorf**		
15:00	Coffee break (14:50-15:20)	Coffee break (14:50-15:20)		
	Session Chair: **Pierre-Antoine Geslin**	Session Chair: Ruirui Song		
	O-09 Invited Talk (15:20-15:50) **Nadiia Mameka**	O-20 Invited Talk (15:20-15:50) **Shan Shi**		
16:00	O-10 Contributed Talk (15:50-16:10) **Mohan Li**	O-21 Contributed Talk (15:50-16:10) **Ilya Okulov**		
	Break (16:10-16:30)	O-22 Contributed Talk (16:10-16:30) **Ulrike Dette**		
	Session Chairs: **Karen Chen-Wiegart, Takeshi Wada, Ilya Okulov**			
17:00	P-01 - P-17 **Poster Slam** (16:30-17:40)			
18:00	P-01 - P-17 **Poster Session** (18:00-19:30)			
19:00		**Conference Dinner** (18:30-20:00)		
20:00				

Symposium Organizers

Conference Organizers

Prof. Takeshi WADA

Institute for Materials Research, Tohoku University, Japan

Prof. Takeshi Wada specializes in materials science and engineering with a focus on metallic glasses, dealloying, and nanostructured functional materials. He received his Ph.D. in Engineering from Tohoku University and has contributed extensively to advancing the understanding of alloy design and microstructural control in non-equilibrium materials. His research combines experimental and theoretical approaches to develop innovative materials with unique structural and functional properties.

Dr.-Ing. Ilya Okulov

Leibniz Institute for Materials Engineering — IWT Bremen, Germany

Dr.-Ing. Ilya Okulov leads the Department of Processing of Functional Materials at Leibn iz-IWT Bremen. His research focuses on additive manufacturing, dealloying, powder metallurgy, metallic glasses, and the design of porous and composite materials. He received his doctorate in engineering in Germany and has held research positions at leading institutions including Helmholtz-Zentrum Geesthacht, TU Dresden, and Tohoku University. Dr. Okulov also serves as Associate Professor at Ural Federal University in Russia and is widely recognized for his contributions to advanced metallic materials processing.

Prof. Yu-chen Karen Chen-Wiegart

Department of Materials Science and Chemical Engineering, Stony Brook University, USA & National Synchrotron Light Source II, Brookhaven National Laboratory, USA

Prof. Karen Chen-Wiegart's research integrates advanced synchrotron X-ray imaging and spectroscopy to study materials' morphological, chemical, and structural evolution. Her group develops multimodal and operando approaches to investigate energy materials, additive manufacturing, metallic nanostructures, and functional materials. She received her Ph.D. in Materials Science and Engineering from Northwestern University and holds a joint appointment at Brookhaven National Laboratory. Prof. Chen-Wiegart is also actively engaged in international collaborations and education at the interface of materials science and synchrotron methods.

Keynote Speakers

Day 1 Keynote Speaker

Prof. Patrick HUBER

Hamburg University of Technology (TUHH), Germany

Prof. Patrick Huber is the spokesperson for the BlueMat: Water-Driven Materials excellence cluster, which aims to develop materials whose properties are actively controlled through interaction with water (e.g. tunable color, mechanical behavior, energy harvesting). His research group uses advanced X-ray methods to study fluid transport, capillarity, and deformation in nanoporous solids — topics that are closely aligned with dealloying processes and the behavior of porous metallic structures. Prior to his leadership of BlueMat, Huber held roles spanning materials physics, imaging, and condensed matter studies, and since 2020 he also heads the Institute for Materials & X-Ray Physics at TUHH and a high-resolution X-ray analytics group at DESY. In addition, he is one of the spokespersons of the Centre for Molecular Water Science (CMWS) Consortium in Hamburg, a Europe-wide research network in the field of molecular water research, crossing subjects, disciplines, and methods.

Day 2 Keynote Speaker

Prof. Mingwei CHEN

Department of Materials Science and Engineering, Southern University of Science and Technology (SUSTech), China

Prof. Mingwei Chen received his Ph.D. in Materials Science and Engineering from Shanghai Jiao Tong University. His research focuses on the relationship between structure and properties of advanced materials, particularly nonequilibrium and nanostructured systems. He is internationally recognized for pioneering contributions to nanoporous materials via dealloying. His recent work has advanced vapor-phase dealloying as a sustainable and versatile method to fabricate nanoporous metals with tunable structures and high functionality for catalysis and energy applications. Before joining SUSTech, he held professorships at Tohoku University and Johns Hopkins University.

Congress President & Day 3 Keynote Speaker

Prof. Hidemi KATO

Institute for Materials Research, Tohoku University, Japan

Prof. Hidemi Kato is a leading researcher in non-equilibrium metallic materials, including bulk metallic glasses, high-entropy alloys, and nanoporous metals. He pioneered the concept of Liquid Metal Dealloying (LMD), a widely adopted method to fabricate novel porous materials and composites. Prof. Kato received his Ph.D. in Materials Processing from Tohoku University in 1999 and has held visiting researcher positions at institutions including MIT. He currently serves as Professor at the Institute for Materials Research at Tohoku University.

Invited Speakers

Day 1

Prof. Dr.-Ing. Norbert Huber
Bundesanstalt für Materialforschung und -prüfung (BAM);
Institute of Materials Physics and Technology,
Hamburg University of Technology, Germany

Prof. Erkin Şeker
Department of Electrical & Computer Engineering
University of California – Davis, USA

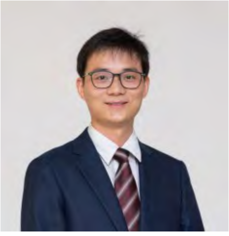
Prof. I-Chung Cheng
Department of Mechanical Engineering
National Taiwan University, Taiwan

Prof. Ian McCue
Department of Material Science and Engineering,
Northwestern University, USA

Dr. Nadiia Mameka
Helmholtz-Zentrum Hereon, Germany
Hamburg University of Technology, Germany

Day 2

Prof. Haijun Jin
Shenyang National Laboratory for Materials Science,
Institute of Meta Research,
Chinese Academy of Sciences, Shenyang, China



Prof. Jiuhui Han
Tianjin University of Technology, China

Prof. Pierre-Antoine Geslin
Mateis laboratory, CNRS /INSA Lyon / UCBL, Villeurbanne, France
ELyTMaX laboratory, CNRS / Tohoku University, Sendai, Japan

Prof. Soo-Hyun Joo
Department of Materials Science and Engineering,
Dankook University, Republic of Korea

Prof. Dr.-Ing. Shan Shi
Research Group of Integrated Metallic Nanomaterials Systems,
Hamburg University of Technology, Germany
Institute of Hydrogen Technology, Helmholtz-Zentrum Hereon

Day 3

Prof. Jörg Weissmüller
Institute of Materials Physics and Technology,
Hamburg University of Technology (TUHH), Germany
Institute of Hydrogen Technology, Helmholtz Center Hereon

Prof. Takeshi Fujita
Kochi University of Technology, Tosayamada, Japan

Symposium Program

Day 1: Monday, October 6, 2025

9:00 Welcome Remark

Hidemi Kato, Tohoku University, Japan

Mon - Morning Session I:
Session Chair: Ilya Okulov

9:10 Keynote Talk O-01

BlueMat: Water-Driven Nanoporous Materials

Patrick Huber, Hamburg University of Technology, Germany

9:50 Invited Talk O-02

Perspectives and pitfalls in modeling of structure-property relationships using machine learning

Norbert Huber, Bundesanstalt für Materialforschung und -prüfung (BAM), Germany

10:20 Contributed Talk O-03

Nanoporous tungsten under irradiation - Mechanical properties, modeling and experiments

Carlos J. Ruestes, Universidad Politécnica de Madrid, Spain

10:40 Coffee break

11:10 Invited Talk O-04

Interfacial and Transport Phenomena in Nanoporous Gold-Based Biomedical Devices

Erkin Seker, University of California, Davis, USA

11:40 Invited Talk O-05

Nanoporous metals as electrocatalysts for CO2 reduction reaction

I-Chung Cheng, National Taiwan University, Taiwan

Mon - Morning Session II:
Session Chair: Takeshi Wada

12:00 Conference Photo

12:10 Lunch

Mon - Afternoon Session I:
Session Chair: Shan Shi

13:40 Invited Talk O-06

Stability of Nanoporous Ultra-High Temperature Ceramics at High Temperatures

Ian McCue, Northwestern University, USA

14:10 Contributed Talk O-07

Accelerating Thin-Film Solid-State Metal Dealloying for Nanostructure Design

Yu-chen Karen Chen-Wiegart, Stony Brook University & Brookhaven National Lab., USA

14:30 Contributed Talk O-08

Ligament morphology and elastic modulus of porous structure formed by liquid metal dealloying

Lijie Zou, Institute of Metal Research, Chinese Academy of Sciences, China

14:50 Coffee break

Mon - Afternoon Session II:
Session Chair: Pierre-Antoine Geslin

15:20 Invited Talk O-09

Hierarchical nanoporous gold modified by electroactive self-assembled mono-layers: A novel soft-hard hybrid material with enhanced actuation

Nadiia Mameka, Helmholtz-Zentrum Hereon, Germany

15:50 Contributed Talk O-10

Electrodeposition-based synthesis of hierarchical nanoporous dealloyed Au nanowire networks and their properties

Mohan Li, Technical University of Darmstadt & GSI Helmholtz Centre for Heavy Ion Research, Germany

16:10 Break

16:30 Poster Slam

18:00 Poster Session

Day 2: Tuesday, October 7, 2025

Tue - Morning Session I:

Session Chair: Nadiia Mameka

9:00 Keynote Talk O-11

Thermodynamics and Kinetics of Vapor Phase Dealloying

Mingwei Chen, Southern University of Science and Technology, China

9:40 Invited Talk O-12

Tensile plasticity of dealloyed nanoporous metals

Haijun Jin, Institute of Metal Research, Chinese Academy of Sciences

10:10 Contributed Talk O-13

Microstructure Evolution of Nanoporous Fe_7Mo_6 Intermetallic Compounds Fabricated via Liquid Metal Dealloying

Ruirui Song, Tohoku University, Japan

10:30 Coffee break

Tue - Morning Session II:

Session Chair: Haijun Jin

11:00 Invited Talk O-14

Phase Transformations in Dealloying at High Homologous Temperatures

Jiuhui Han, Tianjin University of Technology, China

11:30 Contributed Talk O-15

Development of 3D interconnected nanoporous TiZrHfNbTaNi high-entropy alloy via liquid metal dealloying and subsequent synthesis of (TiZrHfNbTaNi)O high-entropy oxide

JaeHyuk Lee, Dankook University, Korea

11:50 Contributed Talk O-16

Formation of porous Ni-Pt alloy by electrochemical treatment using molten salt

Michihisa Fukumoto, Akita University, Japan

12:10 Lunch

Tue - Afternoon Session I:

Session Chair: Ian McCue

13:30 Invited Talk O-17

Kinetics and thermodynamics control of the liquid metal dealloying reaction

Pierre-Antoine Geslin, ELyTMaX laboratory, CNRS/Tohoku University, Japan

14:00 Invited Talk O-18

Development of 3D interconnected high-entropy alloys through liquid metal dealloying

SooHyun Joo, Dankook University, Korea

14:30 Contributed Talk O-19

Morphologies of dealloying corrosion attack at grain boundaries

Nathan Bieberdorf, University of California, Berkeley, USA

Coffee break

Tue - Afternoon Session II:

Session Chair: Ruirui Song

15:20 Invited Talk O-20

Mechanics of Complex Nanoporous Metals

Shan Shi, Hamburg University of Technology & Helmholtz-Zentrum Hereon, Germany

15:50 Contributed Talk O-21

Hierarchical materials via additive manufacturing and dealloying

Ilya Okulov, Leibniz Institute for Materials Engineering, IWT Bremen, Germany

16:10 Contributed Talk O-22

Scalable fabrication and mechanical behaviour of hierarchical network nickel foam

Ulrike Dette, Hamburg University of Technology, Germany

18:30 Conference Dinner

Day 3: Wednesday, October 8, 2025

Wed - Morning Session I:

Session Chair: Soo-Hyun Joo

9:00 Keynote Talk O-23

Joining Dissimilar Immiscible Materials via Liquid Metal Dealloying and its Derivative Reaction

Hidemi Kato, Tohoku University, Japan

9:40 Invited Talk O-24

Nanoporous metal hydrides - model systems for the materials science of energy storage and conversion

Jörg Weissmüller, Hamburg University of Technology & Helmholtz Center Hereon, Germany

10:10 Contributed Talk O-25

Study on Ultrafine-grained Nanoporous Copper Fabricated by Synergistic Selective Laser Melting and Chemical De-alloying and Its Irradiation Resistance

Fei Chen, Wuhan University of Technology, China

10:30 Coffee break

Wed - Morning Session II:

Session Chair: Karen Chen-Wiegart

11:00 Invited Talk O-26

Multi-Elementalization of Nanoporous Alloys and Creation of Unique Reaction Fields

Takeshi Fujita, Kochi University of Technology, Japan

11:30 Contributed Talk O-27

Rapid Synthesis of Activated Nanoporous Zn Powder by Selective Etching of Al from Micrometer-Sized Zn-Al Powder Particles Produced by Gas Atomization and Its Application in On-Demand Hydrogen Generation by Two-Step Water Splitting

Jo Kubota, University of Pennsylvania, USA

12:00 Lunch

Poster Presentations

[P-01] **Reviving Degraded Pt/C Catalyst via Vapor-Phase-Induced Alloying-Dealloying Cycle**
Kaiyue Zhang, Tianjin University of Technology, China

[P-02] **3D nanoporous Cu-Zn intermetallic compounds: room-temperature synthesis and electrochemical acetylene-to-ethylene catalysis**
Min Zhang, Tianjin University of Technology, China

[P-03] **Autonomous Laser-Induced Dealloying in Thin Films Revealed by Multimodal Synchrotron X-ray for 3D Nanostructure Analysis**
Carly Alexandra Zincone, Stony Brook University, USA

[P-04] **Machine Learning-Driven Discovery of 3D Morphologically Complex Nanomaterials via 3D Printing and Dealloying**
Ankita Mohanty, Stony Brook University, USA

[P-05] **3D Bicontinuous Nanoporous Silicon Carbide Fabricated by Liquid Metal Deal-loying and Its Applications in Alkali-Metal Batteries**
Xiao Bian, Tohoku University, Japan

[P-06] **Atomic-scale dynamics of a bulk-diffusion-driven nonconservative phase transformation in vapor phase dealloying**
Pan Liu, Shanghai Jiao Tong University, China

[P-07] **Solid-state electrolyte dealloying**
Xiangwei Geng, Hong Kong University of Science and Technology, Hong Kong

[P-08] **3D Bicontinuous Nanoporous Co@CoO/RuO2 Composites as High-Efficiency Electrocatalysts for Oxygen Evolution Reaction**
Yumin Zhou, Shanghai Jiao Tong University, China

[P-09] **Nanoporous MoS2 via Liquid Metal Dealloying and Direct Sulfurization for Energy Storage and Conversion**
Jiayan Liu, Tohoku University, Japan

[P-10] **Effect of hydrothermal reaction field on CO2 reduction performance of nanoporous gold catalysts**
Ryusei Takayanagi, Tohoku University, Japan

[P-11] **Immiscible Fe-Mg joining by eutectic-melt-induced liquid metal dealloying**
Kota Kurabayashi, Tohoku University, Japan

[P-12] **Effects of alloying elements X (Zr, Nb, Ta, Mo, Si) in ($Ti_{47.5}X_{2.5}$)Cu_{50} on microstructure and properties of Mg–Ti composites fabricated by liquid metal dealloying**
Jihye Seong, Dankook University, Korea

[P-13] **Topology-dependent elastic behavior of monolithic nanoporous gold and nanoporous niobium**
Seoyun Sohn, Hamburg University of Technology, Germany

[P-14] **In-situ microtensile testing and micropillar compression on hierarchical nanoporous gold: role of structural hierarchy and cold working**
Weiche Chang, Helmholtz-zentrum Hereon, Germany

[P-15] **Effects of alloying elements in Mg melt on surface functionalization of Ti alloy via liquid metal dealloying**
HyeokMin Kwon, Dankook University, Korea

[P-16] **Forming bicontinuous microstructures by distributed internal melting**
Zhongyang Li, Technischen Universität Hamburg (TUHH), Germany

[P-17] **Rapid thermo-mechanical performance prediction and multi-objective optimization of tri-directional functionally graded material considering complex geometry and arbitrary graded paths**
Guangshuai Gu, Wuhan University of Technology, China

Abstracts

The abstracts are organized according to the oral [O-] and poster [P-] presentation numbers.

To locate a specific abstract, please refer to the corresponding presentation number.

Oral Presentations

O-01

BlueMat: Water-Driven Nanoporous Materials

Patrick Huber

Hamburg University of Technology and Deutsches Elektronen-Synchrotron DESY

* Email: patrick.huber@tuhh.de

The exquisite diversity and functionality of biological materials is truly remarkable, especially since they are composed of a small set of abundant chemical elements. While engineering materials primarily require specific, often unsustainable, chemical compositions to realize their functions, nature achieves unparalleled functionality through optimized architectures that span multiple length scales. Water, with its ubiquity and unique structural dynamics, plays a pivotal role as a nanoscale “working fluid” in shaping the properties and functionality of nature’s materials. Here, I will introduce a novel class of sustainable, interactive materials that derive their functionality from the interplay between hierarchical structures of hard matter, including nanoporous solids and water. I will show how these “Blue Materials“ can mimic natural processes such as water-driven mechanical actuation, capillarity-driven water transport, and humidity-responsive coloration and light scattering. I will also highlight their potential for innovative applications, including electrical energy storage and generation, thus extending the functionalities observed in nature.

O-02

Perspectives and pitfalls in modeling of structure-property relationships using machine learning

Norbert Huber[1, 2)*

1) Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, Germany
2) Institute of Materials Physics and Technology, Hamburg University of Technology, Germany

* Email: norbert.huber@bam.de, n.huber@tuhh.de

Machine learning (ML) has been increasingly utilized to support microstructure characterization and predict mechanical properties. A successful ML model typically requires a comprehensive understanding of existing knowledge, expertise in translating this knowledge into meaningful input features, an effective ML architecture, and robust validation of the trained model. Despite the rapid growth in publications incorporating ML methods in recent years, there is limited literature specifically addressing nanoporous metals. The talk will give an overview on perspectives and pitfalls in modeling of structure-property relationships using machine learning with focus on various challenges that arise from the specific nature of nanoporous metals including randomness of microstructure, image segmentation, lack of tomography data, feature engineering for property prediction, and implications for plasticity including anisotropic flow and arbitrary multiaxial loading on the lower scale of hierarchy. An outlook will be given on the perspectives of establishing a culture of open data, specifically towards curated data sets needed for training and validation of ML models. Potential use cases are the comparison of data from different sources, mining of more general relationships, and validation of models trained with computer generated data using experimental data.

[1] Y.K. Chen-Wiegart, N. Huber, K.G. Yager, MRS Bull. (2025), accepted.

O-03

Nanoporous tungsten under irradiation - Mechanical properties, modeling and experiments

Carlos Ruestes[1,2]*, Raquel GONZÁLEZ-ARRABAL[1], Miguel MONCLUS[2], Manuel AVELLA[2], Lukas SCHWEIGER[3], Daniel KIENER[3], Ulrich KENTSCH[6], Jon MOLINA-ALDAREGUIA[4,2], Javier SEGURADO[5,2].

1) Instituto de Fusión Nuclear "Guillermo Velarde", Universidad Politécnica de Madrid, Madrid, Spain
2) IMDEA Materials Institute, Madrid, Spain
3) Department of Materials Science, Montanuniversität Leoben, Leoben, Austria
4) Department of Mechanical Engineering, Universidad Politécnica de Madrid, Madrid, Spain
5) Departamento de Ciencia de Materiales, Universidad Politécnica de Madrid, Madrid, Spain
6) Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

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Nuclear reactors pose extreme challenges to their component materials. Radiation can lead to swelling, hardening and embrittlement, ultimately undermining material integrity. Since free surfaces could act as perfect sinks for radiation-induced defects, nanoporous metals (np-metals) have the potential to be extremely radiation tolerant, promising the long sought self-healing solution in radiation environments [1]. In particular, refractory-based np-metals have a remarkable potential for nuclear applications by combining the excellent mechanical and radiation performance of the base material with a radiation tolerant nano-structure.

In this contribution, nanoporous tungsten (np-W) with ~35% porosity and average ligament size of 20-25 nm was manufactured using severe plastic deformation of a coarse-grained W-Cu composite followed by selective dissolution of Cu [2]. The resulting np-W was then implanted with H and He at energies of 82 keV and 160 keV, respectively. The implantation fluence for both cases was selected to be 5×10^{20} m^{-2}. By performing nanoindentation and micropillar compression experiments on as-prepared and irradiated samples, changes in the mechanical properties were evaluated. Moreover, by means of a combination of transmission electron microscopy (TEM) experiments, molecular dynamics simulations of radiation damage and FFT-based crystal plasticity simulations, the changes in mechanical properties were correlated to radiation-induced modification of the material microstructure and were interpreted based on a model accounting for the increased resistance to dislocation glide by helium-implantation-induced defects.

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O-04

Interfacial and Transport Phenomena in Nanoporous Gold-Based Biomedical Devices

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Nanostructured materials offer tremendous opportunities for engineering advanced device components for diagnostic and therapeutic applications. Nanoporous gold (np-Au), produced by a nano-scale self-arrangement process, has significant potential for use in biomedical applications due to its large effective surface area, electrical conductivity, and ease of surface functionalization[1]. In this talk, I will describe our work on electrochemical biosensors (**Figure 1A**)[2] and drug delivery platforms in the context of neural electrodes to monitor electrophysiological activity (**Figure 1B**)[3]. For each application, I will emphasize the molecular transport in np-Au thin films and surface-molecule interactions that play a critical role in device performance. I will conclude the talk with our ongoing efforts toward implementing the described technologies into tissue chips to study the gut-brain axis.

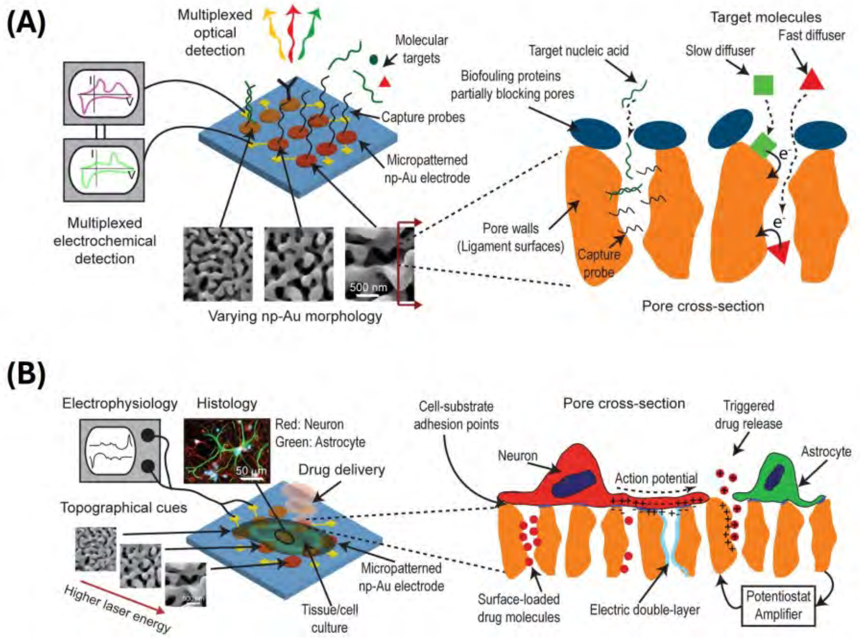

Figure 1. (A) Schematic illustration of nanoporous gold (np-Au)-based biosensors. Multiple electrode np-Au arrays can be created via microfabrication processes, allowing for both optical and electrochemical detection modalities. The tunable porosity permits biofouling-resilient sensing and enhanced selectivity in electrochemical detection of molecules with different diffusivities and charge-transfer rates. **(B) Schematic illustration of a multifunctional neural interface.** Np-Au multiple electrode arrays can support the culture of neural cells and tissue, allowing for electrophysiological recordings with high signal-to-noise ratio. Topographical cues enhance neuron–electrode proximity while reducing astrocyte spreading, which tends to interfere with the neuron–electrode interface. The porous structure and high effective surface area allow for loading and release of pharmaceuticals passively and with chemical/electrical gating, thereby modulating neural behavior.

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O-05

Nanoporous metals as electrocatalysts for CO_2 reduction reaction

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This presentation includes two complementary advancements in materials science and computational optimization. The first investigation examines the role of diffusivity in enhancing the electrocatalytic conversion of carbon dioxide into multicarbon products using dealloyed hierarchically nanoporous copper. By analyzing the structural and transport properties of the catalyst, the study elucidates the relationship between nanoscale porosity and diffusion behavior, providing critical insights for improving catalytic efficiency in CO_2 reduction reactions. The second study introduces a hybrid machine learning–-genetic algorithm (ML-GA) framework for multi-variable optimization in complex engineering and scientific systems. By integrating the predictive capabilities of machine learning with the search and optimization efficiency of genetic algorithms, the proposed approach demonstrates enhanced performance in solving high-dimensional optimization problems. Together, these studies contribute to advancing sustainable energy conversion technologies and computational modeling, offering novel strategies for improving electrocatalytic efficiency and algorithmic optimization.

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O-06

Stability of Nanoporous Ultra-High Temperature Ceramics at High Temperatures

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Ultra-High Temperature Ceramics (UHTCs) are promising materials for use in next-generation hypersonic platforms owing to their high melting points and excellent thermo-mechanical properties. However, despite these advantages, oxidation and evaporative mass-loss in these materials severely limit their long-term service. To address this shortcoming, we are studying the synthesis and high-temperature oxidation behavior of nanoporous UHTCs infiltrated with either an ablative polymer or oxidation-resistant glass. These materials are fabricated by first exposing nanoporous refractory metals to carburizing and/or nitriding environments, and then imbibing with a viscous phase that solidifies inside the pores. The performance of these materials is governed by the length scale of the characteristic feature (the ligament diameter) – with smaller ligaments leading to superior performance – which unfortunately degrade via coarsening during service. In this talk we will discuss the synthesis of these materials, their overall performance at elevated temperatures, and governing kinetic equations describing their stability and decomposition.

O-07

Accelerating Thin-Film Solid-State Metal Dealloying for Nanostructure Design

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Solid-state metal dealloying (SSMD) in thin films has emerged as a promising route to fabricate nanostructured materials with bicontinuous architectures. [1-3] Our recent studies advance this field by integrating machine learning (ML) predictions [4], multimodal synchrotron X-ray characterization, and temperature-gradient processing to uncover the mechanisms and accelerate the discovery of SSMD systems. We investigated thermally driven morphological and chemical transformations through two complementary approaches: (1) controlled isothermal treatment under reducing environments [5] and (2) laser-induced temperature gradient processing enabling continuous thermal space on a single sample. [6] In addition to metal-induced dealloying, our findings reveal that oxidation — particularly of metals — plays a critical role in driving the formation of bicontinuous nanocomposites. Multimodal synchrotron techniques, including X-ray absorption spectroscopy and grazing-incidence small-/wide-angle X-ray scattering, coupled with cross-sectional STEM analysis, provided detailed insights into phase evolution and ligament size transitions with temperature. Additionally, a laser heating platform was used to perform dealloying with a temperature gradient and synchrotron analysis can effectively capture critical transition temperatures for nanostructure formation. The latest development of real-time multimodal synchrotron analysis on dealloying and related activities will also be discussed.

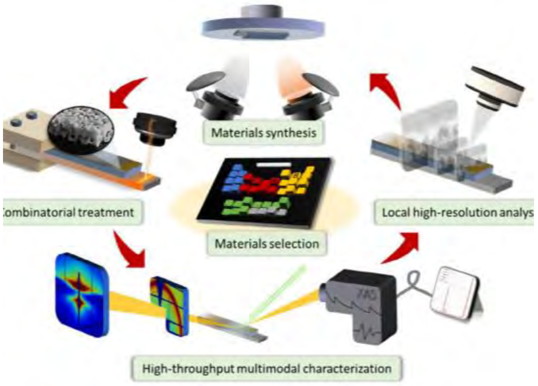

Fig. 1. Workflow for accelerating the discovery of nanostructured materials using thin-film SSMD as a proof-of-concept demonstration.

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O-08

Ligament morphology and elastic modulus of porous structure formed by liquid metal dealloying

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We report that the morphology of ligaments also governs the mechanical properties of dealloyed porous materials, in addition to the topology- and size-effects that have been extensively studied previously. Porous Fe-Cr with similar relative density but different Cr content were prepared by liquid metal dealloying. The mechanical efficiency of this material, which is quantified by relative elastic modulus, decreases dramatically with increasing Cr content, although the relative density and network connectivity do not vary significantly. This is linked to the more severe spheroidization of Fe-Cr ligaments at higher Cr, driven by the large excess energy of solid-liquid interfaces and interface energy anisotropy of Fe-Cr under dealloying environment. A shape parameter is introduced to quantitatively account for this ligament-morphology effect. Current study suggests that tailoring interfacial energy, which was largely overlooked in previous studies, is essential to improving the mechanical efficiency of porous or nanoporous materials self-organized in dealloying.

O-09

Hierarchical nanoporous gold modified by electroactive self-assembled monolayers: A novel soft-hard hybrid material with enhanced actuation

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Hierarchical nanoporous (hc np) metals fabricated through dealloying open up new opportunities for developing lightweight, high-surface-area materials with diverse functionalities in catalysis, energy storage, actuation, and sensing [1, 2]. These materials typically exhibit a bimodal pore size distribution, featuring larger pores (hundreds of nanometers) and smaller nanopores (tens of nanometers) located within their walls. The larger pores at the higher hierarchy level enhance mass transport, while the nanopores at the lower hierarchy level provide abundant active sites [3]. Understanding the influence of this hierarchical porosity on functional performance is critical for optimizing these materials.

In this study, we investigate the actuation behavior of nanoporous gold (npAu) with single and bimodal pore distributions functionalized by electroactive ferrocene-terminated alkanethiol self-assembled monolayers (SAMs). Using in situ dilatometry and cantilever bending experiments in aqueous electrolytes under potential control, we exploit the ferrocene moiety's reversible redox activity to probe impact of material's structure on the electrochemomechanical coupling. Our results demonstrate significant macroscopic length changes in hc npAu/SAM hybrids during voltage-induced redox cycles compared to non-hierarchical npAu/SAM systems. We attribute this phenomenon to surface stress changes arising from redox-driven SAM reorganization on the gold surfaces [4]. Additionally, hierarchical npAu exhibits faster actuation kinetics, highlighting the efficacy of pore hierarchy for responsive material design.

This work underlines the potential of SAM-modified nanoporous metals as integrated platforms for actuation and sensing, capable of transducing molecular-scale interactions and chemical reactions into macroscopic mechanical motion.

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O-10

Electrodeposition-based synthesis of hierarchical nanoporous dealloyed Au nanowire networks and their properties

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By combining ion-track nanotechnology with electrochemical deposition, we synthesize self-supporting 3D interconnected nanowire networks of $Au_{1-x}Ag_x$ alloys. The diameter and interconnectivity of these nanowires can be finely tuned by adjusting fabrication parameters. When the Ag atoms are subsequently dealloyed, we achieve a significant reduction in the material's weight, coupled with a significant increase in its surface area. This innovative approach to design enables the creation of highly stable hiearchical 3D porous Au nanowire networks, with adjustable geometry and exceptional surface roughness. Notably, the surface roughness of these nanostructured samples can be up to ~400 times greater than that of a flat electrode.

In this talk, we will explore the synthesis process of $Au_{1-x}Ag_x$ nanowire networks wih precisely tailored compositions and dimensions, and discuss how these parameters affect the dealloying process. Additionally, we will present our findings on the investigation of these stable 3D nanowire networks, which feature optimized specific surface areas, tailored wettability, and enhanced electrochemical activity, particularly towards methanol oxidation.

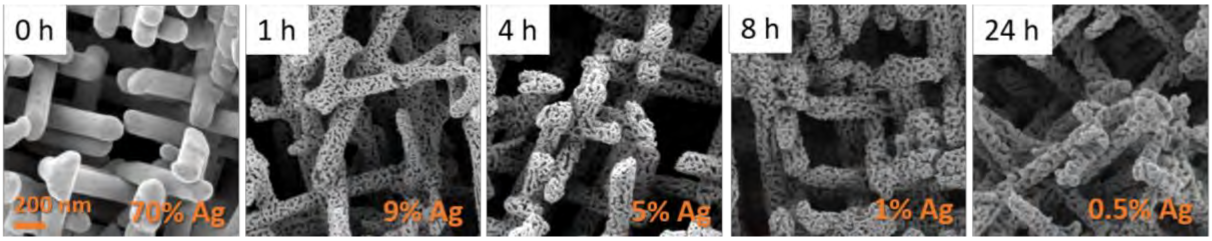

Fig. 1. SEM images and composition of the $Au_{0.3}Ag_{0.7}$ nanowires after different dealloying times.

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O-11

Thermodynamics and Kinetics of Vapor Phase Dealloying

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Vapor phase dealloying (VPD) is a promising technique for fabricating nanoporous materials through selective evaporation of one or more components from a precursor alloy in a low-pressure gaseous environment[1]. The process is governed by the interplay between thermodynamics and kinetics, which dictate the structural evolution and final morphology of the dealloyed nanoporous material. Thermodynamically, VPD relies on the inherent vapor pressure disparity between alloy components. Elements with higher saturated vapor pressures (e.g., Zn in Zn-Cu, Mg in Mg-Ni) preferentially sublimate when heated to above a threshold temperature, leaving behind a porous skeleton[2]. The process is further influenced by chemical potential gradients between the equilibrium vapor pressure and the partial pressure at dealloying fronts, surface energy minimization described by Gibbs-Thomson effects, and sublimation energy. Especially, the sublimation energy determines which element evaporates preferentially and the dealloying temperature threshold. The dealloying kinetics depends on environmental pressure, temperature, and diffusivity of precursor alloys[3,4]. The pore size and porosity can be tuned by controlling dealloying temperature, pressure and composition of the precursor alloys. The kinetics of VPD involve three key stages: (1) Initial decomposition, *i.e.* low-boiling-point elements (e.g., Mg, Zn) sublimate from the sample surface, creating a depletion zone for the nucleation of nanopores; (2) mass transport: bulk diffusion of residual atoms (e.g., Cu, Ni) and/or Knudsen diffusion of Zn or Mg vapor in developed pore channels where the partial pressures of Zn or Mg at the dealloying front reach the local equilibrium between the solid and vapor phases; and (3) surface diffusion drives ligament coarsening.

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O-12

Tensile plasticity of dealloyed nanoporous metals

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Dealloyed nanoporous metals can exhibit high strength and excellent ductility under compression [1]. However, these materials are typically brittle in bending and tension [2–4], which limits their structural or functional applications in practice. Infiltrating their pore channels with a soft polymer phase can toughen the material and significantly improve tensile strain [5-6]; nonetheless, this approach also impairs the surface-enabled functionalities of the nanoporous metals. Notably, most free-standing dealloyed materials with a monolithic nanoporous structure undergo catastrophic failure under tension, with tensile strain rarely exceeding 1% [3-4]. We demonstrate that the introduction of nanoscale pores in metals does not necessarily induce embrittlement. Excellent tensile plasticity can be achieved in nanoporous metals, but at present not for their as-dealloyed state with a typical relative density in the range of 0.25 – 0.50. Compressing nanoporous gold to a high relative density (>0.90) and healing the deformed structure via thermal annealing yields a material with densely dispersed nanovoids [7]; this material exhibits enhanced strength and tensile plasticity compared to its fully dense counterparts [7]. On the other hand, dealloying a dilute Ag(Au) precursor produces nanoporous gold with a relative density below 0.20. This material achieves a tensile strain of up to 8–9% prior to failure, attributed to the toughening effect of microcracks [8–9]. Our recent study further reveals that low-density hierarchical nanoporous gold, with a finely tuned structure, can exhibit intrinsic tensile plasticity with a tensile strain exceeding 60% [10]. While the nanovoids-dispersed metals as a new type of lightweight & strong materials might be explored for structural applications, the compliant & ductile nanoporous metals may be used in a broad range of functional applications.

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O-13

Microstructure Evolution of Nanoporous Fe_7Mo_6 Intermetallic Compounds Fabricated via Liquid Metal Dealloying

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The Liquid metal dealloying strategy has been widely used in fabrication of porous metal/alloy and heterogeneous composite for various applications, such as batteries, catalysts, and hydrogen storage. The high-temperature liquid metal dealloying enables fabricating not only the same phase with precursor alloy, but also chemically ordered intermetallic compounds [1] by phase evolution concurrent with dealloying. The microstructure and phase evolution are crucible to tailor the further functionality of these materials. Recently, the effect of phase evolution in ligaments were explored in electrochemical dealloying process through engineering remained composition of ligaments [2] or further annealing the obtained ligaments [3] to adjust the final phase components of porous materials. Here, both engineering remained composition of ligaments and heat treatment at high temperature can be achieved by one step liquid metal dealloying. Furthermore, unlike the significant coarsening of ligament after annealing, the coarsening behavior of ligament is suppressed a lot in liquid metal dealloying. It is valuable to explore how the microstructure of nanoporous intermetallic compounds evolves during liquid metal dealloying for tailoring the final functionality of porous materials more effectively. The evaluation of obtained nanoporous Fe_7Mo_6 intermetallic compounds from reaction front to the coarsened states reveals a strong dependence on temperature for liquid metal dealloying, which including both microstructure evolution and phase transformation. This study may provide a way for fine structural regulation during liquid metal dealloying.

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O-14

Phase Transformations in Dealloying at High Homologous Temperatures

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Dealloying is a versatile top-down strategy for fabricating porous nanostructured metallic materials with wide-ranging structural and functional applications. Classical chemical or electrochemical dealloying typically involves the direct transformation of alloy precursors into unary metal products, with intermediate phase transformations rarely observed. However, the recent emergence of dealloying techniques conducted at high temperatures—such as vapor phase dealloying (VPD) and liquid metal dealloying (LMD)—has revealed that intermediate intermetallic phases can form prior to the development of the final porous structure. These findings suggest that dealloying at high homologous temperatures may trigger complex phase transformations that can fundamentally influence both the dealloying process and the resulting nanostructure. Despite these advances, the underlying thermodynamics and kinetics governing phase transformations during dealloying—and their interactions with porosity evolution—remain poorly understood. In this talk, I will present our recent research progress on phase transformations in dealloying at high homologous temperatures. Specifically, we find that the VPD of Ni–Mg alloys proceeds through a sequence of temperature-dependent phase transitions in an entropy-controlled dealloying process, which can be interpreted using solid–gas phase diagrams under low-pressure conditions. Furthermore, we demonstrate that rich phase transformation pathways can also be activated during room-temperature electrochemical dealloying through careful energetic landscape design, as exemplified by the Cu–Zn system. Our findings provide new insights into the fundamental mechanisms of dealloying and pave the way for designing advanced nanoporous materials via controlled phase evolution.

O-15

Development of 3D interconnected nanoporous TiZrHfNbTaNi high-entropy alloy via liquid metal dealloying and subsequent synthesis of (TiZrHfNbTaNi)O high-entropy oxide

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In this study, the liquid metal dealloying (LMD) process was employed to develop 3D interconnected nanoporous (3DNP) high-entropy alloys (HEAs) and high-entropy oxides (HEOs). Selective dissolution of Ni occurred in a molten Mg bath from a $(\mathrm{TiZrHfNbTa})_{20}\mathrm{Ni}_{80}$ precursor alloy, while the immiscible elements Ti, Zr, Hf, Nb, and Ta self-organized into 3D interconnected structures. The initial precursor consisted of three distinct phases, which underwent sequential, stepwise selective dissolution due to variations in their phase stabilities at the reaction front. However, after a short processing time of 10 min, the synthesized 3DNP HEAs exhibited homogeneous elemental distributions, facilitated by rapid interfacial diffusion during thermal coarsening. The miscible Ni atoms in the precursor alloy demonstrated exceptional stability in the Mg melt, which contributed to a progressively slow dissolution phenomenon. As a result, the 3D interconnected ligaments retained their ordered orthorhombic crystal structure throughout the process. After 60 min, the Ni concentration decreased to 43.1 at.% and Nb- and Ta-enriched nanoprecipitates were uniformly formed, resulting in the development of a bimodal 3DNP structure. These crystal structure transformations closely matched the equilibrium crystal structures predicted by Thermo-Calc. The synthesized 3DNP HEA was oxidation heat treated at 1200 ◦ C in dry air, producing 3DNP HEOs that retained the 3D interconnected structures. This study demonstrates the potential of the LMD process for fabricating advanced 3DNP materials with tunable compositions and microstructures for various applications.

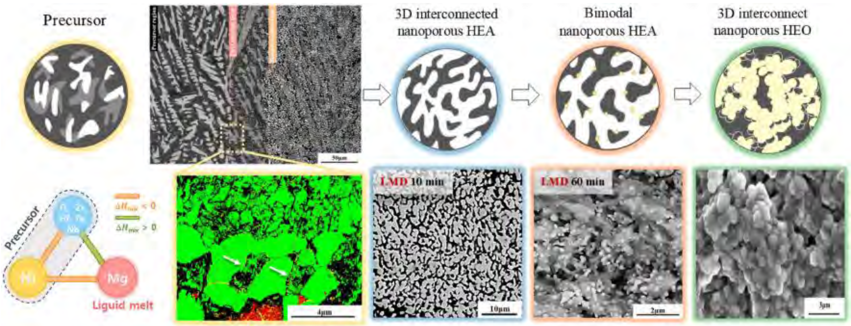

Fig. 1. Synthesis of 3D Nanoporous HEA and HEO via Liquid Metal Dealloying and Oxidation

O-16

Formation of Porous Ni-Pt alloy by Electrochemical Treatment using Molten Salt

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【Introduction】 As an effort to reduce CO_2 emissions, research is being conducted into hydrogen production by alkaline water electrolysis using renewable energy. However, hydrogen produced from renewable energy is currently expensive. In other words, hydrogen must be produced efficiently. In this study, we focused on hydrogen generation electrode catalysts and aimed to develop a high-performance water electrolysis electrode that uses less Pt. Therefore, we attempted to fabricate a porous Ni-Pt alloy electrode using a Ni by the molten salt electrodeposition and dissolution method.

【Experimental】 Ni was used as the substrate. Ni and Pt were electrodeposited from an aqueous solution. A porous Ni-Pt alloy electrode was obtained by electrodepositing and dissolving Al using molten salt. The molten salt was a mixture of $NaCl\text{-}KCl\text{-}3.5mol\%AlF_3$. A carbon rod was used as the counter electrode, and an Ag/AgCl (0.1) electrode was used as the reference electrode. Al deposition was performed at -1.4 V vs. Ag/AgCl, and Al dissolution was performed at -0.5 V vs. Ag/AgCl. The bath temperature was 750°C. For the cathodic polarization measurement, a 10 mass% KOH solution at 30°C was used as the electrolyte solution, a saturated calomel electrode was used as the reference electrode, and a platinum was used as the counter electrode. The hydrogen evolved during water electrolysis at 4.0 V was measured in situ using a hydrogen sensor.

【 Results】 Figure 1 shows the cross-sectional structure of a sample plated with Ni and Pt and then electrodeposited with Al (a), and the same sample with the Al dissolved to make it porous (b). The surface morphology of the porous sample is also shown. From this, in the sample that was not made porous, an alloy layer of the Ni of the substrate and the electrodeposited Al was formed on the surface. A Pt-enriched layer was also observed in the Ni-Al alloy layer. In the sample (b) where this sample was made porous, a Ni-Pt porous layer was formed. The pores were fine, and the Pt-enriched layer was also porous. Small voids were observed on the surface morphology of this sample. A peak of Ni-Pt alloy was observed in the XRD pattern. An investigation of the hydrogen generation behavior showed a significant improvement in performance.

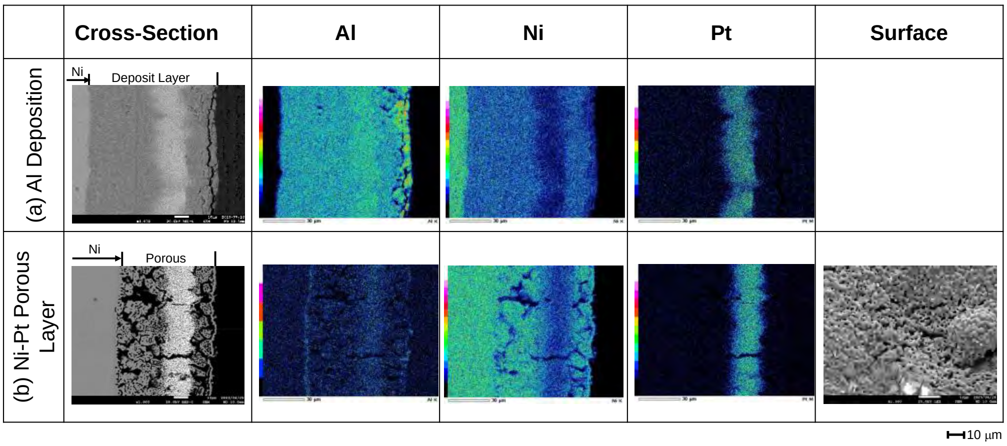

Fig. 1 Cross-sectional structure of a sample on which Al was deposited after Ni and Pt plating (a), and a porous sample (b).

O-17

Kinetics and thermodynamics control of the liquid metal dealloying reaction

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Liquid metal dealloying (LMD) is a novel technique applicable on a wide range of metals to elaborate bicontinuous micro and nano composite and porous materials [1]. It consists in the selective dissolution of an element A from a precursor alloy (A-B) into a metallic liquid bath (C). Upon dissolution of B in the liquid metal C, A reorganizes into a porous connected structure. In this contribution, we will explore and discuss two possible ways of controlling the depth of the dealloyed layer and the microstructure resulting from the reaction.

1. Thermodynamic control. The size of the liquid bath can be reduced such that it becomes saturated in B during the LMD reaction. Eventually, the system reaches a thermodynamic equilibrium between the liquid bath and the A-rich solid ligaments and the dealloying reaction stops spontaneously. In [1], we have used in-situ monitoring of the LMD reaction of FeNi powders dealloyed in Mg demonstrate how the final dealloyed microstructure (in particular the dealloying depth) are sensitive to the size of the Mg bath. These experimental findings are rationalized by the analysis of the FeNiMg phase-diagram.

2. Kinetic control. Another way to control the dealloying depth consists in stropping the dealloying reaction after a given time. The LMD kinetics is limited by the diffusion of B in the liquid metal, and the dealloying depth evolves as the square-root of time: $d \sim \alpha . t^{1/2}$. However, the prefactor α controlling this kinetics depends on the system and varies significantly with temperature, precursor and bath compositions. In a recent contribution [2], we propose a sharp-interface model of LMD that allows rationalizing the dependence of α on these quantities. This numerical approach also yields the composition profiles in the liquid and bath phases as function of time. The model predictions are compared to experimental measurements obtained from the dealloying of NiCu precursors in liquid Ag. The transferability of this model to capture the kinetics and composition profiles of other systems will be discussed.

[1] Lesage, Louis, et al. "Exploring equilibrium conditions in liquid metal dealloying of powders by in situ synchrotron X-ray diffraction." *Materialia* 36 (2024): 102177.

[2] Lesage, Louis, et al. "A diffusion model for liquid metal dealloying. Application to NiCu precursors dealloyed in liquid Ag." *Acta Materialia* 272 (2024): 119908.

O-18

Development of 3D interconnected high-entropy alloys through liquid metal dealloying

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Liquid metal dealloying (LMD) is an advanced metal processing technique that has garnered significant attention since its first report in 2011, owing to its ability to produce unique three-dimensional (3D) interconnected structures. Unlike conventional chemical dealloying, which is limited to noble metals, LMD employs molten metal baths with low oxygen content, enabling the fabrication of nanoscale 3D interconnected structures from a wide range of non-noble metals. To date, extensive studies have demonstrated the formation of 3D interconnected microstructures from various materials—including C, Si, Nb, Fe, stainless steel, Ti, and their alloys.

This study presents the first investigation of the LMD process using a CoCrFeMnNi HEA precursor in molten Cu, reporting complex dealloying and concurrent alloying phenomena. Preferential dissolution of Mn and Ni in the Cu melt led to the formation of 3D interconnected Cu–rich melt channels, while Cu atoms diffused into the remaining CoCrFe–rich ligaments. The resulting heterostructure, formed under local equilibrium conditions, consists of dual face-centered cubic (*fcc*) phases with refined grain sizes and high interconnectivity. The transformation between the precursor *fcc* grains and the dealloyed CoCrFe–rich ligaments follows uncommon orientation relationships based on non–close–packed planes, which likely serve to minimize interfacial energy.

The synthesized heterostructured dual–*fcc* HEA exhibited a 7% increase in hardness and an 82% enhancement in electrical conductivity compared to the precursor alloy. These improvements are attributed to the unique 3D interconnected microstructure and the synergistic effects of multiple principal elements, as supported by density functional theory calculations. Notably, the highly connected Cu–rich *fcc* phase significantly contributes to the enhanced electrical conductivity, demonstrating a prominent ‘cocktail effect’. These findings highlight the promising potential of the LMD process for designing heterogeneous, multifunctional HEAs with tailored structural and functional properties.

O-19

Abstract For 5th International Symposium on Nanoporous Materials by Alloy Corrosion

Title: Morphologies of dealloying corrosion attack at grain boundaries

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Dealloying corrosion at grain boundaries severely compromises the performance of polycrystalline materials across a wide variety of technological applications. The severity of this phenomenon depends upon the morphology and rate of intergranular dealloying, which can range from planar to wormhole-like patterns that rapidly advance into the alloy. Using 2D and 3D multi-phase field simulations, we reveal how diverse microstructures result from a fundamental interplay between alloy composition and a grain boundary migration mechanism that alters diffusional pathways of dealloying. The grain boundary migration mechanism was originally identified in Ref. [1], and leads to deep, linear dealloying channels at the grain boundary that contrast with the tortuous channels inside each grain, as shown in Fig. 1. Inside deep intergranular dealloying channels, corrosion product buildup can spawn new channels that branch into grain interiors, such that alloys can be degraded from the inside out. These processes further lead to an atypical coarsening mode assisted by diffusion in the dealloying agent. We summarize a unifying explanation for dealloying morphology selection in polycrystalline alloys, which provides an important step towards their optimization for dealloying corrosion environments.

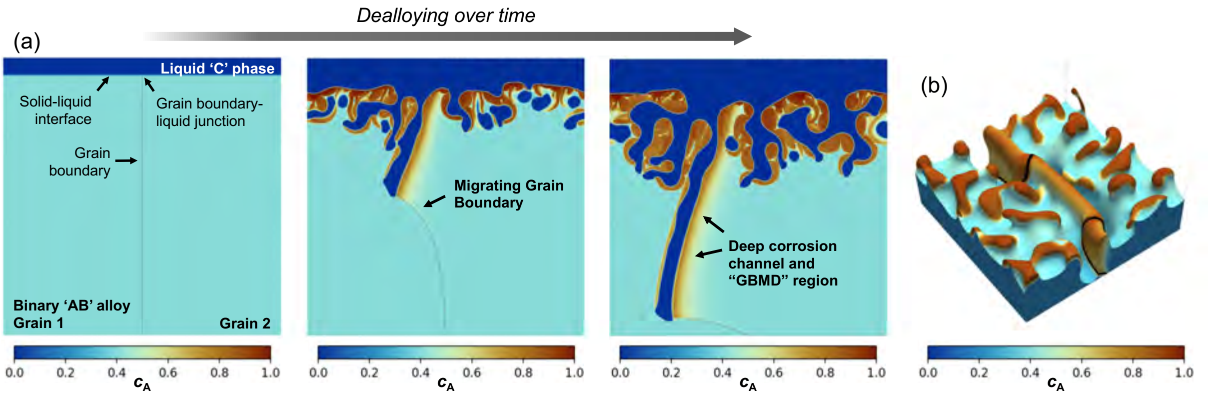

Fig. 1. Multi-phase field simulations of dealloyed bicrystal 'AB' precursor exposed to liquid 'C' dealloying agent. (a) 2D simulation at the initial condition and subsequent snapshots over time, and (b) 3D simulation. The simulations are colored by the local concentration of the non-dissolving alloy species 'A'. The migrating grain boundary is marked with a gray band.

[1] N. Bieberdorf, M. Asta, L. Capolungo, "Grain boundary effects in high-temperature liquid-metal dealloying: a multi-phase field study," npj Computational Materials Vol 9, 127 (2023)

O-20

Mechanics of Hierarchical Nanoporous Metals

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Structural hierarchy offers a powerful route to achieving lightweight materials with high stiffness and strength, spanning from macroscale engineering truss structures to microscale 3D-printed architectures, and down to nanoscale self-organized network materials. At the nanoscale metal ligaments provide not only high strength but also a large surface-to-volume ratio, enabling interface-controlled and stimulus-responsive mechanical behavior—such as tunable strain, stiffness, strength, and Poisson's ratio— of interest for soft robotics and adaptive systems. This talk presents the design, fabrication, and multiscale characterization of hierarchical nanoporous metals with relative densities as low as 10%, synthesized via two-step dealloying [1]. Ligament and pore sizes as well as relative densities are independently tailored at two hierarchical levels and characterized using small-angle and ultra-small-angle X-ray scattering as well as electron microscopy [2]. Mechanical testing on both macroscale specimens and microscale samples prepared by focused ion beam (FIB) milling reveals that structural hierarchy significantly enhances the mechanical properties of nanoscale networks. Scaling laws are proposed and experimentally validated for stiffness, strength, and elastic Poisson's ratio [3] as a function of relative density in hierarchical nanoscale network materials. Furthermore, in situ mechanical measurements under electrochemical control highlight the advantages of hierarchical design on the reversible, switchable mechanical properties in nanoporous metals [4]. The critical roles of network connectivity and dislocation activity in governing structure–property relationships, both in static and stimulus-responsive regimes, will be discussed and emphasized.

[1] Shan Shi, Li Yong, Bao-Nam Ngo-Dinh, Jürgen Markmann, and Jörg Weissmüller. "Scaling behavior of stiffness and strength of hierarchical network nanomaterials." *Science,* 371 (**2021**): 1026-1033. DOI: 10.1126/science.abd9391

[2] Lukas Riedel, Jürgen Markmann, Jörg Weissmüller, and Shan Shi. "Tailoring hierarchical nanoporous gold on dual length scales." *Physical Review Materials,* 7 (**2023**): 116001. DOI: 10.1103/PhysRevMaterials.7.116001

[3] Haonan Sun, Lukas Lührs, Wei-Che Chang, and Shan Shi. "Scaling Behaviour of Poisson's Ratio in Hierarchical Nanoscale Network Materials." *Acta Materialia,* 298 (**2025**) 121393. DOI: 10.1016/j.actamat.2025.121393

[4] Hansol Jeon, Jürgen Markmann, and Shan Shi. "Effects of structural hierarchy and size on mechanical behavior of nanoporous gold." *Acta Materialia,* 273 (**2024**): 119954. DOI:10.1016/j.actamat.2024.119954

O-21

O-22

Scalable fabrication and mechanical behaviour of hierarchical network nickel foam

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Recently, a mechanically stable two-step electrochemically dealloyed hierarchical nanoporous gold structure has been developed. [1] It exhibits improved mechanical properties and reduced density due to the nanoscale hierarchical structure. This presentation focuses on a new method for a scalable fab-rication of low-cost hierarchical nanoscale network metals. Two- and three-level hierarchical network (2L-/3L-HN) nickel samples are successfully produced from nickel foam (NF) using a novel and simple alloying-dealloying process. The resulting 3L-HN-NF samples have three clearly defined sizes of struts or ligaments (~160 µm, <10 µm and <10 nm) and have a low density of up to 0.06. In addition, we perform systematic mechanical investigations using macroscopic compression tests on 2L- and 3L-HN-NF. We present general scaling equations describing the relationship between the mechanical proper-ties and the relative density for HN materials.

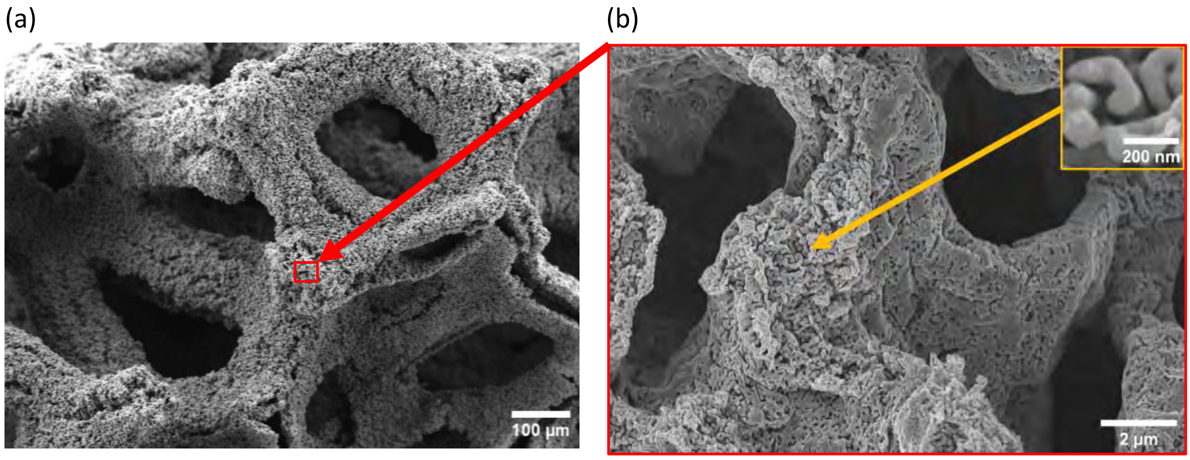

Fig. 1. Morphology of 3L-HN-NF formed by two-times alloying/dealloying. (a) shows the upper level struts, (b) shows the middle level struts after annealing at 300 °C for 10 min in ArH atmosphere and the inset shows the coarsened lower level ligaments.

[1] Shi S, Li Y, Ngo-Dinh B-N, Markmann J, Weissmüller J. Scaling behavior of stiffness and strength of hierarchical network nanomaterials. Science (New York, N.Y.) 2021;371(6533):1026–33.

O-23

Immiscible Dissimilar Material Joints using Liquid Metal Dealloying

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Next-generation transportation equipment must achieve high safety, high-volume, high-speed transport with low environmental impact. Magnesium alloys are being considered as core materials for multi-material systems, replacing conventional materials with new ones where appropriate. Development of joining technologies between Mg alloys and other structural materials like steel plates and titanium alloys has been slow, hindered by the natural tendency of Mg to phase separate from Fe and Ti, preventing bonding. This research employs the liquid metal dealloying method to form a bi-continuous fine composite microstructure of Mg-Fe and Mg-Ti at the joint interface. This achieves a strong, ideal mechanical joint and establishes a Mg alloy dissimilar material joining technology. Specifically, it involves fundamental research using simplified models with pure metals[1,2], then extends to joining studies using practical Mg and Ti -based structural materials, i.e., Ti-6Al-V, ZK60 and AZ31[3].

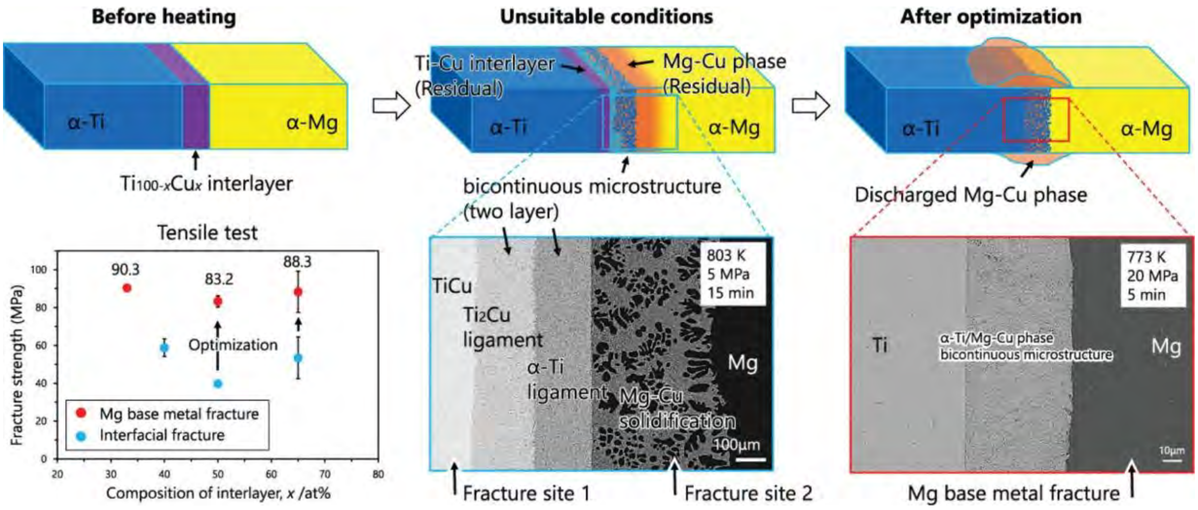

Fig. 1. Optimization of the Eutectic Melt-Induced LMD Joining Process Between Pure Magnesium and Pure Titanium Components Using a Ti-Cu Intermediate Layer [2].

[1] K. Kurabayashi, T. Wada, H. Kato, Scripta Materialia 230 (2023) 115404.

[2] Y. Ohashi, K. Kurabayashi, T. Wada, H. Kato, Materials & Design 244 (2024) 113095.

[3] Y. Ohashi, T. Wada, H. Kato, Materials & Design 258 (2025) 114685.

O-24

Nanoporous metal hydrides – model systems for the materials science of energy storage and conversion

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Nanoporous metals offer exciting opportunities as model systems for fundamental research, due to their exceptionally high microstructural definition, along with their uniformity and reproducibility. The talk combines those opportunities with the ones offered by Pd-H, a model system for equilibrium thermodynamics and non-equilibrium kinetics in solid solutions, with obvious relevance to energy storage and conversion. Experiments on charging/discharging nanoporous Pd with H reveal surprising signatures, a variability by several orders of magnitude in the time constant for equilibration, non-monotonous charging current transients and distinctly different transients for charging versus discharging [1,2]. The observations are not readily reconciled with the standard kinetic rate equation in the field, the Butler-Volmer equation. As an analog to the Butler-Volmer equation, but here applicable to interfaces in solid solutions, we explore a new rate law that rests on the statistical mechanics of an activated state in an extended ergodic reservoir. The new law applies naturally to particle transfer across the interface between two interstitial solid solution phases (here, an adsorbate layer and the bulk) that exhibit a continuum of equilibrium states at different compositions. Besides unraveling the origin of the puzzling experimental signatures, the rate law also points towards experimental strategies for characterizing the nature of the phase transformation in interstitial solid solutions. The transformation may be incoherent or coherent [3], and that distinction is decisive for the size-dependencies of equilibrium chemical potential, miscibility gap critical temperature and charging discharging hysteresis of energy storage nanomaterials such as metal hydrides or lithium compounds [4].

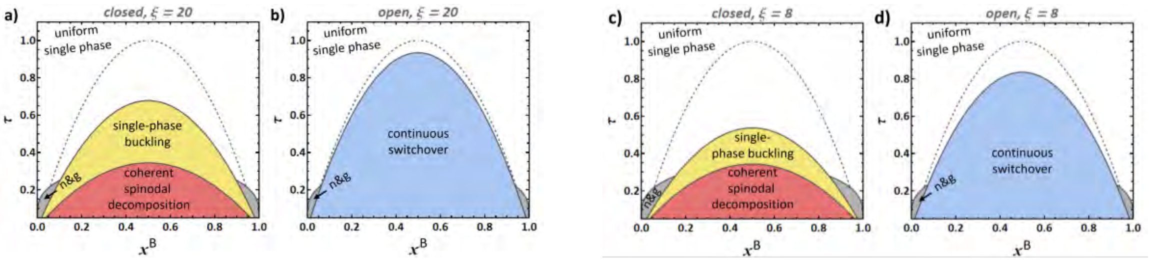

Fig. 1. Exemplifying size effects on coherent phase transformations in metal hydride nanomaterials. Equilibrium alloy phase diagrams for larger system under closed [canonical, a)] and open [semi-grand-canonical, b)] boundary conditions, compared to smaller system [c), d)] under analogous boundary conditions [3].

[1] S. Shi, J. Markmann and J. Weissmüller, *Actuation by Hydrogen Electrosorption in Hierarchical Nanoporous Palladium*. Philos Mag 97 (2017) 1571. https://doi.org/10.1080/14786435.2017.1311428

[2] S. Bapari, J. Weissmüller, *A Pd-Pt-based Bulk Nanoporous Alloy with Continuous Solubility for Hydrogen.* Electrochimica Acta, in press (2025).

[3] J. Weissmüller, *Coherent Phase Change in Interstitial Solutions: A Hierarchy of Instabilities.* Adv Science 11 (2024) 2308554. https://doi.org/10.1002/advs.202308554

[4] Y. Li and J. Weissmüller, *Size-dependent Phase Change in Energy Storage Materials: Comparing the Impact of Solid-State Wetting and of Coherency Stress.* J Chem Phys 162 (2025) 024704

O-25

Study on Ultrafine-grained Nanoporous Copper Fabricated by Synergistic Selective Laser Melting and Chemical De-alloying and Its Irradiation Resistance

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This study proposes an innovative fabrication strategy that successfully prepares ultrafine-grained nanoporous copper with exceptional irradiation tolerance through the synergistic effect of selective laser melting (SLM) and chemical dealloying. Addressing the inherent challenges of melt pool spheroidization and elemental segregation in the Cu-Fe system, the research team effectively suppressed metallurgical defects by optimizing SLM process parameters. After chemical dealloying, the material exhibited a significantly refined microstructure, with an average grain size of 43 nm and continuous ligament widths ranging from 50 to 100 nm. In contrast, micron-porous copper with identical porosity demonstrated grain sizes exceeding 1 µm and ligament widths of 2-5 µm. The ligament distribution and pore structure of the ultrafine-grained nanoporous copper displayed characteristic melt pool features, exhibiting fish-scale-like periodic arrangements with ligaments uniformly oriented toward the melt pool center.

Irradiation experiments revealed that the defect density growth rate in ultrafine-grained nanoporous copper was 37% lower than that in its micron-structured counterpart. The material surface simultaneously exhibited amorphous zones with widths of 15±7 nm and sputtering effects on ligament surfaces. Mechanistic studies demonstrated that under irradiation-induced collision cascades, the nano-ligaments underwent a dynamic process of local melting-fracture, triggering grain re-nucleation and crystallographic orientation transformation. When defect accumulation exceeded a critical threshold, surface-affected zones formed amorphous regions.

This study confirms that grain/ligament nanostructuring in porous metallic materials can significantly enhance irradiation damage tolerance, providing important theoretical foundations and technical pathways for developing irradiation-resistant materials.

O-26

Multi-Elementalization of Nanoporous Alloys and Creation of Unique Reaction Fields

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(1) High-entropy alloys (HEAs) are alloys that form a single-phase solid solution containing multiple constituent elements in near-equiatomic concentrations. These alloys exhibit mechanical and functional properties significantly different from conventional alloys. The introduction of numerous nano-scale open pores into HEAs is expected to enhance multifunctionality, particularly in catalytic applications. However, catalytic properties remain largely unexplored, with typical HEAs containing 5 to 7 constituent elements, some of which are known as catalytic elements. In previous research, we successfully synthesized multi-element nanoporous alloys composed of 14 elements, including almost all transition metals (Cu, Co, Ni, Fe, Mo, Ti) and noble metals (Au, Ag, Ir, Pt, Pd, Ru, Rh) commonly used in organic synthesis, gas reactions, and electrode catalysts. This synthesis was achieved by dealloying Al from an Al-based precursor alloy (Al-Cu, Ni, Fe, Co, Au, Pt, Pd, Ag, Ir, Ru, Rh, Ti, Mo) in an alkaline solution. Few studies have reported the successful fabrication of nanoporous alloys with more than 10 constituent elements. Given that this material includes almost all catalytic elements, it is expected to serve as a versatile platform for various applications[1-4].

Fig. 1 Ultra high-entropy nanoporous alloys

(2) Gas catalysts utilizing discharge reactions have long been used, particularly in exhaust gas purification, and research in this field continues to advance. In particular, gas reactions combining high-power discharge with catalysts have demonstrated promising results in the synthesis of valuable compounds such as ammonia. However, the energy consumption of high-power discharge-based gas reactions is comparable to or even higher than that of conventional thermal reactions, limiting their industrial adoption. To address energy resource challenges, we are developing a system that combines corona discharge with nanoporous metal materials. We have constructed a system in which voltage is applied to nanoporous metals to generate corona discharge and have systematically investigated the conversion efficiency of CO oxidation. The results of these investigations will be presented.

[1] S. Bolar, C. Yuan, S. Jeong, Y. Ito, T. Fujita, Inverse analysis-guided development of acid-tolerant nanoporous high-entropy alloy catalysts for enhanced water-splitting performance, *Journal of Materials Chemistry A*, **13** (2025) 940-950.

[2] Z. X. Cai, S. Bolar, Y. Ito, T. Fujita, Enhancing oxygen evolution reactions in nanoporous high-entropy catalysts using boron and phosphorus additives, *Nanoscale* **16** (2024) 4803-4810.

[3] T. Yoshizaki, T. Fujita, Thermal stability and phase separation of nanoporous high-entropy alloys containing 23 elements, *Journal of Alloys and Compounds* **968** (2023) 172056.

[4] Z. X. Cai, H. Goou, Y. Ito, T. Tokunaga, M. Miyauchi, H. Abe, T. Fujita, Nanoporous ultra-high-entropy alloys containing fourteen elements for water splitting electrocatalysis, *Chemical Science* **12** (2021) 11306-11315.

O-27

Rapid Synthesis of Activated Nanoporous Zn Powder by Selective Etching of Al from Micrometer-Sized Zn-Al Powder Particles Produced by Gas Atomization and Its Application in On-Demand Hydrogen Generation by Two-Step Water Splitting

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Nanoporous metals have earned significant interest in recent years due to their diverse applications in catalysis, electrocatalysis, energy storage, actuation, and plasmonics. While much research has focused on noble nanoporous metals such as Au, Pd, Pt, and Ag, primarily due to their low chemical reactivity, which facilitates synthesis and characterization, less attention has been given to reactive nanoporous metals like Zn, Al, and Mg [1]. The fabrication and characterization of these materials remain challenging due to their high chemical reactivity.

In this presentation, I will introduce a novel and highly scalable strategy for synthesizing hierarchical nanoporous zinc (NP-Zn) decorated with atomic clusters of Ni acting as a hydrogen evolution catalyst for efficient, on-demand hydrogen generation via the metal-water reaction. Our method includes selective etching of Al from micrometer-sized Zn-Al powder particles produced by gas atomization, significantly reducing the fabrication time of NP-Zn from several days to just four minutes, compared to the conventional synthesis method [2]. To analyze the nanoscale morphology and catalyst deposition, we employed focused ion beam/scanning electron microscopy (FIB/SEM) for 3D tomographic reconstruction and inductively coupled plasma optical emission spectroscopy (ICP-OES) for elemental quantification.

This activated NP-Zn powder enables an efficient two-step water-splitting process for large-scale hydrogen production [3], wherein Zn reacts with water to generate hydrogen and a ZnO byproduct, followed by an electrochemical reduction of ZnO back to Zn using clean electricity, such as wind and solar energy. This Zn-ZnO regenerative cycle can be repeated multiple times, offering a sustainable pathway for large-scale green hydrogen production [3]. Our preliminary results indicate that NP-Zn with a catalyst achieves a hydrogen generation yield of approximately 75%, whereas commercial bulk Zn powder yields only 13%.

[1] J. Fu, S.S. Welborn, E. Detsi, Dealloyed Air- and Water-Sensitive Nanoporous Metals and Metalloids for Emerging Energy Applications, ACS Appl Energy Mater 5 (2022) 6516–6544. https://doi.org/10.1021/acsaem.2c00405.

[2] J. Kubota, J. Liu, E. Detsi, Rapid Synthesis of Nanoporous Zn Powder by Selective Etching of Al from Micrometer-Sized Zn-Al Powder Particles Produced by Gas Atomization and Its Application in Hydrogen Generation, ACS Appl Mater Interfaces (2024). https://doi.org/10.1021/acsami.4c13394.

[3] Hydropore, Hydropore Technology, (2025). https://hydropore.com/technology/.

Poster Presentations

P-01

Reviving Degraded Pt/C Catalyst via Vapor-Phase-Induced Alloying-Dealloying Cycle

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Carbon-supported platinum nanoparticles (Pt/C) are the most widely used cathode catalysts for the oxygen reduction reaction (ORR) in hydrogen-oxygen fuel cells. However, their long-term stability remains a critical challenge due to catalyst degradation from nanoparticle agglomeration. In this study, we introduce a vapor-phase-induced alloying and dealloying strategy to *in situ* revive and restructure performance-degraded Pt/C catalysts. Through sequential phase transformations Pt → Pt_5Zn_{21} → PtZn or Pt, large Pt nanoparticles (>7 nm) are converted into a nanoporous structure with a characteristic feature size of ~3 nm, while small nanoparticles (<7 nm) transform into ordered PtZn intermetallic alloys without forming porosity. This size-dependent porosity and phase evolution not only refines the coarsened catalyst structure but also introduces beneficial chemical effects through the formation of PtZn intermetallics, synergistically reactivating and reinforcing the degraded catalyst. As a result, the regenerated catalyst exhibits an ORR mass activity 2.5 times higher than that of the original Pt/C, and a fuel cell mass activity 1.4 times greater. This work demonstrates a novel and effective approach for the structural reconstruction and performance regeneration of deactivated fuel cell catalysts.

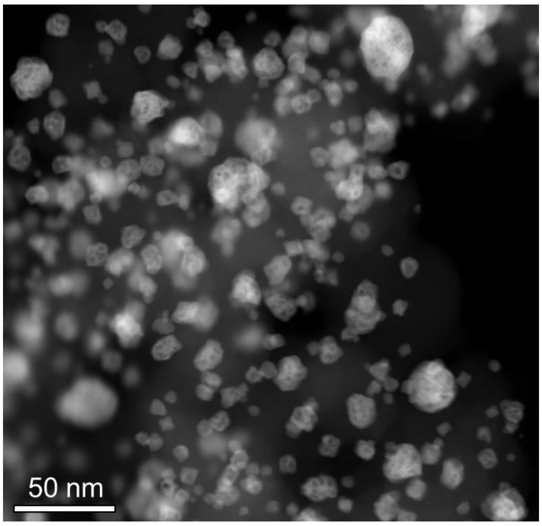

Fig. 1. HAADF-STEM image of the regenerated Pt/C catalyst.

P-02

3D Nanoporous Cu-Zn Intermetallic Compounds: Room-Temperature Synthesis and Electrochemical Acetylene-to-Ethylene Catalysis

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Nanoporous intermetallic compounds featuring macroscopic bicontinuous open porosity and microscopic ordered atomic structures hold great promise as high-activity, robust electrocatalysts for various energy-related reactions. However, their synthesis remains challenging due to the high kinetic barriers associated with forming ordered intermetallic phases—barriers that are difficult to overcome in conventional room-temperature dealloying processes. In this study, we report a Cu–Zn alloy system in which galvanostatic electrochemical dealloying enables the simultaneous development of a 3D nanoporous architecture and potential-dependent, stepwise phase transformations: ε-$CuZn_5$ → γ-Cu_5Zn_8 → β-CuZn → Cu → Cu_2O. This process allows for the controlled fabrication of monolithic nanoporous intermetallic γ-Cu_5Zn_8 and β-CuZn with characteristic ligament/pore sizes of ~6 nm and ~14 nm, respectively. We reveal that these room-temperature intermetallic phase transformations are enabled by the intrinsically low activation energy for atomic diffusion in Zn-rich Cu–Zn alloys and by a “nano effect” induced by the ultrafine porosity formed during dealloying. The resulting 3D nanoporous γ-Cu_5Zn_8 and β-CuZn exhibit high Faradaic efficiency and selectivity for the electrochemical conversion of acetylene to ethylene. This work demonstrates that room-temperature synthesis of nanoporous intermetallic compounds is achievable through careful energetic landscape design, offering a new pathway for developing advanced intermetallic catalysts for energy applications.

P-03

Autonomous Laser-Induced Dealloying in Thin Films Revealed by Multimodal Synchrotron X-ray for 3D Nanostructure Analysis

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5. National Institute of Standards and Technology, Gaithersburg, MD, USA

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Solid-state metal dealloying (SSMD)[1,2] is an emerging technique that enables the fabrication of functional bi-continuous metal-metal nanostructured materials. With conventional methods, it is challenging to precisely determine the time and temperature conditions necessary to design the complex dealloying process for the targeted nanostructures. However, when using an *operando* laser-heating system in conjunction with synchrotron autonomous experimentation, a more advantageous exploration of the SSMD parameter space can be achieved. Additionally, to minimize surface oxidation, the configuration of a sandwich-like structure with metals C/A-B/C multilayers was implemented. In this design, C acts as the dealloying agent, selectively removing one element from the parent A-B alloy. The dealloying process was analyzed through a multimodal approach where multiple signals from two synchrotron beamlines with different techniques were used simultaneously to drive the experiment. Small-angle X-ray scattering (SAXS) and wide-angle X-ray scattering (WAXS) at one beamline, offer data on nanostructure and phase evolution, while X-ray absorption spectroscopy (XAS) at the other beamline reveals chemical bonding distinctions and short-range ordering. Combining these techniques with in-situ laser[3], real-time observation of structural changes during the dealloying process can be achieved. As illustrated in Figure 1, this dynamically data-driven approach was used to explore the parameter space systematically. This approach automates the identification of critical process parameters in the high-dimensional temperature-time landscape, focusing on discovering nanostructures from the dealloying process. Integration of SSMD with autonomous synchrotron X-ray characterization, and in-situ laser heating allows for a multimodal study of phase evolution, porosity generation, and interfacial reactions, accelerating the design of functional nanostructures.

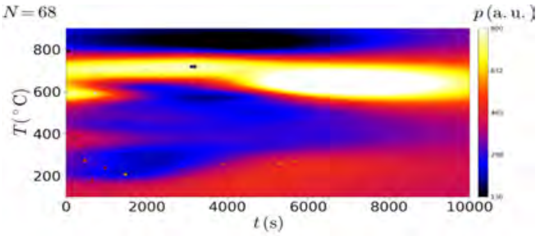

Figure 1. Example of autonomous exploration of SSID in ScVMnSc thin-film system, using V(110) signal in grazing-Incidence WAXS in-situ experiment. The high-dimensional parameter space was explored using a Gaussian process approach via the gpCAM software.

[1] Zhao, C., et al., (2022) Communications Materials *3*, 86.
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P-04

Machine Learning-Driven Discovery of 3D Morphologically Complex Nanomaterials via 3D Printing and Dealloying

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The development of 3D morphologically complex nanomaterials with intricate nanoscale features and hierarchical meso- and macro-scale structures offers exceptional physical, chemical, and mechanical properties. However, establishing a fundamental understanding of the relationship between material processing, morphology, and properties remains a significant challenge. This research addresses this gap by utilizing 3D printing followed by dealloying to fabricate these complex nanomaterials and leveraging machine learning (ML) to accelerate material discovery, informed by multiscale X-ray imaging. By integrating ML-augmented simulations with experimental data, the project aims to predict material behavior based on morphology. Advanced synchrotron X-ray microscopy techniques—including hard X-ray nanoprobe (HXN), and full-field transmission X-ray microscopy (FXI) —provide critical insights across nanometre to millimetre length scales. These approaches will drive the discovery of optimized materials for energy storage, sensing applications, and environmental remediation, with broad technological and societal impacts.

Keywords- 3D printing, dealloying, tomography

P-05

3D Bicontinuous Nanoporous Silicon Carbide Fabricated by Liquid Metal Dealloying and Its Applications in Alkali-Metal Batteries

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Silicon carbide (SiC) is a promising substrate material for electrochemical applications including catalysts and rechargeable batteries [1], owing to its excellent structural stability in long-term use. However, there remains few well-established methods for fabricating high-surface-area SiC, which is essential for enhancing reaction kinetics. The commercial production methods for SiC powder, such as the Acheson process or template methods [2], typically requires high synthetic temperatures over 1400~2500℃, longtime and complex procedures. These SiC particles are hardly to be chemically activated, which limits their practical applications.

In this poster, we will introduce a fabrication process for the synthesis of three-dimensional nanoscale bicontinuous porous silicon carbide (3Dnbp-SiC) by liquid metal dealloying (LMD) [3-4]. First, a precursor alloy of ***A-B*** (***A***=Si,C, and ***B***=Mn) was synthesized in a high-frequency melting furnace by controlling temperature. The precursor was then immersed in molten metal ***C*** (***C***=Bi) to remove ***B*** from the precursor. After cooling to room temperature, the mixture of SiC and ***B***-***C*** was immersed in an aqueous nitric acid solution to remove the Mn-Bi component, and then the target 3Dnbp-SiC was obtained. As shown in Figure 1, the 3Dnbp-SiC contains nano-sized pores and has a high specific surface area. Later, the electrochemical performance of the 3Dnbp-SiC will further tested in alkali metal (Li/Na) batteries, using galvanostatic charge/discharge tests against pure Li foil and Na foil counter electrode in two-electrode half cells.

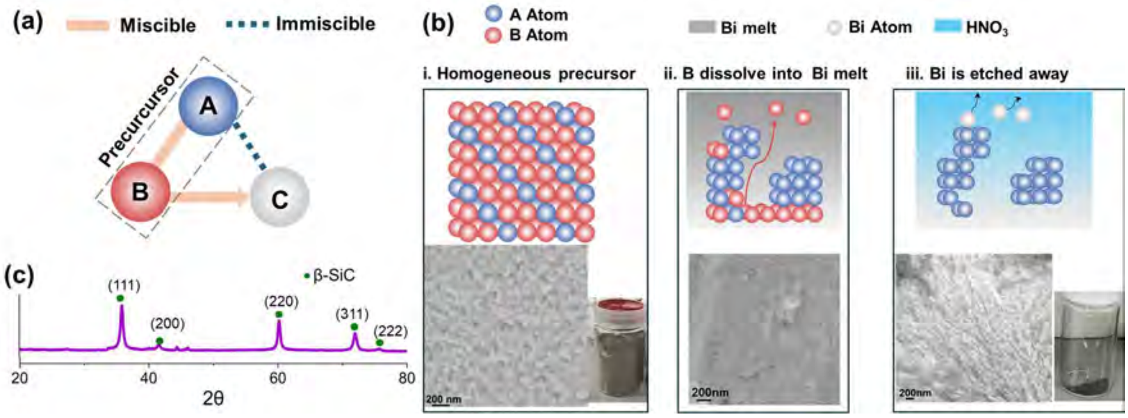

Fig. 1. Design and fabrication of 3Dnbp-SiC. (a) Principle of LMD. (b) Fabrication processes and Morphology observations. (c) XRD pattern of 3Dnbp-SiC.

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P-06

Atomic-scale dynamics of a bulk-diffusion-driven nonconservative phase transformation in vapor phase dealloying

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Solid-state phase transformations (SSPTs) [1] during dealloying dictate the evolution of nanoporous architectures, yet their atomic-scale mechanisms remain elusive due to the dominance of classical surface-diffusion models. Here, by combining vapor phase dealloying (VPD) [2] with aberration-corrected transmission electron microscopy, we directly uncover a nonconservative SSPT pathway in a Co-Zn alloy, governed by bulk diffusion rather than interfacial kinetics. Real-time tracking reveals a coherent transformation cascade: initial Zn sublimation triggers the formation of a metastable Zn-deficient intermediate (γ-CoZn-vac), a derivative of the parent γ-CoZn lattice, followed by atomic column merging and lattice relaxation into α-Co. We further mapped Zn bulk-diffusion trajectories driven by chemical potential gradients and identified crystal planes selectively prone to reconfiguration. This work challenges the long-held assumption that dealloying relies on surface dynamics, establishing bulk atomic diffusion as a universal driver for nonconservative phase transformations. Our findings may provide the theoretical framework for designing functional nanoporous materials through vacancy-mediated engineering.

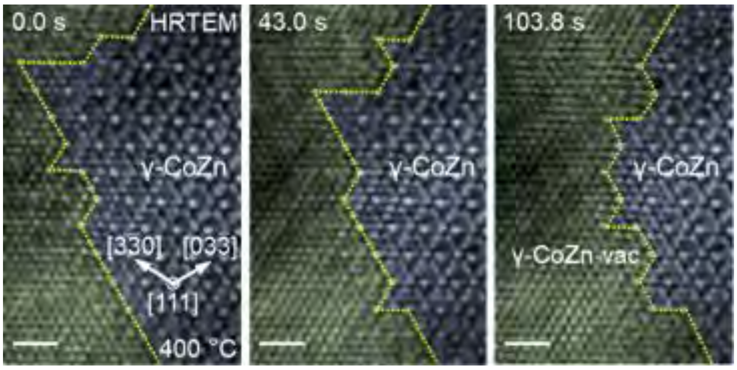

Fig. 1. The formation of a transient structure from γ-CoZn during VPD. Scale bars: 1 nm.

[1] Fu, X.; Wang, X.-D.; Zhao, B.; Zhang, Q.; Sun, S.; Wang, J.-J.; Zhang, W.; Gu, L.; Zhang, Y.; Zhang, W.-Z.; Wen, W.; Zhang, Z.; Chen, L.-q.; Yu, Q.; Ma, E. Nature Materials 2022, 21, (3), 290-296.

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P-07

Solid-state electrolyte dealloying

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Solid-state electrolytes are transforming the battery research field with their promise of safety and stability. They also bring unique opportunities to investigate kinetics of dealloying under an unprecedented setting. Without a flowing electrolyte, dealloying is deprived of percolation dissolution. Yet, bicontinuous nanoporous structures seem still prevalently evolving from solid-state electrolyte/alloy interfaces, a phenomenon highly relevant to the application of alloys in solid-state lithium batteries [1]. Here, instead of air-sensitive lithium-based electrolytes, we pair silver-halide solid-state electrolytes with our most familiar AgAu alloys to investigate the kinetics and morphology evolution under a range of compositions and temperatures. We will discuss how surface and bulk diffusions play out to determine the rate of dealloying and their implication fabrications and failures in batteries.

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P-08

3D Bicontinuous Nanoporous Co@CoO/RuO_2 Composites as High-Efficiency Electrocatalysts for Oxygen Evolution Reaction

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The development of low-cost and effective oxygen evolution reaction (OER) electrocatalysts to expedite the slow kinetics of water splitting is crucial for increasing the efficiency of energy conversion from electricity to hydrogen fuel.[1] Here, we fabricate 3D bicontinuous nanoporous Co@CoO/RuO_2 composites via vapor-phase dealloying of cobalt-based alloys, enabling precise control over feature ligament sizes and chemical compositions. The CoO/RuO_2 shell is constructed by integrating a thin layer of RuO_2 on the inner surface of nanoporous Co, where the CoO interlayer is formed by annealing oxidization. The optimized catalyst exhibits exceptional OER performance, achieving an ultralow overpotential of 198 mV at 10 mA cm^{-2}, and remarkable durability. The enhanced activity stems from charge transfer via Co-O-Ru bonds at the interface and the bicontinuous nanoporous architecture, while the robust CoO/RuO_2 interface ensures durability. This work provides a scalable strategy for designing high-performance OER electrocatalysts.[2]

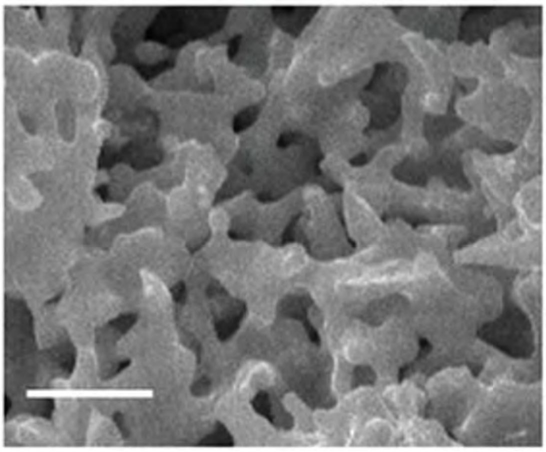

Fig. 1. SEM images of the as-prepared np-Co@CoO/RuO_2 composite. Scale bars: 200 nm.

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[2] Li Y, Zhang Q, Zhao X, Wu H, Wang X, Zeng Y, Chen Q, Chen M, Liu P, Advanced Functional Materials 2023 (17) 2214124.

P-09

Nanoporous MoS_2 via Liquid Metal Dealloying and Direct Sulfurization for Energy Storage and Conversion

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As global challenges such as energy shortage, environmental pollution, and ecological degradation continue to intensify, the development of sustainable energy storage and conversion technologies has become imperative. Lithium-ion batteries (LIBs) have long dominated the energy storage landscape due to their high energy density and long cycle life, while hydrogen energy, derived from water electrolysis via the hydrogen evolution reaction (HER), represents a promising solution for clean and efficient energy conversion. However, both LIB anodes and HER electrocatalysts face critical material challenges. Specifically, molybdenum disulfide (MoS_2), a typical two-dimensional transition metal dichalcogenide, offers considerable potential for both applications, owing to its favorable hydrogen adsorption energy, tunable active sites, and excellent lithium storage capability. Despite these advantages, MoS_2 suffers from structural degradation, limited exposure of active catalytic sites, and poor electronic conductivity, which together hinder its electrochemical performance and catalytic activity.

To address these limitations, this study focused on the fabrication of three-dimensional (3D) nanoporous MoS_2 powder using Liquid Metal Dealloying (LMD) followed by direct sulfurization, aiming to enhance both lithium storage performance and HER catalytic efficiency. The process began with a $Ni_{80}Mo_{20}$ alloy precursor immersed in a magnesium-based LMD bath, followed by acid etching to obtain nanoporous Mo powder. Subsequent sulfurization in a vacuum-sealed tube successfully transformed the structure into nanoporous MoS_2. The resulting material was combined with acetylene black and PVdF, cast onto copper foil, and assembled into CR2032 coin cells for electrochemical evaluation. Characterization techniques such as XPS, XRD, Raman spectroscopy, SEM-EDX, and TEM were employed to investigate the structural and chemical features of the material.

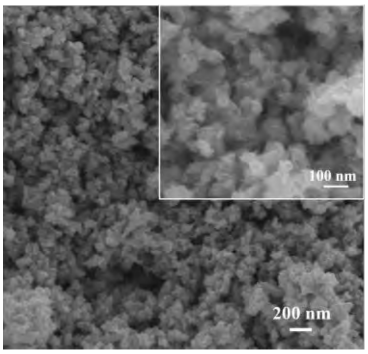

Fig. 1 Morphology of the as-synthesized np-MoS_2

The nanoporous MoS_2 displayed a 3D bicontinuous porous architecture with ligament sizes of approximately 20 nm, providing abundant channels for ion diffusion and electron transport. Electrochemical testing demonstrated an impressive initial irreversible discharging capacity of 1013.2 mA h g^{-1}, and galvanostatic cycling confirmed excellent cycling stability. Voltage profiles and cyclic voltammetry revealed stable lithiation/delithiation behavior, while post-cycling SEM analyses showed preserved structural integrity. Impedance spectroscopy further verified low charge-transfer resistance, underscoring the material's robust electrochemical performance. These findings confirm the potential of nanoporous MoS_2 as a high-performance LIB anode material. Future studies will explore the catalytic applications of this structure, particularly its promising role in hydrogen evolution reactions.

P-10

Effect of hydrothermal reaction field on CO_2 reduction performance of nanoporous gold catalysts

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[Introduction] Electrochemical CO_2 reduction reaction (CO_2RR) is attracting attention as an important technology for achieving carbon neutral society. This is because it can recycle CO_2 using renewable electricity from solar cells and wind generators. However, the slow reaction rate of CO_2RR remains a major challenge for practical applications. Therefore, we attempted to improve the reaction rate by two strategies: employing a porous electrode material with a large surface area and using a hydrothermal reaction field[1] that promotes ion diffusion. This study investigated how the CO_2RR activity of porous electrodes was affected by the hydrothermal reaction field.

[Experiment] The CO_2RR activity was evaluated using a planar Au electrode (hereinafter simply Au) or nanoporous gold electrode (NpAu) as working electrode. NpAu was prepared via an alloying / dealloying method (Fig.1a). The products were analyzed by gas chromatography (GC) and nuclear magnetic resonance (NMR) spetroscopy.

[Result and discussion] The increase in current density due to the introduction of a porous structure is more pronounced at high temperatures, and the combination of the porous electrode and the high-temperature, high-pressure environment increased the current density from -2.21 mA/cm^2 to -79.6 mA/cm^2, an increase of about 35 times. This is possibly due to the improved mass diffusion inside the nanoporous structure and reduced solution resistance, allowing the inside of the nanoporous structure to contribute CO_2RR. Furthermore, the partial current density of each product with respect to pressure changes is shown in Fig.1b. As pressure increased, CO genration decreased and HCOOH generation increased. These results suggested that CO_2RR at the low-coordination sites inside the nanoporous structure showed the differnt reaction pathway of CO_2RR.

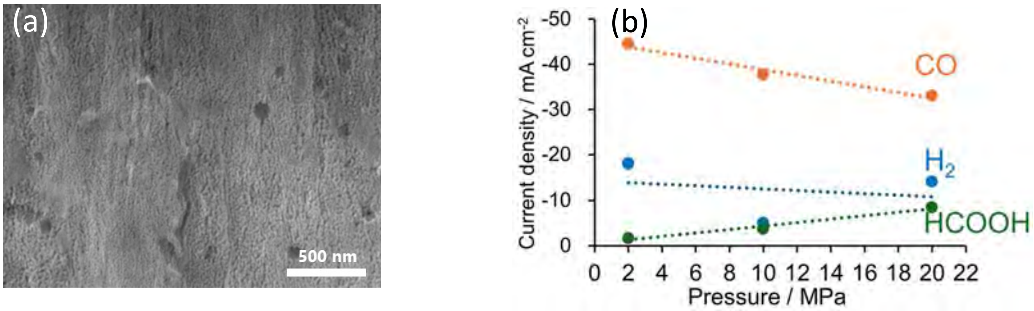

Fig.1 a) SEM image of NpAu, and b) partial current density of each product as a function of pressure.

[Conclusion] Combining nanoporous catalysts with hydrothermal reaction field was found to synergistically increase reaction rates. It is presumed that the hydrothermal reaction field promoted CO_2RR within NpAu and changed the reaction mechanism.

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P-11

Immiscible Fe-Mg joining by eutectic-melt-induced liquid metal dealloying

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Next-generation vehicles are required to achieve not only high safety, but also improvement of environmental performance. The weight reduction in automobiles can lead to a reduction in CO$_2$ emissions and joining steel, as the main structual material, to commercial magnesium alloy, as the lighter material, strongly can save the weight in automobiles effectively. However, the joining techniques are not established because Fe and Mg, the main elements of each alloy, are metallurgically immiscible, making it difficult to achieve strong joints using conventional methods.

As the breakthrough, present research focused on the Liquid Metal Dealloying (LMD). LMD is a process that achieves selective dissolution of an element from precursor alloy into a metallic melt due to the difference of enthalpy of mixing (Fig. 1 (a)). When immersing Fe$_{30}$Ni$_{70}$ precursor in a Mg melt, Ni selectively dissolved into the Mg melt and a bicontinuous composite consisting of Fe and Mg with interconnected morphology was formed at the precursor-melt interface[1]. For the start, our groups attempted to join pure iron and pure magnesium (Fe-Mg) as a simplified model. Fig. 1 (b) shows the schematic of the Fe-Mg joining process. In first process, Ni plating Fe is annealed to fabricate Fe-Ni diffusion layer for LMD. In second process, Fe-Mg joining is performed through LMD at the temperature over Mg-Ni eutectic point (779 K) to induce eutectic melt at the joining interface without melting magnesium base body. The interconnected composite formed at the joininig interface shows anchoring effect and a strong mechanical joining is expected to be achieved. In this poster session, the effect of microstrual morphology of the composite on the strength of Fe-Mg joint will be presented.

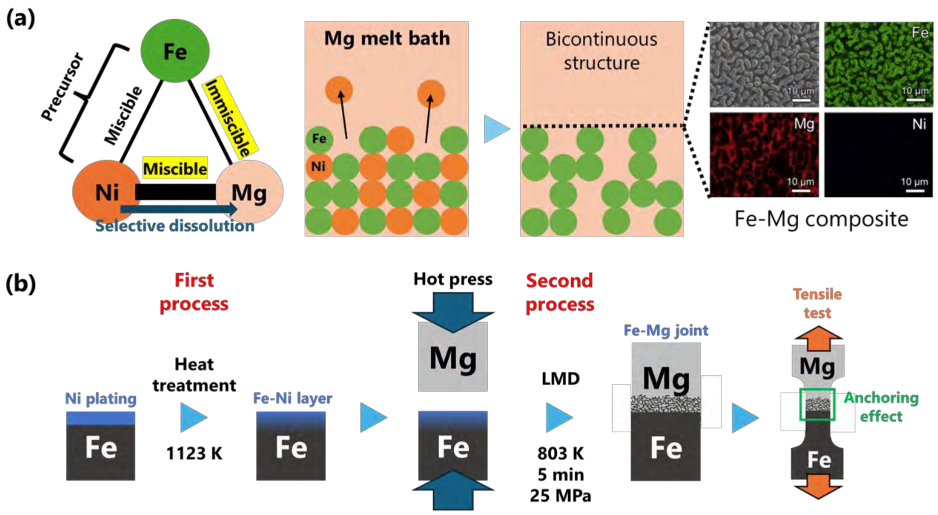

Fig. 1. (a) Liquid metal dealloying (LMD) between Fe-Ni precursor and Mg melt and (b) schematic of the Fe-Mg joining process through eutectic-melt induced LMD.

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P-12

Effects of alloying elements X (Zr, Nb, Ta, Mo, Si) in $(Ti_{47.5}X_{2.5})Cu_{50}$ on microstructure and properties of Mg–Ti composites fabricated by liquid metal dealloying

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The effects of Zr, Nb, Ta, Mo, and Si alloying elements on the microstructure, mechanical properties, and corrosion resistance of 3D interconnected Mg–Ti composites synthesized via liquid metal dealloying (LMD) were systematically investigated. The $(Ti_{47.5}X_{2.5})Cu_{50}$ precursor alloys were immersed in a Mg–10 at.% Ca melt at 600 ℃ and 800 ℃ to evaluate the influence of processing temperature, with 'X' representing the alloying elements. Alloying additions significantly influenced the precursor microstructure, resulting in variations in the synthesized Ti ligament morphology, grain characteristics, and Ti phase crystal structures after LMD. At the higher processing temperature of 800 ℃, the composites generally exhibited an increased Ti phase fraction, enhancing hardness. Notably, Zr, Nb, and Ta additions promoted the formation of fine lamellar α–Ti grains, while Mo addition facilitated the formation of β–Ti grains at 800 ℃. The Zr-added composite exhibited superior mechanical properties, achieving the highest yield strength and work-hardening rate due to uniform load transfer and reduced localized plastic deformation, as predicted by microstructure–based finite element method. Conversely, Nb, Ta, Mo, and Si negatively affected yield strength due to reduced Ti fraction or ineffective ligament morphologies. Corrosion resistance in a 0.6 M NaCl solution was improved by the addition of Zr, Nb, Ta, and Mo, with Zr exhibiting the highest resistance. In contrast, Si addition reduced corrosion resistance, primarily due to increased interphase area. These findings provide key insights into optimizing Mg–Ti composites for advanced biomedical applications, emphasizing the role of alloying strategy in achieving tailored mechanical and chemical performance.

P-13

Topology-dependent elastic behavior of monolithic nanoporous gold and nanoporous niobium

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This study investigates the mechanical behavior of random network structures formed through dealloying, focusing on the role of the network's topological connectivity. We first establish a new scaling relation that incorporates scaled genus, a measure of network connectivity, using nanoporous Au fabricated by aqueous dealloying as a benchmark [1]. This relation is then applied to describe the elasticity of nanoporous Nb synthesized via liquid metal dealloying. Results from X-ray nanotomography and macro-compression tests show that nanoporous Nb exhibits exceptional mechanical compliance compared to nanoporous Au. Tomographic reconstructions attribute this to the lower scaled genus observed in nanoporous Nb, confirming the role of connectivity in elasticity [2]. Furthermore, the structural dispersion observed in nanoporous Nb suggests that additional structural descriptors should be considered to account for the mechanical differences observed between liquid-metal and aqueous-dealloyed materials.

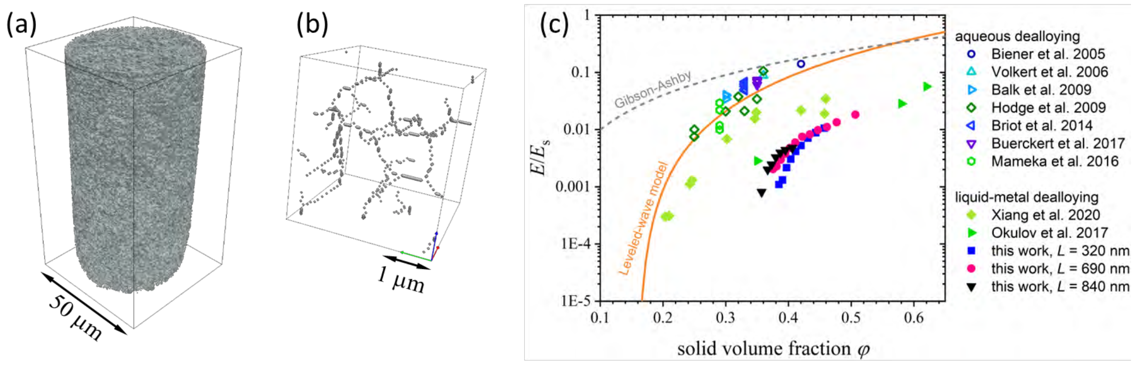

Fig. 1. (a) X-ray nanotomography-based 3D reconstruction of a nanoporous Nb micropillar. (b) Skeletonized structure of (a), cropped to contain two continuous rings. (c) Scaled Young's modulus of nanoporous Nb (this work) and other reported porous materials produced by liquid-metal dealloying (closed symbols), and of nanoporous Au produced by aqueous dealloying (open symbols). The modified Roberts-Garboczi scaling law for the leveled wave model and Gibson-Ashby scaling law are superimposed for reference.

[1] Sohn, S., Richert, C., Shi, S., Weissmüller, J., & Huber, N. (2024). Scaling between elasticity and topological genus for random network nanomaterials. *Extreme Mechanics Letters*, *68*, 102147.

[2] Sohn, S., Shi, S., Markmann, J., Berger, S. A., & Weissmüller, J. (2025). Compressive behavior and connecting topology of monolithic nanoporous niobium. *Materials Research Letters*, *13*(1), 76-85.

P-14

In-situ microtensile testing and micropillar compression on hierarchical nanoporous gold: role of structural hierarchy and cold working

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Nanoporous metals with high specific surface area, low density and tunable structure have shown promising applications as light-weight structural materials and high-performance functional materials in batteries, sensors, and various energy devices. Recently, mechanically robust hierarchical nanoporous gold (HNPG) bulk samples with independently tunable ligament sizes at each hierarchical level have been fabricated by a dealloying-coarsening-dealloying method [1][2]. Both macrocompression and microcompression tests have been performed on HNPG and have shown that that the structural hierarchy can result in improved mechanical properties and reduced density as well as improved electrochemically tunable flow stresses [3]. However, there have been no studies on the tensile properties of HNPG. In this work, we performed in-situ microtensile tests and micropillar compression tests on HNPG to investigate the effect of the structural hierarchy on the tension-compression asymmetry behaviour that observed in nanoporous metals. In addition, we applied one of the most common strengthening approaches- cold working - to adjust the dislocation density, degree of anisotropy and porosity, to address the common issue of tensile brittleness in nanoporous metals and further improve their strength.

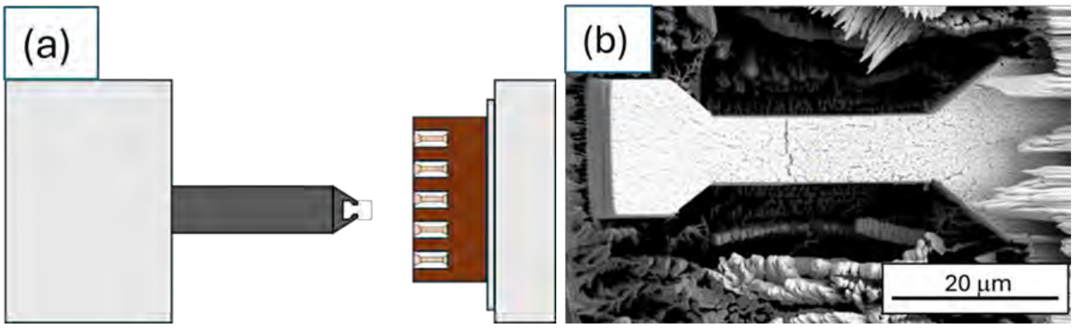

Fig. 1. (a) Schematic picture of in-situ microtensile test setup, (b) Dog-bone shape sample after in-situ microtensile test

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[3] H. Jeon, J. Markmann, S. Shi, Acta Mater. 273 (2024) 119954.

P-15

Effects of alloying elements in Mg melt on surface functionalization of Ti alloy via liquid metal dealloying

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This study investigates the enhancement of surface characteristics in Ti-6Al-4V alloys through surface functionalization via the liquid metal dealloying (LMD) process. LMD is an emerging technique in which a molten metal is employed as the dealloying medium to selectively extract miscible elements from a solid precursor. It has been established that Mg melt facilitates the formation of three-dimensional (3D) interconnected ligament structures on the surface of Al-containing Ti alloys [1]. During the LMD process, Al undergoes preferential dissolution due to its high miscibility with Mg, whereas the remaining immiscible elements redistribute via interfacial diffusion, forming a self-organized 3D architecture. Surface structure evolution during LMD is influenced by multiple parameters, including dealloying temperature, time, precursor composition, and the crucible used to contain the Mg melt [1]. However, the role of alloying additions to the Mg melt in governing dealloying mechanism and the resulting ligament morphology has not been thoroughly explored. In this work, binary Mg-based melts containing 2.0 at.% Si or 0.2 at.% Zr were introduced to tailor the surface structure and properties of the Ti alloy. The formation of porous structures typically leads to a reduction in surface hardness. However, the incorporation of Si or Zr promotes alloying within the solid Ti ligaments, and this results in the formation of hard intermetallic phases or an increased volume fraction of the Ti phase, both of which contribute to improved hardness. The microstructures and mechanical properties were characterized using micro-Vickers hardness, scanning electron microscopy, X-ray diffraction, nanoindentation, and electron backscatter diffraction.

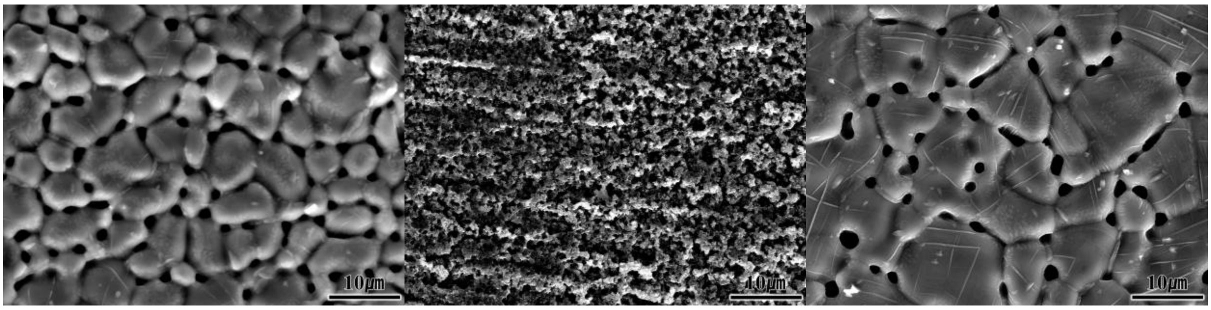

Fig. 1. LMD processed Ti-6Al-4V surfaces in different melt; (a) pure Mg, (b) Mg + Si 2 at%, (3) Mg + Zr 0.2 at%.

[1] Fukuzumi Yuichi, Takeshi Wada, and Hidemi Kato. "Surface improvement for biocompatibility of Ti-6Al-4V by dealloying in metallic melt." *Interface Oral Health Science 2014: Innovative Research on Biosis-Abiosis Intelligent Interface*. Springer Japan, 2015.

P-16

Forming bicontinuous microstructures by distributed internal melting

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Reverse peritectic reactions, and specifically the peritectic melting of TiAg, have been proposed as dealloying-like processes that produce bicontinuous microstructures but avoid the restrictions on sample size inherent in liquid metal dealloying (LMD) [1]. This talk will inspect distributed internal melting in general, at peritectic transitions and at the entrance into solid-liquid coexistence regimes, which prevail in many alloy phase diagrams, as formation processes for bicontinuous microstructures. In respect to the peritectic melting of TiAg, our observations suggest a formation mechanism that is indeed not LMD-like. Instead, the mechanism relies on the migration of liquid films that consume the parent structure and build the bicontinuous product structure in their wake [2]. This process has parallels to diffusion-induced grain boundary migration and to discontinuous precipitation. We show that liquid-film migration (LFM) may produce bicontinuous microstructures in more general scenarios, besides peritectic melting, requiring simply the entrance of a solid solution or compound into a two-phase solid liquid field and a partial wetting of the product phase grain boundaries [3]. That being said, we find the geometry of the microstructure, as it is generated by the distributed internal melting, to depend decisively on the nucleation and growth conditions of the new phase.

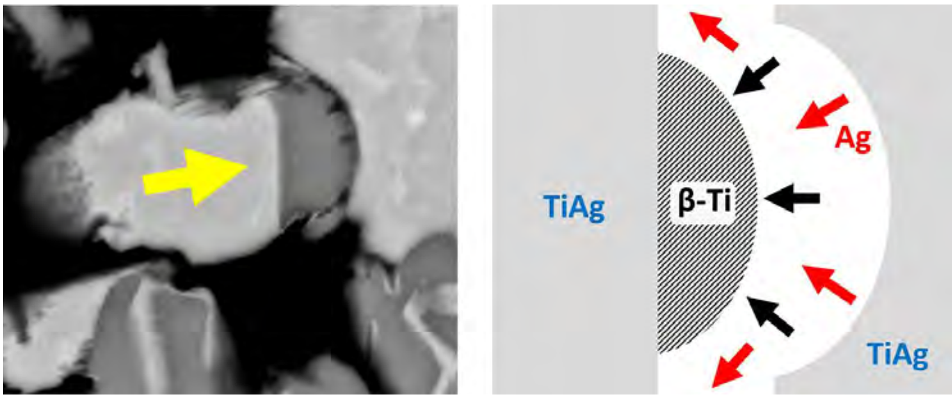

Fig. 1. Schematic of the liquid film migration mechanism.

[1] W.-K. Hu, J.-C. Shao, S.-G. Wang, H.-J. Jin, Phys. Rev. Mater. 3 (2019) 113601.

[2] Z. Li, L. Lührs, T. Krekeler, J. Weissmüller, Acta Mater. (2025): 120917.

[3] Z. Li, L. Lührs, J. Weissmüller, Scripta Materialia 250 (2024): 116192.

P-17

Rapid thermo-mechanical performance prediction and multi-objective optimization of tri-directional functionally graded material considering complex geometry and arbitrary graded paths

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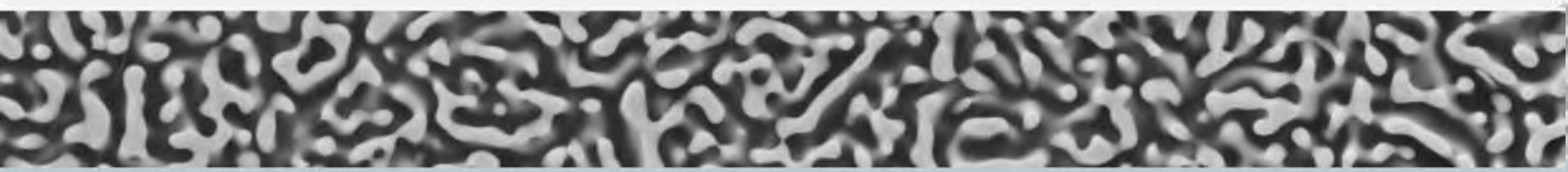
This work proposes an innovative framework for rapid performance prediction and multi-objective optimization of tri-directional functionally graded material, considering complex geometry and arbitrary graded paths in thermal environments. The framework employs non-uniform rational B-splines to describe the material distribution and geometric configuration of tri-directional functionally graded material. Based on three-dimensional elasticity theory and isogeometric analysis, the free vibration and bending behaviors of variable shape tri-directional functionally graded material in thermal environments are analyzed. To replace the time-consuming numerical calculation process, a three-dimensional convolutional neural network is introduced for the first time to construct a rapid performance prediction platform with ultra-high accuracy. Additionally, the multi-objective optimization of the material distribution and shape of tri-directional functionally graded material is realized by combining the non-dominated sorting genetic algorithm III. The framework's effectiveness is verified by several numerical cases, including square plates, cutout plates and cylindrical shells, and the effects of different boundary conditions, temperature fields, and loading conditions on the results are discussed in depth. The results show that, compared with traditional one-directional functionally graded material, the tri-directional functionally graded material with numerous design variables optimized by the proposed framework exhibits significantly improved performance, highlighting the efficiency and versatility of this framework.



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