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35 challenges in materials science being tackled by PIs under 35(ish) in 2024

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Here, we highlight 35 global researchers approximately under the age of 35. This third annual cohort was self-generated by initial seed invitations sent by the editorial team, with each contributor suggesting two more in a nominally supervised self-selecting pyramid-like scheme. The final collection reflects both the diversity and excitement across the field of materials science.

In this third installment of our "35 under 35" highlight article, we again try to present a snapshot of contemporary materials science. Drawing from fundamental physics and chemistry, yet extending to technology and engineering solutions, the field of materials science covers a broad spectrum of areas. Indeed, labeling oneself a "materials scientist" is almost as vague as "researcher," with the clear follow up … "what material?" Even the paths of materials scientists differ, with few researchers having formal "materials" undergraduate degrees, hailing from an assortment of chemistry, physics, engineering, and science departments. Reading the following 35 contributions gives an indication of the diversity of topics but only scratches the surface.

When we published our list last year, it was noted that our contributors were heavily drawn from North American institutes and not representative of the "global" materials science community. This was partially derived from our "pay-it-forward" invitation scheme, where, editorially, we only made the first initial invites to start the self-driven invitation chain: contributor #1 invited contributor #2 who invited contributor #3 and so on. Clearly, a weakness of that approach was that contributors were highlighting peers in the same geographical region—a case of proximity bias. While we still liked the pay-

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Continued

it-forward approach (which both eliminated editorial bias in selection and introduced us to new journal connections), this "localization" criticism was valid. As such, we tweaked our invitation method this year in two ways:

(1) First, we explicitly requested that suggested invitees not only be from a different field but from a different country. Our invites had the following text:

> **A recommendation of two peers to continue the chain** (please provide name and e-mail). To keep the topic areas as diverse as possible, please recommend someone:
>
> 1. That works in a **different field** or has different expertise than your research.
>
> 2. That works in a **different country***
>
> 3. Also, please **cross-check with previous participants** to avoid a repeat!
>
> *For full transparency, our list last year was a little criticized, as it was deemed biased toward North American researchers from established institutes. We just followed the names suggested by our invitees. However, we are hoping this requirement—recommendation of a peer from a different country—will result in a more representative list of the global materials science community.

2) Second, rather than a linear chain resulting in a serial sequence of invitations, we decided to implement a pyramid-like scheme, where each invitee suggested two additional contributors (see Figure 1). This both shortened the time frame needed to collect all 35 contributors and forced two differing fields and countries to be considered. Indeed, two suggestions per contributor would only need a little over 5 "levels" to attain 35 contributors (1 + 2 + 4 + 8 + 16 + 4). Note the participants didn't know which level they were, so technically the 16 contributors in the penultimate round did not need to provide suggested invitations. We used the first respondents chronologically until we accrued 35.

The result this year is 35 responses from 29 institutes across 12 countries (including North America, Asia, Europe, and Australia), with 40% of the responses coming from women. A wider net than last year. Is it perfect? Clearly not, and there is room for improvement. However, the intent is not to be perfect—it is meant to be illustrative. Cumulatively, we have an inspirational and diverse selection of materials scientists advocating for the work they do and challenges they face in the current academic climate (arranged alphabetically):

Isabel Abánades Lázaro, Junior Leader Fellow, University of Valencia

Many applications require engineering complex multifunctional materials, yet materials science is still seeking the control of heterogeneity that nature has accomplished. Metal-organic frameworks (MOFs) are hybrid, porous structures composed of metal ions or clusters linked by multitopic organic ligands. Our research aims to understand their self-assembly for controlling defect multi-functionalization to tailor their properties for improved environmental and healthcare applications. By precisely controlling heterogeneity at a molecular level, we envision storing information within MOFs, unlocking potential groundbreaking applications.

Athina Anastasaki, Assistant Professor, ETH Zurich

Chemically recycling common commodity polymers poses significant challenges. Key issues include the complexity and energy intensity of breaking down long polymer chains, particularly the difficulty of achieving these reactions at low temperatures. Additionally, the presence of additives and contaminants can complicate the process, making it hard to obtain high-purity recycled products. In the long term, economic viability is also a concern, given that the cost of chemical recycling can be higher than producing new plastics. Overcoming these hurdles requires advances in catalysis, efficiency, and implementation of "upcycling" strategies to enhance the

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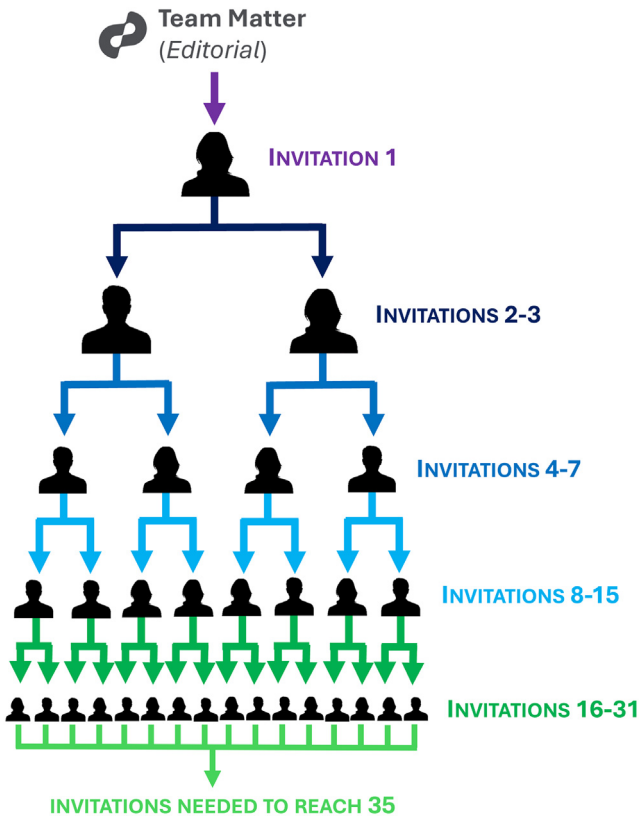

Figure 1. Pyramid-like scheme for pay-it-forward invitations

competitiveness and sustainability of chemical recycling.

Herdeline Ann M. Ardoña, Assistant Professor, University of California, Irvine

Our research program addresses the importance of transduction of conduction-potentiated biophysical signals across the intracellular and extracellular spaces, which provide linkages to form-function coupling across length scales in electroactive systems. Central to our team's mission is the development of molecular design-programmable and hierarchically structured macromolecular materials endowed with the capacity to transduce ionic, optical, electrical, and mechanical cues—serving as platforms to uniquely reveal understudied mechanisms of tissue dysfunction due to space-time asynchrony in contractile cells and offer approaches toward long-standing challenges in the maturation of stem cell-derived cardiomyocytes.

Maxx Q. Arguilla, Assistant Professor, University of California, Irvine

The discovery of new physics and the realization of next-generation devices both rely on the creation of well-defined solids approaching the atomic limit. To this end, the Arguilla group develops atomically precise solids composed of sub-nanometer-thick 1D and quasi-1D chains held by weak van der Waals (vdW) interactions—often thought of as "all-inorganic polymers." The group uncovered families of these ultranarrow functional solids including elusive helical/chiral structures, direct bandgap emitters, topological insulators, and optoelectronic organic-inorganic heterointerfaces. These emergent materials effectively bridge the understanding of molecular and extended lattice solids in the context of structure, quantum/physical properties, device performance, and reactivity.

Abdulaziz S. R. Bati, Ibn Rushd Postdoctoral Fellow, Northwestern University

The urgent need for sustainable energy solutions positions solar energy at the forefront of research. Perovskite solar cells, particularly in tandem configurations where multiple subcells are stacked together to enhance the performance of existing technology, present a promising path for efficient and cost-effective renewable energy. However, the complex structure of tandems introduces significant challenges, such as defect formation, ion migration, and energy losses at interfaces. My current research addresses these critical issues by developing specially engineered materials designed to improve interface quality and stability, thereby enhancing the overall efficiency and long-term viability of perovskite-based tandem solar cells.

Munkhbayar Batmunkh, Senior Lecturer, Griffith University

My research group focuses on designing a broad range of nanoscale materials and understanding their behavior in emerging photovoltaic (PV) devices such as perovskite solar cells and other PV-integrated systems. Particularly, my team aims to address fundamental knowledge gaps in the structure-property relationships of materials and devices by utilizing advanced microscopic and spectroscopic techniques. Our collective effort is to provide far-reaching impact in our society by advancing the knowledge in the fields of nanoscience, nanotechnology, engineering, chemistry, materials science, and energy.

Quinn A. Besford, Group Leader, Leibniz-Institut für Polymerforschung Dresden e.V.

A key challenge in nanomedicine is to overcome biologically imposed barriers to treatment, particularly immune system interactions that drastically reduce material effectiveness. My team develops functional polymer nanoparticles that

strategically avoid immune system interactions in order to better target diseased tissues in the framework of theranostics (treating and diagnosing disease). My team also develops functional polymer materials that contain fluorophores coupled in distinct architectures, such that any movement of the polymer chains produces a macroscopic signal that can be spatially resolved (messenger materials). We use these materials to probe a variety of physico-chemical phenomena (e.g., force, pH) in material and biological contexts.

Michelle P. Browne, Head of Young Investigator Group, Helmholtz-Zentrum Berlin für Materialien und Energie

Green H_2 has the potential to replace fossil-fuel-based energy sources in many processes, which could significantly help to decarbonize our society. Green H_2 is generated by coupling wind turbines/solar panels to electrochemical water-splitting devices. However, this route is partly hindered by the current water-splitting catalysts used due to stability and conductivity issues. In my group, we are using metals/metal oxides (active sites) with and without MXene materials (conductive, high surface area) to create new catalysts for this process. To accelerate materials discovery, my group is understanding the interaction of these materials using an operando lab and synchrotron-based methods at the Berlin X-ray source BESSY II and at Soleil Synchrotron in France. Furthermore, we are integrating these catalysts into practical electrolyzer devices to understand operation under real life conditions.

Saffron J. Bryant, Senior Lecturer, RMIT University

Cryopreservation is vital for almost all fields of biomedical research as well as blood banks, species preservation, stem cell therapy, and assisted reproductive technologies, and yet the basic methods have changed very little in the last 50 years. I am applying fundamental research in the field of physical chemistry to design new cryoprotective agents based on neoteric solvents and to tailor cryopreservation protocols based on high-throughput methods. This research may overcome current challenges in cryopreservation and pave the way for storage of new cell types and maybe one day even organs.

Marco Carlotti, Assistant Professor, University of Pisa

In my group, we are developing new fabrication procedures and synthetic strategies involving innovative precursor approaches and late-stage functionalization to prepare functional and easily processable polymeric systems. The goal of our research in this field is 2-fold. On one hand, we want to bring more functionalities and freedom to 3D microfabrication via additive manufacturing, making it more versatile and appealing for the preparation of smart microsystems and organic electronics devices. On the other, we aim to employ this approach to design materials and nanotechnological solutions that can offer improved performances in energy storage systems, making them more efficient and sustainable.

Claudia Contini, Lecturer, Imperial College London

My research group employs bottom-up synthetic biology strategies to create bio-inspired artificial cell-like systems by combining synthetic and biological molecular building blocks. One of the most exciting challenges we tackle is developing artificial life-like systems capable of autonomous and directional motion in response to their environment and adapting to its changes. Setting inanimate matter in motion provides crucial insights into realizing artificial life mimics. Our cell-like systems mimic the fundamental structure and mechanisms of biological cells, aiming to emulate dynamic behaviors such as motility, fusion, adaptability, and interaction. The aim is to understand biological processes and create innovative biotechnological tools.

Colm Delaney, Assistant Professor, Trinity College Dublin

My group focuses on the synthesis and assembly of nanomaterials to create hierarchical photonic structures that show dynamic and programmable structural color. By employing high-resolution additive manufacturing, we can design and program the response of the photonic structures across the molecular, nano-, and micro-scale. The inspiration behind this work comes from the natural world, where a myriad of organisms not only show structural color but can dynamically change this to camouflage, distract, signal, and regulate body temperature. We use our synthetic models for sensing, actuation, encryption, and energy harvesting.

Emily R. Draper, Professor, University of Glasgow

The Draper group looks at replacing materials that traditionally use metals (chromics, sensors, photovoltaic devices, etc.) with organic water-processable alternatives. By replacing them with organic materials, this can make them more environmentally friendly and cheaper to produce and process, leading to them being more financially accessible. The materials we use are organic self-assembled aggregates, and depending on the method of assembly, the resulting materials have different properties. This means that the same molecule can have various applications just by changing the assembly method and the resulting aggregate formed. This again saves time, resources, and money on new materials discovery.

Aaron Elbourne, Associate Professor, RMIT University

I am a biophysical chemist whose research focuses on utilizing materials, interfacial, and colloid science to treat disease. My team develops next-generation antimicrobial surfaces and

nanoparticles, as well as therapeutic colloids to improve current therapies. Moreover, we use high-resolution imaging techniques, such as atomic force microscopy, to understand the molecular-scale interactions of nanomaterials with biological entities (biomembranes, cell walls, whole cells). This allows us to develop structure-function relationships for nano-bio-therapeutics, which tailor nano-therapeutics for target treatments. Additionally, we are developing next-generation biosensors, smart biomaterials, and vaccine technologies.

Jack D. Evans, Research Fellow and Lecturer, University of Adelaide

My emerging group is interested in investigating the atomistic origins of various macroscopic properties of supramolecular systems and materials to address challenges in the future energy transition. We combine advanced methods across many scales, including quantum chemistry calculations, classical molecular simulations, macroscopic thermodynamic theory, and machine learning approaches. Topics investigated by our group include, but are not limited to, adsorption phenomena, complex phase transformations, and the exploration of new catalysts. Outside of this fundamental research, I am lead developer of the adsorption information format, a community-led action to improve the sharing of adsorption data.

Larisa Florea, Associate Professor, Trinity College Dublin

My group develops responsive materials that can switch between different states upon exposure to external stimuli. Stimulation of these materials using light, temperature, electrochemical potential, or variation of the local chemical environment can result in changes in local charge, polarity, or molecular conformation. The incorporation of such responsive units at the molecular level, combined with 3D design and micro-fabrication, permits the realization of customized 3D architectures that can undergo anisotropic and directional/programmable shape change upon stimulation. Such microstructures have a wide range of applications, from soft micro-robotics to microfluidics.

Antoni Forner-Cuenca, Associate Professor, Eindhoven University of Technology

The goal of my research group (Electrochemical Materials and Systems) is to accelerate the deployment of transformative energy technologies into the real world. We employ principles at the convergence of (electro)chemical engineering, materials science, and physical chemistry to design, synthesize, and simulate materials and systems. Our work provides design principles for porous electrode materials—both in term of their three-dimensional structure and surface composition—which can then be applied to multiple technologies such as large-scale energy storage with flow batteries, energy conversion with hydrogen fuel cells and electrolyzers, and decarbonization of the chemical industry through efficient separations and electrosynthesis.

Alexander C. Forse, Assistant Professor, University of Cambridge

In the Forse group, we research nanoporous materials that can help to mitigate climate change. A central challenge is to understand and tame the disordered structures of nanoporous carbon electrodes to improve their performances in electrochemical energy storage and electrochemically driven carbon dioxide capture. NMR spectroscopy provides unique insights here, revealing the structure of the electrode-electrolyte interface and offering new pathways to improve materials performance. We further use crystalline porous materials, such as metal-organic frameworks, as model systems to unravel the fundamentals of energy storage and carbon dioxide capture.

Miguel I. Gonzalez, Assistant Professor, Dartmouth College

The transition to a sustainable future relies heavily on developing heterogeneous catalysts that enable more atom economical and energy efficient production of fuels and chemicals. These efforts remain largely limited by the lack of methods to tailor heterogeneous catalysts at the molecular level. Ligand design has been an indispensable strategy to optimize molecular catalysts but has been challenging to implement for heterogeneous catalysts due to the propensity of conventional ligands to block active sites. The Gonzalez lab seeks to develop porous ligands that enhance the selectivity of heterogeneous catalysts, while maintaining access to their reactive metal sites.

Simon Krause, Group Leader, Max Planck Institute for Solid State Research

Structure-property relationships dominate the search for new materials in the areas of energy conversion and storage. We would like to shift that paradigm by considering functional dynamics as a key parameter to tune materials properties. We synthesize responsive framework materials with global and local dynamics, resulting in properties away from equilibrium. We further develop *in situ* methods to investigate dynamic features on various length and timescales. By embracing entropy to its fullest while still maintaining a certain degree of structural control, we can create counterintuitive phenomena and novel mechanisms that have a large impact on molecular adsorption, transport, and (photo)catalytic processes.

Hiang Kwee Lee, Assistant Professor, Nanyang Technological University

Nanocatalysis leverages nanometer-scale materials to drive chemical reactions, addressing critical sustainability issues. Despite its promise, current nanocatalytic

processes are hindered by inefficient energy conversion, weak intrinsic catalytic activities, and suboptimal catalyst-reactant interactions, particularly at dilute concentrations. To overcome these challenges, our research focuses on innovative catalytic designs, from individual nanoparticles to their ensembles, effectively squeezing light and manipulating molecules at the nanoscale. These approaches hold immense promise for transforming energy and environmental technologies, facilitating the efficient production of green hydrogen and ammonia as next-generation clean fuels to realize a sustainable hydrogen economy.

Michael M. Lerch, Assistant Professor, University of Groningen

Robotics and control engineering have produced machines with impressive capabilities, leveraging conventional electronic components, actuators, and structural materials. Yet to meet emerging needs at the microscale and in surgical robotics, new solutions for creating robots with softer (hybrid) bodies operated by non-traditional, non-electronic control concepts have to be developed. We believe that chemical reaction networks integrated through mechano-chemical coupling may provide a new type of operating system for next-generation (soft) robots, in which reaction networks respond to their external environment, process information, and program material motion as well as properties in time and space.

Shi Liu, Assistant Professor, Westlake University

Functional materials such as ferroelectric oxides are complex systems with functionalities dictated by emergent properties, which cannot always be easily explained solely through microscopic laws. A significant challenge in computer-aided materials discovery is predicting target properties influenced by structures and processes across multiple time and length scales. My group is dedicated to addressing this challenge by developing a machine-learning-assisted multiscale materials modeling approach. This approach includes (1) a deep-learning-assisted universal force field that facilitates high-throughput large-scale simulations of solid solutions covering diverse types of elements and (2) efficient prediction of functionalities using hybrid physics-driven and data-driven methods.

Nieves López-Salas, Junior Professor, Paderborn University

The ever-increasing energy demand and environmental pollution have made sustainable chemistry an unavoidable endeavor for researchers. The ultimate goal of sustainable chemistry is to develop new solutions that minimize any possible negative impact derived from chemical usage. My main research goal lies in developing new carbonaceous materials with special structural and electronic properties "through" and "for" advanced and sustainable processes with special emphasis on developing energy storage electrodes, as well as photo- and electrocatalysts. To do so, my group avoids classical, rather unpredictable, and resource-consuming carbonization processes to adjust the material's composition and structure.

Francisco J. Martin-Martinez, Senior Lecturer, King's College London

Over 12,000 years since our early ancestors began cultivating wild grains, agriculture still awaits a revolution capable of addressing the challenges posed by our expanding global population. Inspired by terra preta, an anthropogenic soil found in the Amazon rainforest, our research focuses on the development of computationally designed biobased materials from agricultural biomass waste as new carbon sources. By integrating atomistic modeling, computational modeling, and machine learning with biomass thermochemical processing, we advance the understanding of water retention mechanisms and nutrient absorption by plants in biochar-amended soils and design biobased carbon nanoparticles for precision agriculture.

Cristian Pezzato, Assistant Professor, University of Padova

Spatiotemporal control of proton transfer phenomena is ubiquitous in nature but seldom found in synthetic systems. My research deals with the design and testing of water-soluble chemical systems (these being simple organic compounds, macromolecular architectures, or supramolecular host-guest couples) able to act as metastable-state photoacids—i.e., capable of generating proton concentration gradients following visible light absorption. Over the past few years, we have contributed to rationalize the photoacidic characteristics of spiropyran-merocyanine molecular switches, and we are now taking the challenge of improving them toward robust "light-sensitive cofactors" that can be coupled both in space and time with any acid-sensitive system. Our approach is multi-disciplinary, and we believe it may serve as a springboard toward sustainable solutions for energy conversion and storage.

Loredana Protesescu, Assistant Professor, University of Groningen

My research addresses the challenge of developing advanced nanomaterials with unprecedented properties for next-generation applications. We aim to surpass the limitations of lead-based perovskites by developing stable and efficient metal halide/chalcogenide perovskites. We tackle synthesis and surface chemistry hurdles with semiconductor pnictides in infrared photodetectors. For metal borides, we innovate to maintain exceptional properties at the nanoscale for hard coatings and catalysis. We ensure scalable, reproducible synthesis of these colloidal nanocrystals by integrating high-throughput methods and machine learning. Ultimately, we design materials

to withstand extreme environments, pushing nanotechnology's boundaries and addressing critical energy, environmental, and healthcare challenges.

Fredrik Schaufelberger, Assistant Professor, KTH Royal Institute of Technology & University of Warwick

To develop the next generation of biomedical materials and generate breakthrough technologies for drug delivery, tissue engineering, and regenerative medicine, there is a need for innovation of materials structure at the molecular level. Our group uses the toolbox of supramolecular chemistry to improve biomaterials via bottom-up modifications. In particular, we integrate mechanical bonds (rotaxanes, catenanes) and entanglements (knots) into biomaterials to tailor aspects such as mechanical properties and uptake/release profiles for drug delivery applications. Long term, we aim to translate innovative fundamental science into practical biomedical applications that can positively impact human health across the world.

Paula Sebastián Pascual, Assistant Professor, KTH Royal Institute of Technology

Copper shows promising performance for several electrocatalytic reactions, such as carbon dioxide conversion or nitrate reduction to ammonia. These reactions are sensitive to the catalyst structure, i.e., they are affected by the geometry of the active surface sites. To address structure effects in electrocatalysis, it is essential to develop electrochemical methods to determine the number and geometry of the active sites on synthesized catalysts. We perform electrochemical characterization of model single crystalline electrodes and nanostructure electrodeposition to prepare copper surfaces with tailored facet distribution. We aim to tune product selectivity and activity in electrocatalysis by tuning the catalyst surface structure.

Aránzazu Sierra Fernández, Junior Leader Fellow, CIC nanoGUNE

My group focuses on the development of multifunctional hybrid coatings for construction materials and cultural heritage conservation. Our research addresses the challenge of creating protective coatings with self-healing and antimicrobial properties. Using atomic and molecular precision technologies, we design coatings that can self-assemble and adapt to the environment, enhancing durability and reducing maintenance. This multidisciplinary approach aims to produce versatile, cost-effective, and environmentally friendly coatings, ultimately safeguarding both modern construction and historical artifacts.

William A. Tarpeh, Assistant Professor, Stanford University

Wastewaters are usually viewed as costly discharges and vary widely in composition, source, and volume. My group reimagines wastewaters as underutilized feedstocks and explores electrochemical separations and electrocatalysis for wastewater refining, or the generation of tunable portfolios of products from unconventional streams. We study ion transport through selective adsorbents and membranes and develop and interrogate novel electrocatalytic processes and leverage these insights to inform implementation. Selectively capturing and converting pollutants from complex waste streams is a critical challenge for sustainable chemical manufacturing. Our emphasis on understanding and controlling microenvironments enables recovery of high-purity products from wastewaters and facilitates element-specific circular economies.

Gianvito Vilé, Associate Professor, Politecnico di Milano

Achieving sustainable fine chemical manufacturing is one of the biggest challenges today, as it requires precise control over catalytic processes while minimizing waste and resource consumption. Single-atom catalysts (SACs) are a novel class of catalysts that present a groundbreaking solution to this challenge, offering an unprecedented level of atomic efficiency and material usage. However, their complex structures and behaviors remain poorly understood, hindering their widespread application. Our research group focuses on unraveling the local structure of SACs, understanding their properties, and enhancing their performance in important chemical processes. Our work aims to advance our understanding of SACs at the atomic level, ultimately leading to more efficient and selective catalytic systems, and enabling new advancements for sustainable chemical processes.

Larissa K. S. von Krbek, Group Leader, University of Bonn

Processes in nature are predominantly driven by the consumption of energy. In contrast, the process of supramolecular self-assembly used to build artificial systems operates spontaneously and thermodynamically downhill. We believe that taking synthetic systems out of equilibrium will lead to greater complexity and function in artificial materials, namely spatiotemporal control over function, self-healing, adaptivity, emergent behavior, and the ability to perform work as observed in natural systems. Toward this goal, we design and develop tools to investigate new stimuli-responsive metallo-supramolecular systems. Detailed investigation of these synthetic systems will further our understanding of out-of-equilibrium systems and emergent behavior in general.

Hongzhang Wang (汪鸿章), Assistant Professor, Tsinghua University

The strategic design of soft materials, endowed with multi-stimulus responsiveness and adjustable functions, is essential for the progression of soft intelligence. This field, however, faces obstacles such as inherent softness

constraints and the intricacies of functional integration. Our group focuses on integrating liquid metals with soft materials to realize favorable mechanical, optical, electrical, and thermal tunability, facilitating multi-stimulus perception and response in a pure soft system. Our studies aim to advance the fields of soft actuators, sensors, robotics, and artificial skin, with the ultimate goal of propelling soft intelligence that can seamlessly harmonize and interact with biological systems.

Tailin Wu, Assistant Professor, Westlake University

My group develops artificial intelligence methodologies that enhance the simulation, inverse design, and control of complex physical systems ranging from materials to biological entities and partial differential equation (PDE)-based systems. These often feature multi-scale, multi-physics, and highly nonlinear interactions that are challenging and slow to address with traditional numerical methods. We are pioneering the development of innovative generative models and foundational model approaches that integrate the simulation, design, and control of diverse systems into a single coherent generative task. This allows us to rapidly and accurately simulate long-term system evolution while generating optimized, high-dimensional design parameters and control signals for design and control tasks.

DECLARATION OF INTERESTS

The authors declare no competing interests.