35(+2) Challenges in Materials Science being Tackled by PIs under 35(ish) in 2025

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Aisha N. Bismillah, Royal Commission for the Exhibition of 1851-Ramsay Memorial Trust Research Fellow, The Francis Crick Institute & King's College London

Optical technology at the molecular level is a driving force for innovation – it can leverage the manipulation and detection of light for a range of purposes such as biomedical imaging and sensing. To advance the field and create breakthrough technologies we must design materials that can mimic the multi-sensory environments and responses of natural biological systems. My emerging group is bridging supramolecular chemistry with optical technology to create multi-stimuli architectures that exhibit naturalistic characteristics. The long-term aim is to translate fundamental science, through the understanding and control of biochemical processes, into innovative biomedical technologies which improve human health.

Alessandro Bismuto, Junior Professor, Institute of Inorganic Chemistry, University of Bonn

Our research tackles key challenges in the fascinating yet underexplored field of heavy main group chemistry. These elements, often overlooked, can behave in unexpected ways—particularly due to relativistic effects. We are investigating how the presence of a heavy atom influences luminescence, chemical bonding, and catalysis. To do this, we have synthesised and fully characterised SBDIPY and BIDIPY—heavier analogues of BODIPY that incorporate antimony and bismuth, respectively. Our current challenge is to make these compounds stable in water, which would open the door to using them as sensors for detecting a wide range of substances in biological systems.

Anna Blakney, Assistant Professor, Michael Smith Laboratories and School of Biomedical Engineering, University of British Columbia

RNA and nanoparticle systems are at the frontier of biomaterials, yet their interactions with the immune system remain poorly defined. My lab studies how the chemical and structural properties of RNA and nanomaterials govern recognition, transport, and immune activation. By uncovering these mechanisms, we aim to establish design rules that bridge immunology with materials engineering. This knowledge will enable the rational design of delivery platforms and accelerate the creation of next-generation RNA vaccines and therapeutics with enhanced precision, potency, and durability.

Sebastien Callens, Assistant Professor of Orthopaedic Biomechanics, Eindhoven University of Technology, the Netherlands

Restoring durable function to damaged or diseased joints requires materials-based approaches that guide living tissues to rebuild themselves with the right organization. Our group combines engineered microtissues, micro-architected biomaterials, and quantitative imaging to design mechano-driven regeneration strategies, currently centered on articular cartilage. We study how mechanical and geometrical cues program extracellular-matrix organization during growth, and how the resulting tissue architecture governs mechanical properties in health and disease (such as osteoarthritis). By better understanding these instructive cues and how to harness them, we aim to create biomimetic regenerative therapies that restore mobility and last a lifetime.

Céline Calvino, Junior Research Group Leader & Principal Investigator, Cluster of Excellence *liv*MatS, University of Freiburg

A central challenge in the field of stimuli-responsive polymer materials is to achieve responses that are reversible, efficient, and precisely controlled. While many systems can be triggered by light, heat, or mechanical input, few can repeatedly and predictably switch between states without fatigue or side reactions. Advancing the field requires chemistries that remain orthogonal -addressable independently yet compatible within complex matrices- to ensure reliability and design freedom. Developing such orthogonal, reversible covalent systems will be key to next-generation adaptive materials that integrate multiple stimuli, sustain their performance over time, and enable truly programmable, recyclable soft matter.

Stefano Crespi, Assistant Professor, Department of Chemistry - Ångström Laboratory, Uppsala University

My research focuses on the design and study of molecular photoswitches, with an emphasis on developing systems that respond to both light and chemical stimuli. By incorporating elements such as phosphorus into established chromophore frameworks, we aim to access new reactivity patterns and photoisomerization pathways. A particular challenge is to understand how external factors such as solvents, acids, and nucleophiles influence switching efficiency and stability. Using a combination of synthesis, spectroscopy, and theoretical analysis, my group seeks to establish guiding principles for creating photoswitchable molecules that can be applied in responsive materials and molecular devices.

Ricardo Cruz-Acuña, Assistant Professor of Cancer Engineering, Columbia University Irving Medical Center

My laboratory engineers synthetic, tunable hydrogels to model how extracellular matrix (ECM) mechanics and composition regulate epithelial tumor initiation and therapy resistance. Current organoid systems rely on undefined tumor-derived matrices that lack physiologic control and limit translational potential. By creating fully defined biomaterials that incorporate stiffness and ligand cues observed in patient tissues, we can systematically dissect how ECM–cell interactions reprogram transcriptional networks, including TP53- and YAP-dependent pathways. This approach tackles the challenge of building predictive, human-relevant cancer models and enables discovery of new biomarkers and therapeutic strategies for the early interception of cancer.

Locke Davenport Huyer, Assistant Professor, Department of Biomaterials & Applied Oral Sciences, Dalhousie University

My lab engineers' metabolite-based degradable polyesters to control the interface between synthetic materials and immunity. We design and synthesize degradable polymers from small-molecule, intrinsically immunoregulatory building blocks, yielding materials whose degradation products continuously modulate inflammation at implant sites. Through application-specific, data-driven design and fabrication, we develop polymeric implantable devices, drug delivery systems, and regenerative scaffolds that actively engage with the immune system. We envision biomaterials as dynamic participants in immune regulation - materials that communicate with and direct the host response rather than passively endure it.

Jamie H. Docherty, Lecturer in Synthetic Chemistry, Department of Chemistry, Lancaster University

Photochemical dearomatisation converts feedstock heteroaromatics into high-strain, conformationally locked, sp^3-rich structures that we then diversify using catalysis. Excited-state reactivity unlocks 3D-biased fragments for drug discovery, shape-persistent motifs for functional materials, and energy-rich valence isomers for molecular solar-thermal (MOST) storage. The principal challenge lies in the predictive control of site-, regio-, and stereoselectivity through valence-isomerisation and subsequent bond formation, while suppressing side-reactions and rearrangements. Systematic control of these pathways is a first-order challenge – and opportunity – for the next decade. We use metal catalysis to precision-install substituents with defined spatial orientations, accessing modular building blocks for pharmaceuticals and materials.

Liam Donnelly, Assistant Professor, Institute of Chemical Sciences, Heriot-Watt University

Current polymer design locks backbone structure at polymerisation, making properties such as durability, degradability, and recyclability difficult to tune post-synthesis. Conventional post-polymerisation modification only alters pendant groups, leaving the backbone chemically inert. Emerging backbone modification strategies show promise but suffer from limited modularity, reliance on bespoke substrates, and poor compatibility with bio-based or waste feedstocks. My research group tackles these limitations by developing catalytic methods to selectively activate and reprogram linkages in commodity polymers under mild, scalable conditions, enabling modular functionalisation and control of structure and end-of-life pathways.

Joel. A. Finbloom, Assistant Professor. Faculty of Pharmaceutical Sciences. University of British Columbia

Bacteria play an important and complex role in human health and disease. Pathogenic bacteria can cause antibiotic resistant infections, which could result in 10 million deaths per year by 2050. On the other hand, therapeutic microbes such as probiotics have potential to treat numerous conditions, but suffer from poor oral delivery outcomes. My research program develops microbe-interfacing nanomaterials to overcome barriers for both antibiotic and probiotic delivery. In recent work, we leveraged biofilm-interfacing nanoparticles to co-deliver synergistic antimicrobials and treat lung infections. In another project, we are engineering biofilm-mimetic microgels to better encapsulate and deliver therapeutic bacteria to treat ulcerative colitis.

Pratik Gurnani, Lecturer in Pharmaceutical Sciences, University College London

The revolutionary use of mRNA technology to produce vaccines at breakneck speed was crucial for our economical and societal recovery from the COVID-19 pandemic. The susceptibility of mRNA to degradation if administered naked however necessitates a delivery vector for protection and delivery. My group interfaces polymer and lipid materials together to develop new nanoparticles to overcome the critical challenges in mRNA delivery, including tissue specificity, storage stability, immunogenicity and intracellular delivery barriers. We combine organic chemistry, pharmaceutics, advanced nanomaterial characterisation and data driven techniques to accelerate discovery.

Robert Hein, Junior Professor, Organic Chemistry Institute and Center for Soft Nanoscience, University of Münster

Redox-switchable materials are highly promising candidates for the next generation of sensors, actuators and information/energy storage. However, their chemical diversity and application scope remain underdeveloped. To address this challenge, my group explores novel redox-active organic molecules whose colour, fluorescence, charge and/or geometry can be reversibly controlled by electrical stimulation under ambient conditions. The integration of these redox switches into various 2D and 3D architectures, such as surfaces and polymers, can then be leveraged to translate their molecular switching properties to the macroscale, enabling the design of improved responsive materials with hitherto unexplored and emergent (redox) properties.

Jennifer Johnstone-Hack, Royal Academy of Engineering Research Fellow & Lecturer, University of Sheffield

My research group aims to help develop the next generation of electrochemical technologies that are cheaper, more durable, use more sustainable materials and ultimately contribute to achieving ambitious net zero targets. We focus on understanding how and why the materials and components in electrochemical devices, including electrolysers and batteries, fail. We then use these insights to develop and design new materials architectures with favourable properties. To assist with this, we employ a range of advanced, correlative X-ray and neutron imaging methods to visualise morphology evolution and failure in near real time.

Susan E. Leggett, Assistant Professor, University of Illinois Urbana-Champaign & Cancer Center at Illinois

Understanding mechanobiology across scales is critical for predicting cell and tissue behaviors, yet progress is hindered by limited in vivo access and by in vitro models that oversimplify living systems. We build miniaturized, three-dimensional tissues and organ-on-a-chip platforms with tunable biochemical and biophysical cues that recapitulate cellular heterogeneity and microenvironmental mechanics. Integrating live-cell imaging with computational analysis, we model these systems as dynamic materials and extract quantitative relationships linking morphology, migration, and mechanics from subcellular to tissue scales. These spatiotemporal maps support descriptive and predictive frameworks for cell state transitions and emergent behaviors in health and disease.

Nadine Leisgang, Assistant Professor, Philipps-Universität Marburg

The pursuit of scalable quantum technologies has led to an ever-increasing demand for precise control over the quantum properties of materials. Achieving control of individual particles and their interactions remains a long-standing goal in the field. The regime of two-dimensional (2D) materials offers a powerful platform for engineering quantum systems. These atomically-thin layers exhibit properties ranging from metallic to superconducting and insulating to semiconducting. By combining different layers into van der Waals heterostructures, our research aims to create, control, and sense hybrid quantum systems based on 2D semiconductors to manipulate and explore exotic quantum phenomena.

Jason Y. C. Lim, Assistant Professor & Principal Scientist, Institute of Materials Research and Engineering (IMRE), A*STAR

With global production of plastics expected to continue unabated for the foreseeable future, urgent multi-pronged solutions to tackle these versatile materials' currently-unsustainable end-of-life is critically needed. To complement plastic recycling, our team is developing new chemical approaches to upcycle commodity plastics into diverse products useful for society such as, but not limited to, industrially-relevant oxygenated chemicals, functional polymers (e.g. antimicrobials, polymer electrolytes) and metal-organic frameworks. By repositioning plastics at the beginning of the value chain as feedstock rather than waste, we hope to engineer a more sustainable and financially-viable post-use plastics economy.

Kevin Neumann, Assistant Professor, Radboud University

Designing advanced materials for health and technology requires a deep understanding of structure-property relationships. A central challenge in polymer science is achieving precise molecular control, which is essential for linking structure to function, even in complex biological environments. By rethinking polymer design and advancing click methodologies, we enable access to polymers with unprecedented molecular precision, opening the way to systematic studies at the biointerface. With this approach, we identified poly(ylides) as a new class of charge-neutral, hydrophilic polymers and demonstrated their potential in (nano)medicine, for example through ylide-PEGs, termed yPEGs, that modulate nanocarrier-water interfaces and prevent immune responses.

<u>Liliang Ouyang, Associate Professor, Department of Mechanical Engineering, Tsinghua University</u>

The in vitro development of functional tissues and organs remains a fundamental challenge, as the underlying morphogenetic processes are still largely a black box. Current strategies, driven primarily by engineering (e.g., biofabrication) or biology (e.g., organoid technology), are each constrained by their own limitations. Our group (https://llouyang.com/) aims to transcend these boundaries by integrating both fields. We focus on the design, fabrication, and application of complex biomaterial and cellular systems, with a central mission of developing advanced 3D bioprinting and biofabrication technologies to engineer functional in vitro living systems.

<u>Omar Rifaie-Graham, Assistant Professor, Department of Chemistry, Queen Mary University of London</u>

My research addresses the challenge of building synthetic biological systems that can interface with living cells to enable precise control over metabolic activity. A key hurdle lies in engineering artificial compartments, such as polymersomes, that are both robust and selectively permeable, allowing controlled exchange of metabolites, ions, and signals. By integrating light-responsive chemistries and encapsulated enzymes, these systems can dynamically regulate local environments and biochemical pathways. This approach aims to establish programmable, bioinspired platforms that overcome current limitations in stability, responsiveness, and scalability.

<u>Charles Romain, Lecturer in Chemistry, Imperial College London</u>

Designing sustainable polymers is one of the challenges that our modern society needs to tackle for the sake of our civilization and planet. Our research interests span all along the whole life cycle of polymers, from looking at new reactions and methodologies using renewable resources, to developing better catalysts for making well-defined polymers (and hopefully better ones), to using data-driven approaches for the design of polymers primed for chemical recycling. We hope that our emerging contributions are joining the global collaborative efforts aimed at developing materials that will not cost us the Earth!

Rebecca J. Salthose, Research Associate, Department of Engineering, Universitat Politècnica de Catalunya

My research focuses on light-responsive molecular systems, from transition metal complexes for near-infrared OLEDs, where ligand design promotes excimer formation and red-shifted emission, to photoswitches for molecular solar thermal (MOST) energy storage. These photoswitches capture and store solar energy in a high-energy metastable isomer and release it on demand as heat. By exploring the synergy between these two classes of systems, I aim to integrate photoswitchable units with metal complexes to tune their absorption and excited-state dynamics. This approach seeks to create functional materials with controllable optical and thermal properties, opening new possibilities for imaging and other light-driven applications.

Baihao Shao, Vice-Chancellor Assistant Professor, Department of Biomedical Engineering, The Chinese University of Hong Kong

My research group leverages bottom-up nanotechnology and bioengineering approaches to synthesize and engineer phototherapeutic systems for promoting human health. We are interested in developing infrared- and short-wave infrared-activatable molecular systems and translating these photochemical tools into light-activated medicines and drug carriers. We seek to customize purpose-specific light delivery devices to enable effective *in vivo* light delivery and explore living cell-based drug delivery strategies as a practical means to optimize the ADME (absorption, distribution, metabolism, and excretion) properties of phototherapeutics. Through these interdisciplinary efforts, our overall goal is to facilitate the clinical translation of phototherapeutic systems.

Flávia Sousa, Assistant Professor & Principal Investigator, Department of Pharmaceutical Technology and Biopharmacy, University of Groningen

Glioblastoma poses unique therapeutic challenges due to the immunosuppressive tumor microenvironment and the restrictive blood–brain barrier (BBB), which limit the success of immunotherapies. Our research develops RNA nanovaccines encapsulated in lipidic and polymeric nanoparticles to remodel the tumor microenvironment and enhance immune responses. While polymeric systems enable controlled release and brain-targeted delivery, they present major formulation challenges, particularly in maintaining RNA integrity and functionality during encapsulation and release. By addressing these materials science hurdles alongside the biological barriers of glioblastoma, we aim to establish a robust platform for effective and durable brain cancer immunotherapy.

Arnaud Thevenon, Assistant Professor, Institute for Sustainable and Circular Chemistry, Utrecht University

Plastics are ubiquitous in our society. They have excellent properties but were never designed for circularity. My research aims to address this challenge by designing monomers from renewable and waste carbon sources to generate polymers with closed life cycles (bottom-up approach) and developing methods to functionalize existing polymers, introducing weak linkages within the polymer chains for controlled breakdown back to building blocks such as monomers (top-down approach). Central to this work is our expertise in molecular catalyst design and mechanistic understanding, enabling rational design of thermo-, electro-, and photochemical catalysts to achieve novel and efficient transformations.

Ryojun Toyoda, Assistant Professor, Tohoku University

Our research group is developing functional molecular materials based on coordination compounds and photoresponsive molecules. We have explored the use of discrete metal complexes, leveraging their designability and structural diversity, to create self-assembled nanostructures with promising properties. The challenge now is to move beyond simple functional nanomaterials. We aim to precisely arrange and combine these molecular components to create sophisticated molecular devices and molecular robots. Achieving this requires technological innovation, specifically by integrating nanomaterials chemistry with fields like photomanipulation and DNA nanotechnology to open up new research frontiers.

Alexander Vlahos, Assistant Professor, Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology and Emory University

The Vlahos Lab integrates synthetic biology and tissue engineering to develop programmable gene and cell therapies for applications in regenerative medicine, cancer, and autoimmune disease. We design synthetic protein circuits, which are combinations of modular protein components that enable novel input-output signaling behaviors to uncover how intercellular communication drives specific biological responses, such as immune modulation or vascularization. We are particularly interested in applying these synthetic circuits to enhance the long-term engraftment and function of transplanted cells for the treatment of Type I Diabetes. Our long-term goal is to engineer fully autonomous sense-and-response cells capable of systematically probing the immune system to deepen our understanding of intercellular interactions and to translate this knowledge into personalized therapeutic strategies.

Christina Wegeberg, Assistant Professor, Department of Physics, Chemistry and Pharmacy, University of Southern Denmark

Our research investigates the interaction between light and matter by developing photoactive transition metal complexes based on Earth-abundant metals. Most Earth-abundant transition metals exhibit weak ligand fields in common coordination environments, which poses a challenge for promoting photoactive states. We address this fundamental challenge through rational ligand design strategies aimed at achieving long excited state lifetimes and tailored photochemical properties. We use ultrafast pump-probe spectroscopy methods to investigate excited state dynamics and in this way, we can evaluate the photochemical potential of our novel transition metal complexes in electron and/or energy transfer processes.

Jonathan P. Wojciechowski, Research Associate, Kavli Institute for Nanoscience Discovery (Kavli INsD), University of Oxford

Developing the next generation of translational biomaterials requires a detailed understanding of how materials interface with cells and their surrounding biological milieu. My research focuses on both the design of immunomodulatory materials that act as protective barriers against immune-mediated responses and the development of analytical tools for biochemical characterisation. Our team utilises Raman spectroscopy to obtain molecular ‘fingerprints’ of biomaterials, engineered tissues, and biologically derived nanoparticles. In parallel, we design water-soluble Raman vibrational tags to enhance molecular specificity and provide detailed insight into biomolecular structure and chemical composition.

Ruoxiao Xie, Lecturer (Assistant Professor), University of Liverpool

Microvasculature plays a central role in nutrient delivery, disease progression, and drug transport within organs. My group aims to engineer microvascular networks within organoids/engineered tissues to enhance their functionality and physiological relevance for disease modeling and drug testing. The key challenge lies in reproducibly achieving high-fidelity, organ-specific microvasculature that can effectively integrate within target tissues/organoids. To address this, we combine material design, bioprinting innovations, and microfluidic bioreactor engineering to create biomimetic vascular networks and enable their controlled, dynamic maturation within tissues. Our engineering strategies also emphasize reproducibility, miniaturization, and scalability to facilitate high-throughput drug testing applications.

<u>Rong Yang, Associate Professor, Robert Frederick Smith School of Chemical and Biomolecular Engineering, Cornell University</u>

My research tackles the challenge of transforming polymer coatings from static barriers into dynamic, programmable interfaces by controlling polymer organization and interfacial function across molecular to mesoscale levels. Using chemical vapor deposition and in situ microscopy, I develop synthesis pathways for deterministic control of chain conformation and interfacial morphology. That interfacial design is further enhanced by integrating metabolically active microbes, enabling "living coatings". This dual strategy yields adaptive interfaces that self-regulate hydration, modulate inter-kingdom interactions, and advance optical and biological functions. Uniting synthetic precision with biological adaptability promises a paradigm for interfaces that interact, communicate, and evolve with their environments.

<u>Jonathan Yeow, Lecturer in Biomedical Engineering, The University of New South Wales</u>

My group focusses on accelerating biomaterials discovery through the development of robust synthetic and characterisation platforms that can efficiently navigate vast chemical design spaces. To achieve this, we are building high-throughput polymer synthesis pipelines with precision control over polymer architecture and functionality enabling rapid screening of biomaterials for applications across regenerative medicine. Our most recent challenge is in identifying and screening biomimetic synthetic polymers that can replicate and even outperform the biological activity of natural biomacromolecules such as glycans.

<u>Parisa Yousefpour, Assistant Professor, Department of Biomedical Engineering, Columbia University</u>

Precise spatiotemporal control over therapeutic activity is critical for efficacy but remains a major challenge in developing biomolecular therapeutics, particularly when therapeutic activity interfaces with immune mechanisms that are inherently dynamic and context dependent. Our lab addresses these challenges through two complementary strategies: designing stimuli-responsive biomaterials that enable controlled release and localization of therapeutics, and engineering externally or endogenously regulated RNA systems with tunable activation using synthetic biology approaches. Together, these efforts aim to define design principles for adaptive biomolecular systems that dynamically modulate immune responses for the treatment of different diseases, including cancer and infectious diseases.

Nattawut Yuntawattana, Lecturer, Kasetsart University

Polymers are extremely widespread in modern society, with their use spanning many sectors. The increasing use of polymers causes significant threats to our environment and health, owing to their uncontrollable end-of-life. My group addresses these problems at both ends of the life cycle. For initial production, we explore novel metal-based catalysts for various plastic wastes valorization through chemical recycling. This allows conversion of plastic waste into its starting precursors. At the other end, we develop new shelf-life extension packaging from biodegradable polymers and various active substances. This approach helps tackle two connected issues – food and plastic waste – with one solution.

Qi Zhang, Junior Professor, East China University of Science and Technology

The complexity of biopolymers is largely built on the subtle interactions of simple building blocks via engineering covalent and noncovalent bonds. My group is to explore the fundamental principles at the interfaces of supramolecular and dynamic covalent chemistries. We create synthetic polymers, especially poly(disulfide)s, that repair, replicate and recycle akin biopolymers. Our ultimate goal is to artificially synthesize machine-like soft matter that convert external energy into useful mechanical work or storable chemical potential energy.