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# Introduction: Smart Materials

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The emergence of new materials and devices will play an increasingly important role in improving people's health and quality of life. Smart materials are no exception. Because of their unique properties of stimuli-responsiveness and autonomous behaviors, smart materials have become the basis for many new technological developments. Beginning with classic examples such as piezoelectric materials and shape-memory materials, the latest research in smart materials has upended traditional design concepts and greatly expanded their application fields. For example, robotics has seen rapid evolution from rigid-bodied construction to soft robots composed of compliant materials. Future robots may grow, regenerate, and change shape and function to adapt to the physical and chemical environment, calling for transdisciplinary integration of chemistry with mechanical engineering, materials engineering, and bioengineering. In other applications, smart materials provide the foundations for man-made systems that integrate with living organisms, in ways that can blur the distinction between the two. In addition to conventional areas such as environmental sensors and actuators, smart materials are also essential for advances in soft robotics and bioelectronics, with prominent successes in medical technologies for physiological sensing, minimally invasive surgery, drug delivery, human−computer interaction, and rehabilitation. Future smart materials will offer even richer functions, enhanced controllability, and improved biocompatibility and, thus, can serve a better future for humankind.

This thematic issue of *Chemical Reviews* aims to provide an overview of the latest research in the development of smart materials and to highlight the importance of materials chemistry in this exciting field. The first few reviews focus on the use of liquid crystals as stimuli-responsive elements. Liquid crystals have made a crucial contribution to the technological revolution in the past century due to their ability to modulate light by responding to the applied electric fields. As discussed in the review by H. K. Bisoyi and Q. Li, liquid crystals' responsive and adaptive attributes can be further utilized to develop soft smart materials for a wide range of applications, such as advanced photonic devices, smart windows, and biosensors. Liquid crystal molecules can also be chemically connected to produce elastomers featuring dynamic structural and morphological changes in response to external stimuli, providing many opportunities to incorporate smartness into soft materials. The review by E. M. Terentjev and co-workers summarizes the chemical mechanisms driving the dynamic bond exchange in the cross-linked networks of liquid crystal elastomers and highlights their unique properties of reprocessing, recycling, and reprogramming. D. J. Mulder and co-workers discuss how to manipulate the hydrogen bonding in the supramolecular liquid crystalline polymers to enable chemical and dynamic structural responses and the associated self-healing and recyclable properties.

Advances in nanoscience and nanotechnology over the past few decades have underpinned many important developments in smart materials, providing not only active components but also fabrication tools to achieve precise compositional and spatial control. Y. Yin and co-workers summarize various self-assembly approaches that can be used to organize colloidal building blocks into smart materials, emphasizing the importance of particle connectivity in creating responsive superstructures. With a focus on bioelectronic applications, D.-H. Kim and co-workers review the synthesis of nanostructured materials and composites and their integration into the fabrication of flexible and stretchable electronics. The review by M. Su and Y. Song further provides an overview of strategies for printing smart materials into multidimensional and multicompositional architectures suitable for large-scale fabrication of intelligent devices.

Many physical and chemical processes have also been utilized as novel responsive mechanisms in the design of smart materials. As reviewed by P. Fischer and co-workers, ultrasound can induce various effects to trigger biological and chemical processes to enable unique responsive mechanisms and create smart materials. Z. L. Wang and co-workers review the recent studies on contact-electrification at liquid−insulator, liquid−semiconductor, and liquid−metal interfaces, highlighting the successful use of this process for designing triboelectric nanogenerators for applications in probing interfacial charge transfer and harvesting waste energy.

Smart materials are often composites of soft and hard materials. Recognizing the opportunities offered by the interfacial mismatches, B. Tian and co-workers review the fundamental chemical roles and principles for designing such interfaces and explore their associated (bio)chemical, mechanical, and other physical processes. J. A. Rogers and co-workers discuss the importance of materials chemistry in creating multifunctional neural interfaces, especially 3D bioelectronic frameworks, with a focus on the central nervous system, including brain and brainlike engineered tissues.

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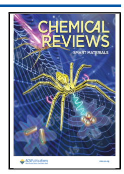





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A major application of smart materials is to construct soft robots capable of tether-free actuation in response to external stimuli. The review by Y. Kim and X. Zhao summarizes the recent development in the design and synthesis of soft magnetic materials, the underlying principles of magnetic actuation, and the integration of soft magnetic materials into soft robotic and electronic devices. The development of new smart materials also makes it possible to miniaturize robots, producing microrobots with distinct capabilities. J. Wang and co-workers highlight four major areas where smart materials can have significant impacts on the further advancement of microrobots, including propulsion, biocompatibility, intelligence, and human−microrobot cooperation.

We thank all authors for their contributions and editors for their assistance with this thematic issue. These articles convincingly demonstrate the essential, central role of chemistry in the development of smart materials. It is our hope that the forward-looking opinions of these authors will stimulate new ideas and directions for future research in this exciting field.

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### Notes

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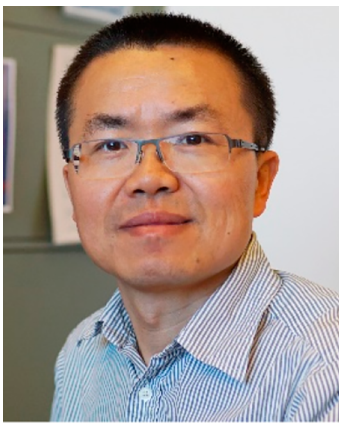
### Biographies



Yadong Yin is a Professor of Chemistry at the University of California, Riverside, with an affiliate appointment in Materials Science and Engineering. He received his B.S. and M.S. in Chemistry from the University of Science and Technology of China in 1996 and 1998, respectively, and then his Ph.D. in Materials Science and Engineering from the University of Washington in 2002. In 2003, he worked as a postdoctoral fellow at the University of California, Berkeley, and later the Lawrence Berkeley National Laboratory, and then became a staff scientist at the LBNL in 2005. He joined the faculty at the University of California, Riverside, in 2006. He is a recipient of several awards, including the Cottrell Scholar Award (2009), DuPont Young Professor Grant (2010), 3M Nontenured Faculty Grant (2010), NSF CAREER award (2010), NML Researcher Award (2016), and MRS Fellow (2020). His research interests include synthesis, self-assembly, colloidal and interfacial properties, and applications of nanostructured materials.

John A. Rogers is the Louis Simpson and Kimberly Querrey Professor of Materials Science and Engineering, Biomedical Engineering and Medicine at Northwestern University, with affiliate appointments in Mechanical Engineering, Electrical and Computer Engineering and Chemistry, where he is also Director of the recently endowed Querrey Simpson Institute for Bioelectronics. He has published more than 800 papers, is a coinventor on more than 100 patents, and has cofounded several successful technology companies. His research has been recognized by many awards, including a MacArthur Fellowship (2009), the Lemelson-MIT Prize (2011), the Smithsonian Award for American Ingenuity in the Physical Sciences (2013), the Benjamin Franklin Medal from the Franklin Institute (2019), and a Guggenheim Fellowship (2021). He is a member of the National Academy of Engineering, the National Academy of Sciences, and the National Academy of Medicine.



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