

Materials Science

Special Topic: Intelligent Materials and Devices

Intelligent materials and devices: Shaping adaptive technologies for sustainable and intelligent futuresPan Li¹, Xianhu Liu², Xiang Lu³, Shifeng Zhou⁴ & Guangming Tao^{1,5,*}¹Center for Intelligent Health Interdisciplinary Science, Central China Normal University, Wuhan 430079, China;²State Key Laboratory of Structural Analysis, Optimization and CAE Software for Industrial Equipment, National Engineering Research Center for Advanced Polymer Processing Technology, Zhengzhou University, Zhengzhou 450001, China;³Key Laboratory of Material Chemistry for Energy Conversion and Storage, Ministry of Education, School of Chemistry and Chemical Engineering, Huazhong University of Science and Technology, Wuhan 430074, China;⁴State Key Laboratory of Luminescent Materials and Devices, School of Materials Science and Engineering, South China University of Technology, Guangzhou 510641, China;⁵Research Center for Intelligent Fiber Devices and Equipment, Wuhan National Laboratory for Optoelectronics, School of Materials Science and Engineering, School of Physical Education, Huazhong University of Science and Technology, Wuhan 430074, China*Corresponding author (email: tao@ccnu.edu.cn)

Received 30 December 2025; Accepted 1 January 2026; Published online 4 January 2026

The dawn of the intelligent era has driven a paradigm shift in materials science, where intelligence, defined by adaptive responsiveness, artificial intelligence (AI) integration, and multifunctional synergy, has become the core benchmark for advanced functional systems. Unlike traditional materials, intelligent materials and devices have the inherent ability to perceive external stimuli (e.g., light, heat, force, electricity, and magnetism), initiate dynamic responses, and even self-optimize their performance. This enables transformative breakthroughs in wearable electronics, intelligent monitoring systems, and personal health management. Ranging from AI-enhanced fibers that can interact with the human body to reconfigurable optical metasurfaces and adaptive thermal management devices, this field is redefining the interaction among materials, devices, and the environment.

Intelligent materials serve as the fundamental building blocks of next-generation smart systems, and device integration significantly enhances their functional potential. The combination of material innovation and intelligent design has overcome the limitations of single-functionality and passivity. To present the recent advancements, challenges, and applications in this rapidly evolving field, we have organized a special topic on “Intelligent Materials and Devices” in *National Science Open*. This collection includes one commentary, three perspectives, three reviews, and five research articles, covering frontier directions such as adaptive thermal regulation, reconfigurable optics, AI-enabled fiber design, multispectral intelligent camouflage, cross-domain intelligent monitoring, high precision sensing, and smart energy storage.

Intelligent thermal regulation and energy storage materials

Thermal management and energy storage are foundational to intelligent systems, demanding adaptive performance and synergistic functionality. Tao *et al.* [1] emphasized the crucial role of standardization in the radiative cooling technology deployment, identified the pitfalls of non-standard measurements, and advocated for a balance between performance standardization and practicality to advance the industrialization of the passive cooling technology. Zhou *et al.* [2] presented a perspective on stimuli-responsive dynamic radiative thermal management materials, highlighting their intelligent passive temperature regulation capabilities and significant potential to reduce building energy consumption for carbon neutrality. Cao *et al.* [3] systematically reviewed the underlying mechanisms and multi-band regulatory principles of dynamic radiation thermal management in terms of visible, near-infrared, and mid-infrared spectrum modulation. They highlighted its transformative potential in enhancing energy efficiency and adaptive thermal comfort and in advancing sustainable building and smart window applications. In smart energy storage, Zhang *et al.* [4] comprehensively reviewed the design principles, mechanistic insights, material challenges, and multi-functional integration strategies of fiber-shaped aqueous batteries, and provided references for the industrialization of fiber-shaped aqueous batteries and the development of next-generation flexible energy storage technologies. Lu *et al.* [5] fabricated polypyrrole-modified PVDF-HFP coaxial composite membranes via electrospinning, integrating intelligent phase change energy storage, joule heating, photothermal conversion, and electromagnetic interference, shielding a paradigm of multifunctional intelligent materials for wearable thermal management.

Reconfigurable optical materials and intelligent structure

Intelligent optics and structural design are advancing toward on demand modulation and miniaturized integration. Ma *et al.* [6] clarified the definition of nonlocal metasurfaces by contrasting them with local counterparts from real and momentum space perspectives, elaborating on core mechanisms such as collective resonances and near-field coupling, and highlighting their pivotal role in developing next-generation multifunctional intelligent flat optical systems. Yang *et al.* [7] proposed a simplified multi-scale design strategy for a ZnS/GST/Cr metadvice, achieving intelligent independent control over visible structural color, near-infrared broadband absorption, and adaptive mid-infrared emissivity, enabling effective multispectral camouflage across visible, infrared, and LiDAR spectra, and paving the way for high-performance intelligent stealth and dynamic display technologies. Wen *et al.* [8] developed a nonlinear terahertz metasurface that integrates intelligent generation and optical modulation of second and third harmonics with ultrafast switching speeds, dynamically manipulating carrier density and mobility to tune harmonic outputs, offering new opportunities for reconfigurable terahertz sources and adaptive nonlinear photonic devices. Xu *et al.* [9] reviewed the advancements of hollow-core anti-resonant fibers in intelligent gas sensing, emphasizing structural innovations and integration with photothermal, photoacoustic, and Raman spectroscopic techniques to achieve highly sensitive, miniaturized, and intelligent detection systems for environmental monitoring and industrial safety.

AI-driven intelligent sensors and integrated systems

Intelligent sensing and cross-domain integration are hallmarks of next-generation smart devices, requiring synergy between material properties and AI algorithms. Tian *et al.* [10] developed a high-accuracy Braille recognizing sensing device that integrates a tailored micro-dome piezoresistive sensor and a one-dimensional convolutional neural network, achieving a recognition accuracy of 98.96% for 26 English letters. This bio-inspired, sliding-mode tactile system offers a portable and efficient solution for autonomous Braille learning. Zheng *et al.* [11] proposed a real-time cross-domain intelligent monitoring scheme for multi-UAV-multi-USV systems, utilizing pairwise matching, efficient block sparse Bayesian learning, and an unscented Kalman filter for trajectory estimation, eliminating USV motion data dependency with low complexity, validated by simulations and lake experiments. Shao *et al.* [12] envisioned the prospective integration of AI across multiscale data acquisition, descriptor identification, and active learning frameworks for intelligent fiber design, highlighting its pivotal role in advancing multifunctional, adaptive, and customizable fiber-based systems. This AI-driven paradigm promises to accelerate the development of next-generation wearable interfaces for human environment interaction.

This special topic showcases the recent research progress in intelligent materials and devices, focusing on their fundamental characteristics of adaptability, responsiveness, and integration. While it cannot cover all emerging directions in this rapidly expanding field, we believe the collected works will provide valuable references for researchers, promote academic exchanges, and drive innovation in intelligent materials and devices. Finally, we express sincere gratitude to all authors for their high-quality contributions, reviewers for their rigorous evaluations, and the editorial team for their meticulous support. We look forward to continuous breakthroughs in intelligent materials and devices that power global technological innovation and sustainable development.

References

- 1 Lu S, Tao G, Lu Y. Standardization as the catalyst for radiative cooling technology deployment. *Natl Sci Open* 2026; **5**: 20250079.
- 2 Zhang J, Han H, Xie W, *et al.* Dynamic radiative thermal management materials for sustainable development and carbon neutrality. *Natl Sci Open* 2025; **4**: 20250045.
- 3 Jiao Y, Li Z, Huang A, *et al.* Dynamic Radiation Thermal Management: Mechanism, Multiband, Multimode, and Application. *Natl Sci Open* 2026; **5**: 20250052.
- 4 Han L, Ling Y, Liu F, *et al.* Fiber-shaped aqueous battery: Design, advancements, and perspectives. *Natl Sci Open* 2025; **4**: 20250051.
- 5 Wei R, Quan B, Han M, *et al.* Polypyrrole-modified PVDF-HFP coaxial electrospun composite membranes for intelligent thermal management and electromagnetic interference shielding. *Natl Sci Open* 2026; **5**: 20250063.
- 6 Tang S, Ma Y. Nonlocal metasurfaces for next-generation flat optics. *Natl Sci Open* 2025; **4**: 20250038.
- 7 Jiang X, Nong J, Yuan W, *et al.* Multi-scale regulation of structure and material for visible-infrared-LiDAR multispectral camouflage. *Natl Sci Open* 2025; **4**: 20250046.
- 8 Ye Z, Wen Y, Wang C, *et al.* Ultrafast control of terahertz harmonic generation by optically modulating carrier dynamics in nonlinear metasurfaces. *Natl Sci Open* 2026; **5**: 20250065.
- 9 Cheng J, Wang H, Zhang L, *et al.* Advancements in hollow-core anti-resonant fiber for gas sensing applications. *Natl Sci Open* 2025; **4**: 20250049.

- 10 Wang L, Zhang Z, An X, *et al.* A high-accuracy Braille recognizing sensing device bio-inspired by human touch sensation based on microstructure-based sensor and machine learning method. *Natl Sci Open* 2026; **5**: 20250078.
- 11 Zheng Y, Zhang HT, Huang J, *et al.* Real-time cross-domain monitoring of multi-UAV-multi-USV systems via efficient block sparse bayesian learning. *Natl Sci Open* 2026; **5**: 20250048.
- 12 Min S, Yue J, Ji J, *et al.* Artificial intelligence reforges intelligent fibers. *Natl Sci Open* 2025; **4**: 20250061.