

Atomic-scale Manufacturing for Chemical Sensing

Bowei Zhang

Shanghai Key Laboratory of Intelligent Sensing and Detection Technology
East China University of Science and Technology, Shanghai, China

Abstract— Advanced manufacturing technologies are rapidly driving chemical sensing materials toward the atomic scale, enabling unprecedented control over sensing performance and underlying mechanisms [1]. Among these advances, single-atom catalysts (SACs), fabricated via atomic-scale manufacturing (ASM) strategies, have emerged as a highly promising class of sensing materials due to their well-defined active sites, maximized atomic utilization, and unique physicochemical properties [2]. The stability of isolated atomic sites and their coordination environments plays a critical role in determining sensing sensitivity, selectivity, and response dynamics.

This presentation systematically introduces atomic-scale chemical sensing, covering aspects from the fundamental concept of atomic-scale manufacturing to the elucidation of manufacturing and sensing mechanisms, as well as from fabrication strategies to practical sensing applications. We explore the fundamental mechanisms governing the formation of atomic-scale sensing materials and their sensing behaviors, with particular emphasis on the synergistic effects between electronic structure modulation and surface interactions at the atomic level. Key manufacturing techniques, including atomic layer deposition, atomic force microscopy, and spatial confinement strategies, are summarized, as they enable precise control over the dispersion of single atoms and the construction of local chemical environments.

Furthermore, representative advances in ASM-enabled sensing materials are highlighted, demonstrating their excellent performance in gas detection [3], environmental monitoring [4], and biomedical diagnostics [5, 6]. Despite the significant progress achieved, challenges remain in realizing scalable synthesis, long-term stability, and real-time applicability of single-atom sensing systems. Finally, future research directions are proposed, emphasizing that the development of synergistically controlled fabrication strategies, guided by structure-property relationships and mechanistic understanding, is essential for addressing the critical issue of performance consistency in sensor arrays. Meanwhile, advancing array-based and scalable manufacturing processes and accelerating the deployment of sensors in industrial scenarios will be key to promoting the rapid development of next-generation chemical sensors.

REFERENCES

1. Xuan, F. and B. Zhang, “Atomic-scale manufacturing for chemical sensing,” *Int. J. Extrem. Manuf.*, Vol. 8, 032003, 2026.
2. Xuan, F. and B. Zhang, “Progress and perspectives of single-atom catalysts for gas sensing,” *Adv. Mater.*, Vol. 35, 2206783, 2023.
3. Xuan, F. and B. Zhang, “An atomically dispersed Pd sub-metallene: Intermediate state of single atoms and metal bonds,” *Adv. Mater.*, Vol. 37, 2504603, 2025.
4. Xuan, F. and B. Zhang, “Nanofluidic sensing inspired by the anomalous water dynamics in electrical angstrom-scale channels,” *Nat. Commun.*, Vol. 15, 7329, 2024.
5. Xuan, F. and B. Zhang, “High-density dual-structure single-atom Pt electrocatalyst for efficient hydrogen evolution and multimodal sensing,” *Nano Lett.*, Vol. 24, No. 31, 9666–9674, 2024.
6. Xuan, F. and B. Zhang, “Single-atom Ni-N₄ for enhanced electrochemical sensing,” *Nano Res.*, Vol. 17, No. 8, 7658–7664, 2024.