

Rational Design of Sensing Materials for Optimizing Highly Accurate Artificial Olfactory Systems

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Abstract

The development of highly accurate artificial olfactory systems is becoming increasingly important for a wide range of applications, including explosive detection, environmental monitoring, disease diagnosis, food quality assessment, and AI-enabled robotics. Unlike conventional single-sensor approaches, reliable artificial olfaction requires the simultaneous discrimination of complex mixtures containing numerous volatile organic compounds (VOCs). Therefore, the realization of an advanced artificial olfactory system requires a multidisciplinary approach integrating functional sensing materials, selective molecular interfaces, scalable sensor-array fabrication, signal transduction, and data-driven analysis. In this presentation, I will introduce our recent strategies for developing high-performance sensing materials and massively integrated sensor arrays toward highly accurate artificial olfactory systems. First, to improve sensing sensitivity, reproducibility, and long-term stability, we have developed an ex-solution-based catalyst functionalization strategy, which enables the uniform formation of catalytically active nanoparticles on the surfaces of sensing materials. The strongly anchored nanoparticles provide enhanced surface reactions with target gas molecules while maintaining excellent structural and thermal stability. Second, we have developed a molecular-sieving-assisted sensing platform in which porous membranes with controlled pore structures and surface chemistry are integrated with sensing materials. Selective transport of gas molecules through these molecular sieving layers suppresses interference from unwanted species and provides an additional molecular-recognition mechanism, thereby significantly enhancing sensor selectivity and discrimination accuracy. Beyond individual sensor performance, we are particularly interested in developing scalable massive sensor-array architectures consisting of hundreds to thousands of sensing elements. By systematically varying sensing materials, catalytic nanoparticles, molecular sieving layers, operating conditions, and transduction mechanisms, a large number of partially selective sensing channels can be generated from a limited number of base materials. Such high-dimensional sensing arrays provide rich chemical fingerprints that are difficult to obtain using conventional electronic-nose platforms and can be further analyzed through machine-learning algorithms for accurate identification and quantification of complex odors. The combination of functional sensing materials, molecular sieving interfaces, massive sensor arrays, optical signal encoding, and AI-based pattern recognition may provide a new pathway toward next-generation artificial olfactory systems capable of analyzing complex chemical environments with high sensitivity, selectivity, and accuracy.