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Editorial

Editorial: Gas sensor



With the rapid development of sensor networks in the Internet of Things (IoT) and the Industrial Internet of Things (IIoT), gas sensors that can convert information of gas compositions and concentrations into electrical signals or other signals have become an indispensable sensing technology. The emergence of gas sensors has made gas detection and analysis technology easier, faster and smarter. In recent years, numerous scientists and engineers have continuously developed new gas sensitive materials, device equipment and detection technologies, which made gas sensors play an increasingly important role in environmental monitoring, gas warning, hazardous chemicals detection, food quality monitoring, medical and health fields. This special issue presents novel results in gas sensors, including metal oxide hybrid materials for gas sensing, structural design of metal oxide gas-sensitive materials, non-metal oxide gas-sensitive materials, device fabrication processes, and non-resistive gas sensor technology.

Metal oxide semiconductors-based gas sensors are the most widely used gas sensors owing to their excellent gas sensing performance, wide sources and low cost. Compounding with other materials with different band gap is an effective way to improve the gas sensing performance of metal oxide semiconductors. Noble metal nanoparticles can be used as chemical sensitizers and electronic sensitizers to improve the gas sensitivity of metal oxides. Wang *et al.* demonstrated a microwave-assisted hydrothermal method to prepare Pt/SnO<sub>2</sub> for CO sensing [1]. Luo *et al.* reported Pd modified ZnO porous nanosheets with enhanced CO sensing properties [2]. Li *et al.* realized synthesis and *in-situ* noble metal modification of WO<sub>3</sub>·0.33H<sub>2</sub>O nanorods from a tungsten-containing mineral, which shows enhanced NH<sub>3</sub> sensing performance [3]. Zhao *et al.* developed a Pd/SnO<sub>2</sub> material for ethylene sensing, which exhibits great potential in fruit quality detection [4]. Alloy noble metals show more abundant properties with single component noble metals. Deng *et al.* used ultra-low content bimetallic PtCu to modify WO<sub>3</sub>·H<sub>2</sub>O hollow sphere for highly sensitive acetone gas sensor [5]. Constructing heterojunctions like p-n, n-n or p-p heterojunctions can effectively control the thickness of the depletion layer and the carrier concentration, which in turn affects the gas sensing performance. Ding *et al.* designed and prepared ZnO-ZnS nano-heterojunction sensing material for a high-sensitivity H<sub>2</sub>S gas sensor [6]. Shang *et al.* constructed 3D laminated CuO/SnO<sub>2</sub> hybrid materials *via* a simple self-assembly method to detect triethylamine [7]. Zhang *et al.* demonstrated that porous Zn-CoO<sub>x</sub> materials exhibits alcohols sensing performance at relative low operating temperature [8]. With the deepening of

graphene research in recent decades, combining metal oxides with graphene has also been found to significantly improve gas sensing performance. Chen *et al.* prepared N-GQDs/SnO<sub>2</sub> nanocomposite for a formaldehyde gas sensor [9]. Tian *et al.* fabricated a NH<sub>3</sub> gas sensor based on reduced graphene oxide-porous In<sub>2</sub>O<sub>3</sub> nanocubes hybrid nanocomposites which can work at room temperature [10].

The optimization of the micro-nano structure can also improve the gas sensing performance of the metal oxides materials. The hierarchical structure is one of the ideal structures of gas-sensitive materials due to its large specific surface area and abundant channels. Zhang *et al.* reported an efficient formaldehyde gas sensor based on metal-organic frameworks-derived ZnO materials with hierarchical structures [11]. Yang *et al.* designed and synthesized hierarchical NiCo<sub>2</sub>O<sub>4</sub> microspheres assembled by nanorods with p-type response for a triethylamine sensitive sensor [12]. Zheng *et al.* synthesized hierarchical shell-core SnO<sub>2</sub> microspheres and applied them in gas sensors [13]. Zhang *et al.* prepared ZnSnO<sub>3</sub> microspheres through microwave-assisted strategy and used them for the detection of ethanol [14]. Two-dimensional (2D) structure has become one of the popular choices for gas-sensitive material structures recently due to its anisotropy and large specific surface area. Ahmed *et al.* explored ZnO hexagonal nanotables for amines sensing [15]. The exposure of the crystal plane is found to be related to the sensing performance of the material, and the researchers have also begun to focus on regulating gas-sensing performance through regulation of exposure surface. Tian *et al.* demonstrated that the most exposed surface of hexagonal WO<sub>3</sub> (001) surface is oxygen vacancy O-terminated surface [16].

Some new progress has also been made in the research of non-metal oxides gas sensitive materials. Sulfides such as two-dimensional MoS<sub>2</sub>, sulfide quantum dots, exhibit great potential for gas sensing. Yu *et al.* prepared two-dimensional molybdenum disulfide for NO<sub>2</sub> detection at room temperature [17]. Tan *et al.* synthesized PbS@MoS<sub>2</sub> composites for NO<sub>2</sub> detection *via* combining the mechanical exfoliation method with the facile wet-chemical precipitation [18]. Moreover, Liu *et al.* synthesized novel Cu<sub>12</sub>Sb<sub>4</sub>S<sub>13</sub> quantum dots@reduced graphene oxide nanosheet composites with high ammonia sensitive ability at room temperature [19]. Ji *et al.* designed RhIr@MoS<sub>2</sub> nanohybrids based disposable microsensor for the point-of-care testing of NADH in real human serum [20]. The gas-sensing properties of polymers are worth exploring because they are quite different from inorganic materials in conductivity, hydrophilicity/hydrophobicity and so on. Chen *et al.* reported tadpole-shaped, polyhedral oligomeric silsesquioxane containing sulfonated block copolymer with

humidity sensing properties [21]. Chen *et al.* designed and prepared superhydrophobic hierarchical porous divinylbenzene polymer for BTEX sensing and toluene/water selective detection [22]. In addition, some other materials have been studied for sensing-related applications. Jin *et al.* fabricated linalool-functionalized hollow mesoporous silica spheres nanoparticles for the application about bacterial [23]. Liu *et al.* demonstrated the design and sensing mechanism of novel calix[6]arene composite for sensitively detecting amine drugs [24].

In addition to sensitive materials, the manufacturing process of the gas sensor devices can affect its performance. Optimizing and developing new gas sensor devices is another way to develop high-performance sensors. Growing the material *in situ* on the ceramic tube can solve the problem of insensitive contact between the sensitive material and the substrate. Meng *et al.* realized *in-situ* growth of  $V_2O_5$  flower-like structures on ceramic tubes for detection of trimethylamine [25]. Flexible sensors are one of the development directions of wearable devices. Li *et al.* constructed a flexible and high-performance trimethylamine sensor *via* depositing  $In_2O_3$  nanofibers on polyimide substrates [26].

The development of new gas sensing technology can fill the deficiencies of resistive gas sensing technology, which promoted the rapid application of gas sensors. Peng *et al.* reported fiber-optical dual Fabry-Pérot interferometric carbon monoxide sensor with polyaniline/ $Co_3O_4$ /graphene oxide sensing membrane [27]. Zhu *et al.* prepared functional ordered mesoporous carbons and applied them as the QCM sensor with ultra-low humidity [28]. Tang *et al.* demonstrated a  $H_2S$  gas sensor based on integrated resonant dual-microcantilevers with high sensitivity and identification capability [29].

Developing gas sensors with high sensitivity, fast response and recovery, high stability and high selectivity remains a challenging field. This special issue introduces readers to some new results on sensitive materials, devices and detection technologies of gas sensors, and hopes to bring readers some new insights in relate areas.

Finally, we would like to extend our most sincere thanks to the authors, reviewers and the editorial team of *Chinese Chemical Letters* for this great special issue.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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