Influence of Sensing Material Characteristics on Gas Sensor Properties

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Sensor-based intelligent systems have entered into the daily-life and found an increased use in health and safety related application areas such as medical diagnostics, air-quality monitoring, food processing and detection of toxic/flammable and explosive gases, adjustment of energy efficiency. These and other applications in harsh industrial environments require the development of fast, sensitive, selective, reliable but also low-cost sensors. Industrial processes relied for many years on gas detection systems using infrared spectroscopy, gas chromatography/mass spectrometry (GC/MS), and chemiluminescent analysis are available with good detection limits and fast response times [1]. These instruments are bulky, expensive, need maintenance, incompatible with high-temperature environments, and require gas sampling systems. In the last two decades, there has been an increasing need for miniaturized, sensitive and selective gas sensors with high stability and detection limits, short response and recovery times in a wider temperature range for in-situ and ex-situ monitoring under fast and repeated gas flows. Semiconductor metal oxides are widely used in gas sensors due to their excellent sensing properties, abundance and ease of manufacture. Moreover, synthesis of these with nanometric crystallite sizes [2] and different morphologies (e.g. nanoparticles, nanotubes, nanobelts, nanowires) resulted in performance improvement of gas sensors leading to increased sensitivity and selectivity, decreased response time and temperature of operation as their long-term stability and reproducibility are preserved [3]. The best examples of these sensing materials are SnO_2 and TiO_2 that have wide bandgap and offer unique set of functional properties such as electrical conductivity and high surface reactivity to gaseous species [4, 5]. The synthesis method controls strongly the morphology/nano-structuring and dopant addition to vary crystallographic structure of metal oxide sensing material. Especially, nanostructures of SnO_2 and TiO_2, in particular 0D, 1D SnO2 [4] and hierarchical 3D structures of TiO_2 [5] have been successfully synthesized and their influences on gas sensing has been demonstrated in the literature. Moreover, surface modification and/or doping of SnO_2 and TiO_2 nanostructures/nanoparticles with redox capable elements and noble metals yield gas sensors with high selectivity for detection in mixed gas environments [6]. In this case, the improvement of sensing performance relies on the creation of new active centers on the metal oxide surface and/or changing electronic structure of the material [7,8].

Recently, two-dimensional structures, such as graphene, transition metal dichalcogenides, transition carbides and hybrid 2D compounds have attracted great interest for various gas sensing applications due to their large surface area, controlled surface chemistry and capability of sensing detection at room temperature [9,10]. Among big family of two-dimensional materials, MXenes and MXene-based structures gained particular attention for the gas sensor related applications owning large surface-to-volume ratio, superior surface conductivity and surface-terminated functionality among which also for gas sensing. The investigation of their sensing performance is quite deficient and their selectivity still remains an issue, requiring further research to enhance and optimize their gas sensor performance, for example, by surface functionalization, coating or fabrication of hybrid materials [11, 12].

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