Nanostructured Materials for Room-Temperature Gas Sensors

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Sensor technology has an important effect on many aspects in our society, and has gained much progress, propelled by the development of nanoscience and nanotechnology. Current research efforts are directed toward developing high-performance gas sensors with low operating temperature at low fabrication costs. A gas sensor working at room temperature is very appealing as it provides very low power consumption and does not require a heater for high-temperature operation, and hence simplifies the fabrication of sensor devices and reduces the operating cost. Nanostructured materials are at the core of the development of any room-temperature sensing platform. The most important advances with regard to fundamental research, sensing mechanisms, and application of nanostructured materials for room-temperature conductometric sensor devices are reviewed here. Particular emphasis is given to the relation between the nanostructure and sensor properties in an attempt to address structure–property correlations. Finally, some future research perspectives and new challenges that the field of room-temperature sensors will have to address are also discussed.

1. Introduction

Gas sensors play a vital role among the most important technologies in our daily life. Typical applications of gas sensors include the detection of toxic analytes and explosive gases for the purpose of public and domestic safety, industrial processes, and monitoring of environmental pollution and air quality. Among the various types of gas sensors,[1–3] resistive gas sensors are the most attractive due to the ease of fabrication, simple operation, low production cost and miniaturization. As gas sensors are inherently simple in concept, it is not surprising that significant advance within this area has been established based on the research and development activities. A typical resistive gas sensor contains an active sensing layer, the conductivity of which is highly sensitive to the surrounding environments. The first commercial gas-sensor device was developed in the 1960s using metal oxide as the sensing layer.[4] Since then, worldwide efforts have been explored in order to improve the sensor sensitivity, selectivity, speed (response and recovery rate), and stability, namely the "4s". The research and development in gas sensors have achieved significant progress driven by the emerging nanoscience and nanotechnology.

Nanostructured materials with small size and dimension and tailored structures have demonstrated great potential for use as the sensing layers. Advantages of using nanostructured materials for gas sensing stem from the large surface-to-volume ratio, high specific surface area, more surface active site, as well as the recently recognized effect of crystal facets with high surface reactivity.[5–10] The interaction between gas molecules and materials mainly takes place on the surface, hence the number of atoms residing at a material's surface is critical for controlling the sensor performance. Due to the large surface-to-volume ratio, nanostructured materials have a much larger portion of surface atoms than bulk atoms in comparison to non-nanostructured materials. Consequently, gas sensors based on nanostructured materials can exhibit better performances. The advantages of using nanomaterials for gas sensing have been discussed in some reviews.[3,11–14]

The sensor sensitivity (S, defined as R_a/R_g or R_g/R_a, where R_a and R_g are resistance in air and gas) can be highly dependent on the grain size (D) of metal oxide nanoparticles when the grain size is comparable to $2L$ (L is the thickness of electron depletion layer).[15] When D is far larger than 2L, only the grain boundary is subject to formation of electron depletion layer, meaning that the surface sensing effect does not affect the sensor resistance

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