Transparent Conducting Oxides: from materials to sensing application

G Kiriakidis\textsuperscript{1,2}, MSuchea\textsuperscript{1,3} and D Dovinos\textsuperscript{1}

1 Institute of Electronic Structure and Laser, Foundation for Research & Technology-Hellas, Heraklion, Crete, Greece
2 University of Crete, Physics Department, Heraklion, Crete, Greece
3 University of Crete, Chemistry Department, Heraklion, Crete, Greece

ABSTRACT

Metal oxides gas sensing properties particularly for In\textsubscript{2}O\textsubscript{3} and ZnO nanostructured thin films will be reviewed. In\textsubscript{2}O\textsubscript{3} and ZnO thin films prepared for ozone sensing may exhibit resistivity changes of five to eight orders of magnitude at room temperature after exposure to UV light and subsequent ozone treatment thus are candidates for low cost, low operation temperature gas sensor applications. The most commonly used techniques are based on conductometric systems. However, encouraging results are anticipated by current improvements and deployment of Surface Acoustic Wave sensors (SAWs). SAWs are becoming nowadays some of the most commonly used sensor types in sensor array systems based on Transparent Conducting Oxides (TCOs). Besides applications in the sensing field novel optoelectronic applications such as sub-micron relief gratings ablated on TCO thin films overlaid on K\textsuperscript{+} ion exchanged waveguide channels showing strong Bragg reflection. Recent efforts on the fabrication of efficient Transparent Thin Film Transistors (TTFTs) based on TCOs and the fabrication of nano-rod structures are demonstrating the growing importance of these simple oxides as a material with diverse interest making their study one very hot field of research.

KEY WORDS: nanostructured metal oxide, thin films, sensors

INTRODUCTION

The significance of the olfactory system becomes profound if we look into its evolution dynamics. The development found in olfaction, dwarfs all other sensory mechanisms available in nature [1, 2]. This development is in response to the diverse, and crucial for survival, information that can be gained through the analysis of gases. To this avail modern technology has attempted to reproduce to a limited extent the function of sensing chemicals in their gaseous form.

Modern efforts have been focused in serving industrial, automotive, health, food industry or domestic purposes. The need to monitor gases like CH\textsubscript{4}, CO\textsubscript{2}, NO\textsubscript{x}, O\textsubscript{2}, O\textsubscript{3}, SO\textsubscript{2} and others has imposed a pressing request upon scientists and technologists to produce cheap, reliable and portable sensors that in many cases must be used under harsh conditions.

In laboratory conditions it has been possible to monitor gases with a high degree of accuracy. The equipment used in this case, for example gas chromatographers, is complex, expensive and its use is not permitted outside the well-controlled laboratory environment. The solution to the above problem has been provided to some degree by solid state gas sensors. Of course these devices could not compete in accuracy and versatility with the dedicated laboratory equipment, but offer an attractive alternative for use in field applications. Metal oxides (MO\textsubscript{x}) encompass a very large range of materials with varied electrical properties. In their majority they are solids of ionic nature, which may be metallic, semiconducting or insulating. They can be easily integrated into portable rugged devices since the principle of their operation is based on the change of their conductivity while exposed to different gases. The mechanisms, which allow gas sensing in these oxides are strongly related to the physics that govern electrical conduction.

The band gap of most semiconductors used for electronic circuits is usually of the order of 1eV. At room temperature the conductivity of such material is fairly low and thus its use is rather limited. Other atoms are therefore introduced in the semiconductor lattice, which can either increase the electron population as donors or decrease it as acceptors. This doping process is what actually enables us to make use of the interesting properties of semiconductors and transform them into useful devices.

In the case of many semiconducting metal oxides the band gap is larger than 1eV, which suggests that the population of free carriers at room temperature is insignificant. Effectively materials of band gap of the order of 3eV should behave as insulators. These ties well with the optical properties of InO\textsubscript{x}, ZnO and SnO\textsubscript{2} which have a wide band gap and are transparent at optical frequencies. In contrast to the above, these materials exhibit significant conductance, which contradicts with a low population of free carriers. The explanation to this subject matter into logical parts and emphasize major elements and considerations. Paradox lies in the doping mechanisms, which may not only be facilitated by the introduction of foreign species but may also originate from irregularities in the lattice.

Of all the MO\textsubscript{x} studied so far InO\textsubscript{x} and ZnO\textsubscript{x} are regarded as the most interesting semiconducting materials due to their wide range of properties and consequently applications they may be used in. They behave as insulators in their stoichiometric form and as highly conducting semiconductors with a wide direct optical band-gap (3-4 eV) in their non-stoichiometric form, providing high transparency in...