Influence of Gas Adsorption on Photoluminescence in Metal Oxide Nanopowders

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Introduction

Creating miniature gas sensors with high speed and selectivity, low power and price, that can detects the active, in particular, toxic and explosive gases is very important problem especially for highly industrialized regions. Sensors based on metal oxide nanomaterials are currently the most promising to solve this issue due to their reliability, and ease of manufacture and application. The metal oxide nanopowders have a high adsorption ability and reactivity and excellent sensing properties due to their high surface to volume ratio. It means a small change in thickness of the surface dead layer strongly influences the photoluminescence signal and electron distribution in materials. Desorption or adsorption of oxygen ions from the surface of metal oxide nanopowders causes a change in band bending, which results in a reduced dead layer and induces a change in the electron distribution in the nanomaterial. The doped zinc oxides with high gas sensitivity and excellent luminescence properties has been of great of interest. The use of doped oxides can lead to find materials that show improved sensitivity, enhanced adsorption ability, extensive catalytic activity.

Methods

Ga_2O_3 nanopowders were obtained using pulsed laser reactive technology by means of a YAG:Nd^{3+} laser. The doping of the samples was carried out by the pulsed laser deposition method of a thin film (*In, Al*) on the nanopowder surfaces. Laser annealing of the nanopowder was performed to activate the impurity and to diffuse it uniformly in the nanoparticle volume. The XRD and SEM methods were used for structural and morphological characterization of obtained materials. Studies of the excitation and photoluminescent spectra were performed using an Edinburg FS5 spectrofluorometer at room temperature. The source of excitation was a xenon lamp with a power of 150 watts. Diffuse reflection spectra were studied on a Shimadzu UV-3600i Plus spectrophotometer. The test samples were placed in a quartz cell connected to a VUP-5M vacuum unit and a multichannel SNA-2 gas inlet system.

Results

X-ray diffractometry (Fig.1), scanning and transmission electron microscopy investigation were conducted to determine the structure, shape, and size of the nanoparticles. In the Figure 2 the room temperature luminescence spectra of doped Ga_2O_3 nanopowders under excitation at 350 nm are presented. The luminescence properties observed in our study exhibit distinctive features specific to this material. In particularly, luminescence of Ga_2O_3, notably including a broad radiation band ranging from 400 to 550 nm. The origin of this broad luminescent band, containing multiple elementary bands, can be explained by the existence of various electron-hole recombination pathways. The blue-green band arises from the recombination of electrons with holes localized within gallium acceptor vacancies. The nature of visible photoluminescence is determined by the intrinsic defects structure of nanomaterial, which is dependent on the technological parameters employed during nanopowder synthesis. Changing the surrounding environment induces a pronounced variation in the intensity and deformation of the photoluminescence spectra. This phenomenon can be attributed to redistribution of existing luminescence centers and the emergence of new luminescence adsorption centers on the surface of the nanopowders. The CIE1931 chromaticity diagrams of the photoluminescence light emitted by the nanopowders were obtained (Fig.3). It was found that the color coordinates vary depending on the gas environment. Consequently, the investigated nanopowders hold promising potential as highly responsive materials for the development of gas sensor systems [2].

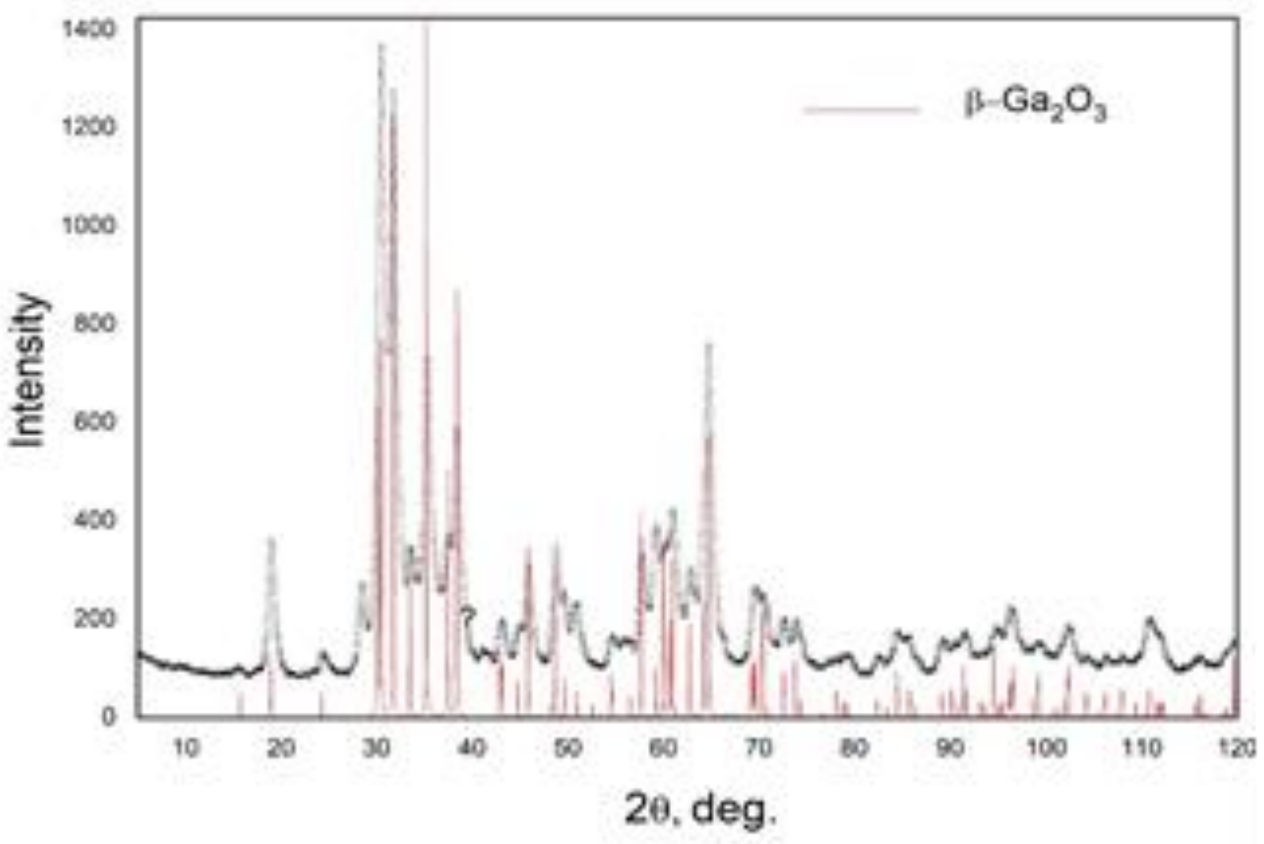

Fig.1. Diffraction pattern for Ga_2O_3 nanopowder

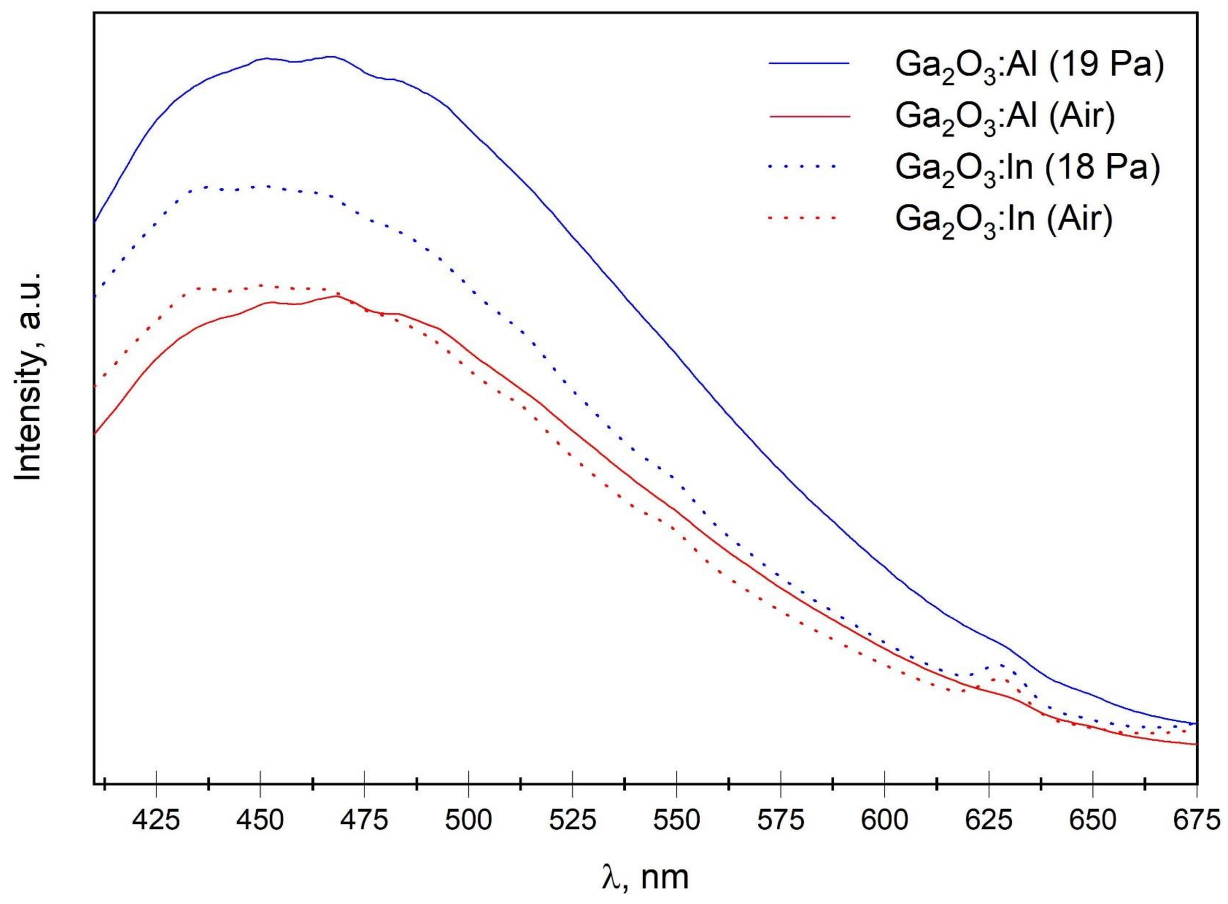

Fig.2. Photoluminescent spectra in different ambient of Ga_2O_3 nanopowders doped by Al and In

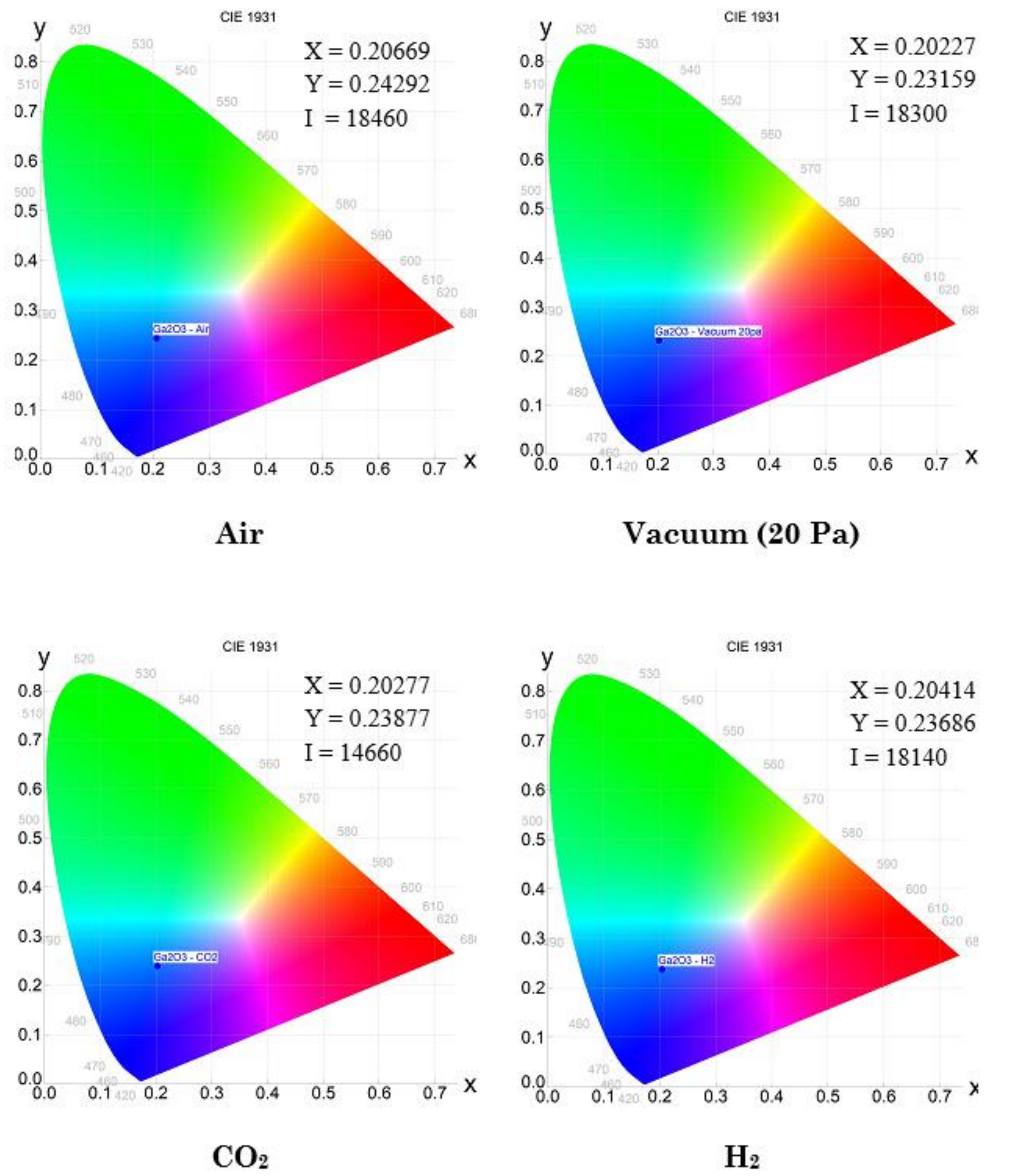

Fig.3. CIE1931 chromaticity coordinates of undoped Ga_2O_3 in different gas ambient

Conclusion

The investigation focused on studying the characteristics of structural, morphological, and photoluminescent properties of metal oxide nanopowder obtained using pulsed laser reactive technology. The variation in the gas environment significantly influences the intensity and deformation of the spectra for the metal oxides, making them promising for gas sensing applications. These alterations can be linked to the redistribution of existing luminescence centers and the appearance of new luminescence adsorption centers on the surface of the nanopowder.

1.Gafiychuk V.V., Ostafiychuk B.K., Popovych D.I., Popovych I.D., Serednytski A.S. ZnO nanoparticles produced by reactive laser ablation // Applied Surface Science. -2011. -257, N 20. -P. 8396–8401.
2.Zhyrovetsky V.M., Popovych D.I., Savka S.S., Serednytski A.S. Nanopowder Metal Oxide for Photoluminescent Gas Sensing // Nanoscale Research Letters. -2017. –12. -P.132(5).