Laser Induced Nanostructures on ZnO Thin Films for Morphology-controlled Gas Detection

U. Palomares, M. Martinez-Calderón, I. Castro-Hurtado, M. Gomez-Aranzadi, A. Rodríguez, S.M. Olaizola, E. Castaño, G. Gª Mandayo

CEIT and Tecnun (University of Navarra), Paseo Manuel Lardizabal 15 20018, Donostia, Spain
upalomares@ceit.es

Abstract

In the last years the social conscience towards climate change and greenhouse effect, as well as the restrictive laws against gas emissions, have increased. These facts lead into a need for the air quality monitoring on a real-time basis. Nowadays, several specialized measurement systems can be found in the market. However, these are usually too bulky, expensive and not valid for all environments [1].

In this context, new micro/nanotechnologies are required in order to create improved devices. They should be capable of overtaking the actual barriers while they work with a minimum energy consumption. Taking into account the actual scenario, chemical sensors based on metal oxide semiconductors represent a promising solution. Indeed, ZnO, SnO_2, In_2O_3 or TiO_2 are well known for their cost-effectiveness, fast response and high sensitivity when exposed to target gases [2,3].

On a general basis, chemical gas sensors are based on the electric response variation caused by the target gas-sensitive material surface chemical reaction. Particularly, conductometric gas sensors suffer a change in their resistance, which is proportional to the detected gas amount [4].

On the other hand, the detection capacity is determined by the reaction temperature as well as the morphology of the semiconductor. Given the fact that this last parameter is highly dependent on the fabrication process, nanostructuring of the sensing material surface is an approach that can be applied to maximize the surface area and increase the sensorial properties of the device.

In the present study zinc oxide is selected as sensing material. Thin films are deposited onto alumina substrates by RF reactive magnetron sputtering with a metal oxide target of 99.999% purity. The sputtering is performed under Argon gas with a pressure of $5\cdot10^{-3}$ mbar and the RF power is maintained at 100 W. The thickness measured with a KLA Tencor Profilometer for a deposition time of 1h is 150nm [5].

On a second step, zinc oxide thin films are processed by laser interference lithography (LIL) with the aim of obtaining a morphology change of the sensing material. The employed system uses a tripled Q-switched Nd:YAG laser source with an output wavelength of 355 nm [6]. The pulse duration is 8 ns and the maximum frequency can be 10 Hz. In addition, the initial laser beam is divided into two by a beamsplitter and then recombined in order to create an interference pattern on the zinc oxide-alumina wafer surface. This interference pattern consists of a series of lines corresponding to the intensity maxima and minima.

The influence of several parameters on the surface patterning by LIL and therefore on the resulting sensing layer surface area has been studied. First of all, the fluences and number of pulses used for the patterning were varied in a range from 85 to 145 mJ/cm^2 and up to 4 pulses, respectively. This allows to determine the energy threshold of the material, which is also affected by the number of accumulation laser pulses [7]. Furthermore, two different periods (300 and 500 nm) were selected and compared to the obtained ones on the nanostructured surface, so that the influence of material´s thermal diffusivity could be derived. All experiments were carried out at atmospheric pressure in a class 100 clean-room [8].

Figure 1 shows the morphological progression of ZnO thin films caused by single pulsed laser interference lithography with fluences between 0 and 145 mJ/cm^2 and a period of 300 nm. The resultant irradiation lines are translated into a localized porosity change, which can be tuned by the parameters mentioned above, in order to find the optimized surface area. As shown in the micrograph, a periodic structure composed of lines with different grain sizes is obtained. The lines which correspond to minimum intensity, i.e. non-processed area, are formed by grains in the range of 30 nm. On the other hand, the region of maximum intensity is melted and shows a planar surface. Moreover, for a fixed period, melted lines´ width increases with the fluence of the incident radiation.