Zinc oxide and gallium doped zinc oxide nanowires for optoelectronics

C. García Núñez, J.L. Pau, E. Ruíz, B.J. García, J. Piqueras

Laboratorio de Microelectrónica & grupo ELySE - Universidad Autónoma de Madrid,
Calle Francisco Tomás y Valiente 7, 28049 Madrid, Spain
carlos.garcia@uam.es

Abstract

Zinc oxide (ZnO) nanostructures are become an important matter of study since they can be used in nanoscale optoelectronics for applications such as memory storage, logic circuits, solid-state gas-, bio- or light-sensors, solar cells, field effect transistors, field effect displays, and short wavelength light emitting diodes. ZnO is a semiconductor with a direct and wide band-gap around 3.4 eV, and therefore is suitable to sense UV light. The electronic properties of one-dimensional (1-D) ZnO structures have been studied in detail [1-4]. In comparison with the current technologies, those structures could improve the sensitivity of devices such as optical switches or gas sensors. Moreover, a few works reported in the literature showed that ZnO NWs are highly insulating with high resistivity values in dark [4]. Therefore, the assembly of ZnO NWs in optoelectronic and electronic devices and the optimization of their electrical properties are crucial challenges to foster technology progress.

In this work, large quantities of ZnO NWs were synthesized by a simple technique based on thermal chemical deposition or vapor phase transport [5,6], in which, Zn powder and O gas were used as source materials (without a metalized catalyst). An amount of 1 g of Zn powder was transferred to a ceramic crucible placed in the middle of a quartz tube furnace and the substrate was located at the end of that tube (Fig. 1). After that, the tube was heated up to 700 ºC with an Ar flow rate of 100 sccm to prevent Zn oxidation. Then, oxygen valve is opened to provide an Ar/O_2 gas flow of 100/100 sccm through the tube during 3 hours. The morphology of the resultant ZnO NWs were analyzed by scanning electron microscopy showing diameters between 50 and 200 nm as shown in Fig. 2.

Transport properties were analyzed by dispersing ZnO NW on 100-nm thick gold contacts. These contacts were patterned by optical lithography on glass and on Si(100) with a 300-nm thick thermally grown SiO_2 layer. To improve the adherence of the Au layer, a 50-nm thick Al-doped ZnO layer was previously deposited on both substrates. The separation between electrodes ranged from 2 to 16 µm (Fig. 3). A 0.06 M ZnO/acetone solution was prepared and heated up to 40 ºC during 3 min. Solution was then dipped in an ultrasonic bath during 3 min. Heating and ultrasonic bath were repeated three times to improve solution homogeneity. A few drops were put on the patterned sample at 40 ºC to provoke acetone evaporation. The full process resulted in a sample surface covered by homogeneously distributed NWs. The conductance of individual ZnO NWs placed between a pair of electrodes was analyzed in dark and with UV illumination at room temperature. The increase and decrease rates of the conductance with and without UV illumination, respectively, were studied for comparison. In addition, optical properties of ZnO NWs were studied by photoluminescence at room temperature.

This work also aims to improve the electrical and optical properties of ZnO NWs by using Ga as a dopant. For that reason, ZnO:Ga NWs were also synthesized using the same method. Zn powder was previously mixed with liquid Ga prior to be transferred to the ceramic crucible. Then, the tube was heated up to 420 ºC in Ar ambient (around the Zn melting point) and this temperature was maintained during 15 min. After reaching 420 ºC, the temperature was increased up to 700 ºC and was held in Ar/O_2 ambient (100/100 sccm) for 3 hours. The incorporation of Ga atoms into the ZnO sub-lattice as an n-type dopant increased the sensibility of the NW surface to the gas exposure and the light illumination.

References

[1] Q.H. Li, Q. Wan, Y.X. Liang, T.H. Wang, Appl. Phys. Lett., **84** (2004) 4556.
[2] C.H. Liu, W.C. Yiu, F.C.K. Au, J.X. Ding, C.S. Lee, S.T. Lee, Appl. Phys. Lett., **83** (2003) 3168.
[3] W.I. Park, G.C. Yi, J.W. Kim, S.M. Park, Appl. Phys. Lett., **82** (2003) 4358.
[4] H. Kind, H. Yan, B. Messer, M. Law, P. Yang, Adv. Mater., **14** (2002) 158.
[5] D. Yu, T. Trad, J.T. McLeskey Jr., V. Craciun, C.R. Taylor, Nanoscale Res. Lett., **5** (2010) 1333.
[6] Z. Zhou, C. Zhan, Y. Wang, Y. Su, Z. Yang, Y. Zhang, Mater. Lett., **65** (2011) 832.

Figures

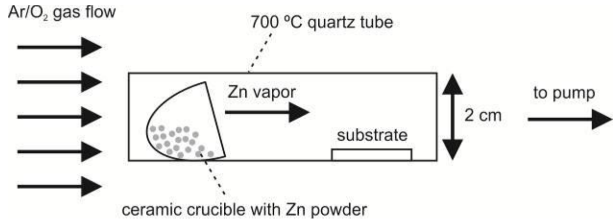

Fig. 1. Diagram of the growth system. The low dimensions of the quartz tube confines Zn vapor to create a high Zn concentration ambient.

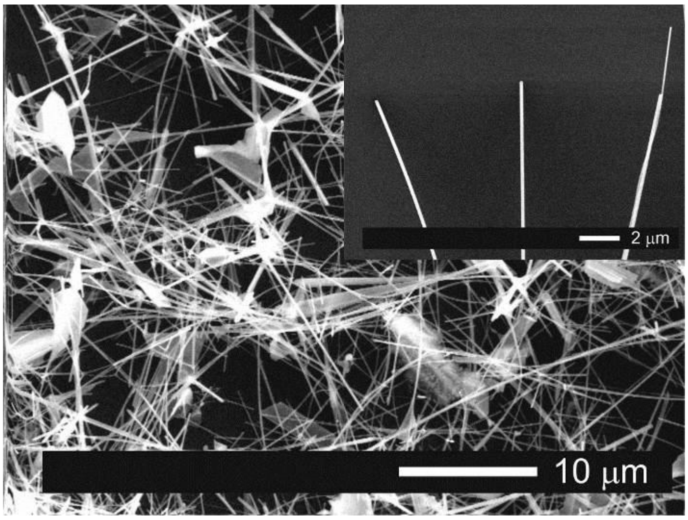

Fig. 2. SEM image of the prepared ZnO NWs.

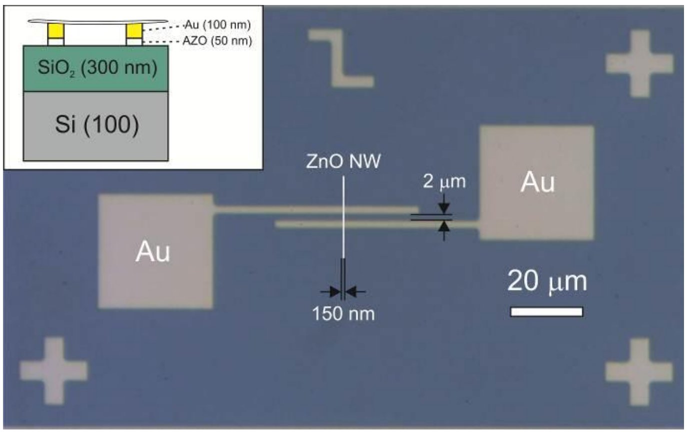

Fig. 3. Optical microscopy image of a ZnO NW places between a pair of Au electrodes. Inset: schematic of the multilayer structure axial view.