Photosensors based on ZnO and CuO nanowires

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Abstract

Nanotechnology tools and materials have introduced new possibilities for the design and fabrication of electron devices and integrated circuits (IC). The reproducibility of nanostructure synthesis and the ways in which those structures are integrated in the IC processing are still important challenges for the massive commercialization of nanoelectronic devices with superior performances. One of the most thoroughly studied nanostructures during the last decade has been the ZnO nanowire (NW). Light emitters and detectors have been reported despite the lack of a stable p-type dopant in ZnO. Electrical studies show that cupric oxide (CuO) NWs behave as p-type semiconductors due to the acceptor property of the Cu vacancies, thus enabling the fabrication of heterojunctions along with n-type materials and nanostructures. This characteristic feature allows, among other things, the design and implementation of nanotransistors or light nanoemitters.

In this work, we present some of the recent advances achieved at the Microelectronics Laboratory at UAM on the fabrication of electron devices based on ZnO and CuO NWs. Both materials are used as building blocks of photosensors and were electro-optically characterized.

ZnO NWs are synthesized by vapor phase transport (VPT) in a horizontal quartz tube furnace by using 0.5-g mass Zn powder (99.999% purity) as solid precursor in a 200-sccm O_2/Ar (1:1) total gas flow at 700 ºC during 30 min (Figure 1). ZnO resulting powder was analyzed by scanning electron microscopy (SEM) and images show a mesh of NWs emerges from bright faceted crystals, also called tetrapods (TPs) exhibiting a random distribution (Figure 2(a)). TPs legs have diameters and lengths between 90-150 nm and 2-20 μm, respectively. A 2-mM ZnO-TPs/ethanol solution was prepared and sonicated in an ultrasonic bath during 15 minutes in order to break TPs and to obtain a homogeneous suspension of ZnO NWs in ethanol. The large aspect ratios (> 100 nm) observed in many NWs are useful for processing and device integration by assembling processes such as dielectrophoresis (DEP).

The CuO NWs are grown by oxidation of Cu foils in a regular hot plate in ambient air. The hot plate is kept at a temperature of about 400 ºC for 1 h. Figure 2(b) shows tapered and vertically aligned CuO NWs with a higher diameter in the base (120-140 nm) than in the body (50-70 nm) and lengths around 10 μm. Energy-dispersive X-ray spectroscopy results show that CuO NW growth take place from a Cu_2O layer near the interface with the substrate (Cu foil). In addition, X-ray diffraction measurements confirm the composition of the NW as CuO.

DEP is a cost-effective method previously used to align NWs and nanoparticles between electrodes allowing electrical probing of these structures [1]. The technique has been used to fabricate single-NW based devices using electrodes pre-deposited by sputtering on SiO_2(200 nm)/Si substrates (Figure 3). The DEP is carried out using an AC signal with a peak voltages (V_{pp}) ranging from 7 to 21 V and frequencies (f) between 1 and 1000 kHz. Al:doped ZnO (AZO) is used as electrode due to its high electrical conductance, ease manipulation and the possibility to form heterojunctions with the NW material. Electrical current measured through the final assembled NW was studied in devices fabricated using different DEP conditions and results show V_{pp} and f strongly affect to the density of assembled NWs and its perpendicular alignment, respectively. On the other hand, the specific geometry of the electrodes enhances the positive DEP by increasing the electrical field gradient between the electrodes which improves the efficiency of the assembling process and then allows the deposition of a single NW between a pair of electrodes. After the NW assembling, Al electrodes are defined by photolithography and lift-off on top of the AZO electrodes to increase the stability of the device and to improve the electrical contact between the NW and both electrodes.

Single ZnO and CuO NW based devices were electrically probed in darkness and under illumination. For spectral measurements, a Xe lamp coupled to a monochromator is used.

ZnO NW device presents a fairly linear current-voltage characteristic and a highly selective ultraviolet response with a cut-off wavelength of 375 nm (Figure 4(a)). The high current levels and responsivities under illumination indicate that optical gain is much larger than one, which should be adequate to perform as light dependent resistors. However, the turn-on and turn-off times are much longer than seconds effects associated to the surface of the NW. In order to prevent those effects ZnO NW based

devices photoresponse was reanalyzed after coating the NWs with thin films composed by different materials such as SiO_2 and Si_3N_4.

CuO NW based devices present a current-voltage characteristic in darkness corresponding to a diode-to-diode behavior with dark currents in the range of a few nanoamperes. A minimum voltage of 1.0-1.5 V is needed for operation as a light sensor. Above that voltage, the spectral response shows a cut-off wavelength around 1024 nm, showing a fairly stable response in the visible and near infrared ranges. The p-type conduction of CuO NWs seems to explain the observed current-voltage characteristic. The p-n heterojunction built between AZO electrodes and CuO would give rise to potential barriers at both sides of the nanowire causing rectifying behavior under both polarities.

The analysis of electro-optical properties of ZnO NWs photodetectors shows high-gain slow response behaviour. A thoroughly study of the response times of both devices based on ZnO and CuO NWs, the latter presents shorter response times in the range of microseconds enabling the fabrication of light nanodetectors.

References

[1] J. Suehiro *et. al*, Nanotechnology **17** (2006) 2567.

Figures

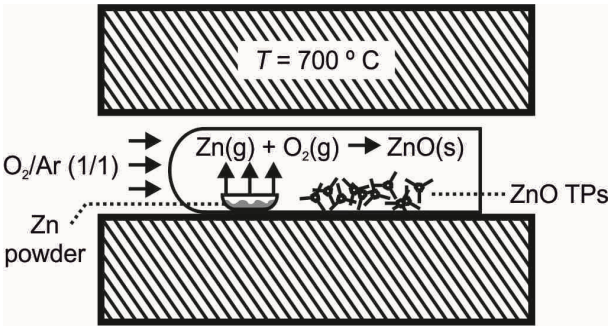

Fig. 1. VPT system used to grow ZnO NWs.

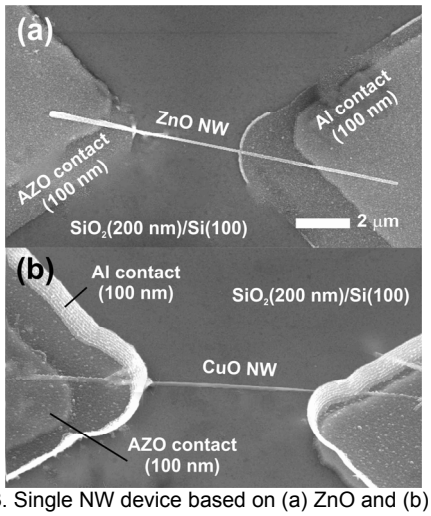

Fig. 3. Single NW device based on (a) ZnO and (b) CuO prepared by DEP.

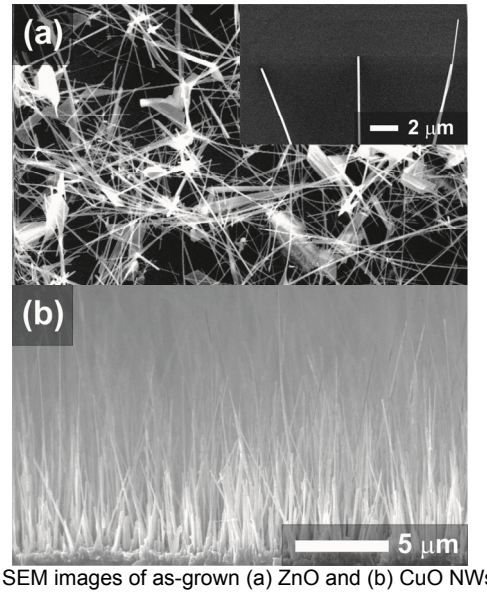

Fig. 2. SEM images of as-grown (a) ZnO and (b) CuO NWs.

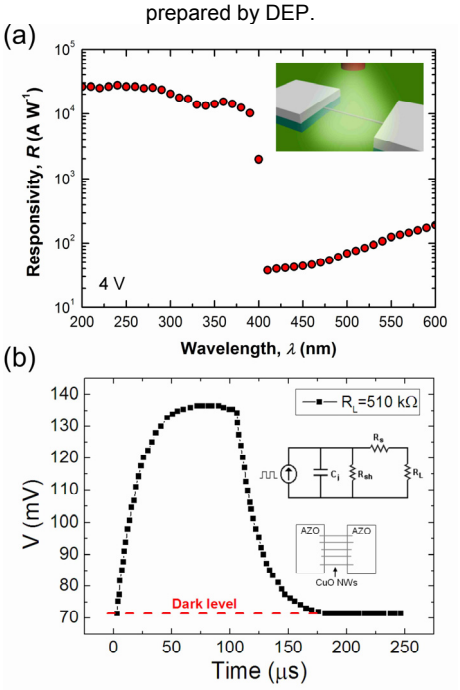

Fig. 4. (a) Single ZnO NW based device photoresponse and (b) turn-on and recovery times of a CuO NW based structure.