

Nano-manipulation of Ag/ZnO Nanoantennas for *in-situ* TEM Electrical Measurements

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Nowadays metal-semiconductor systems have attracted more attention due to their role as an active element in opto-electronic applications, especially in nanoantenna devices where the coupling of a metal with a semiconductor material could lead to the appearing of a resonant system responding to a specific frequency useful to be employed in solar cells, detectors, and nonlinear optical devices [1–2]. Moreover, the *in-situ* monitoring of physical properties associated with different arrays and configurations will lead to controllable opto-electronic properties. In this context, zinc oxide has been recognized as an excellent semiconductor material that meets most of the features required for those applications due to its easiness to be modifiable, i.e. controlling not only its arrangement distribution, leading to a variety of internal structures, but also its morphological configurations. It is known that using a specific method for the synthesis, different features and morphologies could be achieved.

Though, most of the ZnO production methods are based on chemical reactions which involve synthesis and thermal treatments at high temperatures (around 40-500 °C) that lead to nanostructures aligned in a preferential direction axis- with high stability. However, these chemical reaction processes are normally time consuming and costless. More recently Microwave Irradiation Process (MIP) is being employed to overcome those disadvantages, allowing the growth of well aligned crystalline nanostructures in short periods of time. In this work we are reporting a novel method that combines chemical synthesis reactions with a Microwave Irradiation Process to self-assemble ZnO nanorods (ZnO NRs) on silver nanowires (Ag Nws) in a hierarchical nanostructure configuration whose physical appearance resembles that of a nano-antenna. It is shown the *in-situ* electrical properties at nanoscale level of a single multi-pentagonal nanostructures using TEM *in-situ* electrical measurements.

During the self-assembly, an electrical active core silver nanowire supporting zinc oxide nanorods, is grown by a micro wave irradiation process. This metal-semiconductor nanosystem provides a conductive terminals (Ag Nws) behaving as a conducting line chemical-electrical connected to the epitaxial ZnO nanorods that once connected act as an active element on the nanosystem. Figure 1 shows the multi-pentagonal array mimicking an aerial antenna at nanoscale level. From the figure 1 a) it was inferred that the c-axis (0001) of ZnO nanorods grown epitaxially along the pentagonal faces (001) of the silver nanowire. Moreover, it was found that the linear distribution of ZnO nanorods along Ag nanowires could be modulated by controlling the reaction time during the MIP. Figure 1 b) and c) shown the normal distribution reached of Ag/ZnO when the parameters of the experiment are set up for different configuration. For completeness, *in-situ* electrical resistance measurements of a single Ag/ZnO nanostructure at room temperature were performed in transmission electron microscope TEM to elucidate the mechanism through which the active element behave in photo-electronic and nano-technological applications. [3]

References:

- [1] Casadei Alberto *et al*, *Photonicplasmonic* **14** (2014), p. 2271-2278.
 [2] Aouani Heykel *et al*, *The Journal of Physical Chemistry C*, **117** (2013), p. 18620–18626.
 [3] The authors acknowledge funding from RCMi Grant and Colciencias scholarship Francisco Jose de Caldas 512.

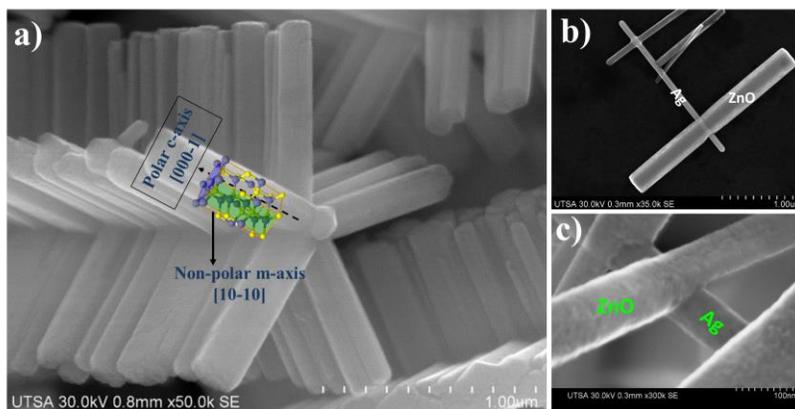


Figure 1. SEM image of a multi-pentagonal arrangement of Ag/ZnO nanorods. a) lateral-cross view section of an experimental nanostructure as growth by microwave irradiation process. b) Controlling the time growing it is possible to obtain an Ag/ZnO nanostructure with ZnO nanorods partially distributed along the silver nanowire. c) ZnO nanorods growing on the pentagonal faces of silver nanowire.

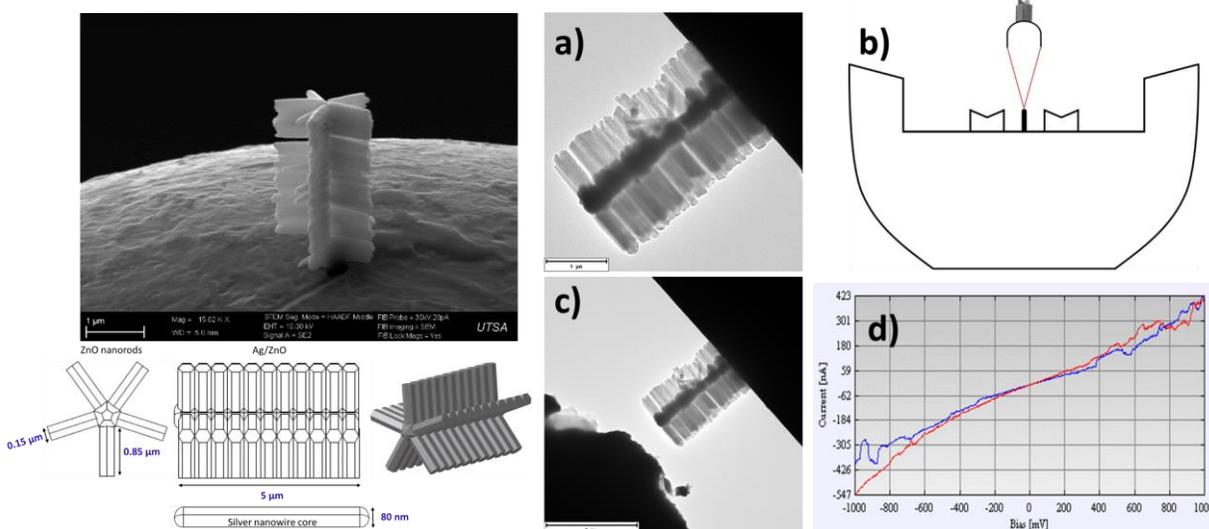


Figure 2. Single multi-pentagonal arrangement of Ag/ZnO. Left) view section of an experimental nanoantenna prepared in Focus Ion Beam (FIB) instrument. Once the Ag/ZnO is set up in a FIB grid *in-situ* TEM electrical measurements were performed. a) – c) shown a TEM image before the electrical probe reached the Ag/ZnO nanosystem closing the circuit. d) shows an I vs V experimental curve depicting a non-ohmic system as expected for the metal-semiconductor arrangement.