Scanning Nanowire Waveguide for Molecular Imaging of Cancer Cells

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Abstract:

A novel near field scanning optical microscopy (NSOM) method promises to achieve sub-50 nm spatial resolution along with enhancing signal to noise ratio (SNR) in optical imaging of single molecules and cell membranes. This technique proposes use of a zinc oxide (ZnO) nanowire plasmonic probe, synthesized by a chemical vapor transport and condensation (CVTC) system based on the vapor-liquid-solid (VLS) nanowire growth mechanism. In the present research, ZnO and graphite were used as source materials and the substrates were coated with 5 nm of thin film gold (Au) catalyst at a temperature of 1000°C and 700°C, respectively. Using scanning electron microscopy (SEM), it was found that the growth and the shape of nanowires were critically dependent on the temperature of the substrates, which is a function of position in furnace and temperature set point.

Introduction:

Cancer research is pointing toward the development of technologies that allow the study of living cancer cells at a single molecule level, in order to achieve a better understanding of this disease. Biomarkers, as Au nanoparticles, have the ability to reveal neoplastic changes; these nanoparticles can be detected in live cells with optical techniques [1]. However, resolving the spatial distribution of individual molecules remains a challenging problem because of light diffraction [2]. NSOM has overcome this limitation, but with a low light transmission inducing a very weak signal [3]. Here, we are proposing a new NSOM method, which consists of a ZnO nanowire probe with an Au nanoparticle at the free end, where the nanowire works as a waveguide and the Au tip enhances the local electric field at tip-sample (Au biomarkers) gap at a single molecule level.

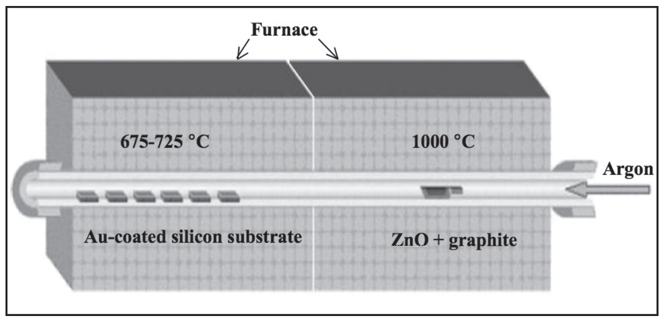

Figure 1: Schematic illustration of the ZnO nanowires growth by CVTC system.

Experimental Procedure:

The synthesis of ZnO nanowires was carried out by a CVTC system based on the VLS nanowire growth mechanism [4]. Single-crystalline silicon was used as a substrate for the ZnO nanowire growth. The substrates were coated with a layer of 5 nm Au thin film using a thermal evaporator under 3×10^{-5} Torr at 30 mA for 10 s. Then, the Au on the substrates was annealed at 1000°C for 20 min under argon atmosphere for the Au island formation. [place Figure 1]

Equal molar amounts of ZnO powder (99,9 %, Kurt J. Lesker Company) and graphite powder (Riedel-de Haën, Sigma-Aldrich lab) were mixed together, transferred to an alumina boat and then placed into a quartz tube (2,3 cm diameter and 118 cm length) in the upstream furnace of an argon flow (Figure 1). The Au-coated substrates were placed in the downstream furnace. The temperature of the upstream furnace was ramped to 1000°C and the downstream furnace was heated at 675°C - 725°C for 30 min under a constant flow of argon of 21 sccm.

The VLS growth mechanism of ZnO nanowires occurred in the following way: when the upstream furnace was heated at 1000°C, Zn, CO and CO2 vapors were produced by the chemical reactions 1 and 2:

$$ZnO_{(s)} + C_{(s)} \rightarrow Zn_{(g)} + CO_{(g)} \qquad (1)$$

$$CO_{(g)} + ZnO_{(s)} \rightarrow CO_{2(g)} + Zn_{(g)} \qquad (2)$$

These vapors were transported by argon to the downstream furnace, which was at a lower temperature. Zn vapor was absorbed by Au to form an alloy droplet; then, the diffusion of Zn through the alloy occurred and when it became supersaturated, reactions 1 and 2 proceeded in the opposite direction with the formation of ZnO nanowires.

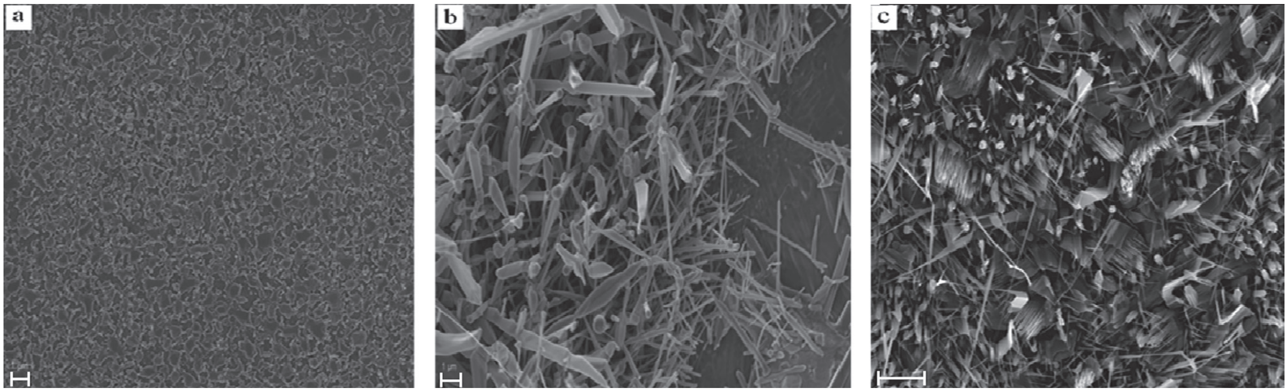

Figure 2: SEM images of ZnO nanowires grown at: a) 675°C, b) 700°C, c) 725°C.

After the furnace was cooled to room temperature, light gray material was found on the surface of the substrates, indicating the deposition of material.

Samples were characterized using SEM and x-ray diffraction (XRD).

Results and Conclusions:

ZnO nanowire growth was analyzed at different substrate position in the downstream furnace and it was found that larger nanostructures were formed in regions located downstream. Nanowire growth was observed at the center of the furnace.

Experiments carried out at temperatures from 675°C to 725°C in the downstream furnace shown that at the low temperature (675°C), the Au catalyst nanoparticles were partially solid and therefore the nanowires were not formed (Figure 2a). At 700°C, adsorption, diffusion and crystallization occurred properly for the nanowire growth. Here, the dimensions of the nanowires (~ 100 nm width, ~ 2 μm length) and the presence of Au at the end indicated that these conditions were optimal for this research (Figure 2b). Higher temperatures (725°C) introduced significant crystal overgrowth and agglomeration (Figure 2c).

Control experiments without graphite did not form nanowires, which indicated that Zn vapor was generated only by a carbothermal reduction of ZnO in this furnace environment. Extensive growth was also found after annealing, due to the formation of Au droplets.

XRD was used to examine the crystallinity and composition of the nanowires. Samples gave similar XRD patterns, indicating high crystallinity of ZnO nanowires (Figure 3). Au peaks were also detected.

Future Work:

After successful growth of the nanowires, the cantilever will be prepare and the ZnO nanowire growth with Au at the tip will be perform on the cantilever based on conditions previously found for optimum growth.

Acknowledgments:

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References:

[1] Aaron, J., et al. Opt. Express. 2008, 16, 2153-2167.

[2] Kusumi, A., et al. Biophys. J. 1993, 65, 2021-2040.

[3] Betzig, E., et al. Biophys. J. 1986, 49, 269-279.

[4] Yang, P., et al. Adv. Funct. Mater. 2002, 12, 323-331.

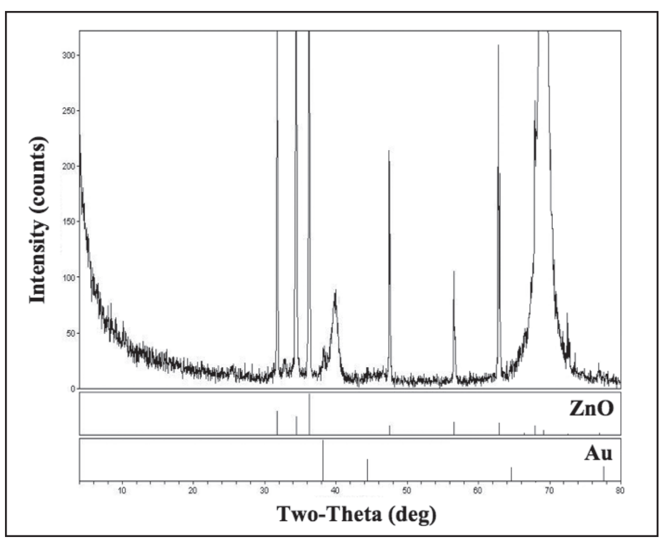

Figure 3: XRD of ZnO nanowires on silicon substrate.