Site Specific Nanowire Growth

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Abstract:

In recent years, one-dimensional solids like nanowires have received increased attention as building blocks for future nanoscale devices. Their small length scale and unique physical and chemical properties make them interesting materials from technological and pedantic viewpoints. In order to fully exploit their advantages, it is necessary to perform experimental characterization on single nanowires. As a first step towards this goal, we are aiming to synthesize zinc oxide nanowires at the site of experimentation. The final goal of this research is to perform mechanical and electromechanical characterization experiments on the nanowires by integrating the nanowire synthesis process with micro-electromechanical systems (MEMS) experimental test-bed. The nanowires are grown by vapor-liquid-solid (VLS) mechanism. The zinc oxide nanowires are synthesized using 1:1 weight mixture of zinc oxide powder and graphite as precursors and gold as catalyst. At 1000°C the graphite reduces zinc oxide to form zinc and oxygen vapor. The nanowire growth is initiated when the gold (evaporated on (100) silicon substrate) is saturated with zinc vapor. The diameters of the nanowires are between 30 nm to 200 nm and the lengths are up to 20 μm.

Introduction:

When the size of material decreases (to micro and nanoscale) many interesting phenomena begin to emerge. Since the dimensions of nanowires coincide with the critical material length scales, they are expected to exhibit unique properties. As a result, they will serve as an excellent system to investigate mechanics at different length scales, coupling between mechanical, electrical and thermal properties and their effect on dimensionality and size reduction. Their mechanical properties coupled with quasi-one-dimensional nature of electronic states make the nanowires potential material for future nanoscale sensors and actuators. Nanowires will be integral in the reduction of size of functional systems and in the enhancement of performance of sensors and actuators. However in order to fully exploit their advantages, it is necessary to perform experimental characterization on single nanowires. One of the challenges is the ability to have the specimens at the site of experimentation. We propose to address this issue by synthesizing zinc oxide nanowires at the site of experimentation. We chose microelectromechanical systems (MEMS) devices for experimental characterization because of the ability to perform *in situ* uniaxial experiments. We chose zinc oxide because ZnO is a key technological material; it is a semiconductor as well as a piezoelectric material. Zinc oxide is also bio-safe and biocompatible.

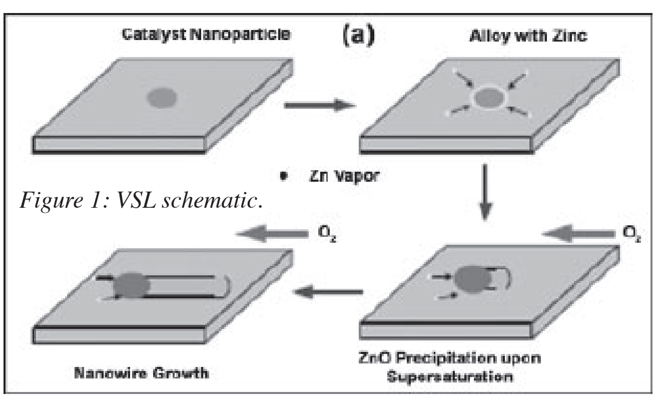

Figure 1: VSL schematic.

The main objective of this research was to study site specific growth of zinc oxide nanowires. We also wanted to study the effects of different process parameters on nanowire growth and control the growth sites and morphology of the wires.

Experimental Procedure:

In this research we grew the zinc oxide nanowires via the VLS mechanism using gold as a catalyst. We started with zinc oxide powder and graphite powder in a 1:1 ratio in an alumina crucible inside the furnace. We placed the silicon samples (100) with 20 nm gold patterns on them downstream from the crucible. As the temperature of the crucible increased to ~ 1000°C, the ZnO powder was reduced by graphite to form zinc and CO vapors. The corresponding chemical reaction can be expressed as:

$$ZnO(s) + C(s) \rightarrow Zn(g) + CO(g)$$

$$CO(g) + ZnO(s) \rightarrow CO2(g) + Zn(g)$$

The argon gas carried the zinc, CO and CO_2 vapors to the samples. Meanwhile the formation of eutectic

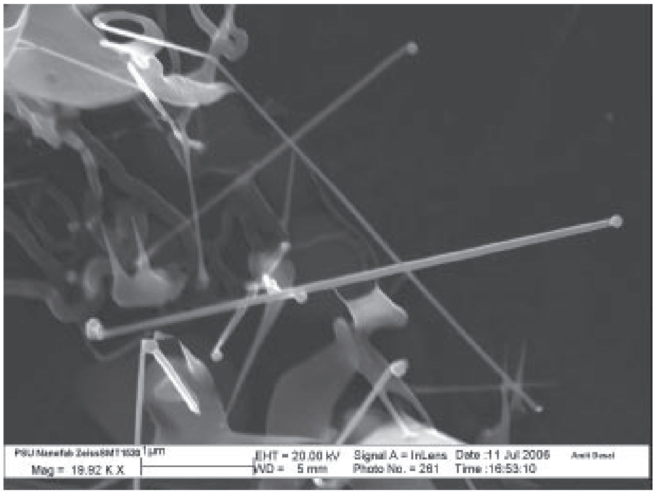

Figure 2: Nanowire at 910°C.

alloy droplet occurred at each catalyst site. The gaseous products produced by the above reactions would adsorb and condense on the alloy droplets. Subsequently, the following reaction was catalyzed by the Au-Si alloy at solid- liquid interface to obtain zinc oxide nanowires.

$$Zn(g) + CO(g) \rightarrow ZnO(nanowire) + C(s)$$

$$C(g) + CO2(g) \rightarrow 2CO(g)$$

The zinc vapor saturated the alloy droplet, followed by the nucleation and growth of solid ZnO nanowire due to the super saturation of the liquid droplet. Incremental growth of the nanowire taking place at the droplet interface constantly pushes the catalyst upwards. Thus, such a growth method inherently provides site-specific nucleation at each catalytic site.

Results and Discussion:

From the existing scanning electron microscope (SEM) images, we estimated the nanowire diameters to be in a range from 30 nm to 200 nm and the lengths up to 20 μm. In some of the nanowires we observed a gold tip at the end of the nanowire providing evidence for VLS mechanism-based growth. In the first run, which was set at 10 sccm argon flow rate, we obtained nanowire growth from 500°C to 910°C. During the second run, also set at 10 sccm, growth appeared from 500°C to 800°C. We also observed some nanobelt growth in the lower temperature region.

We observed no growth at higher flow rates and this is mainly due to the zinc vapors being carried away by the argon leading to low probability for nanowire growth reactions. We also experimented with a different substrate; we tried to grow nanowires on silicon dioxide (SiO_2) at 10 sccm; we did not obtain any growth and this is mainly because SiO_2 is an amorphous substrate.

Future Work:

We will fabricate MEMS devices out of silicon. We will pattern gold on the devices on the desired area and we will grow the zinc oxide nanowires with gold as catalyst. Then we will perform uniaxial tensile experiments on the nanowires inside a SEM using the MEMS device. From the experiments we will estimate the mechanical quantities like stress and strain and electrical entities like voltage and resistance. We will use this information to study the mechanical and electro-mechanical (piezoelectric) properties of nanowires.

Conclusion:

We synthesized ZnO nanowires on a Si substrate by VLS growth process using Au as catalyst. We observed no growth at higher flow rates or on the amorphous substrate. There was furnace tube degradation at every growth run. We also observed nanobelt formation at lower temperatures.

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References:

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