Functionalized Nanowires for Electromechanical Detection of Molecules

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Abstract: This paper describes briefly our progress in the area of controlled growth of nanowires, and the growths of silicon carbide nanowires, as steps towards realizing functionalized nanowire-based electro-mechanical gravimetric sensors.

1. Introduction: Nanoelectro-mechanical systems (NEMS) are emerging as processes are being developed for fabricating structures in the nanometer dimensional range. In this size domain, it becomes possible to create structures that exhibit extremely high resonant frequencies (in GHz range) while possessing very small force constants, due to their extremely small active mass [**1,2**]. These structures also display unprecedented sensitivity to force or to added mass, possibly even down to the single atomic collision event. However, while offering vastly expanded capabilities, NEMS present engineers with unprecedented challenges in materials processing, device design, fabrication and integration.

Two approaches are utilized for accessing the nanometer domain, namely the top-down (derived from standard microfabrication paradigm of thin-film deposition, lithographic patterning and etching) and bottom-top (synthetic approach). An example of top-down approach is the vapor-liquid-solid (VLS) growth process, whereby a metal nanoparticle initiates the growth of a single crystal nanowires with lengths of up to several microns [**3**]. Through this process, large arrays of nanowires with tightly controlled diameters, ranging from 10-50 nm, can be grown *vertically* (Fig. 1a). However, these structures do not function in a practical manner, unless they are interfaced with other devices or external probes. The research aims to develop solutions to the challenges of batch fabrication of mechanical nanodevices and interfacing with external probes. It employs the vapor-liquid-solid method of nanowire growth to realize resonant nanostructures, catalyst nanocluster deposition to control nanostructure size and location, selective immobilization of target molecules on the functionalized metallic caps of the nanowires, novel nanogap device design based on spacer lithography, and novel coupling architectures to excite and detect the fundamental modes of the nanowires.

2. Lateral Growth of Nanowires: By merging the top-down and bottom-top approaches, we have recently been able to achieve *lateral* growth of silicon nanowires, shown in Fig. 1b [4]. This is an important achievement as it enables a variety of NEMS-based devices to be realized, including mechanical resonant detectors, nano-separation devices and thermoelectric generation. Research is underway to control the density and size of these laterally grown nanowires. Atomic force microscopy is also being used to characterize the mechanical properties of these suspended nanowires.

3. Silicon Carbide Nanowires: A wide variety of semiconductor and ceramic materials are available for growth of single crystalline nanowires. Among these, silicon carbide is particularly attractive because of its superior mechanical performance and its physicochemically inert surfaces. The latter property becomes critical at the nanoscale, where most of the device's atoms indeed reside near the surface.

SiC nanowires are synthesized by chemical vapor deposition via vapor-liquid-solid (VLS) mechanism. Figure 2(a) shows the transmission electron microscopy (TEM) image of SiC nanowires grown at 1200°C. The nanowires have diameter of 15–200nm and length of several microns to several tens of microns. The X-ray diffraction pattern shows the nanowires are 3C-SiC phase. The growth direction of SiC nanowires is exclusively <111> as shown in the high resolution TEM image and electron diffraction pattern in Figure 2(b). Vertical arrays of SiC nanowires were achieved on 6H-SiC(0001) substrates since 3C-SiC(111) face is almost identical to 6H-SiC(0001) face which allows epitaxial growth. Figure 2(c) shows the scanning electron microscopy (SEM) image of vertical array from the side view at an angle of 40°. Well-aligned wires are clearly seen in the inset with Pt droplets on their tips.

4. Nanoneedles and Other Novel Nanostructures: Several novel nano-structures such as nanoneedles and nanotubes and nanopipettes have been realized [5]. Using Pt (instead of Au) as the catalyst for VLS growth leads to the growth of nanoneedles (rather than nanowires), as shown in Fig. 3(a). By oxidation and selective etching of Si core, silica nanotubes and nanopipettes have been obtained (Figs. 3(b) and (c)).

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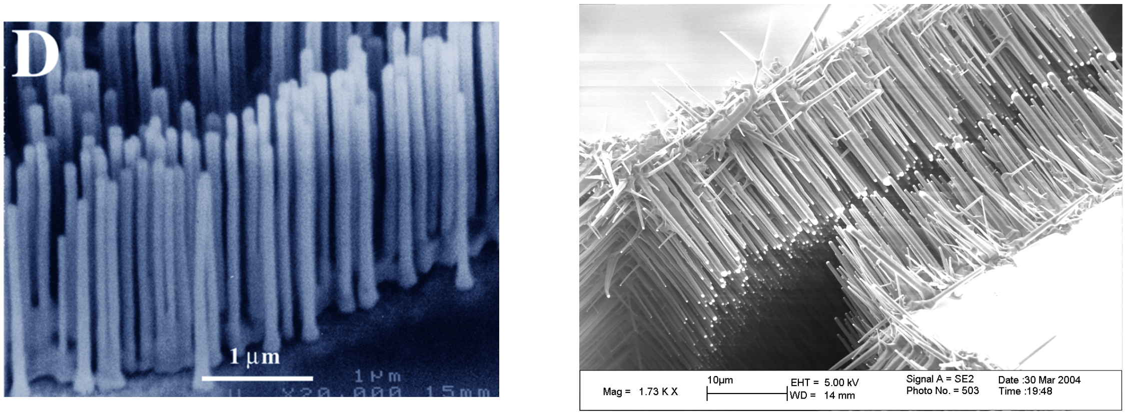

Fig. 1. SEM images of (a) ZnO nanowire vertically aligned; (b) Si nanowires horizontally aligned.

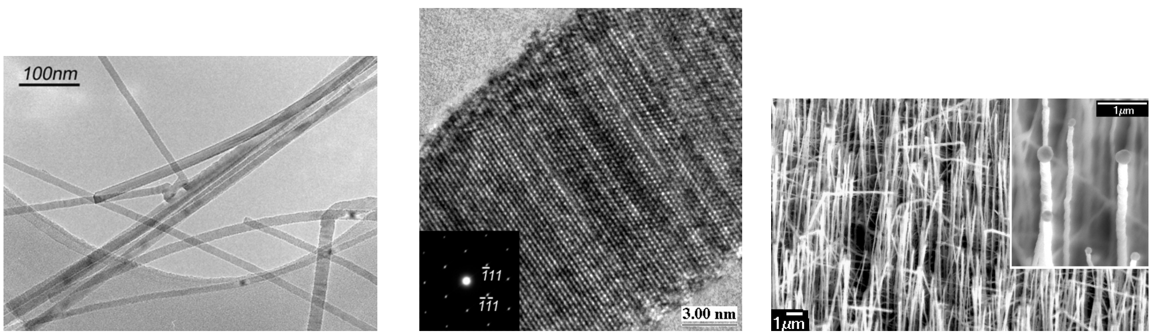

Fig. 2. (a) TEM morphology of SiC nanowires synthesized at 1200°C; (b) HRTEM image of an individual SiC nanowire. The inset electron diffraction pattern taken along [101] indicates the wire growth direction is [$\bar{1}11$]; (c) Vertical array of SiC nanowires on 6H-SiC(0001) substrates.

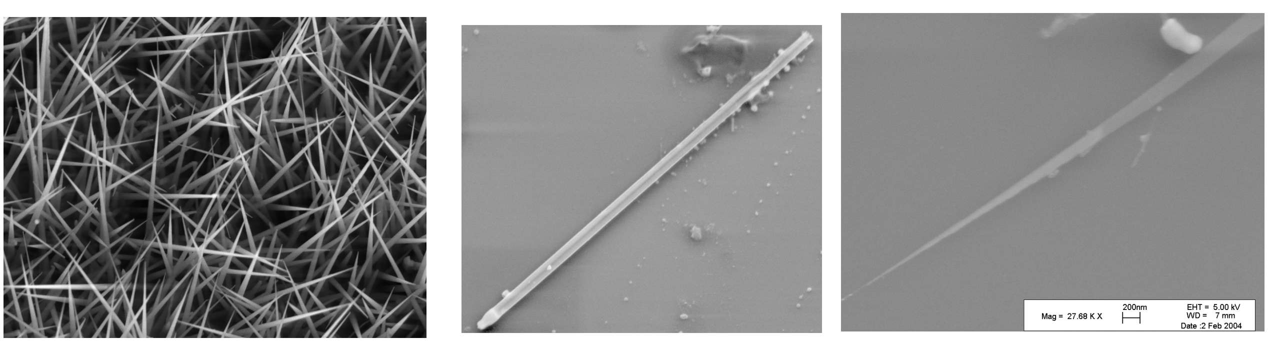

Fig. 3. SEM images of (a) Si nanoneedles obtained using Pt catalyst at 950 C; (b) Silica nanotube obtained by oxidation of Si nanowire and selective removal of the Si core; (c) Silica nanopipette obtained by oxidation of Si nanoneedle and selective removal of Si core.