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Lift-out and in-situ STM-TEM Studies of Individual GaN Nanowires

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GaN nanowires are a crucial component in various nanoscale optoelectronic devices, such as blue light-emitting diodes and short-wavelength ultraviolet nanolasers [1-3]. Grain boundaries, extended defects and impurity incorporation from heterogeneous catalysts used to initiate wire growth can all negatively impact a wire's electronic properties. To understand the specific effects of microstructure and composition on electrical properties, these must be correlated for individual nanowires. Recent measurements [4,5] demonstrate the relationship between electrical resistance and wire microstructure for B-doped SiN nanowires. Quantitative results, however, were limited due to inefficient acquisition of single nanowires for scanning tunneling microscopy (STM) measurements [4]. Here we present a novel and convenient method of collecting single nanowires, and subsequent correlation of electrical and microstructural properties.

We synthesized Ni-catalyzed and $Ga(NO_3)_3$-catalyzed GaN nanowires on Si substrates by atmospheric chemical vapor deposition (CVD) [6]. To extract individual GaN nanowires from the dense batch of wires on the Si substrate, we used an Ascend Extreme Access™ in situ lift-out system mounted in a FEI Nova 600™ Dual Beam focused ion beam (FIB) workstation. A Nanofactory™ STM-TEM holder [7] allowed us to characterize, in-situ, the structures and electrical properties of the extracted wires with a JEOL™ 2200FS transmission electron microscope (TEM) (Fig. 1a). This holder can accommodate samples mounted on Au wires or conventional TEM grids. We extracted nanowires using both Cu microtweezer grids, called End-Effectors™ (Ascend Instruments, LLC) and Au wires (Fig. 1). The use of the End-Effectors provided greater flexibility in site-specific microstructural analysis because of their compatibility with conventional TEM holders.

Electron diffraction studies showed that both Ni-catalyzed and $Ga(NO_3)_3$ -catalyzed wires exhibited a polycrystalline wurtzite structure. The Ni-catalyzed wires possessed strong [011] growth texture, in contrast to the [111] and [001] preferred orientations in the $Ga(NO_3)_3$-catalyzed wires [7]. Point-contact I-V curves (Fig. 3) were obtained using the STM system to quantitatively assess wire resistance. TEM imaging and STEM-based energy dispersive x-ray spectroscopy will be used to determine trends in structure and composition at specific points on a wire. Trends in crystal size, growth orientation and composition along the wire will be compared to IV curves of the same wires. In some cases, the lift-out preserved the catalyst-wire interface, permitting determination of relationships between the catalyst morphology and wire microstructure [8].

References

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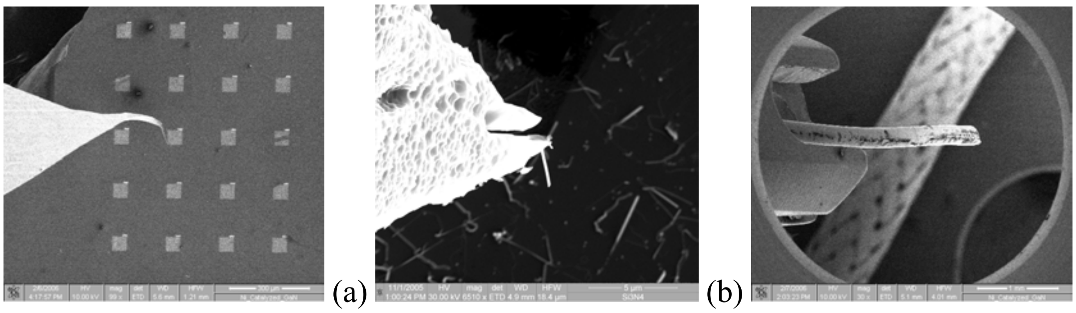
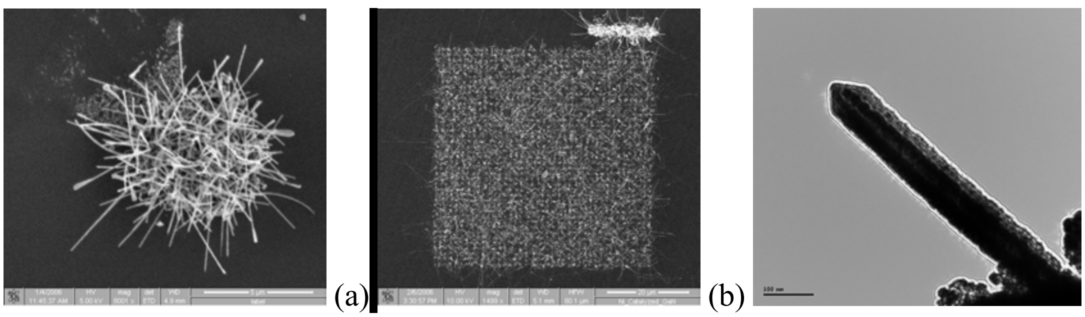


(a) (b) (c)

FIG.1. Secondary electron (SE) images of (a) a Cu end-effector approaching a sample area of interest; (b) a GaN nanowire held by electrostatic force on a ‘microtweezer’; (c) an Au wire in an Ascend carrier.



(a) (b) (c)

FIG.2. SE images of (a) $Ga(NO_3)_3$-catalyzed GaN wires at a nucleation site, and (b) Ni-catalyzed GaN wires at a nucleation grid site; (c) Bright-field TEM image of an extracted GaN nanowire.

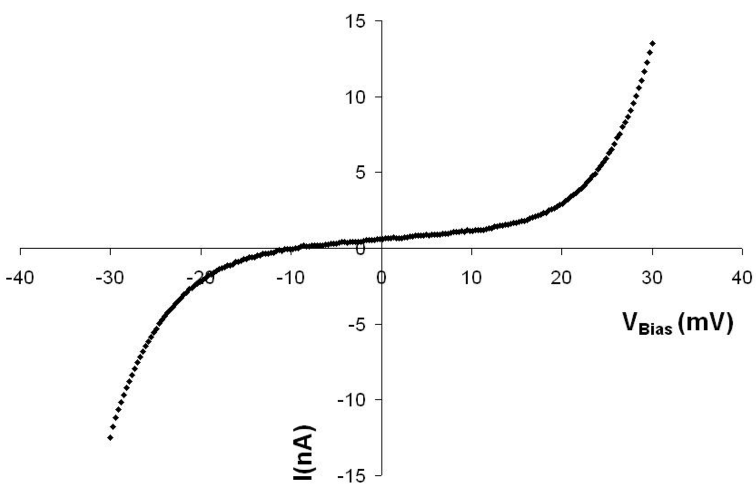


FIG.3. I-V curve of a GaN nanowire using the Nanofactory™ STM/TEM apparatus.

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