Nanomanipulator for Electronic Characterization and Top-Down Construction of Unique Nanostructures

by **B. S. Swartzentruber**

Motivation—Nanostructures have properties that differ from bulk values due to their inherently small size and their high surface-to-bulk atom ratio. One stumbling block in the measurement of nanostructure material and electronic properties is the difficulty to position them precisely where they are needed. The problem is two-fold – imaging the nanostructures and their surroundings, and manipulating them on the nanometer length scale. Current methods for positioning rely on random deposition of nanostructures from solvents, gas phase, and vacuum growth techniques, followed by a post-mortem determination of their location. This methodology limits the throughput and the statistical accuracy of nanostructure property measurements.

Accomplishment—To increase measurement throughput and develop a flexible manipulation framework, we built a scanning-probe-based nanomanipulator inside of a JEOL 6701F field-emission scanning electron microscope (SEM) with ~1 nm resolution. Tungsten probe tips, etched to end radii as small as 20 nm, are coated with a variety of metals to measure different nanostructure interface properties. With fine motion control based on a piezo actuator and coarse motion via stick-slip translation stages, the probes are positioned within ~1 cm^3 volume with sub-nanometer precision. To facilitate manipulation, fine positioning is accomplished through a dual-joystick interface. This allows direct intuitive control while imaging with the SEM in real time. Individual nanostructures are chosen and the probe positioned precisely for contact. Electronic structure measurements are performed with high-precision current-voltage sources.

Figure 1 is a false-colored SEM image of a gold-coated tungsten probe contacting the top of a vertical GaN rod directly on the growth wafer. Current-voltage curves are plotted in Fig. 2. Current passes through the rod and is collected on the growth wafer with large area silver paint serving as the back electrode. Upon initial contact, a Schottky barrier forms at the Au-GaN interface that limits the conduction. This Schottky behavior is plotted in blue in Fig. 2. After passing a large current (> 10 μA) through the rod, the Schottky interface is destroyed and the current increases > 100-fold. The current is then limited by conduction through the rod and is best described by space-charge limited conduction (IV plotted in red in Fig. 2). This sequence of Schottky to space-charge-limited current can be repeated on any number of rods.

Significance—Measuring nanostructure properties in their as-grown configuration eliminates uncertainties due to ex-situ processing. The comparison of measurements on as-grown structures with those with processed contacts gives insight into contact and interface formation. Many nanorods can be individually addressed for comparison and properties correlated with shape and length. Adding multiple probes to this tool will enable not only direct and precise control over the placement of individual nanostructures, but also of their position with respect to each other – a currently unattainable ideal.

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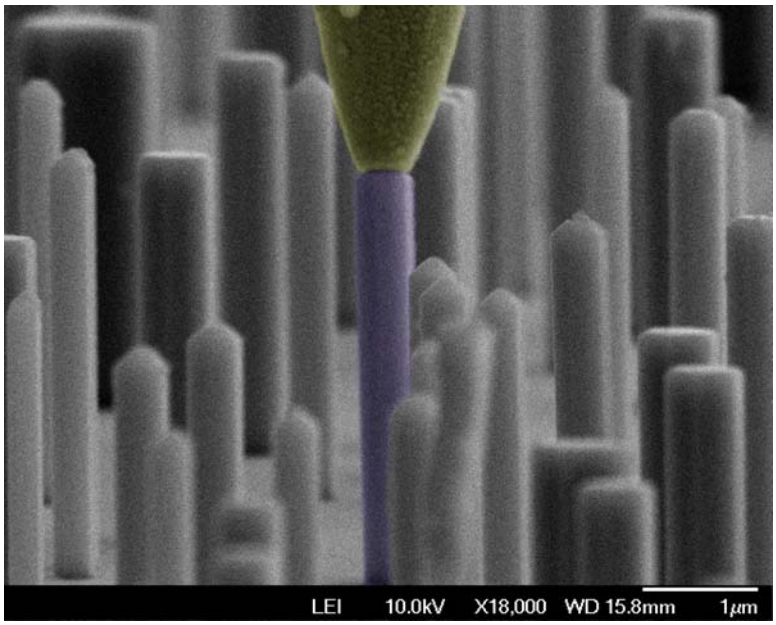

Figure 1. False-colored SEM image of gold-coated tungsten probe contacting GaN rod for electrical characterization. Each rod can be individually addressed.

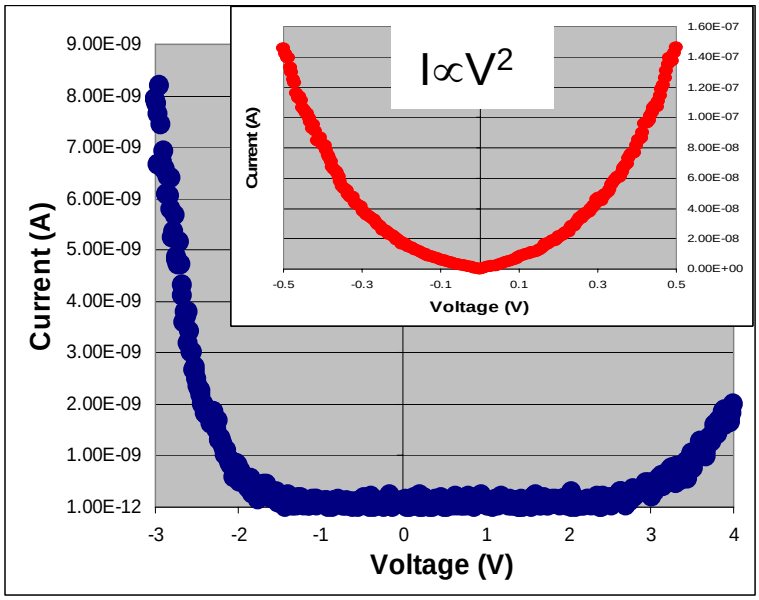

Figure 2. Current versus voltage curves for GaN rods. At initial contact, a Schottky barrier forms at the GaN-Au interface (blue). When the interface is disrupted by pushing harder or through high current, the conduction becomes space-charge limited (red).