Nanomanipulation Using Combined Scanning Probe Microscope and Scanning Electron Microscope

by **B. S. Swartzentruber**

Motivation—Nano-scale structures have properties that differ from bulk values due to their inherently small size and their high surface-to-bulk atom ratio. Potential applications using nanostructures include: high frequency resonators; novel electronic devices; and highly sensitive chemical sensors; among others. One stumbling block in the development of such devices is the difficulty to precisely position nanostructures exactly where they are needed. The problem is two-fold–imaging the nanostructures and their surroundings, and manipulating them on the nanometer length scale.

Accomplishment—I designed and constructed a fully functional scanning probe microscope (SPM) inside the imaging chamber of a commercial (LEO-1430) scanning electron microscope (SEM). Using piezoelectric actuators, this SPM instrument can position the apex of a probe tip with sub-nm precision within ~10 x 10 x 10 μ^3. Mounting the SPM on three orthogonal, electronically-driven, translation stages allows coarse positioning over 7 mm in three dimensions. The SEM images the probe tip and nanostructures in real-time providing visual feedback for manipulation.

The initial work with this system involved the manipulation of various nano-whisker/wire samples–multi-walled carbon nanotubes, semiconducting tungsten-oxide whiskers, silicon whiskers, and germanium whiskers. All of these samples were grown on substrates containing catalytic nano-particles, resulting in a 'nest' of whiskers, anchored to the substrate, ranging in size from 20 to 100 nm in diameter and 300 to 10,000 nm in length, depending on the material system and growth parameters.

Building a three-dimensional structure occurs in two stages. First, the probe tip is used to extract a single whisker from the nest. Second, the whisker is transferred and placed in an appropriate position. In Fig. 1, I show a hooked probe tip pulling a germanium whisker from the nest. Once extracted, the whisker is moved to another area where, either its electronic properties are determined through IV measurements through the whisker between the probe and a gold pad, or it is positioned in a well-defined structure. Figure 2 shows the germanium whisker being placed across the gaps in a lithographically defined circuit element.

Significance—Using custom actuation hardware and software, I am determining the control parameters for pick up, transfer, and placement of nanowires. I can also probe the electrical characteristics of individual nanowires to explore their conduction mechanisms. The visualization afforded by SEM coupled with the precise placement of scanning-probe-like actuators enables a top-down approach to fabricate and manipulate nanostructures unattainable by conventional means. This combined SEM-Nanomanipulation capability is among only a handful world-wide.

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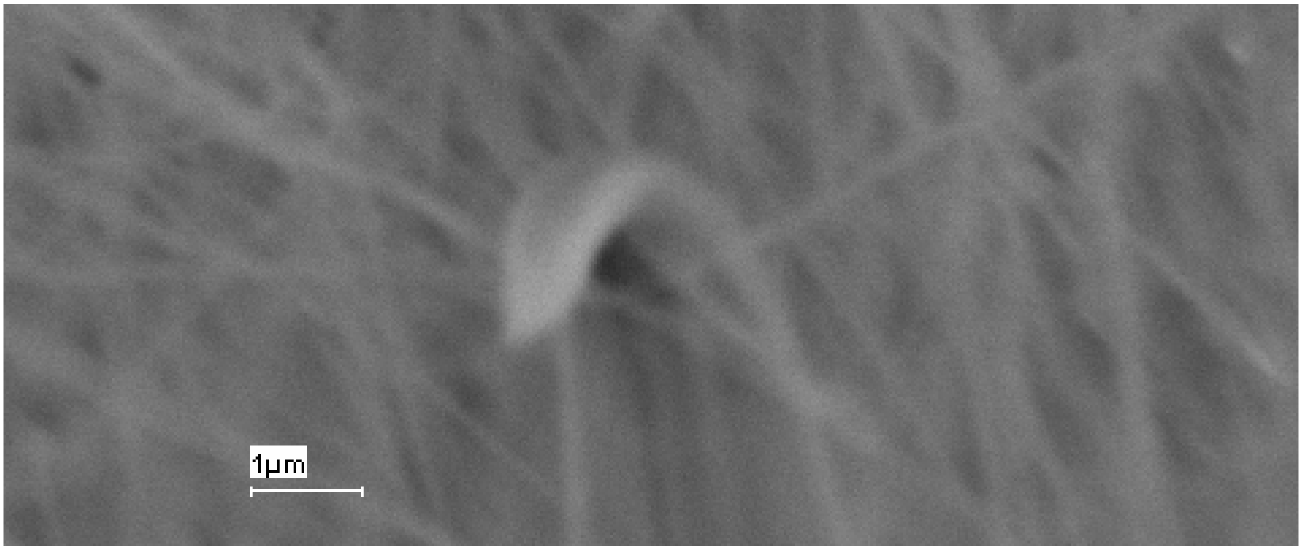

Figure 1. Extraction of a germanium nano-whisker using a hooked probe tip.

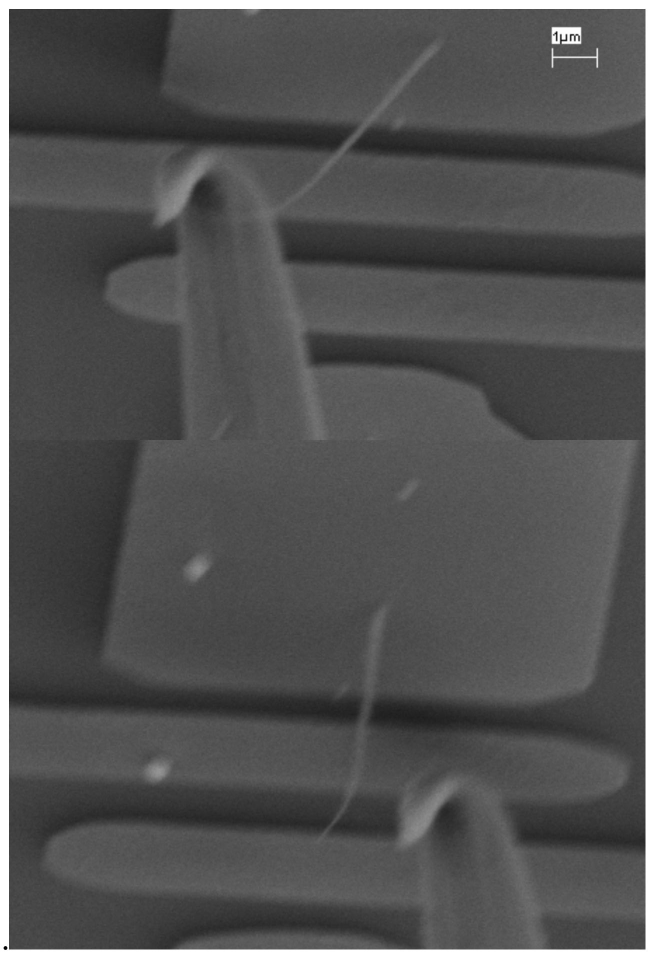

Figure 2. Placement of the germanium whisker across the gap in a gold circuit. Top: in contact with the upper pad. Bottom: after placement and release from probe tip.