Towards Controlled Doping in III-V Semiconductor Nanowires

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Nanowires are quasi-one-dimensional single crystals with lateral dimensions that can be scaled-down to only a few nanometers. They can simultaneously act as active components and interconnects and therefore fulfill the two basic functions of any active device. However, controlled doping of III-V nanowires is challenging due to strong Fermi-level pinning as well as the kinetic and thermodynamic requirements for dopant incorporation through the metal catalyst. To enable flexible and controllable doping of nanowires we are studying two doping approaches: doping through the deposition of a doped epitaxial shell around the nanowire [1] and ex-situ post-growth diffusion doping. Here we concentrate on GaAs nanowires as a model system, although our approaches are applicable to other III-V nanowires.

Shell doping is proposed as a simple in-situ doping method. After GaAs nanowires are grown at 420°C, the reactor temperature is increased to 750°C and silane is introduced during the growth of a conformal GaAs shell, as shown in Figure 1a. Experiments have shown that uniform shells can be achieved, as shown in Figure 1b. To overcome Fermi-level pinning, the shells must be thick and/or heavily doped. Schrödinger-Poisson models predict that at \( N_D = 10^{18} \text{cm}^{-3} \), the minimum shell thickness to achieve doping is 48nm. Experimental studies to validate this prediction and determine the dependence of carrier concentration on shell thickness are currently in progress. We have optimized the design and fabrication of robust, Ohmic electrical contacts onto GaAs nanowires with sufficiently low contact resistance. The contacts are patterned using e-beam lithography followed by e-beam evaporation of Ni(20 nm), Ge (20 nm), and then Au (120 nm). The contacts are then annealed at 420°C for 30 seconds.

To achieve precise control over diffusion doping at the nanoscale, we propose a platform for finely tunable dopant dosages via the creation of a monolayer of dopant-containing molecules [2] on GaAs. First, the GaAs surface is hydrolyzed [3] to create reactive sites for monolayer formation. A controlled dose of silicon is introduced by reacting (3-Mercapto-propyl) trimethoxysiloxane (MPTMS) with the hydroxyl groups on the surface (Figure 2). Silicon atoms are then driven in by a rapid thermal anneal. X-ray Photoelectron Spectroscopy analysis supports the proposed surface functionalization. Preliminary sheet resistance measurements suggest that this platform can be used to dope GaAs. An investigation of dopant dosage control is underway.

REFERENCES


FIGURE 1: a) Schematic of shell doping via co-introduction of silence during epitaxial shell deposition. b) An SEM image of shell-doped GaAs NW. The dark object on the top of the nanowire is the Au catalyst nanoparticle.

FIGURE 2: a) Idealized reaction between MPTMS and hydrolyzed GaAs. Silicon, the n-type dopant, is highlighted in red. b) X-ray Photoelectron Spectroscopy peak shifts suggest a hydrolyzed GaAs surface.