III-V Compound Semiconductor Nanowires

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With the continuous miniaturization of semiconductor materials and devices, high aspect ratio semiconductor nanostructures, such as nanowires, have been lauded by many to be a primary candidate for next generation technology, envisioned as providing a nanoscale framework of both interconnects and functional elements for the 'bottom up' approach. As- and P-based III-V compound semiconductor nanowires are of particular interest for optoelectronic devices due to their high carrier mobility and optical emission efficiency compared to indirect-bandgap group IV materials. With reliable synthesis routes now established, a number of nanowire based electronic and optoelectronic devices have been demonstrated include field-effect transistors, lasers, photodetectors, single electron memory and solar cell devices.

In this report, various III-V semiconductor nanowires, including GaAs, InP, InAs nanowires and related nanowire heterostructures, were grown epitaxially on GaAs, InP, InAs (111)B or Si (111) substrates by metalorganic chemical vapor deposition (MOCVD) using Au nanoparticles as catalyst. Some challenging issues related to the growth and characterization of III-V semiconductor nanowires by MOCVD to understand the growth mechanism and their implications on optical properties will be reviewed. In addition, I also show some prototype nanowire devices fabricated in our laboratory.

Firstly, GaAs nanowires with high optical and crystal quality were demonstrated by choosing an appropriate V/III ratio together with growth temperature [2-4]. By passivating the GaAs nanowires with a AlGaAs shell and GaAs cap layer, photoluminescence efficiency was improved significantly and nearly intrinsic exciton lifetimes (~1 ns) were obtained at 10 K [5], which are comparable to high quality two-dimensional double heterostructures. The carrier lifetime can be further improved by optimizing the AlGaAs shell growth parameters and 1.5 ns of minority carrier lifetime has been obtained at room temperature [6].

Precise control of crystal structure either in zincblende (ZB) crystal or wurtzite (WZ) crystal phase or mixed phases was also demonstrated in various III-V semiconductor nanowires [7-8]. This unique phenomenon in nanowires which can not be realized in their bulk counterpart opens new possibilities for engineering nanowire devices.

Prototype nanowire solar cell devices were fabricated by planarizing the GaAs/AlGaAs/GaAs nanowire structures. The devices exhibit a spectrally broad photo-response and the conversion efficiency can be over 4%. Modeling of Nanowire lasers has also been carried out by calculating the threshold gain for nanowire guided modes as a function of nanowire diameter and length. Gain spectrum for GaAs nanowires as a function of injected carrier density was modeled using microscopic gain theory. Based on these calculations, we have optimized the structure design for nanowire laser devices. The prototype GaAs/AlGaAs/GaAs nanowire laser structures were grown and optically pumped laser operation was demonstrated at both low temperature and room temperature.

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