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# III-V semiconductor hetero-structure nanowires by selective area MOVPE

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Semiconductor nanowires are potential building blocks for future nanoscale electronic and photonic devices due to their superior properties and quantum confinement effects. The ability to fabricate these nanowires with precisely controlled geometrical dimensions, composition, electronic and optical properties makes them highly promising for device applications.

The potential ability of these semiconductor nanowires can be greatly enhanced by introducing heterostuctures within nanowires and recently significant advances have been made on the synthesis of axial heterostructure nanowires and radial heterostructure or core-shell nanowires.[1,2]

In this presentation, we report the fabrication of InP nanowires, and InP/InAs core-multishell nanowire that was designed to embed a single strained radial quantum well (QW) in a higher bandgap nanowire. InP/InAs material system with a lattice mismatch of 3.2% was chosen for the present work.

Figure 1 shows scanning electron micrograph image of typical InP nanowires grown on InP (111)A substrate. Growth temperature was 600 °C. We successfully obtained uniform InP nanowires.[3]

Next, we grew InP/InAs core-multishell nanowires. The layer structure consists of inner InP core, InAs and InP inner and outer shells, respectively, in which the InP core and the outer InP shell serve as the barrier layers while the InAs shell is the strained QW layer.[4] Since the active layer, which is the InAs strained QW, is in the form of a hollow cylindrical tube, this nanostructure is a two-dimensionally (2D) confined system within a one-dimensional (1D) nanowire structure. In spite of the lattice mismatch, InAs 2D layer-by-layer growth occur on the InP nanowire core along the lateral direction. Further, the fact that the inner core and the outermost shell comprise of the same material, InP, intrinsically necessitates InP to be grown axially for the inner core and laterally for the outer shell.

Scanning electron microscopy (SEM) studies clearly indicated that the grown structures were well-defined and extremely uniform. The length of a typical core-multishell nanowire was about 2.5 μm and the diameter was about 140 nm. The grown nanowires were subjected to anisotropic dry etching followed by stain etching to analyze their cross-sectional features. The diameter of the inner InP core and the thickness of the outer InP shell were 70 and 30 nm, respectively. The InAs QW layer exhibited well-defined hexagonal cross-section and the well width was found to be 5 nm, as shown in figure 2.

For further characterization, core- multishell nanowires with different InAs QW widths were grown by varying the InAs growth time. 4K micro- photoluminescence (μPL) measurements were carried out on the core-multishell nanowires with InAs well width of 1.5 nm.

PL spectra of core-multishell nanowires with different pattern periods are shown in Fig. 3. Spectrum (a) shows PL from nanowire array with 3 μm period, whereas (b) is from an array with 0.4 μm period. Since the 3 μm period is greater than the spot size, the spectrum (a) can be concluded to be from a single core-multishell nanowire.[10] The spectrum (a) consisted of two distinct emission peaks. The PL peak observed at energy of 0.861 eV is due to InAs QW formed on the (110) sidewalls of InP nanowires, while the peak at 1.401 eV corresponds to the InP barrier. Further, the InAs layer on top of the InP core is rather thick and does not have any influence on the observed PL spectra.

On the other hand, the spectrum (b), taken from multiple core-multishell nanowires (~30 nanowires considering the spot size) exhibits multiple peaks at around 0.86 to 1.45 eV, which are also due to the emission from InAs radial QWs. To confirm these peak assignments, the ground-state transition energy in strained InAs QWs on InP (110) was calculated using a simple square well potential. The results suggested that the peaks at 0.984, 1.05, 1.154 and 1.292 eV in spectrum (b) correspond to InAs QW widths of 1.16, 0.856, 0.532 and 0.262 nm, respectively. Minimum width for InAs in InP is realized by substituting one-layer of P with As and corresponds to half monolayer thickness for (110). Thus in the elastic continuum model, thinnest InAs QW is expected to be 0.219 nm, and the well width should be its integer multiples. Considering the accuracy of the present model, these results reiterate the formation of InAs QWs on the sidewalls of InP nanowires and the multiple peaks indicate that there might be monolayer QW thickness variations in individual nanowires in an array. The peak broadening, in this case also, can be partly attributed to the inhomogeneous strain in the InAs layer in the nanowire array. Further, the InAs layer thickness is less in nanowires with 0.4 μm period than that of nanowires with 3 μm period. This difference in the InAs layer thickness may be attributed to the gas-phase diffusion of In, in which case the lateral growth rate of InAs on the sidewalls is much higher for smaller density of nanowires i.e. for nanowire array with larger period. However this kind of diffusion model cannot fully account for the vertical growth rate of nanowires, thus requiring more detailed investigation.

In summary, we have designed and demonstrated the fabrication of single-crystalline InP and InP/InAs/InP core-mutlishell heterostructure nanowires consisting of a strained InAs radial QW. The grown core-multishell nanowires exhibited distinct features and the cross-sectional SEM studies revealed that the InAs QW was well-defined with few nm layer thickness which can be accurately defined by growth conditions. PL studies on individual nanowires showed a single emission peak while an array of nanowires exhibited multiple peaks, corresponding to InAs strained QWs formed on InP (110) sidewalls which was confirmed by calculations. These innovative core-multishell nanowires are likely to exhibit distinct quantum phenomena and also unique properties related to electron scattering under applied magnetic field and can thus serve as an ideal platform for both fundamental research and future device applications.

**References**

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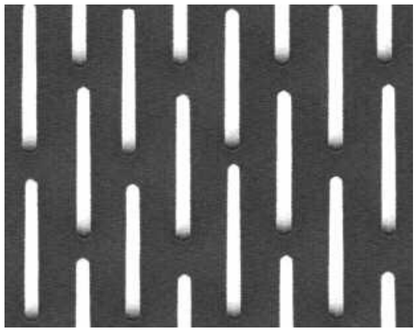

Figure 1. InP nanowire array on (111)A InP.

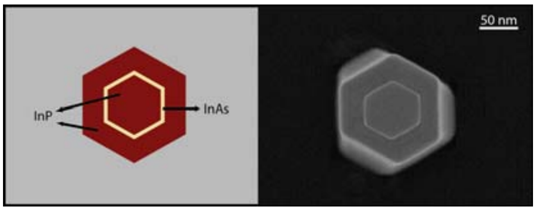


Figure 2. Schematic illustration and high resolution SEM cross-sectional image of a typical core-multishell nanowire observed after anisotropic dry etching and stain etching.

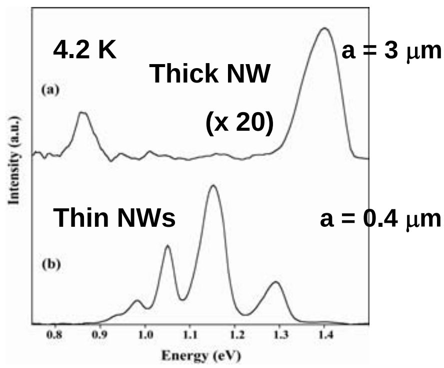


Figure 3. 4K PL spectra of nanowire arrays with (a) 3 μm and (b) 0.4 μm period, respectively.