Growth and Characterization of III-V Compound Semiconductor Nanowires

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Abstract - We review various III-V compound semiconductor nanowires grown by metalorganic chemical vapor deposition. Transmission and scanning electron microscopy, micro-photolumine -scence and micro-Raman spectroscopy have been used to understand the crystal structure, light emission and band structure.

1. Introduction

Semiconductor nanowires and their related heterostructures are intensively being investigated due to their unique growth mechanisms and novel properties. These quasi-one dimensional structures offer unique opportunities to realize novel nanoscale semiconductor devices. III-V compound semiconductor nanowires are of particular interest for optoelectronic devices due to their high optical emission efficiency compared to indirect-bandgap group IV crystals. Various III-V compound semiconductor nanowire-based devices, including solar cells, photodetectors, biosensors, light emitting diodes and single electron devices have already been demonstrated. The typical nanowire growth mechanism is often described as a vapor-liquid-solid (VLS) mechanism, first proposed by Wagner and Ellis for silicon whiskers grown with an Au particle [1]. This growth mechanism has been extremely flexible, for example, nanowire heterostructures can be grown in either the axial direction by alternating precursors or the radial direction (core-shell) by increasing growth temperature. On the other hand, due to the large nanowire surface area in comparison to its volume and the small contact area between a nanowire and its substrate, the strain induced at heterointerfaces in nanowires can be elastically relieved over a thickness of a few monolayers which offers great advantage in integrating two lattice-mismatched materials without forming misfit dislocations.

2. Experiment

All nanowires were grown by horizontal flow metal-organic chemical vapor deposition (MOCVD) reactor at 100 mbar. The substrates were firstly treated by Poly-L-lysine (PLL) solution to attach Au particles onto the surface. Au particles having a diameter of 20-50 nm were used as catalysts here. After Au attachment was finished, the sample was annealed again under AsH_3 or PH_3 ambient to remove contamination and form the eutectic alloys. GaAs or InP nanowires were grown at temperatures between 375 °C and 550 °C for 30 minutes. In the case of GaAs/AlGaAs and GaAs/GaP core-shell nanowires, the shell growth was carried out at 650 °C for 10 minutes.

All nanowires were characterized by field emission scanning electron microscopy (FE-SEM), transmission electron microscopy (TEM), and micro-photolumine

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-scence (μ-PL) and/or micro-Raman measurements.

3. Summary

In summary, growth of GaAs nanowires has been studied in detail by varying the growth temperature, growth rate and V/III ratio. We have demonstrated that GaAs nanowires of high optical and crystallographic quality may be achieved by choosing an appropriate V/III together with growth temperature or growth rate. We also developed a two-temperature growth technique [2]. Using this technique, we demonstrated the growth of defect-free GaAs nanowires with minimized tapering. These nanowires exhibit more uniform diameter and enhanced PL compared to nanowires grown using a one-temperature growth process. Using these defect-free GaAs nanowires as core, we have successfully grown GaAs/AlGaAs/GaAs and GaAs/GaP core-shell nanowires. Nearly intrinsic exciton lifetimes (~1 ns) were obtained in GaAs/AlGaAs core-shell nanowires which are comparable to high quality two-dimensional double heterostructures [3]. It was also found that the PL emission energy from GaAs core in GaAs/GaP core-shell nanowires clearly shifts to higher energies by ~260 meV due to the compressive strain [4].

We have also used transient terahertz photoconductivity measurements to assess the efficacy of two-temperature growth and AlGaAs shell encapsulation on the electronic properties of GaAs nanowires. We demonstrate that two-temperature growth of the GaAs core leads to an almost doubling in charge-carrier mobility and a tripling of carrier lifetime. In addition, overcoating the GaAs core with a larger-bandgap material is shown to reduce the density of surface traps by 82%, thereby enhancing the charge conductivity [5].

Results also show that by choosing a combination of V/III ratio and nanowire diameter, we are able to achieve InP nanowires either in ZB crystal or WZ crystal phase. Mixed phases of ZB/WZ structures were also obtained in a single InP nanowire. Time resolved photoluminescence measurements have shown a type II band alignment in these ZB/WZ mixed phase nanowires. Extremely long carrier lifetime (~8400 ps) was observed in WZ dominant nanowires.

In the case of InAs, pure ZB nanowires, free of twin defects, were achieved using a low growth temperature coupled with a high V/III ratio. Conversely, a high growth temperature coupled with a low V/III ratio produced pure WZ nanowires free of stacking faults. Critical to achieving phase purity are changes in surface energy of the nanowire side facets, which in turn are controlled by the basic growth parameters of temperature and V/III ratio. This ability to tune crystal structure between twin-free ZB and stacking-fault-free WZ not only will enhance the performance of nanowire devices but also opens new possibilities for engineering nanowire devices, without restrictions on nanowire diameters or doping.

4. Acknowledgment

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5. References

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