Epitaxy of III-V semiconductor nanowires towards optoelectronic devices

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Abstract

GaAs and InP based nanowires were grown epitaxially on GaAs or InP (111)B substrates by MOCVD via VLS mechanism. In this paper, I will give an overview of nanowire research activities in our group.

Introduction

Semiconductor nanowires are intensively being investigated due to their unique growth mechanisms and novel properties [1-3]. The 1-dimensional anisotropic growth via vapor-liquid-solid (VLS) mechanism was first developed by Wagner and Ellis more than 40 years ago when they grew um-sized Si whiskers on Si wafers using Au particles as the catalyst [4]. Recently this growth technique has been extended to nm-sized Au particles on a variety of semiconductor materials including III-V, II-VI compound and group IV elemental semiconductors. However, III-V semiconductor nanowires grown via vapor-liquid-solid (VLS) mechanism often exhibit several problems: for example, tapered morphology, high density of planar defects, mixed WZ and ZB crystal structures, kinked heterostructures and low light emission efficiency. These problems have to be resolved before the commercial device applications for nanowires. In this paper, I will present the research activities in our group at the Australian National University to tackle these problems. Results have shown great success in improving morphology, crystal quality and photoluminescence efficiency of GaAs nanowires.

Experimental

Nanowires were grown epitaxially on semi-insulating GaAs or InP (111) semiconductor substrates by metalorganic chemical vapor deposition (MOCVD) using Au nanoparticles as catalyst. Substrates were functionalized by immersion in poly-L-lysine (PLL) solution, and treated with gold colloid solution (10, 20, 30 or 50 nm diameter Au particles). The Au nanoparticles are attracted to, and immobilized on, the positively charged PLL layer. Nanowires, seeded by these nanoparticles, were grown by horizontal flow MOCVD at a pressure of 100 mbar using trimethylgallium (TMGa), trimethylindium (TMIn), trimethylaluminium (TMAl), AsH3 and PH3 precursors. Nanowires were grown at temperatures between 350 and 510 ºC for times of approximately 30 minutes. For core-shell nanowire heterostructures, GaAs and AlGaAs shells were grown at 650 °C, at which radial growth is dominant.

Results and Discussion

Growth parameters of GaAs nanowires have been studied in detail including growth temperature, growth rate and V/III ratio [5]. It was found that the axial growth rate of nanowires increases with increasing V/III ratio. It is also interesting to see that more nanowires tend to kink at a V/III ratio higher than 90. We have demonstrated that GaAs nanowires of high optical and crystal quality may be achieved by choosing an appropriate V/III together with growth temperature. A high V/III ratio markedly reduces the formation of twin defects and minimizes carbon impurity incorporation resulting in nanowires with excellent optical properties. Moreover, unexpected benefits of rapid growth rate were discovered for GaAs nanowires [6]. The resulting GaAs nanowires are markedly less tapered, free of planar crystallographic defects, and have very high purity with minimal intrinsic dopant incorporation. Importantly, carrier lifetimes are not adversely affected. These results reveal intriguing behavior in the growth of nanoscale materials, and represent a significant advance towards the rational growth of nanowires for device applications.

In order to minimize the tapering of nanowires and improve the crystal quality, we also developed a two-temperature growth technique. Using this technique, we demonstrated the growth of twin-free GaAs nanowires with minimized tapering [7]. These nanowires exhibit more uniform diameter and enhanced PL compared to nanowires grown using a one-temperature growth process.

For core-shell GaAs/AlGaAs/GaAs nanowire hetero-structures, GaAs and AlGaAs shells were grown at 650 °C, at which radial growth is dominant. GaAs core was grown at 375°C using the two-temperature growth technique. Nearly intrinsic exciton lifetimes (~1 ns) were

obtained in these twin-free GaAs/AlGaAs core-shell nanowires [8], which are comparable to high quality two-dimensional double heterostructures. These GaAs nanowires allow one to observe state filling and many-body effects resulting from the increased carrier densities accessible with pulsed laser excitation.

Effects of three main growth parameters, including growth temperature, V/III ratio and nanowire diameter, on the crystal structure of InP nanowires were studied. Results show that by choosing a combination of these growth parameters, we are able to achieve InP nanowires either in ZB crystal or WZ crystal phase. Mixed phases of ZB/WZ structure was 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 [9].

Conclusion

In summary, we have reviewed our research activities on III-V compound semiconductor NWs. High quality binary and ternary NWs and their core/shell or axial heterostructures have been synthesized in a controllable way. These NWs may have immediate applications in nano-scale opto- electronic devices.

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