HETEROSTRUCTURE FORMATION IN III-V NANOWIRES GROWN ON SILICON

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INTRODUCTION

III-V nanowires (NWs) have potential applications in many fields, from optics and electronics [1], to solar cells [2] and beyond. While many of the predicted 1D effects in NWs are proving hard to confirm experimentally, currently much promise in the field comes from the growth of heterostructures. This is achieved through growth of lattice mismatched materials, which is facilitated in NWs due to their relaxed strain conditions [3], or crystal-phase engineering [4], both of which present exciting opportunities for band engineering in nanostructures.

The research reported here is concerned with the growth of lattice-mismatched III-V materials in various NW geometries. An overview of electrical and optical properties of these heterostructures will be given, along with the discussion of their growth and potential device applications.

MATERIALS AND METHODS

In this study, NWs were grown via self-catalyzed molecular beam epitaxy (MBE) on Si(111) substrates. Optically we have studied $In_{0.16}Ga_{0.84}As$/GaAs, where $In_{0.16}Ga_{0.84}As$ (band gap at room temperature: 1.196eV) forms quantum wells in GaAs (band gap at room temperature: 1.42eV). The NWs incorporate multiple InGaAs quantum wells formed radially by core-shell growth. Electrically we have studied GaAs/BGaAs, where the bandgap of BGaAs is hypothesised not to deviate greatly from that of GaAs, but due tothe small lattice constant of BAs and other anomalous properties, growth in planar geometry has proven difficult.

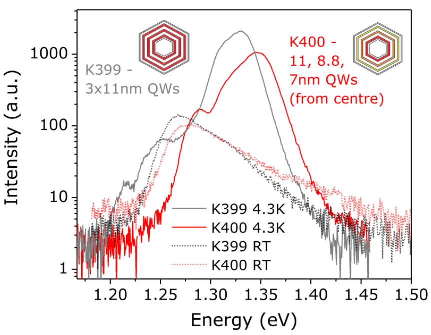

Figure 1: Photoluminescence measurements taken on multi-quantum well GaAs/InGaAs nanowires at room temperature and 4.3K. Inset are the schematics of the radial NW quantum wells.

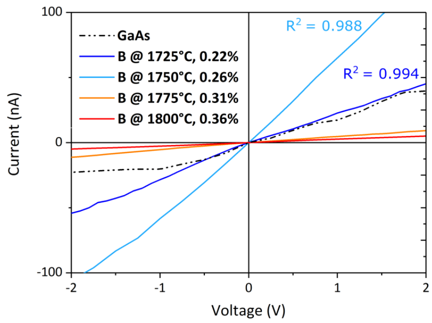

Figure 2: Two-point IV measurements taken on GaAs/(B)GaAs nanowires, with an undoped GaAs reference

Optical measurements were performed with a commerical confocal photoluminescence (PL) setup (Witec Alpha 300). NWs were excited in continuous wave mode via a fiber-coupled 532nm sapphire laser, and the PL spectrum was coupled through a blazed grating spectrometer (BLZ 760nm) enhanced for visible/near-infrared emission. Spectra were recorded on an Andor iDUS CCD cooled to -60C. Measurements were taken at room temperature, or mounted to copper plates and measured at 4.3K in a He closed-cycle cryostat.

Electrical measurements were taken on NWs dispersed on 50nm thermal SiO_2 on Si substrates contacted in 2- and 4pt geometries. Contacts were defined via e-beam lithography and p-type contacts (Au/Zn/Au, 5/10/100nm) were deposited in a Balzers thermal evaporator. This contact metallization was chosen in anticipation of the fact that boron in GaAs acts as a doubly-charged acceptor when incorporated on As sites [5].

RESULTS AND DISCUSSION

Photoluminescence measurements on $In_{0.16}Ga_{0.84}As$/GaAs multi-quantum wells (figure 1) is blue-shifted when the outer quantum well is thinner, regardless of the inner quantum well thickness. This means that recombination of carriers occurs preferentially in outer quantum wells, which suggests that there is downwards band-bending in the NW heterostructure, thus carriers diffuse preferentially to the nanowire edge, regardless of where in the NW they are excited. This is an effect that we would like to further investigate by looking at the surface states and band alignments of our structures, as well as through measurements exploring the carrier dynamics in the NWs.

Electrical measurements on GaAs/(B)GaAs nanowires are shown in figure 2. Adding a small amount of boron during growth disrupts the normal growth process, leading to boron atoms incorporating on antisite defects, where they act as doubly-charged acceptors. This leads to p-type doping of the NWs, which is evident in the fact that Ohmic contacts are formed to NWs at all boron concentrations.

CONCLUSION

The results presented here have an interesting impact on the growth of radial NW heterostructures containing lattice-mismatched III-V materials. BGaAs has never been grown in nanowires, and we have shown for the first time its potential for use in such structures, while highlighting some of the difficulties in its incorporation during growth. At the same time, the fact that recombination preferentially occurs in the outer NW shells must be taken into account when designing band-engineered structures in NWs. The eventual aim of this research is to design such band-engineered structures exploiting the optical and electrical properties of the constituent materials.

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