Abstract

Indium antimonide (InSb) is a competitive semiconductor for the applications in high electron mobility transistor and mid-infrared photodetector. Integration of InSb on GaAs, Ge and Si substrates can increase the performance of devices, decrease the cost of fabrication and become an important component of optoelectronic integrated circuit. Therefore, much efforts has been placed on the investigation of novel heteroepitaxial approaches to overcome the high lattice mismatch (14.6% for InSb/GaAs and 19.3% for InSb/Si) and different crystal structures between InSb and these substrates.

The thesis focuses on the integration of InSb on lattice mismatched substrates (GaAs and Si) using solid-state molecular beam epitaxy (MBE) system. First, interfacial misfit (IMF) array was intentionally formed at the InSb/GaAs interface to accommodate the lattice mismatch via surface anion exchange. The relationship between the growth temperature and the formation of IMF was investigated. Transmission electron microscope (TEM) images of the sample grown at 310 °C demonstrated an IMF array consisting of 90° misfit dislocations distributing uniformly along the interface and their separation (3.2 nm) agreed well with the calculated result. Grow temperature above 310 °C suppressed the surface anion exchange to impede the formation of IMF array. Below 310 °C, island coalescences led to the formation of threading dislocations. InSb on GaAs grown at 310 °C exhibited an electron mobility of 33840 cm^2/Vs at room temperature.

Further optimization of growth process focuses on two areas: pre-growth Sb reconstructions and in situ thermal annealing. Sb atoms owns three kinds of reconstructions on GaAs surface and III-Sb (GaSb and InSb) layers were grown on GaAs with different

pre-growth Sb reconstructions. Simulation demonstrated x-ray reciprocal space map (RSM) can characterize the distribution of misfit dislocations in the IMF array. The results of RSM showed pre-growth (2×8) Sb reconstruction promoted the formation of 90° misfit dislocations in an IMF array. The highest carrier mobilities were achieved in the III-Sb layers grown on GaAs with pre-growth (2×8) Sb reconstruction. The optimized anneal process is 5 minutes at 590 °C for GaSb and 15 minutes at 420 °C for InSb. Compared with as-grown III-Sb layers, lower density of threading dislocations, flatter surface and higher carrier mobility was observed in the annealed ones. Annealing also improved the photoresponsivity of GaSb and InSb photoconductors on GaAs.

To realize the integration of InSb on Si, GaAs buffer is grown on Ge-on-Si substrates followed by InSb grown on GaAs via IMF array. An InSb p-i-n photodetector is developed based on this structure. An electron barrier layer was inserted into the conventional architecture of p-i-n photodetector to suppress the dark current. The electrical and photonic properties of the photodetector were investigated.

Another approach of the integration of InSb on Si through AlSb/GaSb buffer was also investigated. In this buffer, GaSb was grown on Si using IMF array to avoid the formation of threading dislocations and InSb quantum dots (QDs) were grown on AlSb surface to decrease the density of micro-twins. TEM images showed uniform IMF array existed at the GaSb/Si and QDs nucleated at the sites micro-twins to terminate them. AlSb and GaSb were respectively applied on the top layer of buffer to provide a surface for the subsequent growth of InSb. InSb on AlSb surface demonstrated higher crystal quality and electron mobility. Moreover, the photoresponsivity in InSb photoconductor on AlSb is higher than that on GaSb.