Characterisation of GeSn superlattices grown by RPECVD on Si and Ge substrates

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The growth of germanium-tin (GeSn) alloy films for fabricating mid-infrared optoelectronic has been of considerable interest in recent years. Despite a low equilibrium solubility limit for Sn in Ge of less than 1 at. %, remote plasma-enhanced chemical vapor deposition (RPECVD) has been successful in growing GeSn films with Sn content exceeding 10 at. %, opening possibilities for mid-infrared lasers and photodetectors. However, synthesizing high-quality GeSn alloys is challenging, due to the tendency for Sn to phase separate under elevated temperature growth conditions, as well as a significant lattice mismatch between the alloy and the substrate (usually single crystal Ge or Si). Although thin GeSn films are usually strained with low defect density, thicker ones suitable for lasers and photodetectors, on the other hand, relax during growth but contain a high density of defects, which degrade the electrical and optical properties of the alloy. The growth of GeSn-Ge superlattices, where each layer thickness is less than a critical thickness for relaxation depending on Sn content, can potentially provide thicker films that are strain free and contain fewer defects.

In this study, GeSn-Ge superlattices of varying Sn composition, layer thickness and number of superlattice layers have been grown on either a Si or a Ge substrate by RPECVD. The internal strain and defect properties of the final films were measured by different techniques, including Rutherford backscattering spectrometry with channelling (RBSC), Raman spectroscopy (RS), X-ray diffraction (XRD), and cross-sectional transmission electron microscopy (XTEM). RBSC was used to measure the average Sn content of this superlattice (in comparison with the nominal XRD composition) and to examine the lattice expansion and contraction of the layers by channelling along different crystallographic directions. RS monitored defect density by the examining the width of the transverse optical (TO) Ge-Ge mode and could confirm low defect density in strained cases. XTEM showed that a thicker superlattice was partially relaxed, where threading-like dislocations, generated from the interface of the Si substrate and the first Ge-GeSn layers, propagated throughout the remaining superlattice structure. In addition, the individual layers were somewhat corrugated. Selected films were annealed to fully relax the alloy superlattices. Typically, following RPECVD growth on Ge, a small number of thin layers with low Sn compositions resulted in a fully strained superlattice that was defect-free, whereas thicker structures on Si of comparable individual layer thickness and composition tended to partially or fully relax during growth. Characterisation of these superlattice films is critical for building up a complete picture of the superlattice strain and nature of defects as a function of layer thickness, and to further assess which films may be appropriate for device applications.