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Student Paper

Characterization of Epitaxially Grown $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ Layers for Mid-Infrared Optoelectronic Devices

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Abstract:
Quaternary Sb-based alloys have been widely employed for producing excellent mid-infrared optoelectronic devices [1-3]. $In_XGa_{1-X}As_ySb_{1-y}$ is of interest, because of the many mid-infrared applications it affords including thermal photovoltaic energy converters, diode lasers, and photodetectors to name a few [1-6]. Super lattices are also possible with the growth of $Al_xGa_{1-x}As_ySb_{1-y}$ as barrier layers for MQW structures. However, these structures have proven to be extremely difficult to grow due to a wide solid-state miscibility gap [4]. Typically, these structures are grown lattice matched to GaSb or InAs substrates with varying compositions. Liquid phase epitaxial growth is widely used for growing these quaternary compounds, but has been limited to an x value of 0.2 for $In_XGa_{1-X}As_ySb_{1-y}$ [5]. Smooth epitaxial layers have been grown up to x=0.26 with molecular beam epitaxy (MBE), however the ability to grow psuedomorphically declines with increased In composition. Lattice matched layers (<1% mismatch) are ideal for producing direct band gap semiconductor devices. Conversely, strained structures are possible by growing lattice mismatched structures, which offer their own set of benefits. For instance, In induced compressive strain in MQW structures increases the conduction band offset, thereby increasing carrier confinement and opening up new energy level transitions for lower band gap semiconductors.

We report the successful growth of 100nm $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ epitaxial layers grown in a Varian Gen II solid source MBE. The lattice constant is 6.22Å, giving rise to a 2% lattice mismatch when grown on semi-insulated (100) GaSb substrates. Layers were n-doped using GaTe with a carrier concentration of $\sim10^{18}cm^{-3}$ to enhance S/N ratio for optical characterization. Growth temperature was varied between 400-450^{O}C, while growth rate was kept at 0.3 ML/s. The band gap of $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ was calculated to be 0.404 meV using the derivation pioneered by Sadao Adachi [6].

$In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ layers were characterized with Raman spectroscopy. Raman spectra obtained from quaternary layers were compared to that of bare (100) GaSb. Figure 1 shows a notable drop in the Raman intensity from the GaSb substrate to $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ epitaxial layers. Results demonstrate the degradation of smooth growth layers with increased In composition. The LO and TO phonons are clearly distinguishable at 240 cm^{-1} and 260 cm^{-1}, respectively in the GaSb wafer and 220 cm^{-1} and 260 cm^{-1}, respectively in the quaternary alloy. The 20 cm^{-1} shift of the LO phonon in the quaternary alloy with respect to that of the GaSb wafer indicates an increase in scattered photon energy due to the compressive strain induced by the high In content of $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$. The Raman resonances higher in the spectrum in the GaSb wafer are suppressed by the quaternary layer. The InSb-like peaks at 270 cm^{-1} and 290 cm^{-1} of the quaternary layers represent LO and TO phonon vibrational levels. The final peak at 250 cm^{-1} is unattributed, but could represent excess antimony in the layer.

We also examined the Raman spectra of an InGaAsSb/AlGaAsSb MQW structure grown by MBE (earlier, unpublished work). Figure 2 shows the composition of the three well structure. The MQW Raman spectra as compared to a 100 nm layer of $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ is shown in Figure 3. Raman spectra was obtained with an input power of 7.5 mW to excite as many resonant modes as possible for the layer/MQW comparison. Unsurprisingly, the MQW shows an extra resonant peak at 330 which is attributed to an AlSb-like LO phonon vibrational resonance peak. The greater distinguishability in the

MQW structure between resonant peaks is evidence for increased carrier confinement due to the increased strain afforded by multiple lattice mismatched layers of InGaAsSb.

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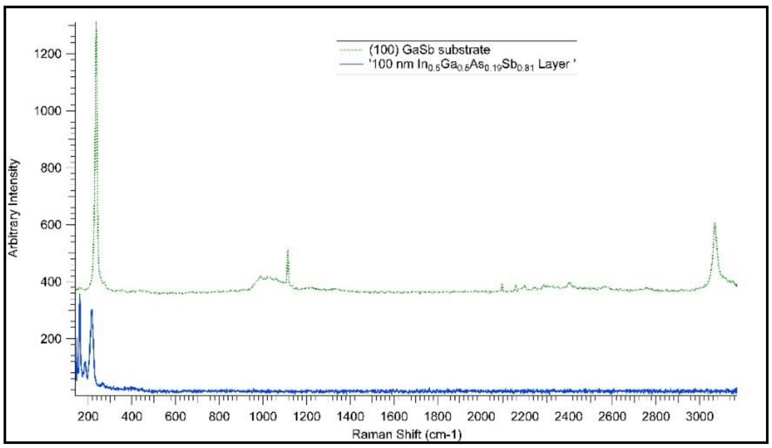

Fig. 1. Raman spectra comparison of a bare (100) GaSb wafer (above) with that of 100 nm layers of epitaxially grown $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ (below). Graphs have been offset for easier comparison.

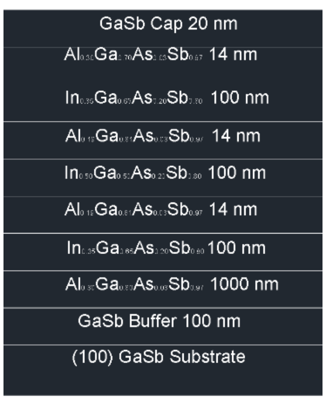

Fig. 2. Schematic diagram of the MQW structure. Composition of layers is as follows: $Al_{0.30}Ga_{0.70}As_{0.03}Sb_{0.97}$/$\mathbf{In_{0.35}Ga_{0.65}As_{0.20}Sb_{0.80}}$/ $Al_{0.19}Ga_{0.81}As_{0.03}Sb_{0.97}$/$\underline{\mathbf{In_{0.50}Ga_{0.50}As_{0.20}Sb_{0.80}}}$/ $Al_{0.19}Ga_{0.81}As_{0.03}Sb_{0.97}$/$\mathbf{In_{0.35}Ga_{0.65}As_{0.20}Sb_{0.80}}$/ $Al_{0.30}Ga_{0.70}As_{0.03}Sb_{0.97}$. Quantum wells are bolded; additionally the well most comparable to grown layer of $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ is underlined. Structure has a maximum well lattice mismatch of 2% on GaSb substrate.

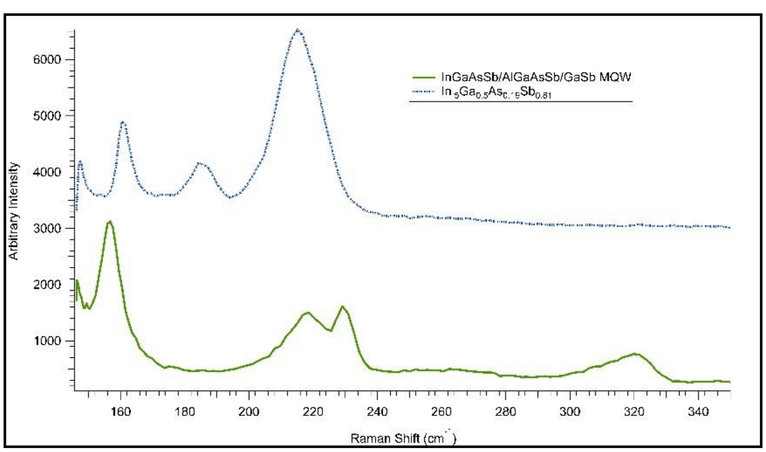

Fig.3. Comparison of the Raman spectra from a single 100 nm layer of $In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81}$ (above) with that of the MWQ structure (below) in Fig. 2. Resonances are more distinguished in the MQW structure due to increased carrier confinement as a result of compressive strain from the 2% lattice mismatch on GaSb (100). Zoomed in view of spectra from 125-400 cm^{-1} presented, because, higher Raman resonances are suppressed in both the layer and MQW.