

Exploring New Active Regions for Type I InAsSb Strained-Layer Lasers

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ABSTRACT

We report on the metal-organic chemical vapor deposition (MOCVD) of mid-infrared InAsSb/InPSb optically pumped lasers grown using a high speed rotating disk reactor (RDR). The devices contain AlAsSb claddings and strained, type I, InAsSb/InPSb active regions. By changing the layer thickness and composition of InAsSb/InPSb SLSs, we have prepared structures with low temperature ($<20\text{K}$) photoluminescence wavelengths ranging from 3.4 to $4.8\text{ }\mu\text{m}$. We find a variation of bandgap from 0.272 to 0.324 eV for layer thicknesses of 9.0 to 18.2 nm . From these data we have estimated a valence band offset for the InAsSb/InPSb interface of about 400 meV . An InAsSb/InPSb SLS, optically pumped laser structure was grown on an InAs substrate with $\text{AlAs}_{0.16}\text{Sb}_{0.84}$ claddings. A lasing threshold and spectrally narrowed laser emission was seen from 80 K through 200 K , the maximum temperature where lasing occurred. The temperature dependence of the SLS laser threshold is described by a characteristic temperature, $T_0 = 72\text{ K}$, from 80 to 200 K .

Introduction

We are exploring the growth of novel mid-infrared ($3\text{-}5\text{ }\mu\text{m}$) emitters (lasers and LED's) by metal-organic chemical vapor deposition (MOCVD) for use in infrared countermeasures and chemical sensor systems. Previously we have made gain-guided,

injection lasers using not intentionally doped, p-type $\text{AlAs}_{0.16}\text{Sb}_{0.84}$ for optical confinement and both strained InAsSb/InAs multiple quantum well (MQW) and InAsSb/InAsP strained-layer superlattice (SLS) active regions [1,2]. We have also reported the first ten-stage cascaded lasers and LED's with type I InAsSb/InAsP quantum-well active regions grown by MOCVD[3]. These cascaded lasers employ a (p) GaAsSb/ (n) InAs semimetal electron/hole source between stages. In compressively strained InAsSb SLSs, it is necessary to maximize the light-heavy ($|3/2, \pm 1/2\rangle$ - $|3/2, \pm 3/2\rangle$) hole splitting to suppress non-radiative Auger recombination. Recently, Bewlwy et al. have reported record high output powers and operating temperatures for mid-infrared $\text{InAs/GaInSb/AlAsSb}$ type II optically pumped lasers using a diamond-pressure-bond heat sinking technique [4]. We are currently exploring the growth of new emitter structures as well as the use of novel materials in these structures to improve our laser performance. In an attempt to further reduce the Auger recombination by increasing the hole confinement we have used InPSb as the barrier layer in the active region. We report on the synthesis and properties of these InAsSb/InPSb SLSs grown by MOCVD and their use in 3-4 μm , mid-infrared optoelectronic heterojunction emitters.

Experimental

The InAsSb/InPSb SLSs were grown by MOCVD on n-type InAs substrates. The SLSs were grown at 500 $^{\circ}\text{C}$, and 70 torr in an Emcore D75 high speed rotating disk reactor using trimethylindium (TMIn), triethylantimony (TESb), 100% or 10 % AsH_3 in hydrogen, 100 % PH_3 , and hydrogen as the carrier gas. The SLS composition and strain were determined by double crystal x-ray diffraction.

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Infrared photoluminescence (PL) was measured on all samples from 16 K up to 300 K using a double-modulation, Fourier-transform infrared (FTIR) technique which provides high sensitivity, reduces sample heating, and eliminates the blackbody background from infrared emission spectra. The laser output characteristics were also measured using double modulation FTIR.

Results and Discussion

The InAsSb/InPSb SLSs were grown at 500 °C, and 70 torr in a high speed rotating disk reactor. The InAsSb layers were grown using a V/III ratio of 7.5 to 15 and an AsH₃/(AsH₃+TESb) ratio of 0.69 to 0.88 for compositions between 0.1 and 0.25 Sb in InAsSb at a growth rate between 2.5 to 5 Å/second. A 1 second purge, with all reactants except for AsH₃ switched out of the chamber, was used between each layer. The growth rate was found to be proportional to the TMIn flow into the reaction chamber and independent of the TESb and AsH₃ flow. The InPSb layers were grown using a V/III ratio of between 400 to 900 and a TESb/(TESb + PH₃) ratio of 0.004 to 0.002 with growth rates of 2.5 to 5 Å/second. If the TESb/(TESb + PH₃) ratio was decreased below 0.002, poor quality superlattices resulted. The SLS composition and strain were determined by double crystal x-ray diffraction. When optimized, the crystal quality of the SLSs was excellent with 4 to 5 orders of x-ray diffraction satellite peaks typically observed. The variation of the Sb composition for the InAsSb layer from 0.115 to 0.18 as a function of AsH₃ flow for a fixed TESb flow is shown in Figure 1. Under similar conditions, the Sb composition could be varied between 0.13 to 0.24 while maintaining constant layer thickness for both the InAsSb and InPSb layers.

The PL peak wavelength dependence on composition for the SLSs is shown in Figure 2. For a change of composition from $x = 0.14$ to 0.20 the PL peak changes from 3.5 to $4.2 \mu\text{m}$ at 16 K . By changing the layer thickness and composition of InAsSb/InPSb SLSs, we have prepared structures with low temperature ($<20\text{K}$) photoluminescence wavelengths ranging from 3.4 to $4.8 \mu\text{m}$. Initial quantum confinement data (Figure 3) indicate that there is about a factor of two greater in the valence band offset between InPSb and InAsSb than between InAsP and InAsSb. Figure 3 illustrates the variation of bandgap from 0.272 to 0.324 eV for layer thicknesses of 9.0 to 18.2 nm . From these data we have estimated a valence band offset for the InAsSb/InPSb interface of about 400 meV .

An optically pumped heterostructure laser was grown on an InAs substrate with a $2 \mu\text{m}$ thick $\text{AlAs}_{0.16}\text{Sb}_{0.84}$ lower cladding followed by a $0.5 \mu\text{m}$ InAs spacer. On top of the InAs spacer, the active region consisted of a 10 period, $\text{InAs}_{0.82}\text{Sb}_{0.18}/\text{InP}_{0.73}\text{Sb}_{0.27}$ ($104 \text{ \AA} / 104 \text{ \AA}$) SLS. In this particular structure, the TESb flows were graded from 80 to 200 sccm over the first 20 percent of both layers growth time to maintain a high TESb concentration at the interface and to increase the P in the barrier layer. The structure was then completed with another $0.5 \mu\text{m}$ of InAs and a $1.0 \mu\text{m}$ top $\text{AlAs}_{0.16}\text{Sb}_{0.84}$ cladding layer. The $\text{AlAs}_{0.16}\text{Sb}_{0.84}$ cladding layer was covered with a 40 nm InAs cap layer to avoid oxidation. The grown heterostructures were cleaved into $1000 \times 80 \mu\text{m}$ bars to form a laser cavity and mounted on a Copper heat sink (with In solder). The SLS laser was pumped with a Q-switched Nd:YAG ($1.06 \mu\text{m}$, 20 Hz , 10 nsec pulse, focused to a $200 \mu\text{m}$ wide line), and emission was detected with an FTIR operated in a step-scan mode. Laser emission was observed from cleaved bars, $1000 \mu\text{m}$ wide, with uncoated

facets. A lasing threshold and spectrally narrowed, laser emission was seen from 80 K through 200 K, the maximum temperature where lasing occurred (See Figure 4(a)). The wavelength of our laser did not appear to shift from 4.00 μm over the 140-200K temperature range. The photoluminescence peak energy for this structure shifted from 3.93 to 4.54 μm over a temperature range of 16 to 300 K. For this InAsSb/InPSb SLS laser, emission occurred nearer to peak of the PL emission than previously reported for MOCVD-grown devices with pseudomorphic InAsSb MQW active regions[1]. The temperature dependence of the SLS laser threshold is described by a characteristic temperature, $T_0 = 72$ K, from 80 to 200 K. (See Figure 4(b)). At 140 K, the estimated peak powers and thresholds of about 10-100 mW/facet and 10-100kW/cm² are similar to those observed for the previously reported InAsSb/InAsP SLS lasers [2]. With further improvement in growth conditions and laser design this high T_0 indicates that higher performance lasers are possible with the InAsSb/InPSb SLSs.

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Figure Captions

Figure 1. Incorporation of Sb into the InAsSb layer as a function of $\text{AsH}_3/(\text{AsH}_3 + \text{TESb})$ ratio in the vapor phase for the InAsSb/InPSb SLSs.

Figure 2. Low temperature PL ($< 20\text{K}$) from 10 period 108\AA $\text{InSb}_x\text{As}_{1-x}/108\text{\AA}$ $\text{InP}_{0.74}\text{Sb}_{0.26}$ SLS's grown on InAs for different Sb content in the InAsSb layer.

Figure 3. Bandgap versus InAsSb layer thicknesses in InAsSb/InPSb SLSs showing the effects of quantum confinement.

Figure 4. (a) Lasing spectrum for a laser with an $\text{InAs}_{0.82}\text{Sb}_{0.18}/\text{InP}_{0.73}\text{Sb}_{0.27}$ (104\AA / 104\AA) SLS active region (b) Threshold optical pump power versus temperature. Above 200 K, InAs is lasing

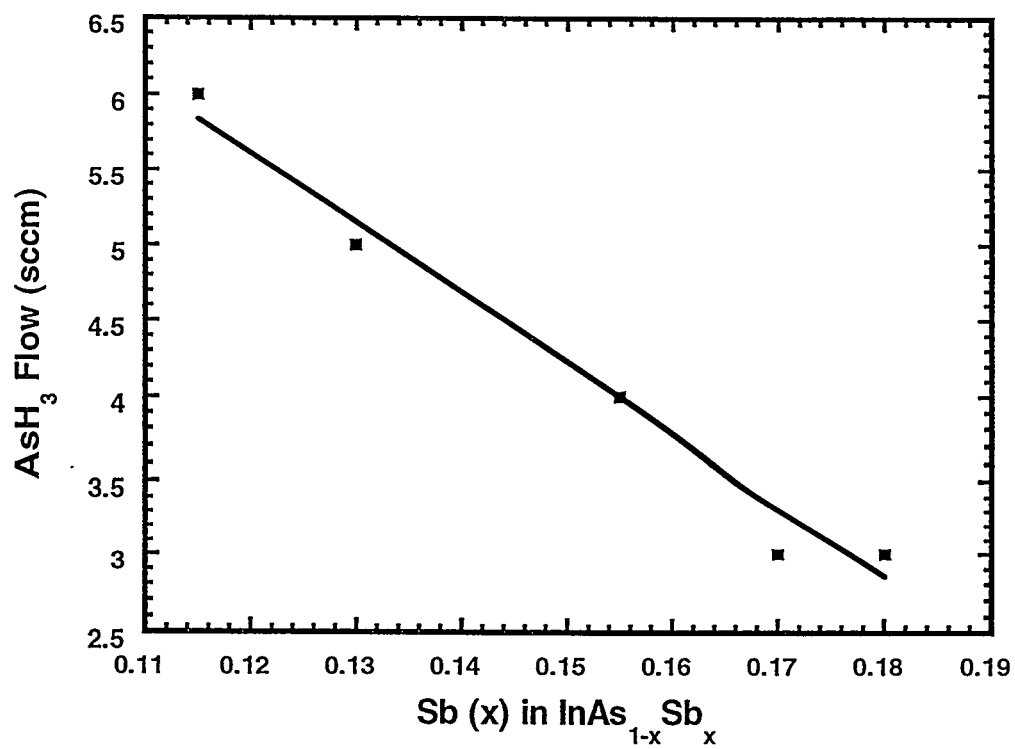


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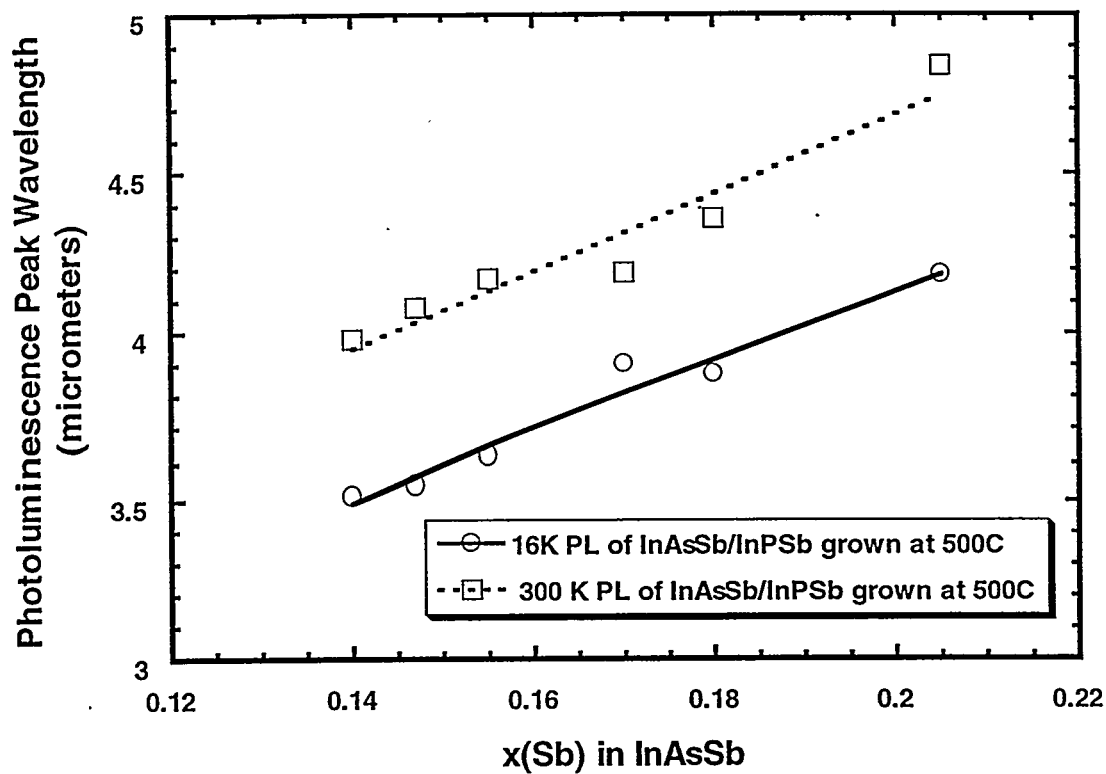


Figure 2. Low temperature PL ($< 20\text{K}$) from 10 period 108\AA $\text{InSb}_x\text{As}_{1-x}/108\text{\AA}$ $\text{InP}_{0.74}\text{Sb}_{0.26}$ SLS's grown on InAs for different Sb content in the InAsSb layer.

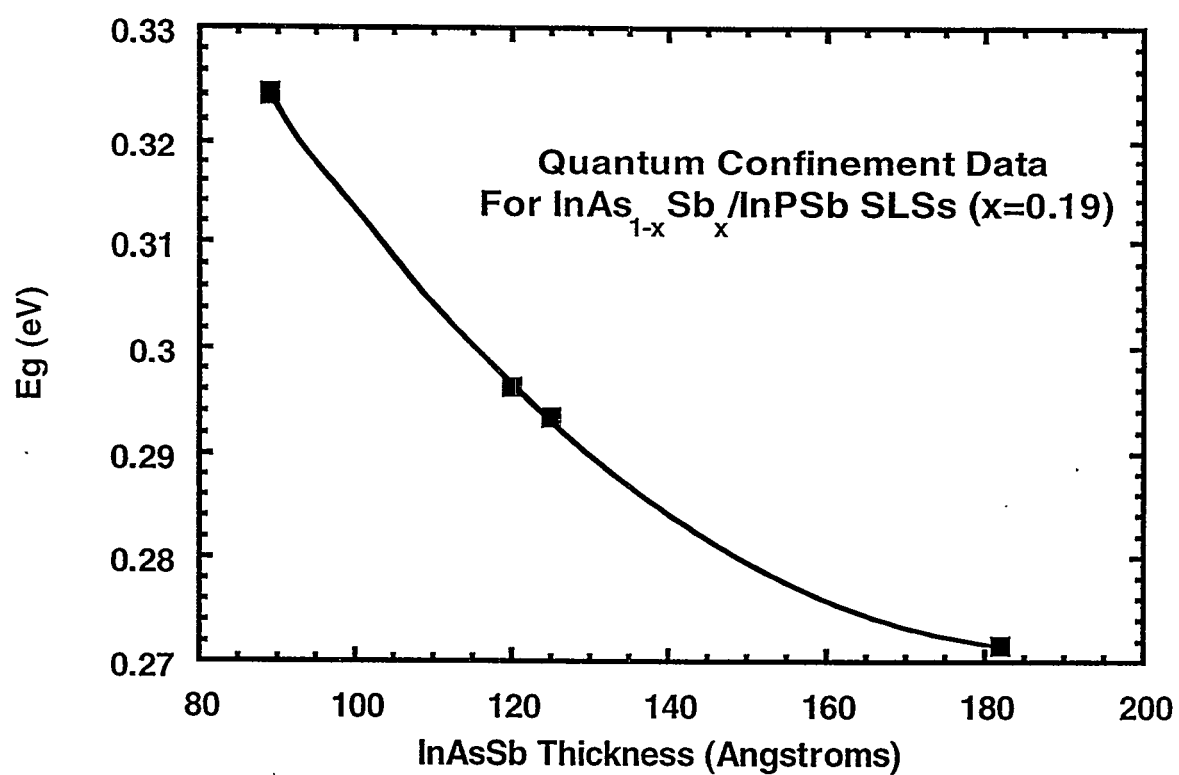


Figure3. Bandgap versus InAsSb layer thicknesses in InAsSb/InPSb SLSs showing the effects of quantum confinement.

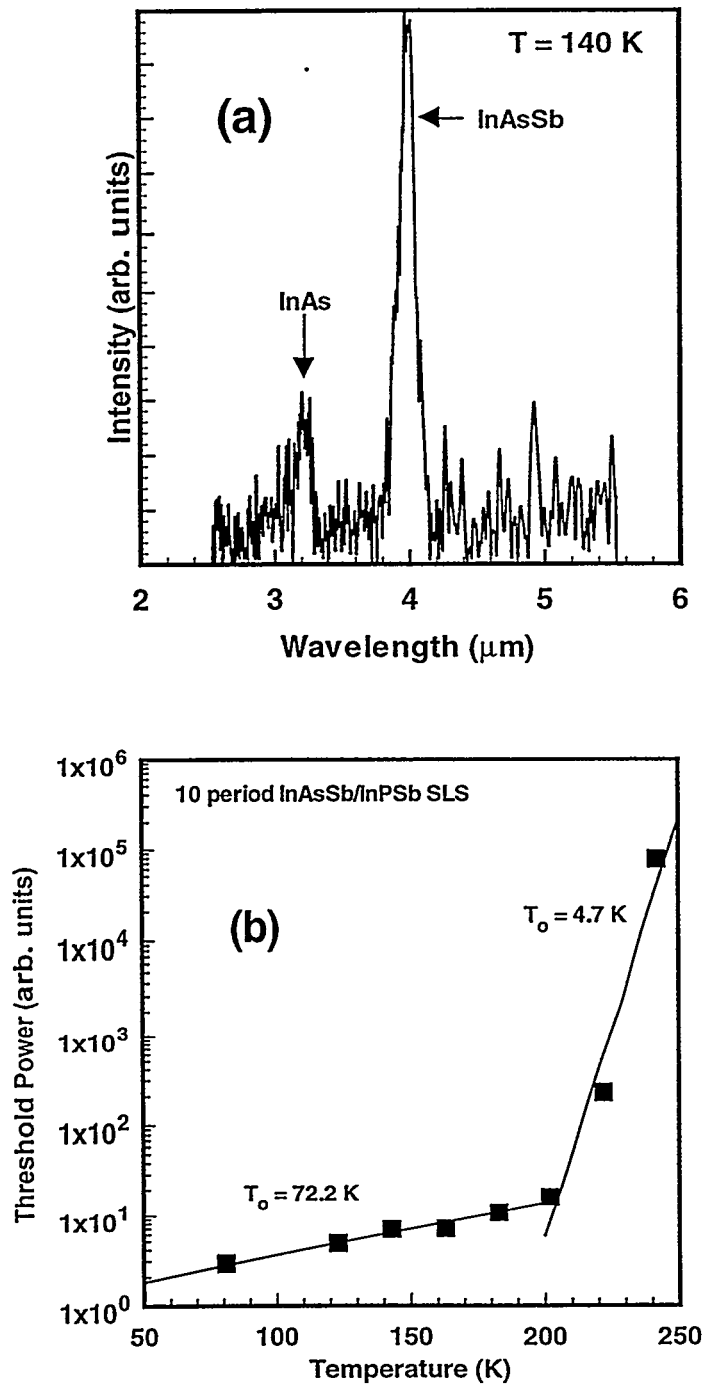


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