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THE GROWTH OF InAsSb/InAs/InPSb/InAs MID-INFRARED EMITTERS BY METAL-ORGANIC CHEMICAL VAPOR DEPOSITION

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ABSTRACT

We report on the metal-organic chemical vapor deposition (MOCVD) of strained layer superlattices (SLSs) of InAsSb/InAs/InPSb/InAs as well as mid-infrared optically pumped lasers grown using a high speed rotating disk reactor (RDR). The devices contain AlAsSb cladding layers and strained, type I, InAsSb/InAs/InPSb/InAs strained layer superlattice (SLS) active regions. By changing the layer thickness and composition of the SLS, we have prepared structures with low temperature (<20K) photoluminescence wavelengths ranging from 3.4 to 4.8 μm. The optical properties of the InAsSb/InPSb superlattices revealed an anomalous low energy transition that can be assigned to an antimony-rich, interfacial layer in the superlattice. This low energy transition can be eliminated by introducing a 1.0nm InAs layer between the InAsSb and InPSb layers in the superlattice. An InAsSb/InAs/InPSb/InAs SLS laser was grown on an InAs substrate with $AlAs_{0.16}Sb_{0.84}$ cladding layers. A lasing threshold and spectrally narrowed laser emission were seen from 80 through 250 K, the maximum temperature where lasing occurred. The temperature dependence of the SLS laser threshold is described by a characteristic temperature, T_0 = 39 K, from 80 to 200 K.

INTRODUCTION

We are exploring the growth of novel mid-infrared (3-5 μm) 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 $AlAs_{0.16}Sb_{0.84}$ 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 ($|3/2,\pm1/2\rangle$ - $|3/2,\pm3/2\rangle$) hole splitting to suppress non-radiative Auger recombination. Recently, Bewley et al. have reported record high output powers and operating temperatures for mid-infrared 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 in place of InAsP as the barrier layer in the active region. We have reported an initial study on the synthesis and properties of these InAsSb/InPSb SLSs grown by MOCVD [5]. In this previous work we reported on the presence of an anomalous low energy transition that can be assigned to an antimony rich interfacial layer. This paper further explores the properties of these novel superlattices including the elimination of the anomalous transition and improvement of the photoluminescence and lasing properties through the addition of an InAs interfacial layer.

DISCLAIMER

EXPERIMENTAL

The InAsSb/InPSb and InAsSb/InAs/InPSb/InAs SLSs were grown by MOCVD on undoped n-type InAs substrates. We optimized the growth of these structures by first investigating the growth of InAsSb/InAs and InPSb/InAs SLSs. We investigated the InAsSb/InPSb SLS growth using different purge times (1, 3, and 5) seconds with and without arsine flowing during the purge between InAs and the ternary layer growth. This was done to determine the effect of an arsine purge on the quality of the photoluminescence for the SLSs. A low V/III ratio is necessary for the growth of high quality InAsSb. Due to the low vapor pressure of Sb, excess Sb tends to cause surface morphology defects. For InPSb, the V/III ratio is dominated by the excess phosphine flow. A high V/III ratio and excess phosphine flow are necessary because of the high decomposition temperature of phosphine. In both cases, InAsSb/InAs and InPSb/InAs, the composition dependence was reproducible and approximately linear versus AsH_3 flow for InAsSb and TESb flow for InPSb for the composition range that was examined.

The SLSs were grown at 500 or 550 °C and 70 torr in an Emcore D75 high speed rotating disk reactor at 1100 rpm. The sources used were trimethylindium (TMIn), triethylantimony (TESb), 100% or 10 % AsH_3 in hydrogen, and 100 % PH_3. The carrier gas and its quantity were 15 liters of hydrogen. The SLS composition and strain were determined by double crystal x-ray diffraction (DCXRD).

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 layers were grown using a V/III ratio of 7.5 to 15 and an $AsH_3/(AsH_3+TESb)$ 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. For the laser structures, a 1 second purge, with all reactants except for AsH_3 switched out of the chamber, was used between each layer. This was the procedure that had been used previously for the growth of InAsSb/InAsP laser structures [2]. For both InAsSb and InPSb the growth rate was found to be proportional to the TMIn flow into the reaction chamber and independent of the TESb and AsH_3 flow. The InPSb layers, whose growth has been described in more detail previously [5,6], were grown using a V/III ratio between 400 to 900 and a $TESb/(TESb + PH_3)$ ratio of 0.004 to 0.002 with growth rates of 2.5 to 5 Å/second for compositions between 0.8 and 0.7 P in InPSb. If the $TESb/(TESb + PH_3)$ ratio was decreased below 0.002, poor quality superlattices resulted. The SLS composition and strain were determined by double crystal x-ray diffraction. The crystal quality of the SLSs was excellent with 4 to 5 orders of x-ray diffraction satellite peaks typically observed, with typical full width at half maximum linewidths of 80-100 arc seconds. The Sb composition could be varied between 0.13 to 0.24 while maintaining constant layer thickness for both the InAsSb and InPSb layers.

For a change of composition in $InAs_{1-x}Sb_x$, for $x = 0.14$ to 0.20, with $InP_{0.72-0.75}Sb_{0.28-0.25}$ barriers, the PL peak changes from 3.5 to 4.2 µm at 16 K and a corresponding shift to longer wavelengths is observed at room temperature. Photoluminescence linewidths (full width at half maximum) of ~15 meV and ~35 meV are typically observed at 16K and room temperature,

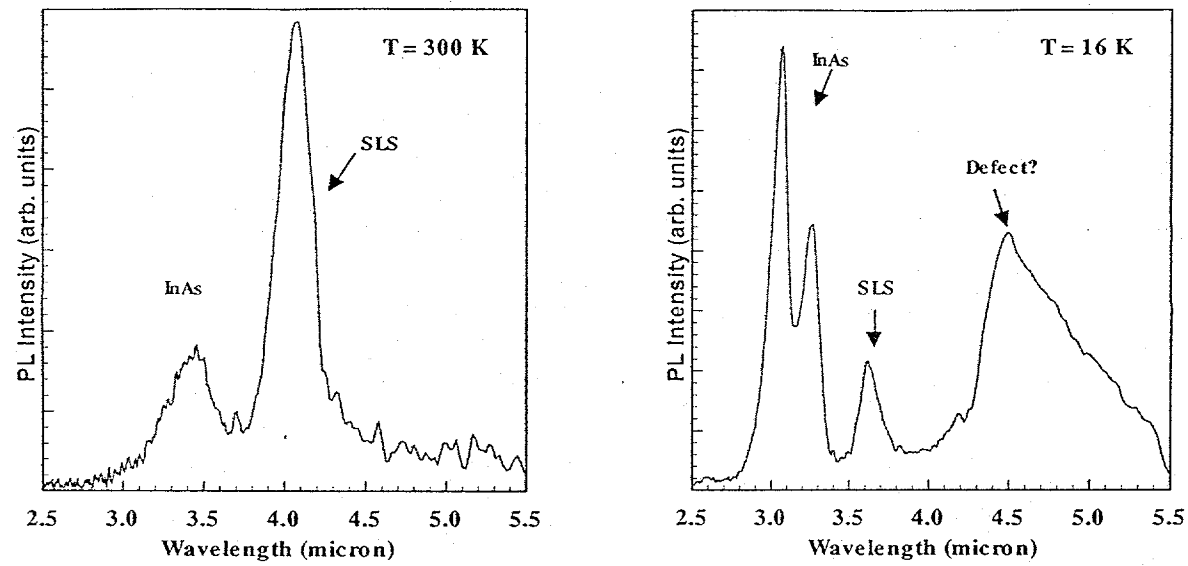

Figure 1. The 300 and 16 K PL spectra of an $InAs_{0.84}Sb_{0.15}$/ $InP_{0.75}Sb_{0.25}$ 10 period SLS grown at 500 °C.

respectively, with no observable dependence on antimony composition. A decrease in the PL peak intensity by an order of magnitude is observed for samples with $InAs_{1-x}Sb_x$, $x < 0.16$, likely due to decreased carrier confinement. By changing the layer thickness and composition of InAsSb/InPSb SLSs, we have prepared structures with low temperature (<20K) photoluminescence wavelengths ranging from 3.4 to 4.8 µm.

We have observed a long wavelength emission in the photoluminescence that was not attributable to InAsSb. Figure 1 shows the 16 and 300 K PL spectra of an $InAs_{0.84}Sb_{0.15}$/ $InP_{0.75}Sb_{0.25}$ 10 period SLS grown at 500 °C. Peaks from the InAs substrate (3.0 and 3.25 µm), the InAsSb layer (3.65 µm) and a longer emission at 4.5 µm are observed in the 16 K spectrum; however, at 300 K the long wavelength peak disappears. This anomalous long wavelength peak could be reduced by growing at 550 ^{0}C and by increasing the Sb content of the InAsSb layer. Figure 2 illustrates the PL peaks that are observed for an InAs / $InP_{0.75}Sb_{0.25}$ 10 period SLS. The PL peaks at 3.0 and 3.3 are due to InAs. We would expect only the PL peaks from InAs and the shorter wavelength emission from InPSb, but we again observed the anomalous long wavelength peak near 5 µm. As illustrated in Figure 2, we have found that this anomalous peak can be effectively eliminated by increasing the AsH_3 exposure of the InPSb/InAs interfaces. Figure 2 shows the PL spectra from three InPSb/InAs SLSs grown with different exposure levels of AsH_3 ranging from a 1 second purge in which no AsH_3 was used in Figure 2a to 3 and 5 second purges with AsH_3 flowing during the purges shown in Figures 2b and c, respectively. From this result we conclude that the anomalous long wavelength PL peak is due to an antimony-rich, interfacial layer that can be minimized by changing the growth conditions at the interface.

As previously reported, we have successfully prepared optically pumped laser structures from these InAsSb/InPSb SLS active regions [5]. However, the performance of these lasers was not as good as our InAsSb/InAsP lasers [2,3]. To improve this performance we have explored the growth of InAsSb/InAs/InPSb/InAs SLSs to be used as active regions in optically pumped lasers. Figure 3 shows the PL results for three 10 period superlattice structures with 1.0 nm InAs layers grown at (a) both interfaces, (b) after the InPSb and before the InAsSb layer, and (c) after the InAsSb layer and before the InPSb layer. The most intense PL was observed for the sample in (a) with InAs layers at both interfaces. The greatest effect was observed when the InAs layer was placed after the InPSb layer and before the InAsSb layer. A long wavelength, low intensity PL

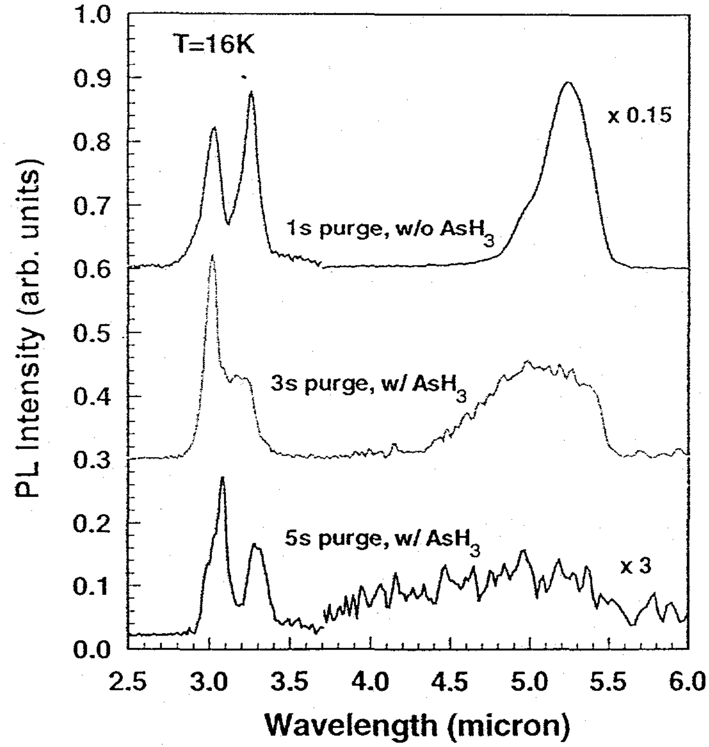

Figure 2. The PL spectra from three InPSb/InAs SLSs grown with different exposure levels of AsH_3 ranging from (a) 1 second purge in which no AsH_3 was used,to 3 and 5 second purges with AsH_3 flowing during the purges shown in Figures (b) and (c), respectively.

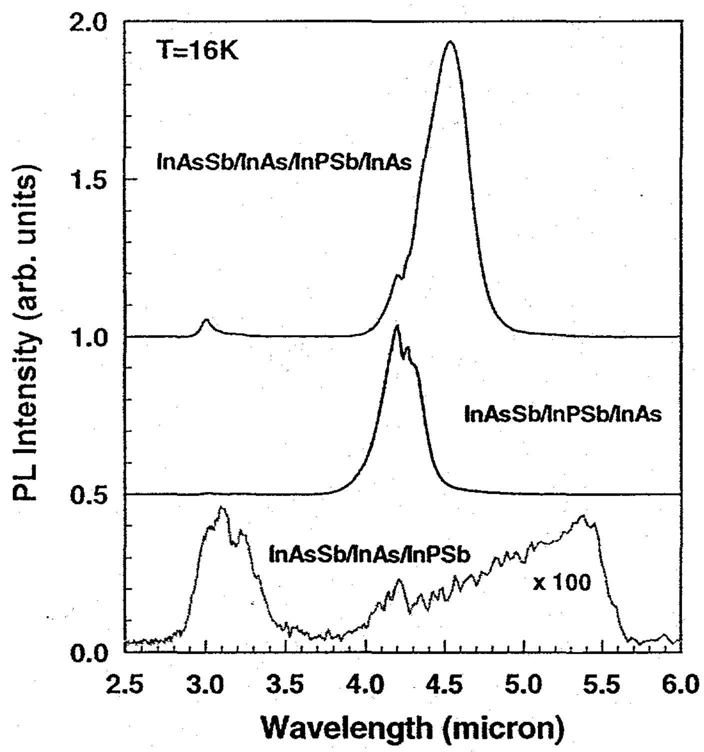

Figure 3. The PL spectra from (a) an InAsSb/InAs/InPSb/InAs SLS, (b) an InAsSb/InPSb/InAs SLS, and (c) an InAsSb/InAs/InPSb SLS.

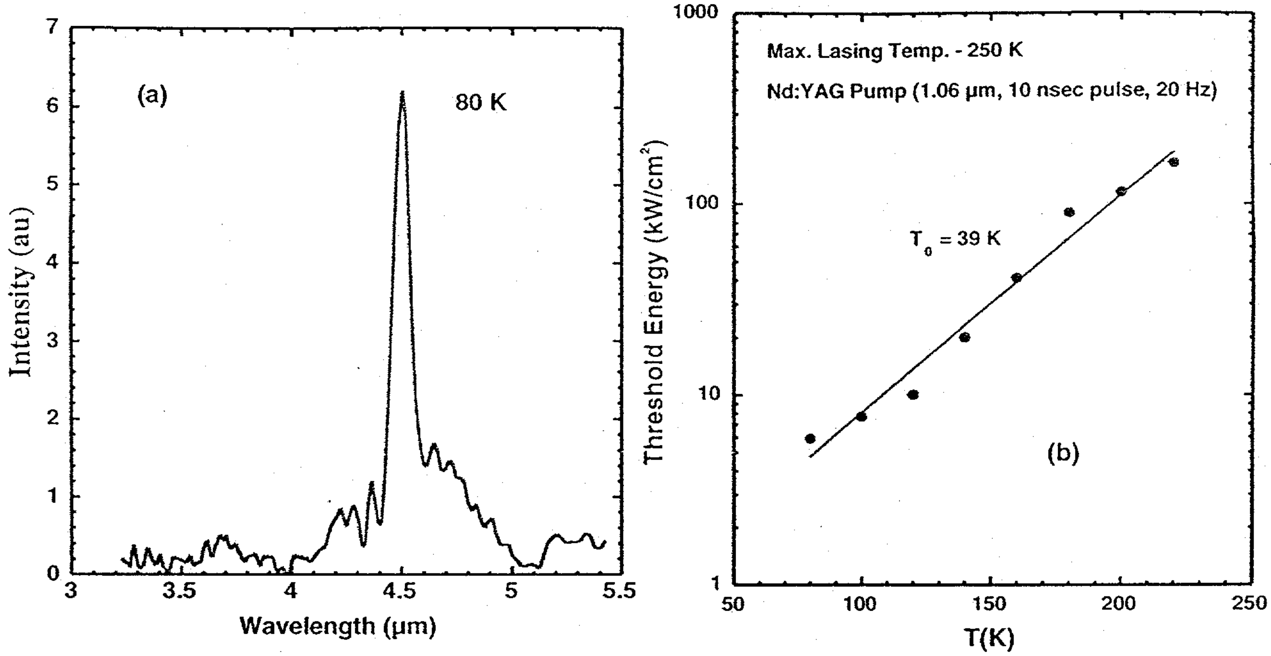

Figure 4. (a) Emission spectra at 80 K for a ten well, InAsSb/InAs/InPSb/InAs optically pumped laser structure. (b) The temperature dependence of the threshold current for the laser in (a)

peak (c), which can not be assigned to the InAsSb layer, was observed when the InAs layer was grown after the InAsSb layer. The intensity of the four layer, 10 period SLS shown in Figure 3(a) was an order of magnitude larger than the intensities observed for InAsSb/InPSb SLSs where no InAs interfacial layers were used. These results again illustrate how important the interfaces are in controlling the quality of the PL of the InAsSb/InPSb SLSs.

An optically pumped heterostructure laser was grown on an InAs substrate with a 2 μm thick $AlAs_{0.16}Sb_{0.84}$ lower cladding followed by a 0.5 μm InAs spacer. On top of the InAs spacer, the active region consisted of a 10 period, $InAs_{0.82}Sb_{0.18}$/InAs/$InP_{0.73}Sb_{0.27}$/InAs (104 Å /10 Å/ 104 Å/10 Å) SLS. The structure was then completed with another 0.5 μm of InAs and a 1.0 μm top $AlAs_{0.16}Sb_{0.84}$ cladding layer. The $AlAs_{0.16}Sb_{0.84}$ cladding layer was covered with a 40 nm InAs cap layer to avoid oxidation. Laser devices were fabricated by cleaving the grown heterostructures into 1 x 5 mm bars, with uncoated facets, and mounting them on a copper heat sink using In solder. The SLS laser was pumped with a Q-switched Nd:YAG laser (1.06 μm, 20 Hz, 10 nsec pulse, focused to a 200 μm wide line), and emission was detected with an FTIR spectrometer operated in a step-scan mode. A lasing threshold and spectrally narrowed, laser emission were seen from 80 (see Figure 4a) through 250 K, the maximum temperature where lasing occurred. The photoluminescence peak energy for this structure shifted from 4.7 to 5.4 μm over a temperature range of 16 to 300 K. The temperature dependence of the SLS laser threshold is described by a characteristic temperature, T_0 = 39K, from 80 to 200 K (see Figure 4b). This value is higher than observed in our previous lasers [1-3], and suggests that the use of InPSb barriers will lead to increased operating temperatures compared to the lasers with InAsP barriers. This higher characteristic temperature is similar to those observed in the current state of the art InAs/GaInSb/AlAsSb type II optically pumped lasers [4]. Estimated peak powers of about 300 - 10 mW/facet and thresholds of 6-170 kW/cm^2 are similar to those observed for the previously reported InAsSb/InAsP SLS lasers [2].

In summary, we have successfully prepared InAsSb/InPSb SLSs by MOCVD. We observed an anomalous long wavelength emission which we have assigned to an interface state by examining the PL of InAs/InPSb SLSs. We have completely eliminated this anomalous emission by inserting an InAs layer at both of the InAsSb/InPSb interfaces. We have prepared optically pumped laser structures using InAsSb/InAs/InPSb/InAs SLSs as the active regions and observed a $T_0 = 39K$ for these type I InAsSb SLS lasers. With further improvement in growth conditions optimization of the interface transition, and laser design, the high T_0 we have observed leads us to believe that higher performance lasers are possible with these InAsSb/InAs/InPSb/InAs SLSs.

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