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NOVEL MID-INFRARED LASERS WITH COMPRESSIVELY STRAINED InAsSb ACTIVE REGIONS

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ABSTRACT

Mid-infrared lasers grown by MOCVD with AlAsSb claddings and strained InAsSb active regions are reported. A 3.8-3.9 μm injection laser with a pseudomorphic InAsSb multiple quantum well active region lased at 210 K under pulsed operation. A semi-metal layer acts as an internal electron source for the injection laser. An optically pumped laser with an InAsSb/InAsP strained-layer superlattice active region was demonstrated at 3.7 μm, 240 K.

INTRODUCTION

Driven by chemical sensing and infrared countermeasure applications, several mid-infrared (2-6 μm) diode lasers with strained InAsSb active regions have been recently demonstrated. Devices with AlAsSb claddings have been grown by molecular-beam epitaxy,[1,2] and metal organic chemical vapor deposition (MOCVD) lasers with higher index, InPSb claddings have also been reported.[3,4] Although AlAsSb claddings provide superior optical confinement, the large conduction band barriers associated with AlAsSb layers can result in poor electron injection and high turn-on voltages. Also, due to lack of satisfactory aluminum sources and residual carbon resulting in p-type doping of AlSb alloys, MOCVD growth of AlAsSb injection devices had not been reported. In this paper, we report the first MOCVD grown lasers with AlAsSb claddings. First, we describe an electrically injected device which utilizes a GaAsSb (p) / InAs (n) heterojunction to form an internal, semi-metal layer. The semi-metal acts as an internal electron source which can eliminate many of the problems associated with electron injection in these devices, and this novel device is compatible with MOCVD materials and background dopings. Furthermore, the use of an internal electron source enables us to consider alternative laser and LED designs that would not be feasible with conventional, bipolar devices. Initial results for an optically pumped laser with an InAsSb/InAsP strained-layer superlattice (SLS) active region also are presented. Due to a large valence band offset, the light-heavy hole splitting in InAsSb/InAsP SLSs is estimated to be ≈ 80 meV, and Auger recombination should be further reduced in this active region.

SEMI-METAL INJECTION LASER WITH PSEUDOMORPHIC InAsSb MULTIPLE QUANTUM WELL ACTIVE REGION

The band alignments [5] for the MOCVD grown, injection laser are shown in Figure 1. As confirmed by x-ray measurements, both the claddings and active region of the laser are nominally lattice matched to the substrate. Following a $GaAs_{0.09}Sb_{0.91}$ buffer, a 2.5 micron thick $AlAs_{0.16}Sb_{0.84}$ cladding is grown on an n-type, InAs substrate. A 200Å, $GaAs_{0.09}Sb_{0.91}$ layer lies between the bottom cladding and a 0.6 μm thick InAs active region containing 10, pseudomorphic $InAs_{0.88}Sb_{0.12}$ quantum wells, each 90Å thick. A 2.5 μm thick $AlAs_{0.16}Sb_{0.84}$ cladding followed by a 200Å, $GaAs_{0.09}Sb_{0.91}$ contact and oxidation barrier layer is grown on top of the active region. AlAsSb and GaAsSb alloys have p-type background doping levels of ≈ $10^{17}/cm^3$, estimated from Hall measurements. The background doping of the InAs/InAsSb active region is n-type, ≈ 10^{15}-$10^{16}/cm^3$. Details of the MOCVD growth are published elsewhere.[6,7]

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For a wide range of Fermi energies, the GaAsSb (p) / InAs (n) heterojunction is a semi-metal, acting as a source/sink for electron-hole pairs. In forward bias (shown in Fig. 1), electrons are generated in the semi-metal and swept into the active region to recombine with holes being injected from the anode (+). The hole flux is replenished by holes generated in the semi-metal and swept away from the active region. Only hole transport is observed in the AlAsSb claddings (labeled points A and B in Fig. 1), and over this segment, the device can be described as unipolar.

Gain-guided, stripe lasers were fabricated with Ti/Au metallizations. The facets were uncoated. Under pulsed operation, lasing was observed in forward bias with 40x1000 or 80x1000 micron stripes. No emission occurred under reverse bias. Devices were tested with 100 nsec pulse widths at 10 kHz (0.1 % duty-cycle). Several longitudinal modes were observed in the 3.8-3.9 μm range, shown in Figure 2 for 80 K and 200 K operation. Characteristic of the pseudomorphic InAsSb lasers, laser emission was blue-shifted by ≈ 20 meV from the peak of the InAsSb quantum well photoluminescence, [3] and consistent with the selection rule for the compressively strained InAsSb quantum well electron (|1/2,±1/2>) -hole (|3/2,±3/2>) transition, laser emission was 100% TE polarized. The lasers displayed sharp threshold current characteristics, and lasing was observed through 210 K. (see Figure 3) Under pulsed operation, peak power levels ≥ 1 mW/facet could be obtained. A characteristic temperature (T_0) in the 30-40 K range was observed, with the lower value (30 K) being misleading due to degradation of the device.

These maximum operating temperature and characteristic temperature values are comparable to the highest values reported to date, for injection lasers of this wavelength with either strained InAsSb or InAs/GaInSb active regions.[2,3,8] Previously, a bipolar laser with a similar, pseudomorphic InAsSb multiple quantum well active region displayed the same characteristic temperature.[3] We believe that the characteristic temperature of both devices is limited by design of the active region and the resulting Auger rates.[3] Unlike bipolar lasers, cw operation of the unipolar laser has not yet been observed. At threshold and 100K, we find that the maximum duration of the unipolar laser output is ≈ 10^{-5} sec, with a comparable recovery time. If the device is driven above threshold with long pulses, lasing ceases and a different, low intensity emission spectrum is observed which indicates extreme band bending and depletion of the semi-metal. Due to capacitive charging within the device, the threshold current of the semi-metal laser was 10x that reported previously for the pseudomorphic, bipolar laser. Lasing pulse duration, duty-cycle, threshold current, and turn-on voltage of the semi-metal emitters may be improved with modifications in doping and heterojunction design.

OPTICALLY PUMPED, InAsSb/InAsP SLS ACTIVE REGION LASER

To further reduce Auger recombination, we are developing lasers with InAsSb/InAsP SLS active regions. Based on band offsets and light-heavy hole splittings measured in other InAsSb heterostructures,[9,10] we find that InAsSb/InAsP SLSs will exhibit large electron and hole confinement energies, and light-heavy hole splittings as large as 80 meV should be easily realized. (See Figure 4) We constructed a InAsSb/InAsP SLS laser similar to the semi-metal injection laser described previously, except a $InAs_{0.88}Sb_{0.12}/InAs_{0.73}P_{0.27}$ (80 Å / 80Å) SLS was substituted in place of the pseudomorphic active region. The unnecessary carriers in the cladding layers and the semi-metal layer may contribute loss to this optically pumped device.

The InAsSb/InAsP SLS laser was pumped with a Q-switched Nd:YAG (20 Hz, 10 nsec pulse), and emission was detected with an FTIR operated in a step-scan mode. Due to the low rep-rate of the pump, the resolution of the experiment was 2 cm^{-1}. Laser emission was observed from cleaved bars, 1000 μm wide. A sharp lasing threshold and spectrally narrowed stimulated emission was seen from 80 K through 240 K, the maximum temperature where lasing occurred. (See Fig. 5 and Fig. 6(a)) The temperature dependence of the threshold is well described by a characteristic temperature, T_0 = 32 K. (See Fig. 6(b)) Unlike the pseudomorphic devices, laser emission occurs near the peak of the spontaneous emission, indicated by the photoluminescence sprectrum in Fig. 5. The wavelength of the SLS laser shifts from 3.5 μm to 3.7 μm due to the decrease in bandgap over the 80-240K temperature range. Overall, the performance (output power, threshold power, characteristic temperature, maximum temperature) of the optically pumped type I, InAsSb/InAsP SLS laser is comparable to that initially reported for a 4 μm, InAs/GaInSb type II laser measured under similar conditions.[11]

SUMMARY

In conclusion, we report MOCVD grown, 3.5-3.9 μm lasers with AlAsSb claddings and strained InAsSb active regions. An injection device utilizes an internal semi-metal electron source, and state-of-the-art performance is obtained under pulsed operation. The use of the InAs/GaSb semi-metal for carrier injection, and the compatibility of the semi-metal with InAsSb devices is unique. An analogous concept is being explored for InAs/GaInSb devices where an "InAs/AlSb/GaInSb like" tunnel-barrier is used to internally generate electron-hole pairs and achieve multi-stage or "cascaded" laser operation.[12] In order to further decrease Auger recombination, lasers with InAsSb/InAsP SLS active region are being developed, and an optically pumped device is reported. Measured under pulsed, low rep-rate conditions, emission was observed at 3.8 μm, 240 K for the type I SLS laser.

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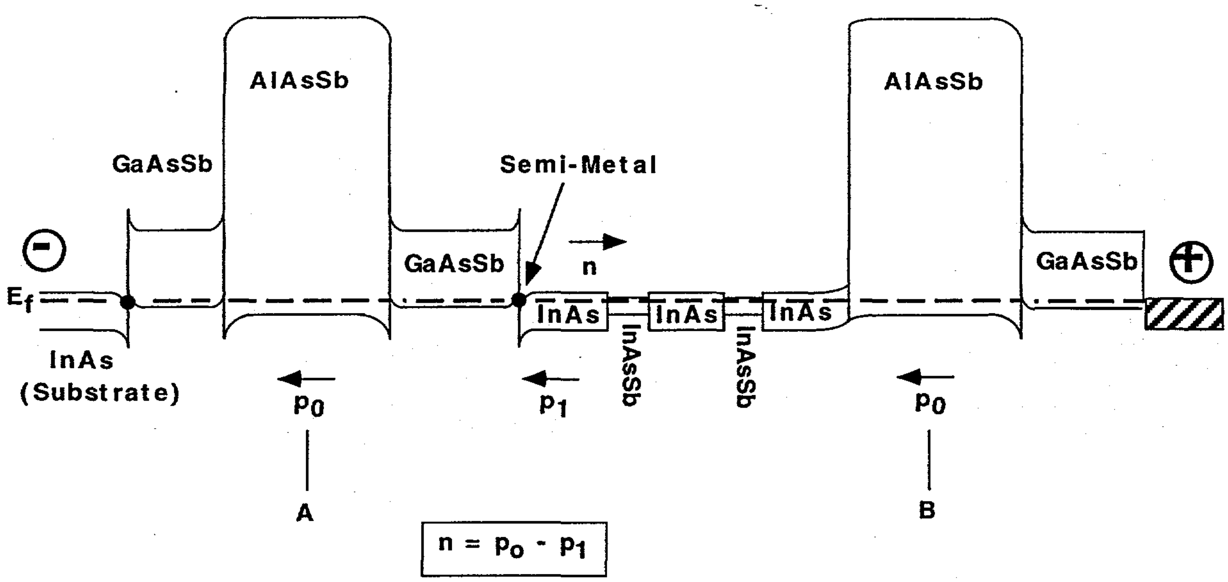

Figure 1 - Heterojunction band alignments for the MOCVD-grown, injection laser with a pseudomorphic InAsSb MQW active region. Forward bias polarity is indicated in the figure.

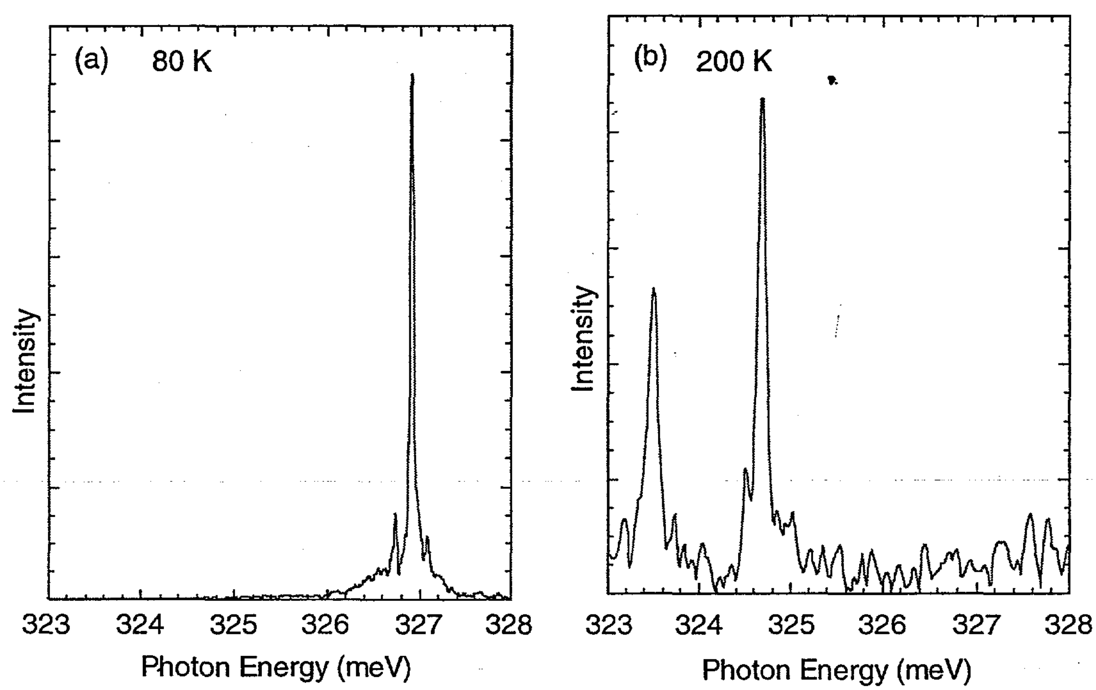

Figure 2 - Injection laser emission spectra at 1.1xIth for (a) 80K and (b) 200K.

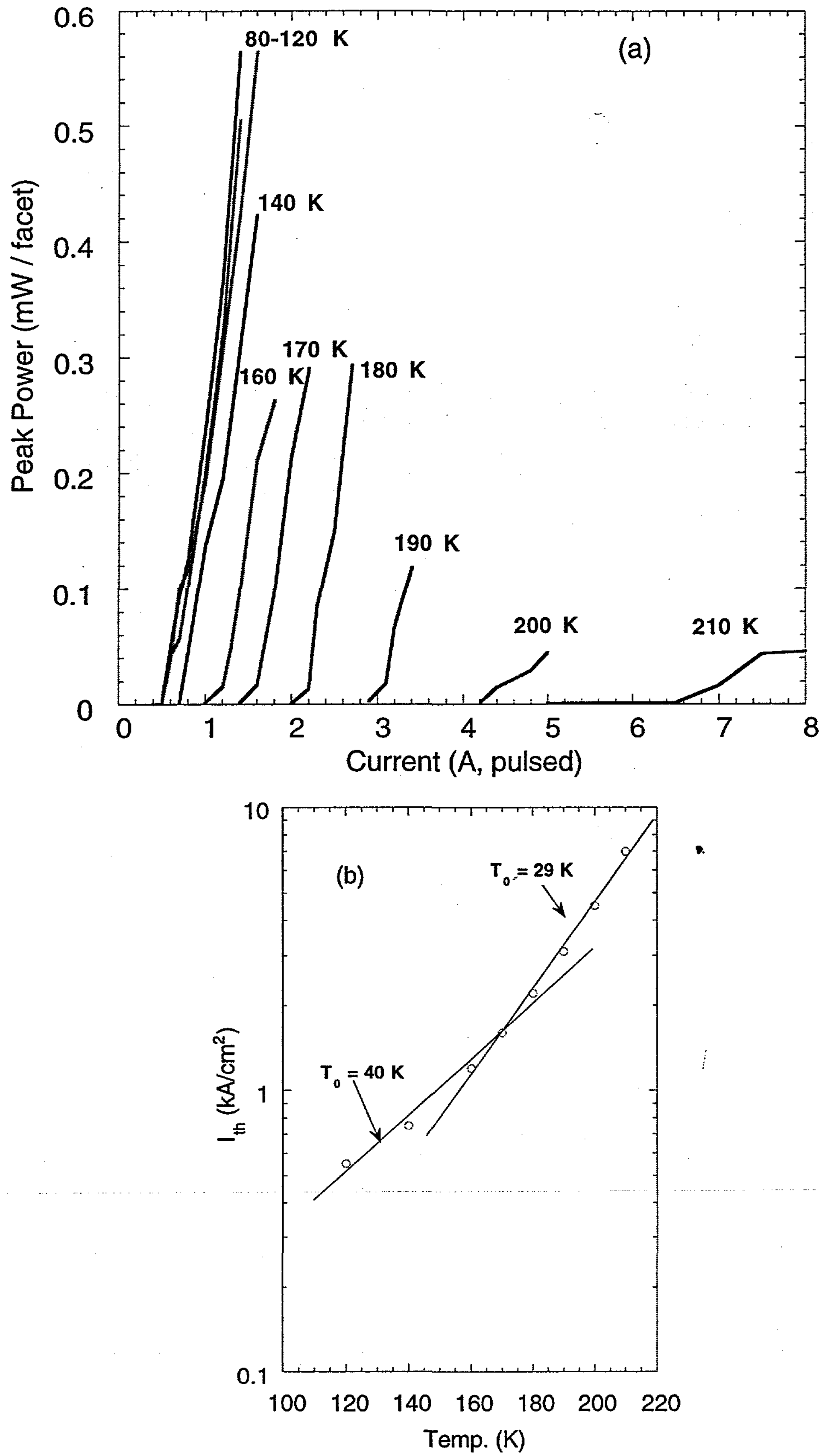

Figure 3 - (a) Injection laser emission intensity versus peak current for various temperatures. (b) Pulsed threshold current density versus temperature. The stripe dimensions were 40x1000 μm.

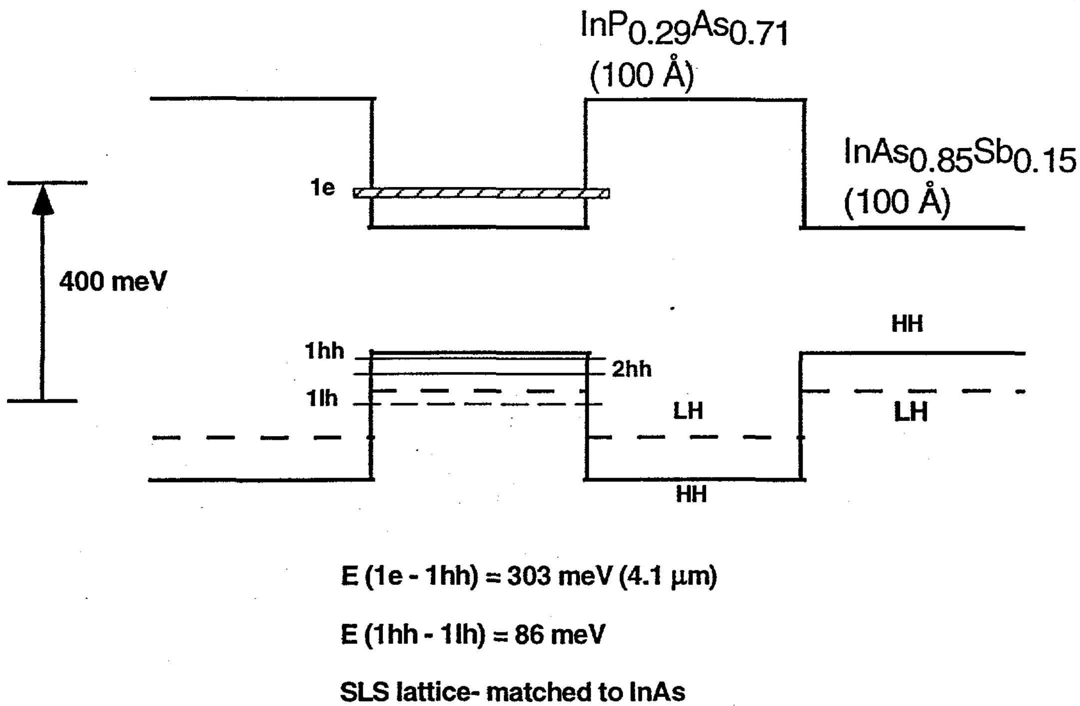

Figure 4 - Band alignments and quantum confinement state energies (drawn to scale) for an $InAs_{0.85}Sb_{0.15}$ / In $As_{0.71}P_{0.29}$ (100 Å / 100 Å) SLS. The estimated bandgap of the unstrained, MOCVD-grown $InAs_{0.85}Sb_{0.12}$ alloy was 218 meV.

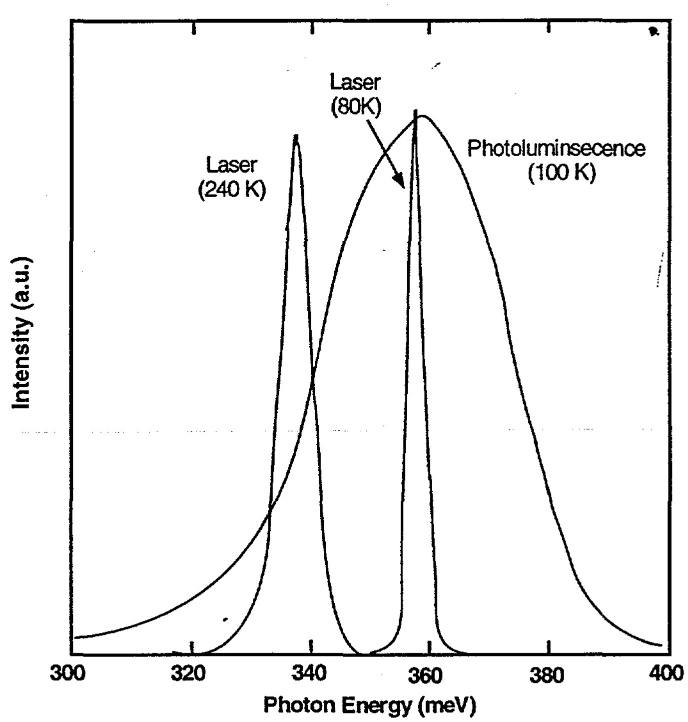

Figure 5 - Photoluminscence and optically pumped laser emission for a device with an $InAs_{0.88}Sb_{0.12}$ / $InAs_{0.73}P_{0.27}$ (80 Å/ 80 Å) active region.

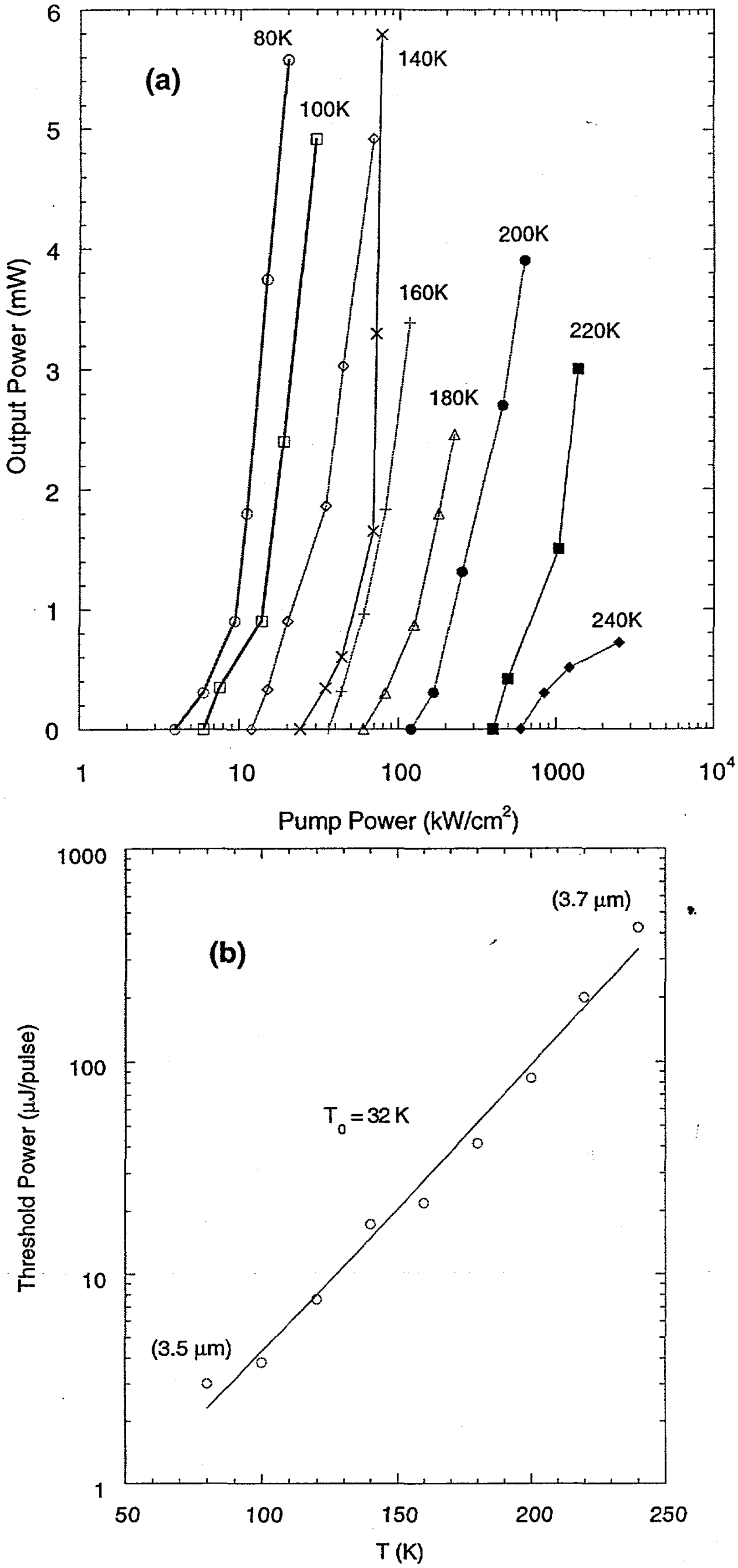

Figure 6 - (a) Peak power output versus temperature and pump power for the InAsSb/InAsP SLS laser. (b) Threshold pump power versus temperature for the SLS laser.