InGaAs/GaAs/InGaP multiple-quantum-well lasers prepared by gas-source molecular beam epitaxy

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We report on the first room-temperature operation of aluminum-free $In_{0.2}Ga_{0.8}As$/GaAs/$In_{0.49}Ga_{0.51}P$ multiple-quantum-well lasers grown by gas-source molecular beam epitaxy. These lasers have low threshold current density J_{th} of 177 A/cm^2, high internal quantum efficiency of 91%, and low internal waveguide loss of 9.1 cm^{-1}. The characteristic temperature T_0 is 150 K, which is the highest value ever reported. These results demonstrate that gas-source molecular beam epitaxy is suitable for growing high-quality $In_{0.2}Ga_{0.8}As$/GaAs/$In_{0.49}Ga_{0.51}P$ lasers.

Strained InGaAs/GaAs quantum well (QW) lasers emitting at wavelength of 980 nm currently receiving considerable attention for the erbium-doped fiber optical amplifier (EDFA) pumping sources because they yield a lower noise figure,[1] higher gain coefficient[2] than 1.48 μm InGaAsP laser. In addition, the InGaAs/GaAs strained QW lasers have lower threshold current and higher slope efficiency.[3–5] Previously, AlGaAs is commonly used for cladding layers in most of the InGaAs/GaAs QW lasers. It is well known in AlGaAs double-heterostructure (DH) laser diodes that the oxidation-induced facet degradation is the major failure mechanism.[6] Therefore, it is very important to use aluminum-free materials for the cladding layers to improve the reliability of InGaAs/GaAs lasers. $In_{0.49}Ga_{0.51}P$ was first introduced as a substitution for AlGaAs cladding layers in strained InGaAs/GaAs single-quantum-well lasers grown by low-pressure metalorganic chemical vapor deposition (LP-MOCVD) by Ijichi *et al.*[7]

The advantages of InGaAs/GaAs/InGaP QW lasers are as follows. Since it is aluminum-free, less surface oxidation during fabrication process and laser operation is expected and it is more suitable for multistep regrowth. The low surface recombination velocity[8] will enhance catastrophic optical damage (COD) threshold of the laser facets, reduce leakage current, and improve the reliability of the lasers. In addition, the availability of selective chemical etchings between GaAs and InGaP makes the process much more easily controlled. In this letter, we report on the first room-temperature cw operation of InGaAs/GaAs 3QW lasers using $In_{0.49}Ga_{0.51}P$ grown by gas-source molecular beam epitaxy (GSMBE).

The InGaAs/GaAs/InGaP 3QW lasers were grown on (100) n-GaAs substrate in a Varian Gen II GSMBE. The growth chamber was equipped with a 5000 ℓ/s cryopump and a 2200 ℓ/s turbomolecular pump. Elemental solid sources were used for group III and doping fluxes while thermally decomposed arsine and phosphine were used for group V fluxes. In order to minimize the interdiffusion of the GaAs/InGaP interfaces, arsine and phosphine were injected separately from two crackers equipped with fast vent/run valves. Switching between AsH_3 and PH_3 was controlled by the vent/run valves and shutters in front of the two injectors. The substrate temperature was ~520 °C and was calibrated by the congruent sublimation temperature of GaAs and the melting point of InSb. The group III fluxes were measured by an ion gauge in the growth position. In/Ga flux ratio was set to 1.33 for lattice matching of InGaP to GaAs. AsH_3 and PH_3 flow rates

p+	GaAs	CAP
p+	InGaP	CLAD
p+	GaAs	ETCH-STOP
p+	InGaP	CLAD
i	GaAs	WAVEGUIDE
i	$In_{0.2}Ga_{0.8}As$/GaAs	MQW 3 x {70Å/200Å}
i	GaAs	WAVEGUIDE
n+	InGaP	CLAD
n+	InGaP/GaAs	SL BUFFER 10 x {100Å/100Å}
n+	GaAs	BUFFER
n+	GaAs	SUBSTRATE

FIG. 1. Layer structure of the InGaAs/GaAs/InGaP lasers.

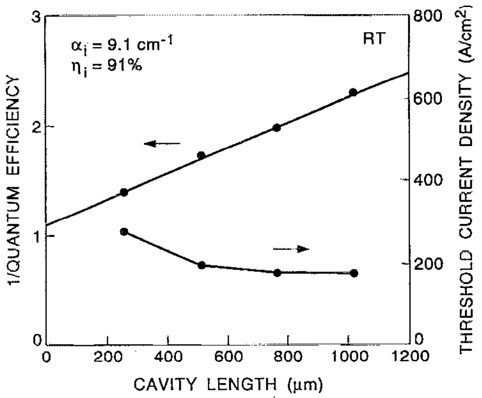

FIG. 2. Cavity length dependence of the reciprocal differential external quantum efficiency $1/\eta$ and the threshold current density J_{th} of the broad-area lasers.

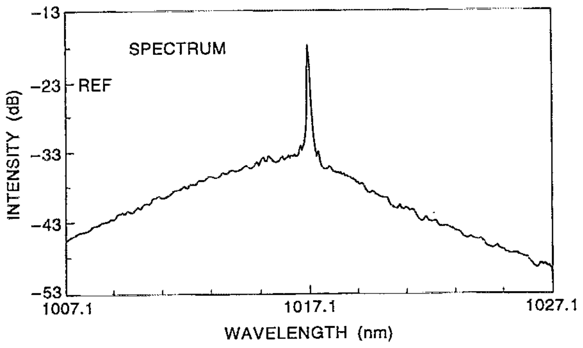

FIG. 3. Lasing spectrum of the $In_{0.2}Ga_{0.8}As/GaAs/In_{0.49}Ga_{0.51}P$ broad-area laser.

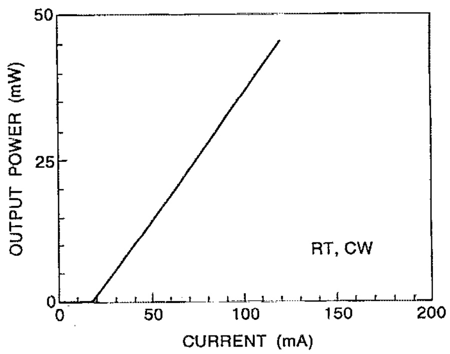

FIG. 5. cw *L-I* characteristics of a 5 μm$\times$508 μm ridge waveguide laser at room temperature.

were 1.3 and 2.4 sccm, respectively. Reflection high-energy electron diffraction (RHEED) oscillations were used to calibrate the growth rate of GaAs, InGaAs, and InGaP. Lattice match of InGaP within $\Delta a/a < 5\times10^{-4}$ was easily and routinely maintained across the 1 in. square wafer, as measured by double-crystal x-ray (DCXR) diffraction. Full width at half maximum (FWHM) as narrow as 19 arcsec has been obtained from a 1.8-μm-thick epilayer. This indicates that the group III fluxes are quite stable. Details of the growth conditions and the structural, optical, and electrical properties of InGaP will be published elsewhere.[9]

The layer structure of the InGaAs/GaAs/InGaP laser is shown in Fig. 1. A 2000-Å-thick n^+-GaAs was grown first followed by ten periods of 100 Å/100 Å InGaP/GaAs superlattice buffer layers. The undoped active layer consists of three quantum wells of 70 Å $In_{0.2}Ga_{0.8}As$ and 200 Å GaAs. The *p*-doped and *n*-doped InGaP layers are used as cladding layers and are 1.5 μm thick. A 50 Å GaAs:Be stop-etch layer is inserted in the InGaP:Be cladding layer. The separate confinement heterostructure (SCH) also has an undoped 800 Å GaAs setback layer on each side of the active region. At each GaAs/InGaP interface, growth was interrupted for a few seconds by shutting the group III shutters while the group V gas streams were switched. This preserved the just finished epilayer and stabilized the subsequent layer by the appropriate hydride gases.

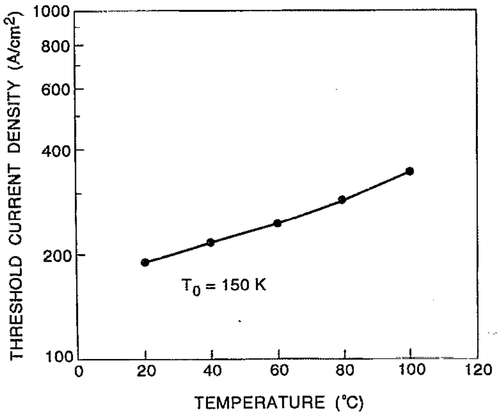

FIG. 4. Threshold current density of a 50 μm$\times$508 μm broad-area laser plotted as a function of temperature under cw operation.

Broad-area lasers with 50-μm-wide strips are fabricated with different cavity lengths ranging from 254 to 1016 μm. Figure 2 shows the cavity length dependence of the reciprocal differential quantum efficiency, $1/\eta$, and the threshold current density, J_{th}. A low threshold current density of 177 A/cm^2 was achieved for a 1016-μm-long laser. A low internal waveguide loss α_i of 9.1 cm^{-1} and a high internal quantum efficiency η_i of 91% are obtained from Fig. 2. The lasing wavelength of these broad-area lasers is 1.017 μm, as shown in Fig. 3.

Figure 4 shows the temperature dependence of the threshold current density of a 50 μm$\times$508 μm broad-area laser. The characteristic temperature (T_0) is 150 K, which is the highest value ever reported for InGaAs/GaAs/InGaP quantum well lasers. Ridge waveguide lasers are also fabricated. The preliminary cw *L-I* characteristics of a 5-μm-wide, 508-μm-long ridge waveguide laser at room temperature are shown in Fig. 5. A low threshold current of 17.5 mA and a high external differential quantum efficiency of 0.44 mW/mA per facet are obtained from this uncoated laser.

In summary, we report on the first room-temperature cw operation of $In_{0.2}Ga_{0.8}As/GaAs/In_{0.49}Ga_{0.51}P$ MQW lasers grown by gas-source molecular beam epitaxy. The broad-area lasers show low threshold current density of 177 A/cm^2, high internal quantum efficiency of 91%, and low internal waveguide loss of 9.1 cm^{-1}. The characteristic temperature T_0 is 150 K, which is the highest value ever reported. A low threshold current of 17.5 mA and a high external differential quantum efficiency of 0.44 mW/mA per facet are obtained from an uncoated 5$\times$508 μm^2 ridge-waveguide laser. These results demonstrate that GSMBE is suitable for growing 980 nm InGaAs/GaAs lasers with $In_{0.49}Ga_{0.51}P$ cladding layers. The reliability of these aluminum-free lasers is currently under study.

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