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Blue-Green Injection Lasers Operating at Temperatures up to 394K

Martin F. H. Schuurmans, James M. Gaines, Ronald R. Drenten

Philips Laboratories, Philips Electronics North America Corp.

345 Scarborough Road, Briarcliff Manor, NY 10510

Recent results on blue-green injection lasers containing $Zn_{1-x}Mg_xS_ySe_{1-y}$ cladding layers are presented. The lasers are separate-confinement heterostructures with a $ZnS_{0.06}Se_{0.94}$ waveguiding region and a single $Cd_{0.2}Zn_{0.8}Se$ strained quantum well. The devices have yielded threshold current densities as low as 500 A/cm^2 (320 A/cm^2 with facet coating) and pulsed output powers as high as 500 mW per facet at room temperature. The lasers have operated at temperatures as high as 394K. CW operation, for a few seconds, was observed at 77K. Emission spectroscopy measurements of the thermal properties are also presented.

Semiconductor laser, visible lasers, II-VI materials, spectroscopy, thermal properties.

Introduction

Shortly after the first reports of nitrogen doped p-type ZnSe obtained using an RF plasma source,[1),2)] blue/green II/VI lasers were demonstrated by Haase, et al.[3)] The first laser was a separate confinement heterostructure laser, containing $ZnS_{0.06}Se_{0.94}$ cladding layers, a ZnSe waveguiding region, and a single $Cd_{0.2}Zn_{0.8}Se$ quantum well.[3)] This structure led to room-temperature pulsed[4),5)] and 77K CW operation.[6)] Meanwhile, Okuyama, et al.[7)] developed the MBE growth of $Zn_{1-x}Mg_xS_ySe_{1-y}$, which had promise for use as an improved cladding layer, providing both a larger bandgap, and possibilities for lattice matching of the entire SCH structure. Their optically-pumped lasers,[8)] made without separate confinement, operated at temperatures as high as 500K. They also obtained CW operation at 77K,[9)] again for a structure without separate confinement. Gaines, et al.,[10)] combined the use of $Zn_{1-x}Mg_xS_ySe_{1-y}$ cladding layers with separate confinement, to produce laser diodes with the lowest reported room temperature threshold current density (500 A/cm^2), highest laser diode operating temperature (394K), and highest room-temperature pulsed output power (500mW/facet). In this paper, the performance of these lasers is described, together with measurements of the thermal properties of II/VI lasers.

Experimental

The laser structure (Fig. 1) was grown on n-type (001) GaAs (300μm in thickness) by molecular beam epitaxy (MBE), in a Varian Gen II system.

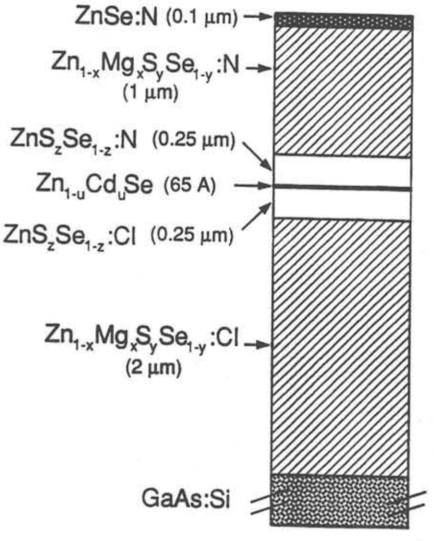

Figure 1
Laser structure; u = 0.2, x ≈ y ≈ 0.1, z = 0.06.

The "majority" sources were Zn, Se, Cd, Mg, and ZnS, and the doping sources were ZnCl and N excited by a plasma source[1)]. The entire structure is pseudomorphic with the substrate. The active layer consists of a single quantum well of $Cd_{0.2}Zn_{0.8}Se$. The n-type doping level was 2 x 10^{17} cm^{-3} in both the n-$ZnS_{0.06}Se_{0.94}$ and n-$Zn_{1-x}Mg_xS_ySe_{1-y}$ layers. P-type doping levels (N_a - N_d) in the $Zn_{1-x}Mg_xS_ySe_{1-y}$, $ZnS_{0.06}Se_{0.94}$ and ZnSe, estimated from C-V measurements on single layers, were about 2 x 10^{17}, 3 x 10^{17}, and 1 x 10^{18}

cm^{-3}, respectively. X-ray fluorescence measurements showed that the composition of $Zn_{1-x}Mg_xS_ySe_{1-y}$, satisfies $x \approx y \approx 0.1$. The energy band-gap is approximately 2.95 eV at 4K, as determined by photoluminescence. Transmission electron microscopy shows that the defect density is less than 10^6 cm^{-2} in the structure.

Lasers were fabricated in a gain-guided geometry. Polyimide was used for the insulator layer. 50 μm stripes were opened in the polyimide, and Au contacts were deposited by thermal evaporation. No thinning of the substrate was done. Contact to the n-type GaAs was provided by the indium used to mount the samples in the MBE system. Devices were cleaved to a length of about 1 mm and mounted substrate-down on copper blocks. Operating conditions included pulse lengths of 10-50 ns at repetition rates of 1-200kHz. The results below are for devices without facet coating, except where otherwise noted.

Laser Operation

The lasing wavelength is 496nm at 85K and 516 nm at 294K. A representative emission spectrum for room temperature operation is shown in Fig. 2a. At room temperature, lasing occurs with about 12V applied to the device.

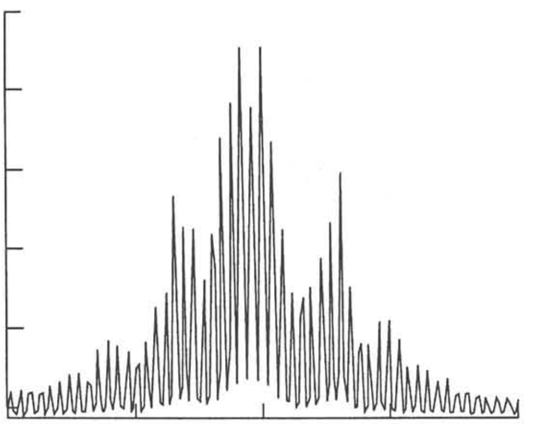

Figure 2a
Room-temperature optical emission spectrum.

In Fig. 2b, the light output power is shown as a function of input current for temperatures between 85 and 394K. From this data (and other data not included on the graph for clarity) T_0 was determined to be about 150K at room temperature. The room temperature (294K) threshold current density was 500 A/cm^2. (With facet coating to increase facet reflectivity to 0.8, the room temperature threshold current density reduces to 320 A/cm^2.) The threshold current density was 2850 A/cm^2 at 394K. A peak pulsed output power of 500 mW was measured from one facet at room temperature. The differential external quantum efficiency, determined from the slope of the individual curves in Fig. 2b, is 0.22, and 0.19 per facet at 85, and 294K, respectively.

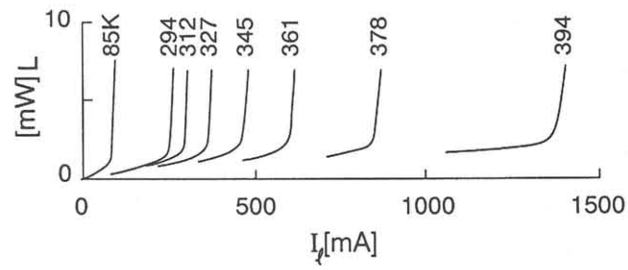

Figure 2b
Laser light output power versus input current.

CW lasing for facet coated devices (R = 0.8) was observed for about 6 seconds at 77K and for about 1 second at 170K. The poor contact to the p-type side of the device is suspected to be a major cause of the short lifetime of these devices.

The laser far-field pattern demonstrates the improvement in optical confinement, relative to lasers containing $ZnS_{0.06}Se_{0.94}$ cladding layers, provided by the $Zn_{1-x}Mg_xS_ySe_{1-y}$ cladding layers. The far field pattern full-width at half-maximum (FWHM) perpendicular to the layers is 33-34°, substantially wider than the FWHM observed for similar structures with x = z = 0 in Fig. 1.

Thermal Characteristics

Time-sampled measurements of laser emission spectra show that, when the lasers are operated with current pulses of duration < 100ns, the lasing wavelength remains virtually constant within the pulse, indicating that no heating takes place. Under these circumstances, the maximum temperature for lasing is determined from the threshold current density as a function of temperature and from the maximum current density (typically 2kA/cm^2) that the devices can carry. A single-quantum-well SCH structure with a ZnSe guiding layer and $ZnS_{0.06}Se_{0.94}$ cladding layers has a threshold current density of 400 A/cm^2 and a T_0 of 150K at a temperature of 170K. The maximum lasing temperature observed is 270K for this structure. The structure of Fig. 1 yields improved values of 290 A/cm^2 and T_0 = 300K at 170K. As a result, lasing in these devices has been observed up to 394K.

The change in lasing wavelength as a function of ambient temperature is found to be 0.10 nm/K around 170K. The wavelengths of the individual longitudinal modes are found to shift at a rate of 0.024 nm/K around this temperature.

Thermal resistance measurements have been performed, using a small DC heating current, superimposed on the pulsed laser drive current. The lasers show nearly linear shifts of both the lasing wavelength and the wavelengths of the individual longitudinal modes, as a function of the dissipated DC power. Comparison to the wavelength changes determined by varying the ambient temperature (described above) shows that both wavelength shifts yield the same thermal resistance value of 40 K/W in the quaternary lasers. This is somewhat higher than the value of around 20K/W, found in lasers with $ZnS_{0.06}Se_{0.94}$ cladding layers.

Once the laser parameters, T_0, the pulsed threshold current I_{th}, the operating voltage V and the thermal resistance R_t are known, one can estimate whether CW lasing is possible from the thermal point of view.[11),12)] An approximation of the condition for CW lasing is given by $T_0/(VR_tI_{th})>2.7$. We calculate that these structures, with facet coating, could nearly yield room temperature CW operation from purely thermal considerations.

Conclusions

The incorporation of magnesium in separate-confinement II/VI heterostructure lasers has led to improvements in the room-temperature threshold current density, the maximum operating temperature, and the maximum room temperature peak pulsed output power. The addition of Mg permits both an increase in the band gap of the cladding layers and the growth of laser structures with all layers pseudomorphic to the GaAs substrate.

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