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Light Emission from Quantum Well Structures Containing ZnS, ZnSe, and Related Alloys

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A high-resolution study of emission spectra from ZnSe-based blue-green laser diodes is reported. At 77K, cw laser emission has been achieved at 470.2 nm -- the shortest wavelength ever produced by a semiconductor diode laser. Blue light emitting diodes have also been fabricated which emit at 475-480 nm at room temperature. ZnS-ZnCdS quantum well structures have been fabricated which display intense photoluminescence at 331 nm (3.74 eV).

1. INTRODUCTION

Rapid advances in controlled substitutional doping of ZnSe and related II - VI compounds have led to a number of demonstrations of incoherent blue and blue-green light emission from diode structures prepared by metalorganic chemical vapor deposition (MOCVD)[1,2] and molecular beam epitaxy (MBE)[3-12]. In addition, blue-green laser diodes have recently been fabricated from ZnSe - based heterostructures by scientists at 3M Company[13] and by a Purdue-Brown research team[14-15].

In this paper the first high-resolution study of emission spectra from ZnSe-based blue-green laser diodes is reported. Analysis of the longitudinal (Fabry-Perot) mode spacing in output spectra from cleaved-cavity, stripe-geometry lasers having cavity lengths L = 185 -1100 µm yields values for the equivalent index of refraction n_e under a variety of excitation conditions. For some samples, the laser emission spectra show satellite peaks located adjacent to each longitudinal (Fabry-Perot) resonance which are associated with lateral resonances. Analysis of the lateral mode spacing yields information concerning the spatial fall-off of the refractive index along the junction plane of these gain-guided devices.

2. EXPERIMENTAL DETAILS

The laser structures were grown by molecular beam epitaxy (MBE) in a special system designed and constructed at North Carolina State University (NCSU) specifically for growth of high-vapor-pressure II-VI compounds[16]. Figure 1 shows the structure of a typical blue-green laser device fabricated in the present study. The laser structure is similar to that employed by the 3M group[13]. It consists of a single separate-confinement quantum well (100-200 Å) of $Zn_{1-x}Cd_xSe$ (x = 0.15 - 0.18) centered in a ZnSe light-guiding layer (1 um thick). Top (~1.0 µm) and bottom

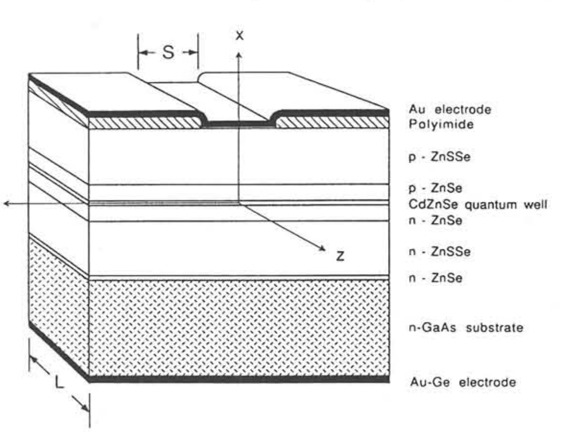

Fig. 1 Schematic of laser diode structure.

(~1.5 µm) cladding layers of $ZnS_{0.1}Se_{0.9}$, along with the ZnSe light-guiding layers, were doped p-type and n-type, respectively, as shown in the figure. All of the major constituents of the various layers of the heterostructure were grown by MBE using elemental Zn, Cd, Se, and S. The p-on-n structure was grown on a (100) Si-doped n^+-GaAs substrate at 250 °C. $ZnCl_2$ (5N5) was used as a solid Cl source for growth of the n-type layers ($n_0 \sim 1 \times 10^{18}$ cm^{-3}) of the heterostructure. The p-type layers ($p_0 \sim 5 \times 10^{17}$ cm^{-3}) were doped with N from an rf plasma source using N_2 gas. Structures containing multiquantum wells have also been fabricated, along with ZnS-ZnSSe and ZnS-ZnCdS multilayers.

3. RESULTS AND DISCUSSION

Figure 2 shows a high resolution spectrum of stimulated emission at 77 K for a laser cavity of length L = 620 μm. For this laser diode, the mode spacing was found to be $\Delta\lambda_q$ = 0.043 nm, corresponding to an effective index of refraction of n_e = 4.24.

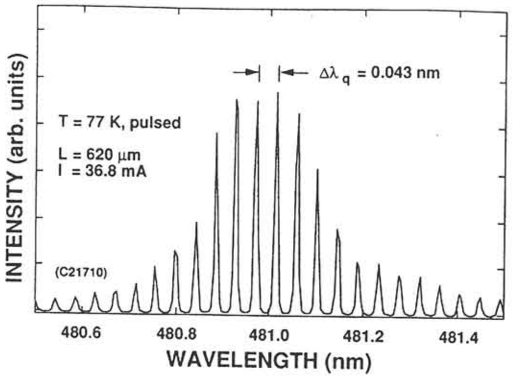

Fig. 2 Laser emission spectrum at 77K.

The measured light output versus current (L-I) characteristics of one of the blue laser cavities is shown in Figure 3. Note that the threshold current for blue stimulated emission is only 39 mA at 77K, which corresponds to a threshold current density of 250 A/cm^{-2} for this laser structure (L = 750 μm; uncoated facets). Differential quantum efficiencies of η=0.22- 0.30 per facet were obtained at 77K. These are similar to values reported by others for blue-green lasers[9,10].

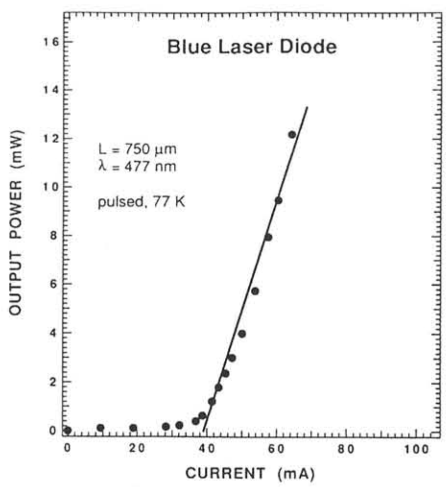

Fig. 3 Light output versus current for laser diode.

Laser turn-on voltages as low as 12-13 V have been achieved at 77 K for devices with uncoated facets.

Light emitting diodes have been fabricated from single and multiquantum well heterostructures which emit blue light at room temperature in the spectral range 476-480 nm. Efficiency measurements will be reported.

ZnS-ZnSSe multiquantum well samples exhibit bright photoluminescence in the U.V. as shown in Fig. 4. We find, however, that the use of Se in the quantum wells produces broad PL peaks due to the lack of electron confinement.

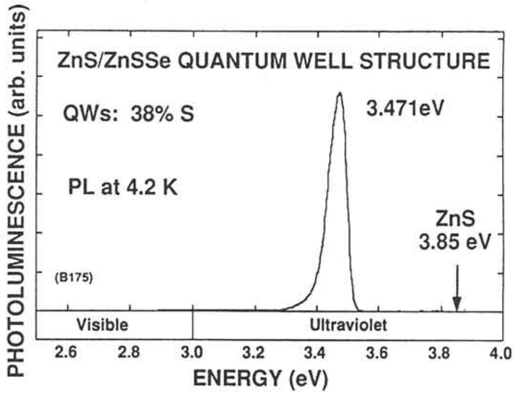

Fig. 4 PL from ZnS-ZnSSe QW samples.

In contrast, bright and narrow PL in the U.V. is obtained from ZnS-ZnCdS quantum well samples as shown in Fig. 5. This implies that the ZnCdS alloy provides much better electron confinement as a consequence of band alignment considerations.

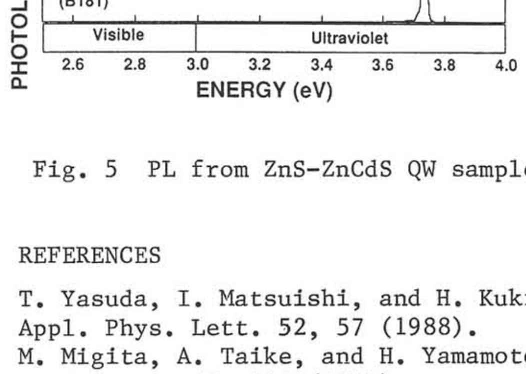

Fig. 5 PL from ZnS-ZnCdS QW samples.

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