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Blue-Green ZnCdSe/ZnSe MQW Laser Diode without GaAs Buffer Layer

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ZnCdSe/ZnSe multi-quantum well (MQW) laser diodes without GaAs buffer layers have been fabricated using a single growth chamber MBE system. A five-second interruption in the MQW growth has been introduced to improve hetero-interface. To reduce series resistance, N-doping was adopted in ZnSe barrier layers of the MQW. On the other hand, Ga doping in this layer is shown to decrease the PL intensity of the MQW. Using these growth conditions, lasers in the wavelength of 492 nm have been successfully operated under pulse conditions at 90 K.

Recently, blue-green laser diodes (LDs) have been achieved using II-VI compound semiconductors.[1,2] The LD structures containing ZnCdSe/ZnSe quantum wells were grown on GaAs epitaxial buffer layers to improve the structural and electronic properties of the II-VI/III-V interface. These LDs were fabricated in a molecular beam epitaxy (MBE) system with two growth chambers for II-VI materials and III-V buffer layers. This paper reports the demonstration of LDs grown with only one MBE growth chamber for II-VI compounds. The growth conditions for ZnCdSe/ZnSe quantum wells have also been investigated to improve lasing properties.

The ZnSe based II-VI semiconductor layers were grown directly on (100) GaAs substrates by MBE. Zn, Se, Cd and ZnS were employed as source materials. A radical N_2 beam from an rf plasma source (13.56 MHz) and Ga were used for p- and n-type dopants, respectively. The carrier concentrations for N- and Ga-doped ZnSe layers were 4×10^{17} cm^{-3} and 3×10^{17} cm^{-3}, respectively, as determined from Hall measurements. Both n- and p-type ZnSSe layers lattice-matched to GaAs had carrier concentrations of 2×10^{17} cm^{-3}. Substrate temperature during growth was 330°C. Beam equivalent pressure ratio of Se to Zn was about two.

Preliminary research was performed on the MQW hetero-interface and impurity doping before laser structure growth.

First, the interruption effect in the growth of the MQW structure has been studied for improving hetero-interface flatness. The abruptness of the ZnCdSe/ZnSe hetero-interface was confirmed by a low-temperature photoluminescence (PL) on single quantum wells (SQWs). Three multilayer structure wafers, as shown schematically in the inset of Fig. 1, were grown with different interruption times (0, 5 and 30 seconds) at hetero-interfaces. They consisted of three ZnCdSe well

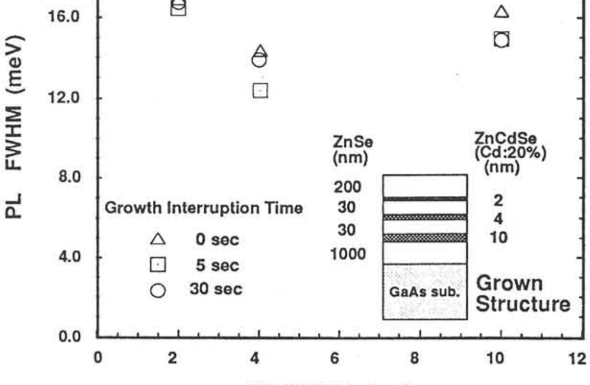

Fig. 1. PL FWHM dependence on growth interruption time

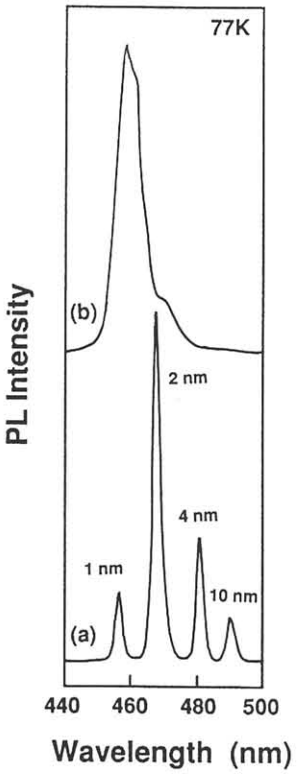

Fig. 2. PL spectra at 77 K of (a) undoped and (b) uniformly Ga-doped SQWs structures

layers with well width of 2, 4 and 10 nm, separated from one another by 30 nm-thick ZnSe barrier layers. PL measurement was carried out at 77 K using a He-Cd laser (325 nm line) as an excitation source. Figure 1 shows the growth interruption effect on the full width at half-maximum (FWHM) of the PL spectrum peak from ZnCdSe/ZnSe SQWs. PL FWHM became narrowest when growth was interrupted for five seconds. The PL FWHM for the 4 nm-thick well grown with a five-second interruption was as narrow as 12.4 meV, and its value was comparable with that for InGaAs/InP SQWs, which have abrupt hetero-interfaces, grown by metalorganic MBE.[3] Based on these results, a five-second interruption was employed in the LD fabrication.

Next, the impurity doping in MQW structures was studied to reduce series resistance of MQW layers since the undoped ZnSe barrier layer had high resistivity ($\rho > 10^4$ Ω·cm). Sample structures were similar to that shown in Fig. 1, except for the addition of a 1 nm-thick well. First, Ga was tested. The PL spectra at 77 K of these multilayer structures are shown in Fig. 2. Four peaks were clearly observed in the undoped sample. On the other hand, for uniformly Ga-doped sample with a carrier concentration of 3×10^{17} cm^{-3}, only a broad peak and a shoulder were observed and PL emission could not be detected from 4 and 10 nm wells. This suggests that SQW structures were destroyed by Ga diffusion with the assistance of strain energy, which was included in this SQW structure. Ga diffusion from a GaAs substrate into a ZnSe epitaxial layer was also observed in SIMS analysis.[4] The diffusion coefficient of Ga was calculated to be 1.4×10^{-16} cm^2/s at 400°C. Furthermore, MQW structures were grown, consisting of five 2-nm thick ZnCdSe wells, separated by 10 nm-thick ZnSe barrier layers. When Ga was doped in the ZnSe barrier layers, PL intensity decreased one twentieth, compared with that for the undoped MQW structure. Next, N-doping was tried in the ZnSe barrier layer. The PL intensity was the same as that for the undoped structure. From these results, N-doping was adopted in the barrier layers of MQW LD structures.

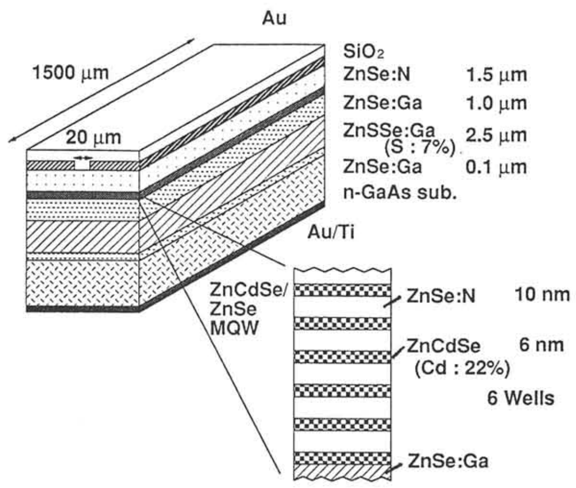

Fig. 3. Schematic laser structure

The LD structure fabricated was a window stripe type, as shown in Fig. 3. This structure is similar to that reported by H. Jeon, *et al.*[2], except for the lack of a GaAs buffer layer and an upper ZnSSe cladding layer, and a SiO_2 film instead of polyimide as a current blocking layer. The active layer had a MQW structure consisting of six pairs of 6-nm thick undoped ZnCdSe well layers and 10 nm-thick N-doped ZnSe barrier layers.

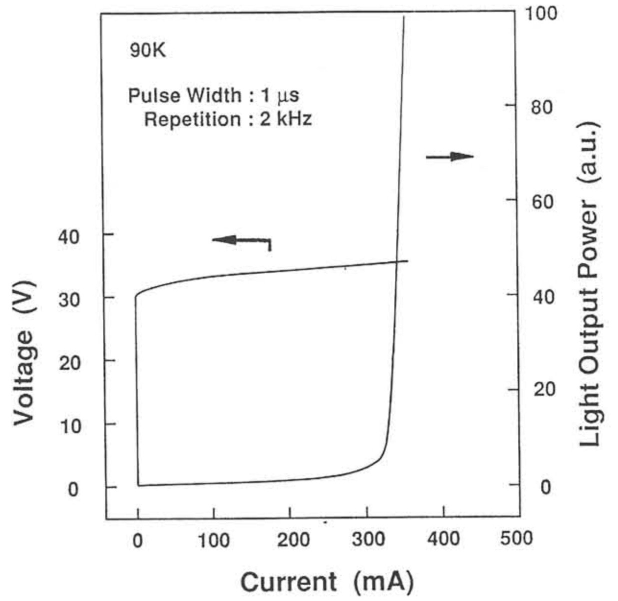

Fig. 4. Voltage-current and light output-current characteristics of laser diode at 90K

The cavity length and their stripe width were 1500 µm and 20 µm, respectively. Typical characteristics of an LD with both cleaved facets under pulsed operation at 90 K are shown in Fig. 4. The pulse width and the repetition rate were 1 µsec and 2 kHz, respectively. From voltage versus current characteristics, the built-in voltage was 30 V. The light output versus current curve showed a distinct kink at 330 mA. Above this value, the light output sharply increased. Applied voltage at this current was 35 V, which is similar to the value reported.5) Figure 5 shows the emission spectra for above and below the threshold current under the same condition as mentioned above. A narrowing in the emission spectrum was clearly observed in the wavelength of 492 nm. The output light was strongly TE-polarized above the threshold current. An elliptical far-field pattern could be observed. These characteristics have confirmed laser operation in the ZnCdSe/ZnSe MQW diode directly grown on a GaAs substrate.6) Moreover, to reduce the threshold current, a high-reflection coating was performed with an electron-beam-evaporated aluminum film through sputtered SiO_2 film. The optical thickness of this SiO_2 film was half the oscillation wavelength. The threshold current was lowered 220 mA and was reduced 33% by high-reflection coating as compared with a cleaved facet.

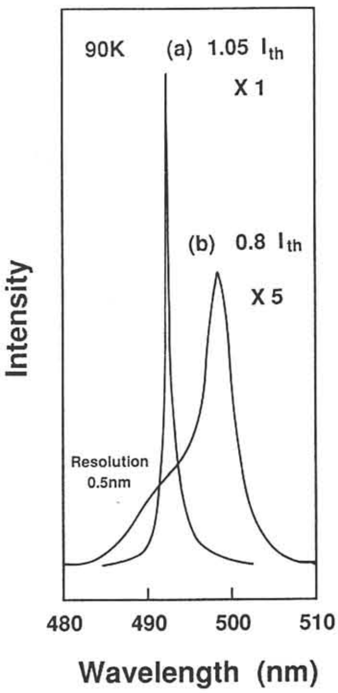

Fig. 5. Comparison of stimulated emission (a) and spontaneous emission (b) spectra at 90K.

In summary, a ZnCdSe/ZnSe MQW LD without a GaAs buffer layer has been fabricated and its laser oscillation has been observed. Growth interruption has been introduced to improve the hetero-interface in MQW structures. Nitrogen doping in ZnSe barrier layers of MQW has been employed to reduce series the resistance of LDs. In the doping in this barrier layer, it has also been shown that Ga degraded the PL characteristics of MQW.

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REFERENCES

1) M. A. Haase, J. Qiu, J. M. DePuydt and H. Cheng; Appl. Phys. Lett., 59 (1991) 1272.
2) H. Jeon, J. Ding, W. Patterson, A. V. Nurmikko, W. Xie, D. C. Grillo, M. Kobayashi and R. L. Gunshor; Appl. Phys. Lett., 59 (1991) 3619.
3) Y. Kawaguchi and H. Asahi, Appl. Phys. Lett., 50 (1987) 1243.
4) N. Kobayashi, Jpn. J. Appl. Phys., 27 (1988) L1597.
5) H. Jeon, J. Ding, A. V. Nurmikko, W. Xie, D. C. Grillo, M. Kobayashi, R. L. Gunshor; G. C. Hua and N. Ohtsuka, Appl. Phys. Lett., 60 (1992) 2045.
6) T. Mitsuyu, K. Ohkawa, S. Yoshii, H. Hayashi and A. Tsujiyama, CLEO'92, Post deadline paper, May 10 - 15, 1992, Anaheim, CA.