Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 53-55

Invited

Room Temperature Pulsed Operation of 498-nm Lasers

S. Itoh, N. Nakayama, H. Okuyama, T. Ohata, M. Ozawa, K. Nakano
A. Ishibashi, M. Ikeda, K. Akimoto* and Y. Mori

Sony Corporation Research Center
Fujitsuka-cho 174, Hodogaya-ku, Yokohama 240, Japan
*Tsukuba University
1-1-1, Tennoudai, Tsukuba, Ibaraki 305, Japan

Room temperature pulsed operation of ZnCdSe/ZnSe/ZnMgSSe separate-confinement heterostructure lasers has been achieved. Light-blue stimulated emission is observed at a wavelength of 498.5nm, which is the shortest wavelength at room temperature ever reported. The threshold current density is 2.8 kA/cm^2 for the diode without facet coating.

1. Introduction

Rapid advances in the field of ZnSe-based II-VI semiconductors have led to a number of demonstrations of blue and green laser diodes(LD) at 77K.[1-3] The groups of 3M Corporate Research Laboratory and Brown University - Purdue University have demonstrated pulsed room temperature operation in the green region[4,5]. The end facets of their lasers were coated for threshold current density reduction because the heat generation due to both high currents and poor ohmic contact to p-type ZnSe makes the room temperature operation of LD difficult. Recently, however, a quasi-ohmic contact to p-ZnSe was obtained using semimetal HgSe layer or ZnSe/ZnTe pseudograded structure[6,7]. We also proposed a ZnSe/ZnTe quantum tunneling structure and Pd/Pt/Au metal structure suitable for p-ZnTe[8,9]. Another important aspect of difficulties in room temperature laser operation is a carrier overflow across the $Zn_{0.8}Cd_{0.2}Se$ active layer. We have proposed a ZnMgSSe compound for the cladding layers of blue and green lasers. ZnMgSSe has a large bandgap and can be lattice-matched to GaAs or ZnSe by changing the composition of Mg and S[10]. Recently, a separate-confinement heterostructure (SCH) LD at a wavelength of 516 nm containing ZnMgSSe was reported by Gains et al.[11]. In the present paper, we report on the room temperature pulsed operation of a II-VI LD whose wavelength is less than 500 nm. The LD has a ZnCdSe/ZnSe /ZnMgSSe SCH structure with the improved contact layer and ohmic metals. The laser diode with a 1 mm cavity length and 10-μm-wide stripe operates at room temperature without any facet coatings.

2. Experimental

The epitaxial layers for the laser diodes were grown on Si-doped GaAs(100) substrates by molecular beam epitaxy (MBE) at a substrate temperature of 280° C. The source materials were Zn (6N), Se(6N), ZnS (6N), Mg (4N grade), Cd (6N) and Te (6N). The n-type doping was carried out using $ZnCl_2$ as a dopant. The p-type doping of ZnMgSSe, ZnSe and ZnTe was achieved using nitrogen plasma, which was produced by electron cyclotron resonance (ECR)[12]. We have determined the alloy composition by photo-luminescence (PL) measurements at 77K referring to the calibrated data.

The schematic structure of the LD is shown in Fig. 1. The epitaxial layers consist of (i) an n-ZnMgSSe cladding layer (N_D-N_A = 8×10^{17} cm^{-3}) ,(ii) an n-ZnSe optical guiding layer (N_D-N_A = 8×10^{17} cm^{-3}), (iii) a ZnCdSe active layer, (iv) a p-ZnSe optical guiding layer (N_A-N_D = 5×10^{17} cm^{-3}), (v) a p-ZnMgSSe cladding layer (N_A-N_D = 2×10^{17} cm^{-3}) , (vi) a p-ZnSe layer (N_A-N_D = 5×10^{17} cm^{-3}), (vii) a p-ZnSe / p-ZnTe multiquantum wells(MQW) and (viii) a p-ZnTe contact layer (p = 3×10^{18} cm^{-3}). The ZnSe / ZnTe MQW is composed of seven 2 nm wide

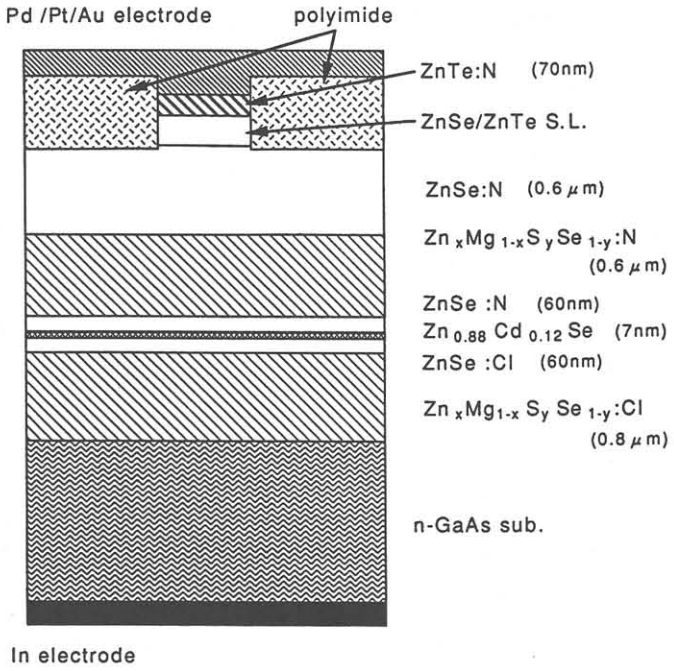

Fig.1. Schematic structure of ZnCdSe/ZnSe/ZnMgSSe SCH lasers (x=0.91,y=0.12)

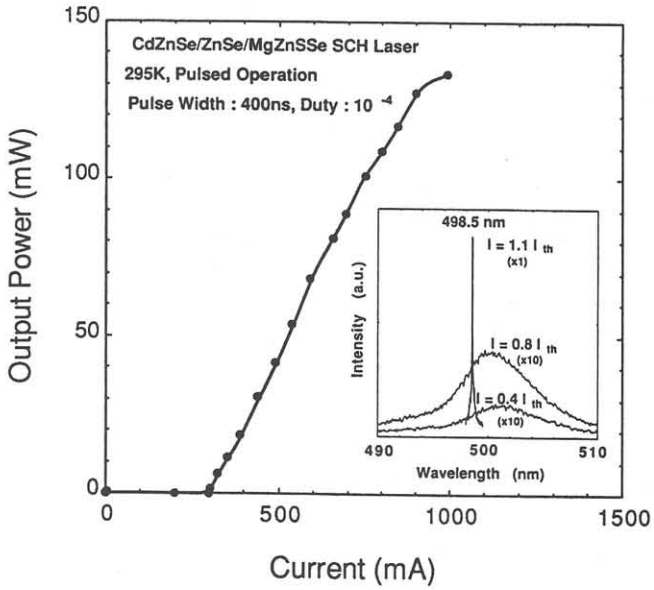

Fig.2. L-I characteristics and emission spectrum of laser diode

barriers of ZnSe and seven (0.3, 0.4, 0.5, 0.6, 0.8, 1.1 and 1.7 nm thick) wells of ZnTe. The energy of the bandedge emission of ZnCdSe and ZnMgSSe at 77K are 2.62 and 2.96 eV, respectively. Therefore, the band gap energy difference between the active and cladding layers is estimated to be 340 meV. The light emitting region is the $Cd_{0.12}Zn_{0.88}Se$ single quantum well. The $Zn_{0.91}Mg_{0.09}S_{0.12}Se_{0.88}$ cladding layer has been confirmed to be lattice matched to ZnSe by X-ray diffraction.

A polyimide insulator defines the 10-μm-wide stripe for the laser diodes with a 1-mm cavity length. The Pd/Pt/Au electrode is evaporated on the ZnTe contact layer, and In serves as an n-metal contact to the n-GaAs substrate.

3. Results and discussion

Mounting the LD with the p-side down on a heatsink, we have obtained pulsed laser operation of the ZnCdSe/ZnSe/ZnMgSSe SCH lasers at room temperature without any coating of the end facets. The relation of the light output power to the current is shown in Fig. 2. The current pulse width and repetition rate used are 400 nsec and 250 Hz, respectively. The laser diodes operate at a duty cycle as high as 10^{-3} at 295 K. We have been able to obtain a peak pulsed output power of 130 mW from each facet at room temperature. The external quantum efficiency is 0.25 mW/mA per facet at 295K. The threshold current I_{th} is 280 mA, which corresponds to a threshold current density J_{th} of 2.8 kA/cm^2. We find that a threshold voltage of ~12V has to be applied across the diode at the threshold current I_{th}. The emission spectrum at room temperature is also shown in Fig.2. The driving current is just above the I_{th}. The lasing wavelength is 498.5 nm, which is the shortest for room temperature laser operation thus far reported. We attribute the short wavelength lasing to the use of ZnMgSSe clading layers, which has larger bandgap energy than $ZnS_{0.06}Se_{0.94}$. Further improvement in the p-contact of the laser diodes and the use of facet coating will lead to a lower threshold current density and therefore to the cw operation at room temperature.

The relation of the light output power to the current of another LD with a high reflection facet coating (70-95%) is shown in Fig.3.The threshold current I_{th} is 93 mA and some LDs show a lower one. This LD has a 5 μ m wide stripe and a 650 μ m cavity length. Without facet coating, the threshold current I_{th} for this device was 500 mA with 10 μ m wide stripe.

There are some requirement for the II-VI LD to realize cw operation at room temperature. We obtain a threshold voltage of ~12V, but it is not low enough because the built-in potential of the p-n junction should be about 3 eV for II-VI LD. Further experiments will be needed for the p-ZnSe/p-ZnTe MQW quasi-ohmic contact to ZnSe. Lower

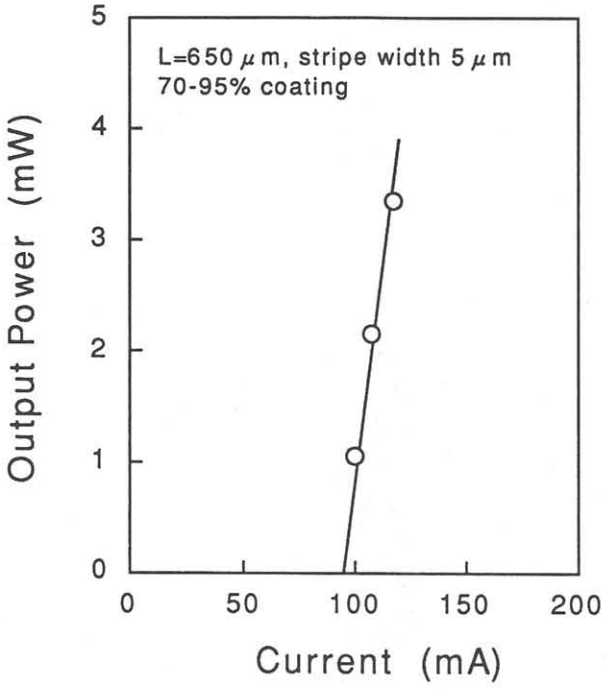

Fig.3. L-I characteristics of the LD with high reflection facet coating.

threshold current will also lead to a smaller heat generation of laser diodes. Improvements in the quality of materials and the structure of LD are also necessary.

4. Summary

We have achieved room temperature pulsed operation at 498.5 nm, the first operation at a wavelength shorter than 500nm, using the ZnCdSe/ZnSe/ZnMgSSe SCH structure. The threshold current I_{th} is 280 mA, which corresponds to a threshold current density J_{th} of 2.8 kA/cm^2. We could make the threshold current lower than 100mA by using both the 5 μm wide stripe and the HR coating.

The authors would like to acknowledge the assistance of S. Matsumoto, F. Hiei and E. Katoh in the crystal growth and device measurements, F. Narui, Y. Kaneko in device fabrication. They also would like to thank Dr. S. Watanabe for his encouragement during the course of this work.

References

1) M. A. Haase, H. Cheng, J. M. DePuydt and J. E. Potts : Appl. Phys. Lett. 59(1991) 1272

2) H. Jeon, J. Ding, A. V. Nurmikko, W. Xie, D. C. Grillo, M. Kobayashi, R. L. Gunshor, G. C. Hua and N. Otsuka : Appl. Phys. Lett. 59(1991) 3619

3) H. Okuyama, T. Miyajima, Y. Morinaga, F Hiei, M Ozawa and K. Akimoto : Electron. Lett., 28 (1992) 1798

4) C. T. Walker, J. M. DePuydt, M. A. Haase, J.Qiu and H. Cheng : 7th Trieste Semiconductor Symp., Trieste, 1992, We-am-1.

5) A.V. Nurmikko, R. L. Gunschor, N. Otsuka and M.Kobayashi : Ext. Abstr. 1992 Int. Conf. Solid. State. Device and Materials, Tsukuba (1992) 342

6) Y. Lansari, J. Ren, K. Sneed, K. A. Bower, J. W. Cook, Jr. and J. F. Schetzina : Appl. Phys. Lett. 61 (1992) 2554

7) Y. Fan, J. Han, L. He, J. Saraie, R. L. Gunshor, M. Hagerott, H. Jeon, A. V. Nurmikko, G. C. Hua and N. Otsuka : Appl. Phys. Lett. 61(1992) 3160

8) F. Hiei, M. Ikeda, M. Ozawa, T. Miyajima, A. Ishibashi and K. Akimoto : Electron. Lett. 29(1993) 878

9) M. Ozawa, F. Hiei, A. Ishibashi and K. Akimoto : Electron. Lett. 29(1993) 503

10) H. Okuyama, K. Nakano, T. Miyajima and K. Akimoto : Jpn. J. Appl. Phys. 30(1991) L1620

11) J. M. Gaines, R. R. Drenten, K. W. Haberern, T. Marshall, P. Mensz and J. Petruzzello : Appl. Phys. Lett. 62 (1993) 2462

12) S. Itoh, M. Ikeda and K.Akimoto : Jpn. J. Appl. Phys. 31(1992) L1316