Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 350-351

C-7-1

Invited

Growth of Wide Gap II-VI Materials, Its Characterization and Device Application

Detlef Hommel, Helmut Wenisch, Martin Behringer, Michael Fehrer, Matthias Klude, Andreas Isemann
and Kazuhiro Ohkawa[1]

Institute of Solid State Physics, University of Bremen, NW1, Kufsteiner Str., P.O.Box 330 440, D-28334 Bremen, Germany
Phone/Fax: +49-421-218-2950/4581, E-mail: hommel@physik.uni-bremen.de
[1]Present: Department of Applied Physics, Science University of Tokyo, Kagurazaka 1-3, Shinjuku, Tokyo 162-8601, Japan

1. Introduction

Although ZnSe-based laser diodes (LD) have been realized first 7 years ago [1] and despite of recent progress [2] the limited lifetime still hampers their application. ZnSe substrates are an attractive alternative to the commonly used GaAs wafers. Homoepitaxial LD's have been realized now on insulating as well as on conducing ZnSe [3-5]. Mean efforts are concentrated on the growth start itself to lower the defect density, improvements of the active quantum well region to reduce point defects and non-radiative recombination and more reliable p-type contacts to lower the driving voltage and heat generation.

2. ZnSe Growth on GaAs

Molecular beam epitaxy in a twin-chamber EPI-930 system was used for growth. Due to the heterovalent interface the initial ZnSe growth start determines the growth mode, the defect density of the whole structure and the electrical properties of the interface region. All structures were grown on GaAs buffer layers with As-rich (2x4) reconstruction. Etch pit densities $\leq 10^4$ cm^{-2} could be realized using Zn-exposure and migration enhanced epitaxy.

3. Heteroepitaxial Laser Diodes on GaAs

The laser structures consist of a 300 nm GaAs:Si buffer, ZnSe and ZnSSe buffers (150 nm), MgZnSSe cladding layers (1 µm), a ZnSSe waveguide (200 nm) and a 3 nm quaternary CdZnSSe quantum well with 35 % Cd. As p-type contact a ZnSe/ZnTe resonant tunneling structure with a thin ZnTe top layer was used. The Pd/Au metal contact stripes were 10 µm wide. No facet coating was used to improve the laser properties. Samples were simply mounted with the substrate on a copper heat plate.

Cw room temperature lasing was observed over more than 3 min with a maximum output power of 18 mW per facet (Fig.1). The voltage at threshold was below 7 V for the best LD's. In figure 2 a typical dependence of the threshold current density on the cavity length is shown.

By changing the duty cycle from 0.1 % to cw operation a spectral red shift of the stimulated emission was observed corresponding to a temperature increase of about 80 K due to heat generation.

Degradation studies performed under low current densities revealed a 1/t decay behavior being characteristic for point defect diffusion as the mean aging process [7].

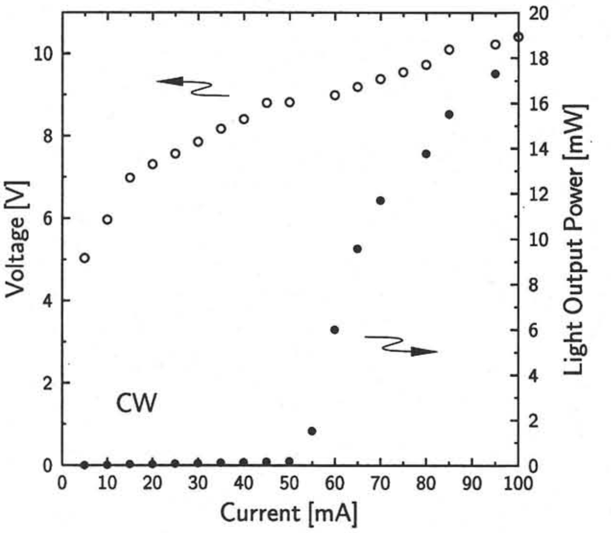

Fig. 1 Voltage - current and light output characteristics of a heteroepitaxial laser diode.

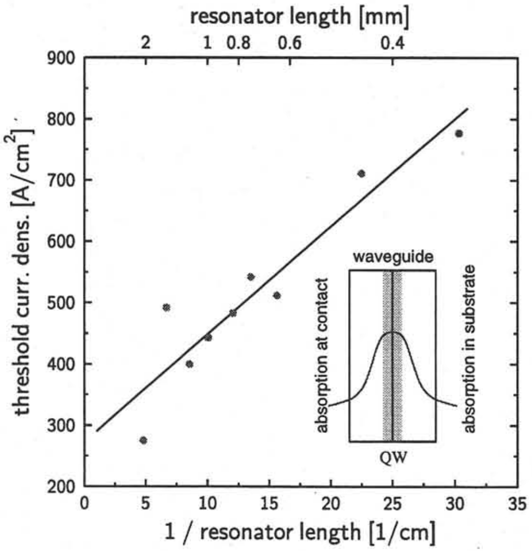

Fig. 2 Dependence of the threshold current density on the cavity length. The insert illustrates that part of the optical wave is absorbed in the substrate and contact region.

4. Homoepitaxy on ZnSe

The mean problem here is the surface quality of the ZnSe substrates. Crystals grown by the modified recrystallization method and by iodine transport method have been used. The latter ones were completely conducting with free carrier concentrations up to 10^{18} cm^{-3} [6]. Essential progress in preparing contamination-free surfaces could be obtained by in-situ hydrogen plasma cleaning. This resulted in device quality structural and electrical properties of ZnSe-based structures.

5. Homoepitaxial Laser Diodes on ZnSe

The LD structures are essentially the same as in heteroepitaxy with cladding layers lattice matched to the ZnSe substrate. The stripe width used here was 20 µm. Three kinds of LD's have been realized: On insulating and on fully conducting ZnSe substrates stimulated emission under pulsed excitation has been observed (Fig. 3). Cw operation at 300 K was obtained on a substrate being converted doped by Al in the upper 200 µm.

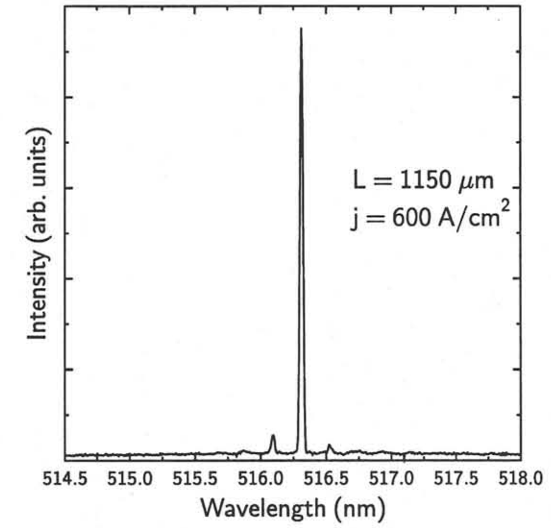

Fig.3 Room temperature stimulated emission under pulsed excitation of a homoepitaxial laser diode with back site contacts on conducting ZnSe substrate.

In one of the LD's no hints for defects starting from the substrate-epilayer interface could be found in transmission electron microscopy. In contrast, for another laser diode a stacking fault density of $2 \cdot 10^5$ cm^{-2} has been observed. Detailed investigations are under way.

6. Discussion

The crucial problems which must be solved now are the reduction of point defects and non-radiative recombination centers, the stability of low voltage p-type contacts under cw operation and a better optical and electrical confinement in the SCH-structures. Superlattice structures are one possible way to improve the latter one because of a higher net acceptor concentration by a factor of 2 in the claddings. Room temperature lasing of such a LD has been demonstrated [7]. Although the homoepitaxial interface between the ZnSe substrate and the epitaxial structure is still not fully optimized first results indicate lower threshold current densities compared to comparable LD's grown on GaAs. This raise the hope of substantial lifetime improvements, if the defect density could be reduced in homoepitaxy below 10^4 cm^{-2} as well.

7. Outlook

Despite of the competition with the GaN laser diodes emitting in the blue and near UV spectral range ZnSe-based LD's are still the best candidate for stimulated emission in the green. Human eye is most sensitive in this spectral region which opens a variety of applications although the market for each of them is much smaller compared to mass production LED's and optical memories. Recent progress in ZnSe-based homoepitaxial laser diodes allows to predict the realization of low voltage, long lifetime laser diodes in the green spectral region.

Acknowledgments

We would like to thank V. Großmann and Dr. H. Heinke for high resolution X-ray diffraction measurements and S. Hesselmann for substrate and device preparation.

References

1) M. A. Haase, J. Qiu, J. M. DePuydt and H. Cheng: Appl. Phys. Lett. **57** (1991) 2127
2) E. Kato, H. Noguchi, M. Nagai, H. Okuyama, S. Kijima and A. Ishibashi: Electron. Lett. **34** (1998) 282
3) A. Ohki, T. Ohno, T. Matsuoka and Y. Ichimura: Electron. Lett. **33** (1997) 990
4) K. Katayama, H. Yao, F. Nakanishi, H. Doi, A. Saegusa, N. Okuda, T. Yamada, H. Matsubara, M. Irikura, T. Matsuoka, T. Takebe, S. Nishine and T. Shirakawa: Appl. Phys. Lett. **73** (1998) 102
5) H. Wenisch, K. Ohkawa, A. Isemann, M. Fehrer and D. Hommel: Elektron. Lett. **34** (1998) 891
6) M. Prokesch, U. Rinas and H. Hartmann: To be published: Proceedings of the 2nd Intern. Symposium on Blue Laser and Light Emitting Diodes,Chiba, 1998
7) M. Behringer, H. Wenisch, M. Fehrer, V. Großmann, A. Isemann, M. Klude, H. Heinke, K. Ohkawa and D. Hommel: Annual Meeting of the German Physical Society, Regensburg 1998, To be published: Festkörperprobleme, Springer Verlag