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Nearly Room-Temperature Photopumped Blue Lasers in $ZnS_xSe_{1-x}/ZnSe$ Multilayer Structures

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Photopumped blue laser oscillation was achieved up to 280K in a $ZnS_{0.18}Se_{0.82}/ZnSe$ multilayer structure grown by MOVPE. This significant improvement of the lasing temperature is attributed to the higher heterobarrier to prevent the thermoionic emission and to the multilayer structure which has the average lattice constant matched to the GaAs substrate at the growth temperature of 515°C. The threshold excitation optical power density below 200K where the thermoionic emission is negligible is less than $50kW/cm^2$,which corresponds to the current density of $14kA/cm^2$.

1. Introduction

ZnSe and ZnS_xSe_{1-x} have been extensively studied to realize optical devices in blue region, such as light emitting diodes and laser diodes. For this purpose, the control of the electrical property, especially p-type conductivity, is necessary for current injection. In order to improve the situation, many doping trials have been done.1)-5) As for the optical property of these materials, electron beam pumping and photopumping techniques have been used to obtain lasing.6)-10) We have also studied photopumped lasing using a $ZnS_{0.12}Se_{0.88}/ZnSe$ multilayer structure to prevent the diffusion of the photoexcited carriers. But the lasing threshold power increased abruptly above 150K and the lasing was limited to below 180K.11) According to a theoretical analysis of the result,11,12) we found that the main factors of the abrupt increase of the threshold power above 150K were due to thermoionic emission over the heterobarriers and surface recombination. This theoretical analysis indicated possibility of lasing action at the higher temperature by using a structure with the higher heterobarriers. In this paper, the photopumped lasing action up to 280K is reported with a $ZnS_{0.18}Se_{0.82}/ZnSe$ periodic multilayer structure which has the higher heterobarriers. The average lattice constant in this structure is lattice matched to a GaAs substrate at the growth temperature of 515°C where the generation of misfits dislocations will be prevented.

2. Film Preparation

ZnS_xSe_{1-x} films were grown by metal-organic vapor phase epitaxy (MOVPE) at atmospheric pressure using diethylzinc (DEZn), diethylselenide (DESe), and diethylsulfide (DES). The films were grown at 515°C with the fixed DESe/DEZn ratio of 6 and the DEZn flow rate of 2.5µmol/min. The S composition was

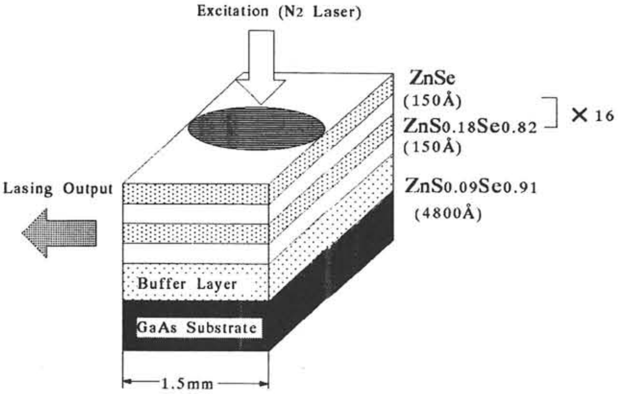

Fig. 1 Schematic of the periodic layered structure used for photopumped lasing.

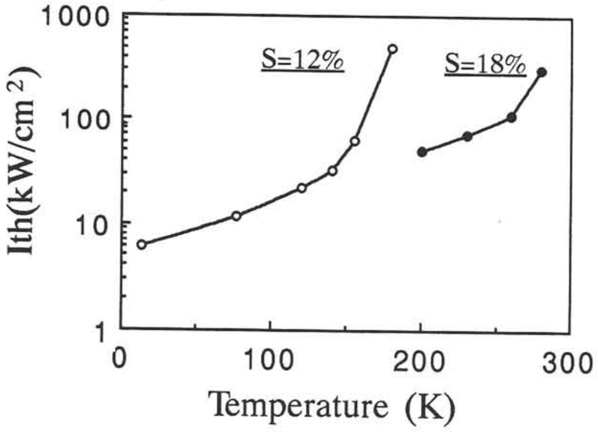

Fig. 2 Temperature dependence of the lasing threshold optical pumping power observed in the former $ZnS_{0.12}Se_{0.88}/ZnSe$ layered structure (open circle) and in the present $ZnS_{0.18}Se_{0.82}/ZnSe$ layered structure (solid circle).

controlled by the flow rate of DES. The layer structure used for photopumped lasing is shown in Fig. 1. After deposition of the 0.48μm $ZnS_{0.09}Se_{0.91}$ buffer layer which was lattice matched to the GaAs substrate at the growth temperature, 16 periods of (150Å-$ZnS_{0.18}Se_{0.82}$)/(150Å-ZnSe) layers were grown. The film thicknesses are the values expected from the growth rate of 6000Å/h for the buffer layer. The grown wafer was cleaved into a bar with the cavity length of 1.5mm. The sample was excited with a pulsed N_2 laser at the wavelength of 337nm. The pulse width and the repetition rate were about 10ns and 8Hz, respectively.

3. Experiments and discussions

The temperature dependence of the lasing threshold excitation power observed in the present $ZnS_{0.18}Se_{0.82}/ZnSe$ structure is shown in Fig. 2. The characteristics observed in the former $ZnS_{0.12}Se_{0.88}/ZnSe$ structure is also shown for reference. In the present structure, a significant reduction of the lasing threshold optical power is clear at the higher temperature. This demonstrates the improvement expected from the higher heterobarrier which prevents the thermoionic emission and the surface recombination of the photoexcited carriers.

In Fig. 3, the measured temperature dependence of the threshold excitation power was studied theoretically. The details of the calculation is described elsewhere,$^{11,12)}$ but the theoretical curves were calculated considering the matrix element of the band-to-band optical transition assuming the k-selection rule. The thermoionic emission over the heterobarrier and the related surface recombination were taken into account. In this calculation, the penetration depth of the excitation light was adjusted to fit the measurement at the lower temperature range. The resultant penetration depth was 900Å. In Fig. 3, the valence band offset, ΔE_V =160 meV, corresponds to the measured structure of the ZnSSe barrier with the 18% S mole mole fraction was estimated after ref. 13. The two characteristics measured in the same structure are shown in Fig. 3 which are in reasonable agreement with the calculation. The theoretical curve calculated with the band offset, ΔE_V=245meV, corresponds to the ZnSSe barrier with the S mole fraction of 30%, where the thermoionic emission is negligible. Therefore the increase of the threshold power for ΔE_V=160meV relative to that for ΔE_V=245meV indicates the contribution from the thermoionic emission.

Fig. 4 shows the light output vs. excitation optical power characteristics measured at 200K, 230K, 260K, and 280K. The decrease of the differential quantum efficiency at the higher temperature corresponds to the increase of the lasing threshold shown in Fig. 3 due to the carrier overflow over the heterobarrier by the thermoionic emission. At the temperature below 200K where the carrier overflow by the thermoionic emission is negligible, the threshold optical power density is the relatively low value below 50kW/cm^2, (corresponds to the current density of 14kA/cm^2). The spectra below and above threshold observed at 260K are shown in Fig. 5. The stimulated emission spectrum above threshold was clearly observed.

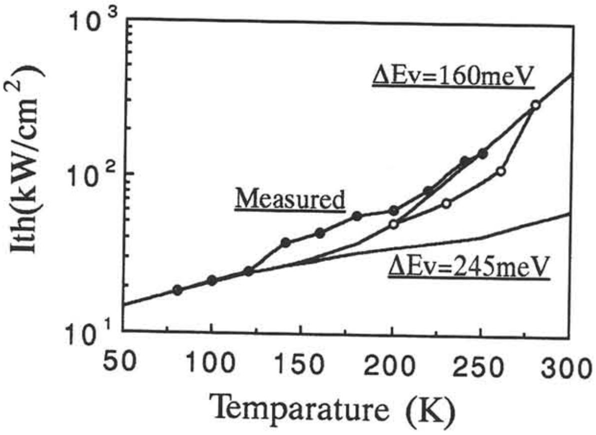

Fig. 3 Analysis of the observed temperature dependence of the threshold optical power. Two solid lines show the calculated value with the respective ΔE_V value. Open and closed circles are the characteristics measured in the two samples with the same structure, which correspond to the calculated curve with ΔE_V=160meV.

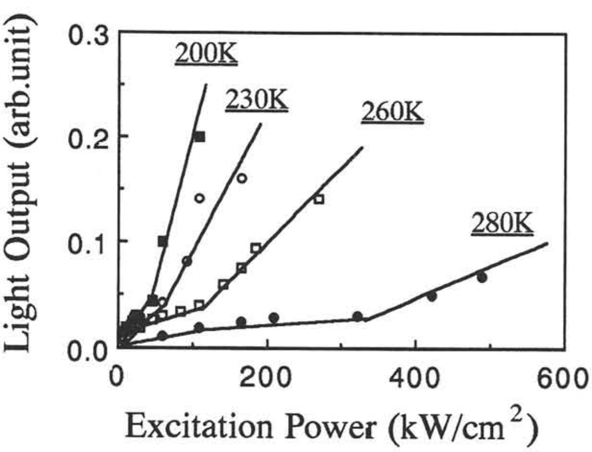

Fig. 4 Light output vs. excitation power characteristics.

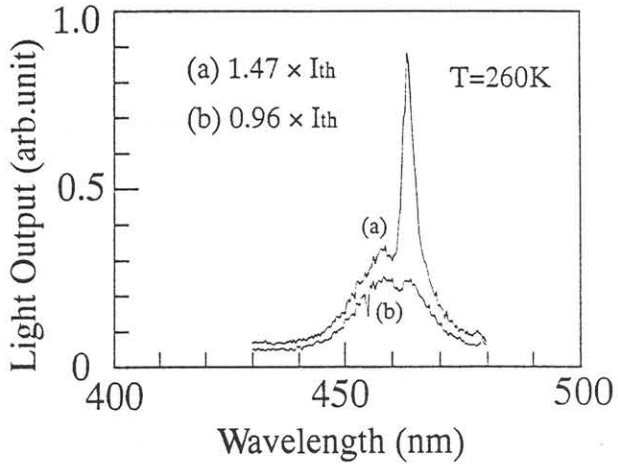

Fig. 5 Observed typical spectra below and above the lasing threshold at 260K.

4. Summary

In conclusion, lasing oscillation in the blue region up to 280K was obtained by photopumping in the $ZnS_{0.18}Se_{0.82}/ZnSe$ multilayer structure. The main factor for this achievement is attributed to the reduction of the thermoionic emission and the surface recombination over the heterobarrier by using the higher heterobarrier in a structure with low misfit dislocations. Lasing operation at the higher temperature will be realized by introducing the higher band offset while preventing misfit dislocations.12)

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