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RT Operation of ZnSe-Active-Layer and ZnCdSe-Active-Layer Laser Diodes

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Abstract

Room temperature operation of ZnSe-active-layer double heterostructure laser diode was succeeded. The emission energy shift with increasing the current is explained by the band-filling and the band-shrinkage. The mechanism of the stimulated emission of II-VI double heterostructure laser diode is concluded to be the recombination of electron-hole plasma. Similar mechanism could be observed in ZnCdSe-active-layer separate confinement heterostructure laser diode.

Since Nakayama et al.[1] reported the first cw operation of II-VI wide-gap LD at room temperature, our group optimized the growth condition and achieved the life time of one-hour of cw operation. If the ZnCdSe is used for the active layer, the thickness of ZnCdSe must be thinner than the critical thickness and large stress exist which may be effective to the degradation. To obtain the reproducible lasing wavelength and blue emission, ZnCdSe layer is not suitable. We succeeded to realized the RT operation of LD using ZnSe active layer of simple DH. We discussed about the mechanism of lasing of II-VI wide-gap laser diodes.

The epitaxial layer of ZnSe-active layer LD (ZnSe LD) was composed of a p-type ZnTe:N contact layer (10nm)/ p-type ZnTe/ZnSe superlattice layer / p-type ZnSSe:N cap layer (500nm) / p-type ZnMgSSe:N cladding layer (800nm)/ ZnSe active layer (62nm) / n-type ZnMgSSe:Cl cladding layer (1μm) / n-type ZnSe:Cl buffer layer (10nm) / n-type (100) GaAs substrate. The epitaxial layer of ZnCdSe active layer SCH LD (ZnCdSe LD) is a p-type ZnTe:N contact layer (10nm)/ p-type ZnTe/ZnSe superlattice layer / p-type ZnSSe:N cap layer (500nm) / p-type ZnMgSSe:N cladding layer (800nm)/ ZnSe active layer (62nm) / n-type ZnMgSSe:Cl cladding layer (1μm) / n-type ZnSe:Cl buffer layer (10nm) / n-type (100) GaAs substrate. The band-gap energy (E_g) of the cladding layer lattice-matched to GaAs, which was measured by photoluminescence (PL) at 77K (RT), was about 3.00eV (2.90eV) and that of ZnSe coherently grown on GaAs was 2.794eV (2.692eV). A Au/Pt/Pd electrode was evaporated on the p-type contact layer. Using lithography, the 10μm-width stripe was formed. No facet coatings were applied.

First we discuss the lasing of ZnSe LD. The relation of the light output power, the operation voltage and the current is shown in Fig.1. The threshold current I_{th} was 1.15A which corresponds to a threshold current density, J_{th} of 20kA/cm². Figure 2 shows RT emission spectra of (a) the emission from the top surface when the current density is 2A/cm² and (b) the stimulated emission observed when the current is 20kA/cm². When the driving current density

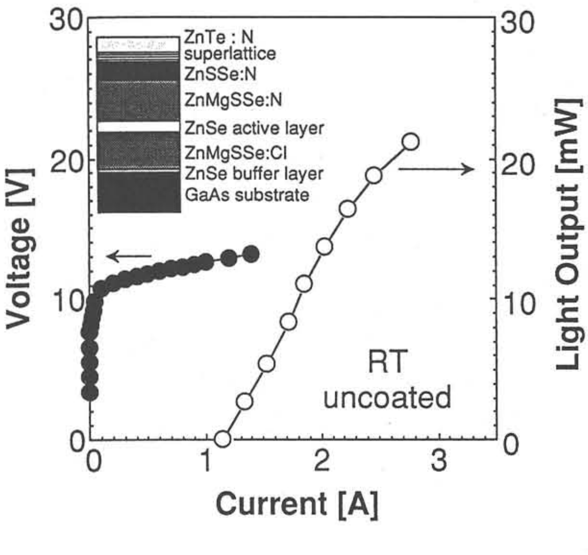

Fig. 1 Schematic structure of ZnSe/ZnMgSSe DH LD and relation between the current and the light output, the operating voltage. The current pulse width was 150ns and repetition rate was 100Hz.

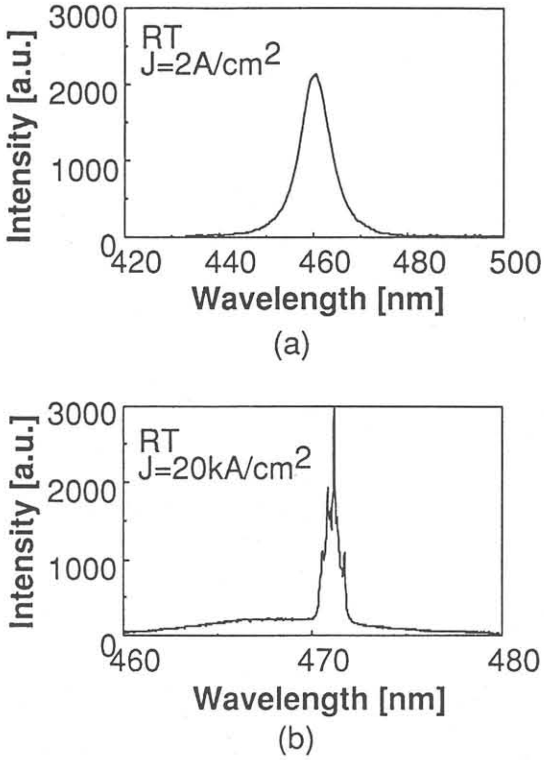

Fig. 2 (a) Emission spectrum from the top surface when the current density is 2A/cm² and the duty cycle is 20%. (b) Emission spectrum observed when the current density is 20kA/cm². The current pulse width was 150ns and repetition rate was 100Hz. The lasing wavelength is 471nm.

is 2A/cm², the injected carrier density is calculated to be about 1×10^{15}cm^{-3} if the carrier life time is about 500ps and there is no overflow current. Figure 2 (a) shows the peak energy of the spontaneous emission is 2.692eV (460.5nm) which coincides with the peak energy of PL. With increasing injected current, the peak energy of the spontaneous emission shifts to the lower energy side. When driving current density was just below J_{th} (about 20kA/cm²), the spontaneous emission peak is observed at 2.652eV (467.5nm). When current density is 20kA/cm² (Fig. 2 (b)), the stimulated emission appears at 2.632eV (471.0nm).

Figure 3 shows the relation between the carrier density and the peak energy of the spontaneous (a) and stimulated emission (b). These energies are calculated as follows [2].

$$E(N) = E_g\,(ZnSe) + \Delta E_{fill} + \Delta E_{g\,shrink} \qquad \text{---(1)}$$

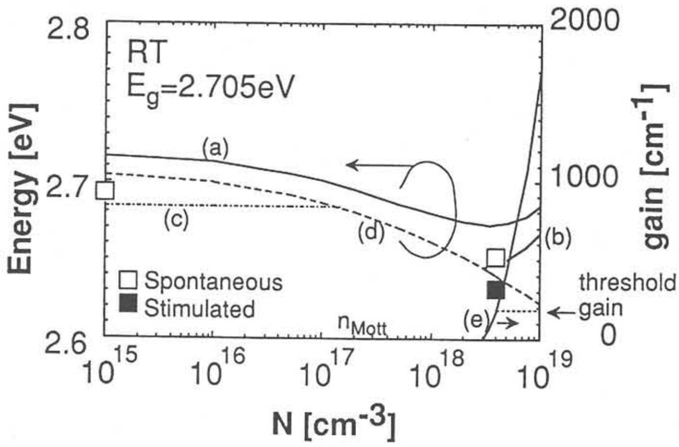

Fig. 3 The calculated dependence of the photon energy of (a) spontaneous emission peak, (b) stimulated emission peak, (c) excitonic emission peak (E_g-E_B) and (d) renormalized band-gap energy (E_g -$\Delta E_{g\,shrink}$). The calculated maximum gain coefficient (e) is over plotted. Horizontal axis shows the injected carrier density. The open and closed squares depict the experimental photon energy of the spontaneous emission and the stimulated emission, respectively.

$$\Delta E_{g\ shrink} = \frac{-3.24 r_s^{-3/4}}{\left(1+0.0478 r_s^{3} J^{2}\right)^{1/4}} E_B \qquad \text{----(2)}$$

$$r_s = \left(\frac{3}{4\pi N}\right)^{1/3}\left(\frac{1}{a_B}\right)$$

Where N is the carrier density of the active region, $\Delta E_{g\,shrink}$ is the band-gap shrinkage of the electron-hole plasma (EHP), kT is the thermal energy and in this paper T=300K and $J=kT/E_B$. r_s is the distance of each carrier. Eq. (2) almost coincides with the experiments [3,4]. ΔE_{fill} is the term of the band filling. E_g (ZnSe) is the band-gap energy of ZnSe. The calculated emission energy is valid when $N > n_{Mott}$. When $N<n_{Mott}$, the emission is excitonic. Figure 3 (c) shows the emission energy , E_g-E_B. At about 1×10^{15}cm^{-3} in this figure, the peak energy is mainly due to the recombination of the exciton. When N= 4×10^{18}cm^{-3} at which lasing occurs, the experimental peak energy of the spontaneous and the stimulated emission almost coincide with the error of about 20meV. This error is almost explained as follows.

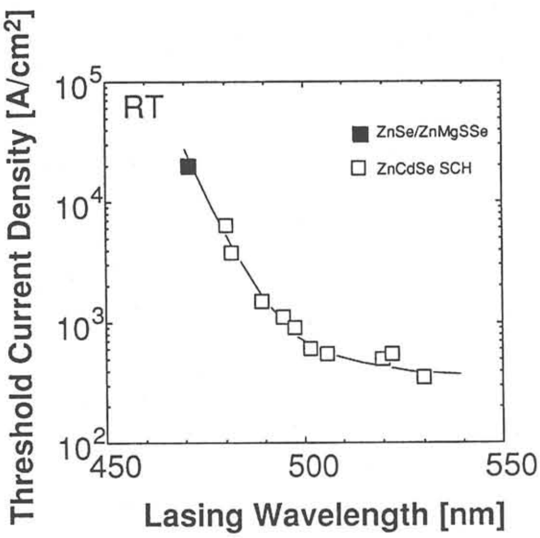

Fig. 4 Relation between the lasing wavelength and the threshold current density of ZnCdSe LD.

1) The calculated band shrinkage is about 10-20meV lower than the experimental value [3] in many II-VI semiconductor. This error is explained to be due to the exciton-phonon interaction in ionic semiconductor. [4]
2) Because the spontaneous emission is observed from the cleaved facet, the self absorption may be the origin of the shift to the lower energy side.
Figure 3 (d) shows the $E_g - \Delta E_{g\,shrink}$ and fig. 3 (e) is the calculated maximum gain coefficient. At threshold carrier density, this gain coefficient is equal to $(1/\Gamma)(\alpha + \ln(1/R)/L)$. where α is the absorption constant, Γ is the confinement factor, R is the reflectivity and L is the cavity length and α=4cm^{-1}, Γ=0.15, R=0.25 and L=0.58mm.

Next we discuss ZnCdSe LDs. The lasing wavelength of these LDs are about 10nm longer than the spontaneous emission. Figure 4 shows the threshold current density of various ZnCdSe LDs without facet coating. In this figure the threshold current density increases with decreasing the lasing wavelength. The threshold current density of ZnSe LD can be plotted on the same curve. This shows that the threshold current can be obtained from the lasing wavelength when the band-gap energy of the cladding layers are constant although the structures are different. Although the further experiment is necessary, there is no need of using the effect of the exciton to explain the experimental results at RT.

In conclusion, RT operation of ZnSe/ZnMgSSe DH LD was succeeded. The lasing wavelength was 471nm. The emission energy shift is explained by the band filling and the band-gap shrinkage. The mechanism of the emission of present II-VI LD at RT is concluded to be the recombination of EHP.

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