Extended Abstracts of the 16th (1984 International) Conference on Solid State Devices and Materials, Kobe, 1984, pp. 137-140

Lasing Characteristics and Structure of Distributed Feedback Surface Emitting Laser Diode with $Al_xGa_{1-x}As/GaAs$ Multilayered Heterostructure

Mutsuo OGURA and Takafumi YAO

Electrotechnical Laboratory, Sakura-mura,
Niihari-gun, Ibaraki 305

We realized the first distributed feedback surface emitting laser diode with $Al_{0.3}Ga_{0.7}As/GaAs$ multilayered heterostructure both by the optical pumping and current injection. Sharp stimulated emission is observed at the selected wavelength determined by the optical cavity. The threshold current is 120 mA at 150 K with the active layer thickness of 6 μm and width of 3 μm. The temperature coefficent of the lasing wavelength is equal to a conventional DFB laser diode.

The surface emitting laser diode(SELD), which emits a laser beam perpendicular to the substrate, is advantageous for its high output power, monolithic laser array formation, and compatibility with other optical systems[1]. The multilayered heterostructure of GaAs and AlGaAs can be designed to have high reflectivity at a selected wavelength [2] and forms a vertical low loss optical cavity [3,4]. The use of an epitaxial multilayered reflector eliminates the necessity for the window etching of the substrate and successive formation of metallic or dielectric reflector. The AlGaAs/GaAs multilayer generates periodic corrugation of refractive index perpendicular to the substrate and each GaAs layer works as an active layer, therefore, vertical distributed feedback (DFB) laser operation is expected[3]. We realized the first DFB type surface emitting laser diode with $Al_{0.3}Ga_{0.7}As/GaAs$ multilayered hetero-structure both by optical pumping and current injection.

Figure 1 shows the cross sectional SEM picture of the AlGaAs/GaAs multilayered optical cavity prepared by the MBE technique. The wafer is made by stacking 50 pairs of $Al_{0.3}Ga_{0.7}As$(64 nm) and GaAs(60 nm)layers with the period of half optical wavelength in the material. White stripes in the SEM picture correspond to the AlGaAs part of the multilayer. Total thickness of the epitaxial layer is 6 μm including a GaAs buffer layer. The vertical optical cavity is produced by the refractive-index corrugation of the multilayered heterostructure. One GaAs layer with doubled thickness separates upper and lower multilayer pairs and works as a phase shifter. This phase-shifter matches the phase condition of the optical cavity formed by the lower 30 pairs and upper 20 pairs of the multilayer reflector. In this structure, lasing wavelength is the same as the Bragg period of the multilayer. The upper reflector has less repetition than the lower reflector because reflectivity of the upper

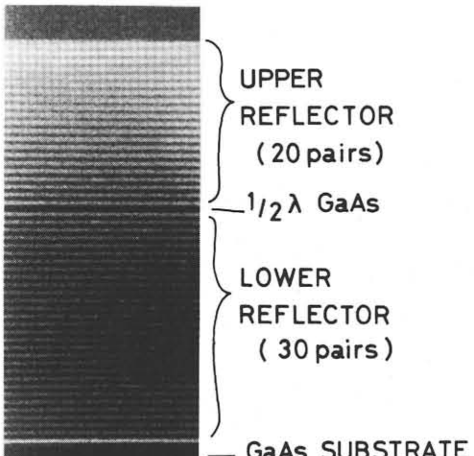

Figure 1 Cross sectional SEM picture of the optical cavity formed by the AlGaAs(64nm)/ GaAs(60nm) multilayered heterostructure.

reflector is enhanced by the reflection at the GaAs-air interface. The center wavelength of the optical cavity can be tuned within several nanometers simply by controlling the AlGaAs/GaAs multilayer periodicity.

For the optical pumping measurement, cleaved facet of the multilayered optical cavity is excited by a dye laser(dye:Rhodamine 6G). In order to excite the whole optical cavity, the incident laser beam is focused in a rectangular shape either by an incident slit of objective lens (Fig.2) or micro-cylindrical lens contacted to the cleaved surface (Fig.3). Figure 2 shows the emission spectra of the multilayered optical cavity at room temperature with increasing the excitation power. The reflectivity of this optical cavity is peaked at around 868 nm. Sharp emission line appeared at 876.5 nm with the half width of 3.4 nm. This emission line is sharpened by more than 15 times compared with the half width of the reflectivity of optical cavity and spontaneous emission band of a GaAs wafer(40-50 nm). The position of this emission line does not depend on the excitation power. Figure 3 shows the emission spectra of the optical cavity tuned at shorter wavelength(845 nm). At room temperature, there are several broad emission peaks corresponding to the reflectivity spectrum of the optical cavity. One of the broad emission peak is sharpened and increases in intensity at the temperatures below 150 K. Temperature coefficient of the position of this sharp emission line is 0.45 Å/K. This value is similar to the conventional lateral DFB laser diode and 3 times smaller than the spontaneous emission band of GaAs[8].

In Figs.2 and 3, the sharp emission lines grow super-linearly with increasing the incident power when the center wavelength of the optical cavities coinsides with the spontaneous emission band of GaAs. Optical absorption is much smaller, and higher wavelength selectivity is expected at longer wavelength than the emission band of GaAs by multiple reflection. However, no sharp emission appeared when the optical cavity is tuned at 888 nm. Therefore, it is confirmed that emission lines from the DFB type optical cavities are sharpened by the stimulated emission.

In order to get laser operation by current injection, pn-junction must be incorporated with this multilayered structure. We employed the modified transverse junction-stripe (TJS) type[5] structure: pn-junction is perpendicular to the multilayer structure and couples with the vertical optical cavity (Fig.4). The lasing threshold current of the SELD is usually very high because of short effective laser length and lack of carrier confinement mechanism. However, the effective laser length in this structure is determined by

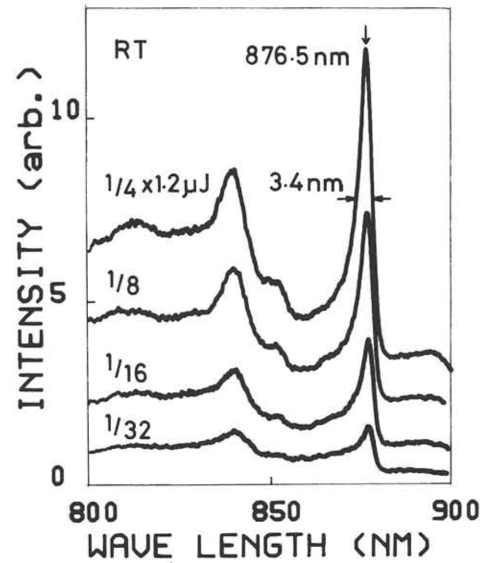

Figure 2 Emission spectra from AlGaAs/GaAs multilayered optical cavity excited by a dye laser. The reflectivity of the cavity is centered at around 868 nm. The excitation power is measured at the incident stop of the condensing objective lens (OIL x100, NA=1.25). Pulse width: 10 nsec, repetition: 11 Hz, dye: R6G(580 nm).

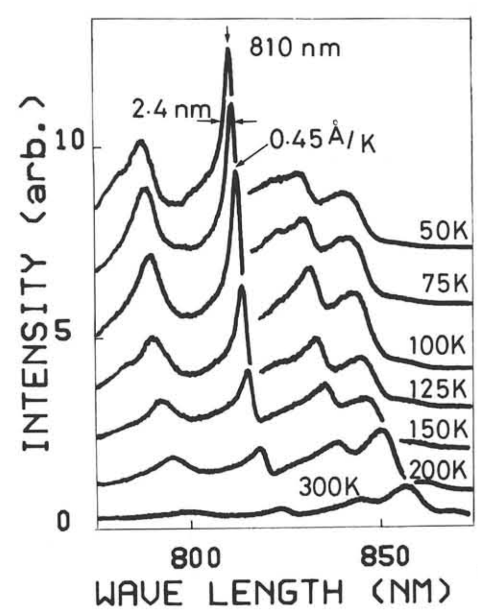

Figure 3 Emission spectra at various temperatures. The reflectivity is centered at around 845 nm at room temperature.

the length of the pn-junction along the cavity and not limited by the minority carrier diffusion length. Carrier confinement is effected by the zinc-induced mixing of AlGaAs/GaAs multilayer as described in the next paragraph. TJS type lateral carrier injection is also preferable to the vertical one where carrier transport is obstructed by the heterostructure conduction band-edge discontinuity.

Figures 4 and 5 illustrate the schematic drawing and cross-sectional SEM picture of the SELD, respectively. The multilayered optical cavity shown in Fig.1 and Fig.3 is used for the fabrication.

The dotted area in Fig.4 is the zinc diffused p-type region, where AlGaAs and GaAs thin layers are mixed. The perpendicular pn-junction is formed by the zinc diffusion from the vertical wall of the first etched step as shown by the broken line. The AlGaAs/GaAs multilayer is originally n-type by silicon doping except for the undoped lower 10 pairs. Electron concentration is 2×10^{18} cm^{-3} for GaAs layers and 3×10^{17} cm^{-3} for AlGaAs layers. Silicon nitride mask prepared by the plasma CVD is used for the first selective step etching and succeeding zinc diffusion. The first selective etch using 30%-H_2O_2 : 30%-NH_4OH : H_2O = 5 : 40 : 10 vol. at room temperature for 6.5 min yields 5 μm deep step. To get the reverse mesa structure,the SiN_x mask is aligned along the <110> direction. Zinc diffusion is performed through the side wall of the mesa at 600℃ for 14 hr in an evacuated silica ampoule sealed with $ZnAs_2$(20 mg). For the zinc diffusion in bulk GaAs at the same condition, carrier concentration is about 7×10^{19} cm^{-3} within 3 μm from the surface. High temperature annealing is then performed at 1000 ℃ for 1 min in an evacuated silica ampoule with a dummy GaAs wafer placed face to face. This heat treatment enhances the luminescent efficiency of the cavity almost one decade. Nearly perpendicular pn-junction is obtained as shown in Fig.5. Multilayers with heavy Zn diffusion are completely mixed to AlGaAs with the average aluminum content[6]. This uniform AlGaAs region works as the barrier for the injected electrons in GaAs layers and carrier-confinement is expected[7]. Zinc doped p-type region is extended about 1 μm from the mixed boundary, which is observed by the enhanced contrast of the stripes in the SEM picture. This unmixed p-region works as the DFB type active layer.

To get the current constriction, the width of the pn-junction is restricted to 3 μm by the second selective side wall etching as shown in Fig.4. The bold arrow in Fig.4 indicates the direction of the laser output. Effective cavity loss is minimized when the upper and the lower reflectors have the same reflectivity. Therefore, it is preferable to concentrate the carrier injection around the center of the optical cavity. In order to obtain this condition, n-type electrode is recessed by 1 μm and the lowest 10 repetition of multilayer is kept undoped. A p-type electrode is formed on the bottom of the step, where high zinc concentration ensures a low parasitic resistance.

Thickness of the silicon doped AlGaAs layer became thinner than the undoped AlGaAs layer after the second high temperature annealing. This phenomena suggests that doped silicon also enhances the mixing of GaAs and AlGaAs at high temperature.

Figure 6 shows the emission spectra of the SELD at the drive current of 120 mA(pulsed) between 54K and 200K. The threshold current was 120mA at 150K, 60 mA at 54K and 20 mA at 8 K. The width of the emission line was less than 5 Å at 120mA, 54K as shown in the inset of Fig.3. The temperature coefficient of the emission line was 0.46Å/K between 54K, and 125K, which is the same

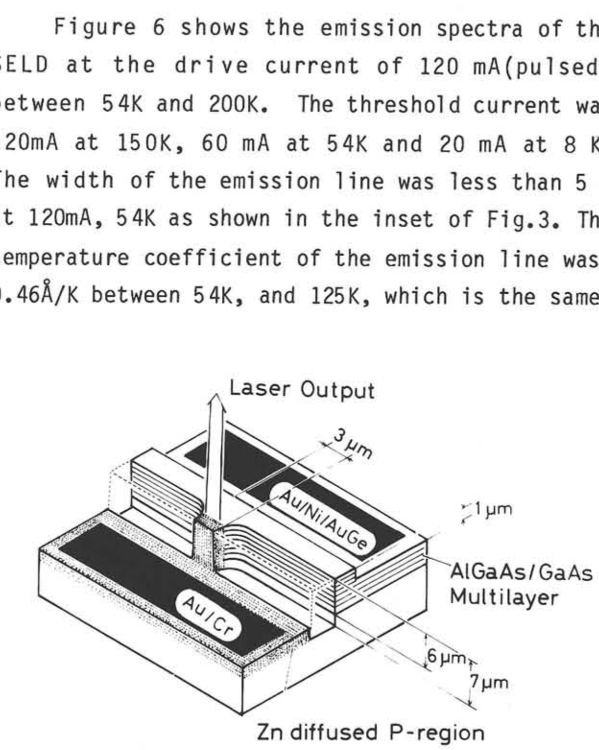

Figure 4 Schematic drawing of the SELD with AlGaAs/GaAs multilayered heterostructure.

as the conventional lateral distributed feedback laser diode [8]. The shift of the emission wavelength with the injection current was negligible up to twice the threshold current. Therefore, it is confirmed that peak wavelength of this SELD is stabilized by the distributed feed-back operation.

In conclusion, the first distributed feedback surface emitting laser diode is realized with $Al_{0.3}Ga_{0.7}As/GaAs$ multilayered heterostructure both by the optical pumping and current injection. Sharp stimulated emission is observed at the selected wavelength determined by the optical cavity. Zinc diffusion technique is employed for the formation of vertical pn-junction. The threshold current is 120 mA/3μm with 6 μm epitaxial-layer thickness at 150K. The stable operation is obtained against the variation of temperature and injection current.

Acknowledgment

The authors are grateful to Professors T.Ikoma, H.Sakaki of the Unversity of Tokyo, Professors M.Iida and T.Kurosu of Tokai University, Professor K.Iga of Tokyo Institute of Technology, Dr.H.Nakashima of Optoelectronics Joint Reserch Lab., Drs. J.Shimada, H.Yajima, K.Hoh and N.J.Kawai of our institute for helpful discussion and encouragement. They also express their thanks to Mr. T.Hata of SHARP Inc., Drs.T.Ishida and M.Murakami of ANELVA Inc., Mr.S.Hamasaki of KATSURA ELECTRO Inc. for the instrumental setup and advices.

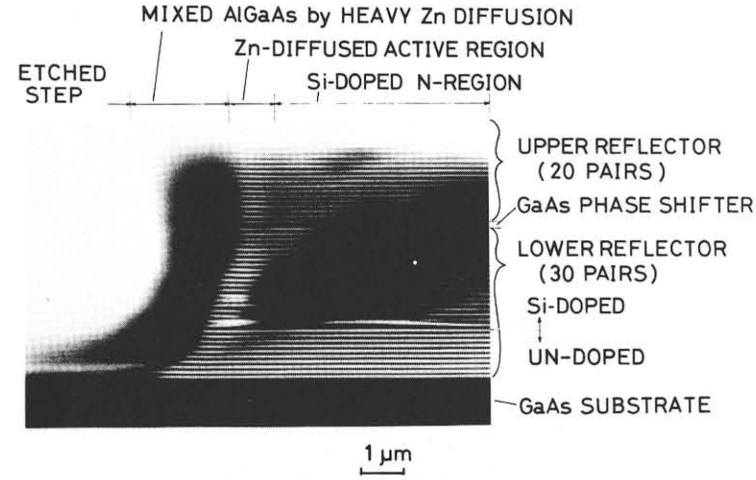

Figure 5 Cross sectional SEM picture of the SELD after zinc diffusion and high temperature annealing. White and black stripes correspond to the stacked 50 pairs of $Al_{0.3}Ga_{0.7}As$ and GaAs, respectively.

REFERENCES

1)H.Soda, K.Iga, C.Kitahara and Y.Suematsu: Jpn. J. Appl. Phys. **18** (1979) 2329.

2)J.P.van der Ziel and M.Ilegems: Appl.Optics **14** (1975) 2627

3)M.Ogura, T.Yao and T.Hata: Collected papers of 2nd Int.Symp. Molecular Beam Epitaxy & Related Clean Surface Techniques,(Jpn.Soc. Appl.Phys.,Tokyo,1982)p.69.

4)M.Ogura, T.Hata, N.J.Kawai and T.Yao: Jpn. J. Appl. Phys. **22** (1983) L112.

5)H.Namizaki, H.Kan, M.Ishii and A.Ito: J. Appl. Phys. **45** (1974) 2785.

6)W.D.Laidig, N.Holonyak, Jr., and M.D.Camras: Appl. Phys. Lett. **38** (1983) 776.

7)I.Hayashi and M.B.Panish: J. Appl. Phys. **41** (1970) 150.

8)M.Nakamura, K.Aiki, J.Umeda, A.Yariv, H.W.Yen and T.Morikawa: Appl. Phys. Lett. **25** (1974) 487.

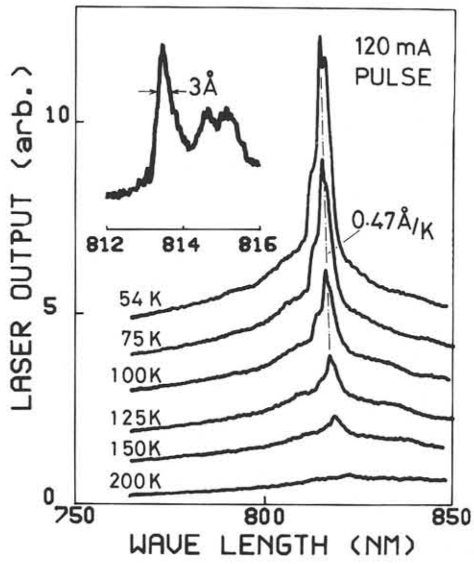

Figure 6 Emission spectra from the distributed feedback SELD at 120mA between 54K and 200K.