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Lasing Characteristics of GaAs/AlGaAs Multilayer Composing Distributed Feedback Cavity for Surface-Emitting Laser

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We report laser oscillation, by optical pumping, of GaAs/AlGaAs multilayer that composes a distributed feedback (DFB) cavity for a surface-emitting laser. The DFB structure is constructed by alternating a multiquantum well for one quarter-wavelength structure and an $Al_{0.7}Ga_{0.3}As$ layer for the other using molecular beam epitaxy. The light emission spectra from the surfaces parallel to the epilayers were measured at room temperature, when cleaved surfaces perpendicular to the epilayers were irradiated by the second harmonics of a Q-switched YAG laser. Single mode laser oscillation was observed with the threshold excitation peak intensity lower than 3.1×10^5 W/cm^2. The longitudinal mode spacing of the cavity, 34 nm, and 2.3-nm half width of emission peaks were observed and compared with calculated values.

1. Introduction

Surface-emitting lasers (SELs) having distributed feedback (DFB) structures have attracted considerable attention.[1,2] The DFB structures are formed by alternating high and low gain materials: e.g., epitaxially grown AlGaAs and GaAs layers.[1] One period of the stacked materials should have an optical path length corresponding to a half of the Bragg wavelength, at which the SEL would oscillate.

SELs with the DFB structure will extend the semiconductor laser application field. They will allow us to form two-dimensional laser arrays and also to integrate electric devices and themselves on a chip.

Ogura and Yao[1] have demonstrated the GaAs/AlGaAs DFB SEL operation with the threshold current 120 mA at 150 K. To improve the performance, a few problems must be solved: (1) Structures for homogeneous excitation of the whole active region should become available; (2) High gain materials for the active region as well as high reflectivity structures for the cavity are required to overcome high reflection loss due to the short cavity length of SELs. (SELs have inevitably short cavities because their cavity length is restricted by practically available epitaxial layer thickness, a few tens microns at most).

For the first problem, etching and Zn-diffusion processes have been examined to form the pn junction perpendicularly across epitaxial layers.[1,3]

One solution for the second problem is the use of multiquantum well (MQW) structures. The GaAs/AlGaAs MQW has been proved to provide a higher gain coefficient than thick GaAs active layers in conventional lasers.[4] We report here laser oscillation, by optical pumping, of the GaAs/AlGaAs multilayer that contains an MQW structure and composes a DFB cavity for a SEL.

2. Experimental

Two multilayer samples with different Bragg wavelengths were prepared to examine the MQW structure as gain material and the DFB structure as a laser cavity. The Bragg wavelength of a sample, referred to as sample A, was designed to coincide with that of emission due to fundamental inter-subband transition in the MQW at room temperature. The Bragg wavelength of the other sample, B, was set to be about 80 nm shorter than

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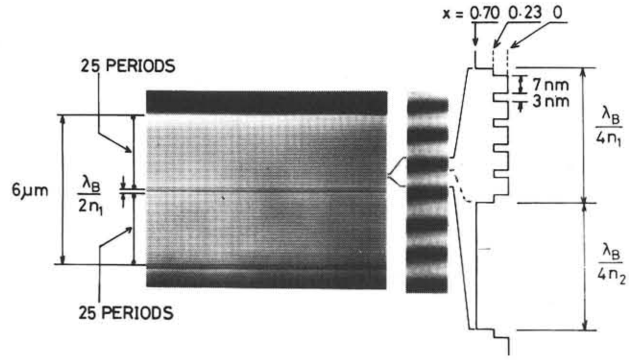

Fig. 1 SEM cross section of a typical DFB cavity and the scheme of the heterostructure.

that of sample A. We expect to have effective laser emission from sample A.

Samples were fabricated on n-(001) GaAs substrates using a computer-controlled molecular beam epitaxy system. Prior to growing the DFB structures, 4-μm-thick $Al_{0.7}Ga_{0.4}As$ buffer layers were grown. The optimized growth condition for AlGaAs[5] was adopted for epitaxial growths. Si was doped as donor in all the layers with doping concentrations 2×10^{17} cm^{-3} in MQWs and 7×10^{17} cm^{-3} in $Al_{0.7}Ga_{0.3}$ As layers.

The DFB cavity of sample A consists of two Bragg reflectors and a $\pi/2$ phase shifter,[6] which is located between the reflectors (Fig. 1). Each Bragg reflector is formed from 25 pairs of an $Al_{0.7}Ga_{0.3}As$ layer (one quarter-wavelength layer) and an MQW structure (the other quarter-wavelength structure), which consists of five 7-nm-GaAs wells and four 3-nm-$Al_{0.23}Ga_{0.77}As$ barriers. We adopted the well width, 7 nm, that is expected to provide the maximum gain coefficient.[4] The MQW structure is inserted between the Bragg reflectors as the $\pi/2$ phase shifter.

The thicknesses d_1, d_2 and refractive indices n_1, n_2 of the MQW and $Al_{0.7}Ga_{0.3}As$ determine the Bragg wavelength λ_B, as $\lambda_B=2(n_1d_1+n_2d_2)$. For sample A, we designed as $d_1=\lambda_B/4n_1$, and $d_2=\lambda_B/4n_2$. These dimensions are estimated from the growth rates. The well thickness was also checked by comparing observed photoluminescence peak energy with the calculated one. The refractive index of the MQW can be estimated to be 3.6[7], and that of the $Al_{0.7}Ga_{0.3}As$ is given as 3.2 in the vicinity of the Bragg wavelength. The coupling constant, $\kappa=\pi\Delta n/\lambda_B$, where Δn is the refractive index difference of the two quarter-wavelength structures, is about 15000 cm^{-1} for the Bragg reflector.

The other sample, sample B, has almost the same cavity structure as that of sample A except that the MQW structure of sample B is constructed from four 7-nm-GaAs wells and three 3-nm-$Al_{0.7}Ga_{0.3}As$ barriers instead of five wells and four barriers for sample A.

We measured reflectivity spectra of the DFB structure using a JASCO CT-10 spectrometer in the nearly normal-incidence configuration. We normalized the reflected light intensities from the sample surfaces by incident light intensities to obtain the reflectivity.

Photoluminescence spectra from surfaces were measured at room temperature by irradiating cleaved surfaces, perpendicular to the emitting surfaces, with the second harmonics of a Q-

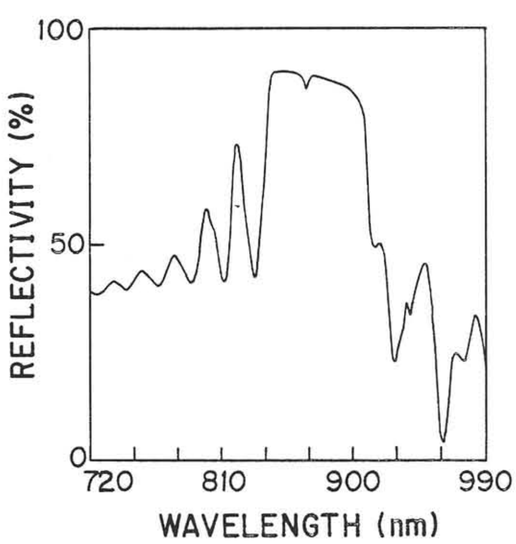

Fig. 2 (A)

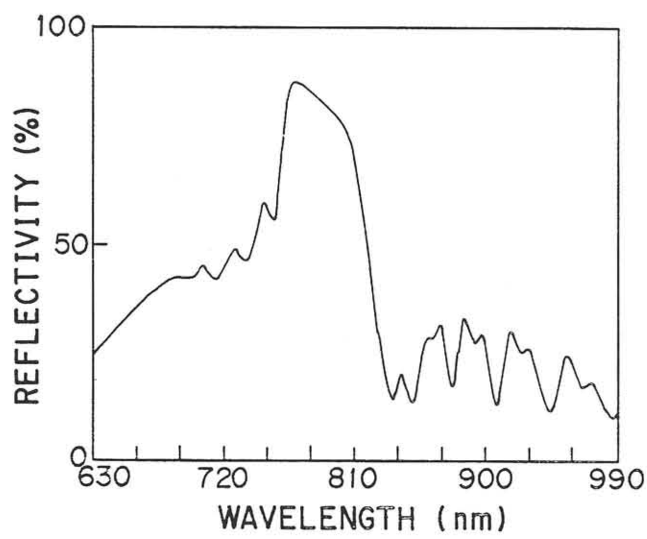

Fig. 2 (B)

Reflectivity spectra of GaAs/AlGaAs multilayer samples, A and B.

switched YAG laser focussed into a 10 μm-diameter spot size. The light pulse width was 200 ns and the repetition rate was 5 kHz. Peak excitation intensity was varied by ND filters from 6.3×10^4 to 3.1×10^5 W/cm^2.

3. Results and Discussion

Figure 2(A) and (B) show the reflectivity spectra of samples A and B, respectively. For sample A, the Bragg wavelength λ_B is 864 nm, as shown by the dip at the center of the high reflectivity band. The maximum reflectivity appears to be 90 %, but it is reduced because of absorption. The broad high reflectivity band is due to large coupling constant κ. The Bragg wavelength of sample B is about 790 nm and is smaller than that of sample A. The maximum reflectivity and high reflectivity band width are decreased in comparison with that of sample A, presumably due to higher absorption coefficient.

Figure 3(A) and (B) show photoluminescence (PL) spectra from samples A and B, respectively, at peak excitation intensities, 3.1×10^5 (a), 1.6×10^5 (b) and 6.3×10^4 W/cm^2 (c), and Fig. 3(C) shows the dominant peak of sample A with an extended wavelength scale. In Fig. 3 (A), the PL peak intensity at the wavelength, 864 nm, is selectively and rapidly enhanced with increasing the excitation intensity from 1.6×10^5 W/cm^2 (b) to 3.1×10^5 W/cm^2 (a). The wavelength 864 nm of this peak coincides with the Bragg wavelength shown in Fig. 2(A). Those facts indicate that the peak at 864 nm of sample A is due to stimulated emission. In contrast to the case of sample A, PL peak intensities for sample B, as shown in Fig. 3(B), increase almost linearly with

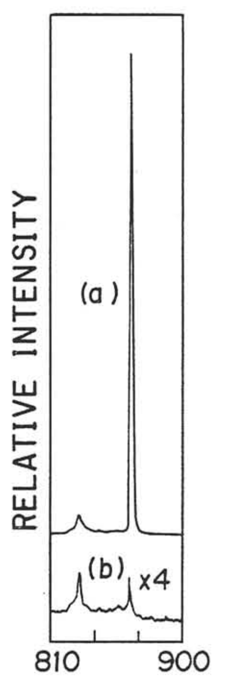

Fig. 3 (A)

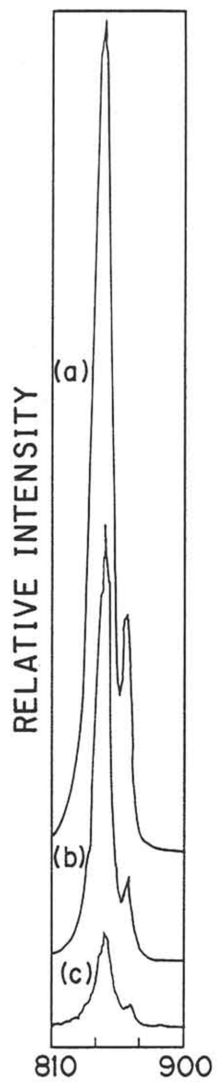

Fig. 3 (B)

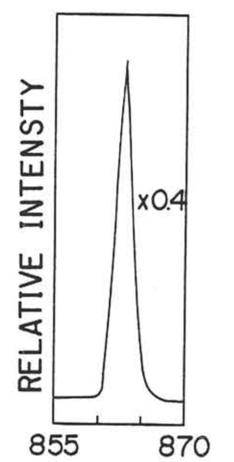

Fig. 3 (C)

Photoluminescence spectra from GaAs/AlGaAs multilayer, sample A, (A), and sample B, (B). Excitation intensities are 3.1×10^5 (a), 1.6×10^5 (b), and 6.3×10^4 W/cm^2 (c). Laser oscillation can be observed at the excitation intensity (a), in Fig 3 (A). Peaks in Fig. 3 (B) increase almost linearly with the excitation intensity. The peak at wavelength, 844 nm, is due to the inter-subband transitions in the MQWs. The peak at 863 nm may also be associated with the inter-subband transitions in the MQWs. Figure 3 (C) shows the highest peak in Fig. 3 (A) with an extended wavelength scale. It indicates that the half width of the peak is rather broad probably due to the high optical loss because of the lack of a waveguiding structure in the sample.

excitation intensities from 6.3×10^4 (c) to 3.1×10^5 W/cm^2 (a). The peak wavelength, 844 nm, of higher intensity peak in Fig. 3(B) does not correspond to the Bragg wavelength seen in Fig. 2(B), but it coincides with the recombination emission peak in single quantum wells with 7 nm width and $Al_{0.23}Ga_{0.77}As$ barriers (not shown here). The other peak, at 863 nm in Fig. 3(B), may also be due to spontaneous inter-subband transitions in the MQW structure. It may be worthwhile to note that the wavelength of the high emission peak of sample A is very close to that of this peak.

The threshold excitation intensity of the stimulated emission in Fig. 3(A) is lower than 3.1×10^5 W/cm^2, which is equivalent to the current density of 130 kA/cm^2. The small peak at wavelength 830 nm corresponds to the first higher order mode. The mode spacing $\Delta\lambda$ is given as $\lambda_B^2/2\bar{n}L_{eff}$, where $\bar{n}$ is the averaged refractive index for the light propagating in the DFB structure, and L_{eff} is the effective cavity length.[8] By assuming the averaged refractive index $\bar{n}$ as 3.4 and the L_{eff} to be 3.2 μm, the calculated mode spacing agrees with the experimental result, 34 nm. The half width of the peak is 2.3 nm, as can be seen in Fig. 3(C). Frequency linewidth $\Delta\nu$ of a DFB laser emission peak is proportional to $\alpha_0/\kappa^2 L_{eff}^3$, where α_0 is the optical loss including the absorption loss and scattering loss.[9] If we assume α_0 of our sample is of the same order with ordinary semiconductor lasers (not a surface emitting laser), the spectral line width, 2.3 nm, is broader than the calculated value by three orders of magnitude. Since $1/\kappa^2 L_{eff}^3$ for our sample is comparable with that of ordinary lasers, large α_0 due to the lack of a waveguiding structure in our sample may be responsible for the large spectral width. Thus, a narrow spectral width will be available by employing an optical confinement structure.

4. Summary

We have observed laser emission from a surface-emitting DFB structure at room temperature by optical pumping. This was achieved by virtue of the high gain coefficient of the multiquantum well used as a quarter-wavelength structure. The Bragg wavelength of the DFB structure was adjusted to that of inter-subband transition emission in the multiquantum wells. Threshold excitation intensity was lower than 3.1×10^5 W/cm^2. The observed longitudinal mode spacing of the cavity, 34 nm, and 2.3-nm half width of laser emission peaks was found out to be reasonable for the sample structure.

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