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Low Threshold GaAs/AlGaAs Double Quantum Well Lasers

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Abstract Low-threshold ridge waveguide lasers with fundamental lateral mode have been fabricated by using GaAs/AlGaAs double quantum well materials. Threshold current of ridge waveguide lasers as low as 5mA under room temperature (RT), continuous wave (CW) operation and fundamental lateral mode output power of 20mW have been achieved for as-cleaved lasers. The total differential quantum efficiency is 74%. The parallel and perpendicular far-field divergence angles are 8°and 41°, respectively. The emission wavelength is near 851nm.

PACC: 4255P, 4280R, 7360F

1 Introduction

GaAs/AlGaAs semiconductor lasers with very low threshold current and good optical beam quality have given rise to considerable attention since they may be used in solid state laser pumping source, integrated optoelectronic circuits, optical computing, optical interconnection and optical communication. Due to these applications, there has been a strong effort to reduce the threshold current of semiconductor lasers. Uncoated stripe geometry lasers with low threshold currents in the range of 0.9～1.8mA, 1.0～1.6mA and 1.0～2.2 mA under room temperature and continuous wave operation have been achieved by growth on etched substrate[1,2], growth on ridge structure[3,4] and Impurity-Induced-Disordering (IID)[5], respecdively. Ridge waveguide stripe geometry quantum well (QW) lasers have

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also achieved low threshold current 5mA by dry etching[6]. Thongh the ridge waveguide quantum well lasers have not advantage of lower threshold current, the fabricating process is simpler and more repeatable.

2 Theoretical analysis

Besides using narrow stripe for reducing the threshold current, it is necessary to optimize the quantum well laser structure and cavity length. Single quantum well (SQW) lasers are a good candidates for decreasing threshold current due to their lower transparency current and internal loss compared with multiquantum well (MQW) and bulk-material lasers[7]. However, the threshold current in SQW laser increases with decreasing cavity length at short cavity lengths, this makes it impossible to reduce the threshold current continuously by reducing the cavity length. It has been observed that as the cavity length decreases below about 300μm, the threshold current increases anomalously. Compared with the SQW lasers, the available gain and optical confinement factor in MQW lasers are larger, this offers the potential of using a shorter cavity length to achieve lower threshold current. It has been found that the optimum cavity length for low threshold operation becomes shorter when the quantum well number increases. MQW lasers have larger internal loss than SQW lasers, but the increase of internal loss with the increasing quantum well number becomes less important at short cavity lengths, since the mirror loss dominates. Because double quantum well lasers possess advantage of both lower internal loss and shorter cavity length for reducing the threshold current, it led to the using of double quantum well (DQW) structure.

The optimum cavity length is usually expressed as[8]

$$L_{opt} = \ln(1/R)/(N\Gamma_w G_0 - \alpha_i) \qquad (1)$$

where α_i is the internal loss coefficient, Γ_w is optical confinement factor of SQW, R is facet reflectivity of uncoated lasers; G_0 is the gain at the optimum operation point. Taking for example a laser with quantum wells of 10nm width in our laboratory, $G_0=1280\text{cm}^{-1}$, $\Gamma_w=0.026$, $\alpha_i=6\text{cm}^{-1}$, $R_1=R_2=R=0.32$, for $N=2$, we obtained $L_{opt}=188\mu$m from (1).

Generally to achieve stable fundamental mode operation both the ridge waveguide geometry and layer composition are critical and it requires two dimensional modal analysis. In practice, the ridge width and the wing thickness (residual $Al_xGa_{1-x}As$ cladding layer thickness after etching) have to be precisely controlled. Taking account into one-dimension shooting method, we calculated the ridge width and wing thickness for obtaining the single lateral mode. Figure 1 shows the calculated stripe width as a function of wing-thickness for double quantum well lasers and single quantum well lasers with cladding layer composition $x=0.5$. From Figure 1, we see that the stripe width is 4μm when the w ing-thickness is 0.25μm for DQW lasers. For low threshold current applications, the ridge is generally narrow and etching can be stopped at the interface between the doped p-type cladding layer and the undoped waveguide layer, but this makes the lasers working at multimodeing.

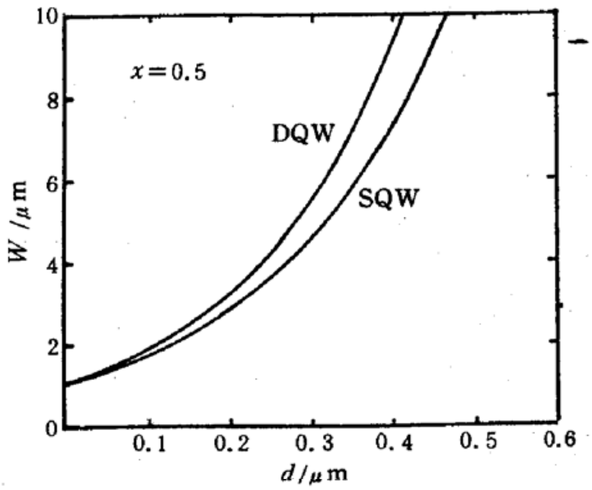

Fig. 1 Fundamental lateral mode strip width W as a function of wing thickness d

3 Device fabrication

The GaAs/AlGaAs lasers used in these experiments consist of graded index separate confinment heterostructure (GRINSCH) double quantum well structure grown on a n-type(100) substrate by MBE growth technique. The layer constitation is as follows:

(1) 0.5μm-thick n-GaAs buffer layer;

(2) 1.2μm-thick n-$Al_{0.5}Ga_{0.5}As$ cladding layer

(3) 0.15μm-thick undoped $Al_xGa_{1-x}As$ composition graded layer, x varies from 0.5 to 0.22;

(4) Double quanum well active region with two 10nm-thick GaAs wells sandwiched between three 10nm-thick AlGaAs barrier layers;

(5) 0.15μm-thick p-$Al_xGa_{1-x}As$ composition graded layer, x varies from 0.22 to 0.5;

(6) 1.2μm-thick p-$Al_{0.5}Ga_{0.5}As$ cladding layer;

(7) 0.1μm-thick p-GaAs cap layer and 20nm p^+-GaAs contact layer.

After the MBE growth, The broad-area lasers with 100μm width and ridge waveguide stripe lasers with 4μm width were fabricated, respectively. 600μm-long broad-area lasers have a threshold current density 260A/cm^2.

By wet chemical etching a 4μm-wide ridge which terminated at ~0.25μm from the top surface of the upper confining layer is defined, this guarantees lasers to work in the fundamental lateral mode. The electrical current is confined in the ridge region by a SiO_2 dielectric mask which was patterned with 3μm width stripes using standard photolithography techniques. The wafer was then thinned to a thickness of about 100μm, p-contact and n-contact layers consisting of Ti/Pt/Au and AuGeNi/Au, respectively, were deposited. After that, the wafer was cleaved into bars of different lengths and diced into chips, the laser chips were mounted p-side up on a Cu-heatsink using indium solder.

4 Device performance

Fig. 2 shows the threshold current for lasers with various cavity lengths. For comparison, the results on SQW GaAs/AlGaAs lasers and triple quantum well(TQW) GaAs/AlGaAs lasers are also presented in the same figure. The active stripe width of SQW lasers is also 4μm. We see that for low threshold current operation, the optimum cavity length of QW lasers decreases with the increasing quantum well number. Approximately, the optimum lengths are 300~400μm for SQW; 200~300μm for DQW and 100~200μm for TQW, respectively. From Fig. 2 we also see that the lowest threshold current obtained is 5mA for an uncoated DQW laser with about 200μm cavity length. Fig. 3 shows the output power-current characteristic of the best DQW laser we have tested so far, and the emission wavelength is at 851 nm. Since the lasers reported here were fabricated by a relatively simple and repeatable process, we expect that the threshold currents of lasers are distributed lmiformly and the yield is high. Fig. 4 shows the threshold current distribution of all devices in a typical laser bar having 200μm -long and 4μm-wide active stripes.

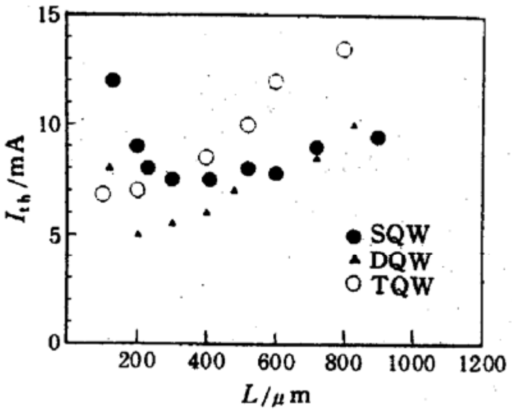

Fig. 2 Threshold current I_{th} of RW-DQW lasers with various cavity lengths L and number of wells

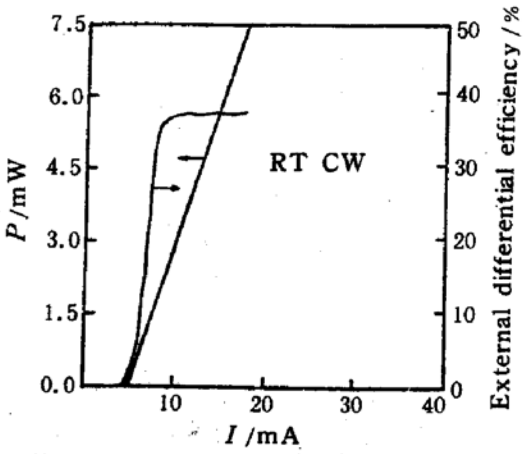

Fig. 3 P-I characteristic of the RW-DQW laser

Fig. 5 shows both the perpendicular and parallel far field intensity profiles corresponding to CW output power 20mW. From Fig. 5 we see that the lasers operate in a fundamental lateral mode with a parallel far-field divergence angle $\theta_{/\!/}=8°$ and a perpendicular far field divergence angle $\theta_{\perp}=41°$ at 20mW. At higher CW output powers (>30mW), a broadening of the lateral far field to about 10° is observed due to the onset of higher-order mode operation. The large perpendicular beam divergence is attributed to the strong optical confinement in the laser structure.

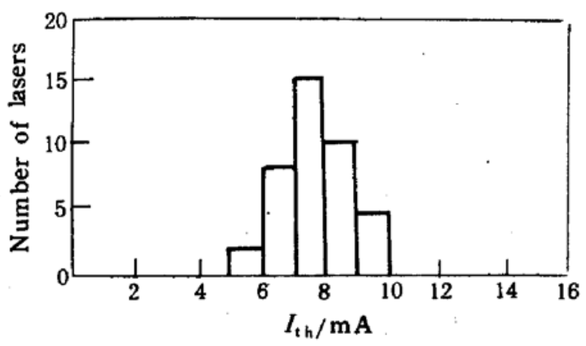

Fig. 4 Threshold current distribution of all the devices in a typical laser bar

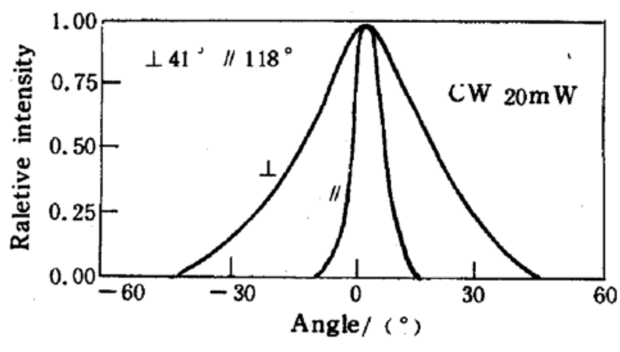

Fig. 5 Perpendicular and parallel far field intensity profiles corresponding to CW power output 20mW

5 Conclusion

We have fabricated low-threshold lasers by wet chemical etching using GaAs/AlGaAs double quantum well materials. Due to optimizations for both the QW structure and device structures, the fundamental lateral mode operation lasers are obtained. The threshold current is as low as 5mA under RT CW operation for uncoated lasers having 200μm-long and 4μm-wide active stripe. The low threshold currents are uniform across the laser bar. The parallel and perpendicular far-field divergence angle are 8° and 41°, respectively. We believe that these lasers are very suitable for the pumping source of self electro-optic effect device(SEED), optical communication and optical interconnection.

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