CHAPTER 6

Ridge Waveguide Laser Diode Characteristics

The previous chapter has introduced a fabrication process of the RW laser diodes. Consequently, the laser chips are tested to investigate their characteristics. This chapter aims to describe testing processes and their results of the fabricated chips. There are 4 investigations performed for the RW lasers in this literature. First, the ridge dimensions are measured to evaluate the etching process and to confirm the residual thickness (*t*) and the ridge width (*W*). Second, a "diode" performance is proved electrically by measurement of current versus voltage (I-V) characteristics. Then a threshold current is examined from output light versus current (L-I) characteristics. Finally, an optical quality is determined in frequency domain via its spectrum of output laser beam.

6.1 Ridge dimension measurement

In this experiment, the laser diodes are fabricated to be Double Heterostructure (DH) with 0.35 μm residual thickness and 4 μm ridge width. An optical microscope is used to take cross-section photographs. A contrast enhancement process has been performed before taking the photographs from the microscope. The process uses an etchant to form the different color between GaAs and GaAlAs. The strained etching is achieved by H_2O_2 : KOH : $K_3Fe(CN)_6$ = 10 ml : 1.8g : 0.8g for 3 second [58]. A photograph taken from the microscope is revealed in Fig. 6.1 which has both residual thickness and ridge width corresponding to the proposed dimensions as discussed in section 4.5.

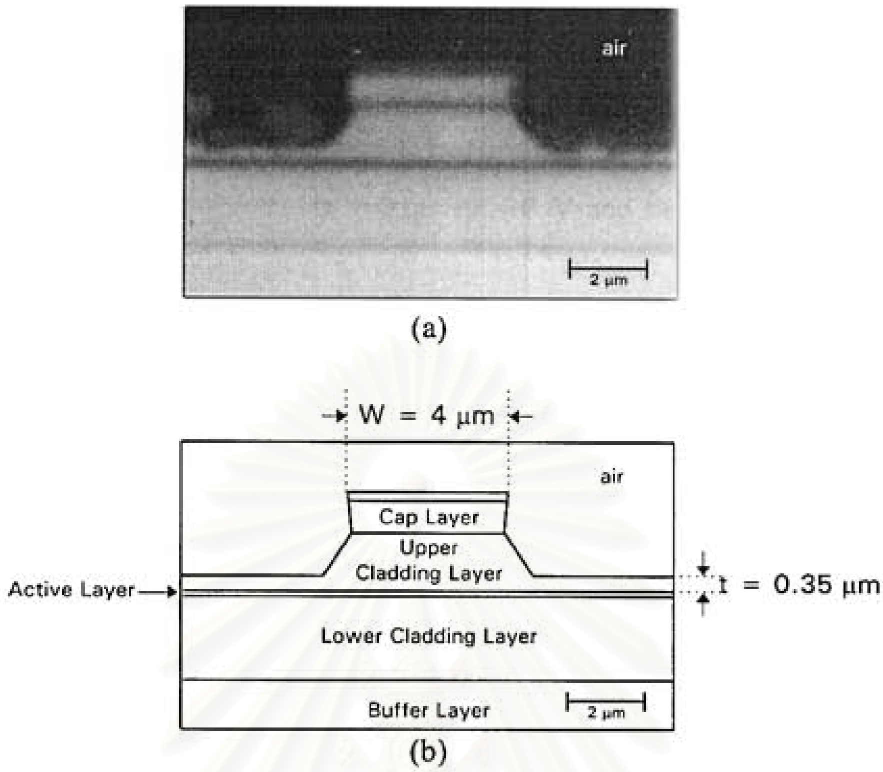


Fig. 6.1 (a) Cross-section photograph of a fabricated RW laser chip taken by the optical microscope and (b) schematic detail of the photograph to describe the dimensions of ridge.

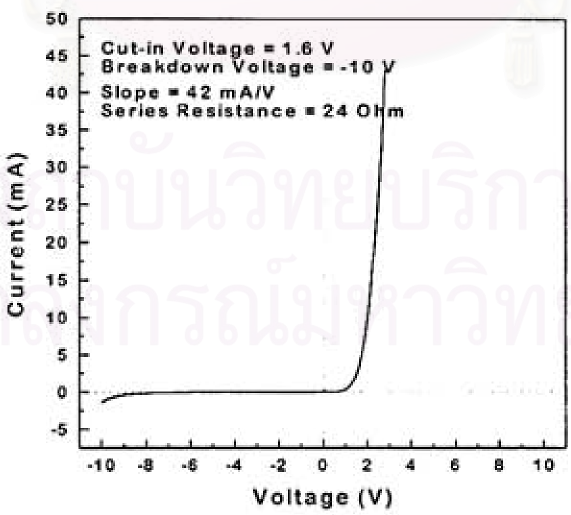


Fig. 6.2 Current - voltage characteristics of a RW laser diode. The curve shows the cut-in voltage of 2.8 V and the series resistance of 43 Ω.

6.2 Current versus voltage (I-V) characteristics

This is a basic electrical test performed by applying the voltages and measuring the currents. Fig. 6.2 shows a resulting curve of a RW laser diode which has the cut-in voltage of 1.6 V, the break-down voltage of -10 V and the series resistance during forward bias of 24 Ω.

6.3 Light versus current (L-I) characteristics

L-I is an emission characteristic which is the measurement of output light power (L) as a function of the device currents (I) and it is a strongly temperature dependent characteristics [10]. Fig. 6.3 shows a resulting curve of a RW laser diode with 600 μm cavity length. It should be noted that (i) the laser chip is operated under pulse-current input with 0.1 μs pulse width and 100 μs period (0.1% duty cycle) and (ii) the output power measured from an *avalanche photodetector* (APD) is reported as the power of continuous wave (CW) operation which equal the read-out power divided by the duty cycle.

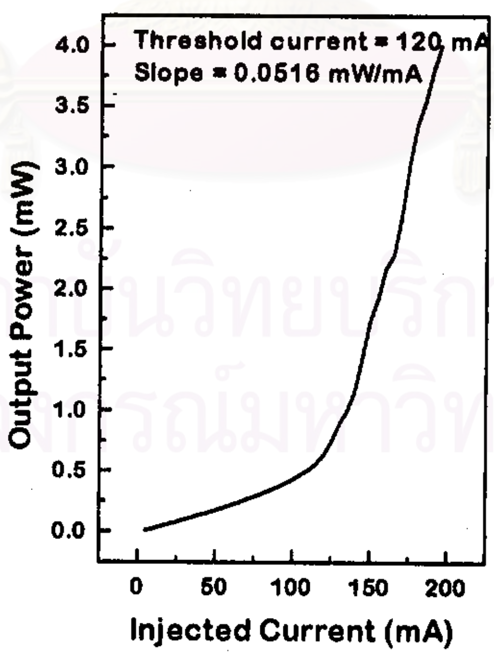


Fig. 6.3 Light - current characteristics of a RW laser diode. The curve shows threshold current of 120 mA and differential quantum efficiency of 3.6%.

From the figure, the *threshold current* (I_{th}) and *differential external quantum efficiency* (η_d) can be found directly. The threshold current of this RW laser diode is I_{th} = 120 mA and the differential quantum efficiency is η_d = 3.6% calculated at laser wavelength of 864 nm from

$$\eta_d = \frac{e}{h\nu}\frac{dP}{dI} \tag{6.1}$$

which *dP/dI* represents to the curve's slope during lasing.

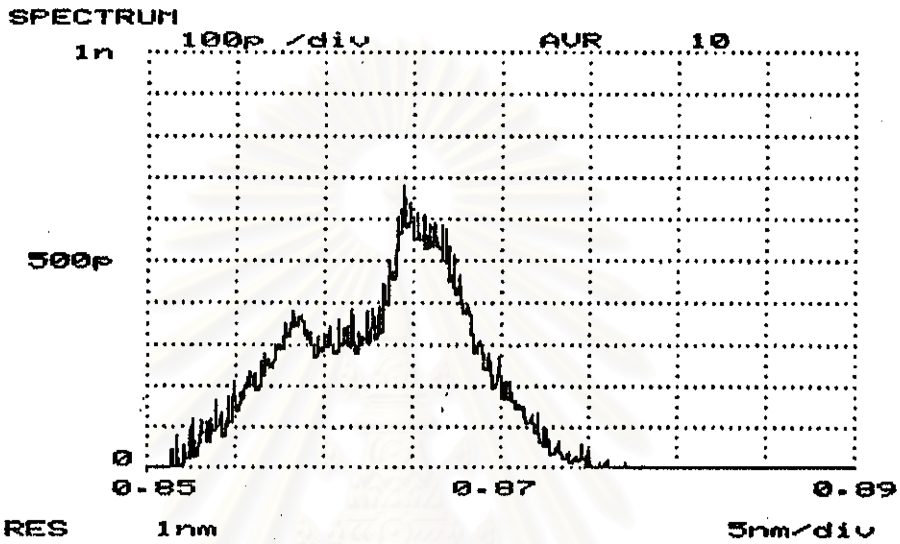
However, both threshold current and differential quantum efficiency are not equivalent in every fabricated chips because the LPE growth process can not provide the uniformity of active layer thickness over each LPE sample surface which is a critical parameter impacted to both values. Table 6.1 shows the individual data of each chip fabricated from the LPE samples. The 8 laser diode chips with 500-600 μm cavity length have the threshold current ranging from 120 to 150 mA and the calculated external quantum efficiency ranging from 2.5 to 3.6%.

Table 6.1 The data of 8 fabricated laser diode chips. All chips are not fabricated from the same LPE sample.

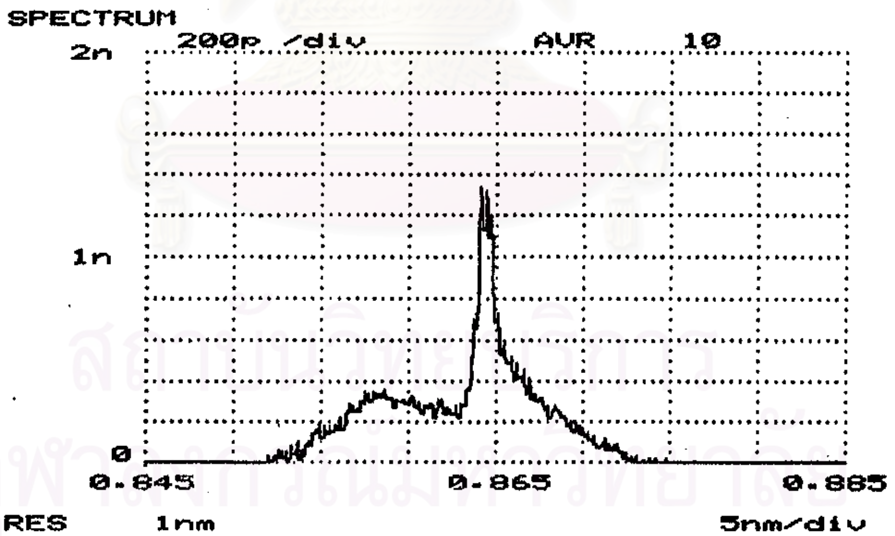
No.	Cavity Length (μm)	Threshold Current (mA)	Differential Quantum Efficiency
1	600	120	3.6 %
2	500	150	3.3 %
3	500	145	2.9 %
4	525	130	2.6 %
5	550	120	3.1 %
6	600	150	3.4 %
7	550	125	2.5 %
8	525	130	2.9 %

6.4 Spectral characteristics

The power spectrum of a laser diode is an important device characteristic since in many applications the spectral control of the laser output is required. Below threshold, the output takes the form of spontaneous emission with a broad spectral width of ~15 nm measured by *full width at half maximum* (FWHM). As the threshold approached, the spectrum narrows considerably and several peaks whose frequencies coincide with the longitudinal mode frequencies appear. In the above-threshold regime, the longitudinal mode closet to the gain peak increases in power, while the power in remaining side peaks saturates. The spectral characteristic is shown in Fig. 6.4 for a 864 nm RW laser diode having the threshold current between 115 and 120 mA.



(a) 115 mA



(b) 120 mA

Fig. 6.4 Spectral characteristics of a RW laser diode at (a) under-threshold current of 115 mA and (b) above-threshold current of 120 mA.

6.5 Result discussions

From the prediction of threshold current per waveguide width analyzed in [59], the GaAs/$Al_{0.3}Ga_{0.7}As$ DH laser diode with the active layer of 0.2 μm and the cavity length of 600 μm, which corresponding to the fabricated chip in this thesis, should has the threshold current per waveguide width of 15 mA/μm. This predicted result was determined by the linear-gain distribution assumption. In this thesis, the RW laser diode with 120 mA threshold current and 4 μm ridge width could be calculated to be 30 mA/μm threshold current per waveguide width which was 2 times of the predicted value. It is obvious that this higher threshold current of RW laser came from its bell-shape gain distribution occured from the stripe contact. Comparing to the data from the gain-guided DH laser diode fabricated in previous research [60], the non-RW laser had the threshold current per waveguide width approximately 3 times of the predicted value. It means that the RW structure could produce less threshold current than the non-RW ones because of its higher gain density from narrow bell-shape gain.

Spatial characteristics of the fabricated devices were not investigated in this research, because the lack of equipment. Anyway, further research should concentrate on the spatial characteristics, especially in the near- and far-field intensity distribution, to prove the single transverse mode of the chips, which was the major aim of the RW design.