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DETERMINATION OF GAIN AND LOSS PARAMETERS OF (AlGa)As-GaAs SINGLE HETEROSTRUCTURE LASERS

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Gain and loss parameters of (AlGa) As-GaAs single heterostructure laser have been determined by changing the reflectivity of one facet of the laser with ZnS optical films evaporated in controlled steps. The measurements gave a linear dependence of gain on threshold current density. The results so obtained on the lasing photon energy and threshold current density were in agreement with the previously reported theoretical models derived on the assumption of high concentration of impurity band tail states.

1. Introduction

For a GaAs laser the relation between gain at threshold g_{th}, absorption coefficient α and endloss of the laser $\frac{1}{2L}\ln\frac{1}{R_1R_2}$ is given as[1])

$$g_{th} = \alpha + \frac{1}{2L}\ln\frac{1}{R_1R_2} \tag{1}$$

L is the length of the laser and R_1, R_2 are the reflectivities of the end facets. The threshold current density I_{th} is related with the gain as[1]

$$g_{th} = \beta\, I_{th}^{b}. \tag{2}$$

Combining equations (1) and (2), we get

$$I_{th}^{b} = \frac{1}{\beta}\left(\alpha + \frac{1}{2L} - \ln\frac{1}{R_1 R_2}\right) \tag{3}$$

where β and b are constants with $b > 1$. $b \cong 3$ is determined experimentally for (AlGa) As-GaAs single heterostructure (SH) lasers at room temperature by varying the cavity length thereby giving a superlinear dependence of gain on current density[2]. $b \cong 1$ is also reported for SH lasers giving a linear dependence of gain on threshold current density at room temperature[1]. The latter value is determined while changing the end loss parameter by producing SiO films of various thicknesses on one mirror of the laser. Apart from SiO, ZnS plays a significant role as its thin film on laser mirror provides a refractive index match in coupling of the laser with the fibre for optical communication[3], a major application for semiconductor lasers.

In the present work ZnS thin films in controlled steps are evaporated onto one mirror of a SH laser for experimentally determining the dependence of gain on threshold current density and the effect of the latter on peak gain energy. These results are compared with theoretical results reported in the literature[4–6].

The design for coating ZnS thin films on semiconductor lasers both as reduced reflection coating and antireflection coating is also presented.

2. *Experimental*

Commercially available (AlGa) As-GaAs single heterostructure laser is used in the present study. The length, width and junction thickness of the laser are 300 μm, 150 μm and 2 μm, respectively. One facet of the laser is coated with a reflective film (reflectivity ~ 0.85) by the manufacturer in order to reduce the threshold current and to increase the light output from other facet of the laser. It is this uncoated facet which is subjected to successive thermally evaporated coatings of ZnS in vacuum in order to achieve the final thickness of $\frac{\lambda}{4}$. After each successive coating, the spectral output measurements are recorded in air at room temperature by usual monochromator, photomultiplier and sampling oscilloscope system, while operating the laser with low duty cycle fast square pulses of 80 ns duration. The value of threshold current is taken at the emergence of a single mode peak from the spontaneous emission spectrum.

During evaporation the thickness of the film on the laser is monitored from time of evaporation and colour produced by the ZnS film deposited on the glass slide placed close to the laser. Approximately 4 to 5 successive coatings on the laser mirror are deposited at a rate of approximately 10 nm per minute, to achieve

$\frac{\lambda}{4}$ thickness and the colour of the same glass slide changed through white-yellow — magenta with increasing order of thickness, while the colour on the laser changed in the sequence of blue—yellow—white. The frequency scans against light intensity of the coated glass slide, using spectrophotometer, at these three colours are given in Fig 1. If n_f and h are the refractive index and thickness of the film, respectively, it is then from the condition of minima $n_f h = \frac{\lambda}{2}$, $\left(\lambda = \frac{1}{f}\right)$. The thickness of the film deposited on the glass slide is calculated and is taken as the thickness on the laser mirror. Knowing h, the reflectivity R of the laser beam at laser — film interface at normal incidence is calculated from the expression

$$R = \frac{r_1^2 + r_2^2 + 2 r_1 r_2 \cos 2\delta}{1 + r_1^2 r_2^2 + 2 r_1 r_2 \cos 2\delta}$$

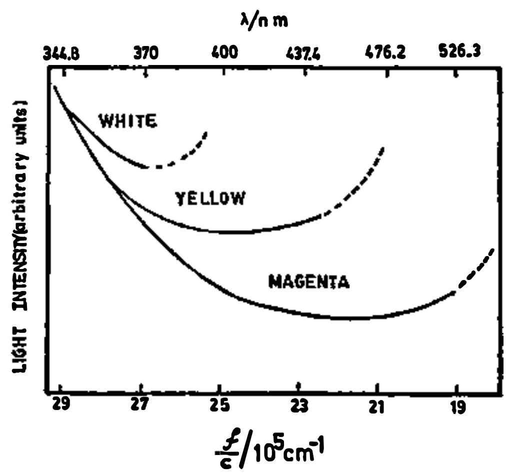

Fig. 1. The frequency scans against light intensity corresponding to three colours on a glass slide after successive ZnS evaporations.

where $\delta = \frac{2\pi}{\lambda} n_f h$; r_1 and r_2 are the Fresnel coefficients at laser-film and film — air interfaces, respectively. If n_l and n_a are the refractive indices of the laser and air respectively, then

$$r_1 = \frac{n_l - n_f}{n_l - n_f} \text{ and } r_2 = \frac{n_f - n_a}{n_f + n_a}$$

The plot of R against h; taking $n_l = 3.6$, $n_f = 2.3$ and $\lambda = 850$ nm, is given in Fig. 2. It is evident from Figs. 1 and 2 that the coating on the glass slide in between the colours of yellow and magenta is approximately 92 nm thick and needed as a $\frac{\lambda}{4}$ film on the laser mirror reducing its reflectivity from 0.32 down to approximately 0.035.

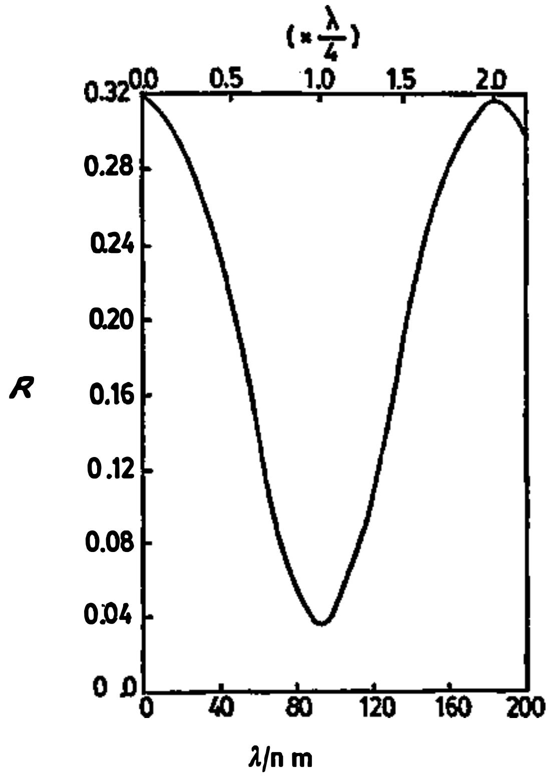

Fig. 2. Reflectivity of GaAs as a function of film thickness of ZnS.

3. *Results and discussion*

Single heterostructure laser used in the present study is well behaved laser and shows only one spectral group. The threshold current for the uncoated laser is 8.8 A. Five successive coatings are made on one facet of the laser and the spectral recordings for each coating at $1.1 \times I_{th}$ after 40 ns of the current pulse are shown in Fig. 3. Up to 4th coating which is of $\frac{\lambda}{4}$-thickness, the threshold current is increased to 14.8 A. The spectra is shifted to the high energy side after each coating, but the 5th coating reduces the threshold current to 12.5 A and in accordance with the spectral group is shifted back to the lower energy side. From these spectral results, a plot of I_{th} against energy E is obtained as shown in Fig. 4, where energy is taken at the peak of each spectral envelope.

The increase in energy with increasing current is probably due to the band filling process and bending of the curve at higher current values indicates the effect of band gap shrinkage. This experimental curve agrees with the results obtained for GaAs by Casey and Stern[4] on theoretical analysis including band tail and band gap shrinkage effects.

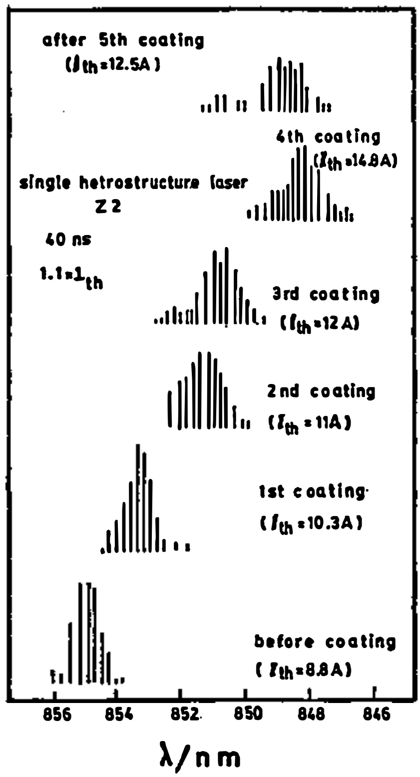

Fig. 3. Time resolved spectra at $1.1 \times I_{th}$ after 40 ns of the current pulse, recorded before and after each of 5-successive coatings of ZnS on one facet of the laser. Each Fabry-Perot resonance is represented by a line of the same magnitude at its wavelength.

The reflectivity at each step is calculated from the thickness on the glass slide, which are 0.32, 0.22, 0.11, 0.052 and 0.035 initially and after the 1st, 2nd, 3rd and 4th coating, respectively. The plot of I_{th} against endloss $\frac{1}{2L} - \ln \frac{1}{R_1R_2}$, shown in Fig. 5, gives a linear dependence of threshold current density on endloss and $b \cong 1$ (Eq. 3) seems to be appropriate, since $b = 2$ will give the intercept as negative which is not plausible. The value of absorption coefficient a, while assuming it to be constant with increase of carrier concentration, can be found from the expression

$$\frac{|I_{th}|_{\text{uncoated}}}{|I_{th}|_{\frac{\lambda}{4}}} = \frac{\left|a + \frac{1}{2L} \ln \frac{1}{R_1R_2}\right|_{\text{uncoated}}}{\left|a + \frac{1}{2L} \ln \frac{1}{R_1R_2}\right|_{\frac{\lambda}{4}}}$$

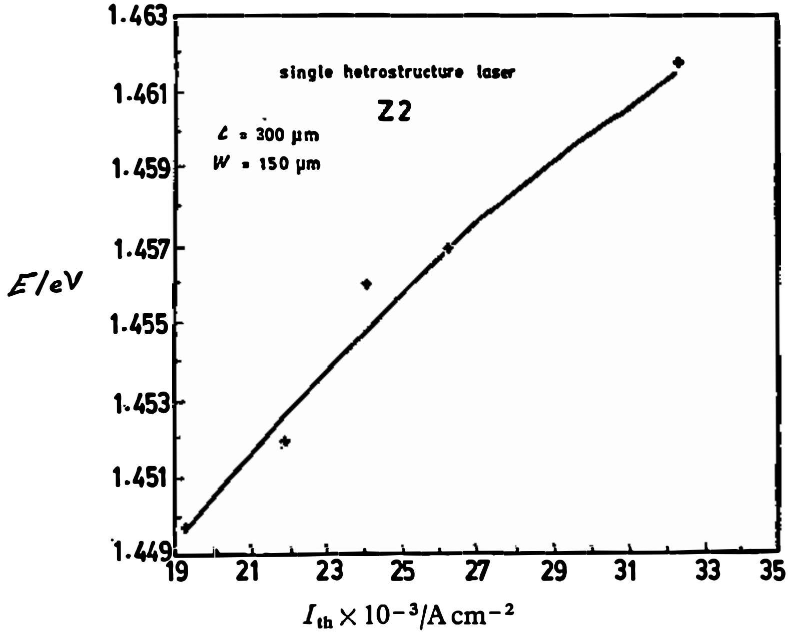

Fig. 4. Lasing photon energy as a function of threshold current density.

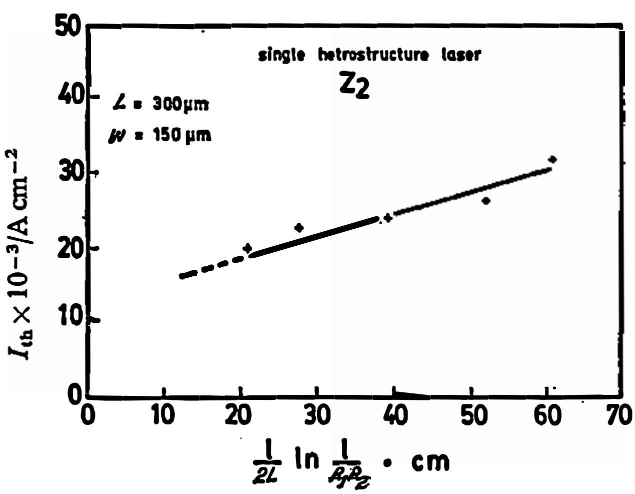

Fig. 5. Variation of threshold current density with endloss. $b \cong 1$ seems to be appropriate.

Substituting the values concerned, α becomes equal to 29 cm^{-1} and $\beta = 2.6 \times \times 10^{-3}$ cm/A. The peak energy of the lasing spectrum E is also found to be related with reflectivity by[6,7]

$$E = E' + E_0 \ln \left(\alpha L + \ln \frac{1}{R_1 R_2} \right)$$

This expression was derived on the assumption of impurity band tail states of exponential form associated with both bands. E', E_0 are fitted parameters and for the laser studied here the values came out to be 1.436 eV and 17 meV, respectively.

4. *Conclusion*

While changing the endloss parameter by controlled deposition of ZnS thin films on one mirror of GaAs single heterostructure laser, the measured gain and loss parameters have revealed a linear dependence of gain on threshold current density. The dependence of lasing photon energy on threshold current density have been found to be in accordance with Casey and Stern's model[4] derived on the assumption of impurity tails both in the conduction and valence bands and including the effect of band gap shrinkage due to high concentration.

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ODREĐIVANJE PARAMETARA POJAČANJA I GUBITKA U (AlGa)As-GaAs JEDNOSTRUKIM HETEROSTRUKTURNIM LASERIMA

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Određeni su parametri pojačanja i gubitaka (AlGa) As-GaAs jednostrukog heterostrukturnog lasera pomoću promjene refleksivnosti jedne strane lasera sa ZnS optičkim filmom naparenim u kontroliranim dozama. Mjerenja su pokazala linearnu ovisnost pojačanja o gustoći struje praga. Dobiveni rezultati za fotonsku energiju emisije slažu se sa postojećim modelima dobivenim pod pretpostavkom visoke koncentracije stanja nečistoće u krajevima vrpci.