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On mirror temperature of a semiconductor diode laser studied with a photothermal deflection method

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ABSTRACT

The mirror temperature response of a diode laser to injection current is studied through the photodeflection method. A theoretical model is presented together with some experimental measurements for a AlGaAs quantum well laser diode.

1. INTRODUCTION

The study of the degradation due to the heating process is of great importance in the field of semiconductor lasers^{1,2}. Therefore the knowledge of the rise temperature of both active zone and mirrors, as a function of the laser diode injection current, become fundamental for the planning and fabrication processes and applications.

In the present paper a new method to measure the mirrors' rise temperature is suggested in alternative to other methods. The present method, based on the photothermal deflection technique ("mirage effect")³ is applied to AlGaAs diode laser samples, prepared as described in ref.4.

2. THEORETICAL CONSIDERATION

A new application of the well-known "mirage effect" is proposed to determine the mirrors' temperature rise (T_m) and its behaviour as a function of laser diode drive current. The "mirage technique"³ (PD) is usually applied to material slabs by heating the sample in a region far from the border with respect to the thermal diffusion length

ℓ ($\ell = \sqrt{2D/\omega}$) where D is the sample thermal diffusivity and ω the angular pump beam modulation frequency), so to neglect edge effects.

In the present paper the theory has been modified for the case of a finite dimension sample, with the heating source in an asymmetric position very close to one edge of the laser diode (see Fig.1). The drive current, modulated at an angular frequency ω , is assumed to be homogeneously distributed along the laser cavity and produces the heat quantity q per unit time and per unit length of the cavity, into the active region which plays the role of the heat source. Beside the heat quantity q , we could introduce a source equivalent temperature T_q defined as $T_q = q/k$ where k is the sample thermal conductivity.

The consequence, as will be clear after, is that the temperature T_q could be directly obtained with a photothermal deflection experimentum, giving also an idea of the bulk average temperature rise.

The temperature distribution is obtained by solving the heat Fourier equations together with the boundary conditions for the geometry of fig.1. Some simplification can be made neglecting the thermal flux in air with respect to the thermal flux going into the copper heat sink. The temperature rise in both bulk and active region is given by ⁴

$$T = \frac{T_q}{w} \left[\frac{\sinh(\beta y)}{\beta \cosh(\beta h)} + \frac{4}{pa} \sum_{n=1}^{\infty} \frac{\sinh(\beta_n y) \cos(npx) \sin\left(\frac{n\pi a}{2}\right)}{n\beta_n \cosh(\beta_n h)} \right] e^{i\omega t} \quad \begin{cases} 0 < z < L \\ -\frac{w}{2} < x < \frac{w}{2} \\ 0 < y < h \end{cases} \quad (1)$$

where a, w, h are the dimensions specified in fig.1, $\beta^2 = \frac{j\omega}{D}$, p is the fundamental

spatial frequency given by $p = \frac{2\pi}{w}$ and $\beta_n = \sqrt{\beta^2 + (n\pi)^2}$.

By a careful inspection of eq.(1), the maximum of the rise temperature is reached in the d.c. case in the active region just at the semiconductor laser mirror, playing a critical role in the degradation of the device. In a typical laser the bulk height ($h \approx 120\mu\text{m}$) and the bulk width ($w \approx 400\mu\text{m}$) are of the same order, while the strip width ($a \approx 10\mu\text{m}$) is much shorter, so that some simplifications can be made using eq.(1) in the calculation of the mirror rise temperature T_m ⁴

$$\frac{T_m}{T_q} = \frac{h}{w} + \frac{w}{a\pi^2} \sum_{n=1}^{\infty} \frac{\tanh\left(2n\pi \frac{h}{w}\right) \sin\left(n\pi \frac{a}{w}\right)}{n^2} \xrightarrow{\frac{2\pi h}{w} > 1, \frac{a}{w} \ll 1} \approx \frac{1}{\pi} + \frac{h}{w} + \frac{\ln\left[\frac{w}{\pi a}\right]}{\pi}. \quad (2)$$

When a probe laser beam travels along the x direction, in the air layer very close to the bulk (see Fig.1), due to the thermal gradients, an angular deflection both in y and in z direction is expected. The photodeflection theory³, applied to the thermal distribution

given by Eq.(1), after some simplifications assuming to operate at high drive current frequency ($\ell < h$), gives for both amplitude and phase of the lateral component of the deflection angle ϕ_y the following expression:

$$\left\{ \begin{array}{l} |\phi_y(y)| = \frac{T_q}{n_a} \left| \frac{dn_a}{dT} \right| \exp\left[\frac{y-h}{\ell}\right] \\ \vartheta(y) = \frac{y-h}{\ell} \end{array} \right. \quad (3)$$

where $|\phi_y(y)|$, $\vartheta(y)$ respectively are the amplitude and phase of the lateral deflection

angle as a function of the offset y , $\frac{dn_a}{dT} \cong -10^{-6} \text{ K}^{-1}$ is the air optothermal coefficient,

$n_a \cong 1$ is the air refractive index. Note that both the phase and the logarithm of amplitude have the same linear behaviour with y , from which ℓ and consequently D are worked out. In principle an easy way to calculate T_q should be by measuring the amplitude at the edge, close to the active region, according with eq.(3) and after some algebra $[T_q = |\phi_y(y=h)| \cdot 10^6 \text{ (}^\circ\text{K)}]$, but in practice, due to the probe beam finite size ($\cong 15\mu\text{m}$), the amplitude in $y=h$ is far away from the value expected in eq.(3) and an extrapolation of data is in general needed

3 EXPERIMENTAL DATA

The experimental values of both $\ln |\Phi_y|$ and phase $\vartheta(y)$ as a function of y/h , for a single-quantum-well AlGaAs/GaAs laser diode⁴ have been plotted, for three different frequencies (40KHz - 62.5KHz - 90KHz), and for a lasing current of 70 mA (see Figs.2). Extrapolated data (see curves a,b and c in fig.2a) in $y=h$, give the source temperature value $T_q = 57 \pm 8^\circ\text{K}$. Knowing the geometrical dimensions of the laser and by using eq.(2), the mirror rise temperature $T_m = 80 \pm 12^\circ\text{K}$ is finally found. The values of the thermal diffusion length for the different frequencies have also been derived from the linear slopes and a bulk thermal diffusivity $D = 0.28 \pm 0.01 \text{ cm}^2/\text{s}$ is obtained. The calculated value of D , which for a quantum-well laser diode has to be considered as an average between the thermal diffusivities of AlGaAs and GaAs, is in good agreement with the values found in literature.

4. CONCLUSIONS

In the present paper, a method is given for determining the quantity of heat generated by the injection current in the active region of a semiconductor laser by using the

photothermal deflection technique, and the results of the theoretical study on temperature rise distribution in the laser diode. The photothermal deflection method allows to determine also the thermal diffusivity of the semiconductor laser diode.

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Fig.1 - Scheme of the configuration

Figs.2 . Experimental results for different frequencies (1) 40KHz - (2) 62.5KHz - (3) 90KHz, and for a laser current of 70 mA. 2a) logarithm of amplitude , 2b) phase.