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Analysis of thermal conditions of pulse operated single quantum well separate confinement heterostructure (SQW SCH) lasers

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Junction temperature affects laser diode performance in many ways. Magnitude of the light output power, a center wavelength of the spectrum and diode reliability are all strongly dependent on the junction temperature. A simple electrical method to measure laser diode junction temperature has been developed. It is based on the measurement of the junction voltage change, which is due to the change of its temperature and is induced by supplying the laser with DC current in parallel to the pulsed driving current. Junction temperature dynamics in the pulse operated GaAs based SQW SCH quantum well broad contact lasers designed for emission at 980 nm was studied and results are presented. Additionally, junction cooling in these lasers as a function of time was also assessed.

Keywords: junction temperature dynamics, laser.

1. Introduction

Temperature of the laser diode junction affects the performance of a device in many ways. This is because electrical and optical parameters such as threshold current, output optical power, and wavelength of oscillating modes are strongly dependent on junction temperature. Knowledge of the temperature distribution plays an important role in the integration and packaging design.

There are several measurement techniques to determine the laser diode temperature. Junction temperature can be deduced from the laser threshold [1] and the stimulated emission [2]. However, these techniques are weakly accurate and of low sensitivity. The thermoreflectance technique provides high sensitivity and high spatial resolution but it works excellently only for low-power laser diodes where the temperature distribution in the laser is weak [3]. The Raman scattering spectroscopy provides temperature profiles with a high resolution of 1 μm; however, the precision of the measurement [4] is as low as 10 K.

In this paper, a study of junction temperature dynamics in the pulse operated lasers is presented. An electrical test method to measure the laser diode junction temperature has been developed for that purpose and described. It provides information about the junction temperature and heat generation rate through the analysis of the cooling down profile of a pulse operated laser.

2. Experiment

The laser under study was a conventional ridge-waveguide, strained layer separate confinement heterostructure (SCH) InGaAs/GaAs laser with a single quantum well (SQW), designed for RT emission at 980 nm. The structure was grown on a (100) GaAs conductive substrate by molecular beam epitaxy (MBE) process. The undoped 60 Å thick layer of the strained $In_{0.20}Ga_{0.80}As$ quantum well active layer is bounded by 0.3 μm thick undoped GaAs layers and together with an $Al_{0.3}Ga_{0.7}As$ *n*-type Si-doped barrier layer and $Al_{0.3}Ga_{0.7}As$ *p*-type Be-doped barrier layer forms a waveguide. The laser cavity was 700 μm long and the width of the ridge and its height were 200 and 500 μm, respectively. Both laser mirrors remained uncoated and reflectivity of their facets (around 32%) ensured approximately the same power emission from both ends.

3. Results and discussion

The measuring technique developed is based on the temperature dependence of the terminal voltage across the laser diode. The method uses a sequence of driving current pulses to cause a change of junction temperature and therefore of the voltage (ΔV_F) measured between the pulses upon constant DC current (I_P) passing. The test circuit and the current and voltage waveforms are shown in Fig. 1.

In the first step, constant DC current I_P is passed through the diode under test and the junction voltage V_{F1} is measured. The low value of the DC current I_P prevents additional heating of the lasers tested. In the next step, the driving pulsed current I_D is

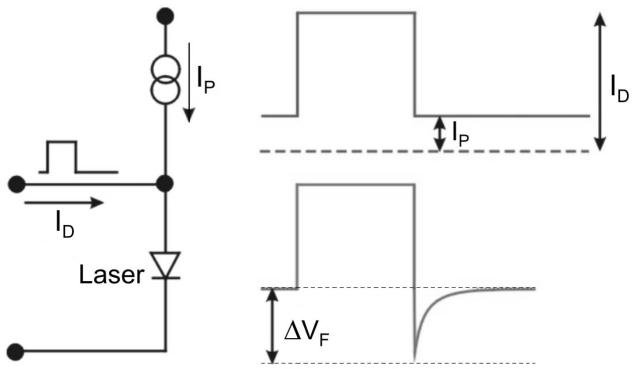

Fig. 1. Test circuit for temperature measurements (left) and the current and voltage waveforms in the circuit (right).

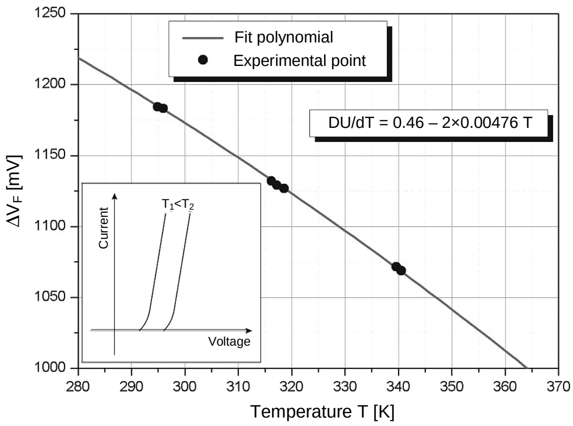

Fig. 2. Voltage V_F measured *vs.* junction temperature $T_J = T_A + \Delta T_J$, where ambient temperature $T_A =$ 300 K.

passed and soon after the junction voltage V_{F2} or the difference $\Delta V_F = V_{F1} - V_{F2}$ is measured. The voltage difference ΔV_F is directly related to the junction temperature increase and its waveform follows the drop of the latter when the laser cools down. Intensity of the current I_P had to be appropriately chosen to assure diminutive heating of the laser. If so, the relationship between the junction temperature T_J increase ΔT_J and the voltage change ΔV_F has been observed as follows:

$$\Delta V_F = \alpha \Delta T_J \tag{1}$$

where α is some correlation factor having typical values in the range of 1.5–2.5 mV/K depending on the particular device structure. Experimental verification of Eq. (1) is shown in Fig. 2. The correlation factor α for lasers investigated in this work was found to be 2.4 mV/K.

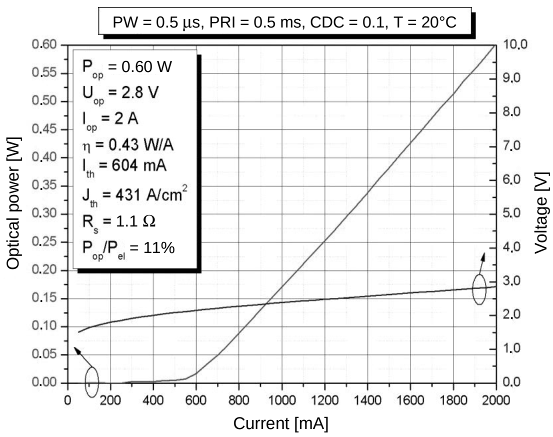

Fig. 3. Current-voltage and current-optical output characteristics of the laser under investigation.

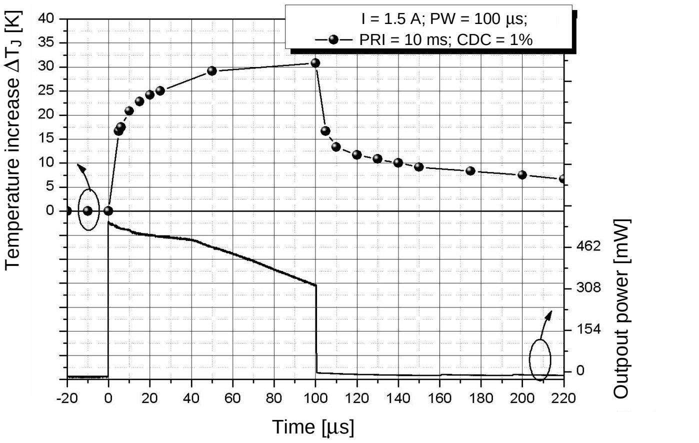

Fig. 4. Dynamics of junction temperature in the lasers tested (top) and the optical output power (bottom) as a function of the current pulse duration time.

The lasers were mounted *p*-type side up on the copper heat sinks and placed on a stage with a thermoelectric cooler to provide temperature stability of the heat sink during the experiment. Although such a configuration was less efficient in heat removing from the laser it gave the advantage of more pronounced thermal effects. Typical output characteristics of the lasers investigated are shown in Fig. 3.

The laser was operated at 1.5 A current pulses 100 µs wide with a filling factor of 1%. The pulse interval was 10 ms and because it was relatively long the laser was returning to the ambient temperature before the next pulse was supplied. Figure 4 shows junction temperature and optical output measured versus time.

The curves illustrate the rate at which junction temperature was increasing and dropping and how this affected the optical output of the laser. Both front and tail profiles of the junction temperature curve can be approximated by an exponential function:

$$\Delta T_J = T_0 + A_1 \exp\left(-\frac{x}{t_A}\right) + A_2 \exp\left(-\frac{x}{t_B}\right) \tag{2}$$

where T_0 is the temperature correlation factor, A_1 and A_2 are amplitude factors, t_A and t_B are fitting exponents for front or tail profiles. For the curve displayed in Fig. 4 the following exponents have been calculated: $t_{\mathrm{frontA}} = 3.1$ µs, $t_{\mathrm{frontB}} = 27.3$ µs, $t_{\mathrm{tailA}} = 3.2$ µs and $t_{\mathrm{tailB}} = 68.3$ µs.

The measured voltage change ΔV_F at the end of the pulse duration was 74 mV, which corresponded to $\Delta T_J = 31$ K. It took 40 µs for the laser to cool down and diminish ΔT_J from 31 to 10 K. It is to be noted that the temperature was increasing by 20 K within single microseconds. This figure could be much higher for lasers with larger series resistance. Total damage of the laser caused by such a temperature rise in the structure within such a short time is highly possible.

4. Summary

In this paper, the results of experimental measurements of laser junction temperature have been presented. The electrical test method applied is based on the temperature dependence of junction forward voltage. Thermal time constants of the laser investigated have been calculated and shown to be in the range of microseconds. The method has potential for being applied to measurements of the thermal impedance of laser diodes.

References

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