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# Analysis of high-power diode laser thermal properties by micro-Raman spectroscopy

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Spatially resolved micro-Raman measurements have been performed to determine temperature distribution over the facet of high power semiconductor diode lasers. This technique is non-invasive and allows one to study the local temperature on the surface of the mirror of semiconductor diode lasers under normal operating conditions. The micro-Raman measurements can also serve as a calibration of absolute temperature for the other contact-less thermometric methods, *e.g.*, thermoreflectance.

Keywords: Raman spectroscopy, catastrophic optical mirror damage (COMD), high-power laser, thermoreflectance.

## 1. Introduction

High-power diode lasers offer a wide range of potential applications. However, limitations connected with the lifetime, emitted optical power and reliability of a device very often preclude these applications. Improving these parameters relies on better understanding of thermal processes taking place in lasers, including those connected with laser facets. The excessive local heating of mirror surface can lead to catastrophic optical mirror damage (COMD) [1]. This is one of the major mechanisms which drastically limit laser lifetime and emitted optical power. The process is irreversible and the mirror is locally destroyed as a result of temperature increase caused by absorption of emitted laser radiation.

A crucial part of optimisation of semiconductor laser parameters is determination of temperature on facets of the devices. Such measurements allow the range of potential uses of semiconductor lasers to be extended.

Several methods proved to be useful to measure the temperature of the laser surface. These are micro-probe band-to-band photoluminescence, thermoreflectance spectroscopy and Raman spectroscopy [2–5]. In this paper, we describe a method of measuring the local temperature of facets of semiconductor laser diodes using micro-Raman spectroscopy. The Raman spectroscopy is based on Raman scattering effect known since 1928. Raman scattering relies on inelastic photon scattering on optical phonons.

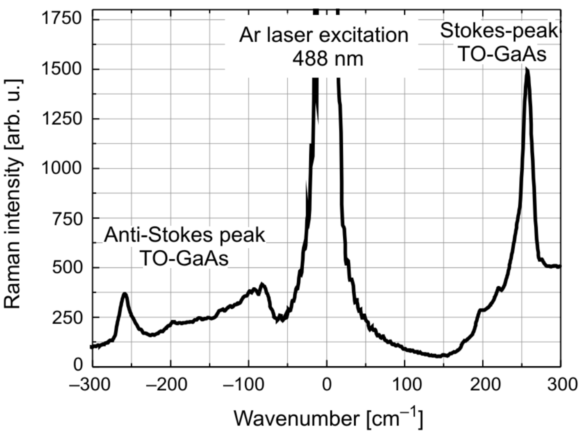


Fig. 1. Raman spectrum from the GaAs surface.

Such a scattering process involves emission or absorption of a phonon. An example of the spectrum of scattered light is shown in Fig. 1.

Figure 1 shows the Raman spectrum from the (110) surface of GaAs. There are two types of Raman scattered light: Stokes, with a Raman light frequency of $(\omega_0 - \omega_{(q)})$, and anti-Stokes, with a Raman light frequency of $(\omega_0 + \omega_{(q)})$, where $\omega_0$ is the stimulating light frequency and $\omega_{(q)}$ is the lattice vibration frequency. The Stokes and anti-Stokes lines caused by scattering at longitudinal optical (LO) phonons were analysed in the experiments. The local temperature of the surface layer was derived in two ways: from the ratio of the intensities of Stokes and anti-Stokes lines and independently, from the spectral positions of those lines. As the change of temperature leads to thermal expansion of the lattice, the phonon frequencies shift with temperature [6]. Determining local temperature from the ratio of line intensities is based on Eq. (1). This method relies on the fact that population of phonons is controlled by Bose–Einstein statistic. Hence, apart from the line position, temperature can be estimated from Stokes and anti-Stokes line intensities ratio:

$$\frac{I_{\mathrm{St}}}{I_{\mathrm{aSt}}} = \left(\frac{\nu_{\mathrm{L}} - \nu_{\mathrm{Ph}}}{\nu_{\mathrm{L}} + \nu_{\mathrm{Ph}}}\right)^4 \exp\frac{hc\,\nu_{\mathrm{Ph}}}{kT} \tag{1}$$

where $I_{\mathrm{St}}$ and $I_{\mathrm{aSt}}$ are the Stokes and anti-Stokes line intensities, respectively, $\nu_{\mathrm{Ph}}$ and $\nu_{\mathrm{L}}$ are the frequencies of the optical phonons and excitation source (cm$^{-1}$), $h$ and $k$ are Planck (Js) and Boltzman (J/K) constants, $T$ is the temperature (K) and $c$ – speed of light (cm/s).

## 2. Experiment

The measurements of facet temperature in CW mode were carried out using a conventional micro-Raman set-up based on a 0.6-m DILOR spectrometer equipped with a microscope and liquid-nitrogen-cooled CCD-multi-channel detector. As an excitation source, we used a 488 nm or 514.5 nm $Ar^+$-ion laser line. The scheme of experimental set-up is shown in Fig. 2.

The excitation intensity was below 50 $kW cm^{-2}$ over 1.5 μm diameter spot. Typical integration times for our experiment were several minutes. The device under examination was mounted on a temperature-stabilized heat sink (25°C) that allowed active alignment of the device with respect to the microscope objective by using *x*-*y*-*z* piezotranslation stages. More details about the set-up and the methodology of experiment are given elsewhere [7].

In this work, we have studied InGaAlAs/GaAs high power lasers emitting at 810 nm. The devices were mounted *p*-side down on silicon carbide (SiC) heat sinks and indium soldered onto copper mounts. Fig. 3 shows the SEM photograph of sample showing location of the laser chip on the heat sink. The *p*-side down mounting technique allows a much better dissipation of heat generated inside the devices. For lasers mounted this way the heat power generated in the active region has to cross only

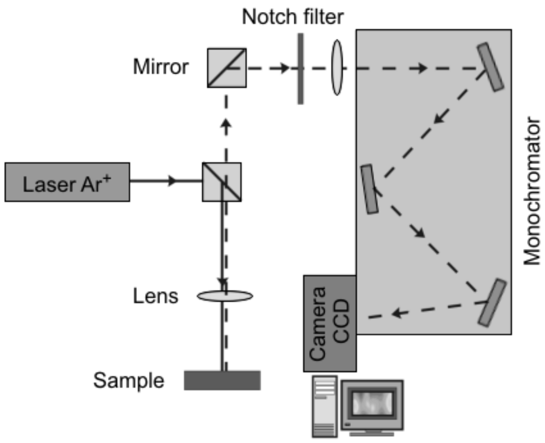


Fig. 2. Scheme of experimental set-up for micro-Raman spectroscopy.

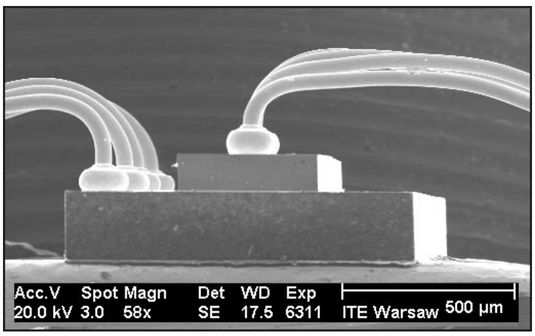


Fig. 3. SEM photograph of high power laser emitting at 810 nm.

the top cladding and when it reaches the copper mount it is easily dissipated since the latter has a thermal conductivity 100 times better than GaAs [8].

## 3. Results and discussion

Figure 4 presents results of measurements for high power laser designed for 810 nm emission wavelength. Fig. 4**a** shows front facet temperatures versus operation current for different points at the laser mirror. The experimental points in the diagram present facet temperatures determined from the respective spectral line positions. It is also possible to determine the temperature from the intensity ratios, but this method has lower accuracy.

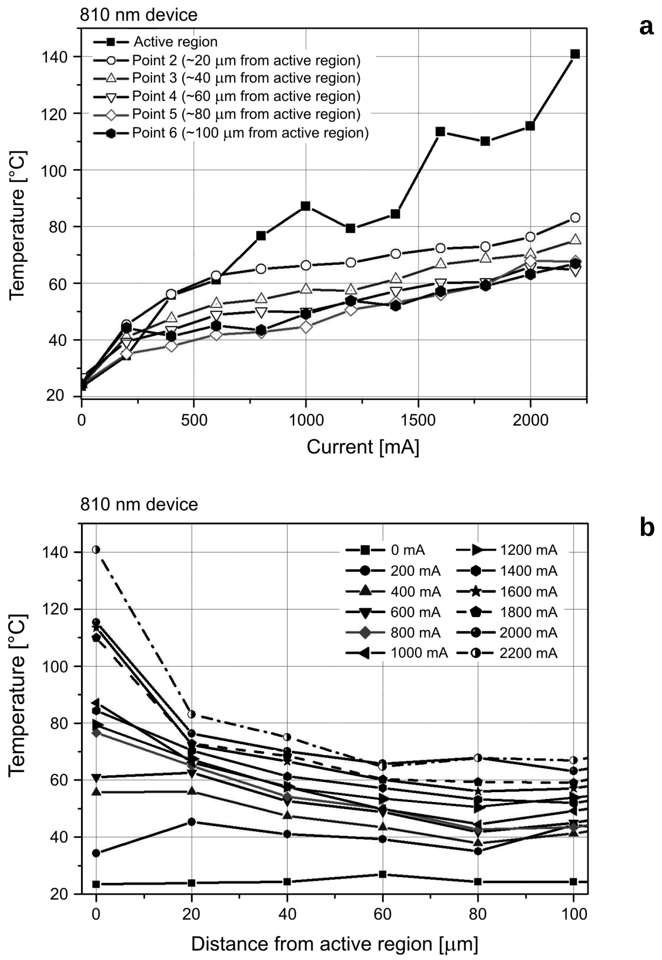


Fig. 4. High power laser temperature *vs.* CW operation current (**a**) and distance from active region (**b**).

We can see that the temperature increases in the vicinity of the active region to reach a value as high as 140°C for current equal to 2200 mA, while for the other points (distant by 20 μm to 100 μm from the active region), the temperature increase for comparable supply currents ranges from 85°C down to 65°C. We can also see that for a small value of current the temperature of the active region does not differ significantly from the temperature of other points. For great values of current the difference between the temperature of active region and point distant from the active region becomes considerable. From this figure, we can clearly see that temperature rises with operating current. The explanation for this result is that the facet heating due to the recombination current is proportional to the carrier density in the laser [9]. Also the optical field density in the resonator increases with an increase of drive current, which results in an increased absorption at the facet.

Measured temperature distributions at the front facet of semiconductor laser diode are shown in Fig. 4**b**. Line scans started in the active region and were measured in the center of the diode laser. We can see that for all values of current from 0 to 2200 mA the temperature is the highest in the active region. The temperature decreases rapidly over the distance of about 20 μm from active region and is nearly constant in the region from 50 to 100 μm away from the active region. The heating power is mostly localized in the active region. The thermal diffusion length estimated from this data is of the order of 20 μm.

## 4. Conclusions

The potential of micro-Raman spectroscopy for determination of temperature profiles on 810 nm laser facets under normal operating conditions has been demonstrated. It can be seen that for lasers mounted *p*-side down, it is only the active region that has a significantly higher temperature, and the rest of the front facet of the laser shows almost the same value of temperature; lower than in the active region. No heat dissipation through the structure is observed. This conclusion might have significant consequences for the optimisation of high power semiconductor laser constructions.

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