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Application of microscope thermography in testing temperature distribution in a semiconductor laser

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Microscope thermography with the use of thermovision camera with spatial resolution 8 μm was applied in testing temperature distribution in semiconductor lasers produced on the basis of nitrides. The conducted tests have shown that the microscope thermography has a potential in characterizing microelectronic devices like semiconductor laser diodes and can be considered as a complementary tool in establishing thermal characteristics of these devices.

Keywords: microscope thermography, blue lasers, semiconductor lasers.

1. Introduction

The majority of electronic devices exert considerable amounts of heat during operation, and its effective dissipation gains particular importance as the excessive temperature of semiconductor devices has a clearly negative impact on their operation in several different aspects. First of all, the increase in temperature leads always to the worsening of the device parameters, such as threshold current and differential efficiency. Furthermore, degradation processes of semiconductor devices are always thermally activated and occur much faster at the increased temperature. An additional mechanism which accelerates the degradation of electronic devices is the mechanical stress that occurs for materials having different temperature expansion coefficients, which is of particular importance during switching them on and off. This problem tends to gain importance because with progress in miniaturisation in electronics, the density of generated power tends to grow. For optimising the method of heat removal, the knowledge of temperature distribution during normal device operation is crucial.

2. Subject of research

The subject of this study was the determination of temperature distribution in violet light emitting, nitride-based laser diodes. The devices were developed in the Institute of High Pressure Physics of the Polish Academy of Sciences in Warsaw.

This type of laser has already been a subject of interest of the optoelectronic industry with view to the already existing applications, as well as potential ones. One of the main applications of blue lasers which has already been implemented in practice is optical information recording in the BlueRay technology, which is based on the fact that a shorter wave allows achieving a higher recording density as compared to red lasers used in the DVD technology. A potential large market for semiconductor lasers are RGB laser projectors, the full implementation of which requires apart from red and blue lasers also the green laser. Works on its development on the basis of nitrides have been undertaken by numerous institutions. Nitride based lasers operating within the range from ultraviolet to blue have already been applied in various ways in medical diagnostics. There is a lot of hope with the potential application of blue lasers in the printing industry.

Laser diodes belong to devices characterised by the highest densities of generated power. The reason for this is that the condition that allows lasing is the achievement of a high current density in the active area of a laser diode. To meet this requirement, the active area is designed in the form of a narrow stripe of a width ranging from single microns for lasers of a lower power, up to a few tens of microns for higher power lasers [1, 2].

As regards lasers produced on the basis of nitrides, power generated in the laser structure is even higher than in the case of red and infrared lasers, because owing to specific properties of those semiconductor materials, laser operation requires higher current density (3–10 kA/cm^2) and voltage (over 4 V), which leads to a very high density of electric power (12–50 kW/cm^2) [3, 4].

To achieve effective continuous wave laser operation, it is indispensable to obtain appropriately low thermal resistance of the entire device. Determination of the active laser area temperature can be achieved by using various optical methods: electroluminescence, Raman spectroscopy, thermo-reflection, or electrical methods, such as testing the voltage of the *p-n* junction. However, the above mentioned methods do not supply information on temperature distribution outside the active area of the laser and in its housing, which is necessary to allow optimisation of the heat dissipation. This type of data may be directly obtained from microscopic thermography [5].

3. Measurements

3.1. Measurement methods

The measurements have been carried out in the Main School of Fire Service (Warsaw, Poland), on a unique stand comprising a thermovision camera Raytheon Radiance HSX

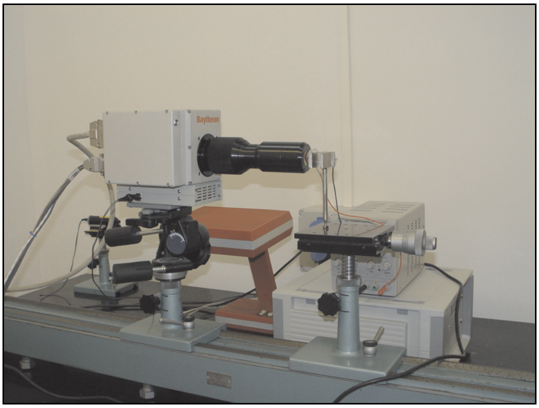

Fig. 1. Photograph of the measurement stand.

with a germanium made lens for microscopic testing with maximum spatial definition 8 μm (Fig. 1). It is a radiometric camera with a cooled detector of InSb, working within the operational spectral range of 3–5 μm.

The performed experiments were aimed at determining temperature distribution in a semiconductor laser, mounted in two different configurations: a standard 5.6 mm laser housing (TO18) and a special, custom made two copper blocks laser mount. In

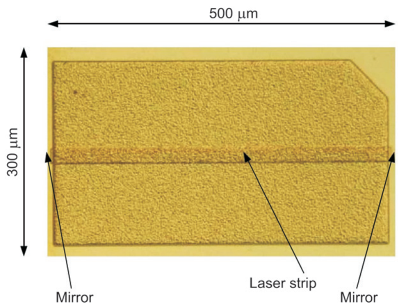

Fig. 2. Laser chip not assembled, top view (on the active side).

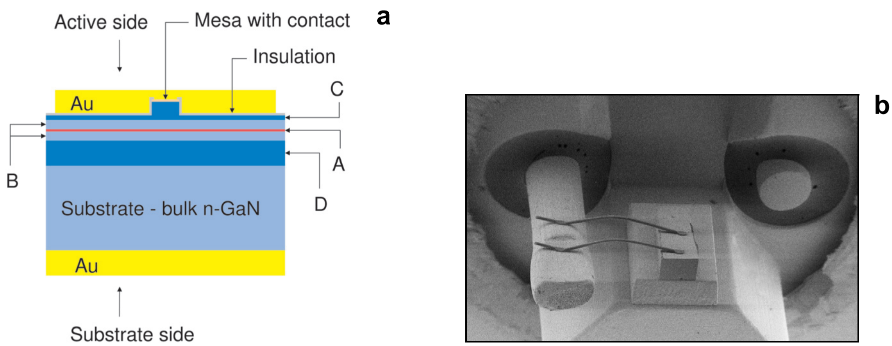

Fig. 3. Typical structure of laser diode: A – active layer, InGaN based quantum wells; B – GaN based waveguide; C – upper cladding layer, *p*-AlGaN based; D – bottom cladding layer, *n*-AlGaN based (**a**). SEM photograph of assembled laser diode (**b**).

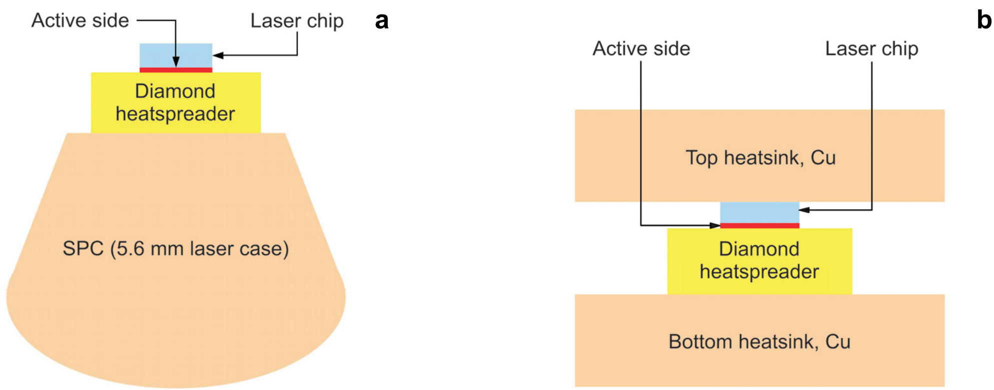

Fig. 4. Methods of laser assembly: in housing 5.6 mm with the active layer towards the housing with a diamond plate (*p*-down with diamond) (**a**), sandwiched between two copper plates (**b**).

both cases, the laser was soldered with AuSn to the diamond heatspreader with the active side faced at a diamond (*p*-type down). The objective was to detect places with the highest thermal resistance. This was to allow determination of the effectiveness of heat removal from the laser active area and potentially proposing methods for further assembly optimisation.

The parameters of tested laser diodes were as follows: wavelength about 410 nm, threshold current between 300 and 400 mA, output power about 10 mW, stripe width of 10 microns. Figures 2–4 present the structure of the tested laser.

3.2. Camera calibration

The tested electronic devices contain diverse metallic and dielectric structures, the emissivity of which is characterised by different values. If such values are not known, it becomes impossible to determine the surface temperature. Incorrect determination of the value of this factor would cause the false temperature readouts for the tested objects. This problem was solved by calibration of a camera using tested device as a pattern. The desired temperature was achieved using the Peltier element and then controlled with an appropriately installed thermocouple. Owing to the diversity of materials used in the testing process, calibration was carried out for each of the tested elements: laser, diamond plate and heat removal element. The calibration curves were made for each pixel of the thermogram of the tested device.

3.3. Results of measurements

Following camera calibration, the distribution of temperature has been determined on the surface of tested devices. This distribution was subsequently measured for various values of the driving current.

Figure 5 presents a thermogram of a laser diode mounted in the standard copper housing, corrected using the above mentioned calibration curves. The electrical supply power was approximately 3 W. The main sources of heat beside of active layer

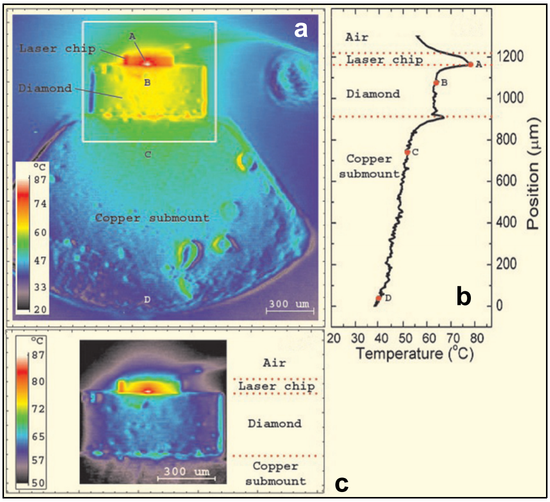

Fig. 5. Thermograms and temperature profiles of laser mounted in standard 5.6 mm copper housing. Temperature distribution for current of 450 mA – temperature of the active area that emits a laser beam (point A) to *ca*. 87 °C (**a**). Temperature profile along the straight section AD with applied points from the map **a** – visible heat accumulation on the interface diamond-base plate of Cu, which proves poor eutectic quality $Au_{0.8}Sn_{0.2}$ applied for joining the diamond and copper (**b**). Part of thermogram **a** in a different temperature scale – it shows a radial way of heat transport within the laser chip and the excellent thermal conductivity of the diamond, which ensures practically vertical heat transport (**c**).

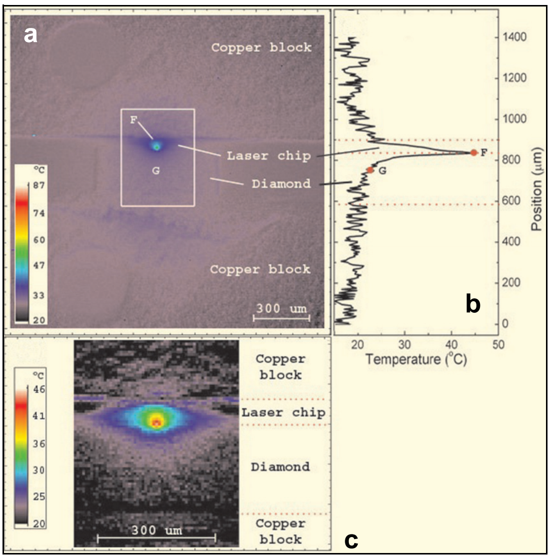

Fig. 6. Thermograms and temperature profiles of laser sandwiched between copper blocks. Temperature distribution for current of 450 mA – temperature of the active area that emits a laser beam (point F) is *ca*. 45 °C (**a**). Temperature profile along the straight line going through the laser stripe with applied points from the map **a** (**b**). Part of thermogram **a** in a different temperature scale (**c**).

of the laser diode are the *p*-type layer and the electric contact to it in the laser stripe area. The temperature of the laser stripe was about 77 °C. We can observe that the temperature jumps up about 15 °C on AuSn junctions between the diamond and the laser and about 5 °C on AuSn junctions between housing and the diamond. One can also point out very uniform temperature of the diamond, what proves that it works very well as a heatspreader. On the other hand, relatively large temperature of the laser housing (40 °C) suggests poor thermal coupling between the housing and the heatsink.

Figure 6 presents a thermogram of a laser diode on the diamond sandwiched between two about 4 mm thick copper plates. Supply power was also about 3 W. In this case, the stripe temperature was about 47 °C and the significant increase in temperature, like previously, was on the AuSn junction between the diamond and the laser, and this time it was above 20 °C. There was almost no temperature difference between the diamond and the copper plate. The temperature difference between the laser and the top copper plate was also relatively small, of the order of 5 °C. Both these connections were indium based. The temperature of copper plates was stabilized at 20 °C.

4. Conclusions

The application of a thermovision camera for visualisation and measurement of temperature distribution in a laser diode device led to the following conclusions:

– the use of a heatspreader is necessary for continuous wave operating lasers,

– the following material junctions: laser/heatspreader and heatspreader/heatsink are the most important and need to be optimized,

– in the case of standard 5.6 mm laser diode housing, a very good thermal coupling to the heatsink is of importance and also needs optimisation.

The conducted tests have shown that the thermovision camera has a potential in characterizing microelectronic devices like semiconductor laser diodes and can be considered as a complementary tool in establishing thermal characteristics of these devices.

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