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Experimental Parametric Investigation of Temperature Effects on 60W-QCW Diode Laser

E. Farsad, S. P. Abbasi, A. Goodarzi, M. S. Zabihi

***Abstract*—**Nowadays, quasi-continuous wave diode lasers are used in a widespread variety of applications. Temperature effects in these lasers can strongly influence their performance. In this paper, the effects of temperature have been experimentally investigated on different features of a 60W-QCW diode laser. The obtained results indicate that the conversion efficiency and operation voltage of diode laser decrease with the augmentation of the working temperature associated with a redshift in the laser peak wavelength. Experimental results show the emission peak wavelength of laser shifts 0.26 nm and the conversion efficiency decreases 1.76 % with the increase of temperature from 40 to 50 ˚C. Present study also shows the slope efficiency decreases gradually at low temperatures and rapidly at higher temperatures. Regarding the close dependence of the mentioned parameters to the operating temperature, it is of great importance to carefully control the working temperature of diode laser, particularly for medical applications.

***Keywords*—**diode laser, experimentally, temperature, wavelength

I. Introduction

QUASI-Continuous Wave diode laser bars and diode laser packages have recently found wide application in medical, industrial markets and aerospace applications [1-3]. However, the high optical efficiency, long life time and a small footprint that can now be achieved by these diodes have opened up a diverse range of applications. In the medical market, QCW diode laser products are used in cosmetic systems such as laser hair removal systems. Their applications in industrial markets include photovoltaic solar cells manufacturing, polymer welding, heat treatment and laser soldering. Also, in the aerospace applications high-power laser diode packages are used for a variety of space-based laser programs as the energy sources for pumping of solid-state lasers. Specifically, 1064 nm Nd:YAG lasers require diode laser arrays emitting at a wavelength of 808 nm operating at quasi-cw peak powers [4].

For many applications of high power diode lasers (HPLDS), stable output optical power alone is not sufficient to ensure reliable operation over time. Diode-pumped solid state lasers and other applications involving the absorption of laser diode light in media with narrow spectral features demand spectral stability of QCW diode lasers as well [5]. In such cases shifts in operating wavelength in the order of 1 nm can be catastrophic to system operation [6]. Factors which can affect wavelength stability include heatsink, solder bonds, facet coatings, electrical contacts and conversion efficiency in the semiconductor. All of these factors tend to change that increases the temperature at the diode junction, causing the emission wavelength to increase for driving current. Regarding the indispensible role of the diode lasers in different applications, it is necessary that they have been well understood and their performance quantified. Reliability and performance data for these components, particularly when operated in a satellite environment, is very limited [7, 8]. On the other hand, the operating temperature of the laser plays very important role in influencing the output characteristics of the diode lasers [9]. Therefore, in planning future laser missions, it is important to get a better understanding of these components and the effect of various environmental and operational conditions.

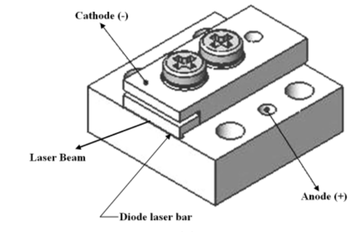
A number of investigations have been reported on the temperature dependent characteristics of low power diode lasers [10-11]. However, as far as our knowledge, no comprehensive study is reported up to now on temperature effects in QCW HPLDs. In this study, the effects of temperature on the electrical-optical characterizations of 60W-QCW diode laser at common package (CS package) have been experimentally investigated and the results of this systematic study have been discussed in this paper.

E. Farsad is with the Iranian National Center for Laser Science and Technology, Tehran, Iran (phone: 0098-262-4453665; fax: 0098-262-4453699; e-mail: ehsanfarsad@yahoo.com).

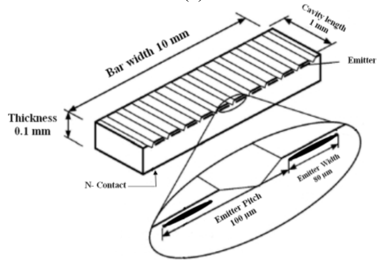
II. Model Structure

A. Diode Laser Package

The diode laser in a CS package investigated in this study is a commercial laser array with part number CsAa06Q0060 manufactured by INLC Co. as shown in Fig.1 (a). This laser contains a GaAs diode bar under quasi continues wave conditions. The laser bar integrates a linear array of single chips



(a)



(b)

Fig. 1 Schematic of (a) the laser package, (b) the laser bar with dimensions (p-contact up) as laser emitters. The laser bar has an emitter width of 80 µm and an emitter pitch of 100 µm, resulting in 100 emitters on a bar with a typical 10 mm total width. The total dimensions of diode laser bar are shown in Fig. 1(b).

B. Water Cooled Heatsink System

The schematic of the water cooled heatsink system is shown in Fig.2 (a). It consists of heat spreader, electrical isolator, heatsink and fluid media. The laser package is mounted on a polished copper heat spreader which provides the anode contact to the diode laser. The waste heat created in the emitters of the laser bar is transported through the heat spreader, electrical isolator and heatsink, respectively. The fluid media consists of six circular channels inside the heatsink. Therefore the waste heat is carried from the heatsink to fluid media (Fig.2 (b)) by the conjugate conduction and convection heat transfer. Finally the waste heat exits the heatsink by increasing the temperature of the water.

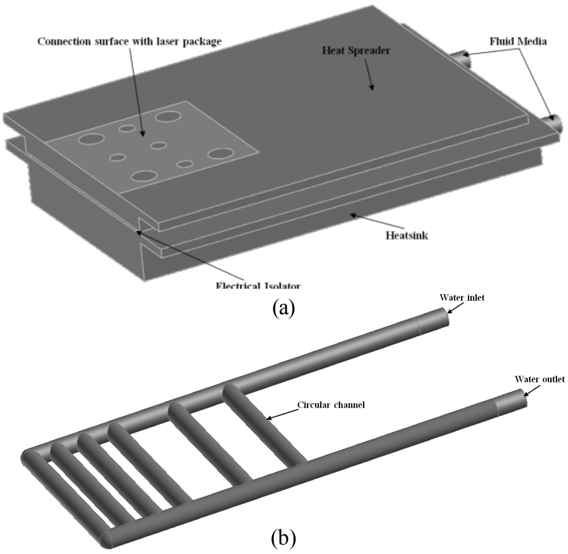


Fig. 2 Schematic of a water cooled heatsink system (a) and the fluid media inside the heatsink (b)

III. Experimental Setup

Experimental setup for temperature investigation on the mentioned diode laser is presented in Fig. 3. A diode laser array (DLA) is tightened on the top of heat spreader with four screws. The common thermal grease was used as the thermal interface material between the backside of the diode laser package and the top surface of the heat spreader to minimize contact thermal resistance. The diode laser was driven under pulse regime (200µs, 150Hz) by a current driver. The laser bar radiation was collected via the integrated sphere detector and transferred to an optical power meter and a spectrometer by optical fibers. The measurement process was controlled by PC using specially software. The software calculates all of the optical and electrical characteristics of laser as output power, threshold current, operating voltage, intensity of lasing spectra, peak wavelength and other specifications.

Since the laser bar temperature cannot be measured directly due to smallness of the quantum well, the temperature of laser bar

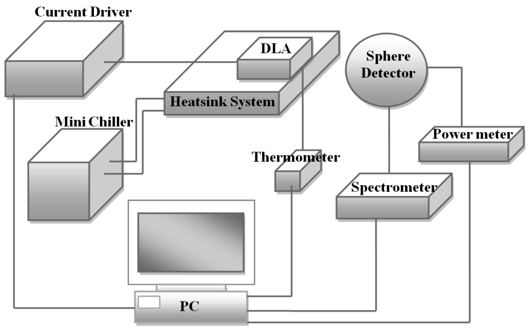


Fig. 3 Schematic of an experimental setup used for temperature investigation of diode laser

and laser package are assumed equal in this study. The package temperature was measured using a K-type thermocouple placed in the edge of the junction between diode laser and heat spreader. A digital thermometer was used to display the temperature readouts from the thermocouple. The calibrated thermocouple has an uncertainty of ± 0.1 C. The package temperature was controlled by a water cooling system. It contained of two parts: the water cooled heatsink and a minichiller. The mini chiller supplied the water flow for heatsink system between 10 to 50 ˚C depending on the test condition.

IV. Results and Discussions

Minimum measured values of the optical and electrical characteristics of diode laser are illustrated in table1 at 20 ˚C heatsink temperature. The output optical power of laser is presented first.

TABLE I
MINIMUM VALUE OF THE OPTICAL AND ELECTRICAL CHARACTERISTICS OF DIODE LASER

Characteristic	Value
Output optical power	≥ 60 w
Threshold current	≥ 11 A
Operating current	≥ 75 A
Operating voltage	1.68 V
Conversion efficiency	47 %
Peak Wavelength	808 nm
FWHM	≥ 2.8 nm
Pulse width	200 µs
Pulse repeat rate	150 Hz
Heatsink temperature	20 ˚C

A. Optical Power

The optical power of diode laser is measured as a function of the driving current (I) and the corresponding curve, referred as the power-current (P-I) curve, is found to be strongly temperature dependent. Fig.4 shows the P-I curves of laser at 80 A driving current and different heatsink temperature 10, 20, 30, 40, 50 ˚C.

Variation of the output power with the package temperature is been shown in Fig.5 at 80A driving current. This figure shows there is a gradual and nonlinear decrease in output power with increasing the temperature. The output power decreases 3.8% with increasing the temperature from 20 to 40 ˚C. Decrease in output power is evident due to nonradiative recombination. The output power depends on the photon density in the active cavity of the laser, which decreases due to enhancement of losses due to nonradioactive recombination with increasing temperature [12].

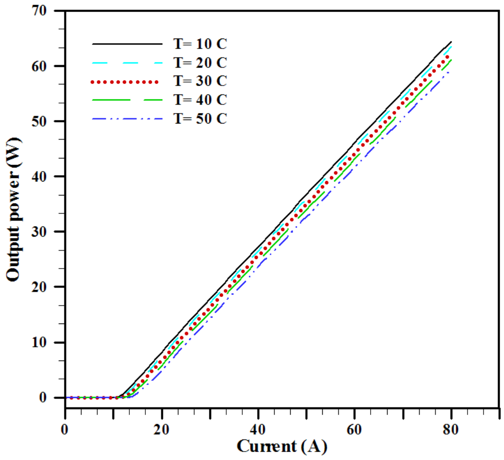


Fig. 4 Power-current (P-I) curves of diode laser as a function driving current at different temperature

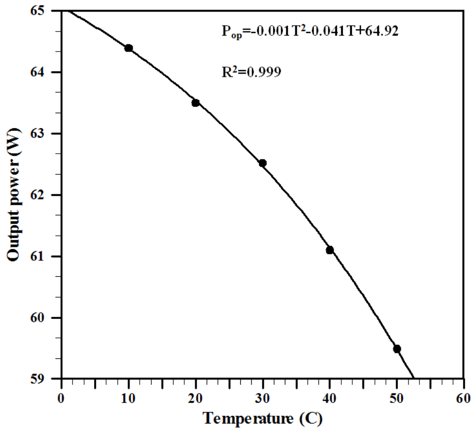


Fig. 5 Effects of temperature on the output power of the diode laser

B. Threshold current

Threshold current (Ith) is an important device parameter and its minimization is desirable. The temperature dependence of this parameter can be described by [13]:

$$I_{th}(T_2) = I_{th}(T_1)\exp(\frac{T_2 - T_1}{T_0}) \quad (1)$$

Here, the threshold current is measured at different package temperatures, T_1 and T_2 and T_0 is the temperature constant of the threshold current. Generally, it is very difficult to get value for T_0 [13]. However, a typical value for T_0 is approximately 155 K for wavelength 808 nm at diode lasers based on GaAs [14].

Fig. 6 shows the effect of temperature difference on the threshold current ratio ($I_{th}(T_2)/I_{th}(T_1)$). It's clear from our measurement and also theoretical (1) that the threshold current ratio increases exponentially with the increase of temperature difference. The threshold current ratio obtained from the present work and theoretically results was found to overlap according to Fig.6. The threshold current ratio increases 1.14 with 30 ˚C temperature difference at experimentally results. With increasing the temperature, quasi-fermi functions for electrons and holes smear out more. As a result, it requires a higher injection carrier density to fulfill condition for lasing, which demands greater

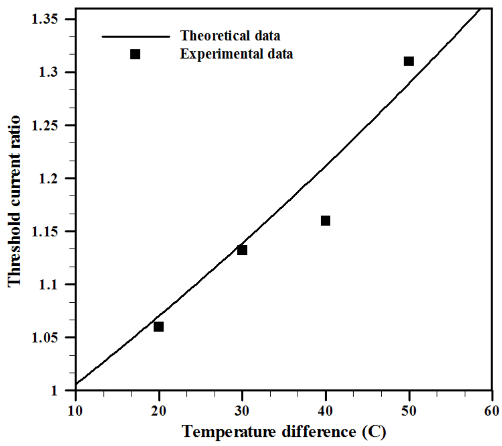


Fig. 6 Effects of temperature difference on the threshold current ratio (($I_{th}(T_2)/I_{th}(T_1)$))

value of threshold current to achieve the gain within the active cavity. At threshold, the gain and losses within the cavity demands to be balance out.

C. Threshold voltage

Threshold voltage is one of the important physical parameters, which decides the minimum required externally applied voltage to have the lasing from the device. The current-voltage (I-V) curve of the diode laser under consideration, obtained for different temperatures, is shown in Fig.7.

In this study, we have used the linear line fit method to calculate the laser threshold voltage. This method simply draws a tangent line along the lasing portion of the I-V curve (rising part) and extends until it intersects the horizontal (voltage) axis. The intercept point is defined as the threshold voltage that it is the turn on voltage for the diode lasing [15].

Fig. 8 demonstrates the effects of temperature on the threshold voltage of the diode laser. One can clearly see in this figure that the threshold voltage increases with the enhancement of temperature. For instance, the threshold voltage increases 1.1% with the increase of temperature from

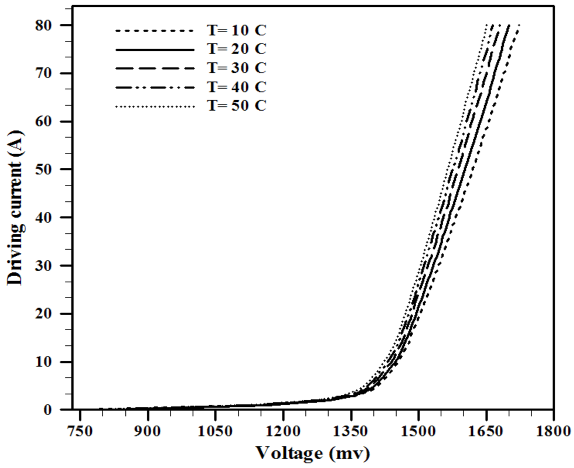


Fig. 7 I-V curve of the diode laser obtained for different temperatures

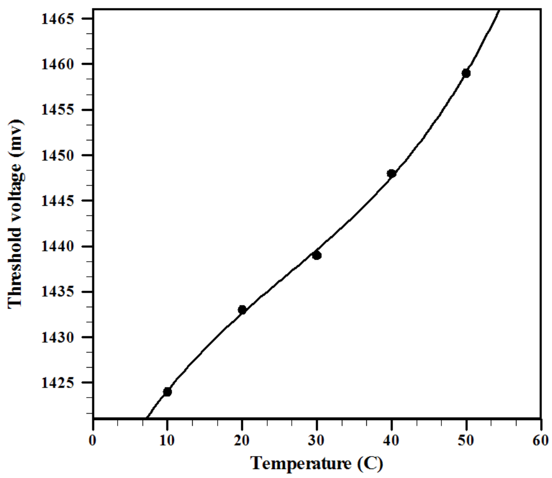


Fig. 8 Effects of temperature on the threshold voltage of diode laser

10 to 30 ˚C. The augmentation of temperature causes electrons and holes distributions are spread out into higher energies.

Consequently, greater fraction of the injected charge crosses over the active region thereby increasing value of the leakage current. Therefore, greater value of threshold voltage is needed to satisfy the oscillation condition and to achieve the sufficient gain within the cavity [12].

D.Series Resistance

The series resistance is one of the important electrical parameter in diode lasers that it can be described by [13]:

$$R_s = \frac{dV}{dI} \tag{2}$$

The effect of temperature on the series resistance of diode laser is shown in Fig.9. It is clear in this figure that the series resistance decreases nonlinearity with increasing temperature. According to the Fig.10, the gradient of the V-I curve decreases with the augmentation of temperature, so the series resistance decreases. For example the series resistance decreases 4.2% with the increase of temperature from 20 to 30 ˚C.

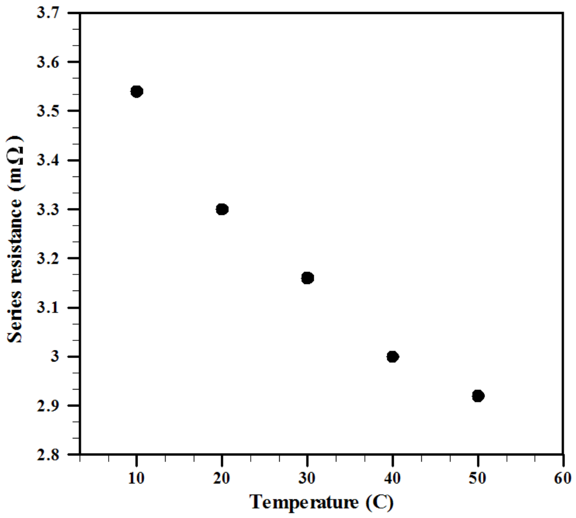


Fig. 9 Effects of temperature on the series resistance of diode laser

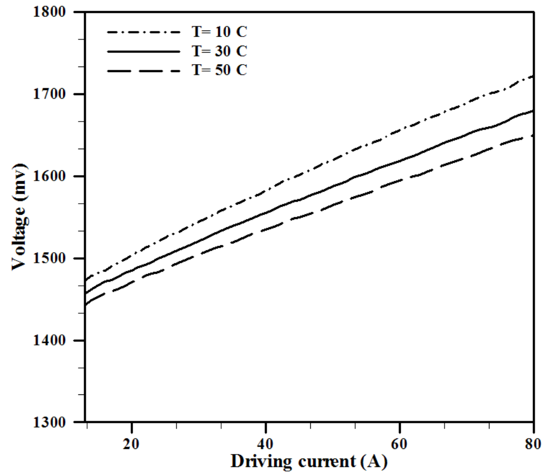


Fig. 10 The V-I curves obtained at 3 different temperatures (10, 30 and 50˚C)

E. Slope Efficiency

The slope efficiency or differential quantum efficiency of diode laser is defined as [13]:

$$\eta_d(\Delta T, \alpha_m) = \frac{\eta_i(\Delta T)\alpha_m}{\alpha_i(\Delta T) + \alpha_m} \tag{3}$$

Where η_i (ΔT) is the internal quantum efficiency, $\alpha_i(\Delta T)$ is the internal loss and α_m is loss coefficient that is function of reflectance of the front facet and the length of the cavity.

Fig. 11 shows the effects of temperature on the slope efficiency of the diode laser. It can be inferred from the variation trend of this parameter that it decreases gradually at low temperatures and rapidly at high temperatures. This behavior would be attributed to the enhancement of nonradiative recombination at the higher temperature and carrier overflow across heterointerface, which causes further free carrier loss within the cavity. This increase in free carrier loss enhances value of internal losses within the cavity and according (3), reduces the value of differential quantum efficiency. Briefly, a greater fraction of leakage charge at

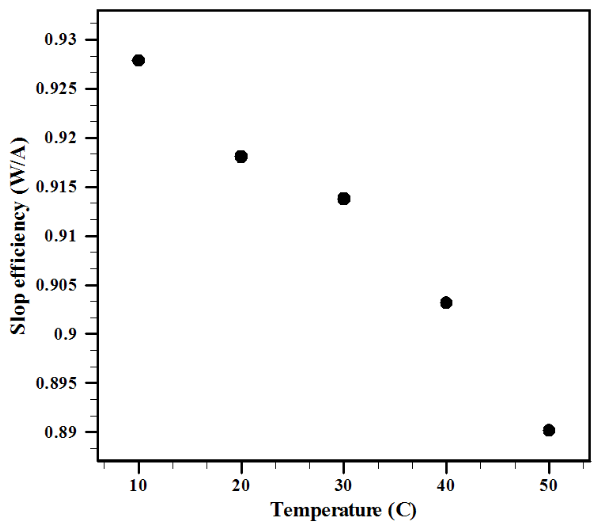


Fig. 11 Effects of temperature on the slope efficiency of diode laser

higher temperature reduces more the slope efficiency. For instance, according to Fig.11 when the temperature increases from 10 to 20 ˚C, the slope efficiency decreases 1%, while at 40 to 50 ˚C temperature increase, it decreases 1.4% in value.

F. Conversion Efficiency

An important parameter of diode lasers is the conversion efficiency (η_c), which is defined as the ratio of output optical power (P_{opt}) to input electrical power ($V_{op} \times I_{op}$) [13]:

$$\eta_c = \frac{P_{opt}}{V_{op} \times I_{op}} \tag{4}$$

The effects of temperature on conversion efficiency of diode laser are shown in Fig.12. According to this figure, the conversion efficiency decreases with increasing the temperature. One can justify this behavior by referring to (4). From this equation, the augmentation of temperature, which leads to the decrease in optical output power of diode laser, consequently result in the reduction of conversion efficiency. For instance, the conversion efficiency decreases 1.8 % with the increase of temperature from 40 to 50 ˚C.

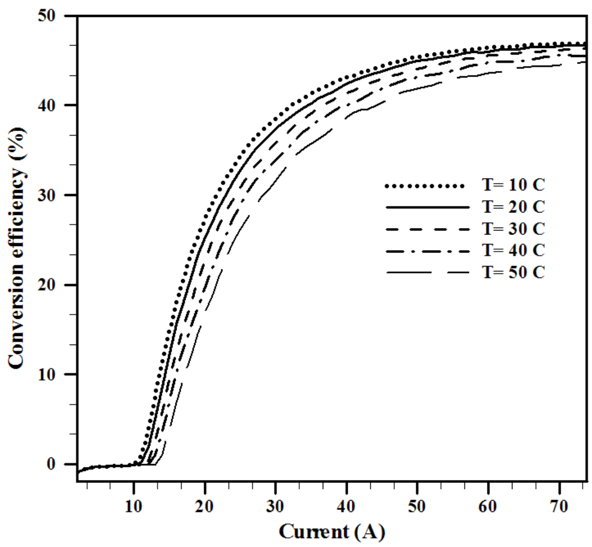


Fig. 12 Effects of temperature on the conversion efficiency

G. Spectral Characteristics

The spectral characteristics of diode lasers are the most important parameter for diode- pumped solid state lasers. In many applications, variations at spectral characteristics like peak wavelength can be catastrophic to system operation. The effects of temperature on the typical emission spectra of diode laser are presented in fig.13. This figure shows the intensity of lasing spectra reduces with temperature increasing. For instance, the intensity of lasing spectra decreases about 10% by the temperature increase from 20 to 30 ˚C. The augmentation of temperature causes the increasing internal and external loss at active region associated with the increase in carrier leakage and nonradiative recombination at defects in the active layer. This phenomenon consequently results in the reduction of the intensity in lasing spectra [16].

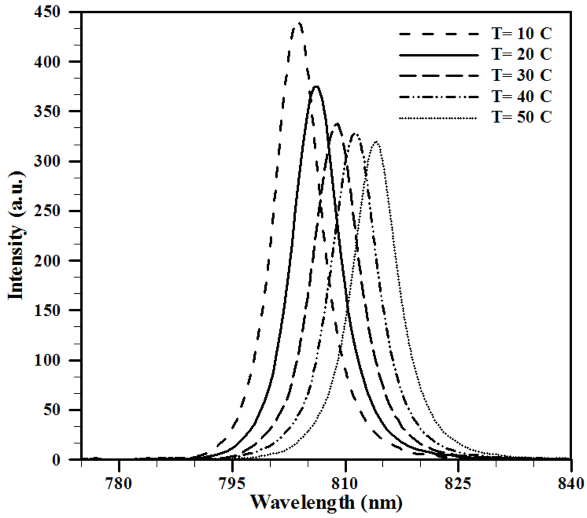


Fig. 13 Temperature dependent lasing spectra of an 808 nm diode laser

Fig.14 shows the temperature effects on the peak wavelength of laser. The peak wavelength shifts with the increase of temperature. By increasing the temperature from 10 to 50 ˚C the peak wavelength of the lasing spectrum increases from 803.6 nm up to 814 nm. This corresponds to a wavelength shift of about 0.26 nm/˚C.

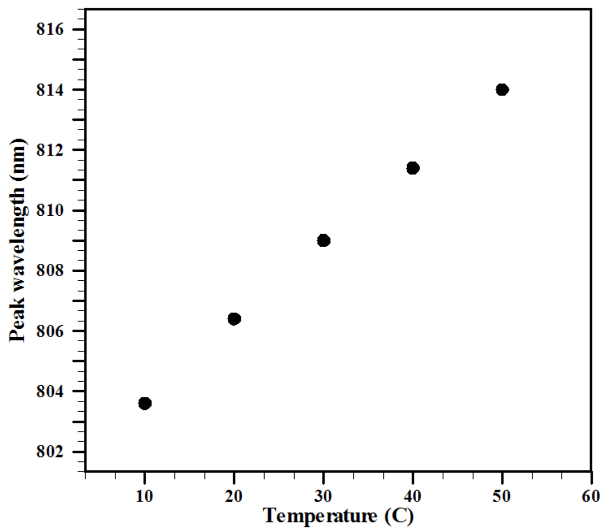


Fig. 14 Effects of temperature on the peak wavelength of diode laser

V. CONCLUSION

This paper presented the temperature effects on the electrical and optical characteristics of 60W-QCW diode laser in a CS package.

A detailed description of the temperature effects on the diode laser characteristics, i.e, output optical power, threshold current and voltage, slope efficiency, conversion efficiency, emission spectra and peak wavelength was obtained. The obtained results can be briefly summarized as follows:

1- There is a gradual and nonlinear decrease in output optical power with the increase of temperature. The output power decreases 3.8% with the increase of temperature from 20 to 40˚C.

2- The threshold voltage increases with the increase of temperature. The augmentation of temperature causes electrons and holes distributions are spread out into higher energies. Consequently, greater fraction of the injected charge crosses over the active region thereby increasing value of the leakage current. Therefore, greater value of threshold voltage is needed to satisfy the oscillation condition and to achieve the sufficient gain within the cavity.
3- The slope efficiency decreases gradually at low temperatures and rapidly at higher temperatures. When the temperature increases from 10 to 20 ˚C, the slope efficiency decreases 1%, while when the temperature increases from 40 to 50 ˚C, the slope efficiency decreases 1.4%.
4- The intensity of lasing spectra reduces when the temperature increase. For instance, it decreases about 10% by the temperature increase from 20 to 30˚C.
5- The peak wavelength shifts with the increase of temperature. The experimental results correspond to a wavelength shift of about 0.26 nm/˚C.

Regarding the obtained results, which reveal the close dependence of the diode laser features to the operating temperature, one can come into this conclusion that it is of great importance to carefully control the working temperature of diode lasers, particularly for medical applications.

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