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Restoration of the output light power of laser diode

Poprawa mocy światła wyjściowego diody laserowej

***Abstract**. The sensitivity of semiconductor laser diodes to changes in the surrounding temperature has earned them a bad reputation. A laser diode's output light power rapidly deteriorates when its threshold current rises in response to an increase in case temperature. As a result, the diode's temperature needs to be stabilized. In this regard, a number of strategies could be used; however, for the task in question, an active cooling strategy utilizing temperature compensation technique was employed. Details design of the circuit is presented for maintenance of temperature of the diode. Experimental results before and after the circuit implementation are presented. A significant improvement in output light power was achieved. This article presents the results of a notable enhancement in the output light power stability as a result of temperature stabilization.*

***Streszczenie.** Wrażliwość półprzewodnikowych diod laserowych na zmiany temperatury otoczenia przysporzyła im złej reputacji. Moc światła wyjściowego diody laserowej gwałtownie się pogarsza, gdy jej prąd progowy wzrasta w odpowiedzi na wzrost temperatury obudowy. W rezultacie temperatura diody musi zostać ustabilizowana. W tym względzie można zastosować szereg strategii; jednak w przypadku omawianego zadania zastosowano strategię aktywnego chłodzenia wykorzystującą technikę kompensacji temperatury. Przedstawiono szczegółowy projekt obwodu w celu utrzymania temperatury diody. Przedstawiono wyniki eksperymentów przed i po wdrożeniu obwodu. Osiągnięto znaczną poprawę mocy światła wyjściowego. W tym artykule przedstawiono wyniki znacznego zwiększenia stabilności mocy światła wyjściowego w wyniku stabilizacji temperatury.*

Keywords: Electronics, Laser Power, Temperature stability, laser diode
Słowa kluczowe: Elektronika, moc lasera, stabilność temperaturowa.

Introduction

Due to extended operation or ambient temperature variations, semiconductor Laser Diodes (LDs) are well known for extreme sensibility for case temperature changes. They have a decrease in power output as a result of their operating point continuously shifting as a temperature rises, that is, their operating point moving farther from its initial position. Temperature-compensated bias systems, which can monitor variations in the surrounding air temperature and so increase the LD's safety, are considered to be the solution to these issues.

Many strategies have been used to maintain the diode's stable operation so that it can operate in continuous wave mode. A conventional approach of accomplishing the goal is to affix the laser diode using a heat sink. The requirement results from the way LDs behave; as temperature rises, output power rapidly decreases, making it challenging to operate the device within the parameters that were intended. The authors Beni et al. [1] reported success in creating a heat sing with microchannels, namely sinusoidal type channels, resulting in a rise in laser diode stability and lifespan. By adding mathematical terms to Pspice simulation software, Borràs et al. [2] created a model. Lastly, a contrast between the actual diode and the model device has been examined. When dealing with a high power diode-pumped Tm: YLF, Duan et al. [3] encountered and researched the similar temperature issue of dependency and stability and were able to achieve a 36.8% optical-to-optical efficiency. A diode laser's self-referenced stabilization was documented by Hakobyan et al. [4]. Nonetheless, the work involved a 2.1W high power laser. Similar to this, Sobczak et al. [5] demonstrated power stabilization in high power lasers to accomplish stability in the lateral modes. This characteristic has been applied to raise the beam quality's stability. By regulating low and high frequency sounds, Ynag et al. [6] attempted to achieve power stability of a laser diode output power; unfortunately, the stability was only temporary. By employing double Q switching, Zhao et al. [7] were able to obtain increased stability and, as a result, mode-locked output. With a good repetition rate, the tested laser diode may reach a peak output of up to 20W. An electrical circuit based on the feedback concept was reported by Zivojinovic et al. [8]. Li et al [16] developed a Pirani gauge using glass material and achieved temperature compensation for it using MEMS to report good precision and reliability. Xu et al [17] also suggested a temperature compensated Pirani gauge which has high sensitivity and temperature stability. However, temperature compensation was based upon CMOS technology. Kristiani et al [14] developed a method for temperature compensation on the lathe head. This helped them to reduce tolerance levels of the product under manufacture. Tang et al [15], worked to develop a high precision temperature compensation circuit for LD, so that they could achieve an accuracy of 3mK at room temperature. The CMOS technology was used to construct the circuit. This circuit produced optimistic outcomes for the hetero-structure laser's average output power for steady, continuous operation. The bias voltage supplied to the LD must adjust as a means of making up for temperature variations to sustain a constant providing optical power for a specified input current level. To investigate the similarities and differences between laser diodes and normal light emitting diodes, Trivellin et al. [9] conducted an examination of a laser diode's structure. Additionally, a comparison of different laser operating modes has been provided. In their study and discussion of laser diode chaos, Sciamanna et al. [10] offered a number of strategies and their benefits for using chaos in a variety of contexts. Variations in the LD's temperature have the potential to permanently harm the device, overheat it, and result in an optical power amplitude that is less than ideal. The LD may sustain irreversible harm should the applied voltage rise over the operational value (due to drop in temperature). Furthermore, an temperature elevation will lead to a modification of the operational point, which will reduce the production of optical power. There are three typical approaches to solving this issue:

1. Continuous current flow.

2. Preserving a steady temperature in the LD is the second goal.
3. Use a power supply that adjusts for temperature to bias the LD.

Nishida et al. [11] recommended constant current power supply circuit, which is shown in the reference. The avalanche photodiode in this circuit is biased by a current stabilizer, while a capacitor Cs serves as the charge bank. The same configuration, though, can be applied to achieve output light power stability due to temperature. This might necessitate carefully reworking the circuit to meet the requirements of the laser diode under consideration. By employing a second diode to generate a reference voltage signal, it is possible to ensure that the LD's voltage follows any alterations in warmth. This is a further technique for achieving temperature compensation. Gardner [12] has provided the schematic layout for a similar circuit, but for a photodiode. In this approach, a Zener diode was put on the same heatsink and utilized as a reference diode. On the other hand, bias control has been achieved by the use of a differential amplifier.

The above-mentioned second method may result in condensation on the LD window, which would reduce power supply and necessitate more regular window cleaning. Using temperature sensing components in a circuit design is the third way to stabilize an LD, as seen in figure 1.

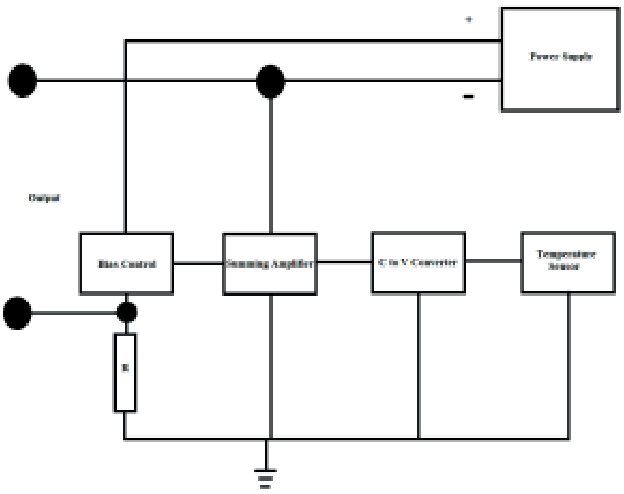

Fig. 1. Temperature maintenance flow plan.

Parts for temperature sensing typically generate an indicator of current that fluctuates in response to temperature changes. The operational amplifier which is configured as I to V converter can possibly be used to convert this output current to a voltage. After that, the output of this sub circuit is connected in a non-inverting configuration to a summing amplifier, which will sum the voltage using a reference voltage of 4 and the adverse amount derived from a traditional power source with high voltage. The bias control transistor's base current is managed by the resulting output.

Design insights

This research used a Toshiba LD, whose data sheet indicates that its temperature coefficient is 1×10–3%/°C. Finding the voltage variation (Volts/°C) for this temperature coefficient requires noting that [12]:

(1) $$\frac{\beta}{V_B} = \mathbf{1 \times 10^{-3}}/\mathbf{100}$$

where *VB β* is its temperature coefficient in volts per degree Celsius. Since V_B in this instance has a value of 3 Volts, therefore Eq (1) results in [13].

(2) $$\beta = 30\,\mu V/℃$$

Figure (2) shows the circuit for an LD's temperature--compensated bias supply. Below is a detailed design and evaluation of the circuit to help understand how it works.

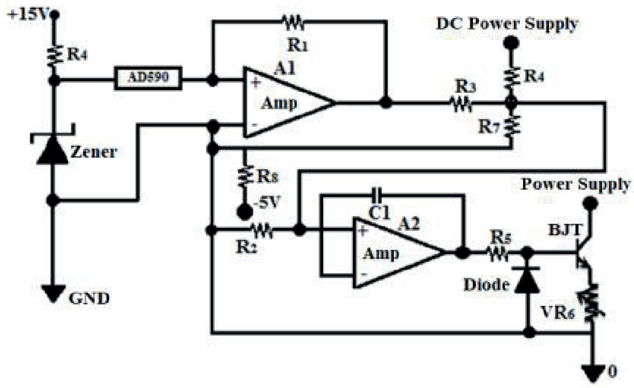

Fig. 2. Schematic for customized power supply for LD.

Steady reference voltage

Using the precision reference diode package LM329, a consistent -6.8 volts as the voltage reference was attained. With the temperature coefficient of 1⭡A/°K, the temperature sensor 1C AD590 was then given this constant reference voltage.

Voltage converter from current

Considering the setup where the operational amplifier A1 and the temperature sensor IC1 are combined. For a temperature increase of T degrees Kelvin, 1C1 will produce a total current of T×10–6A. Therefore, in order for the temperature sensor must provide current I in order to raise the temperature by T°K.

(3) $$I = T \times 10^{-6}\, A/^{o}K$$

Thus, when the feedback resister R1 is connected, the voltage at the op-amp A1's output is used is as follows:

$$T \times 10^{-6} = {V_1}/{R_1}$$

Consequently, the voltage shift V_l becomes

(4) $$V_1 = R_1 \times T \times 10^{-6} V$$

The summing amplifier

Utilizing a summing amplifier arrangement, the operational amplifier A2 added to produce the output voltage V_o, the three voltages supplied at its inputs. A resistor was mounted to supply this output, Vo, to an NPN transistor Q1 base. The configuration of Q1 transistor was designed to minimize conduction between the collector and emitter, with a reduced voltage signal at its base. A current flowed between Q1's emitter and collector when the transistor was conducting. As a result, there was a modification of the output's bias voltage point and the +bias voltage point floated.

This part of the electronic circuit can be described mathematically as: According to Kirchhoff's law for current at a node, the total algebraic summation of current flowing through a circuit at any one time is null (Figure 3). Consequently, the expression for current at the input of A2 that follows Kirchhoff's current law can be expressed as

$$\frac{V_{ref}}{R_2} + \frac{V_B}{R_4} + \frac{V_1}{R_3} = 0 \tag{5}$$

But if you change the value of V in equation 4 to equation 5, what you get is

$$\frac{V_{ref}}{R_2} + \frac{V_B}{R_4} + \frac{T \times R_1 \times 10^{-6}}{R_3} = 0 \tag{6}$$

When equation (6) is differentiated in relation to T, it produces

$$\frac{dV_B}{dT} = -\frac{R_1 \times R_4 \times 10^{-6}}{R_3} \tag{7}$$

After setting $dV_B/dT = \beta$, equation 7 can be expressed as follows

$$\frac{dV_B}{dT} = -\frac{R_1 \times R_4 \times 10^{-6}}{R_3} \tag{8}$$

This provides the value for the LD's temperature coefficient β. Adding this number to equation 5 yields

$$V_B = -\frac{V_{ref} \times R_4}{R_2} + T \times \beta \tag{9}$$

By concurrently solving equations 5, 8, and 9, the resistor values R_2, R_3, and R_4 can be determined.

Practical realization

The particular LD under consideration's bias voltage was ascertained as 3 volts from the data included with the LD; based on this value, the temperature coefficient that was initially estimated was 30 μV/°K. It is necessary to include this voltage value into the equation 2 using R_1 = 20kΩ to determine the proper values for the several resistors that will be used in the circuit, results in

$$V_B = -\frac{V_{ref} \times R_4}{R_2} + T \times \beta$$

Consequently

$$\frac{R_4}{R_3} = \frac{1.5}{1k} = 1.5 \times 10^{-3} \tag{10}$$

Thus, 666R4=R3 is the result. The LD had to function at 300°K in temperature, which is similar to that of a typical room temperature. This implied that the subsequent parameters had to be fixed already:

T = 300°K

β = –300μV/°K

R1=20kΩ

Equation 9 produced a value for the reversed breakdown voltage after these values were entered.

$$\frac{R_4}{R_3} = \frac{1.5}{1k} = 1.5 \times 10^{-3}$$

Moreover, the LD had to be operated at a biasing voltage of VB = 3 Volts. Consequently,

$$3 + 0.09 = -V_{ref}\frac{R_4}{R_2}$$

but V_{ref} =5Volts, therefore,

$$\frac{R_4}{R_2} = 0.618$$

Given the assumption that R2=10kΩ, equation 10 therefore yields

$$R4=10k(0.618)=6.18k \approx 6k\Omega$$

and

$$R_3 = \frac{6.18k}{1.5\times10^{-3}} = 4.1M$$

The power supply for the LD that adjusts to temperature, operated satisfactorily after key design parameters for R_1, R_2, R_3, and R_4 were incorporated into the circuit. Rather than utilizing a fixed value for R_2, a variable resistor was inserted in order to precisely set the temperature coefficient. After that, adjustments could be made to get the necessary output value for bias voltage. Figure 3 depicts the assembled intended circuit on a printed circuit board with two sides.

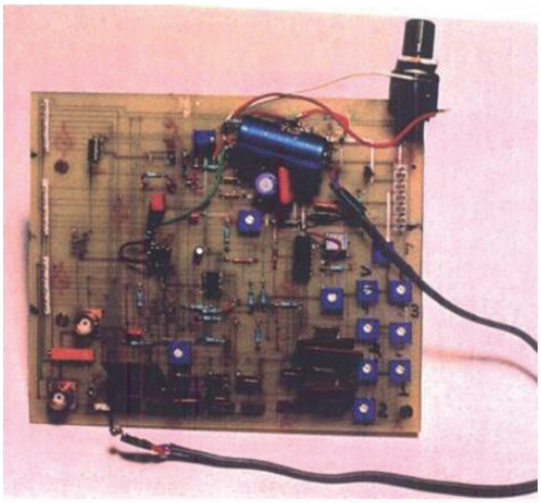

Fig. 3. Circuit assembled for verification and testing.

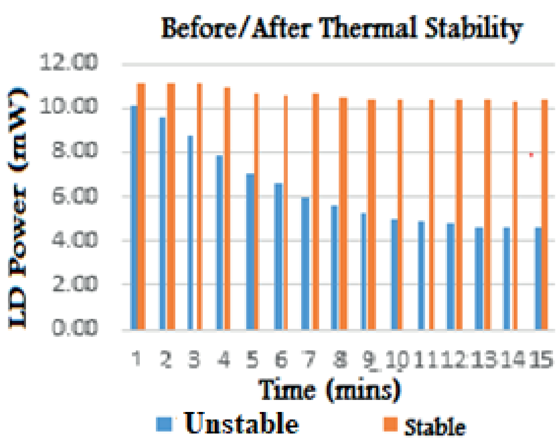

Fig. 4. Thermal stability comparison.

Results and conclusions

On a printed circuit board with two sides, the circuit for LD's temperature adjustment was assembled and implemented in accordance with the component design values determined in the preceding section. As seen in figure 4, observations were made for power output against time for the sake of quantifying variations in the output of optical power. After that, a graph was created using the observations for comparison's sake.

In order to facilitate an easy comparison of the two scenarios, Temperature was not taken into consideration while recording the output power level. Attaching the LD to the temperature correction setup allows for the observation of well--stabilized output optical power.

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REFERENCES

[1] *Baraty Beni, Bahrami, S. A., Salimpour M. R. (2017). Design of novel geometries for microchannel heat sinks used for cooling diode lasers. International Journal of Heat and Mass Transfer, 112, 689–698.*
[2] *Borràs, R., et al., (2019). Laser diodes optical output power model. Measurement, 133, 56–67.*
[3] *Duan, X.M., et al., (2010). Stable output, high power diode-pumped Tm: YLF laser with a volume Bragg grating. Applied Physics B, 99 (3), 465–468.*
[4] *Hakobyan, S., et al., (2017). Full stabilization and characterization of an optical frequency comb from a diode-pumped solid-state laser with GHz repetition rate. Optics Express, 25 (17), 20437–20453.*
[5] *Sobczak, G., et al., (2014). Improvement to the Lateral Mode Stability in High-Power Laser Diodes by Multistripe-Gain Distribution. IEEE Journal of Quantum Electronics, 50 (11), 890–897.*
[6] *Yang, J.-r., et al., (2006). High stable power control of a laser diode. Optoelectronics Letters, 2 (1), 21–23.*
[7] *Zhao, J., et al., (2012). Enhancement of stability and peak power in a diode-pumped doubly QML YVO4/Nd: YVO4 laser with EO and Cr4+: YAG saturable absorber. Optical Materials, 34 (4), 622–626.*
[8] *Zivojinovic, P., Lescure M., Tap-Beteille H. (2004). Design and stability analysis of a CMOS feedback laser driver. IEEE Transactions on Instrumentation and Measurement, 53 (1), 102–108.*
[9] *Trivellin, N., et al., (2017). Laser-Based Lighting: Experimental Analysis and Perspectives. Materials (Basel, Switzerland), 10 (10), 1166.*
[10] *Sciamanna, M., Shore K.A. (2015). Physics and applications of laser diode chaos. Nature Photonics, 9 (3), 151–162.*
[11] *Nishida, K., Nakajima M. (1972). Temperature Dependence and Stabilization of Avalanche Photodiodes. Review of Scientific Instruments, 43 (9), 1345–1350.*
[12] *Gardner, J.W. (1994). Microsensors: principles and applications. Wiley & Son publishers, USA.*
[13] *McIntyre, R. J., Webb P. P., (1984). Silicon avalanche photodiode with low keff. Google Patents.*
[14] *Kristiani, Endah, Wang, Lu-Yan, Liu, Jung-Chun, Huang, Cheng-Kai, Wei, Shih-Jie, Yang, Chao-Tung, (2024), An Intelligent Thermal Compensation System Using Edge Computing for Machine Tools, Sensors, vol. 24, Issue 8, 1–20.*
[15] *Tang, Yu-long, He, Yu-ling, Meng, Yan-song, Wang, Wei-wei, Zhang, Rong-yan, Du, Er-wang, Du, Li-jun, (2021), Temperature control circuit design of high-precision laser diode based on type III compensation network, Journal of Physics: Conference Series, vol. 1827, issue 1, 012003.*
[16] *Li, Ke Wang, Yongjie Li, Gaochao Xu, Zhen Liu, Yuanyuan Shi, Ancun Yu, Xiaoyan and Li, Fang, (2025), Optical Fiber Pressure Sensor with Self-Temperature Compensation Structure Based on MEMS for High Temperature and High Pressure, Photonics, vol 12 Issue 3, P 258.*
[17] *Xu, Shizhen Yang, Gai Chen, Junfu Jiao, Rui Wang, Ruoqin Yu, Hongyu Xie, Huikai Wang, Xiaoyi., (2025), Theoretical and experimental investigations of the CMOS compatible Pirani gauges with a temperature compensation model, Microsystems & Nanoengineering, vol. 11, issue 1, P21.*