مجلة الدراسات التربوية والعلمية - كلية التربية - الجامعة العراقية
العدد السابع والعشرون - المجلد الحادي عشر - علوم الفيزياء - آيار 2026 م
doi.org/10.52866/esj.2026.11.27.14

Operating characteristics of the dpss green laser at low temperatures

Rahma Shamil Sultan , Musab Saleh Mohammed
Department of physics, College of Education for pure science ,
University of Mosul, Mosul, Iraq

Abstract :

This study aimed to determine the effect of low temperatures, ranging from 0°C to -16°C, on the characteristics and performance of a 532 nm green DPSS laser. The results showed a decrease in threshold current with decreasing temperature, consistent with the laser's typical behavior. Temperature is the most important factor in determining the performance and stability of the green DPSS laser. The results showed that increasing temperatures leads to a significant deterioration in optical power, impaired stability, and a decrease in optical conversion efficiency. Conversely, operating the laser at low and stable temperatures showed a significant improvement in energy stability and an increase in optical conversion efficiency, reflecting improved laser output quality. These results indicate that the adoption of precise thermal control systems and operation within low and stable temperature ranges is essential to ensure the reliable operation and high performance of DPSS laser systems, especially in scientific and industrial applications that require spectral stability and high operational efficiency.

Keywords : DPSS green laser , low temperatures ,Frequency output breakdown.

الخصائص التشغيلية لليزر الأخضر من نوع DPSS في درجات الحرارة المنخفضة

رحمة شامل سلطان ، مصعب صالح محمد
جامعة الموصل/كلية التربية للعلوم الصرفة-قسم الفيزياء
E-mail1 :rahma.es1235@student.uomosul.iq
E-mail2 : wesamusab_67@uomosul.edu.iq

مستخلص:

تهدف هذه الدراسة إلى تحديد تأثير درجات الحرارة المنخفضة التي تتراوح من C° (0 – 16) على خصائص وأداء ليزر الحالة الصلبة المضخّم ضوئياً (DPSS) الأخضر بطول موجي nm532. أظهرت النتائج انخفاضاً في تيار العتبة مع انخفاض درجة الحرارة وهو يتوافق مع السلوك النموذجي لليزر. تُعدّ درجة الحرارة العامل الأهم في تحديد أداء واستقرار ليزر الحالة الصلبة المضخّم ضوئياً الأخضر. أظهرت النتائج أن ارتفاع درجات الحرارة يؤدي إلى تدهور في القدرة الضوئية، وضعف في الاستقرار، وانخفاض في كفاءة التحويل الضوئي. في المقابل أظهر تشغيل الليزر عند درجات حرارة منخفضة ومستقرة تحسناً ملحوظاً في استقرار الطاقة وزيادة في كفاءة التحويل الضوئي مما يعكس تحسناً في جودة خرج الليزر. تشير هذه النتائج إلى اعتماد أنظمة تحكم حراري دقيقة والتشغيل ضمن نطاقات درجات حرارة منخفضة ومستقرة أمراً مهم لضمان التشغيل الموثوق والأداء العالي لأنظمة ليزر الحالة الصلبة المضخّم ضوئياً كما في التطبيقات العلمية والصناعية التي تتطلب استقراراً طيفياً وكفاءة تشغيلية عالية.

Introduction

Semiconductor lasers have rapidly and drastically evolved into a variety of shapes and patterns since 1962, reaching highly advanced phases in the development of laser manufacturing [1]. These days, low dimension materials like quantum wells or quantum dots are used as the active region in laser diodes. The threshold current in these lasers is greatly decreased because of the nanoscale size of these materials [2]. created an intracavity frequency-doubled acousto-optic Q-switched Nd: YAG laser in 2019 that used two identical diode-pumped gain modules with fivefold pumping symmetry in a straightforward two-mirror linear cavity arrangement to produce an average green power of 260 W [3]. Individual green-pulse duration was found to be 73 ns at maximum output power, with a beam quality of M2 = 35 and a pulse repetition rate of 18 kHz. Over the course of five hours of continuous operation, the laser's average green power fluctuated by ±0.83 W, indicating its remarkable stability. The pulse-to-pulse amplitude variations and pulse delay time jitter were found to be within ±5% and ±4.25 ns, respectively.

The 532 nm high-power laser's beam quality was subpar in earlier investigations. In order to produce a 532 nm laser with high-power laser's beam quality was subpar in earlier investigations. In order to produce a 532 nm laser with high power and good beam quality, an acceptable resonator was created while taking the crystal's thermal effect into account [4]. Due to its high pump absorption coefficient, which makes it possible to produce effective lasers with short cavities, a Nd: YVO_4 crystal has a number of advantages over a Nd: YAG crystal [5 ,6]. The relationship between threshold current and temperature was calculated using the relationship, $I=I_{th} \exp (T / To)$.The structure of a microchip laser is depicted in Figure 1, which primarily consists of a pump diode laser operating at 808 nm and two crystals bound together: potassium titanyl phosphate (KTP), a frequency-doubling crystal, and the laser gain crystal (Nd: YVO_4). Some traces of 1064 nm remain with green output light, even though the crystals are coated so that only light at 532 nm (green) may leave the cavity while the fundamental lasing wavelength at 1064 nm (NIR) can resonate in the cavity. As a result, we have used optical bandpass filters in our test methods to take advantage of this benefit. The use of microchip Nd: YVO_4 lasers in many equipment is made possible by their rigidity and compact structure [7]. It is important to note that the stiff structure of the Nd: YVO_4 laser is used to make the green laser pointers. The operator for spatial hole-burning (SHB) in (inactive materials). However, a number of methods have been devised to achieve such desired behavior because single longitudinal mode (SLM) operation is necessary for a number of applications, including optical length metrology [8].

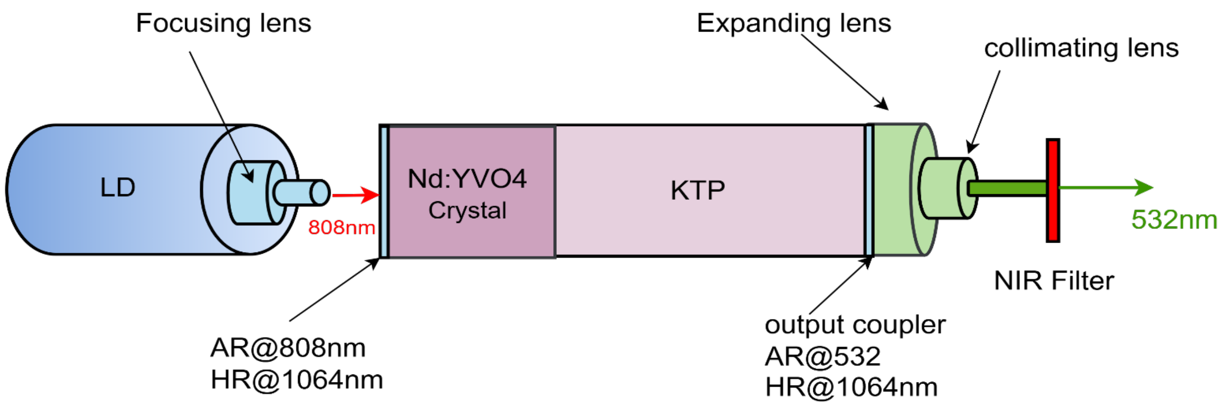


Figure (1) DPSS green laser structure

The potassium titanyl phosphate (KTP) crystal exhibits high frequency doubling efficiency due to its relatively large second-order nonlinearity coefficient, its ability to achieve good phase matching through birefringence, and its suitable spectral transparency. The nonlinear conversion efficiency depends primarily on achieving the phase matching condition ($\Delta K=0$). Any deviation from this condition leads to a significant decrease in the second harmonic intensity due to phase accumulation loss within the crystal. Furthermore, temperature directly affects the refractive indices via the relationship

$\frac{dn}{dT}$. This alters the phase matching conditions and necessitates precise thermal control to maintain the highest conversion efficiency and good spectral stability. The practical design of laser systems based on the KTP crystal requires the integration of selecting the appropriate crystal cutting angle and precise temperature control to ensure good and stable performance. This is confirmed by experimental and theoretical studies in the field of nonlinear optics[9,10].

Experimental part

Figure (2) shows the experimental set up for studying the static characteristics of DPSS green laser at low temperature.

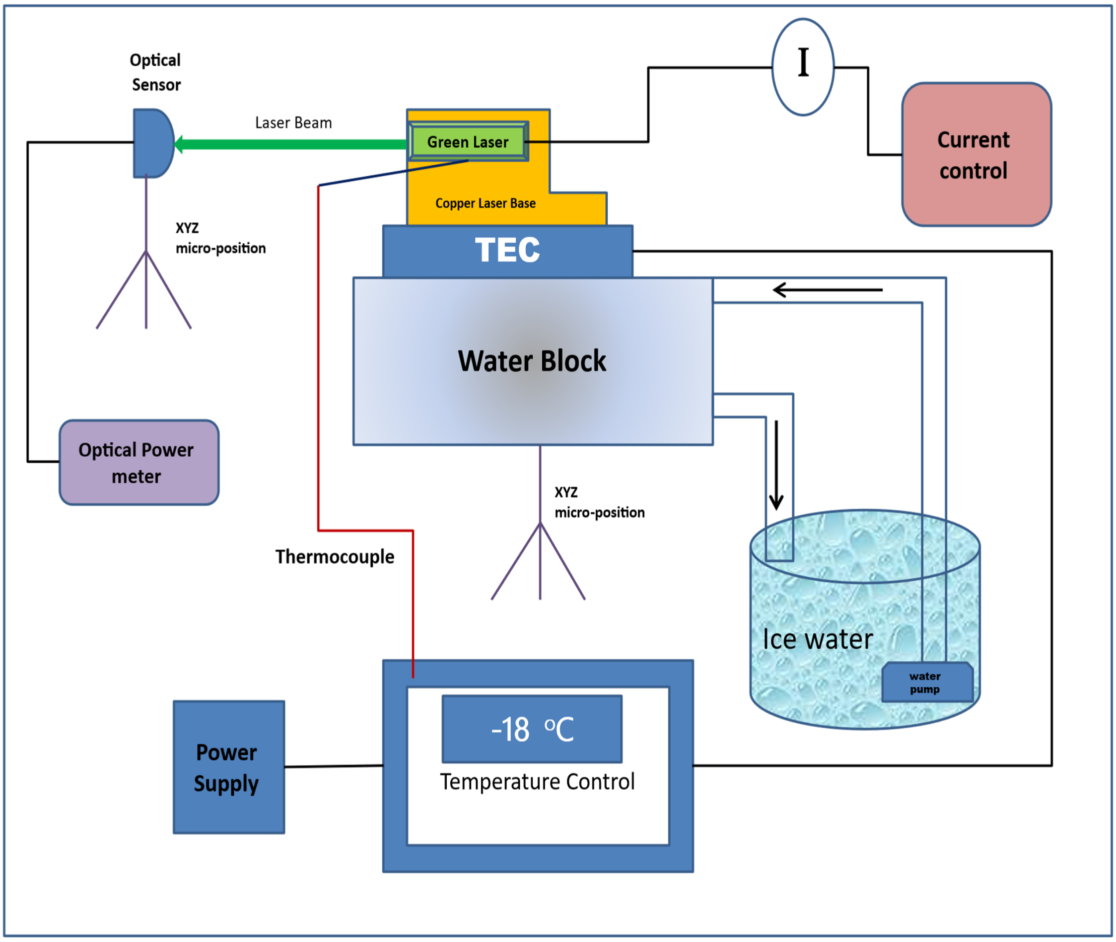
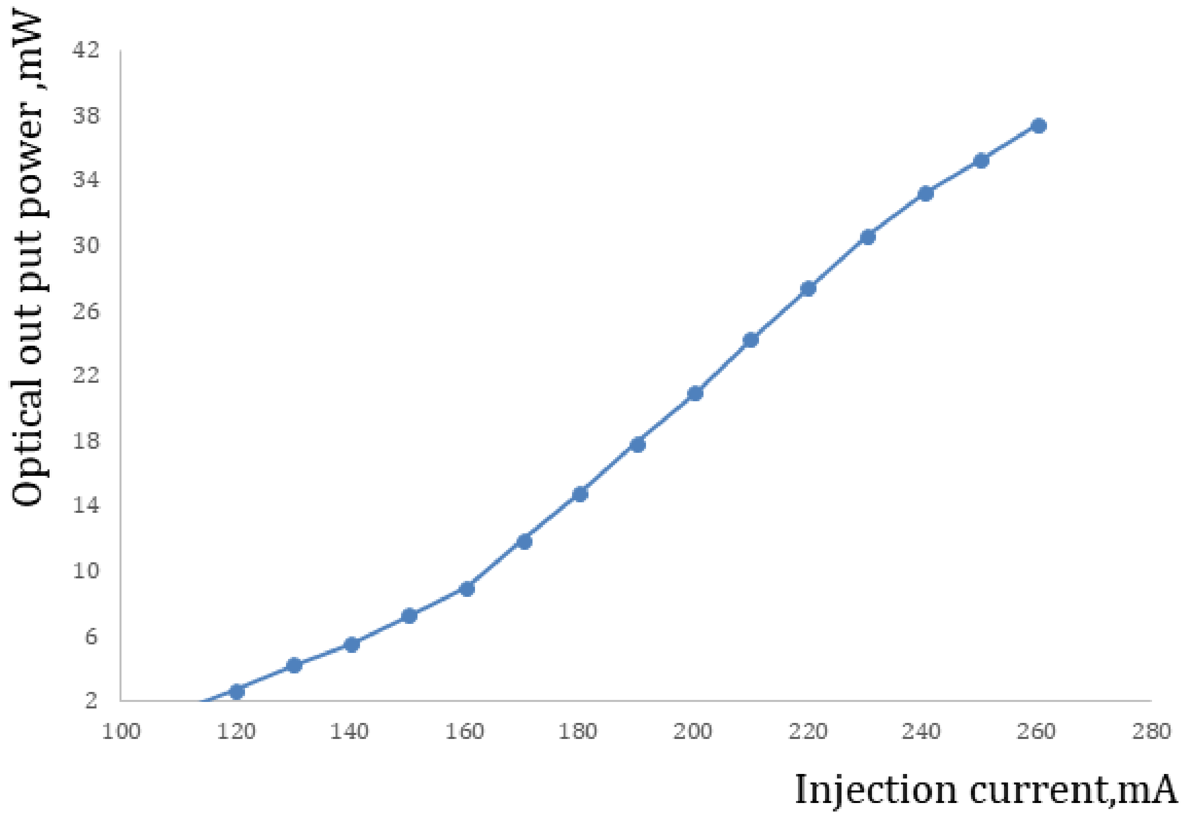


Figure 2. Experimental setup
for studying the properties of green lasers at low temperatures.

The experimental setup consists of a DPSS green laser mounted on the top surface of a Peltier TEC (thermal electrifier). The Peltier TEC ensures the necessary cooling for the laser, which is electronically controlled by a thermal controller circuit that regulates the TEC's operation and maintains its precise temperature. The hot surface of the TEC is placed on a water block through which cold water is passed to ensure efficient heat dissipation to the hot surface. This, in turn, significantly reduces the temperature of the cold surface, easily achieving temperatures below -18°C. The laser light output power was controlled by adjusting the laser bias current via a current controller with an accuracy of ±1 mA. The laser output power was measured using a photometer with a power rating of up to 1MW. The components to be aligned (laser and detector) were placed on a three-dimensional X-Y-Z movable stand to ensure the laser light was aligned with the photometer's detector.

Results and Discussion

Figure (3) shows the L-I characteristics of DPSS semiconductor laser electrodes at laboratory temperature [22°C]. The current was measured on the x-axis and the output power on the y-axis. A slight increase in power was observed at low currents, while at high currents the power became high (near-linear). The threshold current was measured by the intersection of the linear region of the curve with the current axis and found to be 135 mA.



Figure(3) the relationship between the injection current in mA and the optical output power in mW of DPSSFD green laser at room temperature

Figure (4) shows the L-I curves of DPSS green laser at temperature range from (0 to -16) °C It was observed that the L-I curves shift to the right as the temperature decreases, indicating that the threshold current decreases as the temperature decreases. The threshold current can be determined by taking the extent of the linear region at each temperature and its intersection with the current.

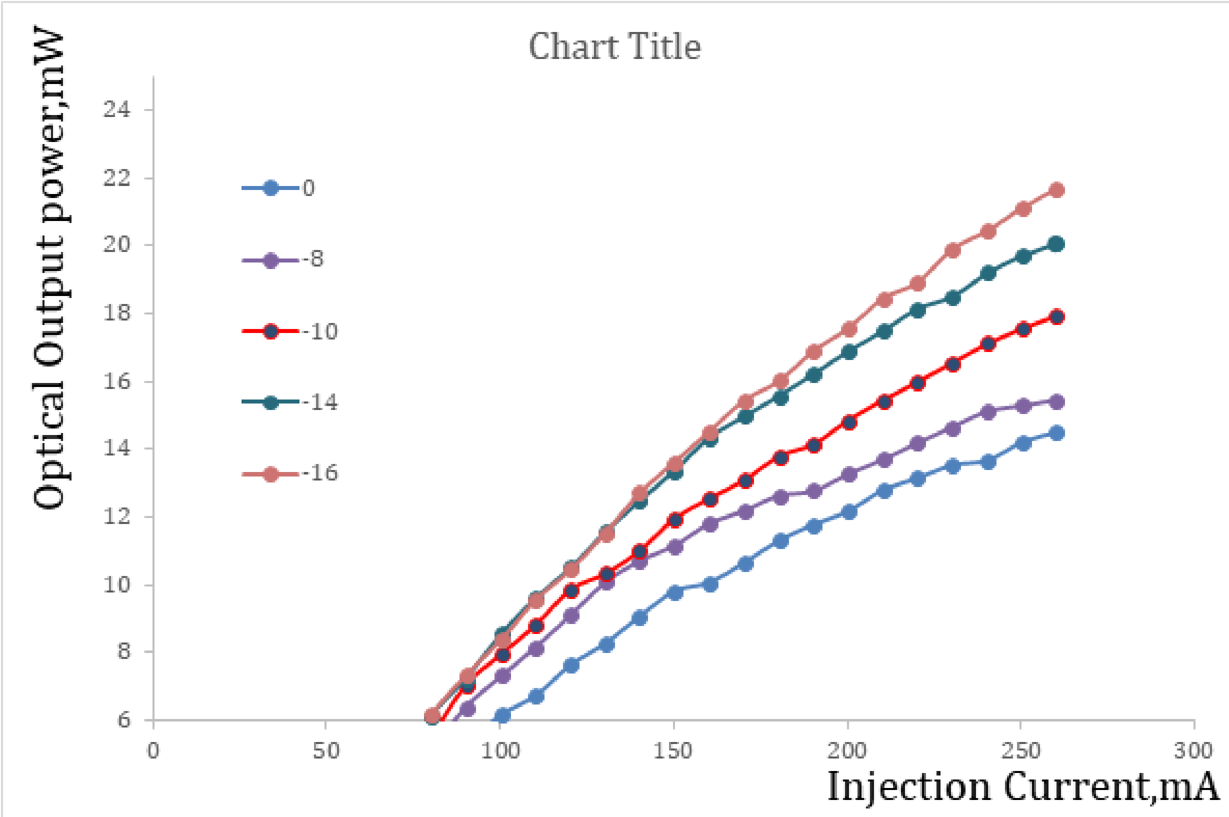


Figure (4) L-I characteristics of DPSS green lasers at low temperatures

Figure (5) shows the relationship between temperature and threshold current for a semiconductor lasers. As is clear from the figure, the threshold current decreases as the temperature decreases. The equation derived from the graph which relates the thres hold current and the temperatures is as : $I_{th} = 1.4654T + 99.048$,The threshold current decreases with temperature by1.4654 mA/^{0}C, which is the common behavior in semiconductor lasers.

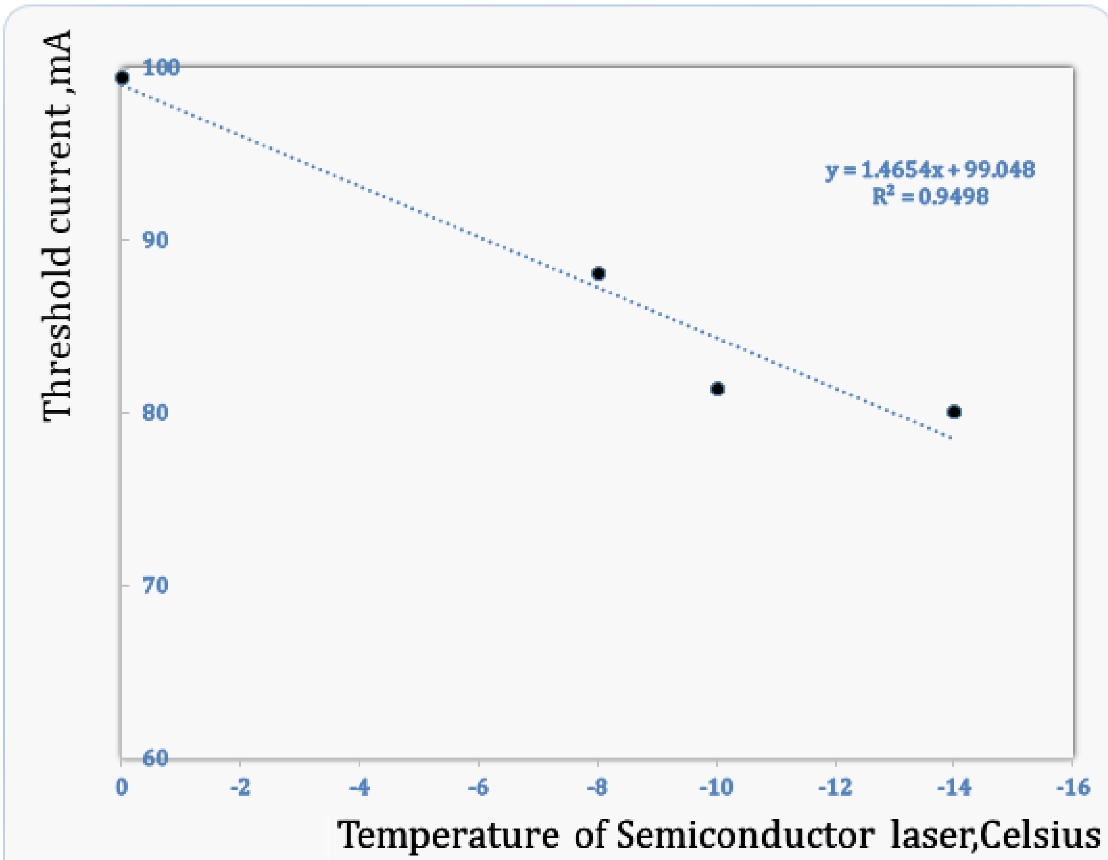


Figure (5) Relation between threshold current and temperature of DPSS green laser

Figure (6) illustrates the relationship between ln(I_{th}) and temperature of a semiconductor laser to find the characteristic temperature coefficient. This figure clearly shows two distinct regions. The first region is in the range of (0 to -8) °C, where To = 137.9 is found. The second region is in the range of (-10 to -16) °C where To = 120 °C . In the first region, To is higher, meaning the laser is more thermally stable at this point. In the second region, To is lower, indicating that the laser may be semi-sensitive in this range of temperature.

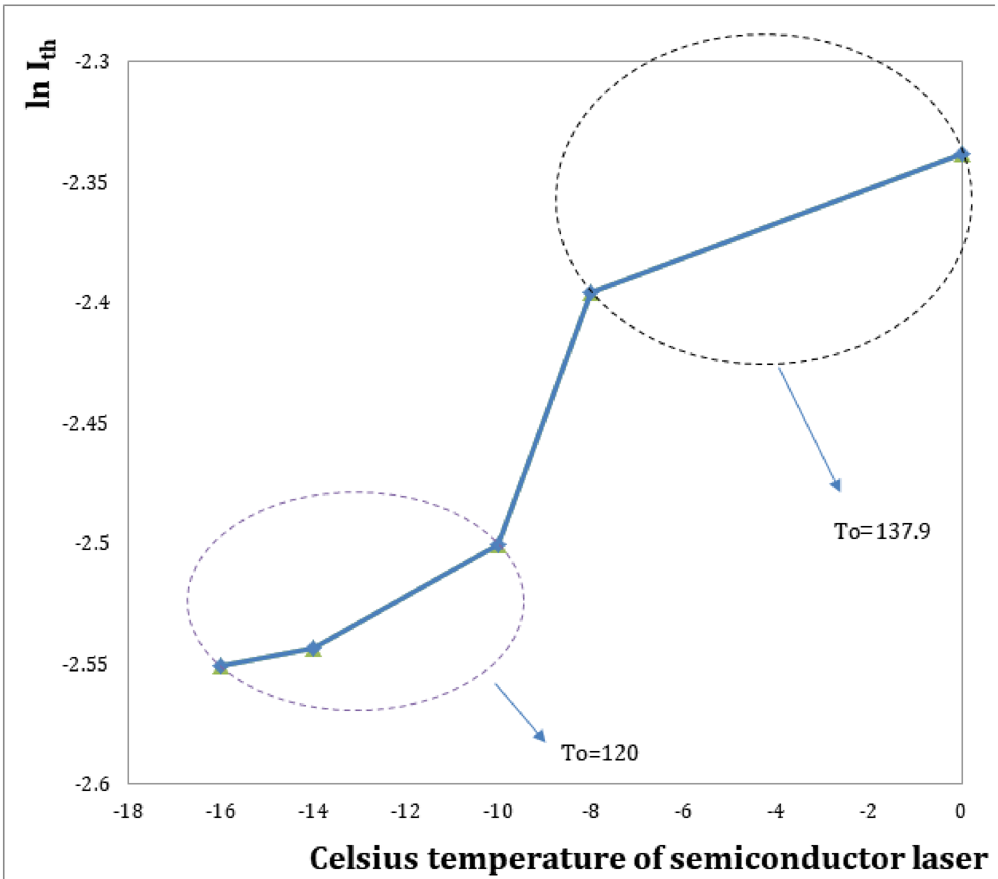


Figure 6 Relation between temperature of DPSS green laser and ln I_{th}

When observing the characteristics of a dpss green laser at low temperatures ranging from 0°C to -16°C, a breakdown in the output frequency of the green laser was observed as the temperature decreased, resulting in a shift towards and IR frequency DPSS. At 0-°C, the laser light was green, but as the temperature decreased, the intensity of the green laser light weakened until it became reddish. With further temperature reductions, the laser light transitioned to pure IR at wavelength.

This is attributed to the fact that the phase-matching process of the KTP crystal is affected by decreasing temperature, thus reducing the efficiency of frequency conversion. Consequently, the 532nm green light output decreases, while the primary laser light output increases at a wavelength of 1064nm, as shown in figure 7(a,b,c) at lower temperatures.

Figure 7(a) laser spot light at(2-) °C the laser light was green

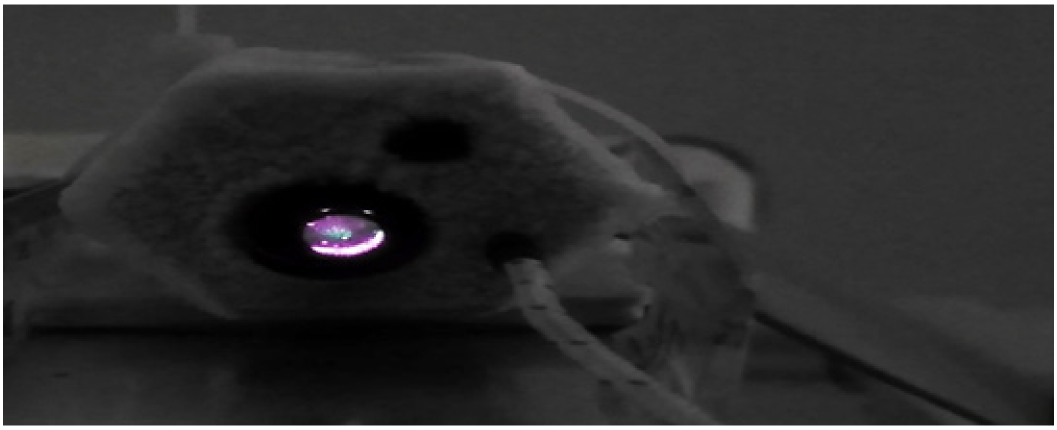


Figure7(b)laser spot light at (-10) °C as the temperature decreases,the intensity of the green laser light weakens and becomes reddish-green

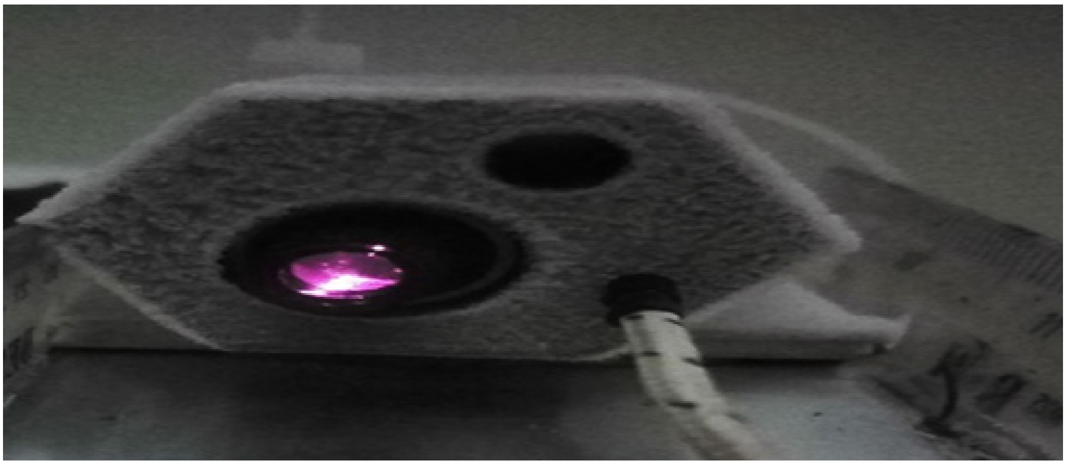


Figure7(c)laser spot light at (-16) °C as the temperature continued to decrease, the laser light converted into infrared radiation with a wavelength of 1064 nm

Applications of lasers with a wavelength of 1064nm

Lasers with a wavelength of 1064 nm are widely used due to their low cost, good efficiency, and high power. They are employed extensively in medical, industrial, and scientific applications. In medicine, they are used in tumor treatment, ophthalmology, pigmentation removal, and hair removal. They are also used in dentistry. In industrial applications, they are used in welding and engraving on materials due to their high energy and ability to induce localized thermal changes. They are also used in communications, scanning, and optical measurements [11]

Conclusion

1-The results of this study showed that a decrease in temperature leads to a decrease in the threshold current, which is the expected behavior of the laser.

2-The characteristic temperature was determined in two regions. The first region was more stable, ranging from 0 to -8°C, while the second region showed increased sensitivity, ranging from -10 to -16°C.

3- A significant decrease in frequency doubling efficiency was observed in the second region. The green color of the 532 nm laser shifted to the red color of the 1064 nm wavelength, resulting in an increase in the core emission at 1064 nm under the same conditions. This indicates that improved power performance does not necessarily translate into improved optical shift.

4- The second wavelength shift in the KTP crystal depends on the phase-matching conditions between the core radiation and the green output. At low temperatures, these conditions are disrupted, reducing the shift efficiency from 1064 nm to 532 nm while the core output power remains high.

5- Laser performance depends on two variables: power and stability on the one hand, and nonlinear shift efficiency on the other. Both must be considered to ensure independent and efficient green output. Operation under low and stable thermal conditions is essential for the reliable operation and performance of laser systems in advanced scientific and industrial applications.

References

[1] Y. J. Liao et al., "An Experimental Study on the Temperature Characteristic of a 940 nm Semiconductor Laser Diode", Optics and Photonics, 6 (2016) 75–82.

[2] F. M. Jasim et al., "The Static Characteristics of Semiconductor Laser at Low Temperatures", International Scientific in Law and Human Sciences (ICLHS-2023) & International Conference on Pure Sciences and Agricultural Sciences (ICPAS-2023), Antalya, Turkey, 19–22 July 2023, pp. 140–148.

[3] A. Singh et al., "260 W of average green beam generation by intracavity frequency-doubled acousto-optic Q-switched Nd:YAG laser", J. Opt., 48 (2019) 512–519.

[4] H. Liu et al., "High-Beam-Quality and High-Brightness 532 nm Laser with Output Power 96 W", Crystals, 13 (2023) 290.

[5] T. Sasaki et al., "Single-longitudinal-mode operation and second-harmonic generation of Nd:YVO4 microchip lasers", Opt. Lett., 16 (1991) 1665–1667.

[6] W. Ma et al., "Single-longitudinal-mode Nd:YVO4 microchip laser with orthogonal-polarization bidirectional traveling-wave mode", Opt. Express, 16 (2008) 18702–18708.

[7] R. M. Ibrahim and M. S. Mohammed, "Effect of Material Irradiated Type and Spot Size on Spot Center Temperature of a Diode-Pumped Solid-State Laser", Iraqi Journal of Applied Physics, Vol. 20, No. 3 (2024), pp. 340–344.

[8] C. Tan-Xiang et al., "High-precision absolute coordinate measurement using frequency scanned interferometry", J. Physics, 9(03) (2014) P03001.

[9] R. W. Boyd, Nonlinear Optics, 3rd ed., Academic Press, 2008.

[10] D. Eimerl, L. Davis, S. Velsko, E. K. Graham, and A. Zalkin, "Optical properties of KTP for frequency conversion," IEEE Journal of Quantum Electronics, Vol. 25, No. 2, 1989.

[11] C. Guo & S. Singh (Eds.), Handbook of Laser Technology and Applications: Laser Applications: Medical, Metrology, and Communication, Vol. 4, CRC Press / Routledge, 2021.