Optimization of Diode Laser Q-Switching Using Optical Choppers for Improved Rhodamine B Degradation

Eman A. Saied
Samira Y. Asoka
Amange F. Boya

Department of Physics,
College of Science,
Salahaddin University - Erbil,
Erbil, Kurdistan Region, IRAQ

Choppers are optomechatronic instruments employed to modulate laser light by generating pulses with unique profiles. This study investigates six chopper designs with rotating wheels, focusing on mechanical active Q-switching modulation to convert continuous wave diode lasers into Q-switching lasers. Four of the designs feature single and dual frequencies, while the remaining two are harmonic frequency optical chopper blades. The research examines key pulse characteristics, such as duration, which range from 9.38 ns to 1.034 µs for single- and dual-frequency choppers. The maximum peak power recorded was 68.98 kW for harmonic oscillation choppers, while the minimum was 1.94 kW for single- and dual-frequency choppers. The influence of chopper motor speed on laser properties is examined. Optimized chopper-laser pulses generate greater peak power and reactive species, leading to accelerated degradation of Rhodamine B, whereas continuous lasers provide slower, less intense energy for degradation.

***Keywords*:** Geometrical optics; Lasers; Q-switching; Optical systems
Received: 26 December 2024; **Revised:** 30 January 2025; **Accepted:** 06 February 2025

1. Introduction

Since the first laser demonstration in 1960, the characteristics of lasers have facilitated the continuous emergence of innovative applications across many domains. Based on the beam properties of the laser, it may be used for communication [1,2], industry [3], biology, and medicine [4]. Ultrafast lasers and ultrashort pulses are particularly advantageous for medical imaging and therapy [5,6].

The prevalent techniques used to generate laser pulses include Q-switching, mode-locking, and pulsed pumping. Q-switching is a technology used to generate lasers with elevated power outputs and reduced pulse durations [7].

An optical chopper with various window configurations is used in several optical research projects and experiments and is one of the most straightforward mechanical Q-switched techniques for generating periodic laser pulses from a continuous laser [9-14]. It is available in several forms: optical shutters [15], rotating discs [16-18], and fixed frequency tuning fork choppers. This research employs a rotating disc chopper composed of variously shaped regular blades on a circular plate, which modulates the continuous wave (CW) and alters the beam's frequency in response to fluctuations in the optical chopper blade's frequency.

The quality of the pulsed laser, crucial for various laser applications, is determined by parameters including coherence, pulse duration, pulse repetition rate, peak power, beam stability, pulse energy, pulse width, and pulse shape, all of which influence the effectiveness of the chosen application.

The precise regulation of the chopper's aperture and its blade shape significantly improved the laser beam's spread [19]. It's achievable to distribute the energy across each pulse evenly. This is especially advantageous for uses where a consistent intensity profile of the laser beam is crucial, like laser annealing [20] or photolithography.

Regulating the pulse repetition rate using a chopper entails adjusting the rotating velocity of the chopper blades; this is beneficial in several applications, including spectroscopy and laser material processing, that need accurate pulse repetition rates [21].

Optical choppers can assist in minimizing the impact of noise and variations in the laser's output by adjusting the beam with the chopper; specific kinds of noise, such as low-frequency shifts or changes in intensity, can be either reduced or completely removed. This results in a more consistent and steady laser output, which is necessary for high-precision activities like laser-based distance measuring or optical coherence tomography [22].

Choppers may regulate the average power of a laser's output by modifying the duty cycle, which is the ratio of the time the beam passes through the chopper to the total duration. Scenarios requiring exact laser power regulation to avert sample destruction or guarantee optimum material interaction might use this capability. This simple method has several disadvantages. The modulator obstructs the majority of the light, making the process very inefficient. Furthermore, the peak power must not exceed the average power of the continuous wave source. The duration of the pulse is likewise limited by the speed of the modulator.

Dye removal from aqueous solutions, owing to lasers' high energy and accuracy. The dye molecules undergo photodegradation when exposed to laser light, particularly in the visible and ultraviolet spectrums, which reduces their toxicity [23]. It has been discovered that pulsed lasers are the most effective of the several laser approaches. The interaction between the laser light and the dye molecules is improved by pulsed lasers, which give energy in brief bursts and produce strong power at certain times. Compared to CW lasers, this leads to a more thorough and quick degradation process because the high peak strength of the pulses can more successfully disrupt chemical bonds in the dye.

2. Experimental Part

Figure (1) illustrates the principle of the experimental apparatus developed for the investigation of chopper wheels, as detailed in table (1). The laser source, a diode laser with a wavelength of 532 nm and an output power of 10 W CW, produces a beam that is modulated by a revolving chopper, powered by a DC motor operating at 12000 r.p.m., which includes a potentiometer for regulating its rotational speed (ω). A photodiode captures the output signal from the chopper, and the resulting modulation functions are documented by a Tektronix TD-5104 oscilloscope, which also transmits the data to a PC.

Fig. (1) Experimental setup for Q-switched diode laser using optical chopper

Active mechanical Q-switching has been accomplished utilizing six different types of optical modulators or choppers. Table (1) presents the configurations of each optical chopper, incorporating three distinct radii (d_1, d_2, d_3) utilized to direct the laser beam, thereby facilitating an examination of the pulsed laser characteristics associated with each radius.

For a circular chopper disc shown in table (1), with a radius R and n wings, the window angles (α) and wing angles (β), the total angle is expressed as:

$$n(\alpha+\beta) = 2\pi \qquad (1)$$

The area of the chopper (circular disc) is expressed as πR^2, which is divided into n wings and windows. The area of a sector of the circular chopper disc is defined as:

$$\left.\begin{aligned} A_{window} &= \alpha\frac{R^2}{2} \quad \text{and} \quad A_{wing} = \beta\frac{R^2}{2} \\ \pi R^2 &= n\left(A_{wing} + A_{window}\right) \\ A_{wing} &= \frac{\pi R^2}{n} - \frac{\alpha R^2}{2} = R^2\left(\frac{2\pi - n\alpha}{2n}\right) \end{aligned}\right\} \qquad (2)$$

The laser beam with the flux φ_{in} went through the chopper, resulting in the transmission flux (φ_{out}), with the transmission coefficient being

$$t = \frac{\varphi_{out}}{\varphi_{in}} = \frac{\alpha}{\alpha+\beta} \qquad (3)$$

Using Eq. (1) in Eq. (3), we have

$$t = \frac{\alpha n}{2\pi} \qquad (4)$$

The minimum angular speed is required to model the chopper [19]. The angular speed is contingent upon the wing area, window angle, rotor diameter, and photodetector frequency, and is expressed as:

$$w_{min} = \frac{2\pi}{n}(1-t) f_{phoD} \qquad (5)$$

where f_{pho} is photodetector frequency

$$w_{min} = \frac{2A_{wing} + \alpha R^2}{R^2}(1-t) f_{phoD} \qquad (6)$$

The continuous light signal traversed the chopper with n wings, producing *n* duplicate pulses, each with a period of τ.

$$\tau = \frac{\alpha}{\omega} \qquad (7)$$

By substituting Eq. (6) in Eq. (7), we get

$$\tau = \frac{\alpha R^2}{f_{phoD}} \frac{1}{(2A_{win} + \alpha R^2)(1-t)} \qquad (8)$$

This experiment used irradiation from a CW laser with optimal peak power at S_5 and a d_3 chopper active Q-switching pulse laser to investigate the degradation of Rhodamine B (RhB) dye in distilled water. The starting concentration of RhB was C_0 = 4.5 mg/L, and degradation was observed at irradiation time intervals of 0.5 h, 1 h, 1.5 h, 2 h, and 2.5 h. After each time interval, the remaining concentration (C) of RhB was measured, providing insights into the photodegradation process induced by the laser. The laser's specific parameters, including the CW and Q-switching pulse characteristics, are illustrated in Fig. (2), which depicts the experimental setup designed to investigate degradation processes for continuous and actively Q-switched diode lasers for sample (S_5, at d_3). The main parameters affecting laser degradation are concentration (C) and extent of deterioration (W).

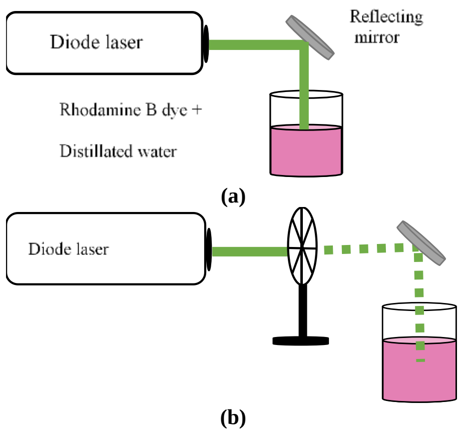


Fig. (2) Experimental set up to irradiate RhB dye with (a) CW laser (b) active Q-switched pulsed laser

Standard RhB solutions with concentrations between 0.5 and 4 mg/L were prepared, and the absorbance of different RhB concentrations was determined using Beer-Lambert equation and a

Hemadzu UV-1800 UV-visible spectrophotometer at the peak absorption wavelength of 555 nm. The linear equation, characterized by a correlation coefficient, was derived by establishing the standard concentration-absorbance curve with R^2 = 0.985403. The degree of degradation was quantified as a percentage of removal, calculable by the following equation:

$$W = \frac{C_0 - C}{C} \times 100\% \qquad (9)$$

Here, W denotes the percentage of RhB solution degradation, C_0 signifies the starting concentration of RhB in mg/L, and C indicates the residual concentration of RhB after exposure to CW laser and pulsed laser

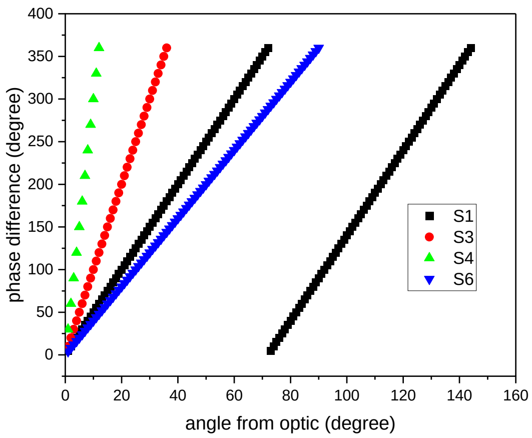
3. Results and Discussion

A 10 W CW laser diode operating at 533 nm was used, and an optical chopper was inserted into the cavity to operate as an active Q-switching element. The current research employs both single- and dual-frequency optical chopper blades, featuring samples (S_1, S_3, S_4, S_6) with varying slot (window) counts of 5, 10, 30, and 4, respectively, alongside harmonic frequency optical chopper blades (S_2, S_5) with slot counts of 8, 16, and 4, 7, respectively.

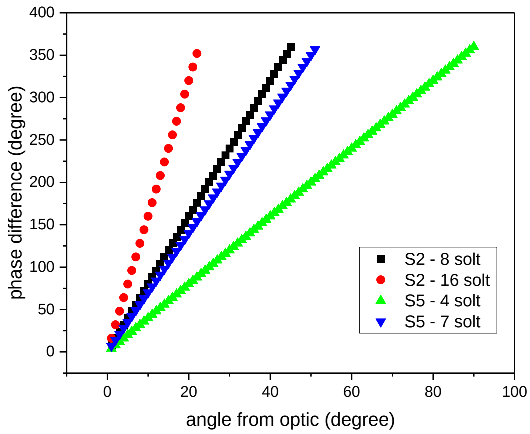
The phase difference (ϕ) for all samples is shown in Fig. (3) and was calculated using $\phi = \theta N$, where θ represents the angle from the optic for one rotation and N denotes the number of slots or windows for each chopper. The phase difference and angle in optics exhibit a linear connection that is also contingent upon the laser beam diameter (2 mm) [24].

Figure (4a) illustrates the oscilloscope trace of the output pulse train from the Q-switching laser using chopper sample S_1, with a diameter of d_1, as presented in table (1). The simulated results are shown in Fig. (4b). The x-axis shows the pulse duration, and the y-axis shows the amplitude. These results match the empirical results shown in Fig. (4a) [25, 26].

The results of various experiments involving different choppers (S_1-S_6) are detailed in table (3). All values were recorded using a Tektronix TD-5104 oscilloscope.



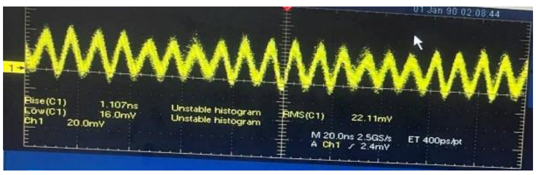
(a)

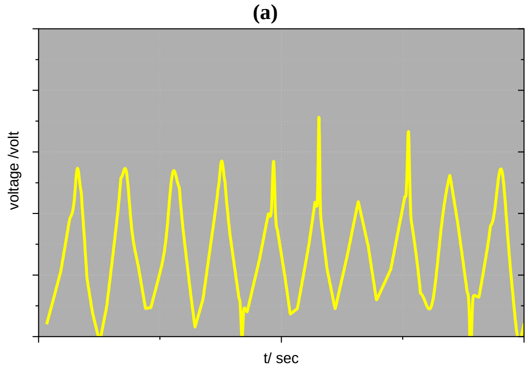


(b)

Fig. (3) Relation between phase difference and angle from optic for different samples (a) S1, S3, S4, S6, (b) S2 d1, d3 and S5 d1, d3

Maximum and minimum pulse durations for S_1 and S_4 were noted at d_3, measuring 1034 ns and 9.38 ns, respectively. S_5 at d_1 exhibits a maximum rise time of 3450.2 ns, whereas chopper S_1 at d_3 demonstrates a minimum rise time of 51.7 ns. The pulse repetition frequency was analyzed within the range of 12 to 333 kHz, which corresponds to the range observed in reference number [27].


(a)



(b)

Fig. (4) (a) Practical results on oscilloscope shown the Q-Switching pulse laser out using sample (S1) at diameter d1, and (b) simulation of the result

The duty cycle for both single- and dual-frequency optical chopper blades (designated as S_1, S_3, S_4, and S_6) varies from 6.81% to 96%. In contrast, the duty cycle for harmonic frequency optical chopper blades (designated as S_2 and S_5) ranges from 14.9 to 97%. The angular dimensions of the chopper wheel's wings and windows can be adjusted to modify the duty cycle accordingly. The two window configurations, circular or linear edged, are utilized for the modulation of a laser

Vol. 21, No. 2, April-June 2025, pp. 209-216

beam with a focused output. The present study delineates the design of a cutter featuring a linear and harmonically edged window, achieved without altering the beam profile [25,28,29]. The peak (pulse) power for all samples across various diameters is presented in Fig. (5) and is typically situated between approximately 300 kW and 2 kW, which aligns broadly with the findings reported in references [13,30].

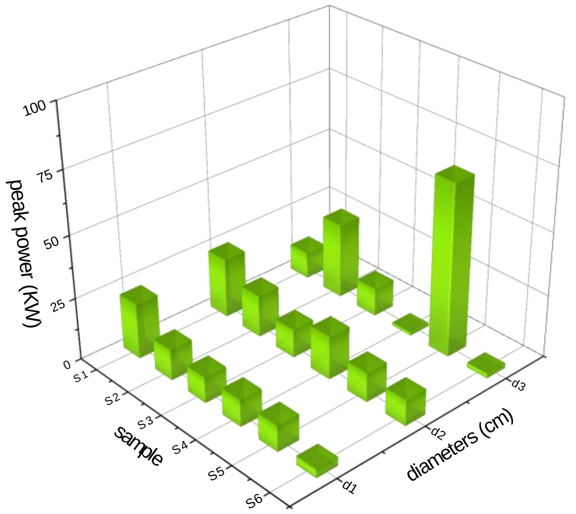
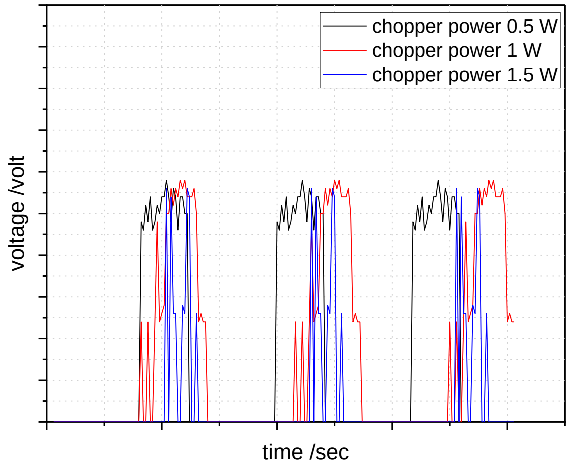


Fig. (5) Peak power of active Q-switched diode laser for different samples and diameters

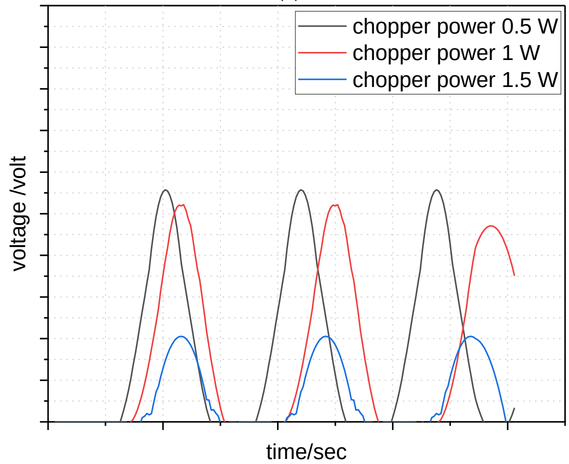
It was found that S_5 at d_3 had the maximum peak power of 68.98 kW at a lower repetition rate of 20.83 kHz and pulse width of 1.959 ns, along with the greatest average power of 10 W. On the other hand, a higher repetition rate of 333 kHz, a peak power of 1.94 kW, and the smallest pulse width of 1.94 ns were examined using S_6 at d_3.

Modifying the rotational velocity of the optical chopper also influences the attributes of the active Q-switching, as illustrated in table (4), which delineates the variations in each parameter as a function of the input chopper power. Figure (6a) illustrates the oscilloscope signal for sample S_1 at distance d_1 under varying chopper power levels, while figure (6b) presents the corresponding simulated results. We posited that the x-axis of the simulation represented time, while the y-axis denoted amplitude.

Degradation of RhB dye was monitored by absorption spectra using UV-visible spectroscopy under CW and an optimum pulsed laser irradiation with a peak power of 69 kW (sample S_5 at d_3), as seen in Fig. (7). The findings indicate a decrease in absorbance for both laser treatments as the dye degrades over time. After 2.5 hours at the standard absorption wavelength of 555 nm, the absorbance for the CW laser decreased from 2.112 to 1.341, indicating a significant level of degradation. Conversely, at the same period, the absorbance for the pulsed laser significantly decreased from 2.112 to 0.45, signifying a much more efficient degradation process [23,31]. The enhanced effectiveness of the pulsed laser in photodegrading RhB is shown by the significant reduction in absorbance observed.



(a)



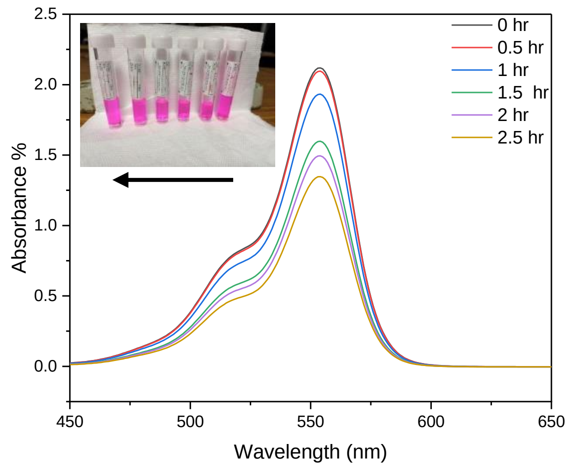
(b)

Fig. (6) Effect of different chopper powers on characteristics of Q-switched diode laser for sample S_1 at diameter d_1 (a) experimental results, and (b) simulation result

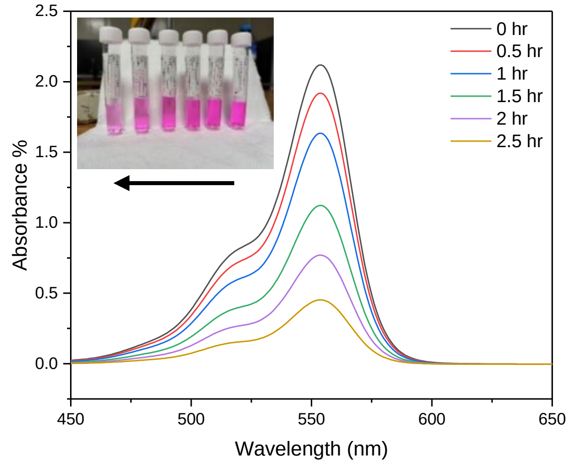
Significant differences exist in the efficacy of RhB dye degradation under CW and active Q-switching pulsed diode laser exposure. The deterioration efficiency of 57.3% at 2.5 hours with a CW laser, as seen in Fig. (8a), indicates a somewhat slower and more uniform photodegradation process. The CW laser progressively degrades dyes through extended photochemical reactions by providing consistent, moderate power over time. The active Q-switching pulsed diode laser attains a much higher degradation efficiency of 78.69% at 2.5 hours, as seen in Fig. (8b), closely resembling the findings of references [32–34]. The elevated peak power delivered in short, intense pulses accounts for this increased efficiency since it accelerates photochemical reactions and the degradation of the dye. Furthermore, the pulsed characteristics of the active Q-switched laser mitigate heat accumulation, hence enhancing degradation

ISSN (print) 1813-2065, (online) 2309-1673

efficiency while preventing excessive thermal buildup. The elevated degradation rate observed with pulsed lasers, relative to CW lasers, suggests that pulsed lasers are more efficient in inducing rapid and intense photodegradation of RhB dye due to their high-energy bursts.

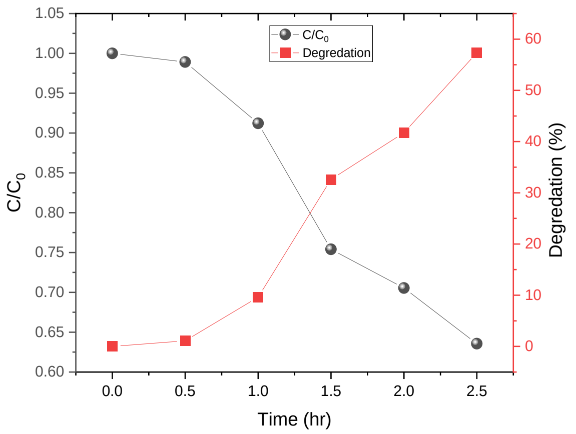


(a)

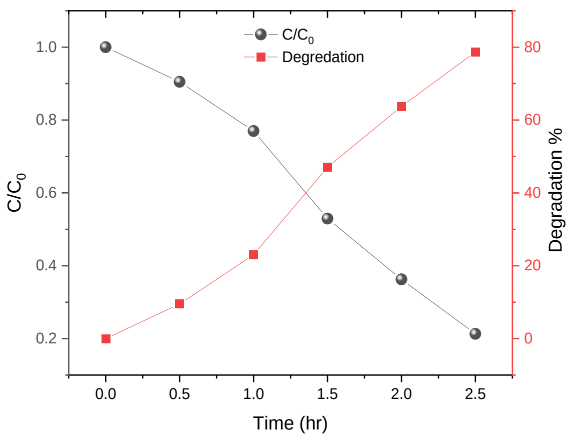


(b)

Fig. (7) UV-visible spectra of RhB dye solution irradiated with (a) CW diode laser, and (b) Q-switched pulsed laser (S5 at d3)



(a)



(b)

Fig. (8) Time-dependent variation of C/C_0 and degradation rate of RhB dye using (a) CW diode laser, and (b) Q-switched pulsed laser (S_5 at d_3)

4. Conclusion

Six choppers for active Q-switching of a 533 nm diode laser are investigated in this study. With pulse widths ranging from 9.38 to 1034 ns, the single, and dual harmonic frequency choppers' pulse laser output characteristics revealed a phase difference proportionate to slot number. Single and dual choppers demonstrated a minimum power of 1.94 kW, but harmonic oscillation choppers recorded a maximum power of 68.98 kW. The pulse patterns for S_1 at a maximum frequency of 1.5 W were affected by the chopper power. Depending on the chopper power, the duty cycle ranged from 12% to 50%. The maximum power of S_1 varied between 10.62 kW at 0.5 W d_3 and 47.14 kW at 1.5 W d_1. After 2.5 hours of irradiation, the active Q-switched pulsed diode laser with a peak power of 69 kW showed a greater Rhodamine B dye degradation efficiency (78.69%) than the CW laser (57.3%).

References

[1] T. Drozd et al., “Free space optical communication based on pulsed lasers"', *Laser Technol.: Prog. Appl. Lasers*, 10159 (2016) 1015911-7.

[2] D.W. Young et al., “Development and demonstration of laser communications systems”, *Johns Hopkins APL Tech. Dig. (Appl. Phys. Lab.)*, 33(2) (2015) 122-138.

[3] M.Q. Chau, “An overview study on the laser technology and application in the mechanical and machine industry”, *J. Mech. Eng. Res. Dev.*, 42(5) (2019) 16-20.

[4] L. Legres et al., “The Laser Technology: New Trends in Biology and Medicine”, *J. Mod. Phys.*, 5 (2014) 267–279.

[5] H. Lubatschowski et al., “Medical applications for ultrafast laser pulses”, *RIKEN Rev.*, 50(50) (2003) 537-539.

[6] S. Svanberg, “Some applications of ultrashort laser pulses in biology andmedicine”, *Meas. Sci. Technol.*, 12(11) (2011) 1777.

[7] S. Zaitsu and T. Tsuchiya, “A Molecularly Modulated Mode-Locked Laser”, *Sci. Rep.*, 8(1) (2018) 12175.

[8] E. Csukas, D. Demian and V.-F. Duma, “Optical choppers: novel approaches for higher chop frequencies", in *Electro-Optical and Infrared Systems: Technology and Applications XX*, D.L. Hickman et al. (eds.), Amsterdam, Netherlands: SPIE, 39 (2023).

[9] V.-F. Duma, “Optical choppers with circular-shaped windows: Modulation functions", *Commun. Nonl. Sci. Numer. Simul.*, 16(5) (2011) 2218–2224.

[10] K.D. Benjamin, A.F. Armitage and R.B. South, “Harmonic errors associated with the use of choppers in optical experiments", *Measur.*, 39(8) (2006) 764-770.

[11] S. Wang et al., “Time-resolved spectroscopy using a chopper wheel as a fast shutter", *Rev. Sci. Instrum.*, 86(1) (2015) 013111.

[12] S.-B. Chen, J.-L. Li, and K.-I. Ueda, “Pulsed azimuthally polarized beam from passively Q-switched rotating Nd:YAG disk laser", *Appl. Phys. Exp.*, 14(4) (2021) 042001.

[13] A.F. El-Sherif and M. Talaat, “Detection and analysis on versatile coding strategies of high frequency active Q-switched Nd:YVO_4 laser for irradiance of different targets", *Opt. Laser Technol.*, 64 (2014) 124-132.

[14] Y. Zhang et al., “High pulse repetition frequency RF excited waveguide CO_2 laser with mechanical Q-switching", *Infrared Phys. Technol.*, 58 (2013) 12-14.

[15] D.G.K. Aboud et al., “A Practical Comparison of Beam Shuttering Technologies for Pulsed Laser Micromachining Applications", *Materials*, 15(3) (2022) 897.

[16] J.A. Dávila-Pintle, E. Reynoso-Lara and Y.E. Bravo-García, “Chopper z-scan technique for elliptic Gaussian beams", *Opt. Exp.*, 24(18) (2016) 21105-21112.

[17] S. Gambhir and M. Singh, “Diffraction effects in mechanically chopped laser pulses", *Am. J. Phys.*, 86(6) (2018) 406-411.

[18] M. Spidell et al., “Geometric contributions to chopper wheel optical attenuation uncertainty", *Metrologia*, 54(4) (2017) L19-L25.

[19] O. Cira and V.-F. Duma, “Design programs for optical chopper wheels with different configurations", in *5th Int. Conf. on Lasers in Medicine: Biotechnologies Integrated in Daily Medicine*, SPIE, (2014) 207-214.

[20] H.S. Tareq, “Study the Effect of Rapid Thermal Annealing on Thin Films Prepared By Pulse Laser Deposition Method", *Eng. Technol. J.*, 32(3B) (2014) 444-452.

[21] H. Kalaycioglu et al., “High-Repetition-Rate Ultrafast Fiber Lasers for Material Processing", *IEEE J. Sel. Top. Quantum Electron.*, 24(3) (2018) 1-12.

[22] N.A. George et al., “Optimization of an optical chopper-laser beam arrangement in low-frequency applications", *Optik*, 126(23) (2015) 3628–3630.

[23] U. Jinendra et al., “Template-free hydrothermal synthesis of hexa ferrite nanoparticles and its adsorption capability for different organic dyes: Comparative adsorption studies, isotherms and kinetic studies", *Mater. Sci. Ener. Technol.*, 2(3) (2019) 657-666.

[24] U. Masud, F. Akram and M. Baig, "Behavioural modeling of an optical chopper for Intra Cavity Absorption Spectroscopy", *Int. Conf. on Computing, Electronic and Electrical Eng. (ICE Cube)*, Quetta, Pakistan. (2016) 22-26.

[25] V.-F. Duma, “Prototypes and modulation functions of classical and novel configurations of optical chopper wheels", *Lat. Am. J. Solids Struct.*, 10 (2013) 5-18.

[26] J. Zheng et al., “Electrically controlled optical choppers based on holographic polymer dispersed liquid crystal gratings", *Chin. Opt. Lett.*, 8(12) (2010) 1167-1170.

[27] G. Li et al., “Pulse shape symmetry and pulse width reduction in diode-pumped doubly Q-switched Nd:YVO_4/KTP green laser with AO and GaAs", *Opt. Exp.*, 13(4) (2005) 1178-1187.

[28] V.-F. Duma, “Classical and eclipse optical choppers", *Opt. Compon. Mater. X*, *SPIE*, 8621 (2013) 862119.

[29] V. Raj et al., “Effect of duty cycle on photothermal phenomenon-A thermal lens study", *Optik*, 186 (2019) 187-193.

[30] Ö. Bazkir, S. Cenk, and K. Mahmoud, “Traceability of laser pulse energy measurements by linking reference standards for CW and pulsed measurements", *J. Phys.: Conf. Ser.*, 972(1) (2018) 012013.

[31] J. Gu et al., “Degradation of Rhodamine B in aqueous solution by laser cavitation", *Ultrason. Sonochem.*, 68 (2020) 105181.

[32] S. Rajendrachari et al., “Photocatalytic degradation of Rhodamine B (RhB) dye in waste water and enzymatic inhibition study using cauliflower shaped ZnO nanoparticles synthesized by a novel One-pot green synthesis method", *Arabian J. Chem.*, 14(6) (2021) 103180.

[33] E. Arulkumar, S. Santhosh Shree, and S. Thanikaikarasan, “Photocatalytic degradation efficiency of Rhodamine-B for CuO/CdO nanosheets attained through simple co-

precipitation method", *Results in Chem.*, 6 (2023) 101169.
[34] W.L. da Silva et al., "The potential of chemical industrial and academic wastes as a source of supported photocatalysts", *J. Mol. Catal. A: Chem.*, 393 (2014) 125-133.

Table (1) optical choppers

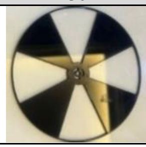
Sample	S1	S2	S3	S4	S5	S6
Chopper type						
Radius d_1,d_2,d_3 /cm	3,4,5	3,4,5	3,4,5	3,4,5	3,4,5	3,4,5

Table (2) Numerical value of angular speed and transmission coefficient

Sample	Radius	No. of Wings	α	β	Wing Area (cm²)	Window Area (cm²)	Wing+ Window Area (cm²)	w_{min}-angular speed (rad/s) from Eq. (5)	w_{min} Eq. (6)	Transmission Coefficient
S1										
	d1	5	37	35	2.74	2.90	28.26	1750	2584	0.014
	d2	5	37	35	4.88	5.16	50.24	1750	2151	0.016
	d3	5	37	35	7.63	8.06	78.5	1750	1890	0.019
S2										
	d1	8	22.5	22.5	1.76	1.76	28.26	1125	1687	0.013
	d2	8	22.5	22.5	3.14	3.14	50.24	1125	1406	0.016
	d3	16	9	13.5	2.94	1.96	78.5	675	837	0.012
S3										
	d1	10	18	18	1.41	1.413	28.26	900	1350	0.013
	d2	10	18	18	2.51	2.512	50.24	900	1125	0.016
	d3	10	18	18	3.92	3.925	78.5	900	990	0.018
S4										
	d1	30	5.5	6.5	0.51	0.431	28.26	325	510	0.011
	d2	30	5.5	6.5	0.907	0.767	50.24	325	426	0.013
	d3	30	5.5	6.5	1.417	1.199	78.5	325	376	0.015
S5										
	d1	4	45	45	3.5325	3.53	28.26	2250	3375	0.013
	d2	4	45	45	6.28	6.28	50.24	2250	2812	0.016
	d3	7	25.714	25.714	5.607	5.60	78.49	1285.714286	1414	0.018
S6										
	d1	4	52	38	2.983	4.082	28.26	1900	2603	0.017
	d2	4	52	38	5.303	7.25	50.24	1900	2153	0.021
	d3	4	52	38	8.286	11.33	78.5	1900	1883	0.023

Table (3) Active Q-switching diode laser characteristics

Sample	Diameter (cm)	Period (ns)	Rise Time (ns)	Pulse Repetition Frequency (kHz)	Duty Cycle (+%)	Area (cm^2)	Peak Power (kW)
S1	d1	9.609	378.87	104	45	3.475	22.20
	d2	9.494	60.729	105	42	3.59	23.86
	d3	9.388	51.729	106	40	3.77	10.62
S2	d1	334.4	2628.2	29.99	81.162	280	12.349
	d2	759.3	3649.9	13.169	59.43	279	16.87
	d3	480	313.12	20.833	40.05	301	30.189
S3	d1	680	1630.7	14.706	96.4	284	10.37
	d2	653.3	1712	15.74	87.589	283.02	11.42
	d3	570	2684	17.544	88.98	281	11.24
S4	d1	336.7	160	42.233	93.181	326.35	10.76
	d2	800	990.05	125	50.781	334.56	17.39
	d3	1034.7	80	9.66	6.81	325.57	1.169
S5	d1	1100	3450.2	9.069	97	277.27	10.40
	d2	480.3	2606.6	20.82	85.55	280.73	11.71
	d3	103.44	2924	96.67	15.9	283.32	68.96
S6	d1	110	2790.6	90.9	28.409	279.32	3.520
	d2	780	962.74	12.82	96.27	276.12	10.38
	d3	300	800	333	51.56	361.9	1.94

Table (4) Active Q-switching diode laser characteristics for different chopper powers using sample S_1 at diameters d_1, d_2 and d_3

Chopper Motor Power (W)	Diameter (cm0	Period (ns)	Rise time (ps)	Frequency (kHz)	duty cycle (+%)	Area (cm^2)	Peak power (kW)
0.5	d1	9.609	378.87	104	45	3.475	22.2
0.5	d2	9.494	60.729	105	42	3.59	23.86
0.5	d3	9.388	51.729	106	40	3.77	10.62
1	d1	5.312	384.55	188.22	21	4.051	47.14
1	d2	5.058	156.74	197.67	12	4.24	8.19
1	d3	9.81	171.71	161.84	45	2.78	13.73
1.5	d1	9.625	1360	103.9	46	2.948	21.55
1.5	d2	9.678	1298	103.33	50	3.122	20.33
1.5	d3	10.107	87.993	98.93	43	3.822	23.02