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Performance evaluation of a 980nm laser system in varying atmospheric conditions

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ABSTRACT

Infrared lasers operating at 980 nm are widely used in telecommunications, medical devices, and industrial applications; however, their performance is strongly influenced by environmental conditions. This study investigates the impact of temperature, humidity, and particulate matter (smoke and dust) on the performance of a 980 nm infrared laser. An experimental setup was developed using an infrared laser module integrated with an array of environmental sensors and Arduino microcontrollers for real-time data acquisition. Experiments were conducted under temperatures ranging from 28 to 55 °C and relative humidity levels between 10% and 80%. In addition, the effects of smoke concentration and dust density were examined. The results demonstrate a clear degradation in laser performance with increasing temperature, humidity, and particle concentration. Elevated temperatures reduced laser efficiency, while high humidity caused additional optical losses due to absorption and scattering. Smoke and dust particles significantly attenuated the laser signal by scattering and absorbing infrared radiation. A pronounced reduction in optical power was observed as dust density increased from 8.57 mg/m³ to 208.44 mg/m³, with power values decreasing from 331.5 µW to 95.2 µW. These findings highlight the sensitivity of 980 nm laser systems to environmental variations and emphasize the need for effective thermal management, humidity control, and particle protection. The study provides practical insights for improving the reliability and performance of infrared laser systems operating in challenging environmental conditions.

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1. INTRODUCTION

Laser technology has become indispensable in various areas, such as medical applications[1], communication systems, and material processing. In some applications, such as fiber optic communications, the 980nm infrared laser is handy and efficient. [2], medical therapy and laser pumping. However, as with all laser systems, external factors significantly influence the 980 nm laser's overall efficiency, stability, and performance [3]. Understanding the relationship between environmental conditions and laser performance is essential, particularly in sensitive applications where accuracy and consistency are critical. This research investigates the impact of several environmental conditions, including temperature, humidity, and smoke, on the performance of a 980 nm laser. By using an experimental setup that includes a 980 nm infrared laser module[4, 5], environmental sensors, and advanced data collection tools[6, 7], this experiment aims to provide a detailed analysis of how these factors affect laser performance. This research is motivated by the need to enhance laser systems for many applications. In several practical scenarios, such as outdoor pursuits or industrial settings, lasers are subjected to variable temperatures, differing humidity levels, and the presence of particulates or smoke.

Such conditions may impair laser efficacy and lead to inaccurate measurements or system failures. The objective of the research is to elucidate these impacts via an extensive investigation and to promote the development of more resilient laser systems capable of sustaining maximum performance under varying conditions [8]. The novel's format begins with a survey of current research on the environmental impacts of lasers, providing background for the investigation. The following section describes the experimental apparatus, including the laser modules, ambient sensors, and data-gathering instruments used. The results section delineates the outcomes of the studies, examining the effects of temperature, smoke, humidity, and dust density on the 980 nm laser. The analysis contextualizes these findings within current research, emphasizing their practical relevance. This study's discoveries might significantly advance laser technology, especially in contexts requiring precise control of laser output. Furthermore, the technique, which employs Arduino for data gathering and control, represents a modern approach to experimental physics, enabling high accuracy and replicability.

2. METHOD

2.1. Experimental Setup and Methodology

The experimental apparatus must be meticulously designed to investigate the impact of various conditions on the performance of the 980 nm laser. The objective was to assess the effects of temperature, humidity, and smoke present on the output power of a laser and an industrial voltmeter. This was facilitated by sophisticated instruments and contemporary data-gathering methods, enabling precise measurements and comprehensive control over experimental settings, as shown in Figure 1.

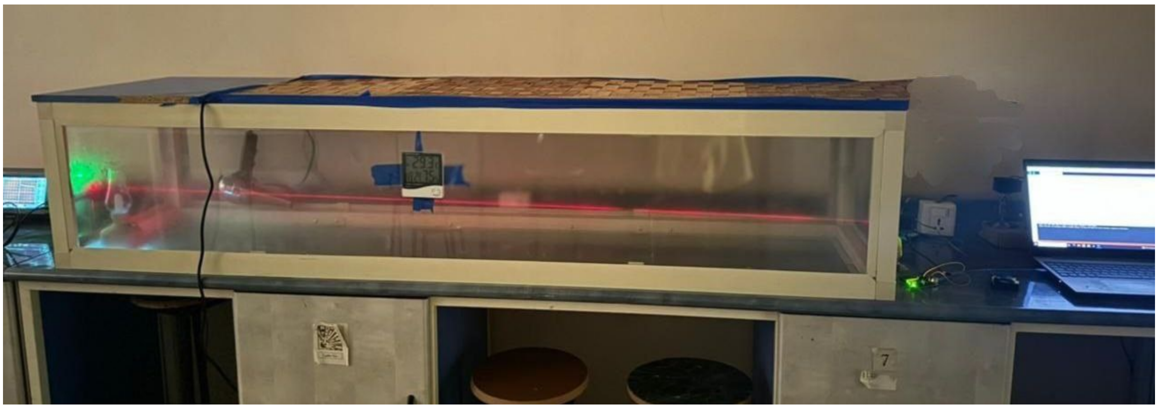


Figure 1. Experimental Setup.

2.2. Laser Modules

The experiment utilized the semiconductor laser a 980 nm 100 mW infrared laser. The 980 nm laser, the primary focus of the study, was chosen for its widespread use across fields such as telecommunications and medical devices. The selection of a 100 mW power rating for the 980 nm laser was based on its relevance to practical applications where moderate power output is typical. The laser modules were mounted on adjustable stands, allowing for precise alignment with the photodetector and other measurement instruments. A regulated power supply powered the lasers, ensuring consistent operation throughout the experiments.

2.3. Environmental Sensors

To monitor and control the environmental conditions during the experiments, a range of sensors was employed:

2.3.1. Temperature Sensor

The ambient temperature inside the experimental chamber was measured using a digital thermometer [9]. It was thereafter affixed to the Arduino Uno microcontroller[10] and linked to a specific node that enables continuous data recording (temperature). The temperature was meticulously adjusted to examine its influence on the laser output**.**

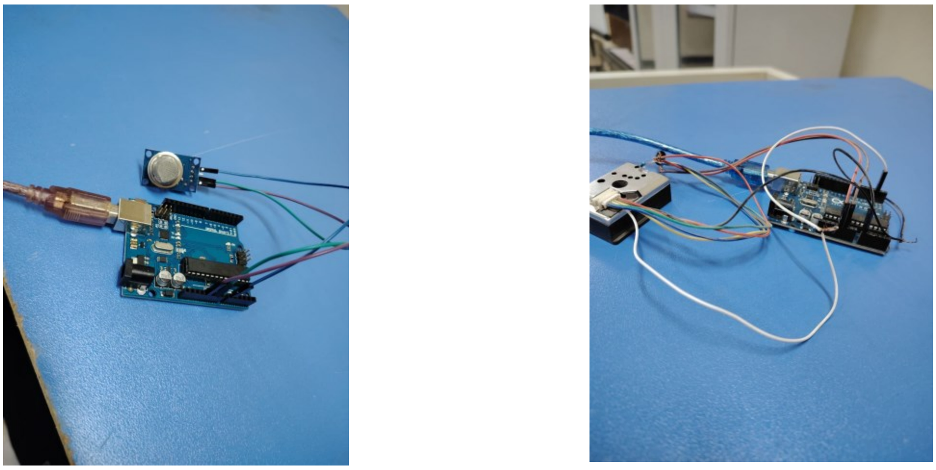
2.3.2. Humidity Sensor

A digital humidity sensor was connected to the Arduino system to assess relative humidity levels [11]. The sensor was used to collect real-world data, as shown in Figure 2, which is fundamental to obtaining sufficient readings for moisture sensing and assessing the effect on laser operations**.**

Figure 2. Digital thermometer.

2.3.2.1. Smoke and dust density

The MQ-2 gas sensor[12] to detect smoke and PM2 [13] as provided in Figure 3. A chamber was fitted with 5 GP2Y1010AU0F dust sensors [14]to gauge the community and contribute to particulate matter concentration. These could keep track of smoke and were necessary for the examination of how far the laser beam was reduced**.**



(a) (b)

Figure 3. (a) The MQ-2 gas sensor, (b) GP2Y1010AU0F dust sensors.

The context information made available by the wearable has been continuously logged through this system, and used as a dataset from which to retrieve data for our subsequent analysis.

2.4. Data Acquisition and Control System

The central part of the proposed experimental system was the Arduino Uno microcontroller (used as a control and data acquisition unit), which provides customization for collaboration, so we have selected the most suitable adapter that can be connected to different sensors and meters- Arduino. The Arduino system was programmed to collect data from the temperature, humidity, smoke, and dust sensors, as well as the photodetector and power meter used to measure laser power.

2.4.1. Photodetector (Si PIN)

A silicon PIN photodetector [15] was used to measure the intensity of the laser beam. The photodetector was aligned with the laser output, and its signal was fed into the Arduino system for real-time monitoring. The photodetector's response was calibrated to ensure accurate measurements of the laser's output power.

2.4.2. Power Meter

A high-precision optical power meter was employed to measure the output power of the 980 nm laser [16]. The power meter was placed in the path of the laser beam, and the Arduino system recorded its readings. The power meter provided crucial data on how the environmental conditions affected the laser's power output.

2.5. Data Analysis

We further processed and analyzed the data from the sensors and measuring equipment to examine the impact of environmental concerns on the 980 nm laser. The investigation focused on the temperature's impact by mapping the correlation between temperature and laser output power, while accounting for any resulting changes in wavelength. Impact of Humidity: The relationship between humidity and laser performance, especially when water vapor is present in the atmosphere, leads to absorption of the laser beam. The impact of smoke and particles: Range tests quantified the attenuation of the laser beam due to smoke and particles to assess their influence on visibility. Statistical Examination. The findings undergo a comparative analysis to determine their significance to the research and to align with the published literature on the subject**.**

3. RESULTS

These studies examine the individual effects of temperature, humidity, smoke, and dust density on the 980 nm laser. After the single-shot experiment, the output powers derived from laser and voltmeter measurements under diverse environmental circumstances were assessed.

3.1. Impact of Temperature on Laser Performance

The experiments involved varying the temperature in the controlled environment from 28°C to 55°C and measuring the output power and voltage of the 980 nm laser at each temperature point. The results are summarized in Table 1. This table compares the performance of a 980 nm laser at various temperatures and presents the results for two use cases: "Without message" and "With messages." This reduces the voltage output from 28°C to 55°C, yielding similar results in both cases, with a lower value when the "send message" feature is enabled. This decrease in voltage output with increasing temperature results from a well-known characteristic of semiconductor lasers: they are temperature-sensitive, with higher temperatures enhancing carrier recombination and thus reducing efficiency.

Table 1. Laser Output and Voltmeter under Varying Temperatures.

Temperature (°C)	Without message		With message	
	Voltage Output (V)	Power Meter (µW)	Voltage Output (V)	Power Meter (µW)
28	10.9	322.5	5.8	382.4
31	10.3	317.1	5.5	378.8
34	9.96	296.6	5.2	345.2
37	9.92	290.1	5.0	334.7
40	9.86	286.2	4.8	322.5
43	9.69	273.5	4.7	301.7
46	9.63	265.3	4.5	293.3
49	9.59	257.1	4.1	291.2
52	9.56	251.6	3.8	289.5
55	9.53	233.2	3.7	242.3

In addition, the power output measured by the power meter generally decreases as temperature increases. However, under the "With Message condition, there is an initial increase in power output at lower temperatures (from 28°C to 31°C), possibly due to a temporary boost in the laser's efficiency caused by the "send message" feature. As the temperature rises further, power output declines in both conditions, likely due to thermal effects that degrade the laser's performance. Overall, the "send message" feature appears to reduce the laser's efficiency, resulting to lower voltage and power outputs across most temperature ranges. As shown in Table 1, the output power of the 980 nm laser decreased steadily as the temperature increased. This decline in power output can be attributed to the thermal effects on the laser diode, which affects the efficiency of the laser’s wavelength. The photodetector's output voltage also decreased with increasing temperature, reflecting a reduction in laser intensity.

3.2. Impact of Humidity on Laser Performance

The effect of relative humidity on the performance of the 980 nm laser was assessed by varying the humidity levels from 10% to 80%. The results are summarized in Table 2.

Table 2. Laser Output and Voltmeter under Varying Humidity Levels

Relative Humidity (%)	Without message		With message	
	Voltage Output (V)	Power Meter (µW)	Voltage Output (V)	Power Meter (µW)
10	10.52	310.7	6.2	348.8
25	9.8	305.2	5.4	320.2
35	9.6	294.3	5.1	318.1
45	9.4	283.9	4.6	299.4
55	8.2	277.1	4.2	287.5
60	7.1	270.4	3.9	279.3
65	6.9	146.3	3.7	178.3
70	5.1	130.2	3.5	167.1
75	3.5	122.5	3.0	130.5
80	2.9	117.2	2.7	125.2

In the same way, .in our study, we examined the effect of different humidity conditions on a 980 nm laser with and without the “send message” feature. The results of that analysis help identify how environmental factors and operational aspects influence laser efficiency. As shown in Table 2, there is a clear relationship between increasing humidity levels and decreasing laser output power and voltmeter readings. As the relative humidity rose from 10% to 80%, the power meter readings and voltmeter showed a significant reduction in laser output, with the most pronounced drop occurring between 60% and 80% humidity. This power reduction can be attributed to the scattering and absorption of the laser beam by water vapor in the air, which attenuates the beam and reduces its intensity.

3.3. Impact of Smoke on Laser Performance

The presence of smoke in the experimental chamber was simulated by introducing controlled amounts of smoke into the chamber. The effect of smoke concentration on the 980 nm laser’s performance was measured, considering two scenarios: with and without the "send message" feature, table 3 demonstrates that voltage and power output both decrease significantly as smoke concentration increases from 182 ppm to 268 ppm. This message condition appears to have reduced the voltage outputs across all 3 conditions, suggesting a drop in efficiency for this feature. In the beginning, when only a bit of smoke is present in the laminar mixture, the message feature wear-off point will be at a higher power output, but it decreases significantly as soon as more smoke appears, especially for the "Without Message" condition. This is an indication that the laser works less optimally under smoky conditions, which makes sense taking into account its messaging property.

Table 3: Laser Output and Voltmeter under Varying Smoke Concentrations

Smoke Concentration (ppm)	Without message		With message	
	Voltage Output (V)	Power Meter (µW)	Voltage Output (V)	Power Meter (µW)
182	10	308.1	6.0	366.2
239	9.63	287.2	5.1	294.5
240	7.43	233.4	4.8	291.3
243	6.72	220.4	4.5	287.3
247	5.15	215.7	3.9	226.7
251	4.22	202.4	3.6	208.8
255	3.9	168.5	3.3	175.5
260	2.6	125.8	2.6	168.2
265	1.9	95.6	2.3	127.6
268	1.4	63.1	1.7	94.4

Table 3 shows that as the concentration of smoke increased, the laser’s output power decreased sharply. The power meter readings dropped significantly as smoke concentration increased from 182 ppm to 268 ppm, indicating that smoke particles were scattering and absorbing the laser light, substantially attenuating the beam.

Table 4: Laser Output and Voltmeter under Varying Dust Density

Dust Density mg/m³	Without message		With message	
	Voltage Output (V)	Power Meter (µW)	Voltage Output (V)	Power Meter (µW)
8.57	9.51	261.1	5.6	331.5
18.33	9.42	205.2	4.2	274.3
28.1	8.12	193.5	3.8	232.1
47.63	7.22	171.3	3.3	221.8
67.16	6.85	157.2	3.1	218.3
76.93	5.45	137.4	2.9	164.4
86.69	4.95	119.7	2.6	125.2
115.99	3.25	102.1	2.2	116.8
203.88	2.42	95.5	1.9	103.5
208.44	2.12	80.4	1.7	95.2

The impact of dust density on the performance of a 980 nm laser was explored in Table 4, focusing on two scenarios: one with the "send message" feature and one without it. The dust concentrations were varied between 8.57 mg/m³ and 208.44 mg/m³, and the effect of this on the laser's output was observed. As the dust concentration increased, both the laser's voltage and power output significantly decreased. This suggests that dust particles in the environment interfere with the laser's performance by scattering and absorbing the laser light. The particles create a medium that disrupts the beam's propagation, causing a notable drop in its efficiency. At lower dust concentrations, the interference is less severe, but as the dust concentration rises, the performance degradation becomes more pronounced.

Overall, the environmental factors (humidity, temperature, smoke concentration, and dust density) have measurable effects on the performance of the 980 nm laser, as shown in Figures 1, 2, 3, and 4, and additional effects when "send message" is selected. In both cases where temperature and humidity are higher, voltage and power output decrease significantly across runs, meaning that the messaging functionality only brings them down to even lower levels, indicating further processing complexity and signal interference. As smoke concentration increases, it noticeably affects laser performance, and at that point, even sending a message yields reduced benefits. The adverse effects on laser efficiency by poor environmental conditions and operational features are demonstrated here, stressing that both need to be well-controlled in practical applications.

3.4. Graphical Representation of Results

To visualize the impact of environmental conditions on the 980 nm laser, data from Tables 1, 2, 3, and 4 were plotted in the following figures, which provide a comprehensive visual depiction of the influence of various environmental conditions on the laser's output power. Figure 4 depicts the reduction in laser output power corresponding to rising temperature, humidity, and smoke levels, emphasizing the thermal sensitivity of the 980 nm laser. This demonstrates how ambient heat can diminish laser efficiency. Figure 5 explicitly illustrates the correlation between humidity and laser output power, showing a decrease in output power as humidity increases. This highlights how atmospheric water vapor can attenuate the laser beam, thereby reducing its efficacy.

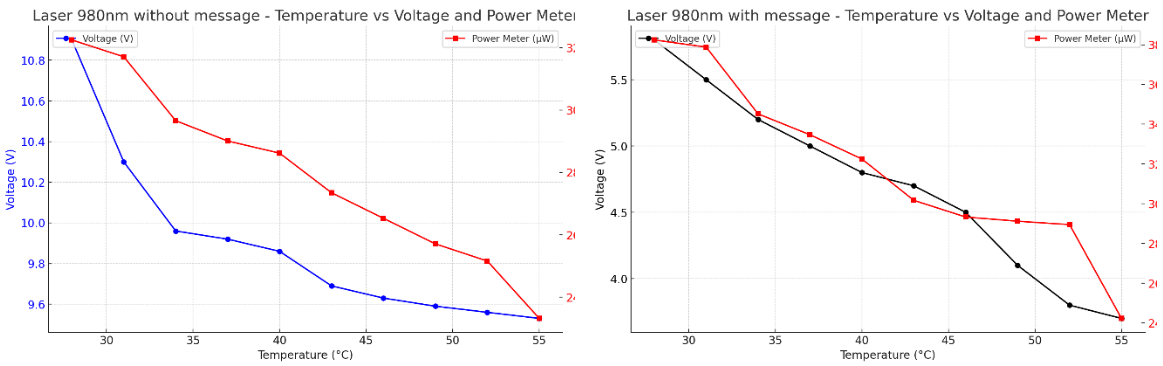


Figure 4. The reduction in laser output power corresponds to rising temperature.

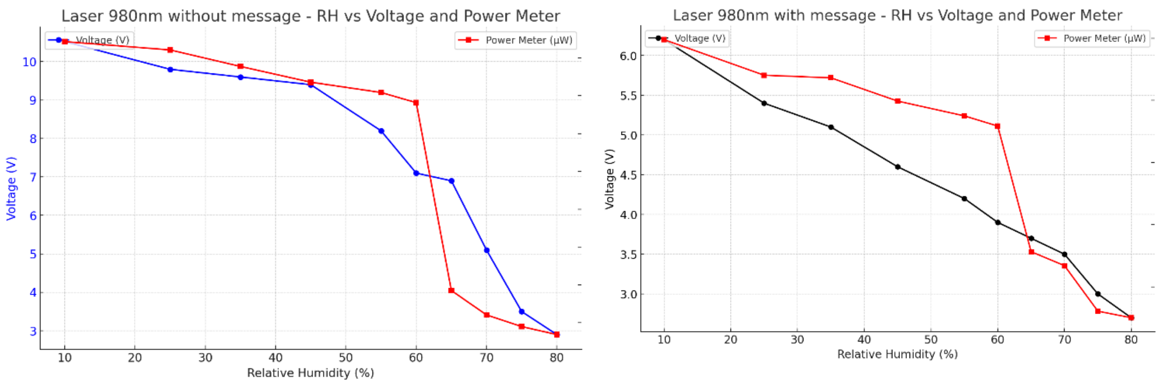


Figure 5. The correlation between humidity and laser output power.

Figure 6 illustrates the significant reduction in laser output power as smoke concentration increases, highlighting the scattering and absorption of laser light by smoke particles, which diminishes its intensity and range. Finally, Figure 7 shows how dust affects laser performance and demonstrates how higher dust density reduces system performance.

Dust particles in the beam path scatter the laser light, causing some of it to stray outside the intended beam path or to be absorbed by surrounding materials. This dispersion means that less power reaches the target. The experimental results for the 980 nm laser show that the power output decreased dramatically from 331.5 μW to 95.2 μW as the dust density increased from 8.57 mg/m³ to 208.44 mg/m³. Dust reduces the laser's efficiency, as evidenced by the inverse relationship between dust density and power stability.

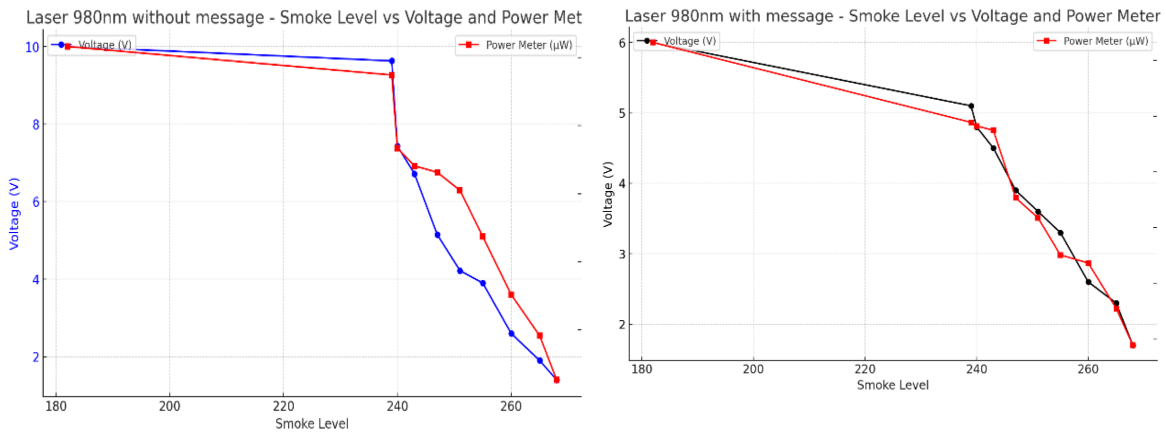


Figure 6. There is a significant reduction in laser output power with smoke concentration.

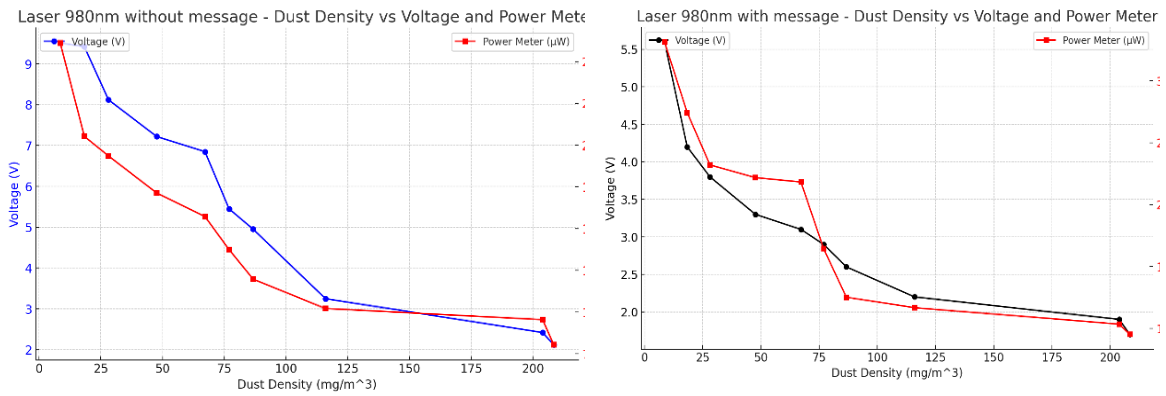


Figure 7. The significant reduction in laser output power with Dust concentration.

4. DISCUSSION

In this study, the experiment provided deep insight into how environmental factors (temperature and humidity, combined with smoke and dust) affect 980 nm infrared laser sterilization. From the results gained, several important observations can be drawn that also have relevance for the practical use of lasers in confronting or changing weather conditions, such as atmospheric turbulence.

4.1. Impact of Temperature on Laser Performance

The experimental data showed a direct relationship between the reduction in laser output power and the increase in temperature. The power output of the 980 nm laser decreased significantly as the experimental chamber temperature increased from 28 °C to 55 °C. The inherent thermal properties of semiconductor lasers could be responsible for this behavior. The carrier density of the laser diode decreases with increasing temperature, reducing the efficiency of the laser's active region. The results showed that, without a message at 28°C: Voltage output 10.9 V, optical power 322.5 μW, and at 55°C: Voltage output 9.53 V, optical power 233.2 μW. The voltage output decreased from 10.9 V to 9.53 V (~1.37 V). The optical power decreased from 322.5 μW to 233.2 μW (~89.3 μW). As a result, increased temperature increases the laser's internal resistance, reducing the efficiency of the electrical-to-optical conversion. At 28 °C, the message showed an output voltage of 5.8 V and an optical power of 382.4 μW. At 55°C, the output voltage is 3.7 V, and the optical power is 242.3 μW. The decrease in output voltage decreased from 5.8 V to 3.7 V (~2.1 V). Optical power decreased from 382.4 μW to 242.3 μW (~140.1 μW).

Despite a significant decrease, the sensor system helps improve signal stability and reduce heat-induced power loss. The study showed that this thermal effect reduces output power. These results highlight the importance of thermal management in laser systems, especially for applications that require precise and stable laser performance. The adverse effects of temperature on laser efficiency could be mitigated by implementing effective cooling mechanisms such as thermoelectric coolers or active cooling systems. Furthermore, integrating temperature sensors and feedback circuits into laser systems could help maintain optimal operating conditions and ensure consistent performance.

4.2. Impact of Humidity on Laser Performance

The experiments also showed that relative humidity significantly affects the performance of the 980 nm laser. The results showed that without the message At 10% Voltage is 10.5 V. Optical power is 310. 7 µW. At 80% voltage is 2.9 V, and the optical power is 117.2 µW. And with the message At 10% the voltage is 6. 2 V, and the optical power is 348. 8 µW. At 80% of the voltage, the optical power is 125.2 µW. There is a gradual and noticeable decrease in both voltage and optical power with increasing humidity. High humidity causes light to be scattered and dispersed by water molecules in the air. Moisture molecules act as scattering agents, which reduces the efficiency of the laser in transmitting the signal. As the humidity increased from 10% to 80%, the laser output power decreased significantly. This power reduction is due to the absorption and scattering of the laser beam by water vapor in the air. Infrared wavelengths such as 980 nm are particularly susceptible to absorption by water molecules, resulting to beam attenuation as it propagates through moist air. For practical applications, these results suggest that humidity control is critical when using 980 nm lasers in environments with fluctuating humidity. In scenarios such as medical procedures or precision cutting where laser power must be constant, maintaining controlled humidity can prevent weakening and ensure the laser performs to its full potential. For outdoor or industrial applications where controlling humidity may be challenging, additional measures, such as protective enclosures or laser wavelengths less susceptible to water vapor absorption, could be considered.

4.3. Impact of Smoke on Laser Performance

The presence of smoke in the experimental environment had a profound impact on the performance of the 980 nm laser. The results showed Without the message 182 the voltage is 10 V. and the optical power is 308.1 µW. At 268 the Voltage is 1.4 V, and the optical power is 63.1µW. With the message at 182 the voltage is 6 V. Optical power = 355.2 µW. At 268 the voltage is 1.7 V. optical power is 94.4 µW, as the smoke concentration increased, the laser's output power decreased sharply. The particles in the smoke scatter and absorb the laser light, causing this attenuation. The fine particles in the smoke act as scattering centers, disrupting the laser beam and reducing its intensity. Given these results, it is clear that the use of lasers in environments with high particle concentrations requires special considerations. Under such conditions, implementing air filtration systems, using smoke-resistant laser designs, or incorporating adaptive optics to correct beam distortions caused by smoke could improve laser performance. Additionally, developing laser systems capable of maintaining effective operation even in the presence of particles would be valuable for critical applications such as firefighting or industrial surveillance.

4.4. Impact of dust on Laser Performance

Environmental factors, such as dust, can significantly impact the laser system's performance and reliability. Dust in the optical path of a laser beam scatters, absorbs, and distorts light, reducing output power and beam quality. This issue may affect communications, industrial, and medical laser settings. As dust particle density increases, scattering becomes more noticeable, weakening laser power. As power decreases, laser signals can become inconsistent, and activities that rely on reliable laser power become less efficient.

Dust scatters laser light in various directions, depending on particle size. At higher dust concentrations, this scattering effect leads to a drastic reduction in laser power. The scattered light either escapes the optical channel or is absorbed by surrounding materials, reducing power to the target. Experimental results for the 980 nm laser showed that increasing the dust density from 8.57 mg/m^3 to 208.44 mg/m^3 resulted in a significant decrease in power output. Without the message, at 8.57 mg/m^3,the Voltage is 9.51 V, and the optical power is 261.1 µW. At 208 mg/m^3 the voltage is 2.12 V and the optical power is 80.4µW. With the message at 8.57 mg/m^3 the voltage is 5.6V, and the optical power is 331.5 µW. At 208.44 mg/m^3, the voltage is 1.7 V. The optical power is 95.2 µW. Dust density hurts laser performance, as evidenced by the inverse relationship between dust density and performance stability. In addition, dust can affect the quality of the laser beam. Dust on lenses and mirrors distorts the beam's focus and intensity profile, resulting to an uneven power distribution. This is particularly problematic in precision applications such as laser cutting and optical measurements. Distorted beam profiles compromise accuracy, increase beam divergence, and compromise signal integrity over long periods.

5. CONCLUSION

This study investigated the effects of key environmental factors temperature, humidity, smoke, and dust on the performance of a 980 nm infrared laser. Experimental results clearly demonstrate that laser output power and signal quality degrade as environmental stress increases. Rising temperatures (28–55 °C) reduced the transmitted power from 382.4 µW to 242.3 µW, while increasing relative humidity (10–80%) caused a significant decrease from 348.8 µW to 125.2 µW. Among all tested factors, smoke and dust had the most severe impact, with laser power dropping from 366.2 µW to 94.4 µW at smoke concentrations of 182–268 ppm, and from 331.5 µW to 95.2 µW as dust density increased from 8.57 mg/m³ to 208.44 mg/m³.

The scientific contribution of this work lies in providing a comprehensive experimental evaluation of how multiple environmental parameters collectively affect 980 nm laser performance, supported by quantitative power measurements under controlled conditions. These findings offer practical insights for designing more robust infrared laser systems for telecommunications, medical, and industrial applications operating in challenging environments.

Limitations: This study was conducted under controlled laboratory conditions, which may not fully represent real-world environments. In addition, the analysis was limited to a single wavelength (980 nm) and a short experimental duration, without considering long-term degradation effects or other environmental influences such as atmospheric pressure, vibration, or electromagnetic interference.

Conflict of Interest:

The authors declare no conflict of interest.

Source of Funding:

This research received no external funding.

Ethical Clearance:

Ethical approval was not required for this study.

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