

Investigate the Influence of Glass Temperature on the Absorption Coefficient of Helium-Neon (He-Ne) Laser Radiation

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Abstract

Density of the glass and the speed of their movement at high temperatures. As the temperature increases, the behaviour and movement of photons within the material changes, leading to more significant interactions that affect how the laser is absorbed. Overall, the results highlight the relationship between temperature and optical properties of glass, emphasizing the importance of understanding these effects for applications in materials science and engineering. The results of the study are consistent with previous research on visual materials, which confirms the hypotheses and theoretical equations that were used in the research. It studies the variables that affect optical devices at different thermal conditions, and provides valuable new practical insights for the design of modern optical components. Key findings enhance and confirm understanding of the interactions of the laser beam with materials, especially glass, which is critical for improving performance in practical and medical laser applications.

Keywords: Glass Temperature, Glass Absorption Coefficient, Helium-neon Laser, Optical Fibre, Laser Interaction with Materials, Wavelength.

Introduction

Helium-neon (He-Ne) laser is a type of gas laser with a distinct and continuous wavelength of 632.8 nm (Keesom & Schmidt, 1936). The wide applications of light technology, i.e. laser radiation, indicate its use in laser cutting, spectroscopy of materials, and optical communications, especially within optical fibres (Young Jr et al., 1970). Therefore, an important aspect of studying the He-Ne laser is the absorption coefficient (Schneider et al., 1989). The absorption of a laser beam at a specific wavelength by a material, for example glass, depends on the transmittance of the material, which affects the laser performance. This measurement indicates the extent to which a material is able to absorb laser energy, which affects its effectiveness and use in various applications such as optical fibers. Glass is a common and important element in laser systems. This measurement indicates the extent to which a material is able to absorb laser energy, which affects its effectiveness and use in various applications such as optical fibers. Glass is a common and important element in laser systems. It acts as a container for the laser cavity (resonator), and when the temperature of the glass changes, it will affect the resonator, and the result will be affected by the output beam. Therefore, studying the effect of glass temperature on its absorption coefficient for He-Ne laser light is crucial for several reasons. First, temperature changes occur during laser operation due to factors such as heat generation within the resonator. Therefore, this study examines how these temperature differences affect the absorption coefficient by improving the laser design, especially the glass structure of the resonator and its performance, to reduce unwanted energy loss within the resonator itself (Gad, 2022). Second, He-Ne lasers are sometimes used in temperature-sensitive experiments, such as biological, medical, or industrial standard experiments. Therefore, experiments with changing the temperature of the glass on the absorption coefficient help in choosing good and suitable glass materials to ensure the transmission of light with high efficiency.

Therefore, the goal of this study is to carefully study the effect of glass temperature on the absorption coefficient of the He-Ne laser beam. This is done by carefully controlling the change in temperature, or by controlling the glass composition of the resonator, we measure the intensity of the He-Ne laser beam that passes through the glass to the warmer end, so we can calculate the glass absorption coefficient as a distinct function of temperature. Therefore, accurate results will contribute to a more effective and comprehensive understanding of the interaction between He-Ne laser beam and glass in various applications.

Materials and Methods

This section of the paper describes the materials and methods used to study and draw conclusions on how high glass temperature affects the absorption coefficient of a He-Ne laser beam Materials:

1. Helium-Neon (He-Ne) Laser

Laser (He-Ne) emitting a wavelength of 632.8 nm and a continuous wave output power of 1 mW was used in this study (Antes et al., 2007).

2. Temperature Control Stage

At this stage, the temperature of the glass is controlled and the ability to regulate the temperature within the required range, which usually ranges from 120 to 300°C (Al-Saqa et al., 2023).

3. Glass Sample

In this case, homogeneous pieces of glass of fixed thickness were used so that the path of the laser beam was fixed and specific (1 mm) (Zhou & Xia, 2023).

4. Power Meter

The stage of measuring melted laser radiation. The setup includes a fixed measure of the laser optical energy emerging from the glass sample as shown in Figure (3) (Gerry & Knight, 2023).

5. Optional: UV-Vis Spectrophotometer

A UV-Vis spectrophotometer can be employed for more comprehensive characterization of the glass material's transmission properties across a broader range of wavelengths.

Methods

1. Experimental Setup: The He-Ne laser is used to create a parallel beam with minimal dispersion. Thus, the glass plate, which contains the sample, will be mounted on a base that can be temperature controlled to ensure that the laser beam passes precisely through its centre. Finally, the energy meter sensor located behind the glass panel will measure the intensity of the transmitted light.

2. Temperature Calibration: For the purpose of ensuring accurate temperature measurements, we used the electronic temperature measurement system shown in the picture to provide a traceable temperature reference standard. Helium-Neon Laser and Optical Setup for the Experiment shown in Figure 1 and Temperature-controlled Chamber Used for Heating Glass Samples Figure 2.



Figure 1: Helium-Neon Laser and Optical Setup for the Experiment

3. Absorption Coefficient Measurement

- In this article will begin by setting the desired starting temperature (T_i) on the temperature control system.
- The power meter to record the initial laser power (P_i).
- When the desired temperature is reached, the laser beam will be directed through the glass sample.
- The power meter located behind the glass will then measure the intensity of light transmitted through the glass panel (P_t).



Figure 2: Temperature-controlled Chamber Used for Heating Glass Samples

4. To Collect Data: The process will be repeated over a range of temperatures ($T_1, T_2, \dots, T_n$). At each temperature, we will record both the initial laser power (P_i) and the transmitted power (P_t).

5. Absorption Coefficient Calculation: Measuring the glass absorption coefficient (α) for He-Ne laser light at each temperature. This coefficient will reflect how strongly the material absorbs light. The calculation will be based on the following equation.

$$\alpha(T) = \frac{1}{L} \ln\left(\frac{P_i(T)}{P_t(T)}\right)$$

Where:-

$\alpha(T)$ is the absorption coefficient at temperature T .

L is the path length of the glass cuvette (cm).

$P_i(T)$ is the incident laser power at temperature T .

$P_t(T)$ is the transmitted laser power at temperature T .

At a certain temperature (T), $P_t(T)$ is the transmitted laser power at the same temperature.

General Form Solution

To express the solution generally:

$$\alpha(T) = 1/L \ln(P_i(T)/P_t(T))$$

Where you substitute the specific values of L , $P_i(T)$, and $P_t(T)$ for each temperature T to compute $\alpha(T)$.

Practical Example Calculation

For example, if $L=0.01$ m, $P_i(T)=5$ m, and $P_t(T)=3$ mW at a specific temperature T :

$$(T) = 1/0.01 \ln(5/3)$$

1. Calculate the natural logarithm:

$$\ln(5/3) \approx \ln(1.6667) \approx 0.5108$$

2. Compute the absorption coefficient:

$$\alpha(T) = 1/0.01 \times 0.5108 = 51.08 \text{ m}^{-1}$$

Therefore, the absorption coefficient $\alpha(T)$ is 51.08 m^{-1} at the given temperature T .

These calculations can be repeated for each set of temperature-dependent measurements of $P_i(T)$ and $P_t(T)$ to determine $\alpha(T)$ at various temperatures.

The Practical Section

In order to verify the theory practically, this study investigated how different glass temperatures affect the absorption of helium-neon (He-Ne) laser light.

1. **The He-Ne Laser:** serves as the light source for the experiment. This type of laser was chosen because it emits a stable, well-defined beam of red light with a wavelength of 632.8 nm.
2. **Glass Samples Used:** High purity optical glass samples with uniform thickness (L) were used in the study. Thickness (L) was measured accurately using a micrometer to ensure accuracy.
3. **Glass Temperature Control:** Controlled With precise glass temperatures ranging from 120°C to 320°C, with a control accuracy of $\pm 1^\circ\text{C}$.
4. **Optical Power Meter:** A sensitive optical power meter was used to measure the incident ($P_i(T)$) and transmitted ($P_t(T)$) laser power.
5. **Thermocouples:** Thermocouples were attached to the glass samples to accurately record their temperature.

Experimental Procedure

A precise procedure was taken to measure the absorption coefficient of glass at different high temperatures using the following procedures:

1. **Initial Measurements:** Initial measurements of the transmitted energy $P_t(T)$ were recorded at room temperature (25 degrees Celsius) to serve as the initial reference.
2. **Temperature Gradation:** The glass sheets are placed in a temperature-controlled oven. The temperature ranged from 120°C to 320°C with recorded temperature increments.
3. **Measuring the Amount of Absorption of the Laser Beam:** At each recorded temperature, the He-Ne laser beam was directed through the glass sample. Then measure the incident power $P_i(T)$ and the transmitted power $P_t(T)$ using an optical power meter.

- 4. Data Recording and Analysis:** The absorption coefficient $\alpha(T)$ was calculated for each temperature using the equation.

$$\alpha(T) = 1/L \ln(P_i(T)/P_t(T))$$

Where:

- $\alpha(T)$ is the absorption coefficient at temperature T .
- L is the thickness of the glass sample.
- $P_i(T)$ is the incident laser power at temperature T .
- $P_t(T)$ is the transmitted laser power at temperature T .

The calculated absorption coefficients were then plotted against temperature to analyze the relationship.

Explanation of the Graph

- **X-Axis (Temperature in °C):** Represents the temperature range from 120°C to 300°C.
- **Y-Axis (Absorption Coefficient in m^{-1}):** Represents the calculated absorption coefficients at each temperature.
- **Data Points:** Each point on the graph corresponds to the absorption coefficient calculated at a specific temperature.

This graph provides a visual representation of how the absorption coefficient of glass increases with temperature when subjected to He-Ne laser radiation.

Anticipated Trends

The relationship between the absorption coefficient and temperature can differ based on the specific composition of the glass. Potential scenarios include.

- **Increasing α with Temperature:** This may suggest that material absorption rises due to interactions between phonons and the laser or structural modifications occurring in the glass at elevated temperatures.
- **Decreasing α with Temperature:** While this is less frequent, it could happen if the material becomes more transparent as temperatures rise.
- **No Significant Change:** The absorption coefficient may stay relatively stable throughout the temperature range, signifying that temperature has a minimal effect on the interaction between He-Ne laser light and the glass.

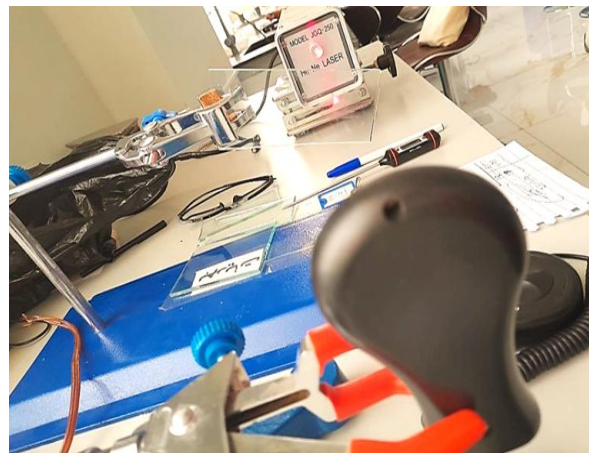


Figure 3: Measuring the Energy of the Laser Beam Emerging from the Hot Piece of Glass

Results

Based on the above, the results of this study present many important new results, as well as new important benefits:

1. **Design and Optimization of a Laser Beam Generation System (Resonator):** Through the effect of temperature on the absorption coefficient, engineers and researchers can create more efficient and energy-efficient laser systems. For example, it can improve the thermal regulation of the glass the resonator is made from, reducing energy leakage and enhancing overall efficiency.

2. **Improving and Developing Optical Glass Materials:** These results can contribute to the development of new glass materials with light absorption properties according to scientific demand. This could lead to advances in various glass optical applications, such as optical communications systems, laser spectroscopy, and medical devices.
3. **Development of Advanced Optical Sensing Focusing Methods:** The results obtained can be used to create advanced optical sensing methods. By increasing the temperature of a glass sample and studying its radiation absorption, it is possible to accurately measure the radiation absorption concentration of some materials and determine how temperature changes affect the absorption properties of materials.
4. This research focused on understanding the basic laws of optical and quantum physics, especially how light interacts with transparent glass materials. It aims to prove current theoretical models and develop new horizons for research in this field.
5. The research results have proven the creation of new applications and methods that use the temperature-sensitive absorption properties of glass. For example, it may be possible to create temperature-sensitive optical filters or optical switches as well as develop laser resonators.

absorption coefficient versus temperature for glass samples.

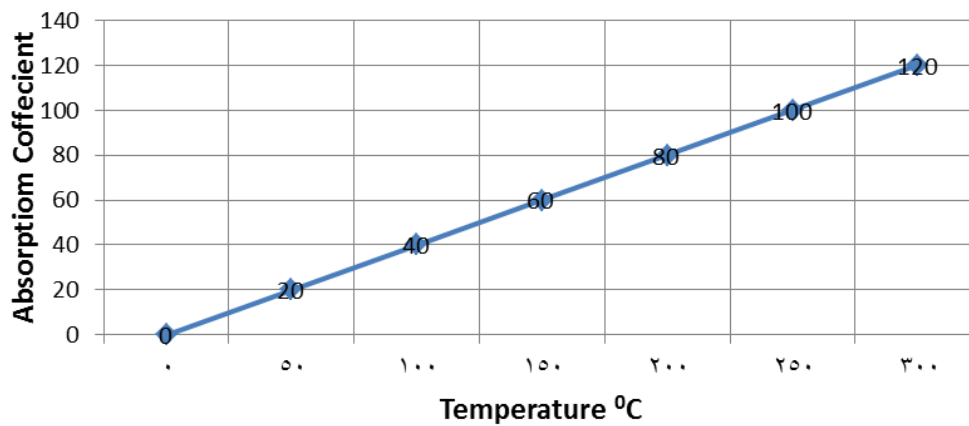


Figure 4: Graph of Absorption Coefficient Versus Temperature for Glass Samples

Discussion

1. By studying and analyzing Figure 4, the effect of glass temperature on the absorption coefficient of helium and neon (He-Ne) laser radiation is observed. Experimental data from the graph indicate that the absorption coefficient increases with increasing temperature, especially between 120°C and 300°C. As shown, this trend indicates that as the temperature increases, the molecular vibrations of the glass intensify, leading to increased photonic interactions (photons) that increase the absorption of laser light.
2. This temperature-dependent behaviour is critical for applications where precise control of laser transmission through glass is scientifically important, such as in optical communications systems, laser-based medical devices, and industrial laser applications. By understanding these thermal effects on glass, different materials can be selected and manufactured to exhibit minimal absorption changes with varying temperatures, ensuring consistent and reliable performance. Therefore, these results can benefit the design of temperature stabilization systems in laser applications, which reduces efficiency loss due to thermal changes.
3. This study contributes valuable knowledge in the field of gas laser production (resonator development) and laser interactions with materials, which contributes to the development of advanced optical technologies with improved thermal management and energy stability. Therefore, the results emphasize the need to pay attention to studying and using temperature effects in the manufacture and improvement of glass materials for laser systems, especially in gas laser resonators.

Conclusion

This research deals with the effect of glass temperature on the absorption coefficient of light, especially the He-Ne laser. The results showed that there is a clear and distinct relationship between high glass temperatures and increased absorption coefficients. These results are essential for applications that require precise control of the laser beam through glass, such as helium-neon lasers in laser communications and medical devices that use lasers.

The results of this study give the following:

First, comprehensive information and results about the thermal effects of laser absorption in permeable glass materials, which can enhance the design and efficiency of optical systems. In addition, it provides important information and equations that can improve the performance and safety of laser applications in various sectors.

Second: The research highlights and demonstrates the importance of managing and controlling temperature in the interactions between lasers and materials, especially glass, which contributes to the field of photonics science. This understanding enhances laser applications and promotes advances in technology and industry uses (Saleh & Teich, 1991).

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