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The Effect of Temperature and Laser Type on Optical Fiber Temperature Coefficient

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Abstract: Optical fibers are widely used in communication and information systems. This needs studying the factors that affect signal quality. In this work and optical fibers having two different laser beams passing through it were exposed to heat by raising temperature from 30°C to 50°C in steps of 2°C. The empirical relation shows linear increase of attenuation coefficient with temperature. This linear relation can shows that the temperature sensitivity of semiconductor and He-Ne laser are 0.01 and 0.4 respectively. This means that using He-Ne laser in transmitting information is better than semiconductor laser because the former is less sensitive to temperature. It also shows that semiconductor laser is suitable to make fiber act as temperature sensor, since its sensitivity is high.

Keywords: Optical Fiber, Attenuation Coefficient, Temperature, Sensor, Sensitivity

1. Introduction

The first theoretical foundation of LASER (Light Amplification by Stimulated Emission of Radiation) and MASER (Microwaves Amplification by Stimulated Emission of Radiation) was given by Einstein in 1917 using Plank's law of radiation that was based on probability coefficients (Einstein coefficients) for absorption and spontaneous and stimulated emission of electromagnetic radiation. *Theodore Maiman* was the first to demonstrate the earliest practical laser in 1960 after the reports by several scientists, including the first theoretical description of *R. W. Ladenburg* on stimulated emission and negative absorption in 1928 and its experimental demonstration by *W. C. Lamb* and *R. C. Rutherford* in 1947 and the proposal of *Alfred Kastler* on optical pumping in 1950 and its demonstration by *Brossel*, *Kastler*, and *Winter* two years later. *Maiman's* first laser was based on optical pumping of synthetic ruby crystal using a flash lamp that generated pulsed red laser radiation at 694 nm. Iranian scientists *Javan* and *Bennett* made the first gas laser using a mixture of He and Ne gases in the ratio of 1: 10 in the 1960. *R. N. Hall* demonstrated the first diode laser made of gallium arsenide (GaAs) in 1962, which emitted radiation at 850 nm, and later in the same year *Nick Holonyak* developed the first semiconductor visible-light-emitting laser. Light produced from the lasers have several valuable characteristics not shown by light obtained from other conventional light sources, which make them suitable for a variety of scientific and technological applications These properties are: Theoretically, waves of light with single frequency v of vibration or single wavelength λ is termed as *single color* or *monochromatic* light source. Practically, no source of light including laser is ideally monochromatic. *Monochromaticity* is a relative term. One source of light may be more monochromatic than others. The most important property of laser is its spectacular monochromaticity. Based on the type of laser media, solid, liquid, or gas and molecular, atomic, or ions, and the type of excitation, produced laser line consists of color bands that range from broad.

Laser can be used in transmitting information through optical fibers. The information can be carried by amplitude, frequency and phase or power meditation or by any suitable modulation process. The carried information can be distorted or subjected to noise by some intrinsic means related to the crystal structure or impurities embedded inside the fiber material. The signal noise can also be caused by external sources like temperature, pressure, external electromagnetic sources. Even the variable magnetic field of the sun spots can also distort the signal.

In hot countries temperature represents on of the unavoidable source of distortion. Temperature change may affect the fiber material, laser beam or even the nature of interaction of laser with fiber material. Different attempts were made to account for the effect of temperature change on optical fiber system [ ]. But, so far, rare studies were made to see how changing the type of laser beam can change the transmitted laser power. This paper is devoted for comparing the effect of temperature change on the attenuation coefficient of optical fiber when two laser types [He-Ne and solid state laser] passes through it. This is done in section 3. Sections 4 and 5 are devoted for discussion and conclusion.

2. Characteristics of Laser Beam

Laser realize stimulated emission of electromagnetic radiation A solid state medium laser have a optical cavity with solid medium in which the electromagnetic radiation emission and amplification take place, a pumping system Pomp system (usually using pulsed emission lamps), and a cooling system. Optical pumping and population inversion are achieved in solid, the radiation emitted in the moment system relaxation is amplified in the optical cavity. By one of which is semi-transparent mirror laser beam is obtained. In the following we address the physical quality of radiation emitted by the lasers.

Monochromaticity The frequency emitted by the laser is given by the difference in energy between the energy levels for which there is radiation emission. It is given by Planck's relationship:

$$v_o = \frac{E_2 - E_1}{h} \tag{1}$$

where: h is the Planck's constant E_2 is upper level energy; E_1 is lower level energy.

The two energy levels between which are laser radiation emission occurs are stable. Thus a single frequency is emitted and amplified in the optical cavity. This means that laser radiation has a single wavelength. This means that the radiation emitted by the laser is monochromatic. Laser with Nd: YAG emits radiation with wavelength of 1.06 µm.

Coherence of electromagnetic radiation means maintaining a constant phase difference between two points of wave front the wave. Coherence is of two types: spatial and temporal. Spatial coherence is limited to a given area and the temporal coherence is limited to a certain time. Laser radiation has high spatial and temporal coherence compared with conventional light sources. Divergence and directionality. The propagation and directionality of radiation is described by diffraction theory. Maximum intensity of radiation is limited by the angle of divergence. In the laser medium will be amplified only radiation propagated on direction of optical cavity axis. Construction of optical cavity leading to a low beam divergence which means a high directionality. For perfectly coherent radiation of aperture D space there will be a given divergence angle from diffraction theory. Angle of divergence is given by:

$$\theta_d = \beta . \frac{\lambda}{D} \tag{2}$$

B = 1.1 is a factor of proportionality While radiation is partially coherent angle of divergence is greater, aperture diameter being replaced by square root of the area of coherence:

$$\theta_d = \beta . \frac{\lambda}{\sqrt{Sc}} \tag{3}$$

The brightness of a light source is defined as the power emitted per unit area and unit solid angle.

$$\beta = \frac{4P}{(\pi D\theta)^2} \tag{4}$$

Maximum brightness is obtained if the radiation emitted is spatially coherent.

$$\beta = \frac{4P}{(\pi\lambda\beta)^2} \tag{5}$$

3. Experimental Work

The experimental work was done in Sudan University of Science & Technology from the following steps:

3.1. Device and Equipment

1. He- Ne laser and Semiconductor.
2. Fiber Optics.
3. Digital AVO-meter model DT9205A.
4. Solar Cell.

3.2. Theory

Light is used in optoelectronics and optical fiber telecommunication for data transmission, in optical fiber interferometers, optical fiber lasers, sensors and optical fiber modulators. The term "light" in fiber transmission, even though commonly used, is not always precise: Light defines only the electro-magnetic radiation from the visual range of 380-780 nm, while in many applications, e. g. optical fiber transmission, the electro-magnetic radiation from near infrared range (850 nm, 1310nm, 1550 nm) is used.

The optical fiber is a waveguide used for transmission of light. It consists of a dielectric fiber core, usually from glass, surrounded by a layer of glass or plastic cladding characterized by the refraction index lower than that of the core. The light transmitted through the optical fiber is trapped inside the core due to the total internal reflection phenomenon. The total internal reflection occurs at the core-cladding interface when the light inside the core of the fiber is incident at an angle greater than the critical angle θθc and returns to the core lossless and allows for light propagation along the fiber. The amount of light reflected at the interface changes depending on the incidence angle and the refraction indexes of the core and the cladding. presents the idea of the light propagation in the cylindrical optical fiber due to the total internal reflection.

The passage of laser beam through the fiber obeys snell's law. Consider two dielectric media with different refractive indices and with $n1 > n2$ and that are in perfect contact. At the interface between the two dielectrics, the incident and refracted rays satisfy Snell's law of refraction—that is:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad (6)$$

Light rays will be confined inside the fiber core if it is input-coupled at the fiber core end-face within the acceptance angle θa. The equation which defines the angle within which the fiber can accept and propagate light and is referred to as the "Numerical Aperture" (NA).

$$NA = n_o \sin\theta_{acc} = \left(n_1^2 - n_2^2\right)^{1/2} \quad (7)$$

When the medium with refractive index n_0 is air, the equation for the NA of the glass fiber simplifies to This equation states that for all angles of incident where the inequality $0 \le \theta_1 \le \theta_{acc}$ is satisfied the incident ray will propagate within the fiber. The parameter NA expresses the propensity of the fiber to accept and propagate light within the solid cone defined by an angle, 2qacc. The equation for the NA can be also expressed in terms of the difference between the refractive indices of core and cladding—that is,

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} = \frac{n_1 - n_2}{n_1} \quad (8)$$

With these simplifications the NA can now be written as:

$$NA = n_1 \left(2\Delta\right)^{1/2}$$

Signal attenuation within optical fibers is usually expressed in the logarithmic unit of the decibel. The decibel, which is used for comparing two *power* levels, may be defined for a particular optical wavelength as the *ratio* of the output optical power Po from the fiber to the input optical power Pi. Loss (dB) = - 10 log (Po/Pi) = 10 log (Pi/Po)

$$P_o \le P_i \quad (9)$$

In *electronics,*

dB = 20 log (Vo/Vi)

The logarithmic unit has the advantage that the operations of multiplication (and division) reduce to addition (and subtraction). In numerical values:

$$Po/Pi = 10^{[-Loss(dB)/10]}$$

The attenuation is usually expressed in decibels per unit length (dB/km):

$$\alpha L = 10\log\frac{P_o}{P_i} \quad (10)$$

α (dB/km): signal attenuation per unit length in decibels.
L (km): fiber length

3.3. Methodology

Laser beams passing through optical fiber and it was exposed to heat by raising temperature from 30°C to 50°C in steps of 2°C. The out signal from fiber optic was measured by receiving the laser input and output power by using photocell which can verts light energy to electric energy. The voltage of the cell was measured by digital AVO-meter model (DT9205A) the results recorded in the table 1 has been carried out through experimental work using two types of Laser, He- Ne Laser and Semiconductor Laser.

Table 1. *Change of attenuation coefficient with fiber temperature for He-Ne laser and semiconductor laser.*

$T/°C$	Laser He-Ne			Semiconductor laser		
	V/mv	$\ln\frac{V_i}{V_o}$	∝	V/mv	$\ln\frac{V_i}{V_o}$	∝
30	101.6	0.674	9.324	156.7	0.536	0.254
32	100.7	0.683	9.946	155.5	0.544	0.271
34	99.9	0.691	10.568	153.7	0.555	0.288
36	97.8	0.712	11.189	153.2	0.559	0.305
38	96.4	0.727	11.811	152.8	0.561	0.322
40	95.8	0.733	12.433	151.9	0.567	0.339
42	94.2	0.750	13.055	151.1	0.572	0.356
44	92.9	0.786	13.680	150.9	0.574	0.373
46	90.0	0.796	14.290	150.7	0.575	0.390
48	89.5	0.801	14.920	150.1	0.579	0.406
50	88.6	0.811	15.540	149.1	0.586	0.423

By using equation (10) and assuming the current I to be pro portional to the voltage V for constant resistance R:
V = RI
Thus:

$$\alpha = \frac{1}{L} 10 Log \frac{R_i V_o^2}{R_o V_i^2}$$

$$\alpha = \frac{10}{L}\left[2Log\frac{V_o}{V_i} + Log\frac{R_i}{R_o}\right] \quad (11)$$

4. Results and Discussion

The effect of temperature on optical fiber attenuation coefficient is very important especially at the day when the sun shine. This requires intensive researches to see the degree of this effect and how to reduce it or even to use it in measuring temperature. The temperature of the fiber is increased from 30 to 50°C in steps of 2°C. The attenuation coefficient $\propto$ was found at each temperature by using equation (11) and measuring input voltage V_i and output voltage V_o of the laser signal (He-Ne) and semiconductor. The relation between attenuation coefficient $\propto$ and temperature T is shown in figures 1 and 2. The two graphs for laser signal (He-Ne) and semiconductor shows linear relation between $\propto$ and T. This relation indicates that the optical fiber can be used as a sensor. The sensitivity of, the He-Ne laser is 0.4 while that of the semiconductor is 0.01. This means that semiconductor laser makes fiber more sensitive to temperature than He-Ne laser.

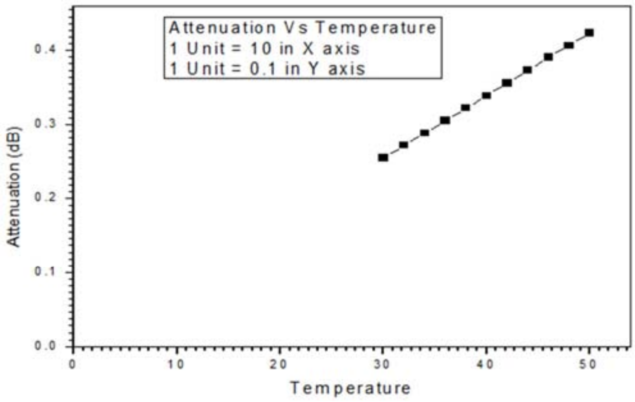

Figure 1. *Attenuation coefficient versus temperature for He-Ne laser.*

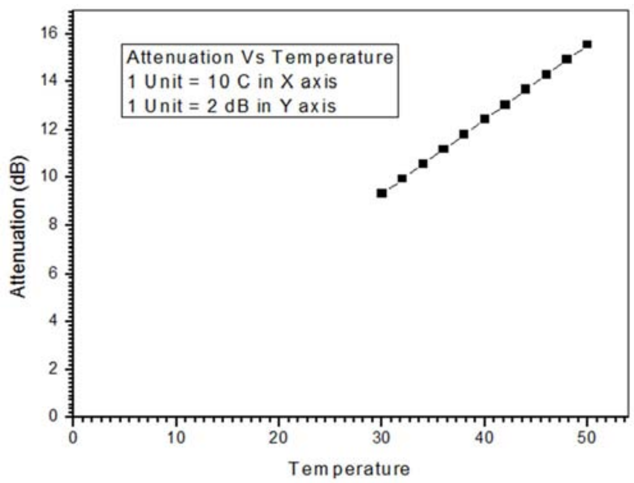

Figure 2. *Attenuation coefficient versus temperature for Semiconductor laser.*

5. Conclusion

The sensitivity of optical fiber to temperature increases when semiconductor laser beam passes through it compared to He-Ne laser. Thus to minimize laser signal noise it is suitable to used He-Ne laser beam. However semiconductor laser is preferable when using fiber as temperature sensor.

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