OPTICAL FIBER TRANSMISSION TECHNOLOGY AND LABORATORY WORK

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OPTICAL FIBER TRANSMISSION TECHNOLOGY AND LABORATORY STUDIES

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To my beloved Mother and Father

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ABSTRAK

Sejak gentian optik dikormersialkan pada 1970-an, teknologi gentian optik telah berkembang selama tiga dekad. Teknologi ini berkembang dengan amat pesat sehingga ia mempengaruhi manusia sejagat. Ia dijangka akan menjadi entiti biasa dalam setiap rumah pada masa akan datang. Dengan pemikiran ini, projek ini mengaji aplikasi-aplikasi gentian optik dalam telekomunikasi, perubatan, dan ketenteraan. Di sampin itu, teknologi struktur SMART juga dikaji di mana gentian optik digunakan sebagai pengesang. Kajian-kajian makmal juga dibuat untuk mengaji ciri-ciri pelbagai jenis gentian optik.

ABSTRACT

Optical fiber technology has spanned over 3 decades since the first commercialized fiber optic was made in 1970s. The technology grows so fast that it virtually affects every human of this world. And it is predicted that in the near future fiber optic will become a common entity in every home. With this anticipation in mind, this project is devoted to study the application of fiber optic in telecommunication, medical and military fields. Study is also made on SMART structures technology where fiber optic being the used as sensors. Laboratory work and software simulation are also carried out to study the properties of the different types of fiber optics.

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1 INTRODUCTION

1.1 Introduction to This Project

The first goal of this project is to gain a better understanding of the principles of operations behind the applications of Optical Fibers in telecommunication, medical, military, and sensors industries. The second goal is to understand the properties of different types of optical fibers. Laboratory and software simulation works are carried out as means to achieve the second goal.

1.2 History of Fiber Optics in Brief

The principle of the total internal reflection was studied by Tyndall in the 1850s. Hundred years later, the principle found its application in optical fiber which is used extensively in the medical and non-destructive testing fields, lighting effects and telecommunications industry. Today, optical fibers have become the leading technology in the various industries that promises to bring them into a higher level of discoveries and achievements.

The evolution of optical fibers roughly can be divided into three stages. The first stage used visible and near-IR (from 600 – 920nm) light sources combined with fiber bundles. The second stage used single, multimode fibers as the channel, with the sources still in the visible and near IR (called short-wavelength sources). The third stage uses so-called long-wavelength sources operation between 1300 and 1600nm in concert with fiber of smaller diameters (called single-mode fibers).

Current development of fiber-optic communication systems are proceeding in two directions. The first is high-data-rate systems for long distance or high throughput applications using long-wavelength sources and single-mode fibers, combined with optical amplifiers. The second direction is toward high-density, short-distance, moderate-data-rate applications such as home data services and computer local area networks (LANs).

1.3 Fundamentals of Fiber Optics

Fiber Optics is a hybrid field that started as a branch of optics. To understand fiber-optic communications, it is essential to have basic knowledge of three fields namely optics, electronics, and communications.

1.3.1 Basics of Optics

The workings of optical fibers depend on basic principles of optics and the interaction of light with matter. The first step in understanding fiber optics is to review the relevant parts of geometrical optics.

From a physical standpoint, light can be seen either as electromagnetic waves or as photons, quanta of electromagnetic energy. This is the wave-particle duality of modern physics. The other useful viewpoint for optics is to consider light as rays traveling in straight line between or within optical elements, which can reflect or refract light ray at their surfaces.

1.3.2 The Electromagnetic Spectrum

Visible light is only a small part of the spectrum of electromagnetic radiation. This radiation travels at the speed of light (c), which is approximately 300,000 kilometers per second (km/s). The quantity that differs in different parts of the spectrum can be measured in several ways. Three areas that are of concern in the study of optical fiber communication are the wavelength (m), the photon energy (eV), and the oscillation frequency (Hz). The relationship between these three measurements is compared physically in the Figure 1.1

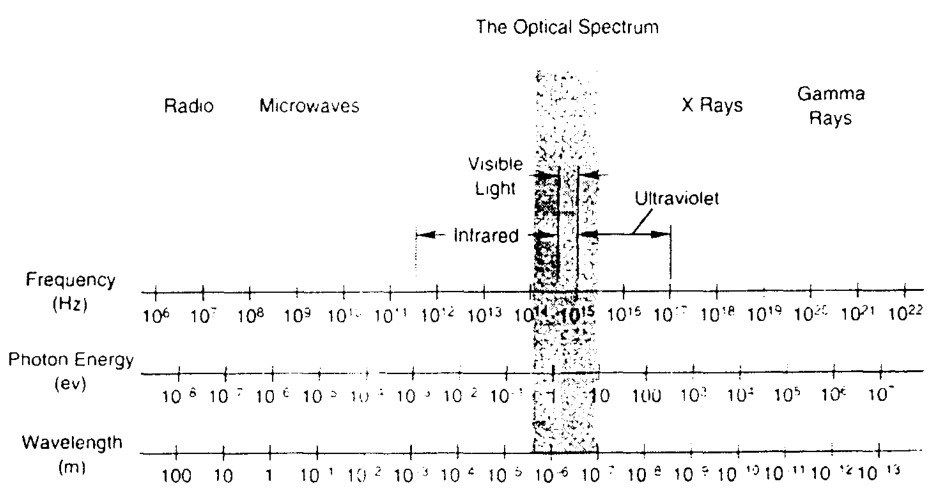

Figure 1.1 Electromagnetic Spectrum [2]

Most of the optical devices work within the shaded region which the wavelength is between 200 – 20,000nm (0.2 – 20μm). However, most light sources for optical fibers communication transmit light at frequency range between 700 – 1600nm (0.7 – 1.6μm).

The relationship between the frequency and wavelength can be determined by the formula below:

$$\lambda = c_0/f \qquad (1.1)$$

Where, λ is the wavelength in meter, f is the frequency in Hertz, and c_0 is the speed of light in vacuum = 3×10^8 m/s.

While the relationship between the photon energy (E) and the frequency can be determined by the Planck's law:

$$E = hf \qquad (1.2)$$

Where E is the photon energy in joules, h is the Planck's constant = 6.626×10^{-34} joule-second and f is the frequency in Hertz.

Formulae 1.1 and 1.2 give another useful formula that determines the relationship between photon energy and the wavelength:

$$E(eV) = 1.2406/\lambda\ (\mu) \qquad (1.3)$$

1.3.3 Refractive Index

Refractive index (n) is the most important optical measurement for any transparent material. It is the ratio between the speed of light in vacuum to the speed of light in the material:

$$n = c_{vac}/c_{mat} \qquad (1.4)$$

Refraction or bending of light occurs when it passes through a surface where the refractive index changes. The amount of bending depends on the refractive indices of the two media and the angle at which the light strikes the surface between them. The relationship between the refractive indexes and the refractive angles are governed by Snell's Law which states:

$$n_i \sin I = n_r \sin R \qquad (1.5)$$

where n_i and n_r are the refractive indexes of the initial medium and the medium into which the light is refracted, and I and R are the angles of incidence and refraction respectively, as shown in Figure 1.2.

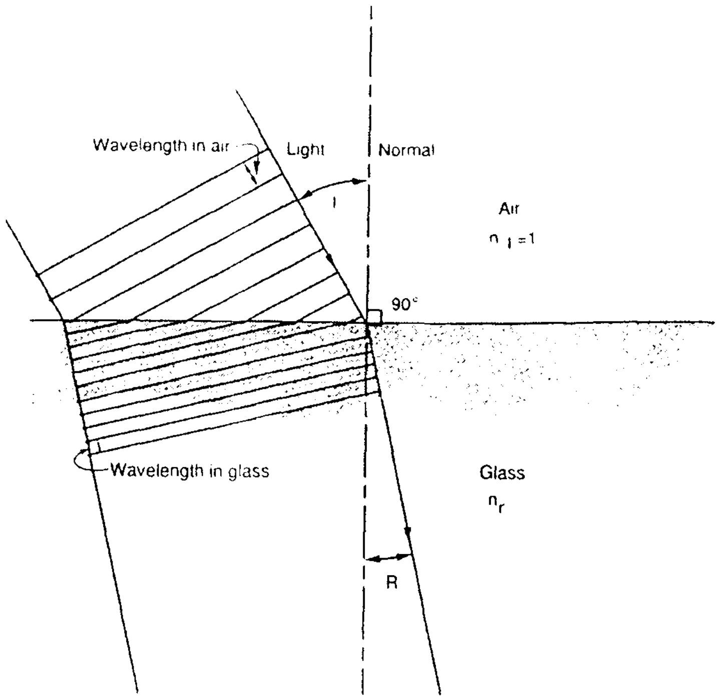

Figure 1.2 Light refraction as it enters glass [2]

Snell's law indicates that refraction cannot take place when the angle of incidence is too large. Light bounces back into the glass when the incidence angle exceeds a value called the critical angle.

$$\theta_c = \text{arcsine}\ (n_r/n_i) \qquad (1.6)$$

This is when the phenomenon called total internal reflection occurs. Here, the angle of incidence equals to the angle of reflection as shown in Figure 1.3. It is this total internal reflection that keeps light confined in optical fibers.

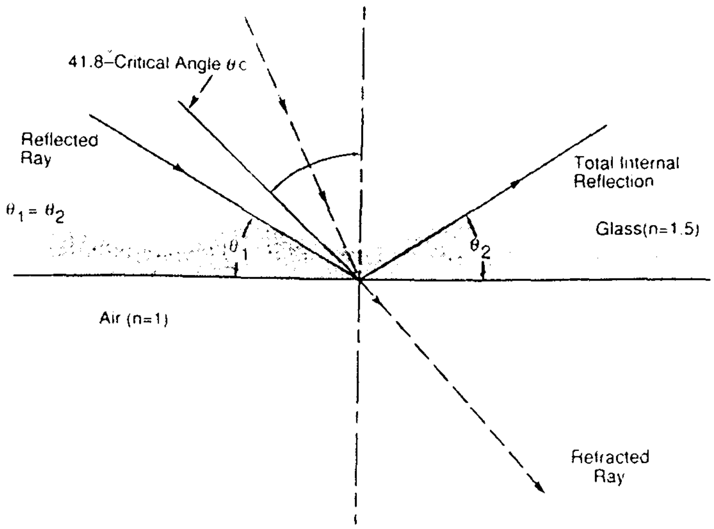

Figure 1.3 Refraction and total internal reflections [2]

1.3.4 Light Guiding

Two basic element of an optical fiber are its core and cladding. The core is the inner part of the fiber, through which light is guided. The cladding surrounds it completely. The refractive index of the core must be higher than the cladding so that light can be confined in the fiber through total internal reflection as shown in Figure 1.4.

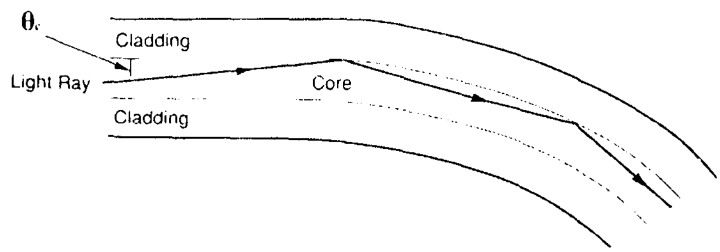

Figure 1.4 Light guiding in an optical fiber [2]

Another aspect of light guiding property in a fiber is the acceptance angle – the angle which the light ray entering the fiber so that it will be guided along its core. It is normally recognized as the numerical aperture (NA) which can be calculated by the formulae:

$$NA = (n_0^2 - n_1^2)^{1/2} \qquad (1.7)$$

$$NA = n_0 \sin\theta_c \qquad (1.8)$$

Where n_0 and n_1 is the refractive index of the core and cladding respectively and θ_c is the confinement angle as shown in Figure 1.5.

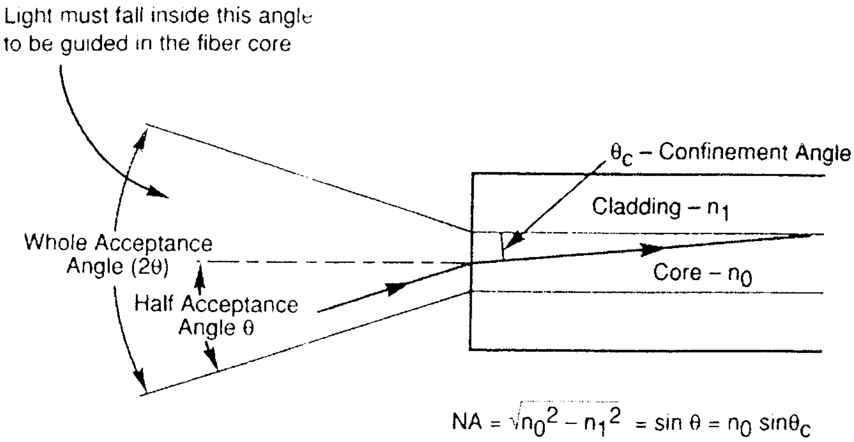

Figure 1.5 Measuring the acceptance angle [2]

Because the acceptance angle is very limited due to the size of the optical fiber itself, a very narrow beam of light source is required in order to effectively couple enough light energy into the fiber core. For small-core fibers, the best match is a semiconductor diode laser, which emits light from a region a fraction of a micrometer high and a few micrometers wide. Light emitting diodes (LEDs), with larger emitting areas, work well with larger-core fibers.

Optical fibers can be joined together through splice, connector or couplers. Unlike the metal-wire counterparts, the transferring light between fibers requires careful alignment and tight tolerances.

1.3.5 Transmission and Attenuation

Attenuation in optical fiber could be caused by the absorption by materials within the fiber, scattering of light out of the fiber core, and leakage of light out of the core caused by environmental factors. The degree of attenuation depends on the wavelength of light transmitted.

Attenuation measures the reduction in signal strength by comparing output power with input power. It can be measured with the formula:

$$\text{dB LOSS} = -10 \times \log_{10}(\text{POWER OUT/POWER IN}) \_\_\_\_\_\_\_\_ (1.9)$$

1.3.6 Dispersion

An optical signal is said to be dispersed when its shape changes as it travels along the optical fiber. It is caused by two dominant mechanisms referred to as Intermodal and Intramodal dispersion.

Intermodal Dispersion

Intermodal dispersion happens when there are more than one mode is excited in an optical fiber. Different mode reaches the destination through different paths thus caused the signal to be distorted as the different modes recombine at the end of the fiber. Figure 1.6 illustrates intermodal dispersion.

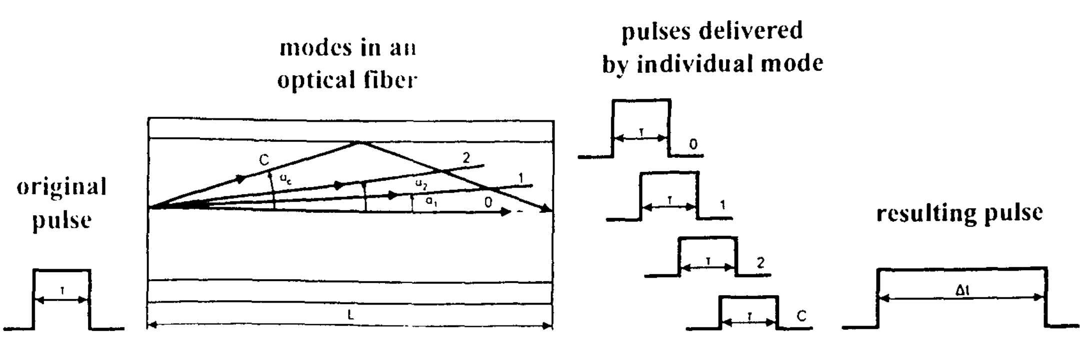

Figure 1.6 Intermodal dispersion [5]