A STUDY ON ANALYSIS OF CONSTRUCTION AND WORKING OF OPTICAL FIBERS

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Abstract: An **optical fiber** or **optical fiber** is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair. Optical fibers are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths (data rates) than electrical cables. Fibers are used instead of metal wires because signals travel along them with less loss; in addition, fibers are immune to electromagnetic interference, a problem from which metal wires suffer excessively. Fibers are also used for illumination and imaging, and are often wrapped in bundles so they may be used to carry light into, or images out of confined spaces, as in the case of a fiberscope. Specially designed fibers are also used for a variety of other applications, some of them being fiber optic sensors and fiber lasers.

Keywords: Introduction, History of optical fibers, Working Process, fiber optics process, etc…………

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Optical fibers typically include a core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by the phenomenon of total internal reflection which causes the fiber to act as a waveguide.[5] Fibers that support many propagation paths or transverse modes are called multi-mode fibers, while those that support a single mode are called single-mode fibers (SMF). Multi-mode fibers generally have a wider core diameterand are used for short-distance communication links and for applications where high power must be transmitted Single-mode fibers are used for most communication links longer than 1,000 meters (3,300 ft).

Being able to join optical fibers with low loss is important in fiber optic communication. This is more complex than joining electrical wire or cable and involves careful cleaving of the fibers, precise alignment of the fiber cores, and the coupling of these aligned cores. For applications that demand a permanent connection a fusion splice is common. In this technique, an electric arc is used to melt the ends of the fibers together. Another common technique is a mechanical splice, where the ends of the fibers are held in contact by mechanical force. Temporary or semi-permanent connections are made by means of specialized optical fiber connectors.

HISTORY OF OPTICAL FIBERS:

Guiding of light by refraction, the principle that makes fiber optics possible, was first demonstrated by Daniel Colladon and Jacques Babinet in Paris in the early 1840s. John Tyndall included a demonstration of it in his public lectures in London, 12 years later. Tyndall also wrote about the property of total internal reflection in an introductory book about the nature of light in 1870:

When the light passes from air into water, the refracted ray is bent *towards* the perpendicular... When the ray passes from water to air it is bent *from* the perpendicular... If the angle which the ray in water encloses with the perpendicular to the surface be greater than 48 degrees, the ray will not quit the water at all: it will be *totally reflected* at the surface.... The angle which marks the limit where total reflection begins is called the limiting angle of the medium. For water this angle is 48°27′, for flint glass it is 38°41′, while for diamond it is 23°42′.

In the late 19th and early 20th centuries, light was guided through bent glass rods to illuminate body cavities. Practical applications such as close internal illumination during dentistry appeared early in the twentieth century. Image transmission through tubes was demonstrated independently by the radio experimenter Clarence Hansell and the television pioneer John Logie Baird in the 1920s. In the 1930s, Heinrich Lamm showed that one could transmit images through a bundle of unclad optical fibers and used it for internal medical examinations, but his work was largely forgotten.

In 1953, Dutch scientist Bram van Heel first demonstrated image transmission through bundles of optical fibers with a transparent cladding. That same year, Harold Hopkins and Narinder Singh Kapany at Imperial College in London succeeded in making image-transmitting bundles with over 10,000 fibers, and subsequently achieved image transmission through a 75 cm long bundle which combined several thousand fibers.[14] Their article titled "A flexible fibrescope, using static scanning" was published in the journal *Nature* in 1954.[15][16] The first practical fiber optic semi-flexible gastroscope was patented by Basil Hirschowitz, C. Wilbur Peters, and Lawrence E. Curtiss, researchers at the University of Michigan, in 1956. In the process of developing the gastroscope, Curtiss produced the first glass-clad fibers; previous optical fibers had relied on air or impractical oils and waxes as the low-index cladding material. A variety of other image transmission applications soon followed.

Kapany coined the term *fiber optics*, wrote a 1960 article in *Scientific American* that introduced the topic to a wide audience, and wrote the first book about the new field. The first working fiber-optical data transmission system was demonstrated by German physicist Manfred Börner at Telefunken Research Labs in Ulm in 1965, which was followed by the first patent application for this technology in 1966.[18][19] NASA used fiber optics in the television cameras that were sent to the moon. At the time, the use in the cameras was classified *confidential*, and employees handling the cameras had to be supervised by someone with an appropriate security clearance.

Charles K. Kao and George A. Hockham of the British company Standard Telephones and Cables (STC) were the first, in 1965, to promote the idea that the attenuationin optical fibers could be reduced below 20 decibels per kilometer (dB/km), making fibers a practical communication medium. They proposed that the attenuation in fibers available at the time was caused by impurities that could be removed, rather than by fundamental physical effects such as scattering. They correctly and systematically theorized the light-loss properties for optical fiber, and pointed out the right material to use for such fibers—silica glass with high purity. This discovery earned Kao the Nobel Prize in Physics in 2009.

The crucial attenuation limit of 20 dB/km was first achieved in 1970 by researchers Robert D. Maurer, Donald Keck, Peter C. Schultz, and Frank Zimar working for American glass maker Corning Glass Works. They demonstrated a fiber with 17 dB/km attenuation by doping silica glass with titanium. A few years later they produced a fiber with only 4 dB/km attenuation using germanium dioxide as the core dopant. In 1981, General Electric produced fused quartz ingots that could be drawn into strands 25 miles (40 km) long.

Initially high-quality optical fibers could only be manufactured at 2 meters per second. Chemical engineer Thomas Mensah joined Corning in 1983 and increased the speed of manufacture to over 50 meters per second, making optical fiber cables cheaper than traditional copper ones. These innovations ushered in the era of optical fiber telecommunication.

The Italian research center CSELT worked with Corning to develop practical optical fiber cables, resulting in the first metropolitan fiber optic cable being deployed in Turin in 1977. CSELT also developed an early technique for splicing optical fibers, called Springroove.

Attenuation in modern optical cables is far less than in electrical copper cables, leading to long-haul fiber connections with repeater distances of 70–150 kilometers (43–93 mi). The erbium-doped fiber amplifier, which reduced the cost of long-distance fiber systems by reducing or eliminating optical-electrical-optical repeaters, was co-developed by teams led by David N. Payne of the University of Southampton and Emmanuel Desurvire at Bell Labs in 1986.

The emerging field of photonic crystals led to the development in 1991 of photonic-crystal fiber, which guides light by diffraction from a periodic structure, rather than by total internal reflection. The first photonic crystal fibers became commercially available in 2000. Photonic crystal fibers can carry higher power than conventional fibers and their wavelength-dependent properties can be manipulated to improve performance.

Record speeds

Achieving a high data rate and covering a long distance *simultaneously* is challenging. To express this, sometimes the product of data rate and distance is specified—*(bit/s)×km* or the equivalent *bit×km/s*, similar to the bandwidth–distance product.

- **2006** – Nippon Telegraph and Telephone transferred 14 terabits per second (Tbit/s) over a single 160 km long optical fiber: 2.2 (Pbit/s)·km
- **2009** – Bell Labs in Villarceaux, France transferred 15.5 Tbit/s over 7000 km fiber: 108 (Pbit/s)·km
- **2010** – Nippon Telegraph and Telephone transferred 69.1 Tbit/s over a single 240 km fiber: 16.5 (Pbit/s)·km
- **2012** – Nippon Telegraph and Telephone transferred 1 Pbit/s over a single 50 km fiber: 50 (Pbit/s)·km

Optical fiber refers to the technology associated with data transmission using light pulses travelling along with a long fiber, usually made of plastic or glass. Transmission using fiber optic communication is preferred to use metal wires as signals are able to travel with less losses. Optical fibers are also unaffected by electromagnetic interference. The fiber optic cable uses the application of Total Internal Reflection of light.

The fibers are designed such that they facilitate the propagation of light along the optical fiber depending on the requirement of power and distance of transmission. A single mode fiber is used for long distance transmission while a multimode fiber is used for shorter distances. The outer cladding of optical fibers need better protection than metal wires.

The optical fiber works on the principle of total internal reflection. Light rays can be used to transmit huge amount of data but there is a problem here… light rays travel in straight lines. So unless we have a straight long wire without any bends at all, harnessing this advantage will be very tedious. Instead, the optical cables are designed such that they bend all the light rays inwards (using TIR). Light rays travel continuously bouncing off the optical fiber walls and transmitting end to end data. Although light signals do degrade over progressing distances, depending on purity of material used, the loss is much less compared to using metal cables.

What Is Fiber Optics And How Does It Work?

Most of us understand that information travels in different ways. When we use our cell phones, for example, our phones send and receive information wirelessly using invisible radio waves. When we make a call through the landline, our voices are transmitted through a series of wire cables. Fiber optics works a little differently. Originally developed for endoscopes in the 1950's, fiber optics is the transmission of information coded in a beam of light, through a glass or plastic pipe. Engineers discovered a way to use this technology to transmit phone calls at the speed of light (300,000km per second), and this speed is one of the main reasons that fiber optics is such a hot buzzword today.

FIBER OPTIC NETWORK CABLING TECHNOLOGY

A fiber optic cable is made up of 100 or more strands of glass or plastic called optical fibers, each one about one tenth as thick as a human hair. The purpose of fiber optic cables is to carry information between two points. If you're interested in a **network cabling career**, you'll know that this technology is being used increasingly in the TV, internet and telecommunications fields.

HOW FIBER OPTICS WORKS

In a fiber optic cable, information in the form of light travels by repeatedly bouncing off the glass cable walls. The light is able to stay within the cable due to its structure, which is divided into two separate parts.The center of the cable, called the core, is the section that light travels through. The core is encased in another layer of glass called the cladding, which is made from yet another type of glass or plastic keeping the light signals inside the core. If you're considering **network cabling training** and are interested in the technicalities, the cladding has a lower refractive index than the core, which causes total internal reflection that keeps signals bouncing down the core.

FROM NETWORK CABLING TO THE MEDICAL OFFICE

The most basic type of fiber optic cable falls into a category called single-mode. This type of cable has a very thin core that is about 5-10 microns (millionths of a meter) in diameter. As you may learn in **network cabling courses**, cable TV, internet and telephone signals using fiber optic technology typically use single-mode fibers wrapped into a huge bundle. Multi-mode is another type of fiber optic cable. Each optical fiber in a multi-mode cable is about 10 times the size of those used in single-mode cables. Although used in many applications, multi-mode cabling is typically used to link computer networks together. A much thicker type of cable is used in a gastroscope. A gastroscope (a type of endoscope) is used by doctors to see down someone's throat into their digestive tract to check for illness in the stomach. A gastroscope is a thick fiber optic cable consisting of many optical fibers. There's even a thicker version of the tool, called a fiberscope which is used to examine inaccessible areas of aircraft engines.

PRINCIPLE OF OPERATION:

An optical fiber is a cylindrical dielectric waveguide (nonconducting waveguide) that transmits light along its axis, by the process of total internal reflection. The fiber consists of a *core* surrounded by a cladding layer, both of which are made of dielectric materials. To confine the optical signal in the core, the refractive index of the core must be greater than that of the cladding. The boundary between the core and cladding may either be abrupt, in *step-index fiber*, or gradual, in *graded-index fiber*.

Index Of Refraction

The index of refraction (or refractive index) is a way of measuring the speed of light in a material. Light travels fastest in a vacuum, such as in outer space. The speed of light in a vacuum is about 300,000 kilometers (186,000 miles) per second. The refractive index of a medium is calculated by dividing the speed of light in a vacuum by the speed of light in that medium. The refractive index of a vacuum is therefore 1, by definition. A typical single mode fiber used for telecommunications has a cladding made of pure silica, with an index of 1.444 at 1500 nm, and a core of doped silica with an index around 1.4475.[51] The larger the index of refraction, the slower light travels in that medium. From this information, a simple rule of thumb is that a signal using optical fiber for communication will travel at around 200,000 kilometers per second. To put it another way, the signal will take 5 milliseconds to travel 1,000 kilometers in fiber. Thus a phone call carried by fiber between Sydney and New York, a 16,000-kilometer distance, means that there is a minimum delay of 80 milliseconds (about of a second) between when one caller speaks and the other hears. (The fiber in this case will probably travel a longer route, and there will be additional delays due to communication equipment switching and the process of encoding and decoding the voice onto the fiber).

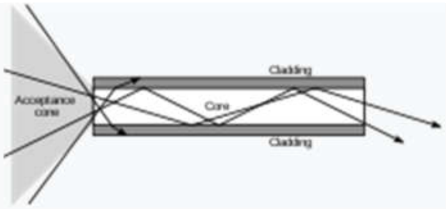
Most modern optical fiber is *weakly guiding*, meaning that the difference in refractive index between the core and the cladding is very small (typically less than 1%)

Total internal reflection

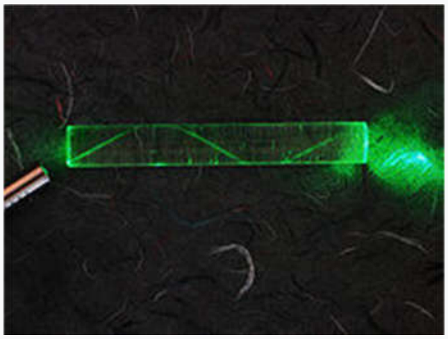
When light traveling in an optically dense medium hits a boundary at a steep angle (larger than the critical angle for the boundary), the light is completely reflected. This is called total internal reflection. This effect is used in optical fibers to confine light in the core. Light travels through the fiber core, bouncing back and forth off the boundary between the core and cladding. Because the light must strike the boundary with an angle greater than the critical angle, only light that enters the fiber within a certain range of angles can travel down the fiber without leaking out. This range of angles is called the acceptance cone of the fiber. The size of this acceptance cone is a function of the refractive index difference between the fiber's core and cladding.

In simpler terms, there is a maximum angle from the fiber axis at which light may enter the fiber so that it will propagate, or travel, in the core of the fiber. The sine of this maximum angle is the numerical aperture (NA) of the fiber. Fiber with a larger NA requires less precision to splice and work with than fiber with a smaller NA. Single-mode fiber has a small NA.

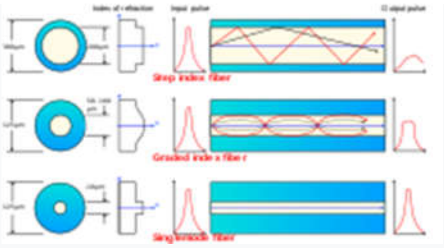
Multi-mode fiber



The propagation of light through a multi-mode optical fiber.



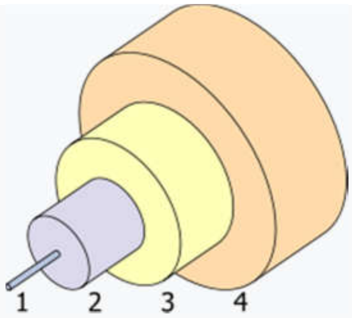
A laser bouncing down an acrylicrod, illustrating the total internal reflection of light in a multi-mode optical fiber.Fiber with large core diameter (greater than 10 micrometers) may be analyzed by geometrical optics. Such fiber is called *multi-mode fiber*, from the electromagnetic analysis (see below). In a step-index multi-mode fiber, rays of light are guided along the fiber core by total internal reflection. Rays that meet the core-cladding boundary at a high angle (measured relative to a line normal to the boundary), greater than the critical angle for this boundary, are completely reflected. The critical angle (minimum angle for total internal reflection) is determined by the difference in index of refraction between the core and cladding materials. Rays that meet the boundary at a low angle are refracted from the core into the cladding, and do not convey light and hence information along the fiber. The critical angle determines the acceptance angle of the fiber, often reported as a numerical aperture. A high numerical aperture allows light to propagate down the fiber in rays both close to the axis and at various angles, allowing efficient coupling of light into the fiber. However, this high numerical aperture increases the amount of dispersion as rays at different angles have different path lengths and therefore take different times to traverse the fiber.



Optical fiber types.

In graded-index fiber, the index of refraction in the core decreases continuously between the axis and the cladding. This causes light rays to bend smoothly as they approach the cladding, rather than reflecting abruptly from the core-cladding boundary. The resulting curved paths reduce multi-path dispersion because high angle rays pass more through the lower-index periphery of the core, rather than the high-index center. The index profile is chosen to minimize the difference in axial propagation speeds of the various rays in the fiber. This ideal index profile is very close to a parabolic relationship between the index and the distance from the axis.

Single-mode fiber



The structure of a typical single-mode fiber.

1. Core: 8 µm diameter
2. Cladding: 125 µm dia.
3. Buffer: 250 µm dia.
4. Jacket: 400 µm dia.

Fiber with a core diameter less than about ten times the wavelength of the propagating light cannot be modeled using geometric optics. Instead, it must be analyzed as an electromagnetic structure, by solution of Maxwell's equations as reduced to the electromagnetic wave equation. The electromagnetic analysis may also be required to understand behaviors such as speckle that occur when coherent light propagates in multi-mode fiber. As an optical waveguide, the fiber supports one or more confined transverse modes by which light can propagate along the fiber. Fiber supporting only one mode is called *single-mode*or *mono-mode fiber*. The behavior of larger-core multi-mode fiber can also be modeled using the wave equation, which shows that such fiber supports more than one mode of propagation (hence the name). The results of such modeling of multi-mode fiber approximately agree with the predictions of geometric optics, if the fiber core is large enough to support more than a few modes.

The waveguide analysis shows that the light energy in the fiber is not completely confined in the core. Instead, especially in single-mode fibers, a significant fraction of the energy in the bound mode travels in the cladding as an evanescent wave.

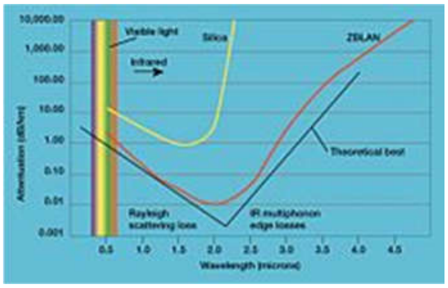
The most common type of single-mode fiber has a core diameter of 8–10 micrometers and is designed for use in the near infrared. The mode structure depends on the wavelength of the light used, so that this fiber actually supports a small number of additional modes at visible wavelengths. Multi-mode fiber, by comparison, is manufactured with core diameters as small as 50 micrometers and as large as hundreds of micrometers. The normalized frequency V for this fiber should be less than the first zero of the Bessel function J_0 (approximately 2.405).

Special-purpose fiber

Some special-purpose optical fiber is constructed with a non-cylindrical core and/or cladding layer, usually with an elliptical or rectangular cross-section. These include polarization-maintaining fiber and fiber designed to suppress whispering gallery modepropagation. Polarization-maintaining fiber is a unique type of fiber that is commonly used in fiber optic sensors due to its ability to maintain the polarization of the light inserted into it.

Photonic-crystal fiber is made with a regular pattern of index variation (often in the form of cylindrical holes that run along the length of the fiber). Such fiber uses diffraction effects instead of or in addition to total internal reflection, to confine light to the fiber's core. The properties of the fiber can be tailored to a wide variety of applications.

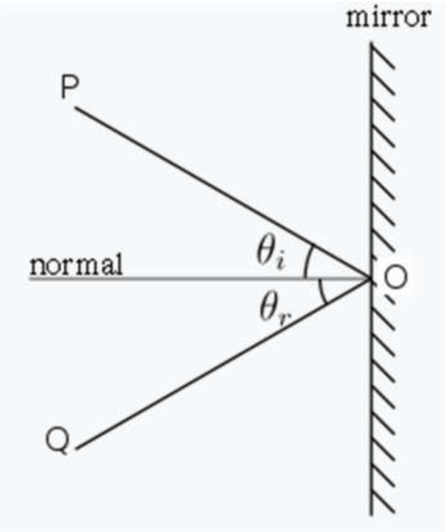
Mechanisms of Attenuation:



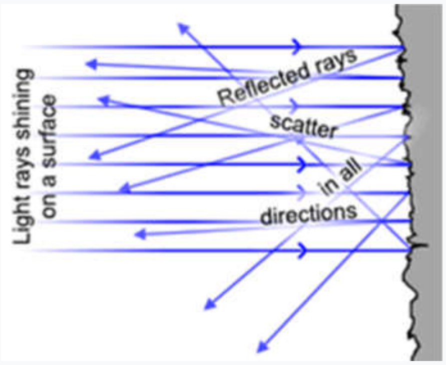
Attenuation in fiber optics, also known as transmission loss, is the reduction in intensity of the light beam (or signal) as it travels through the transmission medium. Attenuation coefficients in fiber optics usually use units of dB/km through the medium due to the relatively high quality of transparency of modern optical transmission media. The medium is usually a fiber of silica glass that confines the incident light beam to the inside.

Attenuation is an important factor limiting the transmission of a digital signal across large distances. Thus, much research has gone into both limiting the attenuation and maximizing the amplification of the optical signal. Empirical research has shown that attenuation in optical fiber is caused primarily by both scattering and absorption. Single-mode optical fibers can be made with extremely low loss. Corning's SMF-28 fiber, a standard single-mode fiber for telecommunications wavelengths, has a loss of 0.17 dB/km at 1550 nm.[53] For example, an 8 km length of SMF-28 transmits nearly 75% of light at 1,550 nm. It has been noted that if ocean water was as clear as fiber, one could see all the way to the bottom even of the Marianas Trench in the Pacific Ocean, a depth of 36,000 feet.[54]

LIGHT SCATTERING



SPECULAR REFLECTION:



DIFFUSE REFLECTION

The propagation of light through the core of an optical fiber is based on total internal reflection of the light wave. Rough and irregular surfaces, even at the molecular level, can cause light rays to be reflected in random directions. This is called diffuse reflection or scattering, and it is typically characterized by wide variety of reflection angles.

Light scattering depends on the wavelength of the light being scattered. Thus, limits to spatial scales of visibility arise, depending on the frequency of the incident light-wave and the physical dimension (or spatial scale) of the scattering center, which is typically in the form of some specific micro-structural feature. Since visible light has a wavelength of the order of one micrometer (one millionth of a meter) scattering centers will have dimensions on a similar spatial scale.

Thus, attenuation results from the incoherent scattering of light at internal surfaces and interfaces. In (poly) crystalline materials such as metals and ceramics, in addition to pores, most of the internal surfaces or interfaces are in the form of grain boundaries that separate tiny regions of crystalline order. It has recently been shown that when the size of the scattering center (or grain boundary) is reduced below the size of the wavelength of the light being scattered, the scattering no longer occurs to any significant extent. This phenomenon has given rise to the production of transparent ceramic materials.

Similarly, the scattering of light in optical quality glass fiber is caused by molecular level irregularities (compositional fluctuations) in the glass structure. Indeed, one emerging school of thought is that a glass is simply the limiting case of a polycrystalline solid. Within this framework, "domains" exhibiting various degrees of short-range order become the building blocks of metals and alloys, as well as glasses and ceramics. Distributed both between and within these domains are micro-structural defects that provide the most ideal locations for light scattering. This same phenomenon is seen as one of the limiting factors in the transparency of IR missile domes.

At high optical powers, scattering can also be caused by nonlinear optical processes in the fiber.

UV-VIS-IR ABSORPTION

In addition to light scattering, attenuation or signal loss can also occur due to selective absorption of specific wavelengths, in a manner similar to that responsible for the appearance of color. Primary material considerations include both electrons and molecules as follows:

- At the electronic level, it depends on whether the electron orbital are spaced (or "quantized") such that they can absorb a quantum of light (or photon) of a specific wavelength or frequency in the ultraviolet (UV) or visible ranges. This is what gives rise to color.
- At the atomic or molecular level, it depends on the frequencies of atomic or molecular vibrations or chemical bonds, how close-packed its atoms or molecules are, and whether or not the atoms or molecules exhibit long-range order. These factors will determine the capacity of the material transmitting longer wavelengths in the infrared (IR), far IR, radio and microwave ranges.

The design of any optically transparent device requires the selection of materials based upon knowledge of its properties and limitations. The Lattice absorption characteristics observed at the lower frequency regions (mid IR to far-infrared wavelength range) define the long-wavelength transparency limit of the material. They are the result of the interactive coupling between the motions of thermally induced vibrations of the constituent atoms and molecules of the solid lattice and the incident light wave radiation. Hence, all materials are bounded by limiting regions of absorption caused by atomic and molecular vibrations (bond-stretching)in the far-infrared (>10 μm).

Thus, multi-phonon absorption occurs when two or more phonons simultaneously interact to produce electric dipole moments with which the incident radiation may couple. These dipoles can absorb energy from the incident radiation, reaching a maximum coupling with the radiation when the frequency is equal to the fundamental vibration mode of the molecular dipole (e.g. Si-O bond) in the far-infrared, or one of its harmonics.

The selective absorption of infrared (IR) light by a particular material occurs because the selected frequency of the light wave matches the frequency (or an integer multiple of the frequency) at which the particles of that material vibrate. Since different atoms and molecules have different natural frequencies of vibration, they will selectively absorb different frequencies (or portions of the spectrum) of infrared (IR) light. Reflection and transmission of light waves occur because the frequencies of the light waves do not match the natural resonant frequencies of vibration of the objects. When IR light of these frequencies strikes an object, the energy is either reflected or transmitted.

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