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Lasers, Holograms and Photonics

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A PRIMER

Compliments of Frank DeFreitas for his web site visitors

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Intro: The Science of Light

Light is a result of excited atoms giving off energy. Atoms are the building blocks of matter and consist of a positively charged nucleus of protons and neutrons orbited by a cloud of negatively charged electrons. Heat, light, and electricity are among the things that can excite atoms. Once excited, the atom’s electrons absorb energy and briefly move from their normal orbit level to one slightly farther away from the nucleus. The electrons then drop back to the more stable state, giving off a particle of light energy, or photon.

Scientists have proven that electromagnetic radiation, or light, behaves like a particle at times and like a wave at other times. The particulate nature of light is characterized by packets of light energy called photons. Photons are different from particles of matter in that they have no mass and always move at the constant speed of 186,000 miles per second when they’re in a vacuum. When light diffracts, or bends slightly as it passes around a corner, it shows a wavelike behavior. The waves associated with light are called electromagnetic waves because they consist of changing electric and magnetic fields, and they radiate outward from the source in a circle.

Visible light, or white light, is that part of the electromagnetic spectrum the human eye can detect. Visible light has wavelengths between 400 nm and 700 nm. Other forms of radiation in the electromagnetic spectrum includes cosmic rays (.00001 nm), gamma rays (.0001 nm), X-rays (.01 nm), ultraviolet rays (100 nm), infrared rays (.00005 m), microwaves (.001 - .1 m), television waves (.5 m), and radio waves (100 m). The difference between these various forms of electromagnetic radiation is a result of their wavelength and frequency.

Electromagnetic waves have crests and troughs, just like waves in the ocean. The distance from crest to crest, or trough to trough, is its wavelength. Frequency is the number of wave crests, or troughs, passing a point in one second. Each form of radiation in the electromagnetic spectrum has a different wavelength. The shorter the wavelength, the higher the frequency; the higher the frequency, the larger the photon energy; and the longer the wavelength, the smaller the photon energy. For example, cosmic rays and gamma rays have a shorter wavelength, higher frequency, and larger photon energy than visible light and radio waves.

Light travels in straight lines. When it strikes an object, it gets absorbed—part of the light energy is absorbed by the object, transmitted—part of the light energy can travel through the object, or reflected—part of the light energy is reflected by the object at the same angle. An object has color because of the light that it reflects. All other visible colors of the spectrum is absorbed by the object, so we don't see them.

Refraction is another property of light and results from light changing speed as it passes from one medium, or material, to another. How much the speed changes depend on the nature of the material light is passing through and the frequency of the light. When white light travels through a prism, each of the different colors of light slows to a slightly different rate. The colored lights therefore separate (refract differently and bend in differing amounts) into a visible spectrum of red, orange, yellow, green, blue, indigo, and violet.

The wavelength and intensity of light in the visible spectrum can be analyzed by using an optical instrument like the spectroscope. The spectroscope consists of a slit for admitting light, a group of lenses, a prism, and an eyepiece. Light enters through the slit, passes through the group of lenses (which make the light rays parallel), and the prism. The image of the slit is then focused at the eyepiece. A series of images of the slit, each a different color, is visible because the light has been separated into its component colors by the prism.
The LASER is an instrument that produces a very special type of light.

Laser Light Timeline

1898—H.G. Wells writes War of the Worlds, in which Martian invaders conquer Earth with "beams of light."
1917—Albert Einstein introduces the field of physics to the concept of stimulated emission.
1951—Charles Townes conceives of the idea of the maser (microwave amplification by stimulated emission of radiation). Similar ideas occur independently to A. Prokhorov and N. Basov in Moscow and J. Weber of the University of Maryland.
1953—Charles Townes builds the first maser with J.P. Gordon and H.J. Zeiger at Columbia University.
1958—Charles Townes and Arthur Schawlow invent the laser, then publish "Infrared and Optical Masers" in the American Physical Society's Physical Review.
1960—Theodore Maiman builds the first successfully operated laser. The laser is built at the Hughes Research Laboratories and uses a rod of synthetic ruby as the lasing material.
1961—Ali Javan, W. Bennett, and Donald R. Harriott build the first continuous gas laser. The laser is built at Bell Laboratories, using a mixture of helium and neon as the lasing material.
1962—The first successful hologram is made by Emmett Leith and Juris Upatnieks.
1964—Charles Townes is awarded the Nobel Prize in Physics for his work on the maser and for his work in quantum electronics connected with both maser and laser devices.
1969—Apollo 11 astronauts place an 18-inch reflector on the surface of the moon. Scientists on earth bounce a laser light off the reflector and calculate the distance to the moon—230,000 miles.
1970—Corning Glass researchers Robert Maurer, Donald Keck, and Peter Schultz produce the first optical fiber with optical losses low enough for wide use in telecommunications.
James T. Russell, working at Battelle Memorial Institute, patents the first digital-to-optical recording and playback system. This was the first compact disc.

A Brief Laser History

Albert Einstein was the first to suggest the idea behind the laser in 1917. Einstein believed that light was made up of a series of particles, which he called photons, traveling in a continuous wave. He also believed that photons were the result of atoms changing from an excited state back to their more comfortable ground state. He postulated that if a photon hit an atom in the excited, high-energy state, the excited atom would release a photon of light that would be an identical twin to the first. Einstein referred to this phenomenon as stimulated emission of radiation.

It wasn't until 1951, however, that Einstein's idea for the stimulated emission of radiation was used. American physicist Charles H. Townes drew upon this idea to drive microwaves, a form of electromagnetic radiation, past a group of atoms, stimulating them to give up energy. Towne's invention, the MASER (Microwave Amplification by Stimulated Emission of Radiation) provided the basic components of the laser. In 1957 Townes and Arthur L. Schawlow began work on an optical maser. In a scientific paper, published in 1958, Townes and Schawlow outlined their theory and design for the optical maser. The two physicists patented their idea in 1959.

At about the same time as Townes and Schawlow were developing their ideas for an optical maser, American physicist Gordon Gould was also working on a device he called a laser. In 1957 Gould had his ideas notarized but did not attempt to patent his ideas. Unfortunately, this mistake resulted in a 30-year legal battle over patent rights. Gould finally gained some recognition for the development of the laser in the late 1980s, when he won the last of his legal battles that left him in control of patent rights for most of the lasers used and sold in the United States.

Theodore Maiman, an American physicist, was the first to build and successfully operate a laser in 1960. Maiman's laser consisted of a synthetic ruby rod with mirrored ends, a spiral shaped photographic strobe lamp, and a high-voltage power supply. The ruby laser differed from the maser in that it utilized visible light. The laser (which amplified light) was much more powerful than the maser (which amplified microwaves), since every photon of light has a hundred thousand times more energy than a photon of microwave energy. The ruby laser is still used today.

People That Made It Happen

Issac Newton

In 1692, Isaac Newton postulated that light was made up of particles he called corpuscles. Later in the same century, Dutch scientist Christiaan Huygens proclaimed light was made up of waves traveling through space. In 1905, Albert Einstein showed that light exhibited properties of both particles and waves by explaining the photoelectric effect (the formation and liberation of electrically charged particles in matter when it is irradiated by light or other electromagnetic radiation). Einstein was awarded the Nobel Prize for this work.

Charles Townes

Charles Townes was born in Greenville, South Carolina, in 1915. Charles Townes received his Ph.D. in physics from the California Institute of Technology. Charles Townes joined the technical staff of Bell Telephone Laboratories Inc. and worked on radar bombing systems during World War II. In 1948 he joined the faculty of Columbia University and three years later had the idea that culminated in construction of the MASER.

Charles Townes did not work with light at first, but with microwaves at much longer wavelengths, building the MASER, for Microwave Amplification by the Stimulated Emission of Radiation. The maser, a device that amplifies electromagnetic waves, created a means for the sensitive reception of communications and for precise navigation. He thought of the key idea in 1951, but the first maser was not completed until 1954. The maser provided the basic components for the laser.

In 1957, Townes and Arthur Schawlow wrote a long paper outlining the conditions needed to amplify stimulated emission of visible light waves. At about the same time, similar ideas were being developed by Gordon Gould, who wrote them down in a series of notebooks. Townes and Schawlow published their ideas for an optical maser in Physical Review in 1958 and Gould filed a patent application. Townes and Schawlow received the patent for their optical maser in 1960. It would take Gould almost 30 years to be credited with his first patent for the laser.

For his work on the theory and application of the maser and for other work in quantum electronics connected with both maser and laser devices, he shared with Nikolai Basov and Alexander Prokhorov the 1964 Nobel Prize in physics.

Arthur L. Schawlow

Arthur Schawlow was born in Mount Vernon, New York, in 1921. He received his Ph.D. in physics from the University of Toronto. While doing postdoctoral research at Columbia University he met Charles Townes, and their collaboration on microwave spectroscopy began. Arthur L. Schawlow co-authored the book Microwave Spectroscopy and worked on the optical maser with Townes. Schawlow did not work on the development of the maser with Townes. However, while at Bell Laboratories, Schawlow and Townes sought ways to extend the maser principle of amplifying electromagnetic waves into the shorter wavelengths of infrared and visible light. They published their proposal, entitled “Infrared and Optical Masers” for the laser in a 1958 issue of Physical Review and received a patent for it in 1960. In 1981 Schawlow received the Nobel Prize in physics for his work in laser spectroscopy.

Gordon Gould

Gordon Gould was born in New York City, in 1920. Gould was working on his Ph.D. in physics at Columbia University, while Charles Townes and Arthur Schawlow were on staff there. Gordon was doing research on microwave spectroscopy when he wrote up his ideas to amplify light and use the resulting beam to cut and heat substances and measure distances. He called this process “light amplification by stimulated emission of radiation.

Gordon Gould has some claim on the invention of the laser. Gordon had his notebook of ideas and drawings notarized in 1957, but didn’t file for a patent because he mistakenly believed he had to develop a working model first. His mistake was costly and required more than 30 years of legal battles to lay some claim to the invention of the laser. During the mid to late 1980s, however, the patent office finally awarded Gould several patents relating to the development and use of the laser. He was awarded a patent for one type of device that amplified light; a use patent, covering the use of lasers for cutting, machining, heating, and other functions; the gas discharge laser amplifier patent, for another device of amplification; and the Brewster's angle patent, for a device to polarize light within a laser.

Theodore Maiman

Theodore Maiman was born in Las Angeles, California, in 1927. Maiman earned a B.S. in engineering physics in 1949 from the University of Colorado and an M.S. in electrical engineering in 1951 and a Ph.D. in physics in 1955 from Stanford University. Maiman constructed the first operable laser, building on the work of Charles Townes and Arthur Schawlow. While employed at Hughes Research Laboratories as a section head in 1960, he developed, demonstrated, and patented the first laser using a pink ruby medium.

In 1962 Maiman founded his own company, Korad Corporation, devoted to the research, development, and manufacture of lasers. He formed Maiman Associates in 1968 after selling Korad to Union Carbide Corporation. Maiman joined TRW (Thompson-Ramo-Wooldridge, Inc) in 1976 and was responsible for directing the management of technology and the establishment of new high-tech ventures.

The Science Behind Lasers

What is a Laser?

The term “LASER” is an acronym. It stands for “Light Amplification by Stimulated Emission of Radiation.” To find out what this means, let’s break down the word “LASER.”

Light

Light is one form of electromagnetic radiation—energy that behaves like a particle and a wave. Laser light is unique because it is directional, intense, monochromatic (of one color), and coherent (of one or just a few wavelengths traveling in phase).

Amplification

Amplification means to increase or strengthen something. In a laser, amplification refers to an increase in the number of photons, light energy. By increasing the number of photons, the light is made brighter and more intense.

Stimulated Emission

Stimulated Emission refers to the act of one light particle (photon) stimulating the emission of another photon. When an atom in a laser is stimulated it becomes excited. As the atom returns to its more relaxed state, it emits a photon. When the photon interacts with a second, similarly excited atom, it causes the second atom to release another photon, with the identical characteristics of the first photon.

Radiation

Radiation is energy that travels in a wave and spreads out as it goes. In lasers, radiation refers to the energy emitted by the laser in the form of radiating light particles or photons. Other forms of radiation include radio waves, microwaves, infrared waves, ultraviolet rays, and gamma rays.

Basically, the acronym “LASER” refers to a device that produces and amplifies light.

How Lasers Work

A laser is a device that controls the way that energized atoms release photons. Although there are many types of lasers, all have certain essential features. In a laser, the lasing medium is “pumped” to get the atoms into an excited state. Typically, very intense flashes of light or electrical discharges pump the lasing medium and create a large collection of excited-state atoms (atoms with higher energy electrons). It is necessary to have a large collection of atoms in the excited state for the laser to work efficiently. In general, the atoms are excited to a level that is two or three levels above the ground state. This increases the degree of population inversion. The population inversion is the number of atoms in the excited state versus the ground state.

Once the lasing medium is pumped, it contains a collection of atoms with some electrons sitting in excited levels. The excited electrons have energies greater than the more relaxed electrons. Just as the electron absorbed some amount of energy to reach this excited level, it can also release this energy. This emitted energy comes in the form of photons (light energy). The photon emitted has a very specific wavelength (color) that depends on the state of the electron's energy when the photon is released. Two identical atoms with electrons in identical states will release photons with identical wavelengths.

Laser light is very different from normal light. Laser light has the following properties:

1. The light released is monochromatic. It contains one specific wavelength of light (one specific color). The wavelength of light is determined by the amount of energy released when the electron drops to a lower orbit.

2. The light released is coherent. The light is “organized” and each photon moves in step with the

others. This means that all the photons have wave fronts that launch in unison.

3. The light is very directional. A laser light has a very tight beam and is very strong and concentrated. A flashlight, on the other hand, releases light in many directions and the light is very weak and diffuse.

To make these three properties occur takes something called stimulated emission. This does not occur in your ordinary flashlight -- in a flashlight, all the atoms release their photons randomly. In stimulated emission, photon emission is organized.

The photon that any atom releases has a certain wavelength that is dependent on the energy difference between the excited state and the ground state. If this photon (possessing a certain energy and phase) should encounter another atom that has an electron in the same excited state, a phenomenon called stimulated emission can occur. The first photon can stimulate or induce atomic emission such that the subsequent emitted photon (from the second atom) vibrates with the same frequency and direction as the incoming photon.

The other key to a laser is a pair of mirrors, one at each end of the lasing medium. Photons, with a very specific wavelength and phase, reflect off the mirrors to travel back and forth through the lasing medium. In the process, they stimulate other electrons to make the downward energy jump and can cause the emission of more photons of the same wavelength and phase. A cascade effect occurs, and soon we may have propagated many, many photons of the same wavelength and phase. The mirror at one end of the laser is "half-silvered", meaning it reflects some light and lets some light through. The light that makes it through is the laser light.

Parts of a Laser

1. Pumping Device
Lasers can use any of the following as a pumping device—a high voltage power supply, a radio frequency oscillator, a high output photoflash or lamp, and even another laser.

2. Lasing Medium
The medium is the material that generates the laser light. The lasing medium can be a gas, solid, or liquid. There are thousands of lasing mediums, but most commercial, scientific, and military lasers fall into one of these categories: crystal and glass, gas, excimer, chemical, semiconductor, and liquid.

3. Optical Resonant Cavity
The cavity encloses the lasing medium and consists of mirrors placed at each end. On most lasers, one mirror is completely reflective, and the other mirror is partially reflective.

Types of Lasers

1. Semiconductor Lasers
Semiconductor (or diode) lasers are generally the most compact lasers and the type we use in this lab activity. Semiconductor lasers use a solid lasing medium. Semiconductor lasers are used in compact audio and video systems, fiber optics, bar code systems, military range finding devices, and hand-held laser pointers. Typical semiconductor lasers produce light in the infrared and red regions.

2. Gas Lasers
Gas lasers represent one of the largest groups of lasers because they are inexpensive and easy to manufacture. Helium-neon, helium-cadmium, argon, carbon dioxide, and krypton are all used in gas lasers. The helium-neon laser, the most common gas laser, is used in bar code scanning, holography, surveying, and laboratory experiments. Most helium-neon lasers emit a characteristic red beam, although different colors (e.g. orange and green) are also possible. CO_2 lasers, among the most powerful gas lasers, can produce a beam that’s intense enough to cut through metal. CO_2

lasers emit light in the blue and green regions. Argon and krypton lasers can produce multiple wavelengths of light, especially in the blue and green regions. Argon and krypton lasers are mainly used in semiconductor manufacturing, medicine, color holography, and laser light show.

3. Solid State Lasers
Solid state lasers use a solid lasing medium. These lasers offer the highest power output. They are generally operated in a pulsed manner to generate a burst of light over a short time. The ruby laser is an example. The ruby laser emits a light that is deep red in color. Another common solid state laser is the Nd: YAG laser. Nd: YAG is composed primarily of the elements aluminum, yttrium, and oxygen, and neodymium. YAG is an acronym for yttrium-aluminum garnet, a synthetic garnet used in jewelry. The Nd: YAG laser emits a light in the infrared region. Solid state lasers are often used in biomedical surgery and imagery.

4. Liquid Lasers
Liquid or dye lasers use liquid dyes as the lasing material. The unique property of liquid dye lasers is that the output wavelength is tunable. By varying the mixture of dyes, it’s possible to change the color of the laser beam from a deep blue to dark red. Liquid dye lasers, because they are both tunable and coherent light sources, are becoming increasingly important in spectroscopy, holography, and in biomedical applications.

Laser Applications

Compact Discs

James T. Russell invented the digital compact disc in the late 1960s. Russell was an avid music listener, but was continually frustrated by the wear and tear suffered by his vinyl phonograph records and their sound quality. In 1970, while at Batelle Memorial Institute, Russell patented the first digital-to-optical recording and playback system. His system recorded onto a photosensitive platter in tiny bits of light and dark, each one a micron in diameter. A laser then read the binary patterns and a computer converted the data into an electronic signal.

Throughout the 1970s, Russell continued to refine the CD, adapting it to any form of data. It was not until 1982, however, that Sony Corporation and Philips Electronics commercially introduced the compact disc.

Fiber Optics

Optical communication systems date back about two centuries, to the "optical telegraph" invented in the 1790s. This system was a series of semaphores mounted on towers, where human operators relayed messages from one tower to the next. In 1880, Alexander Graham Bell patented an optical telephone system, which he called the Photophone. Bell wanted to send light signals through the air, but the atmosphere didn't transmit light as reliably as wires carried electricity.

At about the same time Bell was working on his Photophone, other scientists began transmitting light through glass and quartz pipes. The ability to transmit light through glass or quartz depended on the phenomenon of total internal reflection, in which light is confined in a material surrounded by air with a lower refractive index. By the late 1930s, doctors were using bent quartz rods that could carry light as dental illuminators and illuminated plexiglass tongue depressors.

In the 1930s and 40s scientists began using flexible fiber optic materials of glass and plastic to transmit images. Because the total internal reflection of the fibers was at a glass-air interface, they transmitted images poorly. In the 1960s, this problem was solved in part by covering fibers with a transparent cladding (cylindrical shell) of lower refractive index and the invention of the laser. Although cladding allowed for simple imaging, fiber optic materials were not yet refined enough for large-scale communications.

In 1970 Corning Glass researchers Robert Maurer, Donald Keck, and Peter Schultz designed and produced the first optical fiber, capable of carrying 65,000 times more information than conventional copper wire, with optical losses low enough for wide use in telecommunications. The discovery by the group at Corning paved the way for the commercialization of optical fiber and created a revolution in telecommunications. Today, more than 90 percent of the U.S. long-distance traffic is carried over optical fiber; more than 25 million kilometers has been installed, virtually all of it using the original design of Maurer, Keck and Schultz.

Bar Code Scanners

Wallace Flint, a student at the Harvard University Graduate School of Business Administration, was the first person to suggest an automated checkout system in 1932. Flint proposed a system that allowed customers to select desired merchandise from a catalog by removing corresponding punched cards from the catalog.

Modern bar code began in 1948, when Bernard Silver and Norman Joseph Woodland, both graduate students at Drexel Institute of Technology in Philadelphia, came up with an idea for using patterns of ink that glowed under ultraviolet light. Silver and Woodland's device worked, but the system had problems with ink instability and it was expensive to print the patterns.

On October 20, 1949, Silver and Woodland filed a patent application for a new system. The symbols used in the system were made up of a pattern of four white lines on a dark background. The information was coded by the presence or absence of one or more of the lines. The Silver and Woodland patent application was issued October 7, 1952.

Bar coding was not commercialized until the late 1960s, however, when RCA installed one of the first scanning systems in a Kroger store in Cincinnati. Unfortunately, there were problems with the system, so the National Association of Food Chains (NAFC) proposed a standard code be used throughout the industry. On April 3, 1973, the NAFC selected the UPC symbol (based on a proposal from IBM) as the industry standard.

As computer systems have become more advanced, bar codes have become even more prevalent in society. Now many retail stores, from supermarkets to the military, use bar codes.

Holograms

Holography was invented in 1948, twelve years before the first working laser was built. The theory of holography was conceived to improve the resolution of images produced by electron microscopes. The first holograms weren't three-dimensional, but flat two-dimensional transparencies. It wasn't until 1962 when Emmett Leith and Juris Upatienks, researchers at the University of Michigan, started making three-dimensional laser holograms.

The first holograms had to be viewed as well as created by laser light. Advances in holography during the 60s and 70s, however, made it possible to view laser-created holograms with white light. By the early 1980s a few companies developed low cost ways to mass produce holograms and make them commercially available and in the mid-80s credit card companies started using them on their cards to prevent counterfeiting.

Today holograms are used not only to authenticate credit cards, but also currency, documents, IDs, product labels, stamps, and tickets. In addition, they're used in the packaging and advertising of merchandise and as an outlet for artistic expression. The fields of science and technology have not ignored the importance of holograms either. Because holograms are so accurate, easily examined under microscopes, and easily stored, they are used to examine stress in materials used in nuclear power plants, jet engines, and tires, to study atomic particles and cellular structures, to take minute measurements, and to visually record and catalog objects like dentures and artwork.

Understanding Laser Applications

CDs, CD-ROMs, DVDs, & CD-Rs

• A standard CD is composed of a clear polycarbonate plastic disc, a reflective metallic layer, and a clear protective coating of acrylic plastic. The reflective metallic layer is where audio data is read by a laser.

Minuscule depressions (pits) and contrasting flat regions (lands) are arranged in a spiral track winding from the disc's inner hole to its outer edge. When a disc is inserted into a CD player, a low-intensity infrared laser scans the disc's track. For the laser to maintain a constant scanning rate, the disc's rotation rate decreases from 500 to 200 revolutions per minute as the light beam moves out from the disc's center. When the light beam strikes a land an electrical pulse is generated. When the light beam strikes a pit, however, no electrical pulse is generated. Each “dark” pit on the track is interpreted (based on its length) as a sequence of 0s and each "bright" land is interpreted (again based on its length) as a sequence of 1s. A device known as a digital-to-analog converter is necessary to translate this binary information into audio signals for playback.

• CD-ROMs (i.e. Compact Disc Read Only Memory) are rigid plastic disks, like audio CDs, that store a large amount of data through the use of laser optics technology. CD-ROM drives, the devices used to access information on CD-ROMs, can only read information from the disc, not write to it. CD-ROMs can store large amounts of data and so are popular for storing databases and multimedia material. The most common format of CD-ROM holds approximately 630 megabytes of information. By comparison, a regular floppy disk holds approximately 1.44 megabytes.

• Digital Video Disc (DVD) is an optical storage device that looks the same as a compact disc but is able to hold about 15 times as much information and transfer it to the computer about 20 times as fast as a CD-ROM. A DVD, also called a Super Density disc (SD), can hold 8.5 gigabytes of data or four hours of movies on a side; double-sided and rewriteable DVD discs are under development. DVDs come in two formats: the DVD-Video format and the DVD-ROM (DVD-Read Only Memory) format. The DVD-Video format is used for home movie entertainment through a DVD player. DVD players are backward compatible to existing technologies, so they can also play Audio CD and CD-ROM formats. The DVD-ROM stores computer data. DVD-ROM uses include interactive games, video file storage, and photographic storage. In the future, DVDs may also be used to record data on a DVD-RAM (DVD-Random Access Memory) or DVD-R (DVD-Recordable) disc. When compared to CD-ROM technology, DVD allows for better graphics, greater resolution, and increased storage capacity.

• There are two types of compact discs you can record audio or video information on: CD-Recordable (CD-R) Digital discs and CD Re-Writable (CD-RW) Digital discs. CD-Rs use a laser beam to heat up the substrate and the recording layer to about 250 degrees Celsius. At this temperature the recording layer melts, while the substrate expands into the space where the recording layer used to exist. CDRWs are made of a special alloy, which consists only of crystals in its original state. When the crystal material is heated by the laser beam, it melts. The melted crystal material has a lower reflectance than the unmelted crystals and this difference makes it possible to read the information recorded on the disc.

Fiber Optics

Fiber Optics is the transmission of light through fibers or thin rods of glass or some other transparent material of high refractive index. If light is admitted at one end of a fiber, it can travel through the fiber with very low loss, even if the fiber is curved.

Light traveling inside the fiber center, or core, strikes the outside surface of the fiber in such a way that all the light is reflected toward the inside of the fiber without loss. This is known as internal reflection. Light can be transmitted over long distances by being reflected inward thousands of times. To avoid losses through the scattering of light by impurities on the surface of the fiber, the optical fiber core is clad (covered) with a glass layer of much lower refractive index; the reflections occur at the interface of the glass fiber and the cladding.

The simplest application of optical fibers is the transmission of light to locations otherwise hard to reach, for example, the whole made by a dentist's drill. Also, bundles of several thousand very thin fibers assembled precisely side by side can be used to transmit images. Image transmission by optical fibers is widely used in medical instruments for viewing inside the human body and for laser surgery, in facsimile systems, in phototypesetting, and in computer graphics.

The fastest growing application of optical fibers is in communication. Many long-haul fiber communications networks for both transcontinental connections and, through undersea cables, international connections are in operation. One advantage of optical fiber systems is the long distances that can be maintained before signal repeaters are needed to regenerate signals.

Signal repeater are currently separated by about 60 miles, compared to about 1 mile for electrical systems.

Local area networks are another growing application for fiber optics. Unlike long-haul communications, these systems connect many local subscribers to expensive centralized equipment such as computers and printers. This system expands the utilization of equipment and can easily accommodate new users on a network.

Bar Codes

A bar code is a printed series of parallel black bars and white spaces used for entering data into a computer system. The bar code on a product or package usually contains information about the item and the manufacturer or distributor. The black bars are used to represent 1s and the white spaces are used to represent 0s.

Bar code information is read by a laser in a handheld scanner, bar code pen, or stationary scanner, and interpreted by a computer. One of the most common bar code systems in the United States is the Universal Product Code, or UPC, which assigns each type of food product a unique code. Another popular system is Code 128. Code 128 is used to track products as they are manufactured, distributed, stored, sold, and serviced. These products range from processed foods and dry goods to drugs and medical supplies, automotive parts, computer parts, and even library books. Code 128 is not restricted to supplying numeric information, nor is it restricted to a specific size like the UPC system (12 numbers). Code 128 is capable of designating every number, letter and symbol on a keyboard and can contain as much information as needed.

Individual numbers, letters, and symbols can be interpreted by a series of eleven black bars and white spaces arranged in specific orders. All Code 128 bar codes begin with a standard pattern of 11 bars and spaces (this is known as the Start Code) and ends with a standard pattern of 13 bars and spaces (this is known as the End Code).

Holography

A hologram is a kind of photograph made with a laser and recorded on a light sensitive photographic glass plate or film. The word hologram is Greek and translates into whole picture. Holograms differ from ordinary photographs, because they record an extremely accurate three dimensional image of the original object. The three-dimensional image can appear in different places in relation to the surface of the hologram. A virtual image hologram seems to sink backwards into the picture. A real image hologram seems to project into space in front of the picture. An image plane hologram seems to straddle the surface of the picture, half of it sinking back and the other half coming forward. The holographic image of the object can also be viewed from different angles, just as if it were the real object.

An object can be seen because light is reflected from the object and detected by the eyes. A hologram looks so realistic because it is an exact recording of the light waves reflected from the object. When the image is reconstructed on the photographic plate it reflects light in the same way as the object originally did. The light reflected by the hologram is detected in the same way as the light reflected by the real object.

The image in a hologram is indistinguishable until it’s lit by a light source. This is called reconstruction and makes the image visible. Some holograms can only be seen when lit by a laser, but most holograms only need a white light source. There are two kinds of holograms and they differ in the way they are reconstructed. Reflection holograms are lit by light shining on the front of the photographic surface and transmission holograms are lit by light shining through the photographic surface. In either case, it is the light coming from the surface of the hologram that makes the holographic image visible.

The image’s color depends on the color of the laser used to make the hologram. Multi-colored images are created by using different lasers to light different parts of the object.

A hologram is a photographic record of the interference between a reference beam and the diffraction pattern of the object. Light from a single laser is separated into two beams. The reference beam illuminates the photographic plate, perhaps via a lens and mirror, and the second beam illuminates the object, which forms a diffraction pattern on the photographic plate. If the processed hologram is illuminated by coherent light, not necessarily of the same wavelength that was used to make the hologram, the image of the object is reconstructed, and a three-dimensional image of the object can be obtained.

A hologram differs essentially from an ordinary photograph in that it records not only the intensity distribution of reflected light but also the phase distribution. The film distinguishes between waves that reach the light sensitive surface while they are at a maximum wave amplitude, and those that reach the surface at a minimum wave amplitude. This ability to discriminate between waves with different phases is obtained by having a so-called reference beam interfere with the reflected waves.

Laser Measurements

Lasers make fantastic rulers. They measure distances with incredible accuracy in two major ways. One way a laser can measure distance is by time of flight. The other method is called interferometry.

To measure a distance using time of flight, laser light is shot at an object and the amount of time it takes the light to return is recorded. Because the constant speed of light is 186,000 miles per second, it is possible to determine distances by bouncing a laser beam off a target and measuring the time it takes it to return. Time of flight technology can be used to measure a variety of distances. Hand held laser rulers can measure the length of a room. Light detection and ranging, or LIDAR, can determine satellite positions, the shape of the Earth's surface and properties of the Earth's atmosphere.

Interferometry is used in industry to make extremely small, accurate measurements. Interferometry relies on the wave nature of light and is used to make microscopic measurements. Interferometry works by splitting a laser beam in two, reflecting each part onto a different mirror and then recombining them into one beam. The two parts of the recombined beam will be out of phase, unless the difference between them is an exact whole number of wavelengths. This means that if one mirror is moved, a pattern of light and dark interference fringes will be produced. An interferometer can count these fringes to calculate the difference between the two beams, and therefore the distance by multiplying the number of fringes by the wavelength.

Laser Welding & Cutting

The laser's intense energy when focused makes it ideal for providing concentrated welding and cutting. Laser cutting, and welding can be extremely precise. Clothing manufacturers can use lasers to cut precise fabric patterns. Laser welding can allow the easy welding of two different kinds of metals and alloys, making the resulting product significantly stronger than other techniques. Many car manufacturers use laser welding performed by industrial robots to assemble cars.

Lasers in Medicine

The small, intense bright beam of a laser can be focused with lenses and other optics to provide a point of energy intense enough to burn through living tissue. Because laser scalpels are so small, they can very delicately reach difficult places. The burning action of laser surgery also instantly clots the incision, reducing bleeding dramatically. Reattaching detached retinas and using fiber optics to burn away ulcers in the stomach are two medical uses of lasers. Lasers used in surgery include Nd: YAG crystal lasers (neodymium and yttrium aluminum garnet), argon gas ion lasers, and excimer lasers.

Laser Light Shows

The intense color of laser light has opened a new career path for laser artists to create artwork with lasers. Laser shows are usually performed in planetarium domes and set to music. Laser shows generally use gas ion lasers, including argon, krypton-argon, and helium neon lasers. Sets of high speed vibrating mirrors called scanners move the laser beams in different patterns. Abstract imagery or full-motion animation can be displayed in laser shows. Colors can also be changed by using multi-wavelength lasers (such as argon or krypton-argon lasers) and sending the laser through crystals, which vibrate with sound waves providing full color imagery.

Lasers in the Military

Lasers are used as guidance systems for missiles, aircraft, and satellites. The use of laser beams have also been proposed against hostile ballistic missiles, as in the defense system (SDI or Star Wars) urged by U.S. President Ronald Reagan in 1983. In addition, the ability of tunable dye lasers to excite selectively an atom or molecule is being studied to produce more efficient ways to separate isotopes for construction of nuclear weapons.

Laser Safety

Laser radiation may damage the cornea, lens or retina depending on the wavelength, intensity of the radiation and the absorption characteristics of different eye tissues. The cornea, lens and vitreous fluid are transparent to electromagnetic radiation between the wavelengths 400 to 1400 nm (visible light is between 400 to 700 nm). Damage to the retinal tissue occurs by absorption of light and its conversion to heat.

Lasers are classified into four broad areas depending on the potential for causing biological damage. All lasers are labeled with one of five class designations:

1. Class II
Visible, low power lasers or laser systems that are incapable of causing eye damage unless they are viewed directly for an extended period (greater than 15 minutes). This is the class of laser used in most school lab activities.

2. Class III
Lasers or lasers systems that normally would not produce a hazard if viewed for short periods of time with the naked eye. They may present a hazard if viewed using collecting (focusing) optics.

3. Class IIIa
Lasers or lasers systems that can produce a hazard if viewed directly. This includes intra beam viewing of specular reflections.

4. Class IIIb
Medium-power lasers and laser systems capable of causing eye damage with short-duration exposures to the direct or reflected beam (less than a quarter of a second).

5. Class IV
High power lasers and laser systems capable of causing severe eye damage with short-duration exposures to the direct, reflected, or diffusely reflected beam (less than a quarter of a second). Class IV lasers and laser systems are also capable of causing severe skin damage and igniting flammable and combustible materials.

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