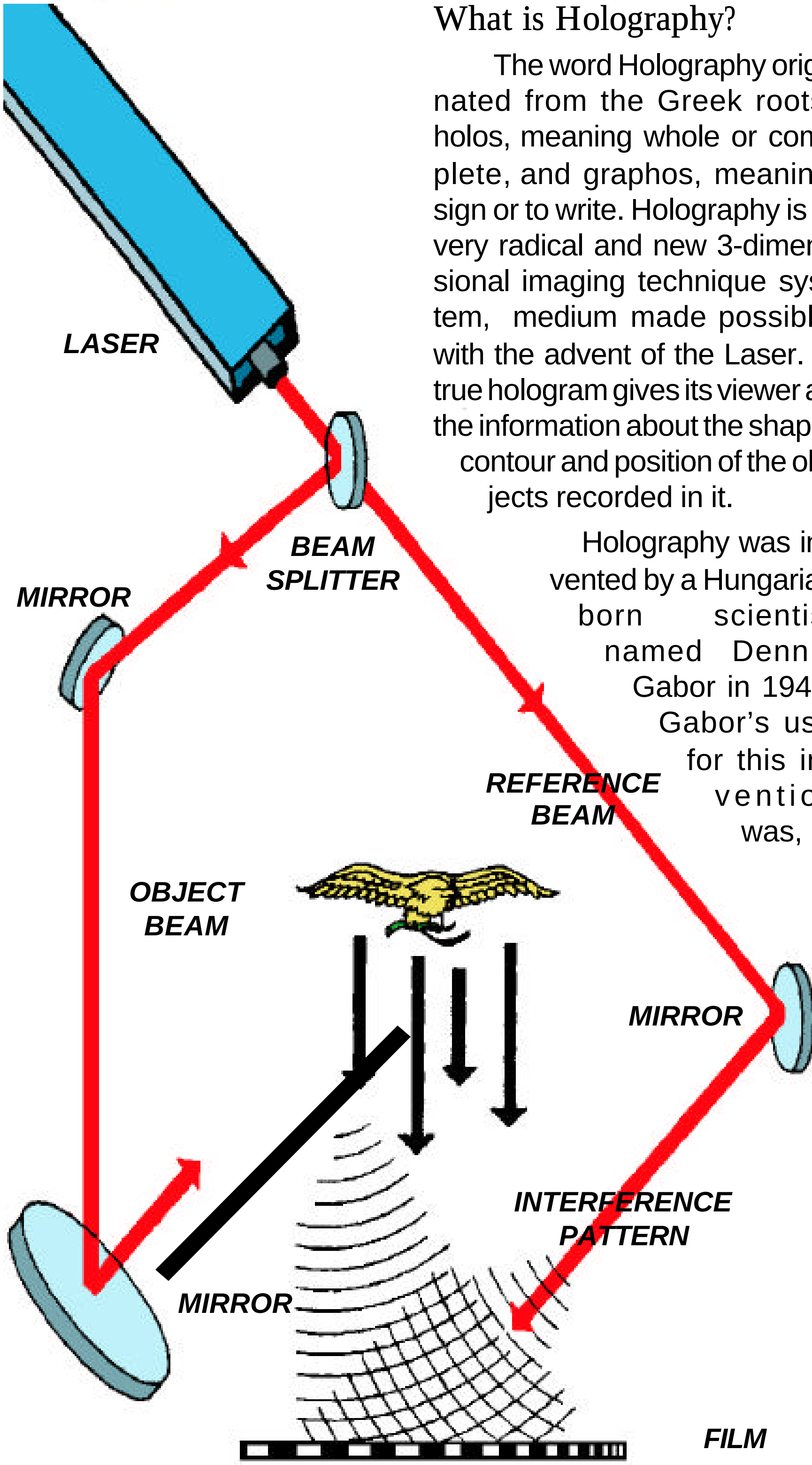
HOLOGRAPHY, HOLOGRAMS AND LASERS



What is Holography?

The word Holography originated from the Greek roots: holos, meaning whole or complete, and graphos, meaning sign or to write. Holography is a very radical and new 3-dimensional imaging technique system, medium made possible with the advent of the Laser. A true hologram gives its viewer all the information about the shape, contour and position of the objects recorded in it.

Holography was invented by a Hungarian born scientist named Dennis Gabor in 1947. Gabor's use for this invention was, in some ways, much less exciting than the 3D images we see today. He wanted a tool which would improve the quality of photographs from the electron microscope. It wasn't until the early 1960s that holograms as we know them were first produced by two researchers working at the University of Michigan in Ann Arbor, Emmett Leith and Juris Upatnieks. Dr. Gabor received the highly acclaimed Nobel Prize in Physics in 1971 for his invention of Holography.

Holograms are possible because of the special property of Laser light known as Coherence. Coherent light is best understood as light which is only one wavelength of the visible spectrum and possesses a high degree of organization. When you make a hologram you split the laser light into two beams, (see illustration), one beam illuminates the object or scene being imaged, the Object Beam. The other beam illuminates the film plate onto which the hologram will be recorded, this is called the Reference Beam. No lenses are used between the object and film during recording. Some of the light shining on the

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***OVERHEAD VIEW** — The making of a film hologram as seen from an overhead view. Note the laser beam is split into two parts, each of which eventually reaches the film—one by direct imaging and one by reflection from the subject.*

A Somewhat Simplified Explanation

What is a Laser? How Does It Work?

THE LASER {LAY'-ZUR} IS A DEVICE THAT PRODUCES A BEAM OF LIGHT THAT IS BOTH SCIENTIFICALLY AND PRACTICALLY OF GREAT USE BECAUSE IT IS COHERENT LIGHT. THE BEAM IS PRODUCED BY A PROCESS KNOWN AS STIMULATED EMISSION, AND THE WORD "LASER" IS AN ACRONYM FOR THE PHRASE "LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION."

Basic Principles

The meaning of "coherent" light is as follows: Light moves in the form of a wave, with crests and troughs. Like all other kinds of electromagnetic radiation, it can be characterized both by its frequency, or number of wave crests passing a given point per second, and by its wavelength, or distance between wave crests. (Beams of such radiation travel through a vacuum at the highest velocity anything can.) Different wavelengths of light are seen as different colors.

Like radio waves, light can also carry information. The information is encoded in the beam as variations in the frequency or shape of the light wave. In fact, because light waves are of much higher frequencies than radio waves, they have a correspondingly higher information-carrying capacity.

The smallest unit of light is the photon, which may be thought of as a particle as well as a wave. In beams of light from ordinary natural or artificial sources, these individual photon waves are not moving along together because they are not being emitted at precisely the same instant but instead in random short bursts. This is true even when the light is of a single frequency. Such beams are called incoherent. A laser is useful because it produces light that is not only of essentially a single frequency but also coherent, with the light waves all moving along together in unison. The maser, using the same principle of operation, generates or amplifies electromagnetic radiation in the longer-wavelength microwave region of the electromagnetic spectrum.

How a Laser Works

A laser is made up of several basic components. One is the so-called active medium, which may consist of atoms of a gas, molecules in a liquid, ions in a crystal, or any of several other possibilities. Another component consists of some method of introducing energy into the active medium, such as a flash lamp, for example. The third basic component is a pair of mirrors placed on either side of the active medium, one of which transmits part of the radiation that strikes it. In the following discussion the active component is taken to be a gas.

Each atom in the active medium of a gas laser is characterized by a set of energy states, or energy levels, in which it may exist. These states may be pictured as unevenly spaced rungs of a ladder, with higher rungs representing states of higher energy. Left undisturbed

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Holography (Continued)

object will be reflected toward the film where it will interfere with light shining directly on the film. This Interference Pattern is recorded in the light sensitive emulsion of the film. After development, the film is re-illuminated by approximating its angle to the Reference Beam. The developed interference pattern in the film bends some of the light striking it into a recreation of the pattern of light which originally came from the Object Beam, because of a property of light known as Diffraction. The reconstructed object beam contains all the information it once carried, so you view the object in full three dimensions, just as if it were actually there.

Holograms can be made as small as the ones you see on your Visa and Master Cards, and as large as displays for trade shows up to 4x6 feet! They are finding new uses daily in science, manufacturing and business.

for a long enough time, an atom will fall to its lowest energy state. This is called the ground state. As a simple example, suppose that an atom has only two energy states that differ by a certain amount of energy. Then consider how this atom interacts with light. According to quantum mechanics, the atom will interact with light of only one particular frequency (determined by a relationship involving a physical constant known as Planck's Constant.)

Three kinds of interaction can take place between the atom of gas in a laser and light. Either the light is absorbed, or spontaneous emission occurs, or stimulated emission occurs. That is, an atom in its lower energy state can absorb light and be excited to its upper state. If the atom is instead in its upper energy state, it can fall spontaneously to its lower state and emit light in the process. The third possibility is that the atom is stimulated by the presence of light to jump down to its lower energy state, emitting additional light while doing so.

Spontaneous emission is unaffected by the presence of light and occurs on a time scale characteristic of the states involved. This time is called the spontaneous lifetime. In stimulated emission the additional light emitted has the same frequency and directional characteristics as the light that stimulates it. This is the crucial feature on which the properties of the laser are based. In order for the laser to work effectively, stimulated emission must predominate over both absorption and spontaneous emission.

Stimulated Emission

The probabilities of occurrence of stimulated emission and absorption are both proportional to the intensity of the light. Stimulated emission, however, can happen only to upper-state atoms, and absorption can happen only to lower-state atoms. For stimulated emission to dominate absorption, therefore, more atoms must be in the upper state than in the lower state. This unusual situation is called population inversion and can be achieved by supplying energy ("pumping" the laser) and carefully selecting the active medium. Typical pumping schemes include the use of light from flash lamps or other lasers, collisions of the lasing atoms with electrically accelerated electrons in a gas discharge tube, excitation with energetic particles from nuclear reactions, chemical reactions, and direct electrical input to a semiconductor. Continuous lasing is harder to achieve than pulsed lasing.

For stimulated emission to dominate spontaneous emission, it is necessary to ensure that the stimulating light is sufficiently strong. Stimulated emission then occurs in a time interval that is short compared to the spontaneous lifetime of the excited state. This situation is achieved by keeping a fraction of the laser light trapped between two mirrors enclosing the active medium. Domination of stimulated emission over spontaneous emission becomes more difficult to achieve as the spontaneous lifetime becomes shorter. Because shorter spontaneous lifetimes are associated with states that emit radiation of higher frequencies, it is difficult to make an ultraviolet-emitting laser, and an X-ray laser was not successfully demonstrated until 1984. Despite their complexity of construction, however, ultraviolet lasers, or excimers, have gained widespread use in industry. Emitting ultraviolet light when a halogen and rare gas atom combine temporarily, they are used in applications ranging from glass etching and photolithography to the sterilization of wines.

Atoms initially in a lower state are raised to the upper state by energy from a flash lamp or some other pumping source. Some of these atoms emit light spontaneously in random directions. Light traveling perpendicular to the mirrors stays within the active medium long enough to stimulate emission from other atoms, whereas light traveling in other directions is soon lost. The light amplified by stimulated emission is now more intense and more likely to stimulate further emission. Some light reaching the output mirror is transmitted to form the laser beam; some is reflected back through the medium to continue the stimulated-emission process.

History

The fundamental principles underlying the operation of the maser and laser were established long before these devices were successfully demonstrated: stimulated emission was proposed by Albert Einstein in 1916, and population inversion was discussed by V. A. Fabrikant in 1940. These fundamental ideas, followed by two decades of intensive development of microwave technology, set the stage for the first maser, an ammonia maser, constructed in 1954 by J. P. Gordon, H. J. Zeiger, and Charles H. Townes. Over the next 6 years many workers, including Nikolai G. Baslov, Aleksandr M. Prokhorov, Arthur L. Schawlow, and Townes, made important contributions that helped to extend these ideas from the microwave to the optical wavelength region. These efforts culminated in July 1960 when Theodore H. Malman announced the generation of a pulse of coherent red light by means of a ruby crystal—the first laser. In 1964, Townes, Basov, and Prokhorov were jointly awarded the Nobel Prize for physics. Schawlow received a later Nobel Prize, in 1981, for his development of laser spectroscopy, but Malman, who had produced the first actual laser, received no prize.

Another aspect of laser history was finally resolved in 1987, when American physicist Gordon Gould won his 30-year battle to obtain a patent for a gas-discharge laser he had conceived in 1957. He had written his ideas in a notebook at the time, and had them officially recorded, but failed to apply for a patent until 1959 because of poor legal advice. (In the notebook he had, in fact, coined the word "laser," as well.) Gould eventually did receive partial patents in 1977 and 1979, but the 1987 patent covers many types of laser, including the helium-neon laser.

Laser Types

A selection of laser types and characteristics is shown in Table I. Many other types exist, a few of which will be listed here without further discussion: carbon-monoxide, color-center, excimer, free-electron, gas-dynamic, helium-cadmium, hydrogen-fluoride, deuterium-fluoride, iodine, Raman spin-flip, and rare-gas halide lasers.

Many of these lasers may be operated so as to produce widely different pulse-duration, power, and wavelength characteristics; the numbers shown in the table are intended only to suggest the capabilities of each type rather than to indicate the complete range or maximum performance. Listed pulse-duration times range from 40 picoseconds (1 psec = 10(-12) sec) to continuous-wave (cw), which is essentially an infinite pulse length. A 1-nanosecond (10(-9) sec) pulse is only about a third of a meter (1 ft) long as it travels through space. Pulse durations shorter than 1 psec have been achieved, opening up possibilities for probing phenomena of very brief duration.

The tabulated power levels cover a range of a million to a billion in magnitude. The lowest tabulated power—3 milliwatts (mW)—refers to a cw laser, whose highly directional beam is too bright to look directly into and can be damaging to the eye. Some benchmarks may be useful to give some feeling for power levels: electrical input to a typical light bulb is 100 watts (W); power generated by a large automobile, 1 megawatt (MW); electrical power generated by a power station, 1 gigawatt (GW). It is important to appreciate the distinction between power and energy. Power is the rate at which energy is transferred, so that one pulse from a 40-psec, 1-terawatt (TW) laser provides the same amount of light energy as does a 40-W laser in 1 sec. The lasers tabulated have wavelengths that range far beyond the visible-light region (430-690 nm).

A few remarks may be made concerning individual lasers. The helium-neon laser, by far the most common laser, is also one of the cheapest, costing as little as $170. The diode laser is the smallest, being packaged in a transistor-like enclosure. Dye lasers are remarkable for their broad, continuously variable wavelength capability. The achievement of new wavelengths justifies the complicated procedure of using one laser to pump another. The carbon-dioxide laser has, at 15-30%, the best efficiency (the ratio of output light energy to input electrical energy).

Applications

In considering the many applications of lasers, the basic properties of light and of laser light in particular will be referred to as follows: (1) The speed of light is the highest speed possible. (2) Light in empty space travels in a straight line. (3) Light can carry information. (4) Light spreads less as it travels and can be focused into a smaller point than can radio waves. (5) Light beams can be readily manipulated by mirrors and can be switched on and off quickly. (6) Laser light is essentially of a single frequency. (7) Pulsed lasers offer the possibility of power multiplication by releasing energy in very brief pulses. (8) Lasers can apply energy swiftly to very small areas. Besides the areas of application given here, lasers continue to find new ones. For example, laser "atomic traps" were developed in the late 1980s to slow down and study living organisms as well.

Laser-Induced Controlled Thermonuclear Fusion

(Neodymium-glass and pulsed carbon-dioxide lasers; properties 4 and 7). The ability to control thermonuclear fusion on a scale much smaller than that typified by hydrogen bombs or the sun would solve our energy problems for the foreseeable future. One approach to this goal involves heating and compressing a microscopic pellet of hydrogen-isotope (deuterium or tritium) fuel by placing it at the focus of a high-power, short-pulse laser beam. Significant efforts are being devoted to fusion research in several countries.

Communications

(Diode and neodymium-yag lasers; properties 3, 4, and 5). Communications links using coded light pulses from lasers traveling in glass fibers are already in use in the Chicago Bell Telephone system (see FIBER OPTICS). A 144-fiber cable can carry 40,000 simultaneous telephone conversations. Light also offers an attractive alternative to microwaves for satellite communications.

Materials Working

(Carbon dioxide, neodymium, and argon-ion lasers; properties 4, 5, and 8). A laser beam can be used to heat-treat a shallow surface layer of a metal component or to melt and weld a pair of components without introducing sufficient heat to distort them. Narrow cuts can be made, and holes can be drilled. Among the advantages over conventional techniques are that there is no cutting-tool edge to become dull with use, and computer control of cutting and drilling operations is straightforward. Delicate adjustments can be made to the size of microelectronic components while monitoring the desired electrical characteristics of the system.

In the late 1980s a novel process called selective laser sintering was being developed. Working from computer graphics, this "desktop manufacturing" device can produce prototype design models by a rapid buildup of fused layers of plastic or metal through use of a laser beam.

Medical Applications

(Carbon dioxide and argon-ion lasers; properties 4 and 8). A laser beam can be used to seal capillaries in a shallow surface layer without damaging deeper tissues. This can be done while painlessly vaporizing a surface tumor or cutting an organ. Noninvasive surgery of the retina (laser light enters through the eye lens) and cauterization of stomach ulcers (light enters via an endoscopic fiber) are important applications. Lasers have also been used to clear cholesterol blockages in arteries (Angioplasty).

Surveying and Ranging

(Helium-neon and ruby lasers; properties 2 and 4). A laser beam can be used as a straight line in surveying. Distances can be measured by timing a light pulse traveling from the laser to a mirror and back to a detector near the laser. This can be done for both terrestrial measurements and lunar ranging.

Holography

(Helium-neon and argon-ion lasers; property 6). Laser sources allow reproduction of three-dimensional images. This technique is known as HOLOGRAPHY. Holographic views of microscopic objects are now being made by using advanced X-ray lasers.

Isotope Separation and Spectrography

(Various; property 6). The detection, separation, and investigation of atoms and molecules based on the light frequencies that they absorb all benefit from the sophistication and tunability of laser light sources.

Military Applications

(Neodymium and carbon-dioxide lasers; properties 1, 2, 4, and 8). Lasers are used for range-finding and target designation, and are being developed as both antIsatellite and ballistic missile defense weapons.

Information Applications

(Properties 3, 5, and 8). Small laser beams are used in printing devices to trace reproducible images. Laser-etched discs are used for large-capacity audio, video, and data recording and playback.