Laser Technology in Peace and War

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Abstract

Lasers emit light with a very high degree of monochromaticity, directionality and can produce much higher intensities than incoherent light sources, such as incandescent lamps, fluorescent tubes and arcs. The first operating laser was realized in 1960, and much early research was funded by military agencies, but at the present time the commercial laser market is four times as large as the military market. Most applications of lasers are for peaceful purposes. Among the most important of these are fiber-optic communications and laser surgery. Other applications include laser printing, laser machining, construction alignment, and data storage on CD disks. Some military uses of lasers are also reviewed.

I. Introduction

The first laser was realized by T.H. Maiman in 1960. The word "laser" is an acronym that stands for "Light Amplification by Stimulated Emission of Radiation." Despite, or perhaps because of, its English origin the word "laser" was rapidly adopted in many other languages, including Russian. The language of science is universal, independent of nationality, race or religion.

The light output has three characteristics that distinguish it from conventional light sources, such as incandescent lamps, fluorescent lamps and plasma arcs. The coherent light emitted by lasers has a very high degree of monochromaticity, the wavelength or frequency is precisely defined. It also has a high degree of directionality. The light is diffraction limited and the angle of divergence in radians is the ratio of the light wavelength to the diameter of the optical aperture. A laser beam emitted from a one meter diameter telescope pointing at the moon, illuminates the size of a football field on the moon's surface. Furthermore extremely high light intensities are achievable, especially when the laser output is focused in space, and confined to a short pulse duration in time. A cw. argon ion laser beam of one watt, focused onto a microscopic spot size of about one square wavelength or about 10^{-8} cm^2, produces a continuous power flux density of 10^8watts/cm ^{2}. To obtain a sense of this magnitude, it should be noted that the sun at the zenith irradiates the surface of the earth with a flux density of only 0.14watts/cm^2. At the surface of the sun the flux density is that of blackbody radiation at 6000°K, which corresponds to about 10^4watts/cm^2, Thus 10^8 watts/cm^2 is a flux density at which materials readily vaporize and are transformed into hot plasmas. These properties attracted the attention of military experts, who visualized the concept of a blob of electromagnetic energy at visible, infrared or ultraviolet frequencies, traveling at the speed of light towards a distant target. The concept was popularized by the media, and an early James Bond 007 spy movie used a laser beam as a "death ray", and a safe was cut open by it.

I remember serving on an advisory panel in Washington, D.C. in 1961 and learned that an intercontinental ballistic missile could be damaged by the deposition of about one mega joule of light. I observed that about one joule of light could be obtained from one cubic centimeter of neodymium glass. Thus a neodymium glass laser of one cubic meter could in principle deliver one mega joule. This sounds straight forward, but the generation and control of such large amounts of light energy present extremely difficult and technological problems. Even today an antimissile defense based on lasers is not practical.

In this lecture the impact of laser technology on our society will be reviewed. This impact is considerable as the annual laser market in the year 2000 amounted to 6.2 billion US dollars. More than eighty percent of this market is for civilian purposes, and less than twenty percent is for military expenditures. The laser market has exhibited a growth curve that is remarkably similar to that of the transistor. The solid state electronics and computer market developed roughly seventeen years earlier than the laser market. Correcting for this time delay, the development of laser market is nearly identical and one could be tempted to predict the laser market in the year 2010 by looking at the computer market in the year 1993.

In this presentation various civilian applications of lasers will be reviewed first. Special attention will be paid to the development of global optical fiber communication systems, in which lasers play a small, but essential role.

II. Civilian Applications

The simplest application based on directionality is the laser pointer. It is a battery operated low power semiconductor laser, emitting a beam in the red. Green beams may be obtained by adding a solid-state up-converting crystal to an infrared semiconductor laser. It is useful in a lecture hall but it has a more important use in the construction industry. It may be mounted on a theodolite and determine horizontals and verticals of buildings. Larger scale applications include their use in the construction of oil and gas pipelines and tunnels. An early example is the alignment of the tunnel under San Francisco bay for the BART transportation system about thirty five years ago. At that time helium-neon gas lasers were used. Now most gas-laser systems are replaced by semiconductor laser arrays, which have a much longer life time, and are more energy-efficient and more economical. Lasers are also used at check-out counters of supermarkets and other stores to read out the strip labels, identifying the nature of the merchandise and the price. The scattered laser light varies in time as the strip pattern is turned in the beam. It can be distinguished from ambient light by its characteristic color. A narrow filter in front of the detector passes the laser light preferentially.

Another early large scale application of lasers occurred in the printing business. Because of its diffraction limited directionality laser beam can in principle be focused on an area of about $10^{-8}cm^2$, equal to the square of the optical wavelength. Because of the concentration in space, a laser beam with one watt of power could produce a power flux density exceeding megawatts/cm^2 in the focal region. This intensity is sufficient to rapidly evaporate a metallic film of aluminum, deposited on a transparent mylar substrate. The focal point can be scanned rapidly across the moving film to etch a desired pattern, for example that of a printed page recorded in another city, on the metallic coated plastic film. Printing ink adheres differently on the plastic, where the metal film was removed by the laser than on the metallic film. Thus newspapers can be printed in another location. A related process is used for digital recording on a CD disk. A semiconductor laser may be pulsed very rapidly by modulation of the driving voltage. Pulse code modulation is used to transfer information with a light beam. A pulse with the laser beam on means "yes" or "one", and a pulse with no light means "no" or "zero". The laser beam is focused on the rotating plastic recording disk, while it is scanned radially. The focal spot size has the dimension of about one micron by one half micron. Thus one bit of information can be stored on an area of $10^{-8}cm^2$. This area is deformed by the light pulse, either by local heating or by photo-induced polymerization of the material. Thus a standard size CD disk can store about 10^{10} bits. The information can be read out by a very small, low-power semiconductor laser, which is present in every CD or DVD player.

Laser beams are used in machine shops, as they can accurately control lengths to a fraction of an optical wave length in an interferometric set-up. Controlled focused laser beams are also used to cut patterns in the textile industry, to cut through abrasive materials such as emory paper, and even to drill holes in diamond for use in the wire-drawing industry. These applications are all based on the high flux densities obtainable in focal points of laser beams with a total power of only a few watts. Heavy metal-working industries, such as the automotive and ship building manufacturing plants, use very high power lasers. Far-infrared CO_2 gas lasers can give continuous power outputs, ranging from a few kilowatts up to thirty thousand kilowatts. Such lasers are used to cut through steel plates one inch thick, to drill holes, or to weld heavy plates together. They are also used to harden surfaces of metallic gears of any shape. In this case, the beam sweeps across the object for a short time, heating each surface element close to the melting point. After the laser beam has passed, the surface cools off rapidly by heat conduction into the interior. The rapid quenching produces a hard surface, reducing wear and tear, while the main body part retains its toughness, as its temperature rise has remained small. Thus cylinder walls of combustion engines are hardened, so can the surface of any complex gear assembly.

Perhaps the most important application for many human individuals is the use of lasers in surgery. Much lower laser powers suffice to cut into a living body than to drill holes in metal sheets. The blue and green light from an argon ion laser is readily absorbed by red blood cells. It can locally heat or vaporize the red tissue.

Since a laser beam can be focused to a linear dimension of one micron, such a beam is ten times sharper than the finest surgical scalpel. Furthermore the cut blood vessel on either side is automatically cauterized by the heat absorbed from the laser beam, which can be manipulated by electronic control of a mirror. For these reasons laser surgery is often cleaner and more precise than surgery with a scalpel. The laser beam may be focused into an optical fiber, which may be inserted into body orifices, or into an artery. Laser surgery has been used to treat cancers on vocal cords, on the esophagus, on ovaries and elsewhere. The removal of plaque in the coronary arteries has been investigated, but it is not (yet) accepted in medical practice, because the laser beam may also readily puncture the artery wall, while removing the plaque. One of the earliest applications of the laser in surgery was the reattachment of a torn retina. The laser beam is directed through the pupil and focused by the eyeball to a spot on the retina next to the detached area. There the laser light is absorbed and damages the blood containing tissue. The resulting scar tissue then re-attaches the retina at that point. This procedure may be repeated many times along a tear in the retina or almost everywhere in case of panretinal detachment. Of course, the fovea, the area of sharp vision should be avoided. It is saved by reattachment of the retina around it. Even low power laser beams can damage vision, if it is inadvertently focused on the fovea. Suitable goggles should be worn by everybody working in laser laboratories.

Port-wine stains were inoperable before the advent of the laser. These birthmarks are caused by areas of skin which have an excess of blood vessels. They are interlaced with normal skin areas. When a laser beam illuminates the area of the stain, the temperature rise in the sections with too many blood vessels will rise higher than in the immediately adjacent areas with fewer blood vessels. The dosage and duration of the pulsed laser illumination is controlled such that the temperature rises above the coagulation temperature of 60°C only in the parts with anomalous blood vessel content. There the skin cells are killed by protein coagulation but the immediately adjacent normal skin areas are not damaged. Thus the port-wine stain can be eliminated, and nobody has to go through life with this disfigurement, which was previously inoperable.

Lasers are also used extensively to correct eye vision by sculpting the outer surface of the cornea. Cornea tissue is removed in a computer controlled manner by scanning laser pulses.

Lasers of different wavelengths may be used to get preferential absorption in different tissues. Dyes have been developed that are absorbed preferentially and concentrated in cancerous tissues. Subsequent laser radiation is preferentially absorbed in the cancerous cells, which may be heated above the degeneration temperature, while normal cells are spared. There are societies and journal devoted exclusively to laser surgery and medicine. Current research will undoubtedly lead to many other medical laser procedures.

The scientific applications of lasers in physics, chemistry, biology, astronomy and metrology are widespread. It is, however, outside the scope of this presentation to discuss science. Laser spectroscopy can be used to trace chemicals, poisons in forensic sciences, pollutants in the atmosphere, but its impact on society is less direct than the examples of laser technology that have been explicitly mentioned.

III. Global Communications

The impact of optical fiber communications systems' which now connect virtually all countries and all major cities around the globe, is arguably even more important than the impact of lasers in medicine and surgery. While the first transatlantic communication link was established in 1983, the rapid development during the past two decades has been described in a book "Erbium doped fiber amplifiers, Device and System Developments" by E. Desurvire and co authors, published by Wiley 2002. The third generation of the Southeast Asia, Middle East, Western Europe cable system with a total cable length of 39,000 km. includes 40 landing points in 34 countries. It is operated by 92 international carriers belonging to 63 countries. The cable has two optical fiber pairs, operating with an eightfold wavelength division multiplexer. It has a transmission capacity of 20 gigabits per second. It can therefore transmit the information contained in the Encyclopedia Britannica between any of the participating countries in less than 10 seconds. There are of course optical cable systems of comparable or even higher capacity under the Atlantic and Pacific oceans.

The technology today is so advanced, that transmission rates of 1 Terabit per second can be achieved over distances of ten thousand kilometers in a single pair of fibers. With ten fiber pairs in the optical cable total system capacity of 10 terabits or 10^{13} bits per second is achievable. This would enable 780 million telephone voice channels, or 1800 high-resolution digital movies to be transmitted simultaneously. The information in the Encyclopedia Britannica could be transmitted in less than one tenth of a second. The investment and annual market in optical communications technology is larger than that of the laser market alone. While the first prototype optical fiber link, connecting two telephone exchanges a few kilometers apart, was laid under the streets of Chicago in 1972, now much improved links span the globe. The enormous progress in three decades has utilized many scientific advances, including erbium-doped optical fiber amplifiers, optical raman-type amplification, optical wavelength multiplexing and soliton propagation. While no details of these scientific and technological advances can be discussed here, the important consequence is that individuals around the globe can now easily and inexpensively, communicate via telephone or e-mail, and have access to the near limitless information on the internet. Furthermore developing countries do not have to build an infrastructure of copper wires for communications. Cell phones and optical fibers will suffice.

Vastly improved communications draw mankind closer together. Clearly the organization of international meetings, which used to rely on airmail, telegrams and telex, is now greatly facilitated by the use of e-mail via optical fibers. The development of a global economy also depends on a global communication system. These nearly unlimited means of communication between nations should increase the dialogue of ideas and decrease the dangers of war.

IV. Military Applications

From the very beginning laser research was financed and stimulated by military considerations. The concept of a “death ray” was already mentioned in the introduction. It took about two decades before the realization of “Star Wars” was seriously pursued in the Strategic Defense Initiative, launched by President Ronald Reagan in 1981. Although there were from the very beginning serious doubts in the scientific community about feasibility, a definitive study on “Directive energy weapons” was published in a special issue of Reviews of Modern Physics in 1987 and widely distributed around the world. It provides an example, how science can have an impact on war strategies. Under the auspices of the American Physical society and funded by private foundations, a study commission of fifteen scientists was assembled under the co-chairmanship of myself and C Kumar N. Pertel. All committee members, experts in the field of lasers, atomic accelerators and missiles, had top-secret security clearance. They had never taken earlier public positions about the Strategic Defense Initiative, but their private political views covered a wide spectrum. The committee had the cooperation of the government officials, including the presidential science advisor, and the top leadership of the SDI. The committee had access to and visited all pertinent government and industrial laboratories. Its task was to write and publish an unclassified report, based on much classified information. Our report was finished in September 1986 and approved by all committee members, without minority opinions. It addressed only scientific and technological issues. Sometimes the committee debated hotly for hours. If the question was of a political nature, it was omitted from the report, but quite often the question was purely technological, but the wording in the draft had political overtones. In that situation the discussion continued until a neutral wording was found. The report was approved by a special blue ribbon scientific review committee, but before it could be published it had to be reviewed by the security office of the SDI organization and then again by the security office of the secretary of defense. Only a few words had to be deleted or modified. It was cleared for public release in April 1987. The main conclusion was that a strategic defense against numerous intercontinental missiles with multiple warheads fired simultaneous from the Soviet Union or its submarines would not be feasible in the foreseeable future, which extended to a decade or more. The report was accepted by the SDI leadership in the sense that it accurately described the state of the art in September 1986, and it could be used as a yardstick from which future progress could be measured. The SDI did not agree with the wording of our conclusions. A lot of political flack, published in newspapers, non-scientific periodicals and elsewhere was vented, but the report was never scientifically challenged and remains accurate today, seventeen years after its completion.

At the present time the U.S. government still has an active missile defense program, budgeted at nine billion per year. The goal is much more modest to shoot down one or a few missiles, fired by a rogue nation or a terrorist organization, instead of the hundreds or thousands of missiles, fired in the cold-war strategic defense scenario. Even so, the program is facing many technological problems. Spaced-based laser systems are not under active consideration, but an airborne system with powerful lasers mounted in an aircraft is still being pursued. It would not be suitable for intercepting missiles in the boost phase, but it could play a role for midcourse or end-phase interception. The role of lasers for this purpose is probably is less important than that of kinetic energy interceptors.

The deployment of any ballistic missile defense system presents a severe political problem, as it undermines basic concepts in international arms control.

Small scale laser weapons have however, been widely used for decades, as target designators and as range finders. Every military tank is equipped with a laser range finder, which emits a short pulse of light. The scattered return from a target is received with a time delay, which is proportional to the distance. The device operates as simple light radar.

Continuous low power laser beams can also be aimed at a target. A missile aimed at the target homes on the scattered monochromatic radiation. This technique permits pin-point accuracy and actually reduces civilian casualties caused by inaccurate targeting.

It is of course possible to use laser beams to blind people or to destroy heat-seeking detectors in satellites or in rocket propelled grenades. The latter shoulder-mounted devices have been used by terrorists and guerillas to attack aircraft on take-off or landing. The installation of a laser-based defense in civilian aircraft is under active consideration. A laser beam would destroy the sensor in the heat-seeking rocket-propelled missile, which would consequently miss its intended target.

The moral issue of blinding soldiers in combat has been raised, but a train of laser shots is certainly less destructive than a volley of machine gun bullets. It is fortunate that lasers are not weapons of mass destruction. Although an airborne high power laser could in principle ignite a swath of large scale fires, incendiary bombs remain more effective for this purpose. At present there are no large-scale public discussions about laser weapons. They play at present no significant role in the important discussions about weapons of mass destruction and arms-control.

V. Conclusion

Laser development was initially stimulated with strong support from military agencies. It is not unusual for new technologies to develop in that manner. It is useful to remember that the current World Wide Web had its origin in the ARPA net, started by the Defense Advanced Research Project Agency. Aviation technology got a big boost both in World War I and in World War II. It is no accident that the civilian airlines, Pan-American (PAA) and Royal Dutch Airlines (RLM) started up in 1919. The latter was based on Fokker aircraft production, while Fokker worked for the German Military during World War I. Following World War II jet engines became available for civilian transport aircraft. Civilian air transport has become a huge industry that contributes to global communication by person-to-person contacts. These gatherings of the International Peace Foundation would hardly take place without travel by commercial jet aircrafts. One should keep in mind that science and technology are morally neutral. They can be used both for peace and for war. It is fortunate that most uses of lasers have turned out to be beneficial for mankind. This is the main conclusion of this presentation.