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A Survey Of Applications And Safety Of Laser Technology

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***Abstract:** Lasers are devices that produce intense beams of light which are monochromatic, coherent, and highly collimated, the wavelength of laser light is extremely pure when compared to other sources of light, and all of the energy that make up the laser beam have a fixed phase relationship with respect to one another. Light from a laser typically has very low divergence and can travel over great distances or can be focused to a very small spot with a brightness which exceeds that of the sun. Because of these properties, lasers have found uses in many fields. As a device, it is now used in medicine, astronomy, geodesy, metrology, chemistry, biology, spectroscopy, holography, power engineering, in various processes in engineering, as well as in communication technology, automation and remote control, in military technology, entertainment industry, art restorations. This paper will review extensively these applications. A summary of laser safety including the human eye, laser hazards, laser safety controls, maximum permissible exposure, and laser accidents will also be presented.*

***Keywords:** Laser, safety, applications, hazards, radiations, exposure.*

I. INTRODUCTION

Laser light, unlike ordinary light, is unique in that it usually consists of only a single color of light. The wavelengths of this single color, while not perfectly uniform in length, occur within a very narrow range. The word LASER is an acronym for Light Amplification by Stimulated E mission of Radiation [1]. The term describes a physical process that leads to the generation of laser radiation. Lasers are used for a wide range of different purposes and accordingly differ in their construction. The range of optical radiation covers the ultraviolet (UV), the visible (light) and the infrared (IR) regions .There are also different types of lasers depending on the active medium: gas, solid, semiconductor and liquid lasers. Lasers differ also in the way how the optical power is emitted: continuously or in the form of pulses. A laser operating with a continuous output for more than 0.25 s is regarded as a continuous wave laser. A pulsed laser delivers its energy in the form of a single pulse or a train of pulses, with pulse duration of less than 0.25 s. The use of lasers by industry and by the academic community continues to increase. Many educational institutions are using a wide variety of lasers in many different ways. Traditional disciplines in universities, colleges and high schools, such as biology, chemistry, and physics, now recognize the laser as an essential teaching element. Unique environments associated with educational institutions (such as civil engineering, earth and planetary sciences, and biomedical research) have also incorporated lasers into their educational processes. Because of the wide ranges possible for the wavelength, energy content and pulse characteristics of laser beams, the hazards arising from their use varies widely. A system of laser classification is used to indicate the level of laser beam hazard and maximum Accessible Emission Levels (AELs) have been determined for each class of laser [2].

II. LASER APPLICATIONS

Laser radiation in various applications was made use of immediately after the first laser became operational [3]. Every home with a CD player has a laser; hardware stores are now selling a wide variety of laser levels; many, if not most, computers, printers, and copiers are using laser technology. Laser applications are so numerous and the following are some of examples of how lasers are used today

A. INDUSTRIAL APPLICATIONS

Industrial applications now include many new procedures, such as:

- ✓ Laser welding, :
- ✓ Laser cutting:
- ✓ Laser glass decoration
- ✓ Three-Dimensional Stereo lithography
- ✓ Photolithography:
- ✓ Laser Marking and Scribing:
- ✓ Laser Quenching**.**

The main advantage of laser operations consists in machining the product without any mechanical contact, e.g. remote machining or machining in a protective atmosphere, in machining parts of the product difficult to access, as well as in technological treatment of materials that cannot be affected by classical methods. High-power lasers have long been used for cutting and welding materials. Today the frames of automobiles are assembled using laser welding robots, complex cardboard boxes are made with laser-cut dies, and lasers are routinely used to engrave numbers and codes on a wide variety of product.

LASER WELDING

Laser welding makes use of optical radiation to melt the material to a desired depth, minimizing at the same time the surface vaporization. In practice, this process utilizes mostly the continuous lasers of the infrared CO_2 spectrum and the Nd:YAG lasers, of a wavelength of 10.6 nm and1.06 nm, respectively[4]. Welding, as against some other processes, uses a lower intensity optical beam and a longer laser pulse [of the order of ms].The advantage of laser welding rests in the absence of physical contact with the electrode, in localised heating and cooling, in welding parts in a protective atmosphere or sealed into optically transparent material .Lasers can weld, e.g., airtight shields of miniature relays, pacemakers, contacts in microelectronics, and metal sheets in car or aircraft industry.

LASER CUTTING

Laser cutting is utilized when some low thermal conductivity material is to be removed. With cutting, the material is to be vaporized as quickly as possible, while keeping the area thermally affected as small as possible. The lasers used for this purpose are again the continuous CO_2 lasers of up to15 kW[8]. In industrial laser cutting, some gas is transported to the cutting spot coaxially with the laser beam; in case of metals, a reactive gas, as, e.g. oxygen. What follows, is an isothermical reaction to speed up cutting. This is how such materials as titanium, low-carbon steels, and stainless steels are cut. To cut non-metallic materials, for instance, ceramics, plastics, and wood, inert gas is transported to the spot only to remove the material that melted down or vaporized. The same technique is applicable to textile, paper, and glass. The advantage of laser cutting rests in its great speed, in cutting various shapes , in its possible automation, in non-contact approach, in the good quality of the cut, and, last but not least, in the limited area of thermal effect.

LASER GLASS DECORATION

Laser glass decoration is a modification of laser cutting. At the spot focused laser beam impinges upon the glass surface, the melted glass will evaporate and cracks will appear on its surface. They will diffuse light producing thus a shiny effect of the lasered ornament. Glass is decorated by lasers whose radiation is easily absorbed by the glass, e.g., by the continuous CO_2 laser.

THREE-DIMENSIONAL STEREOLITHOGRAPHY

Often a designer, having created a complex part on a CAD machine, needs to make a prototype component to check out the dimensions and fit. In many cases, it is not `necessary for the prototype to be made of the specified (final) material for this checking step, but having a part to check quickly is important. This is where rapid prototyping, i.e., three-dimensional stereolithography, comes in. The stereolithography machine consists of a bath of liquid photopolymer, an ultraviolet laser, beam-handling optics, and computer control[6]. When the laser beam is absorbed in the photopolymer, the polymer solidifies at the focal point of the beam. The component design is fed directly from the CAD program to the stereolithography computer. The laser is scanned through the polymer, creating, layer by layer, a solid, three-dimensional model of the part.

PHOTOLITHOGRAPHY

Lasers are used throughout the manufacture of semiconductor devices, but nowhere are they more important than in exposing photo resist through the masks used for creating the circuits themselves. Originally, ultraviolet mercury lamps were used as the light sources to expose the photo resist, but as features became smaller and more complex devices were put on a single wafer, the mercury lamp's wavelengths were too long to create the features. Approximately ten years ago, manufactures started to switch to ultraviolet lasers operating at approximately 300 nm to expose the photo resist. Manufacturers are now using wavelengths as short as 193 nm to get the resolution needed for today's semiconductor integrated circuit applications [6].

LASER MARKING AND SCRIBING

Lasers are used extensively in production to apply indelible, human and machine-readable marks and codes to a wide variety of products and packaging. Typical applications include marking semiconductor wafers for identification and lot control, removing the black overlay on numeric display pads, engraving gift items, and scribing solar cells and semiconductor wafers. The basic marking system consists of a laser, a scanning head, a flat-field focusing lens, and computer control. The computer turns the laser beam on and off (either directly of through a modulator) as it is scanned over the surface to make the mark. Depending upon the application, scanning may occur in a raster pattern (typical for making dot-matrix marks) or in a cursive pattern, with the beam creating letters one at a time. The mark itself results either from ablation of the surface of the material, or by a photo chemically induced change in the color of the material. Another marking technique, used with high-energy pulsed CO_2 and excimer lasers, is to shine the light through a mask containing the marking pattern and focusing the resulting image onto the marking surface. Laser scribing is similar to laser marking, except that the scan pattern is typically rectilinear, and the goal is to create micro scoring along the scan lines so that the substrate can be easily broken apart. A wide variety of materials, including metal, wood, glass, silicon, and rubber, are amenable to laser marking and scribing. Each material has different absorption and thermal characteristic, and some even have directional preferences due to crystalline structure. Consequently, the type of laser used depends, to some extent, on the material to be marked (e.g., glass transmits the 1.06µm output from a YAG laser but absorbs the 10.6µm output from a CO_2laser)[4]. Other considerations are the size of the pattern, the speed of the scan, cosmetic quality, and cost. Currently, most volume marking applications are performed with lamp-pumped YAG-based pulsed or Q-switched lasers. Pulsed and cw CO_2 lasers make up the bulk of the remainder. However, DPSS and fiber lasers are encroaching on this field owing to their higher reliability and lower operating cost. Because of their very short wavelengths (100–300 nm)[9], excimer lasers are used in applications requiring extremely high resolution, or whose materials would thermally damage at longer wavelengths[7].

LASER QUENCHING

Laser quenching can be defined as thermal treatment of metals making use of laser radiation to obtain speedy heating. Compared to other ways of heating, lasers are able to localise thermal treatment even to spots inaccessible by other methods, as well as to secure nondeforming treatment. This procedure is preferred mainly in industry for the so called transformation strengthening of some stressed car and aircraft parts. Also in this case, the source of radiation is the continuous CO_2 laser; this time, however, of a power of several thousand watts.

B. NONCONTACT MEASUREMENT

There are many types of laser-based noncontact measurement techniques in use today including:

- ✓ Scatter measurement
- ✓ Polarimetry and ellipsometry,
- ✓ Interferometric measurement.

SCATTER MEASUREMENT

In the semiconductor industry, patterns of material are deposited on a wafer substrate using photolithographic processes. Defects on the wafer can result in poor reliability, disconnects in circuitry, or complete circuit failure. Consequently manufacturers need to map the wafer to determine the defects’ location and size so that they can either be eliminated or avoided. To do this, they scan the wafer with a laser and measure backscatter with a very sensitive photo detector array. Lasers used in this application have to have excellent pointing stability, constant wavelength and power stability to calculate the correct size of the defects through complex algorithms, and low noise so the little scatter the defect makes can be distinguished from the background laser light. Blue 488-nm argon ion lasers have been the laser of choice for many years[10]. However; as lithography has shifted to shorter and shorter ultraviolet wavelengths, however, we are beginning to see the metrologic techniques for wafer defect measurement also moving to shorter wavelengths. Ultraviolet diode and solid-state lasers are likely to replace the ion laser in the next generation of instruments.

POLARIMETRY AND ELLIPSOMETRY

The optical phase thickness of a thin film can be carefully measured using polarimetry or ellipsometry.A beam of known polarization and phase state enters the thin film layer at an angle. The thin film has a known index of refraction.The measured phase change in the reflected beam is then correlated to an optical phase thickness for that layer using the known index of refraction. This technique can also be used with a thicker transparent media, such as glass, where changes in the polarization and phase state of a beam scanned across the substrate indicate variations in index of refraction due to inclusions or stress-induced birefringence. The most common lasers used in these applications are violet, red and near infrared single-emitter laser diodes and mid-visible diode-pumped solid-state lasers owing to their cw output, low noise, and compact sizes.

INTERFEROMETRIC MEASUREMENT

Interferometric measurement can be used for high-resolution position measurement as well as for measuring waveform deformation of optical beams as they pass through a component or system. The technique uses the wave periodicity of the light beam as a very fine ruler. The position of an object in the path of the beam is computed from the phase of the light reflected from it. Interference between the object beam and a reference beam provides measureable intensity variations which yield this phase information.Distance and velocity measurement can be performed for moving objects as long as the fringe-recording mechanism is paced with it.

Typical applications of this technique include positioning of masks for the lithography process, mirror distance correlation within an FTIR spectrometer, optical feedback in many high-resolution positioning systems, and determining the alignment and flatness of hard disk drive heads. For applications requiring measurement over a long path length, lasers with a single longitudinal mode and long coherence length are often required. In these cases, frequency-stabilized helium neon lasers or solid-state lasers with frequency selective elements are used.

C. LASERS IN MICROELECTRONICS

Since the beginning of the seventies, new procedures have been seen,e.g, laser tuning of rated nominal values of resistors, capacitors, and electric filtres, disconnection of damaged circuits in semiconductor memories, laser groving for separating ceramic, silicone, or gallium arsenide substrates. The idea behind all these procedures is to evaporate a thin layer of material by exposing it to a powerful laser beam, in this case mostly using a pulse Nd:YAG laser of a pulse length within hundreds of ns (10 -9s)[3].Microelectronics will also use methods now under development, i.e., laser addition of dopants into a substrate, which consists in irradiating and thus decomposing a gas containing the dopant over the surface, at the same time melting the substrate. The dopant released by radiation then diffuses into the substrate. The laser is also used to mend damaged lithographic printing plates, to remove impurities from the surface of materials, to initiate silicon growth on a layer of SiO_2, and so on. New types of microelectronic parts can be produced by laser deposition of thin layers, i.e., by evaporating the target material by a laser beam, the vapours condensing on the substrate. This will create a thin layer, stochiometrically identical to the target material. This process is used to deposit supraconductive, ferroelectric, and ferromagnetic layers and multilayer structures [1]. They can be used for new types of non-destructive memories, supraconductive quantum magnetometres, etc

D. SCIENTIFIC APPLICATIONS

Lasers are used extensively in the scientific laboratory for a wide variety of spectroscopic and analytic tasks. The following are interesting examples:

- ✓ Time-resolved spectroscopy
- ✓ Confocal scanning microscopy
- ✓ TIR and Fluorescence Correlation Spectroscopy
- ✓ Microarray scanning

TIME-RESOLVED SPECTROSCOPY

Time-resolved spectroscopy is a technique used to observe phenomena that occur on a very short time scale. This technique has been used extensively to understand biological processes such a photosynthesis, which occur in picoseconds (10^{-12}seconds) or less. A fluorescing sample is excited by a laser whose pulse length is much shorter than the time duration of the effect being observed. Then, using conventional fluorescence spectroscopy measurement techniques, the time domain of the fluorescence decay process can be analyzed. Because of the speed of the processes, mode-locked lasers are used as the exciting source, often with pulse compression schemes, to generate pulses of the femtosecond (10^{-15}sec) time scale, very much faster than can be generated by electronic circuitry.

CONFOCAL SCANNING MICROSCOPY

Scanning microscopy is used to build up a three-dimensional image of a biological sample. In standard light microscopy, a relatively large volume of the sample is illuminated, and the resultant light gathered by the objective lens comes not only from the plane in focus itself, but also from below and above the focal plane [7]. This results in an image that contains not only the in-focus light, butalso the haze or blurs resulting from the light from the out-of-focus planes. The basic principle of confocal microscopy is to eliminate the out-of-focus light, thus producing a very accurate, sharp, and high-resolution image. A visible laser is used as the light source to produce a distinct and spatially constrained point source of illumination. This light is then focused on the sample. A pinhole is placed in front of the detector at an optical distance that is exactly the same as the optical distance between the focus point and the illuminating source point (the confocal condition). Consequently, only the light generated at the illuminating point will, upon reflection or scattering from the sample, pass through the pinhole in front of the detector; out-of-focus light will be blocked by the pin-hole. The signal from the detector is then digitized and passed to a computer. The complete image is digitally built up by scanning the sample in the x and y directions.

TIR AND FLUORESCENCE CORRELATION SPECTROSCOPY

Fluorescence correlation spectroscopy measures the variation in fluorescence emission at the molecular level as fluorochromes travel through a defined field. The data can then used to determine binding and fusion constants for various molecular interactions. Because the measured volumes are so small, measurements are typically made using single-photon or two-photon confocal microscopy techniques (see above). In many cases, the region of interest for fluorescence correlation spectroscopy is the first 100 to 200 nm of the sample's surface. However, the excitation depth (vertical resolution) for conventional confocal spectroscopy is 1 to 1.5 µm, leading to low signal-to-noise ratios and diminished accuracy[4].One means of reducing the excitation volume is to use total internal reflection (TIR) techniques. If a laser beam, passing through a high index material (e.g., glass at $n \cong 1.5$) strikes an interface with a lower index sample material (e.g., an aqueous solution at $n \cong 1.3$) at an oblique angle, there is an angle of incidence (the critical angle) at which all of the light will be completely reflected at the interface, and none will pass into the lower-index material. Because the beam is completely reflected at the interface, there is no energy flux across the interface; there is, however, an electromagnetic field generated in the lower index material, determined by the boundary conditions on the electric and magnetic fields at the interface. This transmitted wave is evanescent, propagating along the surface of the interface, but decaying in intensity exponentially with depth, limiting excitation to a few hundred nanometers—five to ten times better resolution than with confocal techniques alone.Various techniques have been used to obtain TIR. Most commonly, the laser beam is brought in through a prism. Another technique is to bring the beam in through the steeply curved edge of the observing microscope itself, and then filtering out the returning beam with a dichroic mirror.

MICROARRAY SCANNING

In DNA research, a microarray is a matrix of individual DNA molecules attached, in ordered sets of known sequence, to a substrate which is approximately the size of a microscope slide. A single array can contain thousands of molecules each tagged with a specific fluorochrome[6]. The array is then put into a microarray reader where each individual site of the matrix is individually probed by a variety of laser wavelengths at, or near, the excitation band of specific protein tags. The resulting fluorescence is measured and the fluorescence, position, and sequence data are stored in a computer database for later analysis. Microarrays and microarray readers have had a dramatic impact on the speed by which data can be taken. Previously experiments were conducted one or two molecules at a time; preparation and set-ting up could take hours. With microarray readers, the raw data for analysis of thousands of molecules can be taken in minutes. The main driver for microarrays is the pharmaceutical industry. If one can identify the differences in the way genes are expressed in a healthy organ and in a diseased organ, and then determine the genes and associated proteins that are part of the disease process, it may be possible to synthesize a drug that would interact with the proteins and cure or reduce the effect of the disease. The beam from a laser is focused onto a well (molecule) on the molecular matrix. If the appropriate fluorescent tag is present, the resulting fluorescence is measured by a detector. A filter in front of the detector separates the laser wavelength from the fluorescence signal. The laser beam is then moved to the next well. Today's microarray scanner systems use two or more cw lasers, each with a different wavelength. Output power typically ranges from 10 to 50 mW, a power level that allows scanning without damaging or changing the material under test. Laser pointing stability is important as the microarray wells are quite small and repeatability is needed to relocate cells. Power stability and low noise are also extremely important due to the small sample size and the resulting weak fluorescence signal.

The most common lasers in use today for excitation are the blue solid-state (473–488 nm), green solid-state (532 nm) and red diode (650–690 nm) lasers [11]. Solid-state and semiconductor laser technology is chosen primarily for its compact size, reliability, and power efficiency. Other wavelengths, including violet (405 nm) and ultra-violet (375 nm) from diode lasers, are currently being tested for application in microarray-reading applications.

E. CLINICAL AND MEDICAL APPLICATIONS

The ruby laser was verified in practice immediately after it had become operational, namely in ophthalmology in retina surgery, and in dermatology to remove pigmentation spots. Medical doctors were attracted by its ability to concentrate the energy of optical radiation into a small area and the possibility of cutting and vaporizing tissues. It is due to these qualities that the laser has become so important in laser surgery, its advantage being the possibility of performing a non-contact sharp-contour tissue incision and removal of even tiny structures without any damage to the surrounding tissue and any possible infection of the cut. Laser surgery thus makes use of transformation of radiation into heat within the tissue, performing thus both the incision and coagulation. Monochromaticity and coherence, two properties of laser radiation, are utilized mainly in medical diagnostics. Due to further advances in laser physics and to new types of laser devices, the laser has gradually entered many new branches of medicine, namely ophthalmology; dermatology; general, plastic, and cardiovascular surgery; neurosurgery; otolaryngology; urology; gynaecology; dentistry; oncology; gastroenterology; orthopaedics; and others. Many types of lasers are used in clinical applications including CO_2, solid state, and diode lasers, as well as array of gas lasers covering the spectrum from the ultraviolet to the infrared.

LASERS USED IN OPHTHALMOLOGY

Laser light is used here in major surgeries, as, e.g., in treating retina detachment, glaucoma removal, and treatment of diabetic retinopathy, cataract surgery, etc.Unlike the former surgical treatment affecting the eye tissues, these types of laser surgical treatment can make use of the optical properties of parts of the eye. The surgery is quick and less painful, and can mostly be performed on an outpatient basis; at present it can be performed by various types of lasers. In the retina surgery, the early surgical ruby laser was replaced by the quasi continuous argon laser; in secondary cataract surgery, the high-power Nd:YAG laser is now used and for correcting eye defects, i.e.short-sightedness and long-sightedness, the excimer laser is now employed[11].The laser beam passed through the lens and vitreous humor in the eye and focused on the retina, creating scar tissue that effectively sealed the rupture and staunched the bleeding

FLOW CYTOMETRY

Flow cytometry is a technique used for measuring single cells. Not only is it a key research tool for cancer and immunoassay disease research, but it is also used in the food industry for monitoring natural beverage drinks for bacterial content or other disease-causing microbes.

In a basic cytometer, the cells flow, one at a time, through a capillary or flow cell where they are exposed to a focused beam of laser light. The cell then scatters the light energy onto a detector or array of detectors. The pattern and intensity of the scattered energy helps to determine the cell size, and shape. In many cases the cells are tagged with a variety of fluorochromes designed to selectively adhere to cells or cell components with specific characteristics. When exposed to the laser light, only those with the tag fluoresce. This is used in many systems to assist with separation or sorting of cells or cellular components. The most popular lasers used in flow cytometry are the 488-nm (blue) argon-ion laser and the 632-nm (red) and 594-nm (yellow).HeNe lasers [3]. However, new violet, blue and red diode lasers and a variety of new DPSS lasers are entering the field.

SURGICAL APPLICATIONS

Lasers are used in a variety of surgical and dental procedures from cutting tissue, vaporizing tumors, removing tattoos, removing plaque, removing cavities, removing hair and follicles, resurfacing of skin and of course, correcting vision. In many ways, medical applications are like materials processing applications. In some cases material is ablated. In others tissue is cut or welded, and in yet others, photochemical changes are caused in blood vessels to encourage shrinkage and absorption. Understanding tissue absorption characteristics and reaction to wavelength and power are key. Ultraviolet excimer lasers are used for vision correction because they can ablate material from the lens of the eye without causing thermal damage which could blur vision or make the lens opaque[11].Ruby lasers are used for tattoo removal because many of the dyes break down when exposed to 694-nm radiation, yet the skin tissue is left undamaged[5]. Cosmetic treatment of wrinkles, moles, warts, and discolorations (birth marks) is often accomplished with near infrared and infrared lasers. These procedures are often assisted by topical or injected photosensitive chemicals that assist with selective absorption at specific sites.

Lasers are also used to treat macular degeneration, an over-growth of veins and scar tissue in the retinal region, a condition associated with advancing age. In this procedure, the patient is injected with a selective dye, which enhances the absorption of laser light by the blood in the blood vessels. When the blood vessels absorb laser energy, they wither in size, uncovering the active retina. A Multiwatt green DPSS laser is most commonly used for this application because the green wavelength is not absorbed by the lens or aqueous portion of the eye, which allows the laser to affect only the targeted veins.

F. MILITARY APPLICATIONS OF LASERS

Lasers appear also in various military applications, the most widely utilized being the so called laser range finders, an analogy to the ground laser radar that can measure with great accuracy the target’s distance and thus obtain the optimal trajectory of a missile and higher reliability of the hit. For this purpose, the Nd:YAG lasers seem to be best[4]. However, much less sophisticated are the laser markers used in, e.g., guns, to identify the target at a distance of up to 20 m. In this case small diode lasers are used. On the other hand, for intercontinental ballistic missiles to be destroyed, it is necessary to use a high-power laser, i.e., of the CO_2 or chemical type, and mirrors placed in space. Due to minimal free-space path loss, the beam is transmitted without any loss to the next mirror focusing the beam and homing it to the target, e.g., a rocket .To achieve best homing and hit, the mirrors can be moved round according to the rocket' s parametres.The laser can be located at a ground station or on a trajectory.

G. LASERS IN ASTRONOMY, GEODESY, AND GEOPHYSICS

Soon after the laser became operational, it was also used as part of a radar system to emit radiation. In this case, among the characteristics of laser radiation, it is low divergence and its capacity to generate very short pulses (of the order 10^{-12} s) that are utilized. This device, the so called laser radar, can measure distances to objects which reflect laser radiation back to the direction of the coming beam. In order to enhance the intensity of the beam reflected to the source, the objects to be measured carry the so-called satellite laser reflectors, i.e., corner prisms reflecting the coming beam. Depending on the purpose for which the reflectors are to be used, i.e., if in astronomy, geodesy, geophysics, or ecology, they are installed on ground targets, satellites, or the Moon's surface. The distance is measured by measuring the time interval elapsing between the moment the optical radiation pulse is sent to the moment the pulse reflected from the object measured has returned. The laser radar range is calculated from the energy of the reflected signal, i.e., the so called radar equation .According to this equation, the magnitude of the received signal diminishes proportionally to the fourth power of distance. With ground objects, clouds, aircraft, and the like, usually not equipped with the laser reflectors), the laser radar range is up to 20 km. When the Earth’s satellites are measured, distances of tens of thousands of kilometers are spanned; the most distant objects measured by a laser radar are laser reflectors placed on the Moon’s surface, i.e., about 380,000 km away. The accuracy of laser ranging is given by the length of the pulse transmitted, the obtainable accuracy of the time interval measured, geometry of the object measured, the design and placement of the reflectors, and, last but not least, the accuracy of the mathematical model for radiation propagation in the atmosphere. The accuracy ranges from several decimetres [obtained when measuring objects carrying no reflectors], up to several millimetres (for Earth satellite ranging). Results of these measurements provide exact values as to the triangle leg lengths for angular measurements in astronomy; they also help to study the Moon's dynamics and the Earth’s satellites. Evaluations of the long-term satellite laser ranging results helped to determine the exact shape of the Earth geoid with an accuracy of up to 10 cm [using lasers in geodesy].In geophysics lasers helped to determine the drift of parts of continents, reaching 4 to 5 cm in a year. The measurement results are important also for seismology. Transmitters in laser radars are based on solid pulse lasers. The original laser used for this purpose, the ruby laser of pulse length 10^{-9} s, was replaced by the Nd:YAG laser of pulse lengths by three orders lower, i.e. 10^{-12}s. The latest high-precision measurements are performed with a titanium sapphire system in the femto second range (10-15s)[10].Also helium-neon lasers found their use in geodesy, namely in marking out lines on the Earth' s surface and under the ground.

H. LASER RADAR IN EGOLOGY - LIDAR (LIGHT DETECTION AND RANGING)

Ground laser radars are used in ecology to measure air pollution. They are also used in meteorology. In this case it is both reflection and scattering that are made use of in measurements. Passing through the atmosphere, the laser pulse is scattered by the molecules and aerosols present there, causing Mie, Raleigh, or Raman scattering [10]. Part of the radiation scattered backwards is concentrated by a telescope, and passing through a filter detected by a photo detector. The received signal, whose amplitude at any moment is proportional to the intensity of the scattered radiation, is recorded as a function of time, due to which it is possible to obtain also the distance of the scattering body, while the filter width and/or the attached spectrometer determine the spectrum of the received signal. LIDAR serves to monitor the distribution and direction of smoke trails; to measure the bottom level and profile of clouds, of atmospheric turbulence, distribution and areas of various emissions in the atmosphere, etc.

I. LASERS IN COMPUTER SCIENCE

This field of applications requires small-size lasers, so semiconductor or He-Ne low-power lasers seem to be the best[7]. Thus the laser printer, used in computer science, has become standard equipment of computer centres. It is a device that makes use of laser radiation to obtain the image of what is to be printed, i.e., transferred from the rotating drum to paper. The information to be printed, including the intended graphical layout, is encoded into the computer from which it is transferred to the modulator of optical radiation, which, according to the codes, interrupts the laser beam impinging upon the reflection part of the deflection disc. Every single segment on the deflection disc deflects the beam across the drum which is covered with a layer of photosensitive material of specific property, namely that after laser radiation has impinged upon it, its electric resistance at the irradiated dot will decrease by several orders. If this layer prior to receiving the relevant information carries a constant potential, then, upon the incidence of laser beam, in agreement with the code, it will produce an image composed of dots whose potential differs from the original one. The matrix thus created on the drum is then electrostatically covered with a toning medium, whose adhesion to the cylinder is given by the potential of each dot. The image is then transferred to paper. The advantage of this type of printer is its high-quality recording, high resolution of characters and high printing speed (up to 10 pages A4 per minute).

III. CONCEPTS OF LASER SAFETY

The objective of this section is to provide reasonable and adequate guidance for the safe use of lasers by evaluating and minimizing hazards associated with laser radiation in educational and workplace environments. The hazard evaluation procedure used is based on the ability of the laser beam to cause biological damage to the eye or skin during intended use, and is related to the classification of the laser or laser system from Class 1, considered to be nonhazardous, to Class 4, very hazardous. Lasers or laser systems are certified by the manufacturer for the specific hazard class in accordance with the Federal Laser Product Performance Standard.

A. CLASSIFICATION OF LASERS

Lasers are classified to describe the capabilities of a laser system to produce injury to personnel.

Class I lasers are low powered devices that are considered safe from all potential hazards. Some examples of Class I laser use is: laser printers, CD players, CD ROM devices. No individual, regardless of exposure conditions to the eyes or skin, is expected to be injured by a Class I laser. No safety requirements are needed to use Class I laser devices.

Class II lasers (Visible Lasers: 400 to 700 nm) are low power (< 1mW), visible light lasers that could possibly cause damage to a person's eyes. Some examples of Class II laser use are: classroom demonstrations, laser pointers, aiming devices and range finding equipment. If class II laser beams are directly viewed for long periods of time (i.e. > 15 minutes) damage to the eyes could result. Avoid looking into a Class II laser beam or pointing a ClassII laser beam into another person's eyes. Avoid viewing Class II laser beams with telescopic devices. Realize that the bright light of a Class II laser beam into your eyes will cause a normal reaction to look away or close your eyes. This response is expected to protect you from Class II laser damage to the eyes.

Class IIIa lasers are continuous wave, intermediate power (1-5 mW) devices. Some examples of Class IIIa laser uses are the same as Class II lasers with the most popular uses being laser pointers and laser scanners. Direct viewing of the Class IIIa laser beam could be hazardous to the eyes. Do not view theClass IIIa laser beam directly. Do not point a Class IIIa laser beam into another person’s eyes. Does not view a Class IIIa laser beam with telescopic devices; this amplifies the problem.

Class IIIb lasers are intermediate power (c.w. 5-500 mW or pulsed 10 J/cm^2) devices. Some examples of Class IIIb laser uses are CW and pulsed dye lasers used in spectroscopy and entertainment light shows. Direct viewing of the Class IIIb laser beam is hazardous to the eye and diffuse reflections of the beam can also be hazardous to the eye. Do not view the Class IIIb laser beam directly. Do not views a Class IIIb laser beam with telescopic devices; this amplifies the problem

Class IV lasers are high power (c.w. >500mW or pulsed >$10J/cm^2$) devices [4]. Examples of Class IV laser are: Argon ion and Nd:YAG lasers used to pump CW and pulsed dye lasers. The direct beam and diffuse reflections from ClassIV lasers are hazardous to the eyes and skin. Class IV laser devices can also be a fire hazard depending on the reaction of the target when struck. Much greater controls are required to ensure the safe operation of this class of laser devices. Whenever occupying a laser controlled area, wear the proper eye protection. Most laser eye injuries occur from reflected beams of class IV laser light, so keep all reflective materials away from the beam. Do not place your hand or any other body part into the class IV laser beam. The pain and smell of burned flesh will let you know if this happens. Realize the dangers involved in the use of Class IV lasers and please use common sense.

IV. LASER HAZARDS

A. EYE HAZARDS

The eye is the part of the body most vulnerable to laser hazards. Changes to the eye can occur at much lower laser power levels than changes to the skin. And, eye injuries are generally far more serious than injuries to the skin. The human eye is a complex optical system. It is designed to transmit, focus, and detect light. The normal human eye is roughly the shape of a slightly elongated sphere. It’s about the size of a quarter (25 mm, or about 1 inch) in diameter. The potential for injury to the different structures of the eye depends upon which structure absorbs the energy. 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.

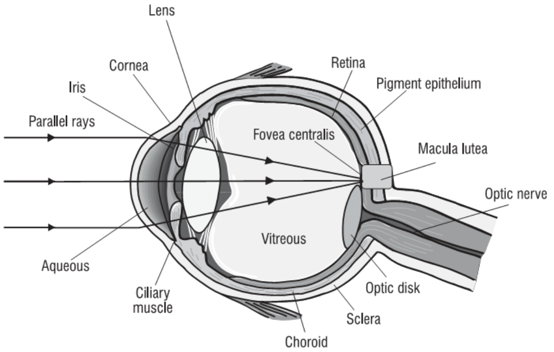

Figure 1: Structure of the eye

OCULAR IMAGE

Wavelengths between 400 nm and 1400 nm are transmitted through the curved cornea and lens and focused on the retina. Intra beam viewing of a point source of light produces a very small spot on the retina resulting in a greatly increased power density and an increase chance of damage. A large source of light such as a diffuse reflection of a laser beam produces light that enters the eye at a large angle is called an extended source. An extended source produces a relatively large image on the retina and energy is not concentrated on a small area the retina as in a point source.

ABSORPTION OF RADIATION BY THE EYE

Certain areas of the eye absorb more light in one spectral region than in other regions. Absorption of laser radiation above a certain level leads to tissue injury. Shorter wavelengths of ultraviolet (UV-C and most UV-B), which range from 315 nm to 280 nm for UV-B and 280 nm to 100 nm for UV-C, are absorbed primarily in the cornea .Longer wavelengths of ultraviolet light (UV-A), which range from 400 nm to 315 nm, are absorbed principally in the lens of the eyeball. Radiation in the visible and IR-A (400 nm to 1400 nm) is the most hazardous and is transmitted by the optical components of the eye. It eventually reaches the retina, where most of the radiation is absorbed in the retinal pigment epithelium and in the choroid, which is a dark brown layer with exceptionally large blood vessels and high blood flow rate. Some infrared radiation in the IR-A, which ranges from 700 nm to 1400 nm, and IR-B, which ranges from 1400 nm to 3000 nm, is absorbed by the lens. Far-infrared radiation, which ranges from 3000 nm to 1 mm, is absorbed primarily by the cornea. Table 1 identifies different wavelength regions coded by symbols from IR to UV.

IR-C	1 mm to 1400 nm
IR-B	3000 nm to 1400 nm
IR-A	1400 nm to 700 nm
Visible light	700 nm to 400 nm
UV-A	400 nm to 315 nm
UV-B	315 nm to 280 nm
UV-C	280 nm to 100 nm

Table 1: Laser Wavelength regions

An important quantity of measure related to laser damage to the eye is retinal irradiance (E), defined as power per unit area, usually expressed in W/cm^2 or mW/cm^2.Irradiance is much higher at the retina than at the cornea or lens. That's because the laser light is focused by a strong converging lens to a small area on the retina and this accounts for the optical gain. The reduced size of the irradiated area means higher values of irradiance. In the condition called intrabeam viewing, the focusing of the incident beam causes a tremendous increase of irradiance.

B. LASER RADIATION EFFECTS ON SKIN

Skin effects are generally considered of secondary importance except for high power infrared lasers. However with the increased use of lasers emitting in the ultraviolet spectral region, skin effects have assumed greater importance. Erythema (sunburn), skin cancer and accelerated skin aging are produced by emissions in the 200 to 280 nm range. Increased pigmentation results from exposure to light with wavelengths of 280 to 400 nm. Photosensitization has resulted from the skin being exposed to light from 310 to 700 nm. Lasers emitting radiation in the visible and infrared regions produce effects that vary from a mild reddening to blisters and charring. These conditions are usually repairable or reversible however depigmentation, ulceration, and scarring of the skin and damage to underlying organs may occur from extremely high powered lasers.

V. NONBEAM HAZARDS

There are five well-known non beam potential hazards associated with the use of lasers and laser systems.

- ✓ Electrical hazard
- ✓ Chemical hazard
- ✓ Collateral Radiation hazards
- ✓ Fire hazard
- ✓ Explosion hazard

A. ELECTRICAL HAZARDS

The most lethal hazard associated with lasers is the high voltage electrical systems required to power lasers. Several deaths have occurred when commonly accepted safety practices were not followed by persons working with high voltage sections of laser systems.

SAFETY GUIDELINES

- ✓ Do not wear rings, watches or other metallic apparel when working with electrical equipment.
- ✓ Do not handle electrical equipment when hands or feet are wet or when standing on a wet floor.
- ✓ When working with high voltages, regard all floors as conductive and grounded.
- ✓ Be familiar with electrocution rescue procedures and emergency first aid.
- ✓ Prior to working on electrical equipment, de-energize the power source. Lock and tag the disconnect switch.
- ✓ Check that each capacitor is discharged, shorted and grounded prior to working in the area of the capacitors.

- ✓ Use shock preventing shields, power supply enclosures, and shielded leads in all experimental or temporary high-voltage circuits.

B. CHEMICAL HAZARDS

LASER DYES

Most dyes come in a solid power form, which must be dissolved in solvents prior to use in the laser system. Improper use of dyes or solvents may present a range of hazards for the laser researcher. Although little is known about them, many organic laser dyes are believed to be toxic and/or mutagenic. Because they are solid powders, they can easily become airborne and possibly inhaled and/or ingested. When mixed with certain solvents (DMSO), they can be absorbed through unprotected skin. Direct contact with dyes and with dye/solvent solutions should always be avoided. A wide variety of solvents are used to dissolve laser dyes. Some of these (alcohols) are highly flammable and must be kept away from ignition sources.

Fires and explosions resulting from improper grounding or overheated bearings in dye pumps are not uncommon in laser laboratories. Dye pumps should be inspected, maintained, and tested on a regular basis to avoid these problems. Additionally, dye lasers should never be left running unattended. Some of the solvents used with laser dyes may also be skin irritants, narcotics, or toxics. Material Safety Data Sheet (MSDS) should be referred, which is supplied by the solvent manufacturer for additional information on health effects [2].

Powered laser dyes should never be handled where the airborne dust could be breathed. Dyes must be mixed only in a properly functioning fume hood. The proper protective equipment (PPE = safety glasses, chemical gloves, and lab coat) should always be used by the person handling the dye. The gloves being used should be resistant to the solvent being handled. Mixing of dyes and solvents should be done carefully, so as to avoid spilling. Any spills or leaks should be cleaned up immediately using appropriate PPE. Avoid breathing fumes from the solvent being used. Clearly identify and mark containers used for mixed dye/solvent solutions. Practice good hygiene and wash your hands well after handling dyes. Limit the amount of mixed dye/solvent being stored in the laboratory. Once mixed, the dye/solvent should be stored in sealed unbreakable plastic containers (beware of solvent incompatibility) until ready to use. Be sure to check transfer lines and pump connections for continuity prior to each use with the dye/solvent. All pumps and dye reservoirs must be placed in trays with sufficient capacity to contain all of the dye/solvent should it leak. This “double containment" method should prevent dye stains on floors and other surfaces. Note that dyes and dye/solvent solutions are considered hazardous wastes and must be disposed of properly.

CRYOGENIC FLUIDS

Cryogenic fluids are used in cooling systems of certain lasers. As these materials evaporate, they replace the oxygen in the air. Adequate ventilation must be ensured. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen comes in contact with any organic material. Although the quantities of liquid nitrogen that are used are small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes.

Compressed gases used in lasers present serious health and safety hazards.

Problems may arise when working with unsecured cylinders, cylinders of hazardous materials not maintained in ventilated enclosures, and gases of different categories (toxins, corrosives, flammable, and oxidizers) stored together.

C. COLLATERAL RADIATION

Radiation other than that associated with the primary laser beam is called collateral radiation [6]. Examples are X-rays, UV, plasma, radio frequency emissions.

IONIZING RADIATION

X-rays could be produced from two main sources in the laser laboratories. One is high-voltage vacuum tubes of laser power supplies, such as rectifiers, thyratrons and crowbars and the other is electric-discharge lasers. Any power supplies which require more than 15 kilovolts (keV) may produce enough X-rays to cause a health hazard [11]. Interaction between X-rays and human tissue may cause a serious disease such as leukemia or other cancers, or permanent genetic effects which may show up in future generations.

UV AND VISIBLE

UV and visible radiation may be generated by laser discharge tubes and pump lamps. The levels produced may exceed the Maximum Permissible Exposure (MPE) and thus cause skin and eye damage.

PLASMA EMISSIONS

Interactions between very high power laser beams and target materials may in some instances produce plasmas. The plasma generated may contain hazardous UV emissions.

RADIO FREQUENCY (RF)

Q switches and plasma tubes are RF excited components. Unshielded components may generate radio frequency fields which exceed federal guidelines.

FIRE HAZARDS

Depending on construction material beam enclosures, barriers, stops and wiring are all potentially flammable if exposed to high beam irradiance for more than a few seconds.

D. EXPLOSION HAZARDS

High pressure arc lamps, filament lamps, and capacitors may explode violently if they fail during operation. These components are to be enclosed in a housing which will withstand the maximum explosive force that may be produced. Laser targets and some optical components also may shatter if heat cannot be dissipated quickly enough. Consequently care must be used to provide adequate mechanical shielding when exposing brittle materials to high intensity lasers.

LASER ACCIDENTS

Studies of laser accidents have shown that there are usually several contributing factors. The following are common causes of laser injuries:

- ✓ Inadequate training of laser personnel
- ✓ Alignment performed without adequate procedures
- ✓ Failure to block beams or stray reflections
- ✓ Failure to wear eye protection in hazardous situations
- ✓ Failure to follow approved standard operating procedures or safe work practices majority of injuries involve the eye and skin injury.

VI. TYPES OF HAZARDS CONTROLS

The hazards posed by Class IIIb and Class IV lasers require systematically applied controls to prevent skin and eye injuries. Control measures may be broken down into three main types: engineering controls, administrative controls, and personal protective equipment.

Engineering controls involve design features or devices applied to the laser, laser beam, or laser environment that restrict exposure or reduce irradiance. Such controls include beam shutters, beam attenuators, remote firing and monitoring systems, and the protective housing placed entirely around some laser systems.

Administrative control measures involve procedures and information rather than devices or mechanical systems. Some important administrative controls are posting of warning signs and labels, establishment of standard operating procedures (SOP), and safety training.

Personal protective equipment is worn by personnel using the laser or in the vicinity of the laser. It includes protective eyewear, gloves, and special clothing.

VII. MAXIMUM PERMISSIBLE EXPOSURE (MPE)

How much exposure to laser light is hazardous? To answer this question, you have to take into account the output characteristics of the laser. Those characteristics include wavelength, output energy and power, size of the irradiated area, and duration of exposure. If you're using a pulsed laser, you also must consider the pulse repetition rate. Sensitivity to a given wavelength varies significantly from person to person. Maximum permissible exposure (MPE) limits indicate the greatest exposure that most individuals can tolerate without sustaining injury. An MPE is usually expressed in terms of the allowable exposure time (in seconds) for a given irradiance (in watts/cm^2) at a particular wavelength. For an argon laser operating at 0.514 µm, the MPE is 2.5×10^{-3}W/cm^2 for an exposure time of 0.25 second, 16.7×10^{-6}W/cm^2 for an exposure time of 600 seconds, and 1×10^{-6} W/cm^2 for an exposure time of 3×10^4 seconds[13]. MPEs are useful for determining optical densities for eyewear or windows. Another quantity of interest in laser safety is called the nominal hazard zone (NHZ). This zone describes the region within which the level of direct, reflected, or scattered (diffuse) laser radiation is above the allowable MPE.

VIII. SAFETY RULES FOR ALL LASERS, REGARDLESS OF OUTPUT POWER LEVEL

- ✓ Avoid looking directly into any laser beam or at its reflection.
- ✓ Remove all unnecessary specular (shiny) reflecting surfaces from the work area.
- ✓ Operate lasers in well-defined areas to which access can be controlled. The area should be posted with appropriate signs to alert persons passing by the area that a potential hazard exists.
- ✓ The laser system should be operated only by or under the direct supervision of a person knowledgeable of the hazards and control methods for both beam and non beam conditions. This individual is usually the laser safety officer (LSO) who is designated by the administration of the company, hospital, or educational institution. The LSO shall have the authority and the responsibility to effect monitoring and enforce the control of laser hazards and to achieve the knowledgeable control of laser hazards.
- ✓ Any accident should immediately be reported to the responsible medical authority. If there is an accidental exposure to the eye, the services of an ophthalmologist should be sought.

IX. CONCLUSIONS

More detailed attention has been paid here only to those fields where lasers are used at present. Based on these laser techniques, some new ones are being developed, as, e.g., for the laser ranging device to be used in cars of the future: the built-in laser radar plus automatic control will keep a safe distance between cars. The spectrally defined laser interact on with matter is made use of in art restorations to remove the dirt from old paintings and statues, as well as in routine maintenance and cleaning of the outer skin of ships and aircraft. Laser holograms help to detect defects in materials, etc. Even this brief survey has shown that the application of lasers is really quite extensive. In each case, however, it is inevitable to consider whether the advantages of laser methods outweigh the disadvantages. Except for laser diode printers, their disadvantages are high costs, need for highly qualified operators, low efficiency coefficient, and high energy consumption. Therefore, the decision whether to use the laser has to be made for every single case, taking into account the economy and output. And, even so, it is true that lasers have become irreplaceable and research into their applications still continues.

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