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REVIEW ARTICLE

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Laser Technology and Its Application in Today's World

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INTRODUCTION

The basic concepts of laser were first given by an American scientist, Charles Hard Townes and two Soviet scientists, Alexander Mikhailovich Prokhorov and Nikolai Gennediyevich Basov who shared the coveted Nobel Prize (1964). However, TH Maiman of the Hughes Research Laboratory, California, was the first scientist who experimentally demonstrated laser by flashing light through a ruby crystal, in 1960.

Lasers are devices that produce intense beams of light which are monochromatic, coherent, and highly collimated. The wavelength (colour) of laser light is extremely pure (monochromatic) when compared to other sources of light, and all of the photons (energy) that make up the laser beam have a fixed phase relationship (coherence) with respect to one another. Light from a laser typically has very low divergence. It 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 are used in a wide variety of applications in all walks of life.

The term "laser" is an acronym for (L)ight (A)mplification by (S)timulated (E)mission of (R)adiation. To understand the laser, one needs to understand the meaning of these terms. The term "light" is generally accepted to be electromagnetic radiation ranging from 1 nm to 1000 mm in wavelength. The visible spectrum (what we see) ranges from approximately 400 to 700 nm. The wavelength range from 700 nm to 10 mm is considered the near infrared (NIR), and anything beyond that is the far infrared (FIR). Conversely, 200 to 400 nm is called ultraviolet (UV); below 200 nm is the deep ultraviolet (DUV).

Laser is a powerful source of light having extraordinary properties which are not found in the normal light sources like tungsten lamps, mercury lamps, etc. The unique property of laser is that its light waves travel very long distances with e very little divergence.

Applications of Laser in Various Fields

It is the laser light energy and power delivered in a narrow directional beam, and, also, monochromaticity, coherence, and collimation, i.e., properties which, as against the conventional light source, provide a better possibility of intervention and greater impact given by the multiple power of laser radiation.

Let us start with the application of laser light in medicine because this was the first field to make use of laser radiation.

Lasers in medicine

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 vaporising 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 utilised 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.

Let us now demonstrate in detail how lasers are used in ophthalmology. Laser light is used here in major surgeries, as, e.g., in treating retinal detachment, glaucoma removal, treatment of diabetic retinopathy [i.e., diabetes-induced retinal dysfunction], 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 surgey 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 quasicontinuous 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 longsightedness, the excimer laser is now employed.

Owing to progress in fibre optics and the feasibility to transmit laser radiation via optical fibres [using laser diodes in communication technology, a part of optoelectronics], lasers can be utilised also in angioplasty, being thus instrumental in removing a blockage from an artery. Also, new methods have been developed to treat, e.g., heart diseases and the digestive system diseases. The laser can even replace the classical dental drilling machine to remove tooth tissues without pain. Another field wide open to photo chemotherapeutic methods is based on selective [in this case, cancerous] cell destruction by optical radiation, a method referred to as photodynamic therapy.

Lasers used in industry

Industrial applications now include many new procedures , such as laser welding, drilling, cutting (e.g., glass decoration, trimming, and milling), annealing, sputtering, and others. 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.

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 CO2 spectrum and the Nd: YAG lasers, of a wavelength of 10.6 nm and 1.06 nm, respectively. 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 (see Fig. 1). Lasers can weld, e.g., air-tight shields of miniature relay, pacemakers, contacts in microelectronics, and metal sheets in car or aircraft industry.

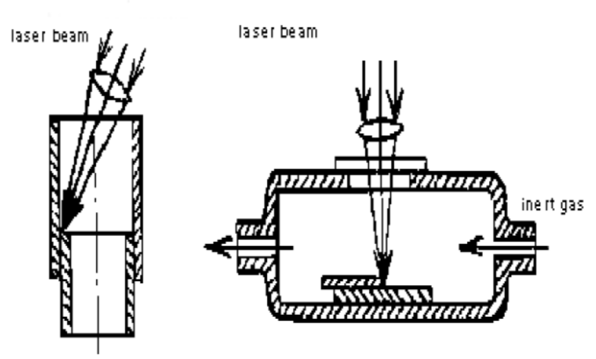

Fig. 1: Examples of laser welding - a/ at a spot hard to access, b/ in an inert atmosphere

Laser drilling is based on removing material by vaporization. The beam intensity should be higher than for welding, and so drilling prefers pulse lasers of pulse length less than 1 nm. The first laser drilling goes back to 1965. Then, a ruby laser was employed to drill drawing diamond die holes. At present, laser drilling makes use mainly of the Nd:YAG pulse laser, its advantage consisting in its ability to drill miniature holes 10 to 100 nm in diameter at spots where other techniques prove difficult or even impossible.

Laser cutting is utilised 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 CO2 lasers of up to 15 kW. 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 noncontact approach, in the good quality of the cut, and, last but not least, in the limited area of thermal effect.

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 CO2 laser.

Laser marking is based on local surface evaporation of the object material. In this case, the laser beam passes through a template with the desired pattern (e.g. letters or numbers). When the laser beam impinges upon the surface of the object, the pattern of the template will show up. Another way to perform this operation is to move the laser beam along the material to be marked, or to move the object. The marks identifying the objects can be lasered onto semiconductor, ceramic, and metallic surfaces, as well as on paper, glass, plastics, ferrite elements, etc. The depth of the marking usually ranges between fractions and units of millimetres, the thickness being of the order of micrometres. This technique is performed by the powerful pulse laser of pulse energy up to tens of joules, or by the continuous laser, i.e., the Nd: YAG or excimer laser. The advantage of laser marking is the non-contact process, eliminating any possible stresses and strains in the lasered material.

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 non-deforming 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 CO2 laser; this time, however, of a power of several thousand watts.

Lasers used in Defence

Laser Range Finder

To knock down an enemy tank, it is necessary to range it very accurately. Because of its high intensity and very low divergence even after travelling quite a few kilometres, laser is ideally suited for this purpose.

The laser range finder works on the principle of radar. It makes use of the characteristic properties of the laser beam, namely, monochromaticity, high intensity, coherency, and directionality. A collimated pulse of the laser beam is directed towards a target and the reflected 1ight from the target is received by an optical system and detected. The time taken by the laser beam for the to and fro travel from the transmitter to the target is measured. When half of the time thus recorded is multiplied by the velocity of light, the product gives the range, i.e., the distance of the target.

The laser range finder is superior to microwave radar as the former provides better collimation or directivity which makes high angular resolution possible. Also, it has the advantage of greater radiant brightness and the fact that this brightness is highly directional even after travelling long distances, the size of the emitting system is greatly reduced. The high monochromaticity permits the use of optical band pass filter in the receiver circuit to discriminate between the signal and the stray light noise.

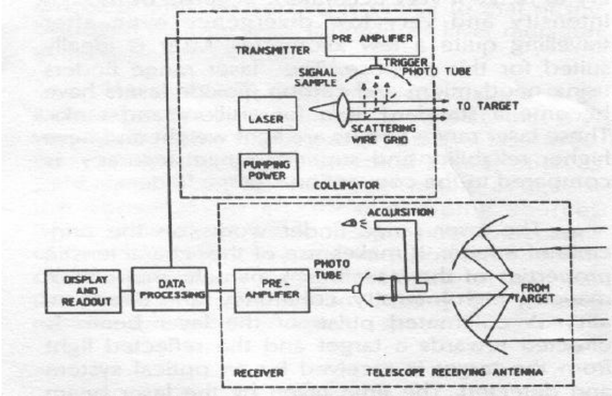

Fig 2 Schematic of Laser Range Finder

A typical laser range finder can be functionally divided into four parts: (i) transmitter, (ii) receiver, (iii) display and readout, and (iv) sighting telescope. An earlier version of a laser range finder is schematically shown in Fig. 2. The transmitter uses a Q-switched Nd:YAG laser which sends out single, collimated and short pulse of laser radiation to the target. A scattering wire grid directs a small sample of light from the transmitter pulse on to the photo-detector, which after amplification is fed to the counter. This sample of light starts the counter. The reflected pulse, received by the telescope, is passed through an interference filter to eliminate any extraneous radiation. It is then focused on to another photo-detector. The resulting signal is then fed to the counter. A digital system converts the time interval into distance. The range, thus determined by the counter, is displayed in the readout. The lighting telescope permits the operator to read the range while looking at the target

Underwater Laser

Lasers can also be used as a source of underwater transmission. For this purpose, a laser giving radiation in the blue-green region is most suitable as the transmission in this region is maximum for sea water. The attenuation in underwater transmission is due to (i) absorption by materials in water, (ii) scattering by suspended particles, and (iii) variation in optical density along the light path. The blue-green lasers have assumed much importance in the systems related to naval applications.

At present, the submarines have to rely on sonar to find the enemy crafts and to avoid the underwater objects. This has serious limitations. The whales, dolphins and other marine life give false signals. Typical sonar cannot give a well-defined picture because the sonar beam is broadened or scattered by sea water. A difference in the saltiness of water can cause the sonar beam to bend and make the target appear where it is not. Another problem of using sonar is that it gives away to the enemy the position of the ship from which it is transmitted.

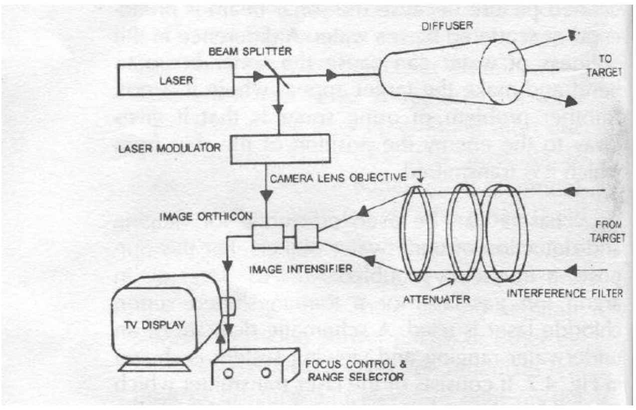

Fig. 3 Schematic Diagram of Underwater Ranging

Lasers can be used efficiently for ranging and detection of underwater objects. For this purpose, a frequency doubled *Nd:YAG* laser or an argon ion gas laser or a Raman shifted xenon chloride laser is used. A schematic diagram of an underwater ranging and viewing system is shown in Fig. 3. It consists of the laser transmitter which sends high power laser pulses of about 10 ns duration to the target at the rate of 30 to 50 per second through a beam splitter and a diffuser small amount of the laser light reflected by the beam splitter is made to fall on the photodiode the ranging and display circuit to start the time interval counter. The reflected light from the target is collected by telescopic optics after stray radiation is eliminated by an interference filter. A range gating circuit helps to avoid unwanted echoes The reflected pulse from the target is intensified by the image intensifier and the output is fed to image orthicon, which gives the display of the object. In this way, both the range and the image of the target are obtained. With high power release of several megawatts power, underwater ranging is possible up to 500 m in clear water.

Lasers can also be used for communication between submarines ensuring absolute privacy and in guidance systems for torpedoes and other unmanned underwater vehicles. Recent underwater laser communication has been established via satellite, i.e., from ground-to-satellite and then to underwater station.

CONCLUSION

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 interaction 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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