8. Laser Applications

Helena Jelínková, Zdeněk Kluiber

Introduction

Laser radiation in various applications was made use of immediately after the first laser became operational. The ruby laser was designed and constructed by Teodor Maiman in 1960, and as early as 1961 its radiation was used to treat eye and skin diseases. Since it was designed thirty years ago, laser has 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, etc. Now let us mention some of the main properties of laser radiation due to which its use is so versatile.

First of all, 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 retina 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 (see Fig. 18); and for correcting eye defects, i.e. short-sightedness and longsightedness, the excimer laser is now employed.

Fig.18: OFTLAS, a high-power pulse Nd:YAG laser, developed for eye microsurgery at FNSPE CTU

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 photochemotherapeutic methods is based on selective [in this case, cancerous] cell destruction by optical radiation, a method referred to as photodynamic therapy.

A wide area of applications is also open to the so called soft lasers, i.e., low-power lasers (see Fig. 19), being used for biostimulation in dentistry, traumatology, etc.

Fig. 19: Diode therapeutic laser by Lasotronic

Along with therapy, lasers are found useful in diagnostics, their low-power radiation being used to examine the eye or internal organs tissues (e.g., early diagnosing of cancerous tumours).

Lasers used in industry

Industrial applications now include many new procedures , such as laser welding, drilling, cutting (e.g., glass decoration, trimming, 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 effected 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

CO_2 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. 20). Lasers can weld, e.g., air-tight shields of miniature relays, pacemakers, contacts in microelectronics, and metal sheets in car or aircraft industry.

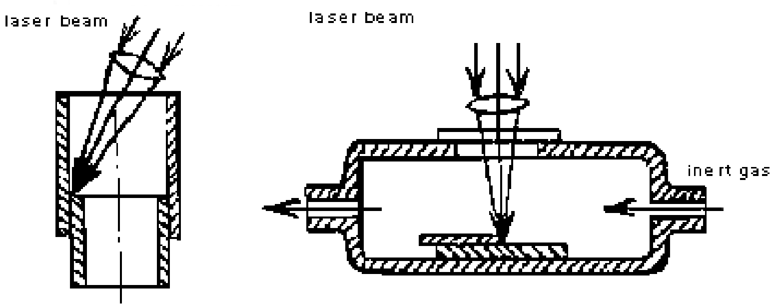

Fig. 20: Examples of laser welding - a/ at a spot hard to access, b/ in an inert atmosphere

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 qiuckly 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 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 advantge of laser cutting rests in its great speed, in cutting various shapes (see Fig. 21), 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.

Fig. 21: Cutting various shapes by CO_2 laser

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 continous CO_2 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 continous CO_2 laser; this time, however, of a power of several thousand watts.

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^{-9} s). 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 surfrace of materials, to initiate silicon growth on a layer of SiO_2, an 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.

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 utilised. This device, the so called laser radar (see Figs. 22 and 23), 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 reflecetd 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 (see next chapter). 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, (see LIDAR in the paragraph below). When the Earth's satellites are measured, distances of tens of thousands of kilometres 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 trasmitted, 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 lenghts 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 geeodesy].

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 femtosecond range (10^{-15} s).

Also helium-neon lasers found their use in *geodesy, namely* in marking out lines on the Earth' s surface and under the ground.

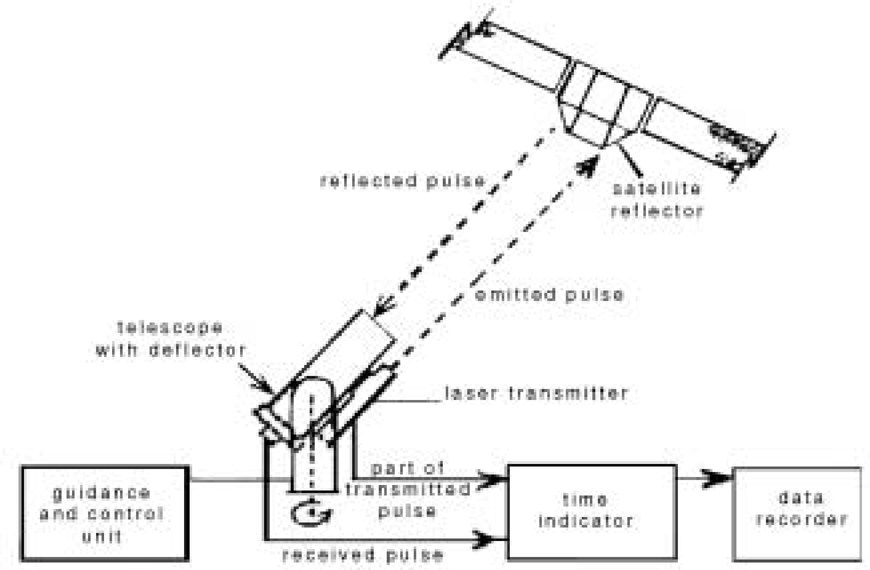

Fig. 22: Schematic showing satellite laser ranging

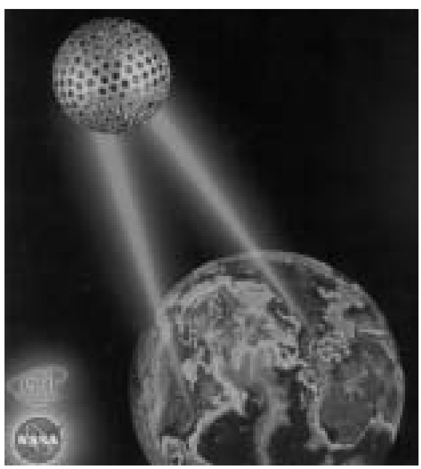

Fig. 23: Satellite laser ranging [LAGEOS LAserGEOdynamics Satellite] by means of Nd:YAG pulse laser converting infrared wave length to green

Laser radar in egology - LIDAR

Ground laser radars (see Fig. 24) 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. Part of the radiation scattered backwards is concentrated by a telescope, and passing through a filter detected by a photodetector. 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 imissions in the atmosphere, etc.

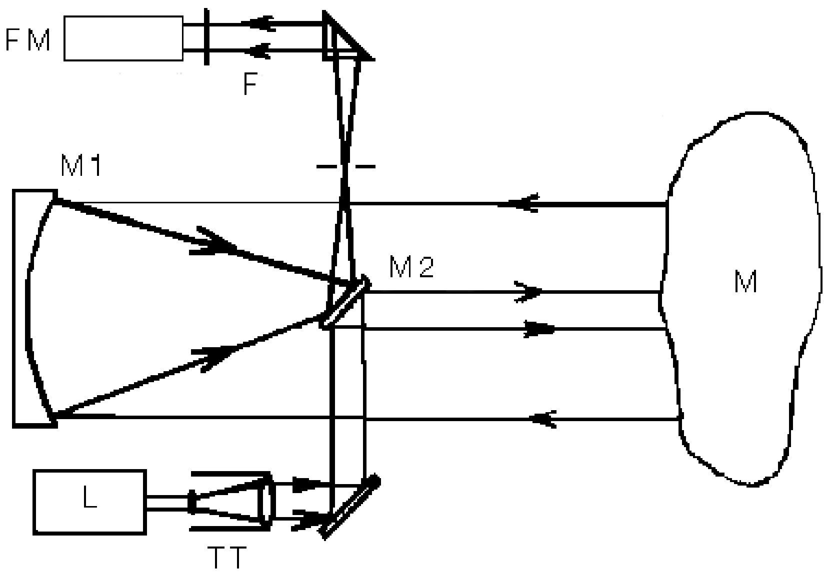

Fig. 24: Schematic of LIDAR with a coaxial receiver and transmitter / L- laser, TT- transmitting telesccope, M1, M2 - mirrors of Newton telescope, M - monitored area, FM - photomultiplier

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. 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 (see Fig. 25). 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).

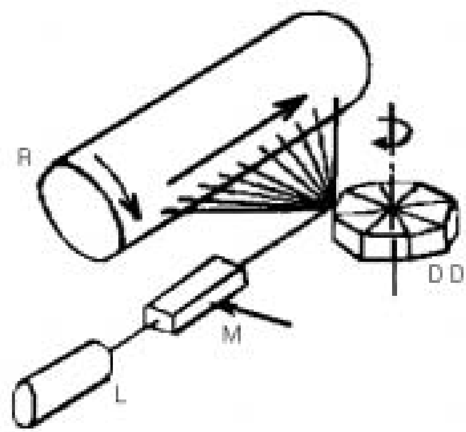

Fig.25: Laser printer principle : L - laser, M - acoustic optical modulator, D - data entry, DD - deflection disc.

Military applications of lasers

Lasers appear also in various military applications, the most widely utilised 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 realiability of the hit. For this purpose, the Nd:YAG lasers seem to be best. 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 (see Fig. 26). 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.

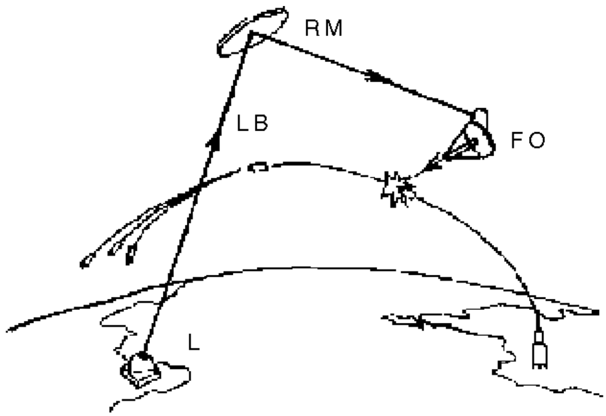

Fig. 26: Laser destruction of intercontinetal ballistic missiles; L - pulse laser, RM - reflecting mirror, FO focusing optics, LB - laser beam

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 interacton with matter is made use of in art restorations to remove the dirt from old paintings and statues, as well as in routine maintenace 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.

References:

[1] Jelínek, M. – Kluiber, Z.: Tenké supravodivé vrstvy. VTM, 1991, 10, p. 41–43.