LASER APPLICATIONS

Chapter Three

Laser Applications

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CHAPTER THREE: LASER APPLICATIONS

3-1) Introduction

Laser applications are currently numerous and cover various fields in science and technology, including physics, chemistry, life sciences, electronics, and medicine. These fields encompass a vast number of applications, most notably industrial applications (cutting, drilling, welding, and hardening), measurements and inspection (distance measurement, optical alignment, and defect detection), medical and biological applications (ophthalmology, surgery, cosmetic procedures, excision, and bioimaging), military applications (guidance, tracking, and range estimation), commercial applications (light pens, laser printers, and CD-ROM drives), and optical communications. These applications are a direct result of the unique properties of laser light.

3-2) Laser Applications in Physics and Chemistry

The invention of the laser and its subsequent development relied on fundamental knowledge drawn from the fields of physics and, to some extent, chemistry. Therefore, it is natural that among the first studies were those on the applications of lasers in physics and chemistry. In the field of physics, the applications of lasers can be summarized as follows:

1) **Studying the Behavior and Interaction of Laser Beams with Materials:** As in nonlinear optics, the high intensity of the laser beam has led to the emergence of a new phenomenon arising from the nonlinear response of matter, such as:
   - ✓ The generation of second and third harmonics, and so on, by doubling the frequency.
   - ✓ Induced scattering: This occurs when an incident laser beam of frequency υ interacts with an excited state of matter at frequency $\boldsymbol{v_o}$ (a sound wave) to produce a coherent beam with a frequency of ($\boldsymbol{v \mp v_o}$). This is called Stock scattering. Raman observed that if intense light of a certain wavelength falls on a molecule, a beam of the same wavelength will scatter away from the molecule, in addition to other weak beams of similar intensity with wavelengths slightly shorter or slightly longer than the wavelength of the incident beam. For example, if the energy of the incident beam is ($\boldsymbol{h_o v_o}$), then the energy of the scattered beams is given by the relation:

$$\boldsymbol{hv = hv_o \mp \Delta E} \quad \text{……….. (3-1)}$$

where ΔE is the energy difference between two oscillating or rotational levels of the molecule, and this quantity is independent of the source. The optical waveform depends solely on the molecular structure of the material. If these lines have a frequency lower than the incident wave, they are called Stokes optical lines.

2) **Very High-Resolution Timescale Measurements of the Behavior of Different Materials After Stimulation by Very Short Light Pulses:** This has opened up the possibility of researching multiple phenomena based on the new capabilities of very short-term analytical measurements.

3) **Spectroscopy:** The bandwidth can be narrowed down to a few tens of kilohertz, allowing spectroscopic measurements to achieve a resolution several orders of magnitude (3–6) higher than that achievable with conventional spectroscopy. The importance of using lasers as light sources in spectroscopy can be summarized as follows:

- ✓ Since the scattered portion of the incident radiation is very small, using a laser beam provides a more precise and easier way to detect and measure this scattered portion.
- ✓ Using lasers increases the resolution of the resulting spectrum due to the spectral purity of the source.
- ✓ Scattering increases with increasing frequency of the incident radiation; therefore, laser sources operating near the blue light spectrum (such as argon-ion lasers) are ideally suited for this purpose.
- ✓ Scattered radiation can be detected using standard detectors available for use in the visible spectrum.

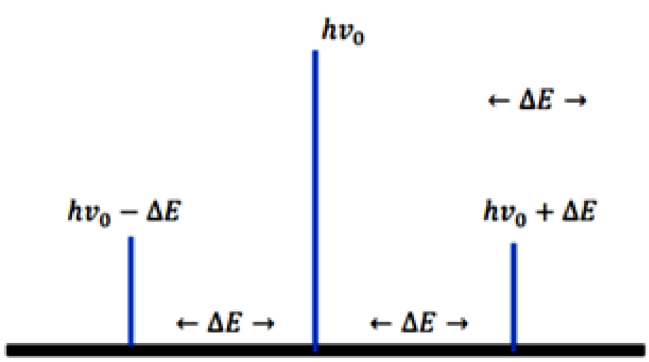

Figure (3-1): Stokes light lines

In the field of chemistry, lasers are used for diagnostic purposes and to produce irreversible chemical reactions (laser photochemistry). Laser applications in this field can be summarized as follows:

1) **Diagnostic Techniques (Inducible Raman Scattering):** This technique provides important information about the structure and properties of polyatomic molecules, as well as for measuring the concentration and temperature of specific molecules.
2) **Photochemistry:** Lasers are used for isotope separation, which involves the selective excitation of a desired isotope by laser beams. This is achieved by photoionizing the desired isotope, such as U^{235}, with light of a suitable wavelength. The isotope is pumped irradially into a number of excited states, and then the ionized isotope is collected using a continuous electric field.
3) **Air Pollution Studies:** Pollutants are detected and their concentrations accurately determined using laser-based spectroscopic techniques. Infrared lasers can be used to apply the principle of spectral absorption by polluting gases, such as carbon dioxide lasers, or by applying scattering methods.

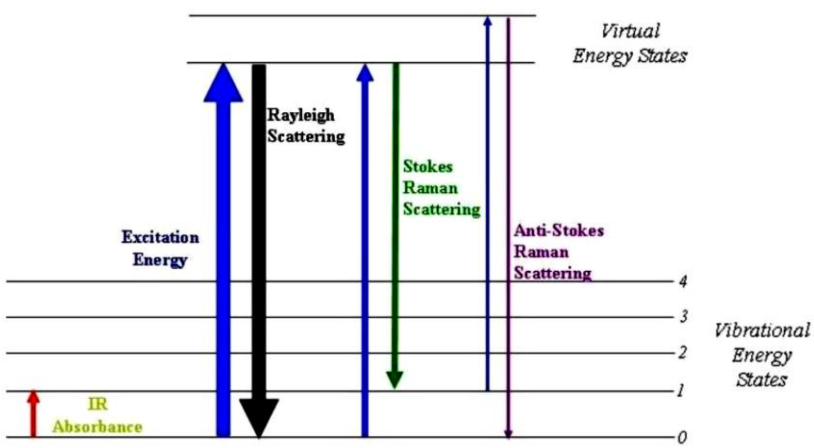

Figure (3-2): Types of scattering

3-3) Laser Applications in Biology

Lasers are used as diagnostic tools or to induce irreversible changes in the living molecules of cells or tissues (photobiology). A laser beam is focused using a microscope onto a region of the cell with a diameter approximately equal to the laser's wavelength to study the cell's function after the laser-induced change in a specific area. Laser techniques used in this field include:

1) Very short pulsed laser fluorescence in DNA.
2) Raman scattering as a method for studying living molecules such as hemoglobin and rhodopsin (responsible for vision).
3) Photon scattering spectroscopy to obtain information on the degree of aggregation of different living molecules.
4) Picosecond photoluminescence techniques to precisely examine the dynamic behavior of living molecules in an excited state.

3-4) Laser Applications in Medicine

Lasers of various types are used in medical diagnosis and surgery, such as neurosurgery, cardiovascular surgery, and general surgery. They are also used in dentistry, ophthalmology, and dermatology. Their uses can be summarized as follows:

1) **For Therapeutic Purposes:** Studies are conducted on how to affect living cells or parts of them using laser beam microscopy. Light passes through the objective lens of a microscope to a small area of the cell, the diameter of which is close to the wavelength of the laser used. The primary purpose of these studies is to observe the cell's reaction and function after a portion of it has been destroyed by the laser.
2) **For Surgical Purposes:** Using a laser scalpel as an alternative to the traditional scalpel, the focused laser beam selects infrared radiation. This part of the radiation is readily absorbed by body tissues and water molecules, causing rapid evaporation of these molecules, followed by tissue cutting.

The advantages of using a laser beam scalpel in surgery can be summarized as follows:

- ✓ The incision can be made at the desired location with high precision, especially when guided by a microscope (microsurgery).
- ✓ The procedure can be performed on hard-to-reach areas.
- ✓ It reduces collateral damage resulting from vascular rupture, which occurs when using a traditional scalpel.

The disadvantages of using a laser scalpel include:

- ✓ High cost and complexity of the surgical technique.
- ✓ Slower speed than a traditional scalpel.
- ✓ Safety concerns associated with its use.

The benefits of using lasers in medical applications can be summarized as follows:

1) No contact between the instruments and the target (surgical site).
2) Less bleeding during surgery and reduced pain during and after the procedure.
3) Minimal impact on surrounding tissues.
4) Clearer visualization during the procedure and greater precision in treatment through computer-controlled operation.
5) Ability to create a precise, localized incision (cutting accuracy).
6) Ability to treat specific tissues (by selecting a specific wavelength).
7) Performing procedures without open surgery (using fiber optics) to treat bladder, lung, and kidney tumors.
8) It reduces the need for local anesthesia, in addition to having a short treatment period and good wound healing.
9) Lasers are used in surgeries for malignant diseases such as cancer, ulcers, and vascular surgeries. They are also used for angioplasty, treating circulatory insufficiency in the extremities, spinal cord injuries, and other surgeries such as the stomach and liver.

- **Ophthalmology:** Treatment of retinal detachment and ulceration using the argon laser. Its green beam is absorbed through the eye's lens by the retinal red blood cells, and the resulting thermal effect allows for retinal reattachment.
- **Otolaryngology (ENT):** Surgery of organs (trachea, pharynx, and middle ear) and organs that are difficult to access or operate on using a microscope.
- **Oral Surgery:** Removal of benign and malignant tumors, stopping bleeding, and relieving pain and the risk of ulceration.
- **Dermatology:** Removal of spots and tattoos, and treatment of vascular diseases that cause skin discoloration and other skin conditions.
- **Cardiac Surgery:** Creating new pathways to the heart for patients suffering from angina and atherosclerosis resulting from blockages in parts of the coronary arteries, and in areas where traditional surgery is not possible.

3-5) Laser Applications in Optical Communications

Communication is the process of transmitting information, usually by modulating it onto a carrier wave. Radio and microwave waves are traditionally used for this purpose. With the invention of the laser, the visible part of the electromagnetic spectrum became possible, leading to the term optical communication. The transition from microwave to visible light increases the carrier frequency by 10^4, meaning a much wider bandwidth is used than with microwaves. It is well-established that the amount of information that can be transmitted is directly proportional to the bandwidth of the carrier wave.

The main advantages of using lasers in communications can be summarized as follows:

1) The directionality of the laser beam makes the antenna of an optical device much smaller than that of a microwave antenna.
2) Laser waves can carry significantly more information than microwave waves because their bandwidth is much larger, and losses are minimal.
3) There is no interference between signals.
4) Interconnections are high-speed.
5) Transmission lines are parallel.

The disadvantages of using lasers in communications lie in the fact that the transmission of visible light depends on the transparency of the medium. Poor weather conditions attenuate the light beam. Therefore, laser use in communications is limited to clear skies, outer space, or short distances. For this reason, optical fibers are used. These are very thin wires of glass or plastic that act as the transparent medium, restricting the transmission of the light beam and minimizing energy loss due to attenuation.

3-6) Laser Applications in Holography

Holography is a technological revolution, enabling the creation of three-dimensional images of objects or scenes. The word "holography" is derived from the Greek words "holo," meaning whole, and "graphos," meaning writing. The holograph was invented by Gabor in 1948 as a proposed method to improve the resolving power of electron microscopes.

Its practical application was further demonstrated after the invention of the laser. Holographic applications include recording and measuring the stress and vibration of objects.

The basic principle of holography can be explained as follows:

1) **Recording on the Hologram:** A semi-transparent mirror splits the laser beam into two beams (**A**) and (**B**) (the transmitted beam). A beam is projected directly onto a photographic plate, and B beam illuminates the object to be photographed. The light scattered from the object is then reflected onto the plate, and the interaction of the two beams creates an interference pattern of fringes on the photographic plate.
2) **Hologram Recognition:** The holographic plate is returned to its position, and the beam **A** interacts with the interference fringes on the plate, causing them to reappear behind the plate. The observer will see the object behind the plate as if it were still there.

The conditions for hologram formation are:

1) High laser intensity sufficient for the interference fringes to appear on the plate.
2) The relative positions of the object and the plate must not change during the plate's exposure time (less than half the laser wavelength) to prevent the interference features from disappearing. (The laser, object, and plate should be placed on a vibration-free table). Movement causes blurring in the fringe recording.
3) High resolution of the holographic plate is required to record the interference fringes. The film's sensitivity must be high to record the fine details of the object as distinct interference fringes.

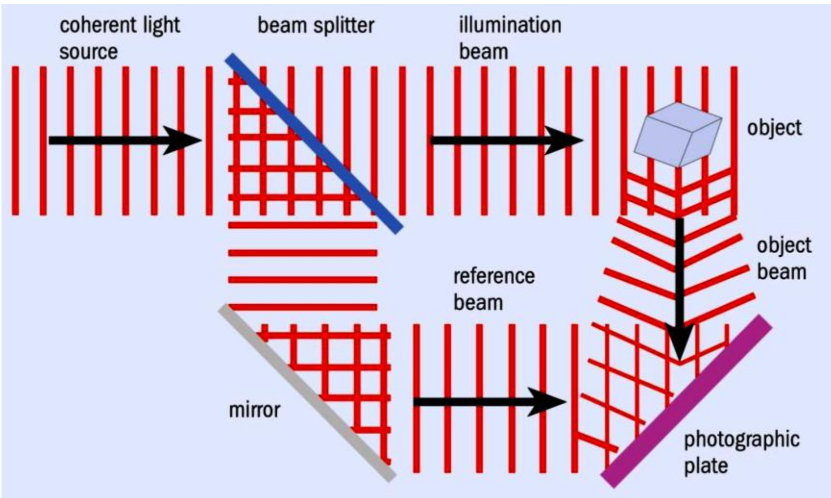

Figure (3-3): The basis of holography

3-7) Laser Applications in Industry

Lasers are used in industry as a heat source, benefiting from their high directionality, small beam divergence, and high power, which allows them to be focused in a very small area with high precision. Lasers are used in the manufacture of many materials, as well as in cutting, drilling, welding, surface treatment, and casting. These processes occur when the material absorbs the laser's energy, which is converted into heat within the material itself, causing it to melt at the point of impact. This process facilitates welding, cutting, or drilling. Because laser beams can be focused into a narrow beam, they have been used to drill diamonds. Lasers can also be used to detect defects within materials by focusing the laser beam and transmitting an image of the internal structure, revealing whether there are any flaws in the crystalline structure.

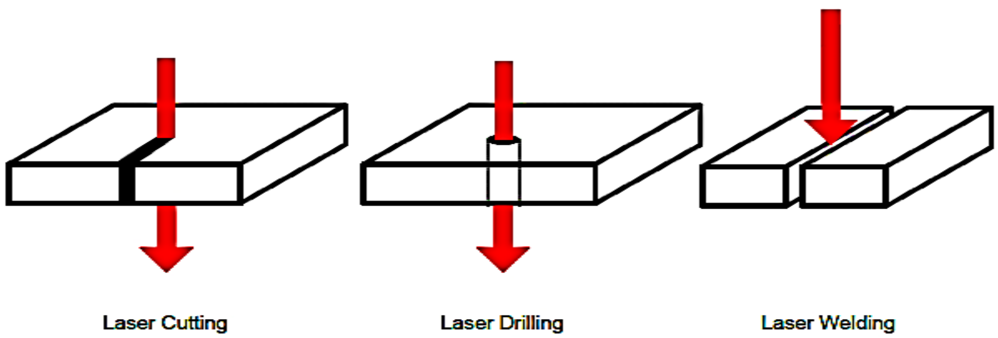

Figure (3-4): Some applications of lasers in the industrial field

The main factors that determine the use of lasers in industry can be identified as follows:

1) The wavelength of the laser beam.
2) Laser beam energy or power (energy for pulsed lasers and power for continuous lasers).
3) Laser beam divergence (preferably as low as possible).
4) Laser beam mode.
5) Treatment area dimensions.
6) Absorption and reflectivity of the material to the laser beam.
7) Thermal conductivity of the material.
8) Thermal diffusion of the material.
9) Laser beam speed.
10) Use of auxiliary gases.

The main advantages of using lasers in industry are as follows:

1) No direct contact between the sample and the laser system, therefore there is no contamination or mechanical stress.
2) The heating of the material resulting from using a laser beam to perform a specific process involving a portion of it is usually less than using conventional methods. Therefore, the distortion of the material as a whole due to heating is reduced, allowing the process to be performed and controlled under better conditions, and very high power outputs can be achieved.
3) Laser use does not affect the physical properties of the material because the affected area is very small.
4) Lasers can be used with various materials such as metals, ceramics, glass, and wood without causing damage for the material.
5) The ability to work in hard-to-reach places, allowing work in difficult areas such as corners and curves. Generally, any position can be handled by a laser if it is detected by an optical device.
6) High speed of execution, resulting in a production rate (welding speed) ten times higher than that of an electric arc welding machine.
7) The ease of automating the process with a programmable device. The laser beam can be executed by moving the optical device, which controls this movement using a computer. This enables precise cutting of complex designs.
8) The ability to perform new operations in metallurgy that were previously impossible. Due to the high heating and melting speeds caused by the laser, metal surfaces can be treated, leading to the production of new types of alloys, in addition to the possibility of crystallizing an amorphous semiconductor surface.
9) Unlike traditional cutting machines, laser machines are not damaged by use.
10) They can operate in quiet conditions, far removed from the noise of traditional machinery.

The disadvantages of using lasers in industry lie in the high cost of the equipment and warranty issues. Continuity of obtaining the laser beam, as the laser system needs good expertise to operate and maintain its operation, in addition to the danger problems in terms of high power, and the laser system also needs precise control and monitoring.

3-8) Laser Applications in Military Field

Lasers are widely used in military applications, as illustrated below:

1) **Laser Range Capability:** This principle is based on the same fundamental principle as radar. A short-duration laser pulse (10 ns) is directed at the target. The reflected beam is received by an optical receiver containing a photodetector. By measuring the laser pulse's travel time (round trip) and knowing the speed of light, the target's range can be calculated.

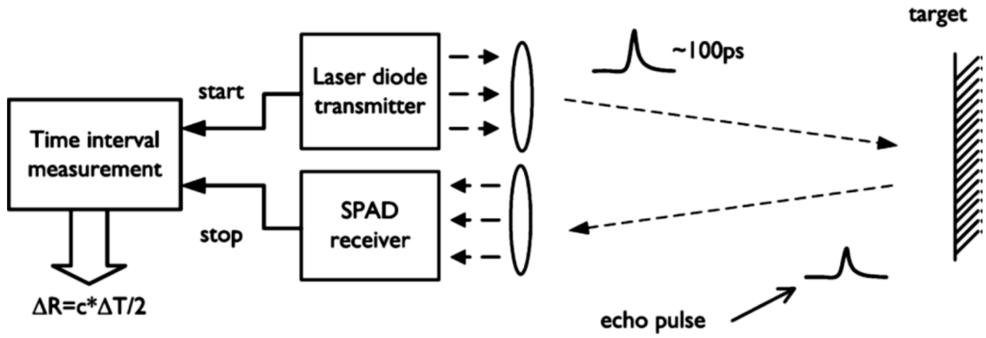

Figure (3-5): Diagram of laser range capability

2) **Control and Guidance:** The laser used for this purpose operates on a simple principle: it is strategically positioned to illuminate the target. Due to the high brightness of the laser beam, the target appears as a bright point when viewed through an optical filter. The target is then located, and the weapon is guided towards it from a ground station or aircraft. The weapon is equipped with a suitable sensor, which may consist of a lens to image the target and project the image onto a photodetector. This, in turn, facilitates the precise movement of the weapon's guidance mechanism, thus guiding it to the target and achieving accurate aiming.

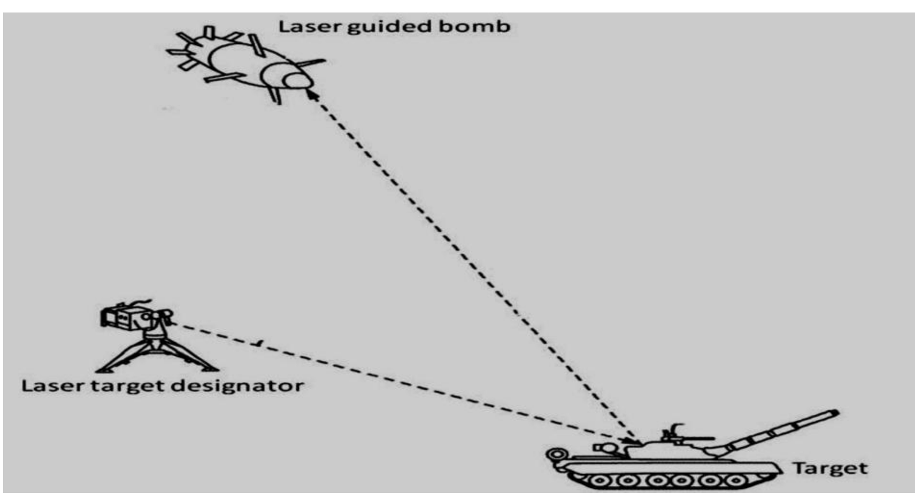

Figure (3-6): Laser use as a targeted weapon

Lasers are also used as targeted weapons. This requires a high-power laser system, typically in megawatts, for a duration of at least a few tens of seconds. The laser beam is directed at the target (aircraft or missile) by the laser system with the intention of causing irreparable damage to sensors or damaging the target's surface, thus causing it to crash. The laser must be carried on a high-altitude aircraft or satellite. Among the most important lasers used in airborne laser stations are chemical lasers (hydrogen fluoride (HF) and deuterium fluoride (DF)) because the required energy can be stored as chemical energy in materials with suitable chemical reactions, without the need for external electrical or other power sources.

3-9) Laser Applications in Agriculture, Construction and Roads

Lasers are used for land alignment, leveling, and demarcating agricultural boundaries. One practical challenge for observers performing laser alignment is that the beam's direction can change due to slight rotation of the device's holder or temperature fluctuations, especially during the device's warm-up period. This difficulty can be overcome by using a weak diverging lens placed in the beam's path to create a secondary focus. By observing the laser beam's center and comparing the images formed by the diverging lens and the laser beam itself, any deviations can be corrected. The image can be visually determined and displayed on a screen, or a photoelectric sensor can be used to pinpoint the beam's position.

Lasers are also used for horizontal surveying. Some devices provide a visual or audible signal when the beam approaches or reaches a specific height. This is used for land leveling, reducing irrigation water loss and increasing agricultural productivity. Other devices are designed for specific purposes such as cable laying, pipe installation, and tunnel alignment. In homes, laser-based devices are used to align ceilings and floors.

3-10) Laser Applications in Commercial

Lasers are used in marketing through laser pens that scan products and identify their production codes, a fast and accurate technology for counting and sorting. Semiconductor lasers are also used in laser printers, providing high precision and focus. Compact Discs (CDs) also rely on lasers for their operation, as lasers are used in the writing and reading processes. Lasers are also used in presentations at events and celebrations.