AN OVERVIEW ON RECENT DEVELOPMENTS IN LASER TECHNOLOGY

Abstract

Major developments in the field of Laser Technology have been made in the past few years. Laser exhibits numerous crucial applications in science, industry and health sectors along with vital military operations and their communication. This chapter highlights the basics of laser and its working principle. Primarily, the presented chapter accentuates the ongoing and existing research progressions in laser machinery. Special mention is made for ultrafast Femtosecond lasers, random lasers used in photonic crystals and laser-assisted microelectronics.

Keywords: Laser exhibits numerous crucial applications in science, industry and health sectors along with vital military operations and their communication.

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I. INTRODUCTION

Optics is the branch of Physics which deals with various aspects of light. It includes different mechanisms of production of light, its propagation, properties, other associated phenomenon such as behavioral patterns, interaction of light with matter and also optical instruments. Study/Learning of Optics starts with classical optics majorly divided into Geometrical and Physical optics. Recently another terminology of '*Modern Optics*' has been coined which comprises of science and engineering concepts based on *quantum optics*. The two sub-categories of classical optics are based upon particle and wave nature of light respectively whereas advent of research and technology has taken into account of quantum effects and properties of light.(1,2,3)

In 20th Century, owing to its many facets optics has become one of the most preferred areas in physics by researchers and scientists all over the world. The pursuit of controlling light emission and transmission led to numerous significant innovations starting from lenses, mirrors, prisms, cameras, light sources, detectors and fiber optical cables etc. at micro level to optoelectronic materials, photonics materials, photonic crystals etc. at nano level.(3,4) One of the vital discoveries in optics due to its cutting edge theme and wide range of applications in research and developments is LASER.

LASER stands for 'Light Amplification by Stimulated Emission of Radiation'. Physics of Lasers and its applications constitute major subfield of modern optics or quantum optics. Lasers are sources of light but with superior features of higher degree of coherence, monochromacity, directionality, and intensity compared to conventional light sources. In simpler words ordinary light sources like tungsten lamps, mercury lamps i.e. incandescent lamps and LEDs spread light in all the directions but laser light is generally monochromatic high energy directional beam. It can travel large distances with very little divergence or angular spread. The laser as a proposition was made by Albert Einstein in 1916. He proposed that under the certain specific conditions excited atoms release energy in the form of light—either spontaneously or when stimulated by radiation. Laser was experimentally demonstrated for the first time by TH Maiman in the Hughes Research Laboratory, California, using a ruby crystal in 1960. (5)

II. LASING ACTION

The basic principles of lasers rely on quantum theory. Every atom has discrete energy levels or states. Atoms in the lowest energy state also called as ground state, when excited by external sources, absorb energy and jump to one of the higher energy levels or excited states. This process is called absorption. Atoms cannot stay at excited states for large durations and eventually return to the ground state, emitting a photon, this process is called spontaneous emission. There could be another possibility, when the atom in its excited state, is made to struck (or stimulated or induced) by an outside photon having precisely the equal amount of energy necessary for spontaneous emission. During this case, two photons are released from the excited level having same energy or rather same phase. This process is called as stimulated emission, is elementary for lasing action.(6) (shown in Figure 1)

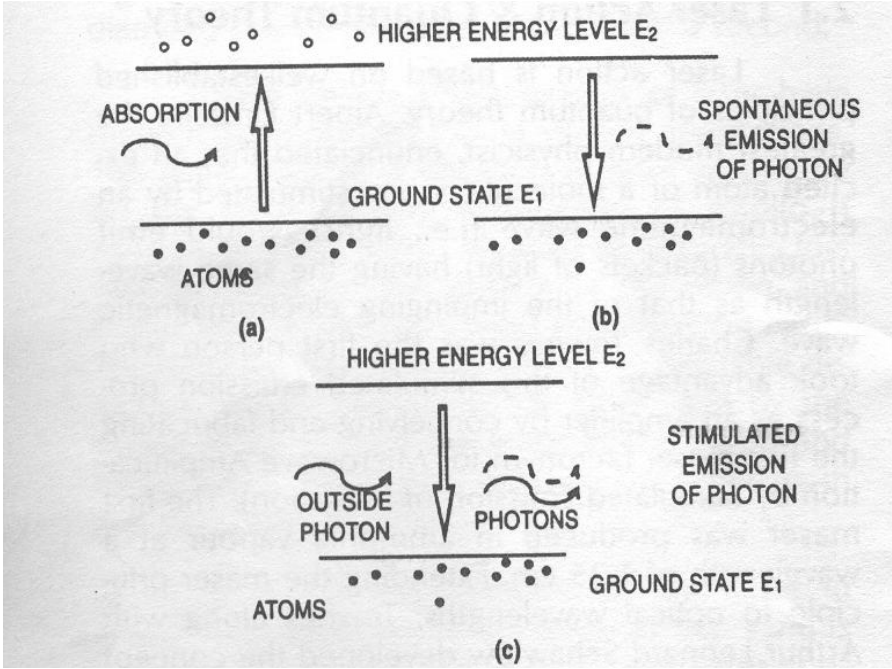


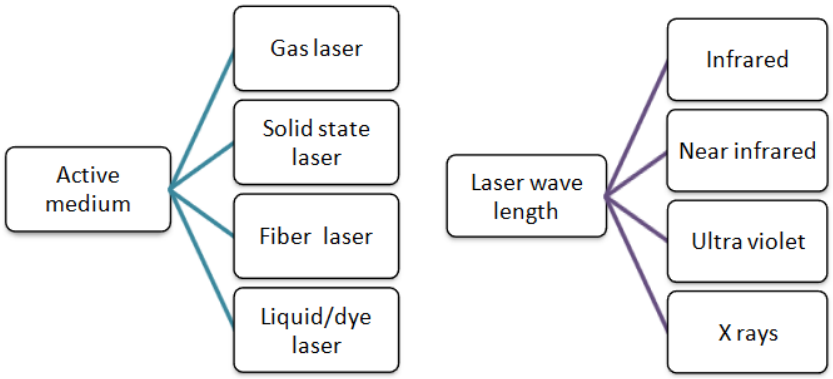
Figure 1: Spontaneous and stimulated emission

Under ambient conditions or non-excited material, usually the population of atoms in ground state is much greater than that of the excited levels in a material. But the process known as population inversion is essential for a laser action. Population inversion occurs when number of atoms in the excited level exceeds that of the lower level.

The three chief constituents for lasing action to occur are a) an active/gain medium, b) a pumping source to produce population inversion between energy levels, and c) a resonator/ resonating cavity containing the active medium which stores the emitted radiation and also provides feedback to maintain the coherence of the radiation. (6)

III. TYPES OF LASERS

Lasers are divided and subdivided into various types according to the active media, modes of operation, pulse durations and laser wavelengths as shown in figure 2. (7)



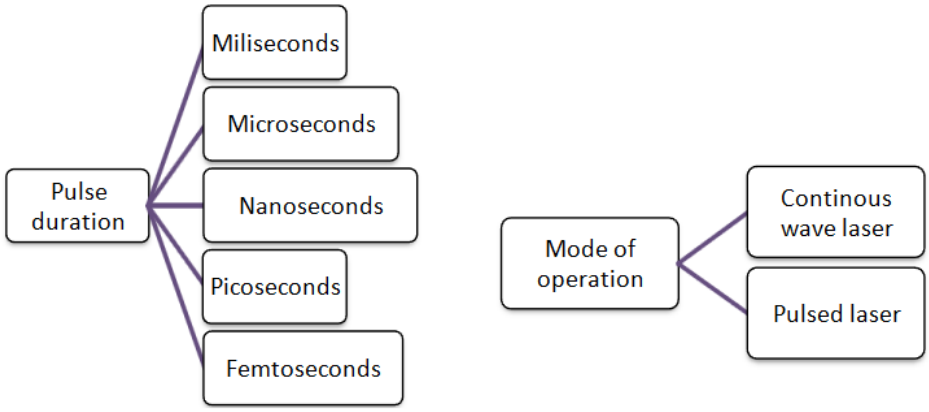


Figure 2: Categories of lasers

IV. APPLICATIONS OF LASER

Contribution of laser technology has been significant in the growth and development of humankind. Laser utilities have branched into communication, scientific research, military, medical, industrial and commercial in short all kinds of fundamental grounds. Some modest applications are barcode readers, laser pointers, holograms, laser scanners, sensing and scanning tools or spectroscopy. Lasers can also be used to perform quantum optical measurements, precise surgery and have even been proposed for the generation of nuclear reactions specifically nuclear fusion.

Military and defense had constantly and forever been relied on the radio signals for communication even when signals are highly at risk to electromagnetic interference (EMI) and other disruptive threats. Radio signals also fail to generate high-resolution images, on-air video conferencing and real-time data transfer. Hence, lasers are extensively investigated in tactical military operations. Due to narrow bandwidth and coherency of laser, meddling with the signals becomes complicated. Laser beams have also been exploited as directed energy laser weapons in combats because of their high power, light weight and economical aspect. Moreover, laser sensors are installed in sensitive war zones or airspaces or difficult terrains for tracking enemy missiles, aircrafts and submarines in water etc. (8,9)

Biomedicine applications of Laser are addressed in dermatology, dentistry, oncology, ophthalmology and histology etc. through pulsed dye laser, the YAG laser, the CO_2 laser and the argon laser. Pinpoint energy delivery through a high powered laser beam is used to make bloodless cuts in tissue or treat eyes and skin disorders. Soft tissue laser surgery done by Neuro surgeons, ENT specialists, oral surgeons or even veterinarians apply highly focused laser beam to vapourize the soft tissue with the high water content. Cosmetic laser surgery is done to remove scars, tattoos, stretch marks and facial hairs etc. It is quick and effective approach to treat skin problems. There are a number of lasers differing in emitted wavelengths, power or in their ability to clot, cut or vaporize tissue. No-touch removal of tumors has made many critical brain and spinal cord surgeries possible. In dentistry, low power lasers have diagnostic applications such as detection of caries using fluorescence emerging from hydroxyapatite or bacterial infection. Laser- driven photochemical reactions have also been used for tooth whitening purposes. Laser surgery has become prominent in

clinical practice nowadays as perfect surgical tool causes safe ablation with minimal tissue damage. (10,11)

Another extraordinary usage of laser is in the form of optical tweezer tool (shown in figure 3) technology readily used in immunology or genome sequencing projects. Nd:YAG laser is employed for mechanical handling of human cells and chromosomes as targets.(12) Using optical tweezers, one can also facilitate optical trapping, manipulation, and characterization of a wide range of microscopic and nanoscopic materials.(13)

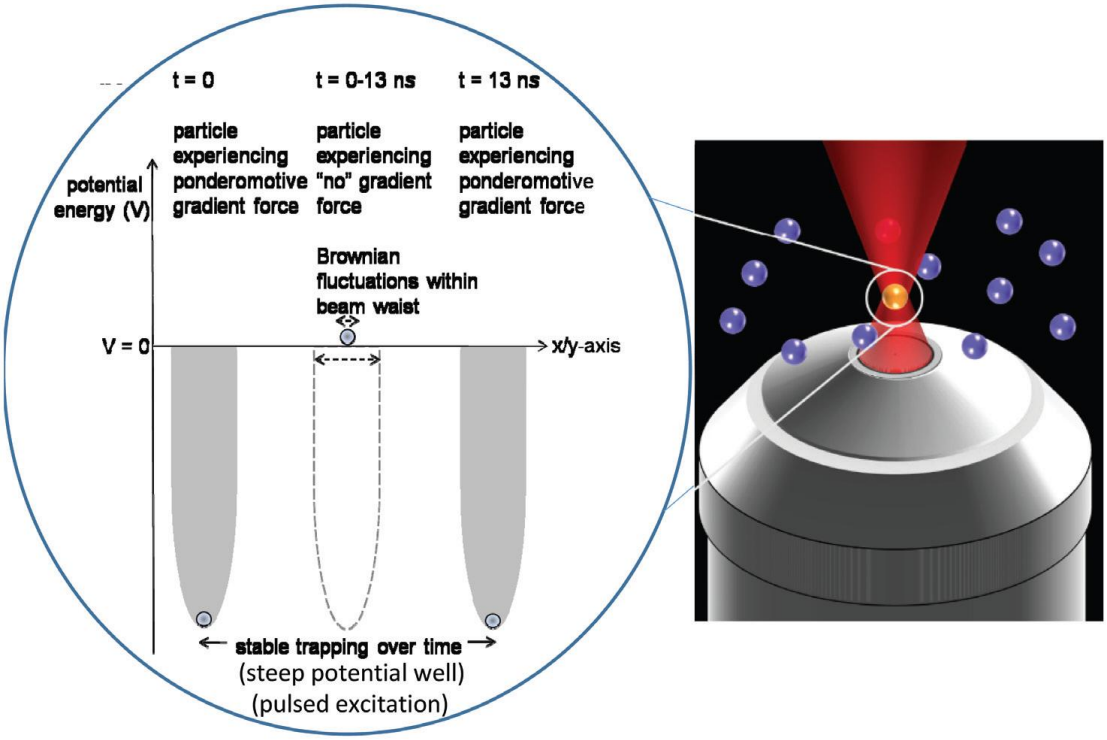


Figure 3: Diagram showing Femtosecond pulsed laser tweezer (14)

Major developments of laser in the field of industry constitute manufacturing of materials and micro-materials processing for microelectronic items. Other popularly used processes include laser additive manufacturing, laser-assisted machining, laser micromachining (shown in figure 4), laser forming, laser surface texturing and laser welding etc.(11,15) In factories, lasers are used in cutting, welding, marking or drilling purposes. Lasers are used to cut thin metal sheets due to its directional property. Laser welding has also found more usefulness compared to ordinary welding processes. In laser welding the beam is focused onto the specific area to be welded and other areas remain unaffected whereas in ordinary welding heat spreads and damages the structure of surrounding material. Laser drilling can produce very small holes which are impossible via mechanical drilling. Lasers can also be used for surface hardening techniques. Mid-infrared laser sources, with new spectroscopic techniques are capable of selective and quantitative tracing of gases. (11,16)

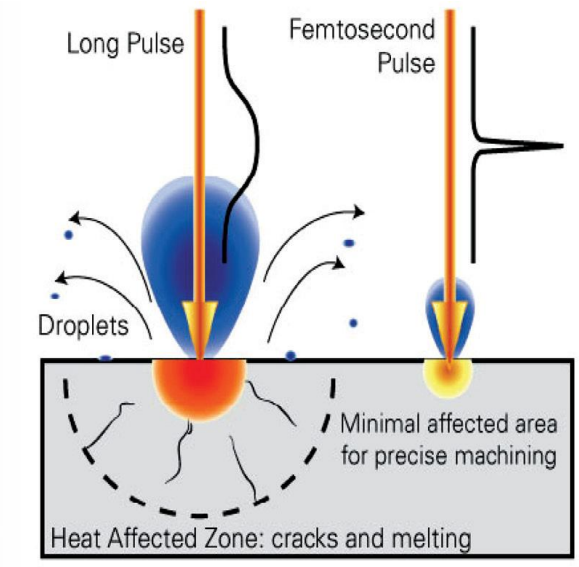


Figure 4: Diagram showing laser machining action (14)

Physical and chemical sensors have also been realized by inducing grapheme with laser irradiation. Sensors thus formed have been integrated in wearable devices, disease diagnosis, intelligent robots, and pollution detection etc.(17) A new kind of random laser has also been designed by scientists by disordering the intrinsic structures of existing photonic materials in order to get improvised optical structures. (18)

Laser ablation and photolithography has been used to fabricate micro-optical three-dimensional materials, or to study and design polymers for quite some time now. (19) Further advancement in this direction introduced ultrafast Femtosecond laser. Femtosecond laser surface processing has overpowered conventional laser ablation methods. It has been used in creating surface structures on metals, glass, ceramics and many semiconductors not just at micro levels but at nano-scales as well. With this technique structural coloring of materials can also be done after altering their optical properties. Highly absorptive black silicon and black metal are created using the above technique only. Femtosecond laser processing demonstrated another extraordinary capability of producing superhydrophilic to superhydrophobic novel materials. In the extreme case, there are reports that superwicking materials can also be created using the Femtosecond laser that can make liquids run upwards against gravity over an extended surface area. (20)

In the field of meteorology, transmitted laser beams through atmosphere facilitates probing for better understanding of it along with other geophysical applications. (21) Self-mixing interferometric technique of Laser diode has also been presented for remote sensing applications. (22)

Latest research reports show diode laser applications in the field of high resolution molecular spectroscopy for determination of any kind of alterations in spectral lines such as transition frequencies, their intensities, broadening and shifting etc.. (23) Plasma of laser has also been experimentally observed by focusing high-power laser beams onto matter. Laser plasma is readily used for accelerating electrons and ions, to generate THz (tera-hertz) power, high-energy-density plasmas and plasma optics, etc.(24) Researchers are also working on synchronization of coupled laser systems exhibiting spatiotemporal chaotic regime which is

then applied on colored image encryption for secured data communications.(25) Self-quenching of laser oscillation in a double-heterostructure GaAlAs laser has also been studied for its usefulness in optical memory readout. (26)

Apart from above mentioned applications, lasers are commonly used in recreational activities too like in sports, music (laser harp) and laser light shows. Laser shooting games are quite popular among new generation i.e. Laser Tag where everyone has a gun which shoots a beam of infrared light at the target. Laser light is also used in parties, videogames and displays etc. Holograms are ubiquitous these days, which appears to be undistinguishable and ordinary lines and hazy objects which when illuminated by a laser beam turns into identifiable three-dimensional pattern.(27)

V. CONCLUSION

This chapter summarizes the mechanisms involved, different types and miscellaneous applications of laser. Most recent and relevant developments in laser technology have also been dealt in the current chapter.

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