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Review on LASER and its Application in Diverse Defence Field

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ABSTRACT

Lasers have opened new fields of science and technology. LASER seems to be very helpful in reducing the complexity and thus provide a better platform and easier to accomplish our task. Lasers have affected many areas in many ways. This paper presents a review the on the various application of laser in various defence fields from current literature on the basics of laser physics.

KEYWORDS: *laser, stimulated emission, monochromatic, coherent, defence.*

I. INTRODUCTION

Laser is one of the outstanding inventions of the last century. Laser has become a valuable tool in a variety of fields starting with medical to communications. Laser is a light source but it is very much different from many of the traditional light sources. The word LASER stands for Light Amplification by Stimulated Emission of Radiation [1, 2]. 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). 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.

"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 a very little divergence."

In case of a conventional source of light, the light is emitted in a jumble of separate waves that cancel each other at random and hence can travel very short distances, the light waves are exactly in step with each other and thus have a fixed phase relationship. It is this coherency that makes all the difference to make the laser light so narrow, so powerful and so easy to focus on a given object. The light with such qualities is not found in nature. A high degree of directionality and monochromatic is also associated with these light beams. Therefore, in a laser beam the light waves not only are in the same phase but also have the same color (wavelength) throughout their journey. The beam of the ordinary light spreads out very quickly. On the other hand, the laser beam is highly collimated and spreads very little when travels through space. Another remarkable feature of laser is the concentration of its energy to extremely high intensities, the intensity remaining almost constant over long distances because of low divergence. This concentrated energy is so intense that it easily ionizes the atmospheric air to create sparks. These unique characteristics of laser have made it an important tool in various applications. New applications of lasers in the various fields are announced almost every day. Laser finds applications in the fields of communication, Industry, medicine, military operations, scientific research, etc. Besides, laser has already brought great benefits in surgery, photography, holography, engineering and data storage.

II. PRINCIPLE OF QUANTUM THEORY

Laser action is based on well-established principles of quantum theory. Albert Einstein, the greatest modern physicist, proclaimed that an excited atom or a molecule, when stimulated by an electromagnetic wave (i.e., light), would emit photons (packets of light) having the same wavelength as that of the colliding electromagnetic wave.

III. ACTION OF LASER

Interaction of electromagnetic radiation with matter produces absorption and spontaneous emission. Absorption and spontaneous emission are natural processes. Most atoms exist naturally in a low energy (ground) state. Electrons in their ground state can be excited to a higher energy state when they absorb thermal, optical or electrical energy. An electron in a higher energy orbit is unstable and wants to return to the ground state; when it does, it releases its defined energy as a photon (particle of light). The amount of energy released determines the wavelength or color of the light emitted. This is known as spontaneous emission (Figure 1). In spontaneous emission the photon emitted travels in random directions.

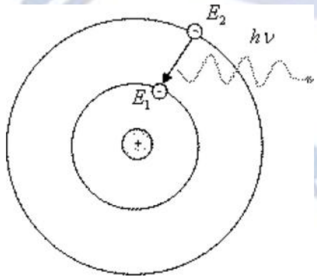

Figure 1: Spontaneous emission

For the generation of laser, stimulated emission is essential. Stimulated emission has to be induced or stimulated and is generated under special conditions as stated by Einstein in his famous paper of 1917[3, 4]

If an electron already in an excited state encounters a photon of the proper energy, the electrons drop to a lower orbit and emit a photon. The stimulating photon is not absorbed but continues on its way, resulting in two photons of identical energy or wavelength. Einstein called this stimulated emission[4] (Figure 2).

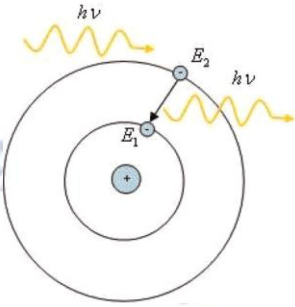

Figure 2: Stimulated emission

i.e., when the population inversion exists between upper and lower levels among atomic systems, it is possible to realize amplified stimulated emission and the stimulated emission has the same frequency and phase as the incident radiation. Einstein combined Plank's law with Boltzmann's statistics in formulating the concept of stimulated emission. In electronic, atomic, molecular or ionic systems the upper energy levels are less populated than the lower energy levels under equilibrium conditions. Pumping mechanism excites say, atoms to a higher energy level by absorption.

IV. AMPLIFICATION BY STIMULATED EMISSION & POPULATION INVERSION

"When favorable conditions are created for the stimulated emission, more and more atoms are forced to give up photons thereby initiating a chain reaction and releasing vast amount of energy, This results in rapid build-up of energy of emitting one particular wavelength (monochromatic light), traveling coherently in a precise, fixed direction." This process is called amplification by stimulated emission. The number of atoms in any level at a given time is called the population of that level. Normally, when the material is not excited externally, the population of the lower level or ground state is greater than that of the upper level. When the population of the upper level exceeds that of the lower level, which is a reversal of the normal occupancy, the process is called population inversion. This situation is essential for a laser action. For any stimulated emission, It is necessary that the upper energy level or met stable state should have a long life time, i.e., the atoms should pause at the Meta stable state for more time than at the lower level. Thus, for laser action, pumping mechanism (exciting with external source) should be from such, as to maintain a higher population of atoms in the upper energy level relative to that in the lower level.

V. MAIN COMPONENTS OF LASER

A laser generally requires three components for its operation:

(a) an active medium in the form of a laser rod, with energy levels that can be selectively populated;

(b) a pumping process to produce population inversion between some of these energy levels

(c) a resonant cavity containing the active medium which serves to store the emitted radiation and provides feedback to maintain the coherence of the radiation , are shown in figure 3.

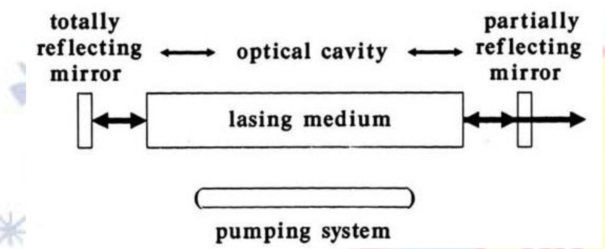

Figure 3: Schematic diagram of a basic laser

The main problem in designing a laser is to produce a sufficiently high population of atoms in the excited state. The most common method of centre excitation is by sending an intense beam of light from a flash lamp or a continuous source of light through the material in the form of a cylindrical rod or a container tube with a suitable gas. Only those materials which can be pumped to achieve population inversion are used to give laser radiation. Long life time of a level and the sharpness of the spectrum lines usually go together, and so, the materials that can be best used to give laser radiation are crystals with sharp lines, and gases at low pressure. To maximize the process of stimulated emission, an important aspect of the laser operation involves the design of a resonator cavity. The stimulated radiation multiplies by bouncing back and forth many times between the two mirrors one having less reflectivity and other 99 per cent reflectivity and passing through the laser medium. And, when it exceeds a certain limit, the laser light comes out citation in the form of a narrow pencil beam through the semi-transparent mirror. Different types of lasers operate in different electromagnetic spectrum-some in the visible region, some in the infrared region, and others in the ultraviolet region. Some lasers produce continuous light beams while others give pulses of light (of less than millisecond duration).

VI. PROPERTIES AND CHARACTERISTICS OF A LASER BEAM

The use of a laser for a variety of applications depends on the properties of the laser beam, as the steering characteristic, divergence, and the wavelength or frequency range, which can be adjusted by the laser components. Characteristics that affect the properties of the laser beam include: size of the gain medium, the location, the separation and the reflectivity of the mirrors of the optical cavity, and the presence of losses in the beam path in the cavity. Some of these characteristics determine the unique properties of the laser beam, called laser modes. The laser modes are wave properties relating to beam characteristics of the oscillation when the beam passes back and forth through the amplifier and grows at the expense of existing losses.

The first action of the laser was demonstrated in a ruby crystal by Maiman in 1960. Since then, a large number of materials in various media have been found to give laser action at wavelengths in the visible, the ultraviolet and infrared regions. These include a variety of gases, solids, liquids, glasses, plastics, semiconductors, and dyes. In addition to the ruby crystal, many other doped crystals (introduced as an impurity) with rare earth ions have been found light to give a very good laser. The main categories are: optically pumped solid-state lasers, liquid (Dye) lasers, semiconductor gas lasers , free electron lasers , lasers, X -ray lasers , and chemical lasers.

VII. VARIOUS APPLICATIONS IN DEFENCE: RANGE FINDER LASER

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 kilometers, laser is ideally suited for this purpose. The laser range finders using neodymium and carbon dioxide lasers have become a standard item for artillery and tanks. These laser range finders are light weight and have higher reliability and superior range accuracy as compared to the conventional range finders. 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. 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. A typical laser range finder can be functionally divided into four parts: transmitter, receiver, display and readout, and sighting telescope.

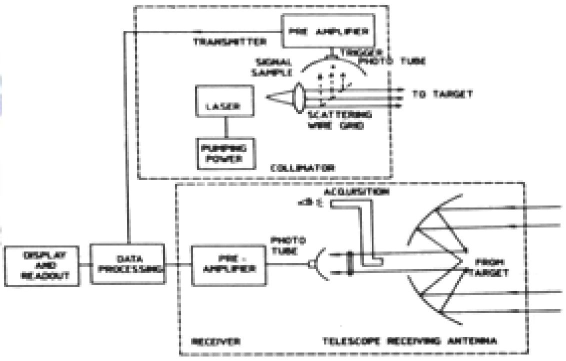

Figure 4: Schematic Diagram of Range finder Laser.

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 Special circuits have been used to eliminate Spurious signals with the help of range gating and to make the use of laser range finder Possible under all weather conditions for which the targets can be seen visually through the sighting telescope. The modern versions of the laser range finders Use either high repetition pulsed Nd:YAG laser or carbon dioxide laser with range gating system. In ranging a target about 10 km away using these systems, accuracy within 5 m is easily obtained. The laser range finders of medium range (up to 10 km) are used in several Defence areas., including

• Tank laser range finder for artillery, an armored vehicle, or a truck.

• Portable laser range finders used in the field artillery fire control systems. These are intended for field application in conjunction with artillery fire control systems

• Airborne laser range finder, pod-mounted and servo-positioned for the Air Force.

VIII. UNDERWATER LASER

Lasers can also be used as underwater source of transmission. For this purpose, a laser providing radiation in the blue - green region is most appropriate that the transmission in this region is maximum for seawater. The attenuation of the submarine transmission is due to the absorption by the materials in water by dispersion of the particles in suspension, and the variation of the optical density along the light path.

Blue-green lasers have become increasingly important in systems related to naval applications . Currently, submarines must rely on sonar to find the enemy ships and avoid underwater objects . This has serious limitations. Whales, dolphins and other marine animals give false signals . A typical sonar cannot give a clear picture because the sonar beam is expanded or scattered by the sea water. A difference in salinity can cause the sonar beam to bend and make the target appear where it is not . Another problem with the use of sonar is that it gives away to the enemy ship's position from which it is transmitted.

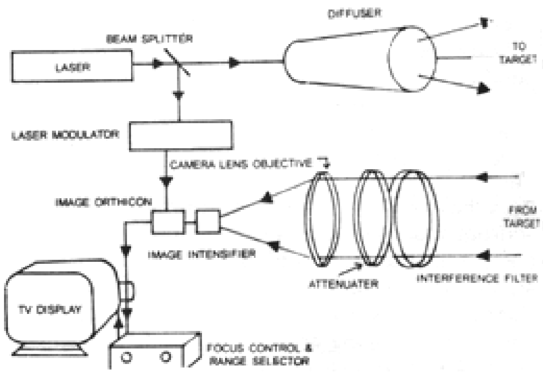

Figure 5: Schematic Diagram of Underwater Laser

Lasers can be effectively used for ranging and detection of underwater objects. For this purpose, a frequency-doubled Nd: YAG laser or an ion gas laser or argon laser Raman shifted xenon chloride is used. It consists of the laser emitter which emits laser pulses of high power of about 10 ns duration at the target for 30 to 50 seconds through a beam splitter and a small diffuser amount of the reflected laser light by the beam splitter is made to fall on the photodiode and the screen from the circuit to start the timer interval. The light reflected by the target is collected by the telescopic optical dispersion after radiation is removed by an interference filter. Trailing circuit avoids false echoes the pulse reflected from the target is intensified by the image intensifier and the output is supplied to the orthicon image, which gives the display of the object. In this way , both the extent and the target image are obtained . With the high power version of several megawatts of power, underwater ranging up to 500 m is possible with clear water. Lasers can also be used for communication between submarines ensuring absolute privacy and referral systems for torpedoes and other unmanned underwater vehicles. Recent underwater laser communication has been established by satellite or sol- satellite and then to the railway station under water.

IX. STATUS OF LASER DEVELOPMENT IN INDIA

The research and development work in the field of lasers started in India 31 years back on a very small scale at a few research laboratories of the Defence Research & Development Organization, Bhabha Atomic Research Centre, National Physical Laboratory, IIT, Kanpur, and IISc, Bangalore. Later, a number of research laboratories and teaching institutions also entered into this area. A Study Group on Lasers, constituted in 1971 by DRDO and INSA Laser Committee constituted under the Chairmanship of Prof. P Venkateswarlu in 1976 (the author was a member of the two committees) made detailed studies to assess the status of R&D work on laser at both international and national levels and gave suitable recommendations for development of lasers and laser systems in the country. In 1988, Dr DD Bhawalkar, Director, Centre for Advanced Technology (CAT), Indore, gave a status report on lasers to the Science Advisory Council to the Prime Minister. India has developed its first Laser Guided Bomb (LGB), a weapon that can hit a target with a greater accuracy, with technological support from city-based Instrument Research and Development Establishment (IRDE). The development of technology for producing LGB is part of on-going research towards achieving self-dependency in defense area being done in IRDE, a lab of DRDO.

X. CONCLUSION

LASER seems to be very useful in reducing the complexity and therefore providing a better and easier platform to perform our task. The main important features of the LASER are their application in field of defence, medical and in engineering sector. There is a great scope in the field of Defence and medical. When used in defence LASER creates a simpler path for the army to achieve any task by minimizing the man loss and time.

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