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Laser Technology: A Review

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Laser is a vigorous source of light having amazing properties which are not found in usual light sources like mercury lamps, tungsten lamps etc. The special property of laser is its light waves travel long distances with a very slight divergence. A high nick of monochromaticanddirectionality nature is also associated with these light beams. So, all through their journey of a laser beam, the light waves are not only in the same phase but also of same colour & wavelength.The principle of a laser is based onStimulated emission within an amplifying medium and Interaction of electromagnetic radiation with matter causes absorption and spontaneous emission .Spontaneous emission and absorption are natural processes. For the creation of laser, stimulated emission is vital. Stimulated emission has to be made or stimulated and is created under special conditions as Einstein stated.

I. INTRODUCTION

A laser emits light of optical amplification based on the stimulated emission of electromagnetic radiation. The term "LASER" originated as an acronym for "Light Amplification by Stimulated Emission of Radiation”. The first laser was built in 1960 by Theodore H. Maiman at Hughes Research Laboratories, based on theoretical work by Charles Hard Townes . A laser differs from other sources of light in and emits light coherently. Spatial coherenceallows a laser to be focused to a spot, enabling applications such as laser cutting and lithography. Spatial coherence also allows a laser beam to stay narrow over great distances (collimation), enabling applications such as laser pointers. Lasers can have high temporal coherence, which allows them to emit light with a very narrow spectrum. Temporal coherence can be used to produce pulses of light as short as a femtosecond. The word laser is an acronym (an abbreviation pronounced as an ordinary word) of Light Amplification by Stimulated Emission. Lasers are devices that produce or amplify a beam of narrow light with a well-defined wavelength within optical region of the electromagnetic spectrum, covering the infrared, the visible and the ultraviolet. The laser is different from other 20^{th}century inventions as it first appeared as an imaginary literary creation.

A laser consists of following fundamental elements:

- An amplifying or gain medium (this can be a solid, a liquid or a gas). This medium is composed of atoms, molecules, ions or electrons whose energy levels are used to increase the power of a light wave during its propagation. The physical principle involved is called stimulated emission.
- A system to excite amplifying medium (also called a pumping system). This creates conditions for light amplification by supplying the necessary energy. There are different kinds of pumping system: optical (the sun, flash lamps, continuous arc lamps or tungsten-filament lamps, diode or other lasers), electrical (gas discharge tubes, electric current in semi-conductors) or even chemical.

These two components are sufficient to amplify an existing light source. This is known as a laser amplifier. However, most lasers also incorporate an optical resonator (or cavity) in order to produce a very special radiation. Technically, the whole device is known as a laser oscillator, but this term is often shortened to simply “laser”. The laser oscillator uses reflecting mirrors to amplify the light source considerably by bouncing it within the cavity. It also has an output beam mirror that enables part of the light wave in the cavity to be removed and its radiation used.The different components that make up a basic laser are illustrated in diagram :

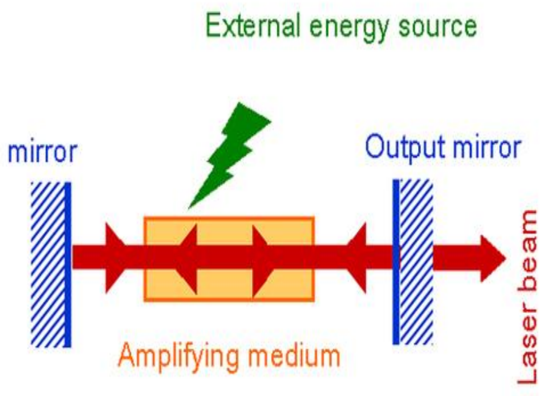

FIG 1Basic Laser diagram

II CONCEPT

The laser is a light source that exhibits different properties. Since first demonstration of a ruby laser by Maiman in 1960, there has been a phenomenal development in field of lasers. Lasers dominate our modern world in a variety of forms ranging from small diode lasers in all CD and DVD players to large industrial laser devices, used extensively for cutting and welding, e.g. in automobile manufacturing.

Lasers are used in thousands of applications in every section of modern society, including consumer electronics ,entertainment, science and industry, information and communications technology, the medical field. The laser triggered photonics revolution and is foundation of modern photonics. Alaseroscillator usually comprises an optical resonator (laser resonator, laser cavity) in which light can circulate (e.g. between two mirrors), and within this resonator a gain medium (e.g. a laser crystal), which serves to amplify the light. Without gain medium, circulating light would become weaker and weaker in each resonator round trip, because it experiences some losses, e.g. upon reflection at mirrors. However, gain medium can amplify circulating light, thus compensating the losses if gain is high enough. The gain medium requires some external supply of energy – it needs to be "pumped", e.g. by injecting light (optical pumping) or an electric current (electrical pumping → semiconductor lasers). The principle of laser amplification is stimulated emission.

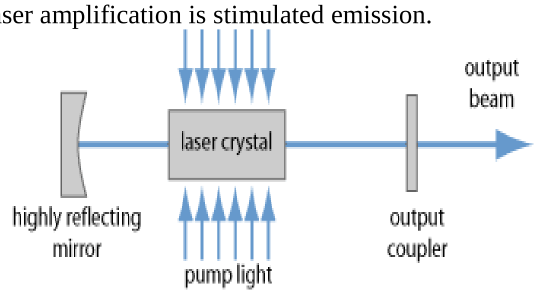

Fig 2 Setup of a simple optically pumped laser

The laser resonator is made of a highly reflecting curved mirror and a partially transmissive flat mirror, the output coupler, which extracts some of the circulating laser light as the useful output. The gain medium is a laser crystal, which is side-pumped, e.g. with light from a flash lamp.

III COMPONENTS OF LASER

Every LASER consists of three basic components. These are -

1. Lasing material or active medium.
2. External energy source.
3. Optical resonator.

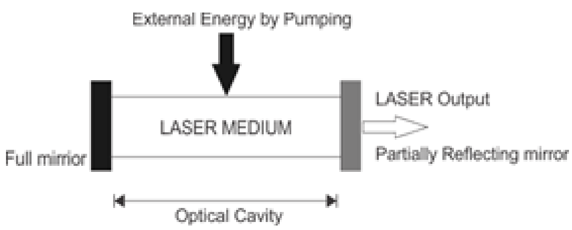

Fig 3 Component of Laser

- The active medium is excited by external energy source(pump source) to produce population inversion. In the gain medium that spontaneous and stimulated emission of photons takes place, leading to phenomenon of optical gain, or amplification. Semiconductors, organic dyes, gases (He, Ne, CO_2, etc), solid materials (YAG, sapphire (ruby) etc.) are usually used as lasing materials and often LASERs are named for ingredients used as a medium.

- The excitation source, pump source provides the energy which is needed for population inversion and stimulated emission to the system. Pumping can be done in many ways - electrical discharge method and optical method. Examples of pump sources are electrical discharges, arc lamps, flash lamps, light from another laser, chemical reactions etc.
- Resonator guide basically provides guidance about simulated emission process. It is induced by high-speed photons. Finally, a laser beam will be generated.

IV TYPES OF LASER

Laser can be classified into various types described as follows:

Gas Laser:

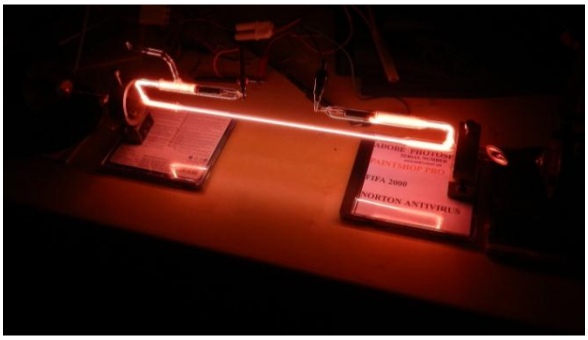

Fig 4gas Laser

Gas lasers all have in common same pump source: The gaseous species enter the excited state either directly, by collision with electrons, or indirectly, by collision with gases, themselves electrically excited.

Gas lasers cover whole optical spectrum, from the ultraviolet to far infrared. However, spectrum is not continuously covered: gas lasers emit very narrow spectral lines. The most common gas lasers (from the UV to the far IR) include:

- excimer lasers (ArF:193 nm, KrF:249 nm, XeCl:308 nm)
- argon-ion lasers (blue and green wavelengths)
- helium-neon lasers (Neon is used for the laser effect) 632.8 nm, 543.3 nm, 1.15 µm, 3.39 µm
- CO_2 lasers: a large number of wavelengths around 9.6 µm and 10.6 µm.

Only CO_2 lasers are really efficient (15 to 20%). They are used in the industry for processing materials. The efficiency of others is mostly less than 1%. Gas lasers are often need a great deal of water-cooling (almost all the energy provided by the pump is lost as heat). Even though those operating in the visible (Argon, Helium, Neon) are tending to be replaced by solid state lasers, excimer lasers and CO_2 lasers are still very frequently used (for the treatment of materials in the broadest sense).

Dye Lasers:

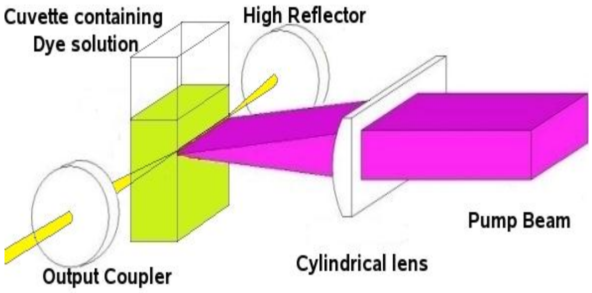

Fig 5dye Laser

Dye lasers use organic materials that generally emit in visible spectrum and are thus coloured. These molecules are diluted in a solvent (usually an alcohol, like ethylene glycol or methanol).The pump source of dye lasers is optical: either an arc lamp or, in the majority of cases, another laser (gas or solid state).The whole of visible spectrum is covered. In fact, the dyes are complex organic molecules that have many energy levels. The levels are so close as they are considered as an energy band. In general, a molecule of dye covers continuously a region of about fifty nanometers in the visible. Dye lasers are the only ones to cover the visible spectrum entirely. Despite these interesting properties, dye lasers are little used because their implementation is impractical to prevent molecules from being destroyed by the pump source, the dye circulates in the pumping zone from a reservoir. In addition, the dye and solvent mixture degrades with time and must be changed regularly.

Solid State Laser:

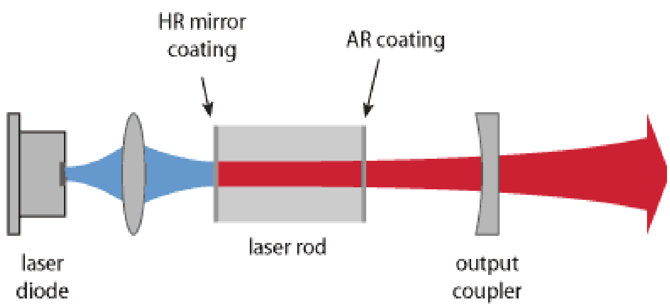

FIG 6Solid State Laser

Solid state lasers are either semiconductor (or diode) lasers pumped electrically or those with a crystalline or glass matrix pumped optically.

Diode Lasers:

Diode lasers use recombinations between “electron-hole” pairs found in semiconductors to emit light in the form of stimulated emission. The pump source is electrical with an efficiency that can reach 60%. The wavelength can cover from the near UV to the near infrared depending on the materials chosen (GaN, GaAlInP, AlGaAs).These are the most compact (the cavity uses the cleaved sides of the semiconductor and is barely 1 mm long) and the most efficient lasers available. The power can now reach several kilowatts by putting together hundreds of diode lasers and combining them in the same optic fibre. The only disadvantage of these diode lasers are poor spatial quality of the emitted beam and that they cannot operate at a pulsed rate (Q-switching, see section IV).

Other solid state lasers

Other solid state lasers can compensate for disadvantage of diode lasers. They use matrices that cannot conduct current so cannot be pumped electrically. They are pumped optically by either diode lasers or arc lamps (flash lamps). The matrices are doped with ions whose transitions provide the laser effect (Nd^{3+},Yb^{3+}, Er^{3+},Ti^{3+}). In general, solid state lasers emit in the red and near infrared. Of particular interest is the wavelength of Nd^{3+}:YAG($Y_3Al_5O_{12}$) with an emission at 1064 nm.

Following host and ions used, the emission spectra can be narrow (fraction of nm) or wide (undredth of nm). Tr^{3+} : sapphire is a material having the largest spectrum : for 700 nm to 1100 nm.

With the help of non-linear optics, it is possible to convert the wavelength of solid state lasers into visible and the ultraviolet. In fact, when the electric field intensity is very high, as is case for laser waves, matter does not respond linearly to the electromagnetic excitation of light. It responds by emitting new frequencies.

V APPLICATIONS OF LASER

Medical applications:

The highly collimated beam of a laser may be further focused to a microscopic dot of extremely high energy density. This concept makes it useful for cutting and cauterizing instrument.

Cutting and Welding:

The highly collimated beam of a laser may be further focused to a microscopic dot of extremely high energy density for welding and cutting.

For instance, the automobile industry makes extensive use of carbon dioxide lasers with powers up to several kilowatts for computer controlled welding on auto assembly lines.

Surveying:

Helium-neon and semiconductor lasers have become standard parts of the field surveyor's equipment. A fast laser pulse is sent to a corner reflector at the point to be measured and time of reflection is measured to get distance.

Garment industry:

Computer controlled laser garment cutters can be programmed to cut out 400 size 6 and then 700 size 9 garments. The usefulness of laser for such cutting operations comes from fact that beam is highly collimated and can be further focused to a microscopic dot of extremely high energy density for cutting.

Laser nuclear fusion:
Telephone fiber drivers may be solid state lasers the size of a grain of sand and consume a power of only half a milliwatt. They can sent 50 million pulses per second into an attached telephone fiber and encode over 600 simultaneous telephone conversations.

Communication:
Digital data transmission plays a pivotal role in modern society. Optical communication is any form of telecommunication that uses light as transmission medium. An optical communication system consists of a transmitter, which encodes a message into an optical signal, a channel, which carries signal to its destination and a receiver, which reproduces message from the received optical signal.

Laser printing:
The laser printer has in a few years become dominant mode of printing in offices. It employs a semiconductor laser and xerography principle. The laser is focused and scanned across a photoactive selenium coated drum where it produces a charge pattern which mirrors the material to be printed.

Optical discs and CDs:
Analog sound data is digitized by sampling at 44.1 kHz and coding as binary numbers in the pits on compact disc. As the focused laser beam sweeps over pits, it reproduces the binary numbers in the detectioncircuitry.

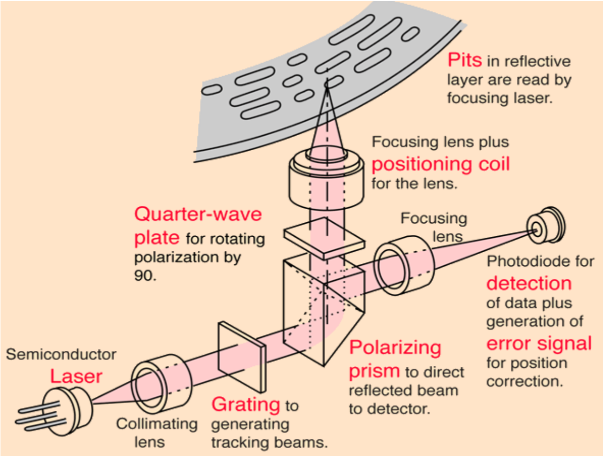

Fig 7 Optical Drives Write Cds/Dvds

Spectroscopy:
Laser spectroscopy has led to advances in precision with which spectral line frequencies can be measured, and this has fundamental significance for our understanding of basic atomic processes.

Heat treatment:
Heat treatments for hardening or annealing have been long practiced in metallurgy. But lasers offer some new possibilities for selective heat treatments of metal parts.

Barcode scanners:
Supermarket scanners typically use helium-neon lasers to scan the universal barcodes to identify products. The laser beam bounces off a rotating mirror and scans the code, sending a modulated beam to a light detector and then to a computer which has the product information stored. Semiconductor lasers can also be used for this purpose.

VI CONCLUSION

Laser communication in space has long been a goal for NASA it would be enable data transmission rates that are 10 to 1000 times higher than traditional waves. While lasers and radio transmissions both travel at light speed, laser can pick more data. It's similar to moving from a dial-up internet connection to broadband. Astronomers could use lasers like very accurate rulers to measure movement of planets with unprecedented precision. With microwaves we are limited to numbers like a meter or two in distance, whereas (lasers have) a potential for getting down into well beyond centimeter range.

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