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Laser and its Utilities in Different Fields

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ABSTRACT: A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The word "laser" is 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 and Arthur Leonard Schawlow. A laser differs from other sources of light in that it emits light which is coherent. Spatial coherence allows a laser to be focused to a tight 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 and lidar (light detection and ranging). Lasers can also have high temporal coherence, which allows them to emit light with a very narrow spectrum. Alternatively, temporal coherence can be used to produce ultrashort pulses of light with a broad spectrum but durations as short as a femtosecond.

Lasers are used in optical disc drives, laser printers, barcode scanners, DNA sequencing instruments, fiber-optic and free-space optical communication, semiconducting chip manufacturing (photolithography), laser surgery and skin treatments, cutting and welding materials, military and law enforcement devices for marking targets and measuring range and speed, and in laser lighting displays for entertainment. Semiconductor lasers in the blue to near-UV have also been used in place of light-emitting diodes (LEDs) to excite fluorescence as a white light source. This permits a much smaller emitting area due to the much greater radiance of a laser and avoids the droop suffered by LEDs; such devices are already used in some car headlamps.

KEYWORDS: laser, utilization, fields, electromagnetic, radiation, lithography, light, sequencing

I. INTRODUCTION

Lasers are distinguished from other light sources by their coherence. Spatial (or transverse) coherence is typically expressed through the output being a narrow beam, which is diffraction-limited. Laser beams can be focused to very tiny spots, achieving a very high irradiance, or they can have very low divergence in order to concentrate their power at a great distance. Temporal (or longitudinal)[1,2] coherence implies a polarized wave at a single frequency, whose phase is correlated over a relatively great distance (the coherence length) along the beam. A beam produced by a thermal or other incoherent light source has an instantaneous amplitude and phase that vary randomly with respect to time and position, thus having a short coherence length.

Lasers are characterized according to their wavelength in a vacuum. Most "single wavelength" lasers actually produce radiation in several modes with slightly different wavelengths. Although temporal coherence implies some degree of monochromaticity, there are lasers that emit a broad spectrum of light or emit different wavelengths of light simultaneously. Some lasers are not single spatial mode and have light beams that diverge more than is

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required by the diffraction limit. All such devices are classified as "lasers" based on the method of producing light by stimulated emission. Lasers are employed where light of the required spatial or temporal coherence can not be produced using simpler technologies.[3,4]

The first device using amplification by stimulated emission operated at microwave frequencies, and was named "maser", an acronym for "microwave amplification by stimulated emission of radiation". When similar optical devices were developed they were first known as "optical masers", until "microwave" was replaced by "light" in the acronym. All such devices operating at frequencies higher than microwaves are called lasers (including infrared laser, ultraviolet laser, X-ray laser and gamma-ray laser). All devices operating at microwave or lower radio frequencies are called masers. A laser that produces light by itself is technically an optical oscillator rather than an optical amplifier as suggested by the acronym. It has been humorously noted that the acronym LOSER, for "light oscillation by stimulated emission of radiation", would have been more correct. With the widespread use of the original acronym as a common noun, optical amplifiers have come to be referred to as "laser amplifiers". The back-formed verb to lase is frequently used in the field, meaning [5,6] "to give off coherent light," especially in reference to the gain medium of a laser; when a laser is operating it is said to be "lasing". The words laser and maser are also used in cases where there is a coherent state unconnected with any manufactured device, as in astrophysical maser and atom laser.

A laser consists of a gain medium, a mechanism to energize it, and something to provide optical feedback. The gain medium is a material with properties that allow it to amplify light by way of stimulated emission. Light of a specific wavelength that passes through the gain medium is amplified (increases in power). Feedback enables stimulated emission to amplify predominantly the optical frequency at the peak of the gain-frequency curve. As stimulated emission grows, eventually one frequency dominates over all others, [7,8] meaning that a coherent beam has been formed. The process of stimulated emission is analogous to that of an audio oscillator with positive feedback which can occur, for example, when the speaker in a public-address system is placed in proximity to the microphone. The screech one hears is audio oscillation at the peak of the gain-frequency curve for the amplifier.

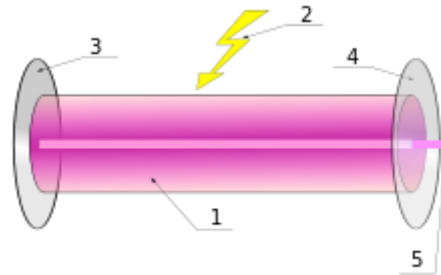
For the gain medium to amplify light, it needs to be supplied with energy in a process called pumping. The energy is typically supplied as an electric current or as light at a different wavelength. Pump light may be provided by a flash lamp or by another laser. The most common type of laser uses feedback from an optical cavity—a pair of mirrors on either end of the gain medium. Light bounces back and forth between the mirrors, passing through the gain medium and being amplified each time.[9,10] Typically one of the two mirrors, the output coupler, is partially transparent. Some of the light escapes through this mirror. Depending on the design of the cavity (whether the mirrors are flat or curved), the light coming out of the laser may spread out or form a narrow beam. In analogy to electronic oscillators, this device is sometimes called a laser oscillator. Most practical lasers contain additional elements that affect properties of the emitted light, such as the polarization, wavelength, and shape of the beam.

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Components of a typical laser:

1. Gain medium
2. Laser pumping energy
3. High reflector
4. Output coupler
5. Laser beam

Since the early period of laser history, laser research has produced a variety of improved and specialized laser types, optimized for different performance goals, including:

- 1) new wavelength bands
- 2) maximum average output power
- 3) maximum peak pulse energy
- 4) maximum peak pulse power
- 5) minimum output pulse duration
- 6) minimum linewidth
- 7) maximum power efficiency
- 8) minimum cost

and this research continues to this day.

In 2015, researchers made a white laser, whose light is modulated by a synthetic nanosheet made out of zinc, cadmium, sulfur, and selenium that can emit red, green, and blue light in varying proportions, with each wavelength spanning 191 nm.[11]

In 2017, researchers at TU Delft demonstrated an AC Josephson junction microwave laser. Since the laser operates in the superconducting regime, it is more stable than other semiconductor-based lasers. The device has potential for applications in quantum computing. In 2017, researchers at TU Munich demonstrated the smallest mode locking

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laser capable of emitting pairs of phase-locked picosecond laser pulses with a repetition frequency up to 200 GHz. In 2017, researchers from the Physikalisch-Technische Bundesanstalt (PTB), together with US researchers from JILA, a joint institute of the National Institute of Standards and Technology (NIST) and the University of Colorado Boulder, established a new world record by developing an erbium-doped fiber laser with a linewidth of only 10 millihertz

II. DISCUSSION

Lasers are everywhere around us. Surgeons use them for eye surgery and cancer treatments. Manufacturers use them for material processing to cut, mark, weld, clean, and texture various types of materials. Some people need them for tattoo or hair removal, and everyone has seen laser light shows during music concerts. More recently, new applications like laser holography are emerging.

Different types of lasers are needed for these applications. Based on their gain medium, lasers are classified into five main types:

- Gas Lasers
- Solid-State Lasers
- Fiber Lasers
- Liquid Lasers (Dye Lasers)
- Semiconductor Lasers (Laser Diodes)

Additionally, these five types of lasers can be divided into subcategories based on their mode of operation: continuous-wave lasers and pulsed lasers. Furthermore, there are also multiple types of pulsed lasers. [12]

1. Gas Lasers- A gas laser is a laser in which an electric current is sent through a gas to generate light through a process known as population inversion. Examples of gas lasers include carbon dioxide (CO₂) lasers, helium–neon lasers, argon lasers, krypton lasers, and excimer lasers. Gas lasers are used in a wide variety of applications, including holography, spectroscopy, barcode scanning, air pollution measurements, material processing, and laser surgery.

CO₂ lasers are probably the most widely known gas lasers and are mainly used for laser marking, laser cutting, and laser welding.

2. Solid-state lasers- They use a solid (crystals or glasses) mixed with a rare earth element as their source of optical gain. The mixed element is typically neodymium, chromium, erbium, thulium, or ytterbium.

The most known solid-state laser is the ruby laser, since it is the first laser ever constructed. The Nd:YAG laser (neodymium-doped yttrium aluminum garnet) is also common in material processing applications. Solid-state lasers are also used for LIDAR technology as well as various medical applications, including tattoo and hair removal, tissue ablation, and kidney stone removal.

3. A fiber laser- It is a special type of solid-state laser that is a category of its own. In fiber lasers, the gain medium is an optical fiber (silica glass) mixed with a rare-earth element.

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The light guiding properties of the optical fiber are what makes this type of laser so different: the laser beam is straighter and smaller than with other types of lasers, making it more precise. Fiber lasers are also renowned for their small footprint, good electrical efficiency, low maintenance and low operating costs. Fiber lasers are used in a range of applications, including material processing (laser cleaning, texturing, cutting, welding, marking), medicine, and directed energy weapons. Examples of fiber lasers used for these applications include ytterbium and erbium-doped fiber lasers.

4. Liquid lasers-They use an organic dye in liquid form as their gain medium. They are also known as dye lasers and are used in laser medicine, spectroscopy, birthmark removal, and isotope separation.

One of the advantages of dye lasers is that they can generate a much wider range of wavelengths, making them good candidates to be tunable lasers, meaning that the wavelength can be controlled while in operation. In laser isotope separation for example, lasers are tuned to specific atomic resonances. They are then tuned to a specific isotope to ionize the atoms, making them neutral as opposed to negatively or positively charged. They are then separated with an electric field, achieving what is called isotope separation.

5. Semiconductor lasers- Laser diodes, also called diode lasers and semiconductor lasers, are similar to regular diodes in that they have a positively-negatively (PN) charged junction. The difference is that laser diodes have an intrinsic layer at the PN junction made of materials that create spontaneous emission.[13] The intrinsic layer is polished so that the generated photons are amplified, ultimately converting the electric current into laser light. Although most semiconductor lasers are diode lasers, a few of them are not. This is because there are semiconductor lasers that do not use the diode structure, such as quantum cascade lasers and optically pumped semiconductor lasers. Like fiber lasers, laser diodes can be classified as solid-state lasers since their gain medium is solid. However, they are in a category of their own because of their PN junction. Laser diodes are often used as energy sources to pump other lasers. These lasers are referred to as diode-pumped lasers. In these cases, laser diodes are typically arrayed to pump more energy, as shown in the following image. Laser diodes are extremely common. They are used in barcode readers, laser pointers, laser printers, laser scanners, and several other applications.

III. RESULTS

All types of lasers can operate using one of two methods: their laser beams can either be pulsed or continuous. This is what we call their mode of operation.

- With continuous-wave lasers, there is a constant flow of energy, meaning that the laser continuously shoots a single, uninterrupted laser beam. The most common example of this is a laser pointer's uninterrupted beam. Continuous-wave lasers are commonly used for laser cutting and laser welding.[14]
- With pulsed lasers, the laser beam is interrupted at regular intervals to allow the energy to build up and reach a higher peak power than continuous-wave lasers. The laser beam is released as pulses that have a specific duration called the pulsed duration. These high energy densities are required for many applications like spot welding and engraving.

Continuous-wave lasers may seem more powerful than pulsed lasers because the advertised laser power is typically much higher, but this can be misleading. This is because lasers are named according to their average laser power, and the average power of pulsed lasers is usually lower even if they reach higher peaks

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of power. For example, a 6,000W continuous-wave laser continuously releases 6,000W of laser power. Conversely, a 100W pulsed laser can release pulses of 10,000W each.

Pulsed lasers are divided into several categories based on the duration of their pulses.

A modulator is used to control the number of pulses per second. As a result, each pulse has a precise duration, called pulse duration, pulse length, or pulse width. The pulse duration is the time between the beginning and the end of a pulse. [15]

Several modulating methods are used to pulse laser beams: q-switching, gain-switching, and mode-locking are some examples. The shorter the pulse, the higher the energy peaks. Here are the most common units used to express pulse duration.

- Milliseconds (one thousandth of a second) are the longest time units used to express pulse duration and have hence the lowest energy peaks. For example, laser hair removal pulses may vary between 5 ms and 60 ms depending on the hair thickness.
- Microseconds (one millionth of a second) are probably the least common pulse durations. They can be used for material processing applications, but the following pulse durations are more commonly used, as they offer more precision. Microsecond lasers can also be used for applications like spectroscopy and hair removal.
- Nanoseconds (one billionth of a second) are very common pulse durations used for applications like laser material processing, distance measurements, and remote sensing. Laserax, for example, uses nanosecond fiber lasers to perform laser marking, cleaning, texturing, and engraving.
- Picoseconds (one trillionth of a second) and femtoseconds (one quadrillionth of a second) are the shortest pulse durations, which is why the terms ultrashort pulses and ultrafast lasers are used. These lasers offer the most precise results and have the lowest heat affected zones. This prevents undesirable melting and allows for very precise engravings. They are used in material processing, medicine (such as eye surgery), microscopy, measurements, and telecommunications. [16]

IV. CONCLUSIONS

Various uses of Lasers are:-

1. Laser range(LiDAR)-finding technology itself is a remarkable advance, but one of its most remarkable applications is in LiDAR, a technology that is essentially RADAR except with light. The applications of LiDAR are numerous and have given us everything from the laser rangefinder you can find in your local hardware store to recording the distance to the Moon, thanks to the reflective mirrors astronauts left on the Moon when they traveled there in 1971. What's more, LiDAR from orbiting satellites is responsible for most of the high-resolution maps we use today and are significantly more precise than anything that came before it.

2. Optical Tweezers- How can you move around a single molecule, or even a single atom? Obviously, no physical tool could do the job, but thanks to laser technology, individual molecules can be manipulated and turned, and single atoms can be isolated and trapped. This kind of precision opens the door to all kinds of nano-technology, from chemistry and medicine to engineering and physics.

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3. Laser Scalpel-Sometimes, you need a scalpel instead of a hacksaw, and then sometimes you need a laser scalpel. Traditional scalpels are incredibly sharp at the macro level. However, at the cellular level, there is still a considerable amount of damage to the surrounding tissue that may be okay for some surgeries, but become a danger when working on organs like the brain, where an unintended incision can have drastic consequences for the patient.[17]

4. Laser Cutters- Metal cutting has been an important driver of innovation since metal was first used by humans millennia ago. Lasers have increased the precision of these cuts considerably and have become an industry standard way of cutting complex shapes and pieces from metal sheets in a way that grinders and other mechanical cutters can't easily match.

5. Laser Welding- Welding has been a crucial industrial technique for centuries, but only in the 20th century did welding go beyond the hammering of molten metal pieces into a single shape.

With the advent of laser-welding, precise, controlled joints could be made with different metals that were physically impossible before and was instrumental in developing automated assembly lines that have revolutionized manufacturing around the world.

6. Fiber Optics- The introduction of fiber optic cables built the Internet we have today. The rapid transmission of information that lasers provide through fiber optic cables allows for extremely fast download and upload speeds, which anyone alive during the dial-up era of the Internet can appreciate, and makes streaming content possible.

7. Optical Storage- CDs, DVDs, and Blu-Ray Discs have increased the single unit storage capacity by orders of magnitude since the first Compact Disc was introduced in the 1970s. Modeled on old gramophones and vinyl records, the optical disc provides much of the mass storage we use in computers today due to its low cost, higher capacities, and long-term reliability.

8. 3D Scanners- Before 3D scanners, modeling a physical object for study, testing, or other practical purposes was expensive and limited to those who had the skill to do so, or money enough to pay someone who could. With 3D Scanners, which use lasers to take the dimensions of a scanned object and turn them into digital representations, a physical object can be scanned and sent to a scanner to reproduce the exact item anywhere in the world in minutes. This technology is only just beginning to take off, but is set to revolutionize manufacturing around the world.

9. Ultra-Fast Photography- The shutter speeds of many cameras have advanced to the point where the fastest phenomena were slowed down enough to become visible. However, the real advance in this technology came when laser pulses are used to flash illuminate the subject in rapid sequence, creating a strobing effect that can appear to stop the subject entirely at every frame of the shot. This technique leads to much higher resolution imaging of an incredibly fast moving object than otherwise possible.

10. Discovery of Gravitational Waves- In 2015, LIGO announced that it had been able to identify and record the gravitational waves of a collision between two black holes light years away from Earth. Long theorized, up until 2016, it had been impossible to detect these waves in the fabric of space-time because gravity isn't all that strong—after all, even a fly can generate enough energy to overcome the force of gravity with the beating of its wings. By

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using lasers shot over long distances, physicists were able to detect these waves as they passed by Earth and began a new era of Astronomy.[18]

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