



A REVIEW STUDY ON THE PROPERTIES AND THE APPLICATION OF LASER IN DIFFERENT ASPECT

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ABSTRACT:

Light Amplification by Stimulated Emission of Radiation (LASER) was introduced in 1960 by Theodore Mainman. LASER works on the principle of stimulated emission, it has properties of coherency and a high amount of monochromaticity making it reach extremely high powers. LASER has fulfilled many applications in various industries, be it optical communication and storage, LASER cutting and machining, LIDAR, military and defense, meteorology and geophysical applications, LASER imaging and holography, healthcare and aesthetics, and many more. The applications are widespread in various industries and continue to expand till date. This paper will focus on delivering the excerpt of various applications and advancements in LASER technology.

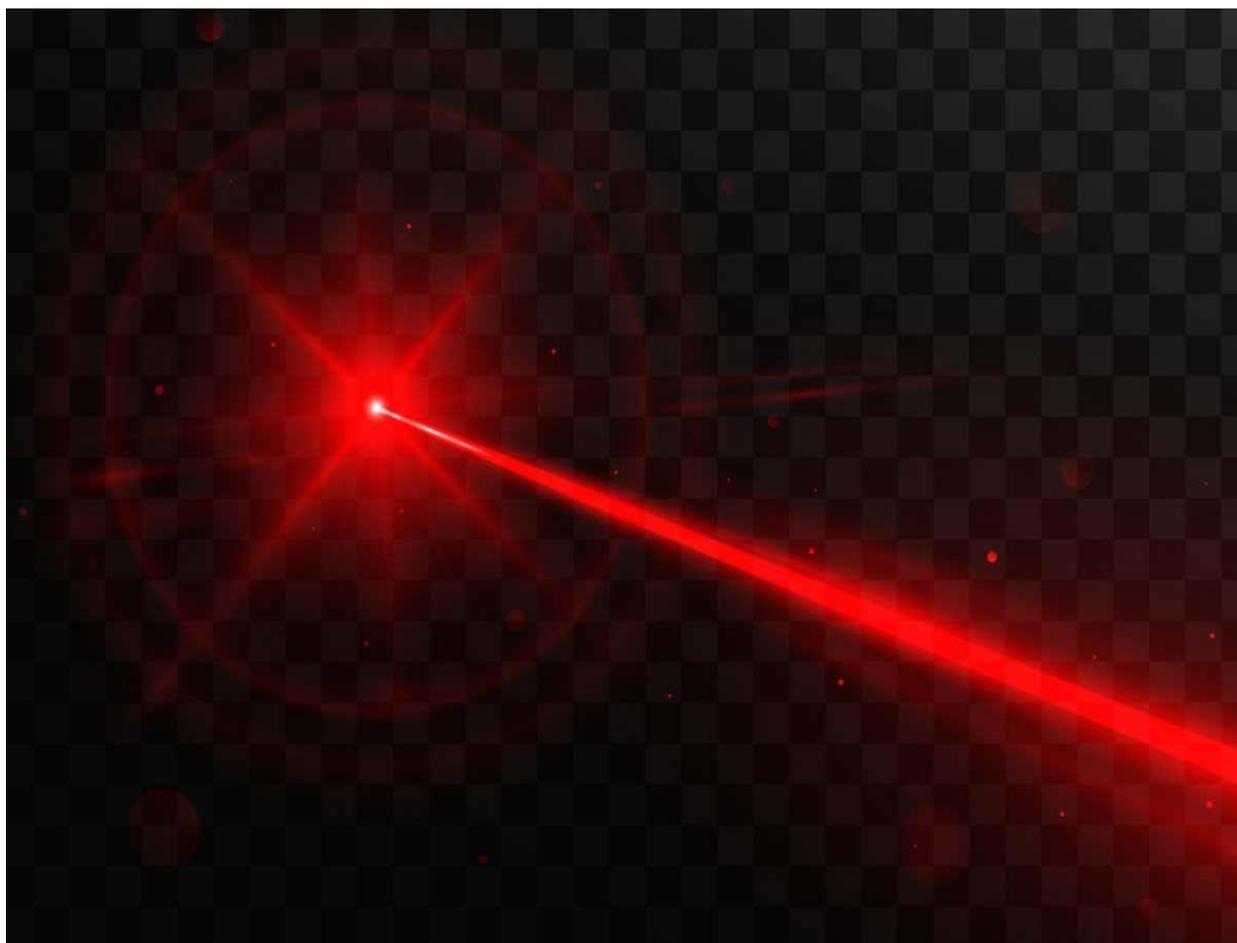
Keywords: LIDAR, Optical Communication, Military and Defence, Healthcare, Microlasers.

[1] INTRODUCTION

The first successful LASER was invented on May 16th, 1960 by Theodore Mainman. It was a ruby rod with shiny silver coated surfaces on which a high power flash lamp was shone, giving rise to a breakthrough in science and technology. It works on the principle of stimulated emission, irradiating visible, infrared or ultraviolet light.

Laser delivers coherent, monochromatic, well controlled, and precisely directed light beams. This unique combination of properties makes them ideal for concentrating light in space, time or in a particular wavelength. Despite being initially considered as poor choices for general

purpose illumination, lasers have been successfully applied in various practical and technical applications. The unique properties of laser light makes it a remarkable source of light. Unlike conventional light sources, laser light has the ability to travel long distances with minimal divergence due to its coherent nature. This property is not found in Tungsten, Mercury or Sodium lamps which emit light in a jumble of separate waves that cancel each other out at random.



In a laser, the light waves are precisely in step with each other, maintaining a fixed phase relationship. This coherence is essential for the laser's unique properties, including its directionality and monochromaticity. The coherence of laser light is characterized by both spatial coherence, which refers to the correlation between electric fields at different locations within the beam, and temporal coherence, which refers to the correlation between electric fields

at the same location but at different times. High-intensity lasers play a crucial role in scientific research, particularly in fields like plasma physics, planetary astrophysics, stellar astrophysics, and nuclear physics. These lasers are used to study and simulate complex phenomena, such as nuclear reactions and high-energy particle interactions. Beyond scientific research, ultrafast lasers find applications in various areas, including nuclear weapons stockpile stewardship, industry, cutting and machining, optical communication, military and defense and in medicine and aesthetics.

[2] APPLICATIONS IN VARIOUS FIELDS

Optical communication and storage.

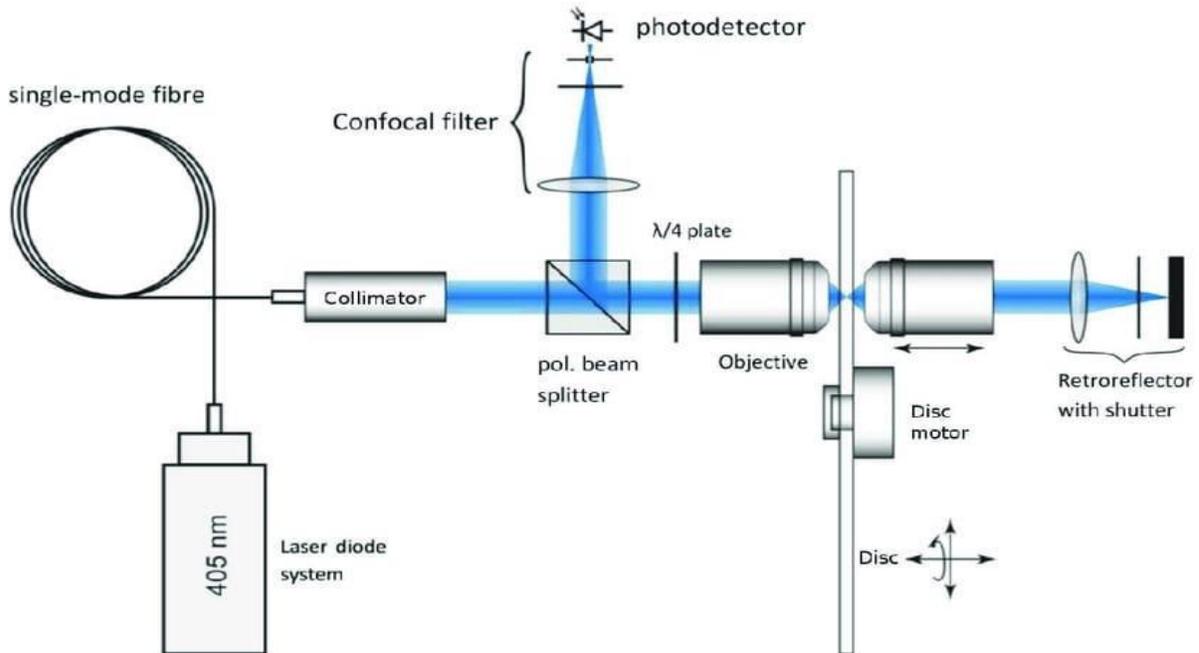
Optical fiber communication is a method of transmitting information from one place to another by sending pulses of infrared or visible light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. Fiber is preferred over electrical cabling when high bandwidth, long distance, or immunity to electromagnetic interference is required. This type of communication can transmit voice, video, and information across long distances at incredible speeds.

Fiber optic communication is a powerful technology that has revolutionized the way we communicate. It offers high-speed data transfer, low latency, and immunity to electromagnetic interference, making it ideal for a wide range of applications.

Laser diodes are crucial components in fiber optic communication systems. They convert electrical signals into optical signals, which are then transmitted through hair-thin optical fibers made of glass or transparent plastic. The light signals are received by photo detectors, which convert them back into electrical signals.

Laser diodes are versatile devices that find applications in various fields due to their compact size and coherent light emission. They are used in telecommunications, data storage, medical treatments, displays, barcode scanners, and manufacturing, among other applications.

Laser-based communication involves using laser diodes or infrared devices to transmit voice signals wirelessly through the atmosphere. This technology has the potential to provide high-speed data transmission over long distances with minimal interference.



LASER machining and cutting-industrial applications

Industrial applications of lasers include cutting and welding, as well as marking and engraving. High-powered lasers are used for cutting and welding metals and other materials, making them a standard in industries such as automotive, aerospace, and electronics. Laser marking and engraving provide a permanent and precise solution for product identification and decoration, used in various industries like medical devices, firearms, and jewelry.

Laser cutting is a high-precision CNC thermal process that uses a high-power laser beam to cut, melt, or burn a material sheet. It is ideal for various material types, including metals, wood, and polymers, and is particularly useful for the fabrication of metals due to its high precision, reliability, and smooth finishes.

Laser cutting is a versatile and precise process suitable for various materials and applications. Its advantages include high accuracy, speed, and customization, while its limitations include budget, safety, and thickness constraints. Understanding the process, its components, and its costs is essential for effective use in manufacturing and fabrication.



LIDAR (Light Detection and Ranging)

In place of RADAR (Radio Detection and Ranging), to estimate the size and shape of distant objects or war weapons. The difference between RADAR and LIDAR is that, in the case of RADAR, radio waves are used whereas in the case of LIDAR light is used.

Lidar is a key technology that utilizes lasers for a variety of applications:

Laser Ranging

Lidar uses laser pulses to measure the distance to an object or surface by timing the round-trip of the laser light. This allows for highly accurate 3D mapping and surveying.

Atmospheric Monitoring

Lidar can be used to study the composition and structure of the atmosphere by analyzing the backscattered laser light. This has applications in weather forecasting, air quality monitoring, and climate research.

Autonomous Vehicles

Lidar sensors are crucial for self-driving cars, providing high-resolution 3D data about the

vehicle's surroundings to enable safe navigation and obstacle detection.

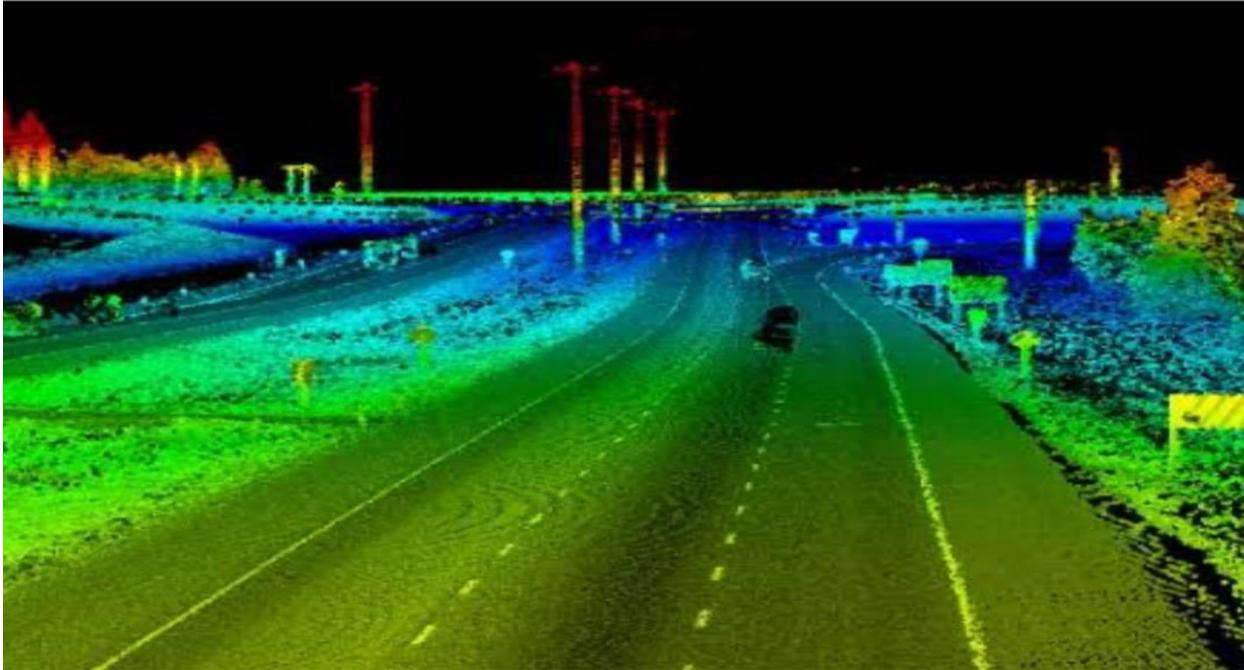
Forestry and Ecology

Airborne lidar systems can map forest canopies, measure biomass, and assess biodiversity, supporting applications in forestry management and ecological research.

Surveying and Mapping

Lidar is widely used for high-precision topographic mapping, creating detailed 3D models of landscapes, buildings, and other structures.

The key advantages of lidar are its ability to rapidly collect accurate 3D data, operate in diverse environments, and provide real-time information. The evolution of laser technology, including the emergence of quantum lidar, continues to expand the capabilities and applications of this versatile remote sensing technique.



Military and Defense

Lasers have numerous applications in military and defense, including calculating distances to targets by measuring the time it takes for a small laser beam to reach them. They are also used to designate targets for smart bombs. Laser guns are used in battle simulations to enhance training and situational awareness.

Underwater communications is another area where lasers are used to replace radio communication, ensuring secure and efficient data exchange between submarines. Directed energy weapons, which deliver concentrated energy to targets, offer precision strike capability with minimal collateral damage.

Laser-targeting systems are used to ensure precise delivery of munitions, reducing collateral damage and enhancing mission success rates. Fiber lasers are utilized for various military applications, including high-power directed energy weapons and target designation. Laser marketing systems are used to provide customization and superior customer service for firearms, optics, and field gear.

Underwater communication is another area where lasers are used to replace radio communication, ensuring secure and efficient data exchange between submarines. Directed energy weapons, which deliver concentrated energy to targets, offer precision strike capabilities with minimal collateral damage. These applications highlight the versatility and precision of lasers in military and defense contexts, enhancing the effectiveness and efficiency of various operations.

Laser weapons are directed-energy weapons that use lasers to inflict damage. They are still in the experimental stage, with several projects being developed and tested. Some notable examples include:

Laser Weapon System (LaWS)

A 30-kW laser weapon system tested on the USS Portland (LPD-27) that can destroy small UAVs and other targets.

HELIOS

A 60-kW laser weapon system is being developed for use on Arleigh Burke-class destroyers, capable of targeting small boats and drones.

Iron Beam

An Israeli anti-missile defense system using lasers to destroy incoming missiles.

Light Blade

An Israeli system deployed as part of the Iron Dome defense system to shoot down balloons.

These laser weapons face challenges such as atmospheric thermal blooming, which can reduce their effectiveness in certain conditions. Additionally, there are concerns about the potential for laser-induced blindness and the ethical implications of using such weapons.

Lasers have numerous applications in military and defense, including:

Range Finders

Calculating distances to targets by measuring the time it takes for a small laser beam to reach them.

Bomb Designation

Designating targets for smart bombs using laser beams, which are detected by sensors on the bombs.

Battle Simulations

Using laser guns to simulate battles, enhancing training and situational awareness.

Underwater Communication

Replacing radio communication underwater, ensuring secure and efficient data exchange between submarines.

Directed Energy Weapons

Delivering concentrated energy to targets, offering precision strike capabilities with minimal collateral damage.

Target Acquisition

Using high-resolution laser targeting systems to ensure precise delivery of munitions, reducing collateral damage and enhancing mission success rates.

Countermeasure Systems

Utilizing fiber lasers for various military applications, including high-power directed energy weapons and target designation.

Laser Marking

Providing laser marking systems for firearms, optics, and field gear, offering customization and superior customer service.

These applications highlight the versatility and precision of lasers in military and defense contexts, enhancing the effectiveness and efficiency of various operations.

Meteorology and geophysical applications

Laser technology plays a crucial role in both meteorology and geophysics. In meteorology, lasers are used for remote sensing and atmospheric monitoring. Atmospheric lidar systems, for instance, employ laser light to study atmospheric properties from the ground up to the top of

the atmosphere. Elastic-backscatter lidars are used to derive temperature profiles from the upper atmosphere, while multi-wavelength elastic-Raman lidar systems can extract microphysical properties of aerosols, such as their size distribution and refractive index. In geophysics, lasers are used for non-invasive observation of processes in the atmosphere and subsurface. Techniques like radar and laser technology, along with satellites, allow for the measurement and characterization of the earth's physical states and phenomena. This information is then used to model and forecast meteorological and geophysical phenomena. The applications of laser technology in both fields include:

Atmospheric Temperature Measurement

Laser-based systems can measure temperature profiles in the upper atmosphere, which is essential for understanding atmospheric dynamics and climate modeling.

Aerosol Characterization

Laser-based systems can extract microphysical properties of aerosols, such as their size distribution and refractive index, which is crucial for understanding their impact on climate.

Remote Sensing

Laser technology enables remote sensing of atmospheric and subsurface processes, allowing for non-invasive observation and monitoring of these phenomena.

Overall, laser technology is a vital tool in both meteorology and geophysics, enabling researchers to study and understand the complex interactions within the Earth system.

LASER imaging and holography

Laser imaging and holographic techniques use coherent light to record and reconstruct three-dimensional images.

Basic Principles of Holography

Holography records the interference pattern between light diffracted by an object and a reference beam, capturing both amplitude and phase information.

This allows for the reconstruction of a three-dimensional image with depth cues like parallax and perspective.

Continuous-Wave Laser Holography

A laser beam is split into two parts: an object beam that illuminates the subject and a reference beam that interacts with the object beam on a photographic plate.

The interference pattern recorded on the plate contains information about the phase and amplitude of the light waves, allowing for the reconstruction of a three-dimensional image.

Types of Holography

Electron Holography: uses electron waves instead of light waves to improve the resolution and avoid aberrations in transmission electron microscopy.

Acoustic Holography: generates sound maps of objects by measuring the acoustic field at multiple points.

Atomic Holography: uses atomic mirrors and Fresnel diffraction lenses to create holograms of atomic beams.

Neutron Beam Holography: uses neutron beams to see inside solid objects.

X-ray Holography: uses synchrotrons or x-ray free-electron lasers to generate holograms with higher spatial resolution.

Applications of Holography

Holography has various applications, including data storage, microscopy, and interferometry. It can also be used to measure stress, strain, and vibration in engineering structures, and to visualize fluid flow and radiation dosimetry.

Computer-Generated Holograms

These holograms are created digitally by modeling and combining two wave fronts to generate an interference pattern image.

They can be printed onto a mask or film and illuminated with an appropriate light source to reconstruct the desired wave front.

These techniques have revolutionized the field of imaging and have many practical applications across various disciplines.

Healthcare and aesthetics

LASER medicine is the use of lasers in medical diagnosis, treatments, surgeries, and therapies. Examples include laser photodynamic therapy, photorejuvenation, and laser surgery. Lasers are

used in procedures such as angioplasty, cancer treatment, dermatology (e.g. scar revision, skin resurfacing, laser hair removal, tattoo removal), ophthalmology (e.g. LASIK, laser photocoagulation), lithotripsy, and more.

In the aesthetic industry, lasers have revolutionized treatments by offering more precise and effective options with less downtime. Lasers can be used for skin resurfacing, rejuvenation, treating vascular lesions, removing unwanted hair and fat, and more. Advancements in laser technology have enabled treatments on a wider range of skin types with better safety and efficacy.

Lasers have revolutionized surgery by offering minimally invasive procedures with reduced bleeding and faster recovery times. They are used in various fields such as:

Eye surgeries (LASIK)

Lasers are used to reshape the cornea, improving vision in patients with refractive errors.

Dermatology

Lasers are used for skin treatments, such as removing tattoos, hair removal, and skin resurfacing.

Dentistry

Lasers are used for dental procedures like cavity removal, gum reshaping, and teeth whitening.

Cancer treatments

Lasers are used to destroy cancer cells and tumors, reducing the need for invasive surgery and improving patient outcomes

Medical Imaging

Lasers play a crucial role in medical imaging techniques such as:

LASER-induced fluorescence

This technique uses laser light to excite fluorescent molecules in tissues, helping to diagnose diseases like cancer.

Confocal microscopy

This technique uses laser light to create high-resolution images of tissues, allowing for detailed analysis of cellular structures.

Optical Coherence Tomography (OCT)

This technique uses laser light to create detailed cross-sectional images of tissues, helping to diagnose and monitor diseases like diabetes and cancer.

Angioplasty

Lasers are used to open blocked blood vessels and restore blood flow.

Cancer diagnosis

Lasers are used to detect and diagnose cancer by analyzing the light reflected from tissues.

Dermatology

Lasers are used to treat various skin conditions, such as acne, rosacea, and psoriasis.

Gastroenterology

Lasers are used to treat gastrointestinal conditions like bleeding ulcers and polyps.

Ophthalmology

Lasers are used to treat various eye conditions, such as cataracts, glaucoma, and age-related macular degeneration.

These applications highlight the significant impact lasers have on medical practices, offering precise and minimally invasive treatments for a wide range of conditions.

FUTURE ADVANCES

High-Power Diodes

Startups and innovative companies are optimizing laser performance using high-power diodes. These diodes enhance efficiency and enable applications in manufacturing and data acquisition

Hybrid LASERs

Hybrid LASER systems combine different laser sources (such as fiber lasers and solid-state lasers) to achieve superior performance. They find applications in precision cutting, welding, and additive manufacturing.

Microlasers

Microlasers are miniaturized laser devices that offer high precision and can be integrated into compact systems. They have potential in medical diagnostics, telecommunications, and sensors.

Quantum LASERs

Quantum LASER leverages quantum effects for improved performance. They promise breakthroughs in secure communication, quantum computing, and sensing applications.

LASER-Enabled 3D Printing

Advances in LASER-based 3D printing allow for faster, more precise additive manufacturing. This technology is transforming industries like aerospace and healthcare.

LASER Communication

LASER-based communication systems enable high-speed data transfer between satellites and ground stations. They play a crucial role in space exploration and global connectivity.

LiDAR Technology

LiDAR (Light Detection and Ranging) uses laser light to create high-resolution 3D maps. It's essential for autonomous vehicles, environmental monitoring, and urban planning.

[4] CONCLUSION

LASER emerged as a versatile and highly concentrated form of energy and an enlightening source of many past researches. It proved to be one of the most powerful tools for medical surgeries and imaging, having enormous usage in weaponry and warfare. It has tightened security in security alarms. It creates holographic effects in cinema and helps in creating beautiful images. It makes communication easier by the use of laser diodes in optical fibers. It is used in everyday scanning of barcodes to obtain information about the product or show information. LiDAR improved our ranging and detecting, making it more efficient in place of RADAR.

Moreover, future advances in LASER technology will continue to improve our lives and modernize the industries we depend upon and the world around us.

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