

Analysis of Optical Communications, Fiber Optics, Sensors and Laser Applications

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Abstract – The fields of optical communications, fiber optics, and sensors and laser applications have undergone significant evolution, revolutionizing the way we transmit and receive data and having a profound impact on various industries. With ongoing advancements and research, these fields hold immense potential for future developments. In-depth information on optical communications, fiber optics, and sensors may be found in this study. The constraints and limits of optical communications as well as the qualities of optical fibers and the many kinds of optical fibers utilized in optical communications are discussed. Additionally, it also covers the use of fiber optics in sensing applications, different types of fiber-optic sensors, and recent developments and future trends in the field. The article provides a comprehensive overview of the current state of the field, highlighting the significance of technology and its impact on various industries. The article also aims to give readers a better understanding of the current state of the field and its potential for future developments.

Keywords – Optical Communications, Fiber Optics, Sensors, Laser Applications, Fiber Bragg Gratings.

I. INTRODUCTION

Optical communications, fibre optics, and sensors are interrelated fields that have greatly impacted the way we transmit and receive data today. fibre optics is the use of plastic or glass threads to direct and transmit light signals, and is a subset of optical communication systems, which use light to transport information. Sensors, on the other hand, are devices that detect and respond to physical or chemical changes in the environment. The field of optical communications has its roots in the early 19th century, with the invention of the telegraph and the telephone. The first telegraphs used electrical signals to transmit information, but it was soon realized that light could also be used for this purpose. In the 1920s, Alexander Graham Bell proposed the use of light to transmit information, which laid the foundation for the development of optical communications. The first optical communications systems were based on the usage of light-emitting diodes (LEDs) and photodiodes to transmit and receive signals. However, these systems had a limited range and were prone to interference. The invention of optical fibre in the 1970s by Corning Glass Works revolutionized the field of optical communications by providing a reliable and efficient means of transmitting data over long distances.

Today, fibre optics is the backbone of modern telecommunications systems, providing high-speed and high-bandwidth data transmission [1]. The use of fibre optics has led to the development of many new technologies and applications, including the internet, data centres, and cloud computing. New modulation methods and wavelength-division multiplexing (WDM) are expanding the capabilities of optical communications via fibre-optic lines. The field of fibre-optic sensors has also seen significant growth in recent years, with applications in various fields such as medicine, industrial process control, and environmental monitoring. Using fibre optics in sensors enables long-distance detection, increased sensitivity, and protection against electromagnetic noise.

This study aims to give a comprehensive review of the literature on optical communications, fibre optics, and sensors. This article will discuss the benefits and drawbacks of optical communications, as well as the characteristics of optical fibres and the many kinds of optical fibres, modulation methods used in fibre-optic communications, and other related topics. It will also discuss the many kinds of fibre-optic sensors now available, as well as recent innovations and anticipated advances in this area. This study article is confined to topics in optical communications, fibre optics, and sensors. It will not cover other related fields such as laser technology or photonics. The article will provide a comprehensive overview of the current state of the field, with an emphasis on recent developments and future trends.

Optical communications, fibre optics, and sensors have revolutionized the way we transmit and receive data today and have significant impact in various industries. The field continues to evolve and has a lot of potential for future developments. This research article aims to provide an in-depth analysis of the field and its recent developments to give a better understanding of the current state of the field.

This article has been organized as follows: Section II provides a discussion of optical communications, where specific details provided: (i) how optical signals are transmitted and received; (ii) discussion of different types of optical fibres and their properties; (iii) analysis of various modulation techniques used in optical communications; and (iv) examination of the challenges and limitations of optical communications. Section III discusses fibre optics and sensors, with details provided: (i) explanation of how fibre optics is used in sensing applications; (ii) discussion of different types of fibre optic sensors and their properties; (iii) analysis of the advantages and disadvantages of fibre optic sensors compared to traditional sensors; and, (iv) examination of recent developments and future trends in fibre optics and sensors. Section IV focuses on the laser application, discussing: (i) explanation of different types of lasers and their properties; (ii) discussion of the main applications of lasers in various fields, such as medicine, industry, and telecommunications; (iii) analysis of the challenges and limitations of laser technology; and (iv) examination of recent developments and future trends in laser applications. Lastly, Section V draws final remarks to the paper and recommends future research.

II. OPTICAL COMMUNICATIONS

Explanation of how optical signals are transmitted and received

According to [2], communication by light is referred to as optical signals. Telecom, fibre optics, and lasers are just few of the many technologies that rely on these signals. The generation of a light source, like a laser or an LED, is the first step in the process of conveying an optical signal. Information may then be sent by altering this light source. For example, in a telecommunications system, the data being transmitted is converted into a stream of ones and zeros, and then encoded onto the light signal using a technique called intensity modulation.

A narrow strand of either plastic or glass called an optical fibre carries the controlled light signal across vast distances. The optical fibre is made up of a core, which is the part of the fibre that carries the light, and a cladding, which surrounds the core and keeps the light from escaping. The core and cladding have different refractive indices, which cause the light to bend, or refract, as it travels through the fibre. This allows the light to travel for many kilometres without losing much of its power.

Table 1. Types of Optical Fibres

Single-mode fibre [3]	The core width of single-mode fibres is generally between 8 and 10 microns. This small core size allows for the transmission of only one mode of light, which allows for a higher bandwidth and longer transmission distances. Submarine cables and high-speed broadband internet are two examples of the kinds of applications that make use of single-mode fibres for long-distance information and communications transmission at high speeds.
Multimode fibres [4]	Multimode fibres have a larger core diameter, typically around 50 to 100 microns. This larger core size allows for the transmission of multiple modes of light, which increases the capacity for data transmission but also limits the distance over which the signal can travel. Short-distance communications systems, such as those found in home systems or LANs, often use multimode fibres (LANs).
Polarization-maintaining fibre (PMF) [5]	Due to their unique construction, PMF fibres are able to preserve the orientation of the different wavelengths, even across great distances. This makes them useful in applications where the polarization of the light is important, such as in fibre-optic gyroscopes and interferometry.
Photonic crystal fibre (PCF) [6]	PCF fibres have a unique structure that allows for the manipulation of the properties of the light being transmitted. They have the potential to increase the capacity for data transmission, improve signal strength, and increase the distance over which signals can travel. PCF fibres are still in research and development phase.
Specialty fibres [7]	Erbium-doped fibre amplifiers (EDFAs) are fibres that are doped with the rare-earth element erbium, which amplifies the light signal as it travels through the fibre. Raman amplifiers, on the other hand, use the Raman scattering effect to amplify light signals. Both types of amplifiers are used to boost the power of signals transmitted over long distances.

A photodetector is used to turn an optical signal directly into an electromagnetic output that can be read by electronics after it has arrived at its destination. The most common types of photodetectors are photodiodes and photo transistors. Photodiodes are semiconductor devices that convert light into an electrical current. Phototransistors are similar to photodiodes but they have an additional transistor that can amplify the electrical current generated by the detector.

Oscillating a light source like a laser or LED and passing the resulting signal via an optical cable is how optical communications are conveyed. A photodetector then processes the incoming signal and turns it into an electrical output

that can be read by other electronics. This technology has many advantages like high bandwidth, high security and immunity from electromagnetic interference. This technology is widely used in telecommunications, internet and data transfer, and other fields.

Discussion of different types of optical fibers and their properties

In order to send light across great distances, we make use of something called an optical fibre, which is a tiny strand of glass or plastic. They are an important technology in telecommunications and data transfer, as they can transmit large amounts of data at high speeds with minimal loss of signal strength. There are several types of optical fibres, each with their own unique properties and advantages (in **Table 1**).

Optical fibres are an important technology in telecommunications and data transfer. Each type of optical fibre has its own unique properties and advantages, making them suitable for different applications. Single-mode fibres are best for long-distance telecommunications, multimode fibres are best for shorter distance applications, PMF fibres are best for applications where polarization is important, PCF fibres are best for applications where manipulation of light properties is important and EDFAs and Raman amplifiers are best for boosting signal power over long distances.

Analysis of various modulation techniques used in optical communications

For transmission across an optical fibre, data is modulated onto an optic carrier frequency. Among the most typical forms of modulation are (in **Table 2**):

Table 2. Modulation Techniques Used in Optical Communications	
Amplitude modulation (AM) [8]	In amplitude modulation, the information signal is represented by a change in the intensity of the optic carrier frequency.
Phase modulation (PM) [9]	To represent the data signal, PM shifts the amplitude of the optic carrier frequency.
Frequency modulation (FM) [10]	In FM, the data signal is represented by a shift in the wavelength of the optic carrier frequency.
Quadrature amplitude modulation (QAM) [11]	In QAM, both the magnitude and the phases of the optic carrier frequency are modulated to convey the information signal, making it a hybrid of amplitude modulation and phase modulation.
On-off keying (OOK) [12]	In OOK, the binary data signal is represented by the on/off state of the optic carrier frequency.
Pulse-position modulation (PPM) [13]	In pulse position modulation (PPM), the data signal is represented by shifting the location of a waveform within a constant time period.
Pulse-code modulation (PCM) [14]	To create a digital signal, PCM takes periodic samples of the intensity of the optic carrier frequency and quantizes and encodes them.
Differential phase-shift keying (DPSK) [15]	In DPSK, the data signal is represented by a phase change in the optic carrier frequency. It is commonly used in wavelength-division multiplexing (WDM) systems.
Differential quadrature phase-shift keying (DQPSK) [16]	DQPSK is a variant of DPSK that uses quadrature phase modulation to encode two bits of data per symbol. This increases the data rate but also increases the complexity of the receiver.
Orthogonal frequency-division multiplexing (OFDM) [17]	For data transmission, OFDM uses a large amount of frequency band that are tightly spaced. This allows for a high data rate and is resistant to channel impairments such as dispersion and attenuation.
Spectral amplitude coding (SAC) [18]	The program in SAC is a series of optical pulses that modulates the intensity of the optic carrier frequency. There is a predetermined autocorrelation function included into the coding that facilitates signal identification at the receiver.
Spectral phase coding (SPC) [19]	In SAC, a coding, which is a series of optical pulses, modulates the intensity of the optic carrier signal. One of the goals of the code was to create a particular correlation function that would make signal recognition straightforward at the receivers.

In summary, there are various modulation techniques used in optical communications, each with their own advantages and disadvantages. The choice of modulation technique depends on the specific requirements of the communication system, such as data rate, transmission distance, and channel impairments. Each of these modulation techniques has its own advantages and disadvantages, depending on the specific application and the requirements of the communication system.

Examination of the challenges and limitations of optical communications Challenges

Data may be sent from one location to another by means of optical communications, commonly known as fibre-optic transmission. This technology has revolutionized the way we communicate, as it allows for faster data transfer and higher bandwidth compared to traditional copper wire-based systems. However, despite its many advantages, optical communication also comes with its own set of challenges and limitations. One of the main challenges of optical communication is the attenuation of the signal as it travels through the optical fibre [27]. Attenuation is the decrease in the power of a signal as it travels through the medium, and in optical communication, it can be caused by various factors, such as absorption of light by impurities in the fibre, scattering of light due to imperfections in the fibre, and bending loss caused by the curvature of the fibre. To overcome this, optical amplifiers are often used to boost the signal, but these can be costly and introduce noise into the system, which can negatively impact signal quality.

Distortion of the signal is another difficulty caused by the optical fiber's ability to transmit light of various wavelengths at different speeds. Due to the signal's dispersion and distortion, this might make detection challenging. Both the index of refraction of the fibre changing with wavelength and the varying speeds at which the multiple variants of light pass through it may contribute to dispersion. One solution is to utilize dispersion-compensation fibres, which slow down the slower wavelengths, or wavelength division multiplexing (WDM) [20], which uses physical separation of the wavelengths to lessen the effect of dispersion. The fragility of the optical fibres themselves is another limitation of optical communication. These fibres are made of glass or plastic and can be easily damaged by bending, crushing, or exposure to high temperatures. This makes them vulnerable to physical damage and can lead to costly repairs or system downtime. This fragility can also make it difficult to install and maintain the fibre-optic networks. Finally, there is the issue of security, as optical communication systems are vulnerable to tapping or eavesdropping. This can be mitigated by using encryption methods, but these add complexity and cost to the system. Additionally, it's difficult to detect any unauthorized access to the system, which further increases the risk of security breaches.

Limitations

While optical communication offers many benefits, it also comes with its own set of challenges and limitations. These include attenuation, dispersion, fragility, and security. Researchers and engineers continue to work on developing new technologies to mitigate these limitations and make optical communication even more reliable, secure, and cost-effective. Another limitation of optical communication is the limited distance over which it can transmit the signal. The signal strength decreases as it travels through the optical fibre, and after a certain distance, it becomes too weak to be detected. This is known as the optical signal-to-noise ratio (OSNR) threshold [21], and it limits the maximum distance over which an optical signal can be transmitted without the need for signal amplification. Optical multipliers or transceivers may be employed to improve the transmission range, although doing so raises both the price and the system's complexity.

Another limitation is the cost of implementing an optical communication system. While the cost of optical fibres and components have decreased over time, the initial investment and installation cost of a fibre-optic network can still be high, particularly in cases where the network needs to be installed over a long distance or in remote areas. Additionally, the maintenance and upkeep of the fibre-optic network can also be costly, as it requires specialized equipment and trained personnel. Finally, there is the issue of inter-operability, as different systems, components and vendors may not be compatible with each other. This can cause problems when trying to connect different systems or expand an existing network, and can lead to costly and time-consuming integration efforts [28].

In addition to these limitations, there are also environmental issues that can affect the performance of optical communication systems. For example, temperature changes, humidity, and exposure to saltwater can affect the performance of optical fibres and components, and can lead to system failures. Optical communication offers many advantages over traditional forms of communication, but it also comes with its own set of challenges and limitations. These include attenuation, dispersion, fragility, security, limited distance, cost, inter-operability and environmental challenges. Despite these challenges, researchers and engineers continue to work on developing new technologies and solutions to overcome these limitations and make optical communication even more reliable, secure, and cost-effective.

III. FIBER OPTICS AND SENSORS

Explanation of how fiber optics is used in sensing applications

Transmission of light over great distances is made possible by fibre optics, a technique that employs thin, flexible fibres made of glass or plastic. In sensing applications, fibre optics can be used to detect changes in temperature, pressure, strain, and other physical parameters. One of the most common ways fibre optics is used in sensing applications is through the use of fibre Bragg gratings (FBGs) [22]. FBGs are tiny structures inscribed onto the core of a fibre optic cable that reflect a specific wavelength of light back to the source. When the physical parameter being measured changes, it causes a shift in the wavelength of light that is reflected back, which can be detected and used to determine the value of the parameter. FBGs are widely used in a variety of sensing applications, such as temperature sensing, strain sensing, and pressure sensing. In temperature sensing, for example, an FBG can be used to detect changes in temperature along a fibre optic

cable, making it useful for monitoring temperature in industrial processes or in areas where traditional temperature sensors would be difficult to install.

Another way fibre optics is used in sensing applications is through the use of interferometry. In this technique, light is sent through a fibre optic cable and then split into two paths, one of which passes through the area being measured. The light from the two paths is then recombined and the interference pattern that is created is analysed to determine the value of the parameter being measured. This technique can be used to measure changes in strain, displacement, and other physical parameters. fibre optics also has advantages over traditional sensing methods such as electrical sensors, including immunity to electromagnetic interference, high resistance to harsh environment, and long distance transmission capabilities.

fibre optic sensors are also used in the field of biomedical engineering, specifically in the development of medical devices and instruments. For example, fibre optics can be used to measure blood flow, oxygenation, and other physiological parameters in the human body. This type of sensing is often referred to as "optical biopsy" and it is non-invasive, meaning it does not require the insertion of a probe or sensor into the body. Structural health monitoring (SHM) is another area where fibre optics may be put to use. fibre optic sensors are implanted in bridges, buildings, and airplanes to monitor their state and identify any deterioration or damage. By using fibre optics, engineers can detect changes in strain, temperature, and other physical parameters that may indicate the presence of a defect or damage. The monitoring and control of industrial processes also make use of fibre optic sensors. Temperatures, pressure, and rate of flow are just some of the variables that sensors using fibre optics can track and adjust throughout production. This allows manufacturers to optimize their processes and improve efficiency, while also reducing costs and minimizing waste. In addition, fibre optics are used in oil and gas exploration, mining, and other industrial applications. For example, they can be used to detect leaks in pipelines, to measure the level of oil in tanks, or to monitor the condition of drilling equipment.

In summary, fibre optics is a versatile technology that is widely used in sensing applications. It has many advantages over traditional sensing methods, including immunity to electromagnetic interference, high resistance to harsh environments, and long-distance transmission capabilities. These properties make fibre optics a valuable tool in various industries such as biomedical engineering, structural health monitoring, industrial process control, and monitoring, oil and gas exploration, mining, and many more. fibre optics is a versatile technology that is widely used in sensing applications. By using techniques such as fibre Bragg gratings and interferometry, fibre optics can be used to detect changes in temperature, pressure, strain, and other physical parameters with high accuracy and over long distances. Its unique properties such as immunity to electromagnetic interference, high resistance to harsh environment, and long distance transmission capabilities makes it a valuable tool in various industries.

Discussion of different types of fiber optic sensors and their properties

One form of sensor is the fibre optic sensor, which utilizes light to collect data on a wide range of physical quantities including temperatures, pressure, stress, and deformation. These sensors are becoming increasingly popular in various industries due to their high accuracy, immunity to electromagnetic interference, and ability to transmit signals over long distances. **Table 3** shows some of the different forms of fibre optic sensors and their properties:

Table 3. Different Forms of Fibre Optic Sensors	
fibre Bragg Grating (FBG) sensors [23]	These are: (i) Tiny structures inscribed onto the core of a fibre optic cable, which reflect a specific wavelength of light back to the source. (ii) Detect changes in physical parameters by measuring shift in the wavelength of light that is reflected back. (iii) Widely used in temperature sensing, strain sensing, and pressure sensing.
Interferometric sensors [24]	These: (i) Use the principle of interferometry to measure changes in physical parameters. (ii) Split light into two paths, one passing through the area being measured, and recombine them to analyse the interference pattern to determine the value of the parameter. (iii) Often used to measure changes in strain, displacement, and other physical parameters.
Extrinsic and intrinsic sensors [25]	(i) Extrinsic sensors use a separate element, such as a reflector, to modulate the light penetrating the fibre. (ii) Intrinsic sensors rely on the properties of the fibre itself to modulate the light passing through it.
Light source-based sensors [26]	(i) Different types of light sources used in fibre optic sensors include infrared, visible, and ultraviolet light. (ii) Each type of light source has its own advantages and disadvantages. For example, infrared light is often used for temperature sensing because it can penetrate through materials, while visible light is often used for displacement sensing because it is easily visible to the human eye.

fibre optic sensors are a versatile technology that can be used to measure various physical parameters with high accuracy, immunity to electromagnetic interference, and long-distance transmission capabilities. Different types of fibre optic

sensors are available to suit different applications and requirements. This includes FBG sensors, interferometric sensors, extrinsic and intrinsic sensors, and light source-based sensors.

Analysis of the advantages and disadvantages of fiber optic sensors compared to traditional sensors

fibre optic sensors have become increasingly popular in various industries due to their high accuracy, immunity to electromagnetic interference, and ability to transmit signals over long distances. One of the main advantages of fibre optic sensors associated to traditional sensors is their immunity to electromagnetic interference (EMI). Because of this, fibre optic sensors do not suffer from the same faults or inefficiencies that conventional sensors do when exposed to electromagnetic waves. This makes fibre optic sensors ideal for use in environments with high levels of EMI, such as near electrical equipment or in areas with high radio frequency interference. fibre optic sensors also have a high resistance to harsh environments. They are resistant to extreme temperatures, pressure, and chemicals, which makes them suitable for use in a wide range of industrial and extreme environments. Additionally, fibre optic sensors are non-conductive and can be used in explosive or high-energy environments without risk of sparking or explosions.

Another advantage of fibre optic sensors is their ability to transmit signals over long distances. Traditional sensors often require a wired connection to transmit signals, which can be limiting in terms of the distance between the sensors and the monitoring or control system. fibre optic sensors, on the other hand, can transmit signals over several kilometres without significant loss of signal strength or accuracy. fibre optic sensors also have a higher accuracy and resolution compared to traditional sensors. This is because they are able to detect small changes in physical parameters, which allows for more precise measurements.

Another advantage of fibre optic sensors is their small size and lightweight, which makes them easy to install in tight spaces or in areas with limited access. They are also flexible and can be bent and twisted to fit into tight spaces. This makes them an ideal choice for applications such as structural health monitoring, where sensors need to be placed in hard-to-reach areas of a structure. It is possible to multiplex fibre optic sensors, allowing for the use of a single optic fibre cable to house a network of sensors. This makes it possible to detect numerous parameters—including temperatures, pressure, and stress a single fibre at once. This can save costs and space, and also increase the efficiency of data collection.

Although fibre optic sensors have numerous benefits, they do have some drawbacks as well. Installation and upkeep costs are a major drawback. Some businesses may be put off by the higher initial and ongoing costs associated with fibre optic sensors. fibre optic sensors are more complex than traditional sensors, and as a result, technicians who possess the necessary expertise and sophisticated equipment are harder to come by. Another disadvantage is that fibre optic sensors can be more fragile than traditional sensors. The thin, flexible glass or plastic fibres that make up the sensor are more susceptible to damage than traditional sensors, which can affect their accuracy or even render them inoperable.

fibre optic sensors have many advantages over traditional sensors, including immunity to electromagnetic interference, high resistance to harsh environments, long-distance signal transmission, and high accuracy and resolution. However, they also have some disadvantages, such as higher cost of installation and maintenance, and fragility. When considering the use of fibre optical sensors, it is important to weigh the advantages and disadvantages and determine whether the benefits outweigh the costs for a particular application. In addition to the cost, another disadvantage of fibre optic sensors is that they require specialized equipment to read and interpret the signals they produce. This equipment can be expensive and may require specialized training to operate. This makes it more difficult for some organizations to adopt fibre optic sensors. Another disadvantage is that fibre optic sensors are sensitive to bending, twisting and external stress, which can cause them to break or malfunction. This can be a problem in harsh or industrial environments where the sensors are subject to high vibration, or in areas where the sensors are likely to be damaged by impact.

Examination of recent developments and future trends in fiber optics and sensors

Significant progress has been made thanks to recent breakthroughs in fibre optics and sensors, and various areas of advancement and research are expected to determine the direction of these technologies. One of the most significant recent developments in fibre optics is the use of photonics for data transmission. Photonics, which is the science of harnessing light to transmit information, has the potential to significantly increase the speed and capacity of data transmission. This is particularly relevant in today's digital age, where the demand for high-speed internet and data storage is constantly growing.

Micro- and nano-fibre optics have also contributed significantly to the advancement of the fibre optics industry. These tiny fibres, which are smaller than traditional fibres, have a number of advantages over larger fibres. They are more flexible, can bend and twist more easily, and can be used in a wider range of applications. This has led to an increase in the use of micro- and nano-fibres in biomedical applications, such as in optical biopsy and in the development of medical devices. In the field of sensors, recent developments have focused on the use of smart sensors. Smart sensors are sensors that are equipped with on-board communication and processing capabilities, which allows them to perform more complex tasks and to communicate with other devices. This has prompted the creation of increasingly sophisticated sensor systems with broad potential uses, such as the surveillance of industrial operations or the surveillance of patients' condition.

fibre optic and sensors are two technologies that are projected to undergo significant future development. For example, research is ongoing to improve the sensitivity and accuracy of fibre optic sensors, which will enable them to be used in a wider range of applications. As a result of the need for constant monitoring of physical characteristics in real time, there is

a rising interest in the creation of fibre optic sensors that may be incorporated into other technologies, such as telephones and wearables. The incorporation of artificial intelligence (AI) and machine learning algorithms is another development that has the potential to impact the development of fibre optics and sensors in the future. By using these technologies, it will be possible to analyse the large amounts of data generated by fibre optic sensors and to extract useful information more efficiently. This will lead to the development of more advanced sensor systems that are capable of performing more complex tasks, such as predicting failures and identifying patterns.

In sum, recent developments and future trends in fibre optics and sensors are likely to shape the technology to be more sensitive, accurate and efficient. The integration of AI and machine learning algorithms and the development of smart sensors will enable to extract more useful information from the data generated by the sensors. This will result in the creation of more sophisticated sensor systems, which may be put to use in fields as diverse as industrial monitoring and patient health screening.

IV. LASER APPLICATIONS

Explanation of different types of lasers and their properties

Known formally as light-amplification-by-stimulated-emission-of-radiation (laser) devices, these flashlights produce a narrow, intense beam of illumination. They have several uses, ranging from basic fabrication tasks like cutting and welding to more complex ones like measuring distances and even medical operations. There are many different types of lasers, each with their own unique properties and advantages (in **Table 4**).

Gas Lasers	Gas lasers use a mixture of gases, such as helium and neon, to generate laser light. These lasers are often used for cutting and welding materials, as well as for measuring distances and performing scientific experiments. They are also commonly used in medical applications, such as in laser surgery.
Solid-State Lasers	To create laser light, solid-state laser beams employ a solid medium, such a crystalline or glass. These lasers are often used in industrial applications, such as in laser cutting and welding, as well as in scientific research. They are also used in medical applications, such as in laser therapy and dental procedures.
Semiconductor Lasers	Semiconductor lasers use a semiconductor material, such as a diode, to generate laser light. As they are both small and effective, they find widespread usage in fields as diverse as communications, data storage, and laser engraving.
Excimer Laser	This type of laser uses a mixture of gases such as xenon and chlorine to generate laser light. These lasers emit ultraviolet light, which is useful for a variety of use cases e.g., microfabrication, laser micromachining, and laser ablation.
Fibre Laser	This type uses a doped optical fibre to generate laser light. They are used in different industrial, scientific, and medical applications, such as cutting, welding, marking, engraving, and medical procedures. They are also known for their high efficiency and low maintenance.

Discussion of the main applications of lasers in various fields, such as medicine, industry, and telecommunications

Lasers or Light Amplification by Stimulated Emission of Radiation are used in various fields, such as medicine, industry, and telecommunications. One of the main applications of lasers in medicine is in laser surgery. Lasers are used in a wide range of surgical procedures, such as ophthalmology, dermatology, and general surgery. They are used to cut and vaporize tissue, as well as to seal blood vessels and nerves. This results in less bleeding, less pain and faster recovery time for the patients. In addition, lasers are also used in non-surgical procedures such as laser therapy and laser dentistry.

In the field of industry, lasers are widely used for cutting, welding, and marking materials. They are used to cut different materials, e.g., metal, plastic, and wood, and are highly precise and efficient. They are also used for welding and bonding materials, which results in a stronger, more precise weld. In the manufacturing of electronics and automobiles, for example, lasers are used to engrave serial numbers and other forms of identification into the components using the products' unique identifying materials. Lasers are used to send information across great distances in the field of telecommunications. Data is sent by a beam of light via a fibre optic cable; this technology is known as fibre optics. To transmit data quickly and across great distances, fibre optics is a crucial component of the telecommunications infrastructure. The internet, television, and phone services are just some of the many places this technology is put to use.

In addition to these main applications, lasers are also used in scientific research, such as in spectroscopy and microscopy, as well as in entertainment, such as in laser shows and lighting effects. They are also used in military and security applications, such as range finding, target designation and illumination. In the field of medicine, research is ongoing to develop new laser-based treatments for a wide range of medical conditions, such as cancer and heart disease. In industry, research is focused on developing new laser-based manufacturing techniques that are more efficient, precise and

cost-effective. In telecommunications, research is focused on developing new fibre optic technologies that can support even higher data transmission speeds and longer distances.

In addition, lasers are also being developed for new and emerging applications such as autonomous vehicles, drones, and robotics. The high precision and accuracy of lasers make them ideal for use in navigation and control systems for these types of vehicles. It's conceivable that lasers' already significant influence in a broad variety of disciplines and applications will become much larger in the years to come. Their unique properties and advantages make them a versatile and powerful tool that will continue to be developed and improved upon to meet the ever-growing demand for more advanced technologies. Another important field where lasers are used is in environmental monitoring. Lasers can be used for remote sensing, which allows for the detection and measurement of pollutants, gases, and other environmental factors from a distance. They can also be used for atmospheric sensing, which allows for the measurement of factors such as temperature, humidity, and wind speed.

In addition, laser-based technologies are also being developed for use in the field of renewable energy. For example, lasers are used in the production of solar cells, which convert sunlight into electricity. They are also used in the production of wind turbines, which generate electricity from the wind. Another field where laser technology is increasingly being used is in the field of 3D printing. Lasers are used to fuse together layers of powdered materials to create three-dimensional objects. This allows for the rapid production of complex and customized parts, which can be used in a wide range of industries. Lasers are also used in the field of security and surveillance. They can be used for surveillance of large areas, such as borders or ports, and can also be used to detect and track targets. They are also used in the field of identification, such as in biometric systems, which use lasers to scan and identify fingerprints, irises, and faces.

The applications of lasers are numerous and diverse. They are used in various fields such as medicine, industry, telecommunications, environmental monitoring, renewable energy, 3D printing, security and surveillance. Their versatility and precision make them an important tool in a wide range of applications, and research and development in laser technology is ongoing to improve and expand their capabilities. The future of laser technology is expected to have a significant impact in many fields, and new applications are likely to be discovered in the future.

Analysis of the challenges and limitations of laser technology

Light Amplification by Stimulated Emission of Radiation (LaSER) technology is a strong and flexible instrument with many uses in fields as diverse as health, manufacturing, telecommunications, and surveillance systems. However, like any technology, laser technology also has its own set of challenges and limitations (in **Table 5**).

Table 5. Challenges and Limitations of the Laser Technology	
Safety	Lasers can be dangerous if not handled properly, as they emit powerful beams of light that can cause eye damage or burns. This is particularly true for high-power lasers, which are used in industrial and medical applications. To ensure safety, proper precautions such as protective eyewear and barriers must be taken when working with lasers.
Cost	The development and manufacture of laser systems can be expensive, and the cost of these systems can be a barrier for some organizations. Additionally, the cost of maintaining and repairing laser systems can also be high.
Heat	Lasers produce heat when they are used, and this can cause problems in some applications. For example, in laser welding, the heat generated by the laser can cause the material being welded to warp or melt. This can cause problems with the accuracy and precision of the weld.
Sensitivity to environmental factors	Due to these conditions (humidity, vibration, and temperature), the laser's effectiveness may suffer, leading to inaccurate assessments or cuts. This can be a problem in harsh or industrial environments where the lasers are subject to high vibration or where the temperature is not controlled.
Accuracy and precision	Factors such as the shape and alignment of the beam can affect the accuracy and precision of the measurements or cuts, which can cause errors or inconsistencies.

There are various uses for laser technology due to its many benefits, however, it also has its own set of challenges and limitations. Safety, cost, heat, environmental factors and beam quality are some of the main challenges and limitations of laser technology. To overcome these challenges and limitations, organizations must take proper precautions and invest in high-quality equipment that is designed to withstand harsh environments and maintain accurate measurements and cuts. Additionally, research and development in laser technology is ongoing to improve and expand its capabilities and overcome these challenges.

Examination of recent developments and future trends in laser applications

Laser technology, or Light Amplification by Stimulated Emission of Radiation, has come a long way since its invention in the 1960s. Recent discoveries in the discipline have led to substantial improvements in laser technology, which is now employed in a variety of fields and industries, including medical, manufacturing, communications, and ecological monitoring. This article has examined some of the recent developments and future trends in laser applications.

One of the most significant recent developments in laser technology is the use of high-power lasers. Ultrafast lasers, or high-power lasers, produce light pulses on the scale of picoseconds or femtoseconds in duration. These lasers have a broad variety of uses, from cutting and welding to calculating distance and even medical treatments. They are also used in scientific research and industrial applications, where their high power and precision can be used to create new materials, manipulate atoms and molecules, and even create plasma. Another recent development in laser technology is the use of fibre lasers. Fibre lasers use a doped optical fibre to generate laser light, and they are known for their high efficiency and low maintenance. They have many practical uses in industry, science, and medicine, including cutting, welding, labelling, inscription, and surgical operations. They are also put to use in the telecommunications industry, where they are transmitted through fibre optic cables to cover great distances.

The ability to 3D print using a laser is another relatively new application of laser technology. Using a laser to fuse together layers of powdered materials, 3D printing (also known as multiplicative production) produces three-dimensional objects. This technology is used in a wide range of industries, such as aerospace, automotive, and healthcare, and it is expected to have a significant impact on manufacturing in the future. In addition to these recent developments, there are also several trends that are shaping the future of laser technology. One of these trends is the use of laser-based technologies for renewable energy. For example, lasers are used in the production of solar cells, which convert sunlight into electricity. They are also used in the production of wind turbines, which generate electricity from the wind. Another trend that is shaping the future of laser technology is the use of laser-based technologies for autonomous vehicles, drones, and robotics. The high precision and accuracy of lasers make them ideal for use in navigation and control systems for these types of vehicles. Lasers can be used for surveillance of large areas, such as borders or ports, and can also be used to detect and track targets. They are also used in the field of identification, such as in biometric systems, which use lasers to scan and identify fingerprints, irises, and faces.

Another trend that is shaping the future of laser technology is the integration of artificial intelligence (AI) and machine learning algorithms. By using these technologies, it will be possible to analyse the large amounts of data generated by laser systems and to extract useful information more efficiently. This will lead to the development of more advanced laser systems that are capable of performing more complex tasks, such as predicting failures and identifying patterns. In the field of medicine, research is ongoing to develop new laser-based treatments for a wide range of medical conditions, such as cancer and heart disease. In industry, research is focused on developing new laser-based manufacturing techniques that are more efficient, precise and cost-effective. In telecommunications, research is focused on developing new fibre optic technologies that can support even higher data transmission speeds and longer distances.

As laser technology continues to evolve, it is likely that new applications and uses will be discovered. The versatility and precision of laser systems make them an important tool in a wide range of applications, and research and development in laser technology is ongoing to improve and expand their capabilities. The future of laser technology looks promising, and it is expected to have an even greater impact in various fields. One area where laser technology is expected to have a major impact in the future is in the field of quantum computing. Using quantum-mechanical phenomenon like entanglement and superposition to process information is the basis of the emerging field of quantum computing. Laser technology is expected to play a key role in the development of quantum computing, as it is used to create the necessary quantum states and to control the interactions between quantum systems. Another area where laser technology is expected to have a major impact in the future is in the field of biotechnology. Laser technology is already used in a wide range of medicinal applications, such as therapy and laser surgery. However, in the future, it is expected to play a vital role in the development of new treatments for a wide range of medical conditions, such as cancer, Alzheimer's disease, and heart disease.

In sum, laser technology is a potent and flexible resource that has many practical uses in fields including healthcare, manufacturing, communications, and even environmental control. Applications and benefits will undoubtedly be found in the future as a result of recent breakthroughs and future projections in laser technology. Some of the areas where laser technology is expected to have a major impact in the future are quantum computing and biotechnology. As the field continues to evolve, it is important to continue to invest in research and development to improve and expand the capabilities of laser technology and to discover new applications and uses. Laser technology has come a long way since its invention and continues to evolve. Recent developments and future trends in laser technology are shaping the field to be more versatile and powerful, with the use of high-power lasers, fibre lasers, and laser-based 3D printing being some of the recent developments. The integration of AI and machine learning algorithms, the use of laser technology for renewable energy, autonomous vehicles, drones, robotics, security and surveillance, and medical treatments are some of the future trends shaping the field. New uses and applications will likely be found in the future, and current advances and trends are projected to have a wide-ranging influence on many other fields of study and business.

V. CONCLUSION AND FUTURE RESEARCH

This article has offered a comprehensive review of optical communications, fiber optics, and sensors. Having covered the several varieties of fiber optic sensors, their characteristics, and their benefits and drawbacks over more conventional sensors, we may now conclude. We have also looked at the state of the art as well as the next trends in fiber optics and sensors. The article's primary findings highlight the adaptability and accuracy of fiber optic sensors, as well as their expanding use in fields like healthcare, manufacturing, and communications. Additionally, the use of fiber optics in telecommunications has revolutionized the way data is transmitted over long distances. The implications for future research include the continued development and improvement of fiber optic sensors to make them more efficient and cost-effective. Additionally, research should be conducted on the integration of fiber optic sensors with other technologies such as artificial intelligence and machine learning to further enhance their capabilities and applications. Overall, the field of fiber optics, optical communications, and sensors is a rapidly growing and evolving field with a lot of potential for future research and development. As technology continues to advance, it is likely that new and innovative applications for fiber optics and sensors will be discovered. It is important to continue to invest in research and development in this field to fully realize its potential and make a positive impact on our society.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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