Research on U-band Fiber Lasers

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Abstract. The U-band fiber laser has attracted the attention of many researchers and industry due to its outstanding performance characteristics. U-band fiber laser is a type of laser that operates in the ultraviolet wavelength range, and its research background mainly stems from the demand for ultraviolet lasers in scientific research, medical treatment, material processing, and other fields. However, traditional ultraviolet lasers often use gas laser media, which have large volume, high power consumption, and high maintenance costs, limiting their promotion in practical applications. Therefore, researchers have begun to explore the use of fiber optic technology to achieve miniaturization, efficiency, and stability improvement of ultraviolet lasers. This article provides an overview of the working principle and application fields of U-band fiber lasers and proposes the future development direction of U-wave fiber lasers. Intended to provide useful references for further research on fiber lasers. Through continuous technological innovation and process improvement, this paper promote the further development of U-band fiber laser technology, expand its application areas, improve performance and stability, and promote its widespread application in industrial and scientific research fields.

Keywords: U-band; fiber; laser.

1. Introduction

Due to the unique spectral characteristics of 1.7 μm band lasers, they have enormous application value in many fields[1]. The absorption peak in the U-band located at the carbon-hydrogen bond can be used for targeted skin treatment of lipids/fats[2], processing and welding of plastics or certain polymers[3], detection of organic gases such as methane[4]. The birth of U-band fiber laser products and the continuous optimization of performance will accelerate the application speed of lasers in multiple fields, which will undoubtedly improve the technical level of various industries and people's quality of life. The U-band fiber laser is a light source device with important application value in fields such as optical communication, optical sensing, and optomedicine. With the continuous development of optical communication, optical sensing, and optomedicine, the demand for fiber lasers in the frequency band is also increasing. The U-band has been proven to have penetrability in high-resolution optical coherence tomography[5-6] and other applications. Therefore, studying fiber lasers in the frequency band is of great significance. The development process of U-band fiber lasers can be traced back to 2015. The Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, proposed a new U-band laser scheme based on Er-doped phosphate fiber, and realized the laser performance with the longest laser wavelength, highest efficiency and maximum output power in the self-developed 15 cm long Er-doped phosphate fiber. In recent years, with the continuous innovation and development of fiber materials and pumping technology, the performance of U-band fiber lasers has been significantly improved[7]. At present, U-band fiber lasers have been widely used in fields such as radar, biomedicine, and industrial manufacturing. The significance of studying fiber lasers in the frequency band lies in expanding the application range of fiber lasers, improving the performance indicators of fiber lasers, and meeting the needs of different fields. At the same time, studying fiber lasers in the frequency band can also promote the development of optical communication, optical sensing, and optomedicine, and promote innovation and progress in related technologies. The research topic methods can include the selection and design of fiber materials, optimization of the structure and process of fiber lasers in the frequency band, performance testing and analysis of fiber lasers, etc. By combining theoretical analysis and experimental research, the characteristics and performance of fiber lasers in the frequency band can be comprehensively

explored for further application. The research goal is to develop a new type of fiber laser in the frequency band, improve the output power and beam quality of the fiber laser, expand the working range of the fiber laser, improve the stability and reliability of the fiber laser, and promote the application of the fiber laser in the fields of optical communication, optical sensing, and optomedicine.

This article aims to improve the power and efficiency of fiber lasers in different application fields by summarizing research progress and development trends. Improve the stability and reliability of band fiber lasers to enhance their application value in industrial production and scientific research. Reduce the volume and weight of wavelength fiber lasers to facilitate integration into various devices and systems. Expand the wavelength range of band fiber lasers to meet the needs of different material processing, medical treatment, and communication transmission fields. Improve the beam quality and stability of band fiber lasers to achieve more accurate processing and measurement. Reduce the cost of wavelength fiber lasers to promote their popularization and promotion in large-scale applications.

2. Characteristics of U-band Fiber Lasers

The U-band fiber laser is based on the principle of fiber amplification and laser excitation process, and its main components include laser medium, pump source, output mirror, and fiber. Among them, the laser medium is the key component for generating the laser, the pump source is used to provide excitation energy, the output mirror is used to reflect and adjust the direction and shape of the laser beam, and the fiber is used to transmit the laser. The specific working principle is to provide energy to the pump source, excite the dopants in the fiber to the excited state, and generate the excited energy level. When photons stimulate excited particles, they will transition to the ground state, releasing energy. These energies are emitted in the form of photons, forming a laser beam. This process is called the stimulated radiation process. In optical fibers, laser beams are constantly reflected and refracted, constrained by waveguide effects. When the laser beam is reflected back into the laser medium, it is re-excited, thereby enhancing the intensity of the laser beam. This process is called the stimulated emission process. Through this repeated process of stimulated radiation and stimulated emission. Compared to other types of solid-state lasers, 1.7 μm band lasers[8-9] U-band fiber lasers can generate high-power, high brightness, and high spectral purity laser beams.

2.1. High Power and Efficiency

U-band fiber lasers have high photoelectric conversion efficiency and can achieve efficient energy transmission in the field of communication.U-band fiber lasers also have high output power, which can meet the needs of high-capacity data transmission and long-distance communication. In optical communication systems, U-band fiber lasers can achieve high-speed data transmission between fiber amplifiers, fiber lasers, and detectors, improving the overall performance of the communication system.

In addition, U-band fiber lasers can also be used in fields such as Laser radar and fiber optic sensors, providing important technical support for achieving high-precision measurement and detection. With the growth of communication demand, the demand for high-power and high-efficiency U-band lasers is also increasing. Researchers are working hard to develop new materials and structures to improve the power and efficiency of U-band lasers.

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2.2. Single-mode and Multi-mode Lasers

In single-mode lasers, U-band fiber lasers can achieve high-speed and long-distance communication transmission. Due to the high photoelectric conversion efficiency and output power of U-band fiber lasers, efficient energy and data transmission can be achieved in single-mode lasers.

This is very important for long-distance communication transmission and high-capacity data transmission.

U-band fiber lasers can achieve high-power output and meet the high-power requirements of multi-mode fiber communication systems. Multi-mode lasers are commonly used for short-distance communication and data center applications, and the high-power output of U-band fiber lasers can improve the efficiency and reliability of data transmission. Researchers are developing single-mode and multi-mode U-band fiber lasers for different application requirements. Single-mode lasers are suitable for applications that require high beam quality, while multi-mode lasers are suitable for some specific sensing applications.

2.3. Wavelength-tuning

In terms of wavelength: U-band fiber lasers can provide a specific wavelength range, which is beneficial for Wavelength Division Multiplexing in optical communication systems.WDM technology allows for the transmission of multiple optical signals of different wavelengths on the same optical fiber, achieving high-capacity and efficient data transmission.

The U-band fiber laser provides a wavelength range suitable for WDM technology, which can support multi-wavelength optical signal transmission, thereby improving the data transmission capability of communication systems.WDM technology allows for the transmission of multiple optical signals of different wavelengths on the same optical fiber, achieving high-capacity and efficient data transmission. The U-band fiber laser provides a wavelength range suitable for WDM technology, which can support multi wavelength optical signal transmission, thereby improving the data transmission capability of communication systems.

U-band fiber lasers can coordinate with other optical devices to achieve efficient optical signal transmission and processing. Various optical devices in optical communication systems need to coordinate their work within a specific wavelength range to achieve efficient optical signal transmission and processing. The U-band fiber laser can work in coordination with other optical devices, providing efficient optical signal transmission and processing capabilities for optical communication systems.

Wavelength-adjustable U-band lasers are crucial for fiber optic communication and sensing applications. Researchers are researching and developing coherent U-band lasers to meet applications with different wavelength requirements.

2.4. Integrated Optical Circuit

In the integrated optical path:U-band fiber lasers can serve as light sources, providing high-quality laser sources for integrated optical systems. Integrated optical path is a technology that integrates multiple optical components on a single chip, enabling highly integrated, miniaturized, and high-performance optical systems. The U-band fiber laser can provide a wavelength range and output power that meets the requirements of integrated optical systems, providing important support for the laser light source requirements of integrated optical systems.

In addition, U-band fiber lasers can also serve as light sources for optical modulators and detectors in integrated optical systems, achieving the functions of transmitting and receiving optical signals in integrated optical systems. This is crucial for achieving efficient optical communication and sensing systems. With the development of fiber optic communication systems, the demand for integrated optical paths is also increasing. Researchers are studying the integration of U-band lasers into optical chips to achieve more compact and high-performance fiber optic communication systems.

2.5. Wavelength Division Multiplexing

Wavelength resources are abundant, and WDM systems achieve multiplexing by transmitting multiple optical signals of different wavelengths in the same fiber. The U-band fiber laser provides abundant wavelength resources and can provide wavelength light sources that meet the requirements for WDM systems, thus supporting multi-channel optical signal transmission.

In terms of increasing transmission capacity, WDM technology can overlay optical signals of different wavelengths for transmission in the same optical fiber, effectively increasing the transmission capacity of fiber optic communication systems. U-band fiber lasers can provide a wavelength range suitable for WDM systems and support high-capacity data transmission through multiplexing.

In terms of cost, WDM technology can achieve multiple data transmissions without increasing the number of optical fibers, thereby reducing the cost of communication systems. The U-band fiber laser can provide high-quality wavelength light sources for WDM systems, which helps to reduce the construction and operation costs of optical communication systems.

Wavelength division has flexibility and scalability, and WDM systems have good flexibility and scalability, allowing for the addition or reduction of optical channels as needed to adapt to the growing communication needs. The U-band fiber laser provides a wavelength range suitable for WDM systems, which can meet the flexibility and scalability requirements of communication networks of different scales and requirements.

Overall, the research focus of U-band fiber lasers includes improving power and efficiency, developing single-mode and multi-mode lasers, achieving wavelength tuning, and integrating optical path technology. These studies will promote the application and development of U-band fiber lasers in the fields of communication and sensing.

3. Improvement of U-band Fiber Laser

In terms of material selection and optimization, it is first necessary to screen and optimize fiber optic materials suitable for the U-band, including the selection and concentration optimization of dopants, as well as the performance evaluation and improvement of the substrate material. In terms of structural design and optimization, design the waveguide structure and optical cavity structure of the U-band fiber laser, and optimize the performance and stability of the laser through numerical simulation and experimental verification. In terms of laser preparation and debugging, prepare U-band fiber laser samples according to the design scheme, and carry out systematic debugging and optimization to obtain stable and efficient laser output. In terms of optical device research, carry out research on optical devices suitable for the U-band, such as gratings, polarizer components, etc., to improve the performance and stability of lasers.

4. Application of U-band Fiber Laser

In terms of application research, we will conduct research on the application of U-band fiber lasers in fields such as communication, medicine, and biochemistry, exploring their performance and advantages in practical applications. In terms of experimental verification and performance evaluation, performance evaluation is conducted on the fiber laser samples obtained through experimental verification, including testing and analysis of output power, wavelength stability, spectral purity, and other indicators. In terms of technology promotion and transformation, research results will be promoted and transformed to promote the application and industrialization of U-band fiber laser technology.

U-band fiber lasers have been widely used in various fields, such as in Laser radar applications. U-band fiber lasers are suitable for remote and long-distance Laser radar systems, such as meteorological and environmental monitoring, autonomous vehicles, and drone obstacle avoidance. Its high power and high energy density characteristics make it outstanding in high-resolution and highly sensitive Laser radar systems. In the field of biomedicine, U-band fiber lasers can be used for photocoagulation therapy of biological tissues, microprocessing, spectral analysis, and medical imaging. It has advantages such as high precision, high energy density, and low scattering, and can be applied in various biomedical and diagnostic technologies. In industrial manufacturing, U-band fiber lasers can be used in fields such as cutting, welding, marking, and surface treatment. With

advantages such as high efficiency, high precision, and low cost, they can replace traditional processing methods and help improve production efficiency and processing quality[10]. In addition, in the fields of communication and photoelectrons, it can be used for the emission, transmission, and processing of optical signals. Its high frequency and high power characteristics make it have good application prospects in fields such as high-speed fiber optic communication, quantum communication, and satellite communication.

In the development process of U-band fiber lasers, there are a series of challenges, including how to improve output power and beam quality, how to reduce noise, and how to improve stability.

5. Conclusion

Due to the wide range of applications of U-band fiber lasers, they face different challenges. In the field of LiDAR, it is necessary to improve the output power and energy density of U-band fiber lasers to achieve longer distance detection and more efficient signal processing; In the field of biomedicine, U-band fiber lasers are required to have higher beam quality and lower scattering to reduce damage and side effects on biological tissues.

Future research can address these challenges from the following aspects. Firstly, optimize the design and manufacturing process of fiber lasers to improve output power, beam quality, and stability. This includes optimizing the drawing process of optical fibers, improving the preparation and purification technology of dopants, and enhancing the stability and reliability of pump sources. Secondly, explore new types of fiber materials and structures to improve the performance of U-band fiber lasers. Thirdly, study the nonlinear effects and applications of U-band fiber lasers to improve their energy density and output power. Finally, expand the application areas of U-band fiber lasers to meet the practical needs of more fields.

With the continuous innovation and development of fiber materials and pump technology, the performance of U-band fiber lasers will be further improved. Meanwhile, with the continuous expansion of application fields, the application range of U-band fiber lasers will also continue to expand. With the continuous development of emerging technologies such as 5G and the Internet of Things, U-band fiber lasers are expected to play an important role in these fields.

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