Study of U Band Optical Fiber Amplifiers (1600 - 1700 nm)

Yiran Peng[1, *], Xinyi Wu[2], Yuxin Zhan[3]

[1]Department of Communication and Information Engineering, Xi'an University of Post and Communications, Xi'an, China

[2]Department of electronic information, Fuzhou University, Fuzhou, China

[3]Department of Optoelectronic Information Science and Engineering, Southern University of science and Technology, Shenzhen, China

*Corresponding author: 1910732109@mail.sit.edu.cn

Abstract. In recent years, with the digital transformation of various industries, the demand for network data transmission has been growing exponentially. Optical networks, as the underlying bearer networks, are crucial for network development, so there is an urgent need to improve the capacity of optical fibre communication systems, and the development of U-band has become one of the important ways to expand the capacity of the system. The development of U-band (1650-1700 nm) optical amplifiers based on doped rare-earth ion optical fibres has become an optimal solution for the development of U-band active devices and the expansion of communication system capacity. This paper mainly introduces the background and working principle of fibre-optic amplifiers, focuses on the research direction and progress of U-band fibre-optic amplifiers, and introduces the working wavelength and working principle of this band fibre-optic amplifiers, as well as the current domestic and international research status. Finally, the development trend of U-band fibre optic amplifier is summarized.

Keywords: U band, Optical fiber amplifier.

1. Introduction

Optical Fiber Communication is the transmission of messages by means of a coherent and directed laser (also called an optical carrier), and by means of optical fiber transmission. It has many merits such as broad band width, big transfer capability, little loss, long relay distance and excellent EMI capability, and so on. It has already been a major part of high speed communication network. In conventional fibre transport systems, it is essential to set up a regeneration relay at intervals in order to compensate for the scattering and loss of light signals. But it is not possible to adopt the "optics, electronics, optics" transform way in which the device is costly, complicated, unstable, and so on. Because of its excellent performance in form and speed, it can not only reduce the propagation speed and transmit range, but also make the whole optical fibre communication system more easy and flexible. So, the appearance of the OFC has made great contribution to the progress of OFC, which is considered as a "landmark" in OFC.

2. Optical fiber amplifier

2.1. Introduction

The Optical Fiber Amplifier (Optical Fiber Amplifier) is an all optical amplifier for amplifying the signal, which can achieve high-gain, wide-band, low-noise, low-loss and so on. The proposed method has many merits such as low coupling loss, no need to be paid attention to optical polarization status, and high transparence of transmitting signal. Twenty five years ago, EDFA, the first EDFA in the world, has been developed [1]. EDFAs have been applied extensively in all kinds of optical fibre communication systems. But the exponential increase in network traffic in recent years due to increasing demand will result in overloads ("capacity squeeze"). Because EDFA is restricted in its operational scope and can only operate in the spectrum between 1530-1600 nm [2], it is essential to seek out a new technology for widening the spectrum. Since the majority of optical amplifiers are composed of rare earth elements, it is possible to use other rare earth elements besides Erbium-Doped ones which can be used to cover the shorter (1200 - 1500 nm) and longer (1600 - 1700 nm) spectrum areas. This paper show optical amplifiers in the U band and at wavelengths in the (1650-1750 nm) range.

2.2. Fundamental principle

U Band Fiber Amplifier is an instrument which utilizes special components to enhance the Optical Signal in the Near Infrared Spectrum Spectrum.

The most common doping elements are erbium (Er) and thulium (Tm). Erbium is a common dopant in U band optical fiber amplifier with a maximum gain of about 2.7 nm [3,4]. Conversely, Thulium shows higher gain properties in the 2.0 to 2.1 micrometer wavelength range [3,4]. While the incoming light is transmitted across a doped fibre, the electrons in the doped element are stimulated to a high energy level. Then, as the excitatory emission takes place, the electrons in the doped element leap from the high-energy state to the low-energy state and emit the radiation energy. During this process, the optical signal is enhanced and the signal strength is enhanced. To obtain efficient amplification, U band optical amplifier often adopts double refraction optical fibre. The design can decrease nonlinearity and enhance the performance of the amplifier.

Because of this, U band fiber amplifier is widely used in optics, sensor and laser. Through continuous advances in R&D of U Band Fibre Amplifier, its properties can be enhanced, including gain, bandwidth, and noise ratio, which will offer a more reliable and fast capability for high-speed and large-volume optical fibre communication.

3. Research progress

3.1. Research progress

More and more widely used fibre amplifiers are needed along with the progress of optical communication. The U band (1625 - 1675 nm) is regarded as a under-used band by the researchers. Using U band allows optical fiber communication systems to be able to expand their transport capability and range, thus offering more bandwidth and better data transfer speed [5]. Recently, researchers have started to investigate the use of Thallium, which is suitable for U band, in order to amplify U wave by controlling its density and distributing. Moreover, it has been proposed that optimization of optical fibre structures, such as PCF and MDF, will enhance the capability of U band AF in both gain and bandwidth. Furthermore, the research has been carried out in order to forecast and assess the influence of various parameters and structures on the performance through analysis and optimization of U band AF [6]. Although there is a limited amount of information available, this progress indicates that some preliminary studies and theories have been made in the area of U band optical amplifiers.

3.2. Challenge

The major issues and challenges encountered in current research on U band AF are the choice of material, fibre loss, cross-resonant and cross-talk, the design and optimization of the equipment, as well as the manufacture and integration of the components [7]. In terms of material choice, searching effective dopants for operating in the U band is a challenge. The usual dopants like Erbium (Er) have a low gain in U band, so it is necessary to develop a novel dopants [8]. The U band optical fibres often have high losses, which limit the amplifier gain. In order to increase the efficiency of U band fibre, it is necessary to solve the problem of cross-resonant and cross-talk in the vicinity of U band, which may result in the distortion and disturbance of the signal. Furthermore, it is necessary to take into account the characteristics of the fibre, the nonlinearity of the material, the fibre coupling, and the braids in order to obtain a high efficiency, stability and reliability of the amplifier. Moreover, commercialization and mass production of UW-band optical amplifiers are also a challenge. The production of high quality U band fibres and components and their integration into existing optical communication systems needs to be solved in terms of technology, cost and reliability.

3.3. Development

Along with the development of U Band Optical Amplifier, the performance of U Band Optical Amplifier has been improved continuously. According to the related documents about U band AF, it is found that the main way to develop U band AF is to develop a new material.

This development is mainly the innovation of doped ions, as well as the innovation of the main glass core. For example, in 2005, Chung, W. J. found the PR trivalent doped Se Glass Fibre for U-type Optical Amplifier. The germanium-gallium-antimonial -selenium main glass has good fiber stretching ability, and the minimal loss of the fibre is estimated to be 0.4 dB/m at 1.65 um[9]. In 2017, Firstov, S. V discovered the broadband bismuth-erbium-doped fiber amplifier in the U band . It is a bismuth-erbium-co-doped germanium silicon fiber made by MCVD technology, a broadband optical amplifier with an operating wavelength of 1515-1775nm (bandwidth greater than 250nm) and gain of no less than 15db. The output power is 350mw[10]. Through the innovation of doped ions and the main glass core, the performance of the light amplifier is better. In 2022, Mirza, J. et al. innovatively proposed the design of an erbium-doped fiber amplifier in L + u band . The gain band is over 82 nanometers in the spectrum from 1578 to 1660nm. According to the simulation study, 12m is the optimal length for erbium-doped fiber, and the optimal doping concentration of erbium is 100 × $1024m^{-3}$ [11].Their energy level transitions are shown in Fig.1, Fig.2 and Fig.3.

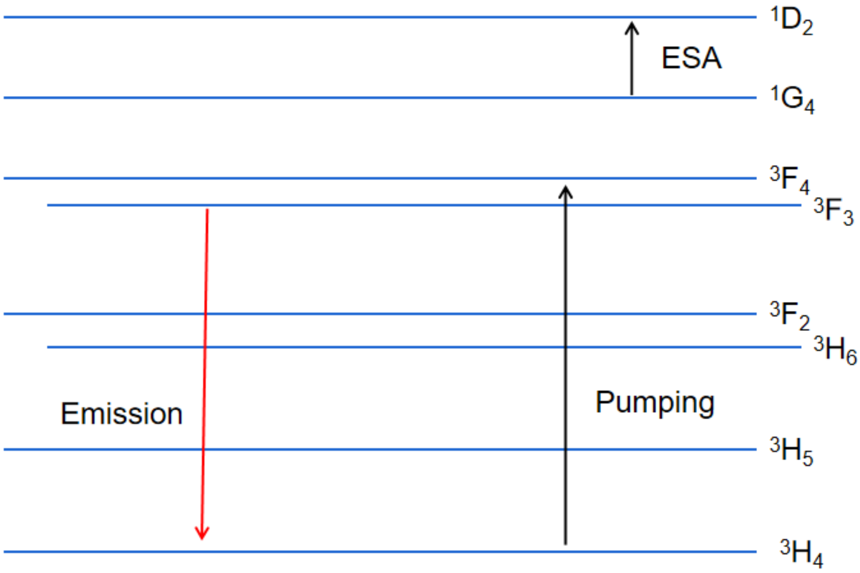

Fig. 1 Energy level diagram for Pr^{3+} (Original)

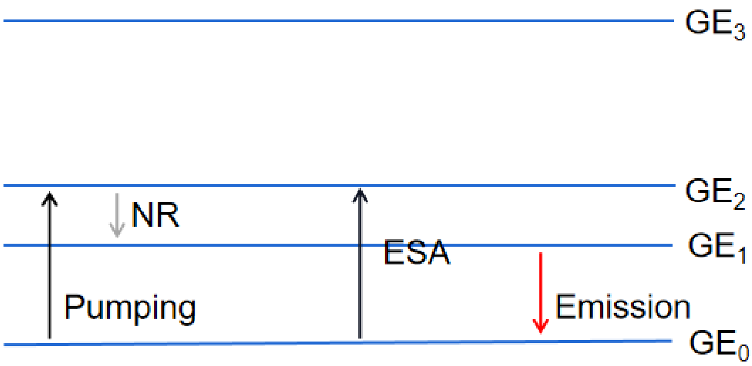

Fig. 2 Energy level diagram for Bi^{3+} (Original)

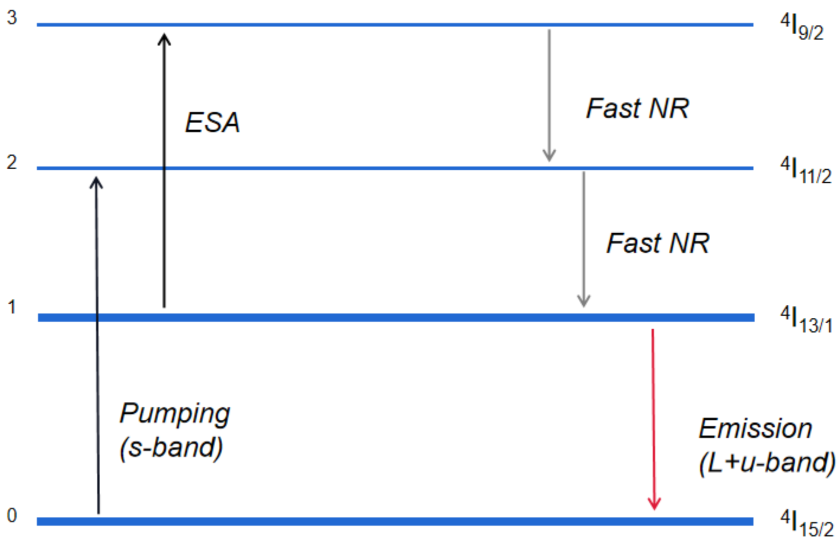

Fig. 3 Energy level diagram for Er^{3+} (Original)

4. Conclusion

Recently, there have been significant advances in the study of U band optical amplifier. As for the structural design of the amplifier, there are two kinds of WDM, EDFA and LDW, which have been improved significantly in gain band, noise ratio and power transfer efficiency. At the same time, as far as the choice of materials is concerned, EDFA is the most common material for U band optical amplifier. New erbium-doped fiber materials such as niobate glass, cadmium sulfide and zinc sulfide have shown good performance in recent years.

Performance optimization is a key issue in this field. Great advances have been achieved through the optimization of the dopant concentration, the modification of the geometrical shape of the fibre and the application of the novel fibre. The noise value is decreased by optimization of the dopant concentration, for instance, and a modification of the fibre geometry contributes to increasing the gain bandwidth. All of these optimization methods are critical for improving the stability of fiber amplifiers and improving their performance.

It is expected that U band optical amplifier will be more demanding in the future. In order to satisfy the requirement of high speed data transfer and high precision sensor, more attention should be paid to improving the gain band and decreasing the noise. Moreover, it is also possible to develop more powerful amplifiers and achieve a more efficient wavelength conversion. At the same time, it will be possible to integrate U band optical amplifier with other equipments to improve its capability and extend its applied range.

To sum up, remarkable advances in the field of U band optical amplifier has been achieved, such as structure design, material choice and property optimization. The next step is to increase the capability and extend the range of applications in order to satisfy the increasing requirements for optical communication and sensing. Thanks to the constant improvement of technology, U Band Fibre Amplifier will be able to offer more effective, steady and reliable solutions to the Optical Communication System and Sensor.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Naji A W, Hamida B A, Cheng X S, et al. Review of Erbium-doped fiber amplifier[J]. International Journal of the Physical Sciences, 2011, 6(20): 4674-4689.

[2] Eid M M A, El-Meadawy S, Mohammed A E N A, et al. Wavelength division multiplexing developed with optimum length-based EDFA in the presence of dispersion-compensated fiber system[J]. Journal of Optical Communications, 2021 (0): 000010151520200302.

[3] Miniscalco W J. Optical and electronic properties of rare earth ions in glasses[J]. OPTICAL ENGINEERING-NEW YORK-MARCEL DEKKER INCORPORATED-, 2001, 71: 17-112.

[4] Firstov S V, Riumkin K E, Khegai A M, et al. Wideband bismuth-and erbium-codoped optical fiber amplifier for C+ L+ U-telecommunication band[J]. Laser Physics Letters, 2017, 14(11): 110001.

[5] Davis C C, Murphy T E. Fiber-optic communications[J]. IEEE Signal Processing Magazine, 2011, 28(4): 147-150.

[6] Mirza J, Ghafoor S, Salman A, et al. Design of L+ U-band Erbium-doped fiber amplifier based on a single S-band forward pump source[J]. International Journal of Communication Systems, 2022, 35(13): e5250.

[7] Sirleto L, Righini G C. An Introduction to Nonlinear Integrated Photonics: Structures and Devices[J]. Micromachines, 2023, 14(3): 614.

[8] Nandi P. Erbium and ytterbium doped phosphotellurite glasses for lasers and optical amplifiers[D]. , 2007.

[9] Chung W J, Seo H S, Park B J, et al. Selenide glass optical fiber doped with Pr3+ for U-band optical amplifier[J]. Etri Journal, 2005, 27(4): 411-417.

[10] Firstov S V, Alyshev S V, Riumkin K E, et al. A 23-dB bismuth-doped optical fiber amplifier for a 1700-nm band[J]. Scientific reports, 2016, 6(1): 28939.

[11] Mirza J, Ghafoor S, Salman A, et al. Design of L+ U-band Erbium-doped fiber amplifier based on a single S-band forward pump source[J]. International Journal of Communication Systems, 2022, 35(13): e5250.