Cladding Pumped Amplifier Using Seven-core EDF

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ABSTRACT We have developed a multicore erbium doped fiber (MC-EDF) with an increased absorption coefficient for the batch pumping. We fabricated a cladding-pumped type amplifier using the developed fiber and realized a gain of 18.0 dB, a noise figure (NF) of 6.1 dB and a core to core crosstalk of -44.0 dB in the C-band.

1. INTRODUCTION

Increases on the internet traffic, such as the increase of the mobile network utilization, the start of IoT related services, etc., are still accelerating. Efforts to increase the communication capacity, such as a higher speed of the transmission speed itself, a multiplexing, etc., are under way and the development is accelerating towards the realization of the space-division multiplexing transmission technology which is a new multi axis. The major topic of the space-division multiplexing is a multicore optical fiber and a utilization of the mode-division multiplexing technology. A standard optical fiber has a core arranged in the center portion of the fiber to propagate a signal, whereas a multicore fiber has a plurality of cores arranged in one fiber so that the transmission capacity is physically expanded. The mode-division multiplexing technology is the one that increases the number of modes propagating in one core and can treat each mode independently. In recent years, a lot of research results, such as an ultra large capacity transmission experiment using a multicore fiber and a mode-division multiplexing technology, etc., have been reported and the space-division multiplexing transmission is also beginning to be adopted in practical use.

Along with the expansion of the number of cores used in the fiber cable due to the development of the space-division multiplexing technology, the avoidance of increasing the load for the repeater apparatus is also required. It can be said that the most common repeater apparatus is an amplifier. Up to now, the multiplexing has been performed on the frequency axis and the time axis of one fiber. Therefore, it was not necessary to increase the number of amplifiers, but for the multicore fiber, one amplifier is required per core. For this reason, the necessity of the space-division multiplexing inside the amplifier as well as in the transmission line cable is also increasing. In other words, it is important to minimize the area for the equipment in the repeater station by performing an integration including the peripheral devices, together with a multicore EDF used in the amplifier. Furthermore, the suppression of the increase in the power consumption due to the increase of the number of cores is also an important issue.

In this report, we introduce the size reduction technology of the amplifier with a multicore erbium doped fiber amplifier (MC-EDFA) and the effort to reduce the power consumption corresponding to the request for the expansion of the communication capacity.

2. CONSTRUCTION OF THE SPACE-DIVISION MULTIPLEX AMPLIFIER AND ITS ELEMENT TECHNOLOGY

The basic configuration of the space-division multiplexing amplifier is summarized in Figure 1. The EDF is used as an amplification medium, but the EDFA is divided into the core-pumped type and the cladding-pumped type by the EDF pumping method. In the core-pumped type, one pumped light is required per one core. Therefore, it is thought that there is no major difference from the case where a multiple of standard EDFAs are arranged from the device size point of view. If the core-pumped type is further subdivided, it can be divided into a split type space-division multiplexing amplifier in which a multiple of EDFAs are arranged in the repeater and an individual pumping type MC-EDFA using the MC-EDF as an amplifying medium. Individual pumping type MC-EDFA is attractive from the degree of integration viewpoint, but it is hard to say that there is a major breakthrough when considering the power consumption. On the other hand, because the cladding-pumped EDFA can amplify the signal that is propagating through all the cores in the

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MC-EDF with one uncooled multimode laser diode (MM-LD), it is attractive from the reduction of the device size and of the power consumption point of view. The biggest difference between the EDFs used for the core-pumped type and the cladding-pumped type is to have a double cladding type structure in the cladding-pumped type. The signal light is propagated through the core and the pumped light is propagated through the inner cladding and by reducing the refractive index of the outer cladding on the outer periphery, the confinement of the pumped light of the inner cladding in the fiber is achieved.

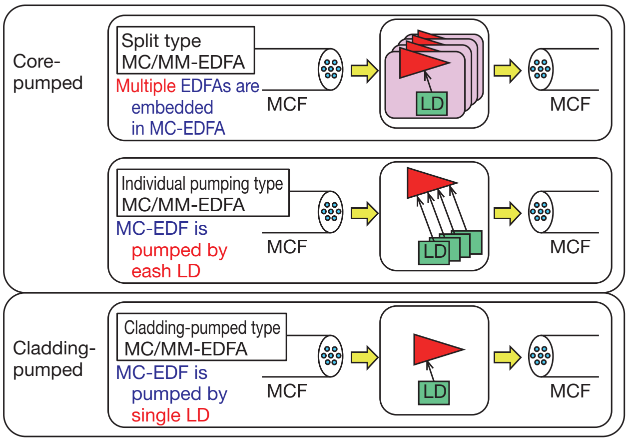
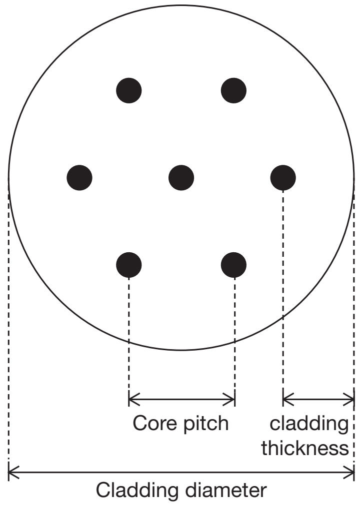


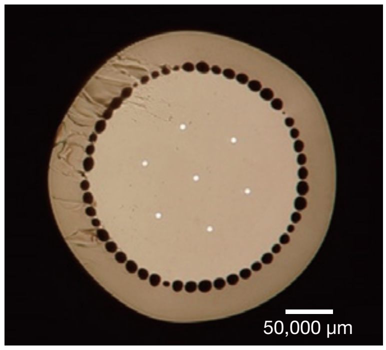
Figure 1 Configuration of a multicore EDFA.

Two types of structures have been proposed as a double cladding type MC-EDF. One is an air cladding type and the other is a polymer cladding type. Each type is shown in Figure 2. All of the MC-EDFs shown in Figure 2 are seven-core type. Figure 2(a) shows the basic structure. In the air cladding type shown in Fig. 2(b), the pumped light is confined in the silica glass (refractive index of about 1.44) with air (refractive index about 1.0) by densely arranged holes in the outer circumference. In this structure, it is easy to achieve a large difference in the refractive index and it is possible to efficiently propagate the pumped light, whereas it is difficult to guide the pumped light into the MC-EDF. Furthermore, because it is difficult to keep the hole diameter uniform, the fiber structure tends to be unstable. This is also disadvantageous in coupling the signal light to the MC-EDF.

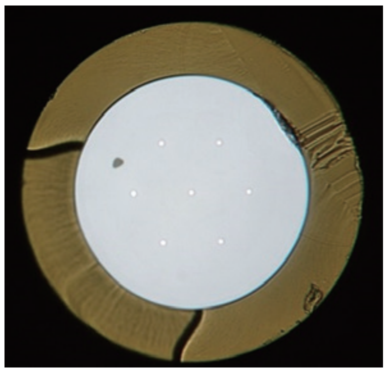
On the other hand, the polymer cladding type shown in Figure 2(c) is superior in the usability because the manufacturing method is comparatively close to the one for the standard optical fiber and the introduction of the pumped light is relatively easy by removing the polymer coating. Further, a fiber having a stable structure is easy to fabricate and the coupling loss with the signal light is easily reduced. Therefore, in this report, only studies using the polymer cladding type MC-EDF will be introduced. Table 1 displays the parameters of the polymer cladding type MC-EDF shown in Figure 2(c).



(a) Structure of the MC-EDF.



(b) Air cladding type MC-EDF.



(c) Polymer cladding type MC-EDF.

Figure 2 Various types of double cladding MC-EDF.

Table 1 Structural parameters of polymer cladding type MC-EDF.

	Unit	Typical MC-EDF
Number of cores	number	7
Mode Field Dimeter	μm	6.2
Core pitch	μ m	45.0
Inside Cladding Diameter	μ m	180
Outside Cladding Diameter	μ m	220
Material for outside cladding	—	UV curable resin
Refractive Index of outside cladding	—	1.4

3. CLADDING-PUMPED TYPE MC-EDFA

We introduce the cladding-pumped type MC-EDFA construction using the MC-EDF introduced in Chapter 2. Figure 3 shows the configuration of the cladding-pumped seven-core EDFA. Individual isolators are connected to the seven input/output units. The isolator and the seven-core MCF are connected via a fiber bundle type fan-out (FBF). The pumped light by the MM-LD is input to the seven-core MC-EDF with a laterally coupled type pump combiner. The pumped light input to the cladding is removed by the pump stripper at the opposite end of the MC-EDF. Figure 4 shows the output power characteristics of the L-band amplifier using the MC-EDF of 108 m in this configuration. It indicates that the output power exceeds 20 dBm for each of the cores and this can be used as a repeater amplifier [2].

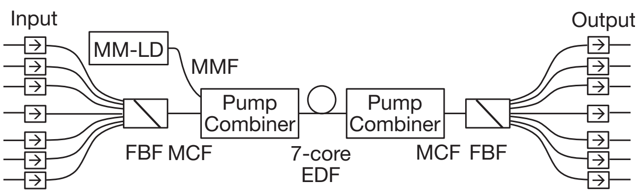


Figure 3 Configuration of cladding-pumped seven core MC-EDFA.

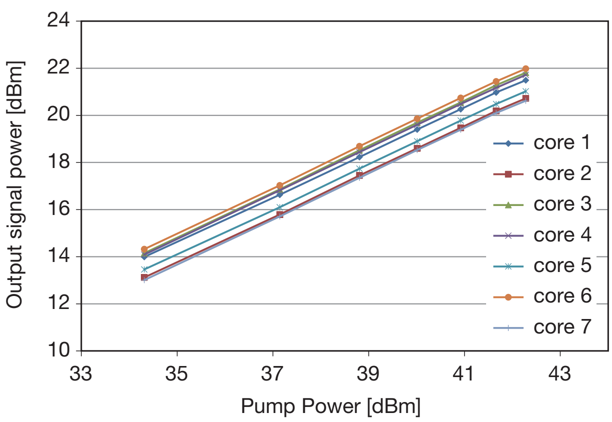


Figure 4 Output power characteristics of the MC-EDFA for the L-band (input power 7.5 dBm).

4. SEVEN-CORE MC-EDF WITH AN INCREASESD CLADDING ABSORPTION

In Chapter 3, we introduced the early day's cladding-pumped type MC-EDFA. In the current system based on the assumption of the WDM transmission, the output light power mentioned before was insufficient. Although the EDFA with an output of +20 dBm or more has been reported as a practical EDFA, the amplification band was limited to the L-band and the output power of the C-band by the batch pumping remained at +10 dBm or less[1]. On the other hand, it is well-known that when a multi-core erbium-ytterbium doped fiber (EYDF) co-doped with Er-Yb is used in the core, a large output can be obtained even when it is used in the C-band since the pumped light conversion efficiency is high[3]. However, we believe that the Er-Yb co-doped fiber has a narrow band and is not suitable for amplifying the WDM signal arranged in the entire C-band. We believe that the output power of the cladding-pumped EDFA can be increased by increasing the pumping efficiency of Er ions and we tried 2 approaches. The first one is to enlarge the core diameter. We attempted to improve the absorption characteristic by increasing the overlap coefficient between the signal light field propagating in the fiber and the size of the core. Another approach is to reduce the cladding diameter. The purpose of this is to have an effect to increase the power density when the same power is inputted into the cladding. Figure 5 shows a photograph of the end face of the MC-EDF with an increased absorption coefficient. The cladding diameter and the core pitch were set to 135 μm and 38.5 μm, respectively. The core diameter is 1.8 times larger in comparison to the one of the conventional MC-EDF[1, 2]. The cladding diameter is reduced to the half in terms of the cross sectional area in comparison to the conventional construction of 180 μm. This indicates that the pumped light density has doubled.

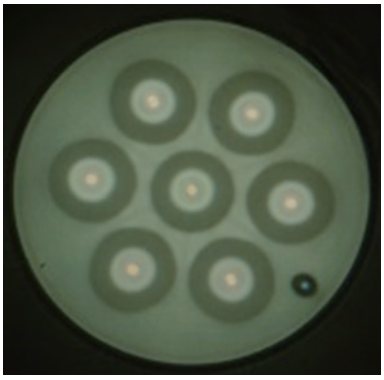


Figure 5 MC-EDF with an increased absorption efficiency.

By applying a low refractive index UV coating to this fiber and confining the pumped light, a double cladding structure is achieved. Also, the glass protection is performed by the coating. Figure 6 shows the comparison result of the absorption spectrum with the conventional fiber. The absorption coefficients are 6 dB/m and 11 dB/m, respectively. Although the Er addition amount of the core is the same for both fibers, the increase of the absorption coefficient by 5 dB is achieved by increasing the core diameter and by reducing the cladding diameter.

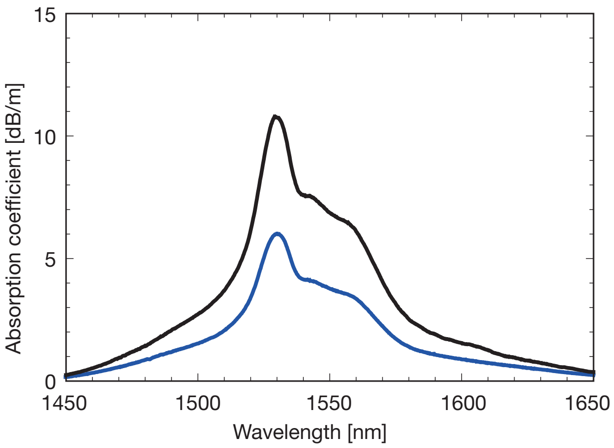


Figure 6 Comparison of the absorption coefficient for a conventional MC-EDF (blue) and the MC-EDF with an increased absorption coefficient (Black).

(a) Appearance of the optical component housing.

(b) Overall appearance of the MC-EDF.

Figure 7 Appearance of the MC-EDF.

A cladding-pumped amplifier fabricated using the fabricated MC-EDF is shown in Figure 7. Figure 7(a) is an arrangement that houses the optical components and its size is 400 mm x 300 mm x 38 mm. In addition, Figure 7(b) shows an amplifier that houses peripheral components and enables the mounting of 19-inch racks. The gain characteristics in the C-band and the L-band of the amplifier shown in Figure 7(b) are introduced in the following.

4.1 L-band Amplification Characteristics

In order to obtain the optimum characteristic in the L-band, the length of the MC-EDF in the amplifier was adjusted to 50 m and the amplification characteristics in the L-band were measured. Figure 8 shows the gain and the NF characteristics of this amplifier. For the input signal, a 33 channel WDM signal in the range of 1570-1610 nm was inputted. The input signal power was set to 7.5 dBm in total for each core and the pumped light power was set to 42.3 dBm. The minimum gain and the maximum NF obtained for each core were 13.1 dB and 5.8 dB, respectively. The variation of the gain for each core was 3.5 dB at the maximum and the variation of the gain and the NF between cores were 1.4 dB and 0.6 dB, respectively. The total output power for each core exceeds 22.1 dBm in all cores.

The measurement of the core to core crosstalk was performed by observing the leakage signal from another core when 2 signal lights separated by 1 nm are put to the different core respectively and the pumped light is inputted. The intensity of the input signal light and the pumped light are 0 dBm and 40 dBm, respectively. Figure 9 shows the core to core crosstalk characteristics of the MC-EDFA for L-band. The core to core crosstalk was -53 dB, and the variation was 4.3 dB.

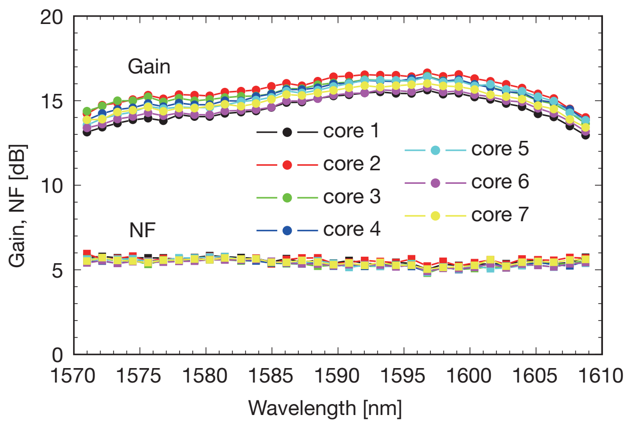


Figure 8 Amplification characteristics of the MC-EDF for the L-band.

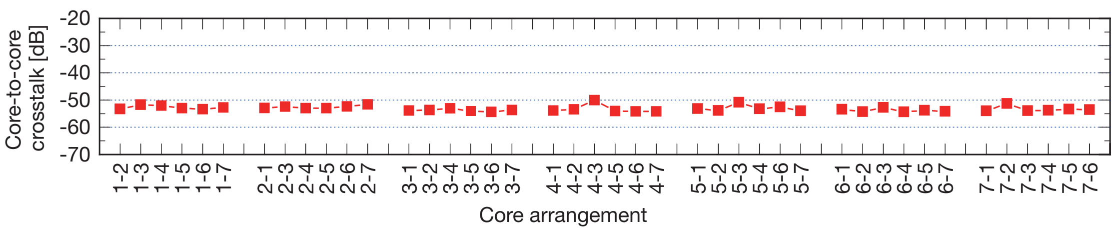


Figure 9 Core to core crosstalk characteristics of the L-band seven-core EDFA.

4.2 C-band Amplification Characteristics.

In order to obtain the optimum characteristics for the C-band, the length of the MC-EDF inside the amplifier was set to 8 m and the amplification characteristics for C-band were measured. The gain and the NF are shown in Figure 10. An 8 channel WDM signal with a total of -5.0 dBm is inputted to each core and the power of the pumped light at this time was set to 42.3 dBm. The maximum gain and the minimum NF of each core were 18.0 dB and 6.1 dB, respectively. According to Figure 10, a flat gain was observed and the gain deviation in all the cores was about 3.3 dB. The variation of the gain and the NF between the cores is suppressed to 0.9 dB and 0.6 dB or less, respectively.

Figure 11 shows the input signal strength dependence of the output power. In this measurement, the pumped light power is fixed at 39.9 dBm and the input signal is an 8 channel WDM signal. According to Figure 11, an output power of 15 dBm or more is obtained in each core, and as the total input power increases by 5 dB, the output increases by 0.8 dB. According to this result, in the MC-EDFA for the C-band, the input signal light power which the output reaches the saturation region is shown to be larger than 13 dBm and it is indicated that further higher output may be obtained. The core to core output deviation was 0.8 dB or less.

Figure 12 shows the core to core crosstalk characteristics of the C-band seven-core EDFA. The average crosstalk and the variation obtained were -43.6 dB and 10 dB, respectively.

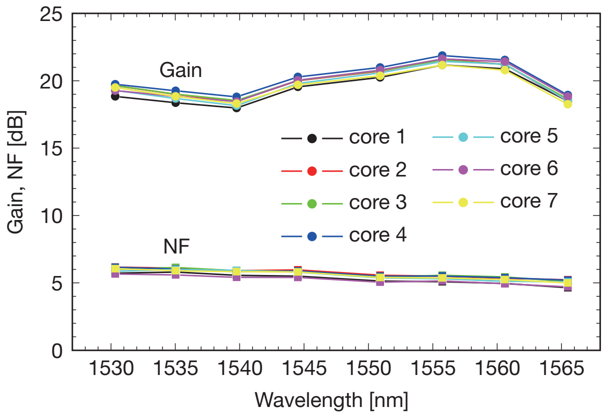


Figure 10 Amplification characteristics of MC-EDFA for C-band.

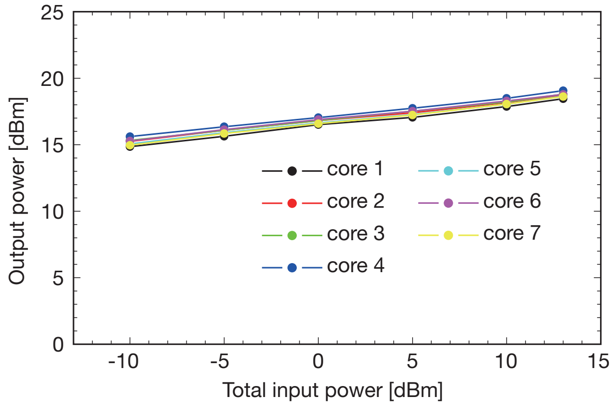


Figure 11 Output power of MC-EDF for C-band.

5. SUMMARY

The characteristics of the cladding-pumped amplifier using the MC-EDF were introduced. It was proven that enlarging the core diameter and reducing the cladding diameter are effective to increase the output power. The absorption coefficient at 1530 nm was successfully increased to 11 dBm. The characteristics for the L-band were confirmed using the fabricated MC-EDF of 50 m and we achieved a gain of 13.1 dB, a NF of 5.8 dB and a total output power of 22.1 dBm when using a 33-channel WDM signal with a total input power of 7.5 dBm. At this time, the deviation of the gain between the cores and the NF were 1.4 dB and 0.6 dB, respectively and the core to core crosstalk was -53 dB. Furthermore, when the MC-EDFA is configured using the MC-EDF of 8 m for the C-band and a 8-channel WDM signal with a total input power of -5.0 dBm is inputted, a gain of 18 dB, a NF of 6.1 dB and an 8 channel total output power of 15 dBm were obtained in the C-band.

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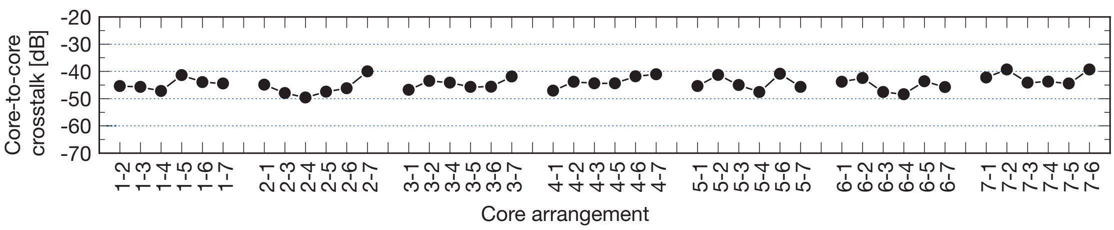

Figure 12 Core to core crosstalk of the C-band seven-core EDFA.

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