

Compact Optical Fiber Amplifier

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ABSTRACT Recently, WDM systems have been increasingly installed. As a result, we have been developing optical fiber amplifiers for WDM systems.

Compact optical fiber amplifiers for single channel and small channel applications are needed for SDH systems and for WDM systems to compensate for insertion losses of optical passive components. In response, we have developed compact optical fiber amplifiers using a coaxial pumping laser. However higher output power and higher gain have recently been demanded. Therefore, compact optical fiber amplifiers using a butterfly pumping laser or a mini-DIL pumping laser have been developed. These amplifiers are reported in this paper.

1. INTRODUCTION

The spread of the Internet is leading to increased communication traffic and requires the evolution of Dense Wavelength Division Multiplexing (DWDM) technology. The Erbium Doped Fiber Amplifier (EDFA) developed using a gain flattening filter technique^{1, 2)} and an expansion of the signal wavelength range to L-band (approximately from 1570 to 1605 nm)^{3, 4)} have supported this progress in the DWDM communication region.

Compact optical fiber amplifiers for single channel and small channel applications are needed. Their output power and gain are not so high and they are mainly used in a single channel SDH system as a booster amplifier and a preamplifier, or in the DWDM system to compensate for insertion losses of optical passive components such as Optical Multiplexer (OMUX), Optical De-Multiplexer (ODMUX), Optical Add / Drop Multiplexer (OADM), and Optical Switch (OSW). As a compact optical fiber amplifier, we have developed a name card-sized amplifier using a coaxial pumping laser. However higher output power and higher gain have recently been required because of increasing losses from optical passive components due to increments in the number of signal channels and complexity of configuring DWDM systems. To achieve higher output power and gain, we have developed platforms as compact optical amplifiers using a butterfly pumping laser and a mini DIL pumping laser.

They are reported below.

2. LINE-UP OF COMPACT OPTICAL FIBER AMPLIFIERS

Generally, optical fiber amplifiers are categorized according to signal wavelength ranges: C-band (approximately 1530~1560 nm) and L-band (approximately 1570~1605 nm), or applications: booster amplifier, inline amplifier and preamplifier.

In the case of compact optical fiber amplifiers, they should be categorized by type of pumping laser: butterfly type and mini-DIL type. Mini-DIL pumping lasers do not need temperature control because the operating forward current is not so high and they do not need a cooling device. This contributes to reducing power consumption. On the other hand, butterfly pumping lasers need temperature control because the operating forward current is high to achieve a high pumping power. This difference is important because it has an impact on the design of the electrical circuit. (In this paper the butterfly pumping laser and the mini-DIL pumping laser are called cooled pump and uncooled pump, respectively.)

Two platforms need to be designed. One includes the cooled pump and the other includes the uncooled pump. The dimensions are the same, 90(W)×70(D)×12(H) mm. The height of the compact optical fiber amplifier with the uncooled pump can be reduced to 10.5 mm.

Furthermore in the case of compact optical fiber amplifiers with the cooled pump, if a 1480-nm pumping laser is used, for instance, for L-band amplification, a heat sink is needed to radiate heat emitted by the laser diode and the cooling device, because the operating forward current is higher than in the case of using 980-nm pumping laser. So, a platform with a heat sink was developed.

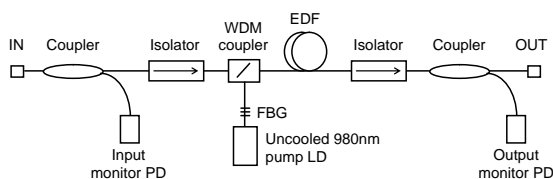
Table 1 shows a summary of platforms for compact optical fiber amplifiers.

Next, the actual characteristics of compact optical fiber amplifiers are introduced according to the categories shown in Table 1.

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Table 1 Line-up of compact optical fiber amplifiers.

Division 1 (Pumping laser)	Division 2 (Signal wavelength and application)	Notes
Uncooled pump	Mainly C-band Booster- and Pre-amplifier	Low power consumption 980-nm LD pump
Cooled pump	Mainly C-band Booster- and Pre-amplifier	High output power Mainly 980-nm LD pump
Cooled pump with heat sink	Mainly L-band Booster- and Pre-amplifier	Higher output power Mainly 1480-nm LD pump

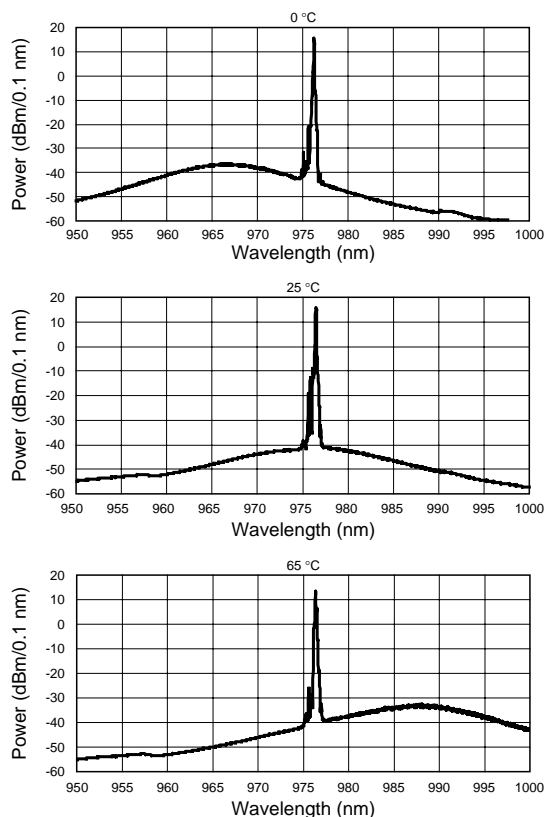
**Figure 1** Optical configuration of amplifier with uncooled pump LD.**Figure 2** Appearance of uncooled pump LD (L) and cooled pump LD (R).

3. COMPACT OPTICAL FIBER AMPLIFIER WITH UNCOOLED PUMP

The optical configuration of the compact optical fiber amplifier with an uncooled pump is shown in Figure 1. The package size is 90×70×12 mm and some optical components such as uncooled pump, Photo Diode (PD), optical coupler, optical WDM coupler, optical isolator, and EDF are included in this package. The wavelength of the uncooled pump is around 980 nm.

The appearance of the uncooled pump is shown in Figure 2. The appearance of the cooled pump is also shown in the same figure.

As mentioned above the uncooled pump does not include a cooling device. So, the oscillation wavelength changes according to ambient temperature. This behavior causes a degradation in the conversion efficiency of the amplifier, because the absorption band of EDF around 980 nm is very narrow. To avoid this phenomenon a Fiber Bragg Grating (FBG) is set in the output fiber of laser. This FBG keeps the oscillation wavelength stable, in spite of

**Figure 3** Temperature dependence of output wavelength of uncooled pump LD with FBG.

the change of ambient temperature. See Figure 3. The spectra of the output of uncooled pump are shown in this figure. They are measured under conditions with ambient temperature of 0, 25, and 65°C. They show that the wavelength is locked by the FBG in spite of the change of ambient temperature, although the oscillation wavelength of the uncooled pump moves. (The curves near the bottom line are the output spectra of the uncooled pump.)

Figure 4 shows the optical characteristics of the compact optical fiber amplifier with an uncooled pump. It is designed for a higher output power. The upper figure is the required pumping power vs. signal wavelength, and the lower figure is the noise figure vs. signal wavelength when the input power is -10 dBm and the output power is adjusted to +11 dBm. Output power of +11 dBm was obtained under the condition that the signal wavelength was from 1530 to 1566 nm and the ambient temperature was from 0 to 65°C. The noise figure was less than 5.5 dB and the required pumping power was under 80 mW.

These results are summarized in Table 2.

Figure 5 shows the optical characteristics of the compact optical fiber amplifier optimized as a preamplifier. It is designed so that the gain is over 22 dB when the input power is -25 dBm. The noise figure was under 5.7 dB. These results are summarized in Table 3.

Figure 6 shows a compact optical fiber amplifier with an uncooled pump.

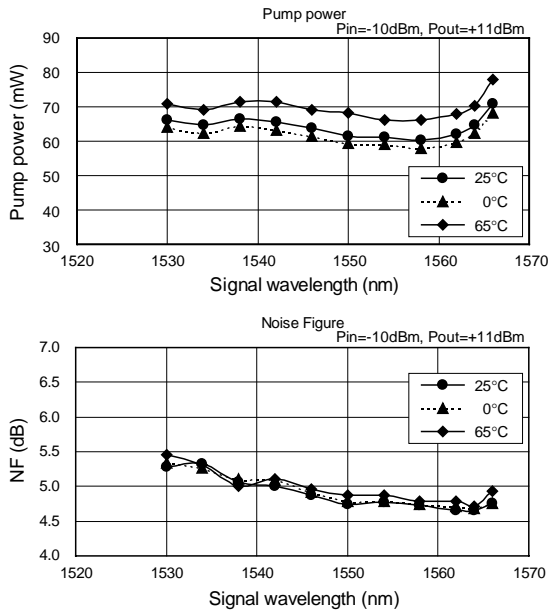


Figure 4 Characteristics of compact optical fiber amplifier with uncooled pump LD (I).

Table 2 Summary of compact optical fiber amplifier with uncooled pump LD (as a booster amplifier).

Items	Characteristics
Operating temperature	0 to 65°C
Signal wavelength range	1530 to 1566 nm
Input power	> -10 dBm
Output power	> +11 dBm
Noise figure @ $P_{in}=-10$ dBm	< 5.5 dB

4. COMPACT OPTICAL FIBER AMPLIFIER WITH COOLED PUMP

The optical configuration of the compact optical fiber amplifier with a cooled pump is shown in Figure 7. It is the same as that with an uncooled pump with the exception of the pumping laser. The wavelength of the pumping laser is around 980 nm. The butterfly pumping laser is in the same package as the mini-DIL pumping laser. This amplifier includes an input power and an output power monitor.

A higher output power is achieved compared to the uncooled pump optical fiber amplifier.

Figure 8 shows the optical characteristics of the compact optical fiber amplifier optimized as a booster amplifier. It is designed for an output power of over 15 dBm when the input power is -10 dBm. The upper figure is the required pumping power vs. signal wavelength, and the lower figure is the noise figure vs. signal wavelength when the input power is -10 dBm and the output power is adjusted to +15 dBm. An output power of +15 dBm was obtained under the condition that the signal wavelength was from 1530 to 1561 nm and the ambient temperature

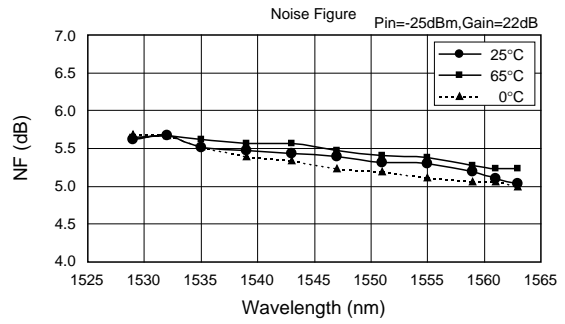


Figure 5 Characteristics of compact optical fiber amplifier with uncooled pump LD (II).

Table 3 Summary of compact optical fiber amplifier with uncooled pump LD (as a preamplifier).

Items	Characteristics
Operating temperature	0 to 65°C
Signal wavelength range	1529 to 1563 nm
Input power	-40 to -20 dBm
Gain	> 22 dB
Noise figure @ $P_{in}=-25$ dBm	< 5.7 dB



Figure 6 Appearance of compact optical fiber amplifier with uncooled pump LD.

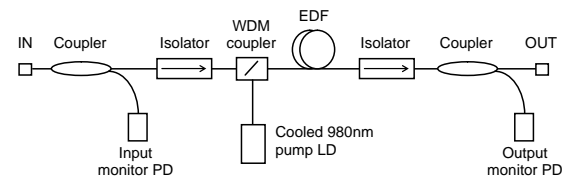


Figure 7 Optical configuration of amplifier with cooled pump LD.

was from 0 to 65°C. The noise figure was less than 5.0 dB and the required pumping power was under 150 mW. It was confirmed that the radiation of heat was good and the cooling device functioned well, even when the ambient temperature was 65°C.

These results are summarized in Table 4.

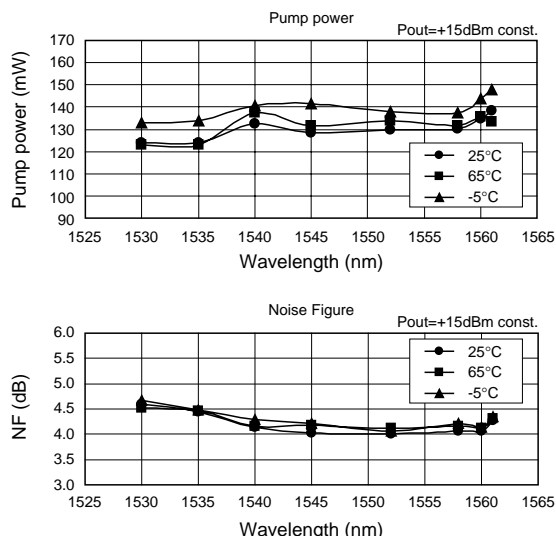


Figure 8 Characteristics of compact optical fiber amplifier with cooled pump LD.

Table 4 Summary of compact optical fiber amplifier with cooled pump LD (as a booster amplifier).

Items	Characteristics
Operating temperature	-5 to 65°C
Signal wavelength range	1530 to 1561 nm
Input power	> -10 dBm
Output power	> +15 dBm
Noise figure @ $P_{in}=-10$ dBm	< 5.0 dB

5. COMPACT OPTICAL FIBER AMPLIFIER WITH A HEAT SINK

A 1480-nm pumping laser is used for a higher output power amplifier and a L-band amplifier, because it is known that the efficiency of pump to signal conversion when pumped by a 1480-nm laser is higher than that by 980-nm laser. However the operating forward current of the 1480-nm laser is apt to be higher and this causes an increment of cooler current. So, a heat sink is needed to radiate heat. A compact optical fiber amplifier platform with a heat sink was developed for higher output power amplifiers and L-band amplifiers. The heat sink was optimized by simulating actual conditions, operating forward current, and cooler current, which depend on the output power of optical fiber amplifier.

Figure 9 shows an example of a compact optical fiber amplifier with a heat sink. The dimensions are 90 (W)×70 (D)×25 (H) mm.

The characteristics of an optical fiber amplifier using this platform are introduced in this section.

Figure 10 shows the optical configuration of the compact optical fiber amplifier for L-band. An isolator is located between two EDFs; here, the ratio of these two EDFs in length is about 1:10. (This isolator is called a middle isolator in this paper.)

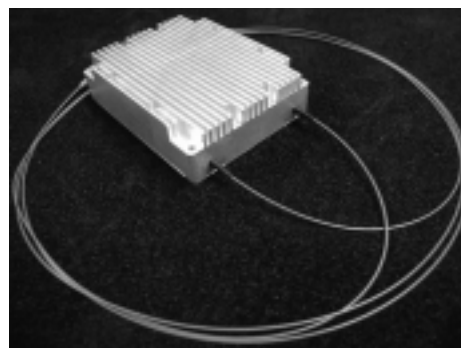


Figure 9 Appearance of compact optical fiber amplifier with heat sink.

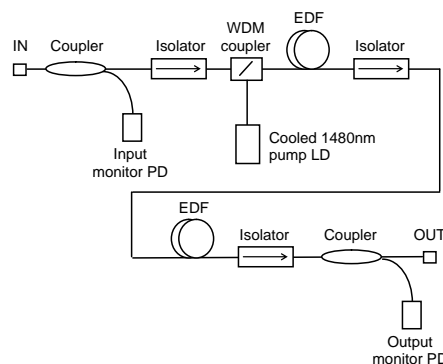


Figure 10 Optical configuration of amplifier for L-band.

A forward pumping configuration (without middle isolator) is one of the normal configurations of optical fiber amplifiers, but it has the weak point that the backward Amplified Spontaneous Emission (ASE) wastes pumping power near the input terminal of the EDF, and this behavior causes a degradation of the output power of the amplifier and noise figure characteristics. Therefore, the middle isolator is used to correct this. This middle isolator prevents the ASE from going back to the input end of EDF and wasting pumping power. Although this middle isolator is designed so that insertion loss is lowest for the C-band, the pumping and signal light can pass the isolator under the condition that losses at these wavelengths are only 0.2 or 0.3 dB larger than that of the C-band. For this reason, WDM couplers in front of and behind the middle isolator, which make the pumping light bypass the middle isolator, are not used.

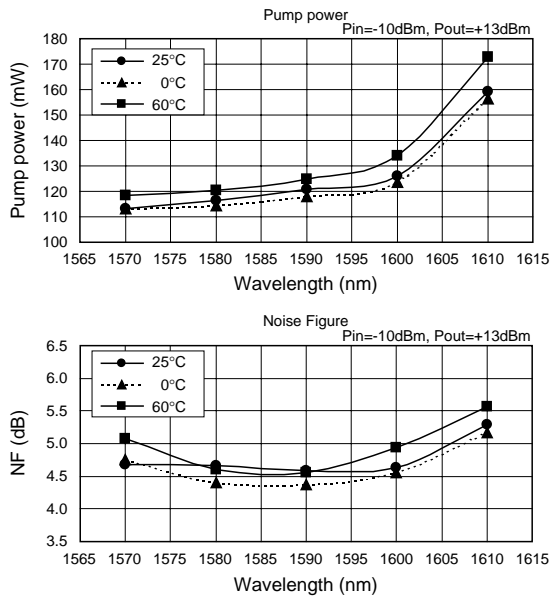
In the case of the optical fiber amplifier for L-band, it is necessary to make the EDF much longer than for the C-band to obtain enough gain because the gain coefficient at the L-band is very small. The long EDF must be put into a compact package. To solve this problem a reduced cladding EDF was developed. The parameters of this EDF are shown in Table 5. Because the diameter of the normal EDF is 250 μ m, the volume occupied is reduced to less than half. The EDF length was about 60 m. By increasing the density of Erbium the EDF length can be shortened, even if a higher gain is needed.

Table 5 Parameters and characteristics of reduced cladding EDF.

Items	Characteristics
Mode field diameter	5.21 μm
Cladding diameter	80 \pm 2 μm
Coating diameter	167 \pm 5 μm
Cutoff wavelength	867 nm
Erbium density	1446 wtppm
Al density	3.3 wt%

Table 6 Summary of compact optical fiber amplifier for L-band.

Items	Characteristics
Operating temperature	0 to 60°C
Signal wavelength range	1570 to 1610 nm
Input power	> -10 dBm
Output power	> +13 dBm
Noise figure @ $P_{in}=-10$ dBm	< 5.7 dB

**Figure 11** Characteristics of compact optical fiber amplifier for L-band.

The characteristics of the compact optical fiber amplifier for the L-band are shown in Figure 11. It is designed for an output power of over 13 dBm when the input power is -10 dBm. The upper figure is the required pumping power vs. signal wavelength, and the lower figure is the noise figure vs. signal wavelength when the input power is -10 dBm and the output power is adjusted to +13 dBm. Output power of +13 dBm was obtained under the condition that the signal wavelength was from 1570 to 1610 nm and the ambient temperature was from 0 to 60°C. The noise figure was less than 5.7 dB and the required pumping power was under 180 mW. It was confirmed that radiation of heat was good and the cooling device operated adequately even when the ambient temperature was 60°C and the operating forward current was over 700 mA.

These results are summarized in Table 6.

6. CONCLUSION

The following three platforms for compact optical fiber amplifiers have been developed.

- (1) Compact optical fiber amplifier with uncooled pump
- (2) Compact optical fiber amplifier with cooled pump
- (3) Compact optical fiber amplifier with heat sink

Examples of optical fiber amplifiers using these platforms have been reported.

Various compact optical fiber amplifiers for single channel and small channel applications will be designed for use with these platforms.

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