Broadband Optical Amplifiers for DWDM Systems

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ABSTRACT The spread and expansion of DWDM (Dense Wavelength Multiplexing) systems are going on keeping pace with various technology developments of optical amplifiers and, in particular, the bandwidth broadening of EDFAs (Erbium Doped Fiber Amplifier). In this technology area, gain-equalizing technology has been developed to flatten the gain peaks around 1532 nm, making available a wide range of wavelengths from 1530 to 1560 nm. Furthermore, development of gain-shift technology is under way, in which gain is shifted to the long wavelength band of 1570-1600 nm using long lengths of Erbium doped fibers (EDFs). This paper reports on the optical amplifier products that Furukawa Electric has developed so far: 1) modularized optical amplifier for 1530-1560 nm, which permits flexible control using a micro-processor; 2) desktop optical amplifier having a gain band shifted to 1570-1600 nm; and 3) ultra compact gain module for single channel use, which compensates for the loss due to passive components in DWDM systems, thus improving flexibility in the system design.

1. INTRODUCTION

The rapid increase of communications demand triggered off by the Internet has strongly supported the development and practical use of the DWDM systems. Thus, the DWDM system that had been a subject of discussion at academic meetings until only a few years ago has come into practical applications with a rush, and the number of multiplexed channels is reaching a figure as many as 100.

Such spread and expansion of the DWDM systems have been progressing keeping pace with the technology developments to broaden the bandwidth of EDFAs.

The band broadening technology of EDFAs based on silica fibers includes: flattening of the gain vs. wavelength characteristics for 1530-1560 nm (i.e., C-band) using gain equalizer [1]; and shifting gain to longer wavelengths using long lengths of EDFs with a low population inversion rate ensuring a sufficient gain at 1570-1600 nm (i.e., L-band) [2, 3]; and both technologies have been practically used. Moreover, EDFFA (Er Doped Fluoride Fiber Amplifier) has been developed and actually used, in which silica fiber as host glass is replaced by fluoride glass fiber [4, 5]. Recently, EDTFA (Erbium Doped Tellurite Fiber Amplifier) based on tellurite glass has been developed, achieving excellent amplifier characteristics over an entire wavelengths of 1530-1600 nm --unattainable with EDFAs [6)~8)].

Optical amplification in most of the 1500-nm band has become practicable, as described above, using optical fiber amplifiers based on EDFs. On the other hand, the 1400-nm band is now drawing attention as a new communications band, since the problem of absorption loss due to water contamination in fiber has been solved thanks to the advances in fiber manufacturing technology. TDFA (Thulium Doped Fiber Amplifier) has been developed and reported to cover the 1400-nm band, which is based on stimulated emission using Thulium [9), 10)]. What is more, unlike optical amplification based on stimulated emission, Raman amplification enables amplification at an arbitrary wavelength by selecting a suitable pumping wavelength. Based on this principle, an ultra-broadband amplifier system has been developed, in which Raman amplification and EDFA are adopted for the 1400-nm and the 1500-nm band, respectively [11)]. It is interesting to note that Raman amplification was a major research concern before EDFA appeared. It was discarded as impracticable, however,

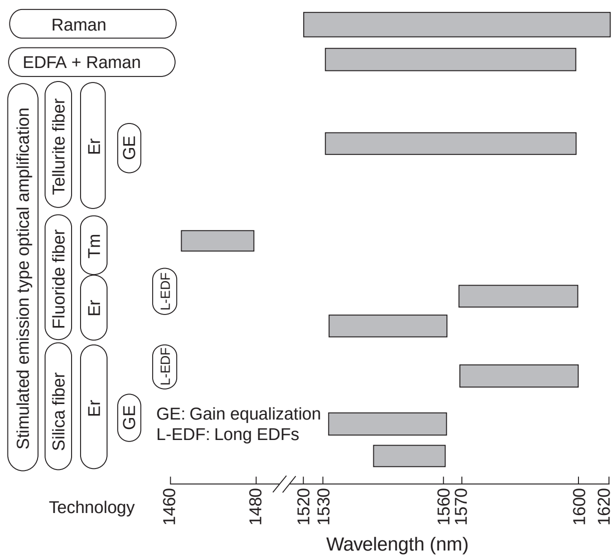

Figure 1 Development status of optical amplifiers for DWDM systems

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because of the fact that it necessitated large pumping power and that EDFA was invented in the late 1980s. Recently it is drawing attention again, since in the course of EDFA development, the pumping laser for the 1480-nm band has made such an improvement in its output power that it now provides a pumping power sufficient for obtaining practical Raman gains. A growing need for broadband amplification also supported reconsideration of this technology [12].

Figure 1 shows applicable wavelength bands of optical amplifiers thus developed [13]. It can be seen that the 1500-nm band and the 1400-nm band are covered by the stimulated emission type amplifiers using Erbium and Thulium respectively, and that the band for Raman amplification is located to supplement or to partly overlap the two bands. It is anticipated that, from now on, such technologies as EDFA, TDFA, and Raman amplification are integrated to pursue practical development of photonic network systems that utilizes the entire wavelength band spanning 200 nm.

Furukawa Electric has been keenly developing EDFAs for DWDM systems from the late 1990s, and is now developing element technologies for Raman amplification, taking notice of the effectiveness of this technology. This paper reports on the development of EDFAs for DWDM systems based on silica fibers, leaving out the introduction of Raman amplification development for a certain paper [14].

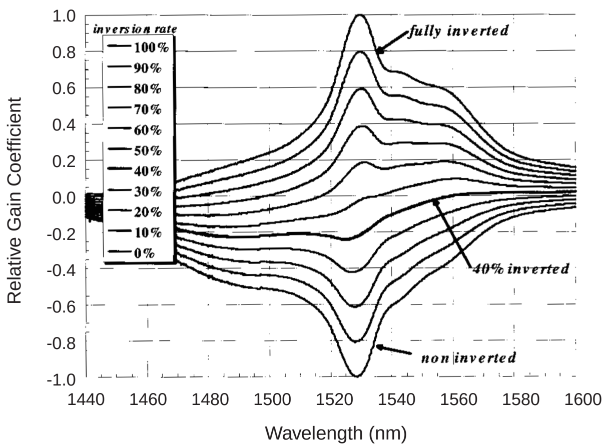


Figure 2 **Gain coefficients of EDFs with population inversion rate as a parameter**

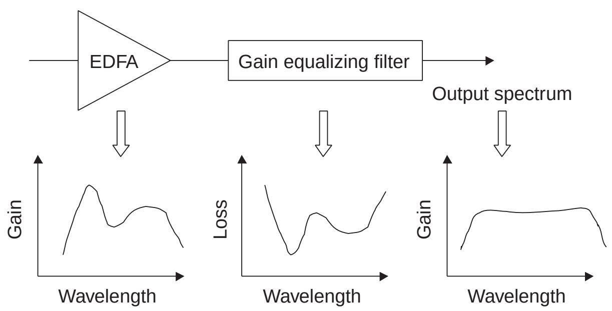


Figure 3 **Conceptual diagram of gain flattening using gain equalizing filter**

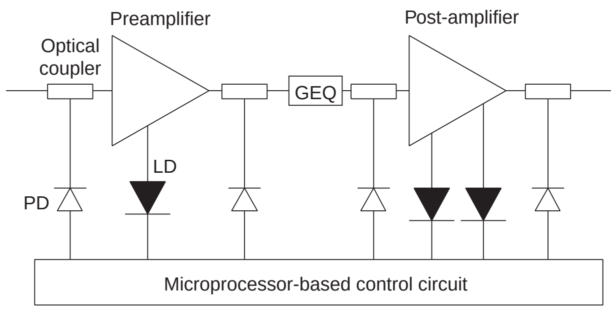
2. DEVELOPMENT OF EDFA FOR 1530-1560 NM (C-BAND)

Characteristics required for optical amplifiers for DWDM are flatness in the gain vs. wavelength performance and high output power. Of these, since DWDM systems have to amplify multiple optical signals of different wavelengths simultaneously, the flatness of gain with respect to wavelength (i.e., gain flatness) is considered to be most important. Development of EDFAs for DWDM is identical to, in other words, technology development of how to achieve a gain flatness.

Figure 2 shows the gain coefficient spectrum of EDFs with population inversion rate as a parameter. When we pay attention to the 1540-1560 nm band of the spectrum, it is seen that the spectrum shows a negative slope with respect to wavelength when the population inversion rate is high and a positive slope when the rate is low. In the case of Figure 2, an optimum flatness is obtained when the population inversion rate is controlled to around 70%. When it comes to the entire bandwidth of 1530-1560 nm, however, the steep gain peak at around 1532 nm constitutes an obstacle making it impossible to obtain flat gain characteristics only by controlling the population inversion rate. Accordingly, it is normal practice to use gain-equalizing filter to flatten the gain in this band. Figure 3 shows a conceptual diagram of gain flattening using a gain-equalizing filter, in which it is illustrated that the filter is provided with a loss spectrum that is reversed to the gain spectrum of an EDF, thereby resulting in a flat gain spectrum.

2.1 ErFA3300

ErFA3300 has been developed to respond to various needs of DWDM systems for inter-office trunk lines, in an effort to offer EDFAs that are flexible enough in optical characteristics as well as in electrical controllability. Figure 4 and Photo 1 show the configuration and appearance of ErFA3300, respectively. ErFA3300 allows mounting of three pumping lasers, i.e., one for the preamplifier and two for the post-amplifier. A gain equalizing filter is installed between the preamplifier and post-amplifier, thereby enabling amplification for the 1530-1560 nm band with a gain flatness of 1 dB or better. An output power of 20 dBm maximum is available by using a high-power pumping laser for 1480 nm in the post-amplifier. Figure 5 shows an



GEQ: Gain equalizing filter, PD: Photo diode, LD: Pumping LD

Figure 4 **Configuration of ErFA3300**

output power spectrum of ErFA3300 with 32 channels of different wavelengths signals incident on this amplifier, demonstrating that flat gain characteristics are obtained for the entire band of 1530-1560 nm.

ErFA3300 offers a variety of features and functions valuable for DWDM EDFAs as follows.

- A microprocessor is provided to permit arbitrary setting for any of the automatic gain control, automatic level control, or automatic pumping power control of each amplifier stage simply by selecting the program.
- Output power level is adjustable in 64 steps.
- Both the serial and parallel interfaces are provided.
- The dynamic range is 40 dB or greater and the input and output monitoring function has an accuracy of ±0.25 dB on average.

Photo 1 Appearance of ErFA3300

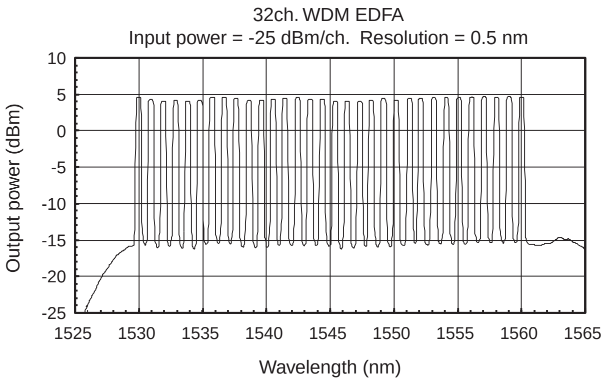


Figure 5 Output power spectrum of ErFA3300

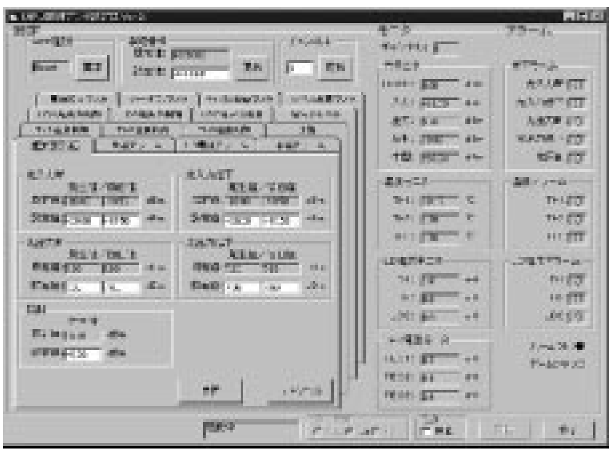


Figure 6 Graphical user interface of ErFA3300

- Interconnection with an external computer enables, through graphical user interface, monitoring and setting of the input and output power, operating conditions of each pumping laser, and operating conditions of EDFA. See Figure 6.

2.2 ErFA3100

ErFA3100 has been developed aiming at offering a low gain-, low output power-, low cost-EDFA to such optical communications systems as metropolitan DWDM systems and optical LANs which are expected to grow rapidly. While the amplifier, like ErFA3300, has a flattened gain spectrum over the 1530-1560 nm band using a gain-equalizing filter, it allows mounting of just one pumping laser and has a rather small maximum saturation output power of 13 dBm. Photo 2 shows its appearance. It is based on a simple optical configuration consisting of a single stage amplifier and a gain-equalizing filter at the output side; and the 980 nm band was selected as pumping wavelength taking noise characteristics into account. Automatic gain control is adopted for control scheme, in which the influence of ASE (Amplified Spontaneous Emission) is automatically compensated for when the optical signal level is low, thereby a specified gain is precisely maintained. Other electrical specifications are identical to those of ErFA3300. Figure 7 shows its gain flatness deviation with the input level as a parameter, indicating that the flatness is maintained irrespective of input level changes.

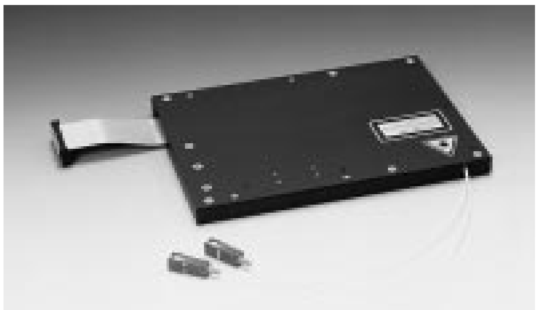


Photo 2 Appearance of ErFA3100

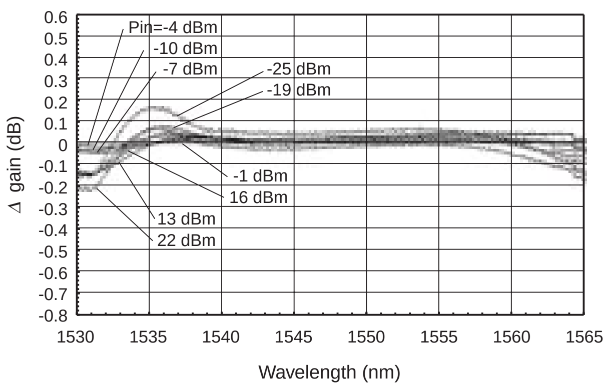


Figure 7 Characteristics of ErFA3100: gain flatness deviation vs. input level

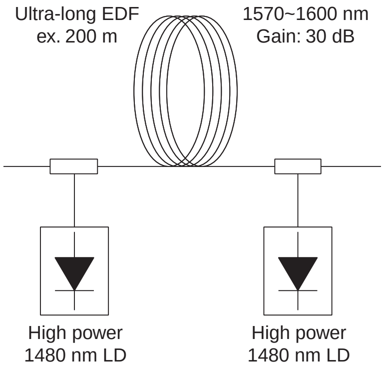


Figure 8 Configuration of L-band EDFA

Photo 3 Appearance of ErFA1419, a desktop optical amplifier using L-band EDFA

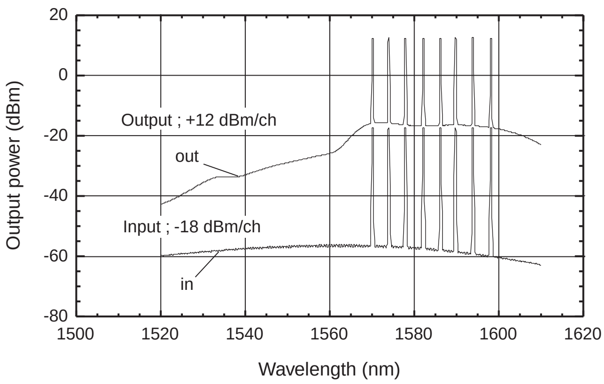


Figure 9 Characteristics of L-band EDFA

3. DEVELOPMENT OF EDFA FOR 1570-1600 NM (L-BAND)

It was known that usual silica based EDFs had amplification property at wavelengths longer than 1570 nm. This fact had been neglected, however, until a strong need for amplification band expansion arose from the DWDM systems side because of the poor amplification efficiency at such long wavelengths. When we review Figure 2 focusing on the band near 1570-1600 nm, it can be seen that the EDFs have optical gains at the long wavelength band of 1570 nm and higher. However, the gain available at 1570 nm and higher is so small that long lengths of EDFs together with a large pumping power is needed to obtain a gain of 25-30 dB --a practical level for an optical amplifier-- by accumulating small gains along the fiber length [13].

Development of EDFAs for the 1570-1600 nm band has made a rapid progress since it was reported in 1997 [2, 3]. The technological background of this rapid development consists in the fact that element technologies for the optical amplifier development are the same as for the conventional 1530-1560 nm EDFA, and that high power pumping lasers were already available through development.

Figure 8 shows the configuration of an L-band EDFA and Figure 9 typical characteristics. L-band EDFAs require long lengths of EDFs longer than those for conventional C-band EDFAs by as much as five to ten times. One of the characteristics of L-band EDFAs is that almost flat gain performance is obtained over the entire band of 1570-1600 nm dispensing with gain-equalizing filters. Although foreseeable from Figure 2, this is something that can not be achieved by C-band EDFAs. Photo 3 shows an appearance of ErFA1419, a desktop optical amplifier developed for R&D purpose using an L-band EDFA. It has achieved a gain flatness of 1 dB in addition to a saturation output power of +20 dBm or higher at the 1570-1600 nm band.

4. DEVELOPMENT OF ULTRA COMPACT GAIN MODULE FOR PASSIVE COMPONENT LOSS COMPENSATION

Passive components having large insertion loss are often used in such major stages of practical DWDM systems as optical multiplexer, optical de-multiplexer, optical add-drop multiplexer, and optical cross connect. If an EDFA is available to compensate for these passive components losses on a unit channel basis, it will greatly enhance system design flexibility, thus making construction of low-cost systems feasible. ErFA1974, an ultra compact gain module of the name card size, has been developed in response to such needs. ErFA1974 simply consists of a Peltier-element free coaxial package of the 1480 nm pumping laser

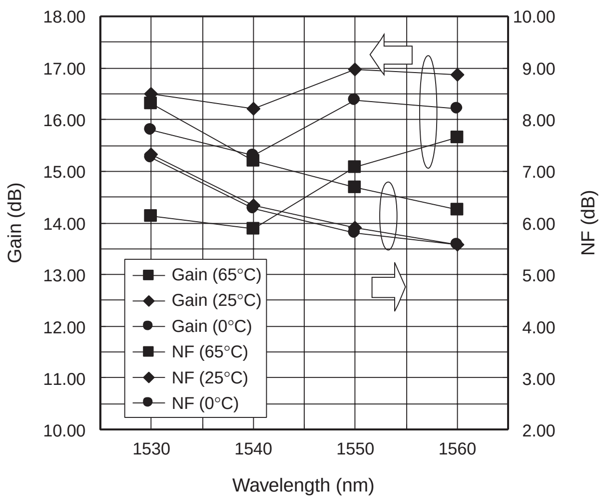


Figure 10 Gain and noise characteristics of the ultra compact gain module

and a coupler that combines the pumping and signal lights. It measures 85 x 53 x 8 mm, the name card size, and allows mounting of an optical isolator if necessary. Figure 10 shows typical characteristics.

5. CONCLUSION

We have described the development status of optical amplifiers for DWDM systems including EDFAs for the 1530-1560 nm and 1570-1600 nm bands and an ultra compact gain module for passive component loss compensation. It would be an unexpected pleasure for us if such technology developments could make some contribution to the growth of not only DWDM systems of today and tomorrow but also the photonic network systems in the future.

We would like to take this opportunity to thank all those who cooperated and worked with us in the course of development.

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