Overview of Wideband Optical Fiber Amplification Technologies

Makoto Yamada†

Abstract

Optical fiber amplifiers are essential for increasing the scale and performance of communication systems. They play a major role in determining the operating wavelength region of a network, especially in long-haul transmission systems. This article gives an overview of wideband technology for rare-earth-doped fiber amplifiers and fiber Raman amplifiers as an introduction to the other articles in this special feature.

1. Importance of wideband optical fiber amplifiers

With the use of personal computers and other information terminals spreading and multimedia technologies including the Internet and electronic commerce becoming more popular, the communication network is growing in scale and complexity. To handle this growing traffic, photonic networks are being developed for long-haul communication network systems [1]. Photonic networks can increase the transmission capacity by handling optical signals of different wavelengths in an optical fiber by dense wavelength division multiplexing (DWDM), and optical nodes that function as optical cross-connects and add/drop multiplexers etc. improve system flexibility and functionality. Optical fiber amplifiers are important system components in the construction of photonic networks based on DWDM transmission. They can compensate for loss in transmission optical fiber and in optical devices (such as optical add/drop multiplexers and optical switches) that make up a network and enable greater network scale and transmission distances. It is no exaggeration to say that the amplification bandwidth or operating wavelength region of the optical fiber amplifiers determines the operating wavelength region of the network. Thus, to create large-capacity photonic networks, we must expand the bandwidth of optical fiber amplifiers. Efforts to increase network capacity are being combined with efforts to expand the optical fiber amplification bandwidth to the C band (1530–1565 nm), L band (1565–1625 nm), and S band (1460–1530 nm) [2]-[3]. **Figure 1** shows the development of optical-fiber transmission capacity over time [3]. Large-volume transmission of 10.92 Tbit/s has been demonstrated using a combination of the S, C, and L bands.

In recent years, we have also seen the introduction of coarse wavelength division multiplexing (CWDM) as a transmission scheme for constructing low-cost networks (compared with DWDM) for short- and medium-distance transmission systems and metropolitan networks. Adding optical fiber amplifiers to this type of transmission system should also lead to greater transmission capacities and longer transmission distances.

In addition to studying optical fiber amplifiers for DWDM or CWDM using the 1500-nm band, we are studying the introduction of optical amplification technologies and ways of improving network characteristics in the 1300-nm band (O band: 1260–1360 nm) for short- and medium-distance transmission systems and in the U band (1625–1675 nm), a wavelength region used for supervision. Last year, this journal published a letter from a co-worker and I describing ultra-wideband amplification technologies for optical fiber amplifiers [2]. This issue expands upon that theme with a special feature of four articles.

† NTT Photonics Laboratories
Atsugi-shi, 243-0198 Japan
E-mail: myamada@aecl.ntt.co.jp

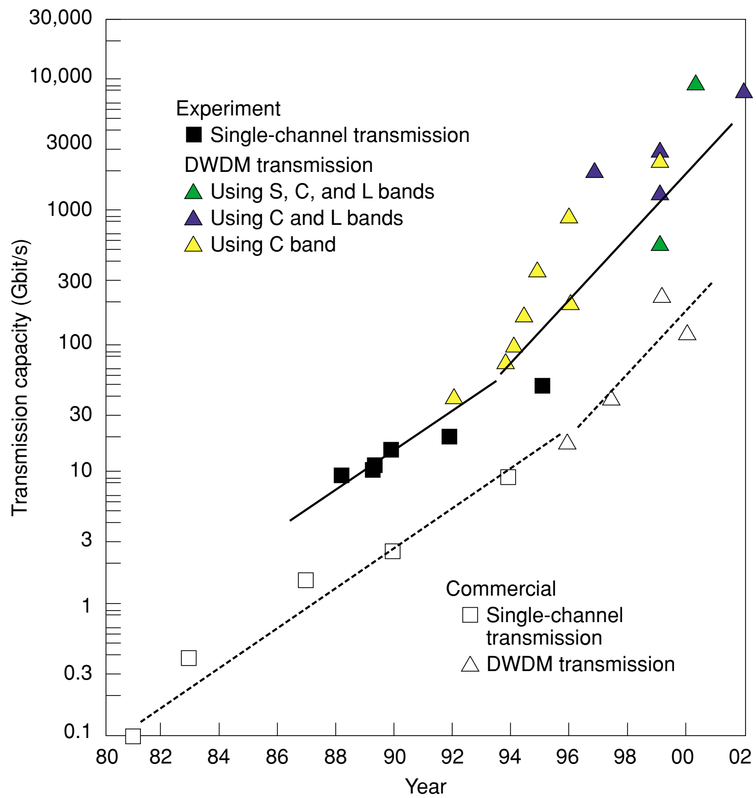


Fig. 1. Development of optical-fiber transmission capacity over time.

2. Overview of wideband efforts

There are two types of optical fiber amplifier: i) rare-earth-doped fiber amplifiers, such as the erbium-doped fiber amplifier (EDFA) and ii) the fiber Raman amplifier (FRA), which uses stimulated Raman scattering. For rare-earth-doped fiber amplifiers, the bands for which amplification can be performed depend on the type of rare-earth ion used. For example, Er^{3+} (erbium) corresponds to optical amplification in the S, C, and L bands, Tm^{3+} (thulium) to the S and U bands, and Pr^{3+} (praseodymium) to the O band. Erbium- and thulium-doped fiber amplifiers are known as EDFAs and TDFAs, respectively. The fiber Raman amplifier, on the other hand, while inferior to rare-earth-doped fiber amplifiers in terms of excitation efficiency, can amplify a signal of any wavelength by using a pump light on the short-wavelength side of the wavelength band targeted for amplification (for the 1500-nm band, a wavelength about 100 nm shorter than that of the signal is used).

Figure 2 shows the amplification bandwidth of rare-earth-doped fiber amplifiers and the fiber Raman amplifier developed so far and the loss spectrum of transmission fiber. **Table 1** summarizes wideband concepts using fiber amplifiers and gives the requirements and associated amplifier configurations [4]. Wideband technologies are being developed to expand the WDM transmission bandwidth based on the following two methods:

1) Connecting optical fiber amplifiers having different amplification bandwidths in parallel and
2) Expanding the amplification bandwidth itself.

In particular, we are developing practical C-band and L-band EDFAs as wideband, parallel-type rare-earth-doped fiber amplifiers and TDFAs and S-band EDFAs as S-band rare-earth-doped fiber amplifiers. Furthermore, to expand the bandwidth of the amplifiers themselves, we have replaced the silica fiber used in EDFAs with a new glass fiber such as tellurite or bismuth fiber, and have developed C+L dual-band amplification technology that extends the C-band EDFA amplification bandwidth into the L-band and S+C dual-band amplification technology that extends the S-band TDFA amplification bandwidth into the C band.

As for the fiber Raman amplifier, we are working to expand its bandwidth through wavelength multiplex-

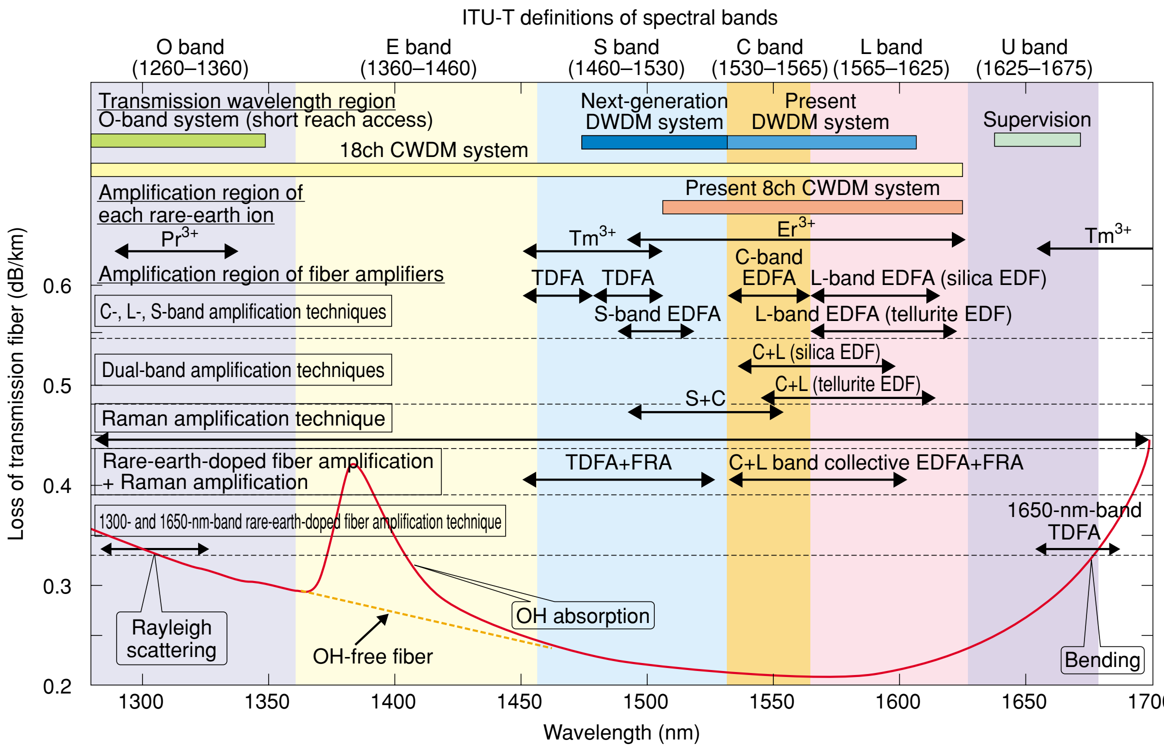
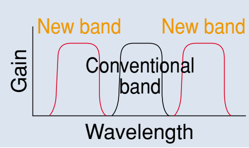
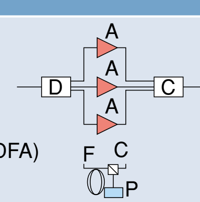
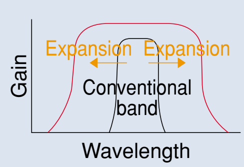
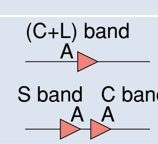
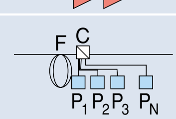
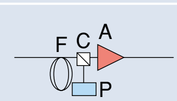


Fig. 2. Amplification bandwidth of rare-earth-doped fiber amplifiers and the fiber Raman amplifier developed so far and the loss spectrum of transmission fiber.

Table 1. Ways of achieving wideband amplifiers.

Concept	Technique	
Parallel configuration 	• C-, L-, S-band rare-earth doped fiber amplification • C-band EDFA • L-band EDFA • S-band amplification (TDFA, S-band EDFA) • Fiber Raman amplification (FRA)	
Expansion of the amplification band itself 	• New fiber glass host (tellurite, bismuth) for rare-earth-doped fiber amplifier and FRA	
	• Dual-band amplification • C+L bands • S+C bands	
	• Multi-wavelength pumping for FRA	
	• Combination of a rare-earth-doped fiber amplifier and FRA	

A: Rare-earth-doped fiber amplifier, F: optical fiber for Raman amplification
C: multiplexer, D: demultiplexer, P: pump source for Raman

ing excitation technology and are investigating further bandwidth expansion through the use of tellurite glass fiber as a Raman amplification medium in the same technology. We have also proposed technology for connecting rare-earth-doped fiber amplification and fiber Raman amplification devices in series to supplement the amplification bandwidth of rare-earth-doped fiber amplifiers with Raman amplification and have shown this to be effective in expanding bandwidth. Using parallel amplification technology, bandwidth can also be expanded by combining an FRA with a rare-earth-doped fiber amplifier.

At present, we can perform amplification throughout the whole wavelength region (1300–1650 nm) usable by transmission fiber by combining various technologies: C-band, L-band, S-band, C+L dual-band and S+C dual-band rare-earth fiber amplification, wideband-fiber-Raman amplification that can amplify optical signals in any band, series-connected rare-earth-doped fiber amplification and fiber Raman amplification, 1300-nm-band Pr^{3+}-doped fiber amplification, and 1650-nm-band TDFA amplification. In the future, we expect to see large-scale, broadband photonic networks or optical communication systems that make effective use of all of the above optical-fiber amplification bandwidths.

The next three articles in this special feature give more details about the following technologies that NTT Photonics Laboratories has been developing: 1) wideband rare-earth-doped fiber amplification to expand the gain bandwidth in the L and C bands, 2) S-band amplification through TDFAs and S-band TDFAs and O-band amplification through Pr^{3+}-doped fiber amplifiers, and 3) wideband Raman amplification using tellurite fiber. We also introduce CWDM optical fiber amplifiers that we recently made using these wideband technologies.

References

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Makoto Yamada

Senior Research Engineer, Supervisor, Photonic Processing Devices Research Group, Photonics Integration Laboratory, NTT Photonics Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from the Technical University of Nagaoka, Nagaoka, Niigata in 1983 and 1985, respectively. He joined NTT Laboratories in 1985, where he was engaged in research on guided-wave optical devices. Since 1989, he has been engaged in research on optical fiber amplifiers. In 1998, he received the D.E. degree for work on optical amplifiers from the Technical University of Nagaoka. He received the 1994 Paper Award from the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan. He is a member of IEEE, IEICE, and the Japan Society of Applied Physics.