Fields of Electronics, Information, and Communication

Achievement

Distinguished contributions to global long-distance, high-capacity optical fiber network through the development of semiconductor laser pumped optical amplifier

Prof. Masataka Nakazawa (Japan)
Born: September 17, 1952 (Age: 70)
Distinguished Professor, Specially Appointed Professor,
Tohoku University

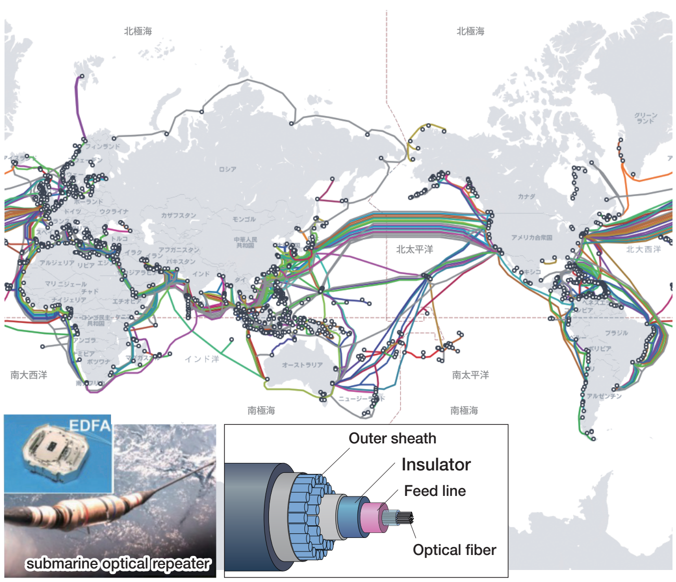
Mr. Kazuo Hagimoto (Japan)
Born: January 8, 1955 (Age: 68)
Principal Researcher,
National Institute of Information and Communications Technology

The optical transmission system connecting the world

Submarine cables are used to bridge the distances between continents and connect the world, and the term optical communication refers to the transmission of information as signals that travel along optical fibers within those cables. Information is sent using flashing light that represents the binary 0s and 1s in digital data, which allows information to be sent faster and over longer distances.

Optical fibers are made of high-purity glass and other materials in order to minimize signal loss, but when transmitting over long distances, there will always be some loss of signal strength. For example, it is impossible to deliver a signal that crosses the Pacific Ocean from Tokyo to San Francisco (roughly 8,300 km) with a single transmission of an optical signal. To resolve this issue, optical repeaters are installed on submarine cables anywhere from a few dozen kilometers to one hundred kilometers apart, and the optical amplifiers inside boost signals that pass through to compensate for signal loss. The erbium-doped fiber amplifiers (EDFA) developed by Nakazawa and Hagimoto to amplify signals in this way are now being used worldwide.

Figure 1: The intercontinental optical submarine cable network



Map source: Submarine Cable Map (https://www.submarinecablemap.com/)

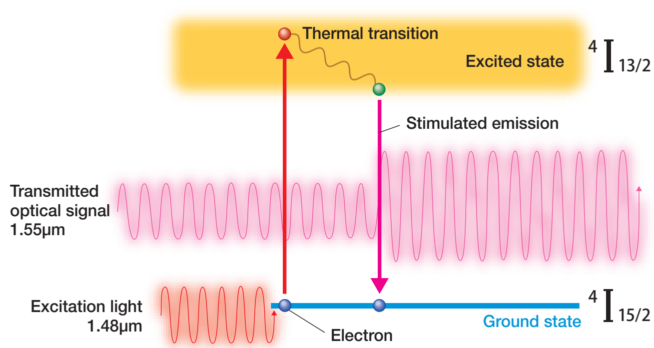
Principles of optical amplifiers and their advantages

Single-mode optical fibers were put into practical use in the 1980s. However, at that time, signal amplification was achieved using electrical amplifiers, which converted optical signals into electrical signals which were then amplified. Such devices were large and required a large amount of power, so there was demand for a compact, highly efficient, broadband optical amplifiers that could amplify the original signals without having to convert them first.

Nakazawa was the first person to propose using a 1.48 µm InGaAsP (Indium, Gallium, Arsenic, Phosphorus) laser diode to excite erbium-doped fibers. The principle under which such an optical amplifier works is shown in Fig. 2. A diode emits an excitation signal at 1.48 µm, which gives energy to an electron in the ground state in an erbium atom ($^4I_{15/2}$) and raises it to an excited state ($^4I_{13/2}$). Energy is released from that electron in a phenomenon called stimulated emission, and it is used to amplify the 1.55 µm optical signal.

Currently, optical communication is carried out in the 1.5 µm band (the minimum loss wavelength), which has the lowest possible optical attenuation at 0.2 dB per kilometer. Energy produced by stimulated emission in erbium atoms occurs in this band precisely, and it provides a gain of 12.5 dB (corresponding to the ratio of input to output strength). Furthermore, it was shown that amplification wasn't limited to a single wavelength; this stimulated emission could be used to amplify signals within a range of 40 nm.

Figure 2: Principles of optical amplifiers



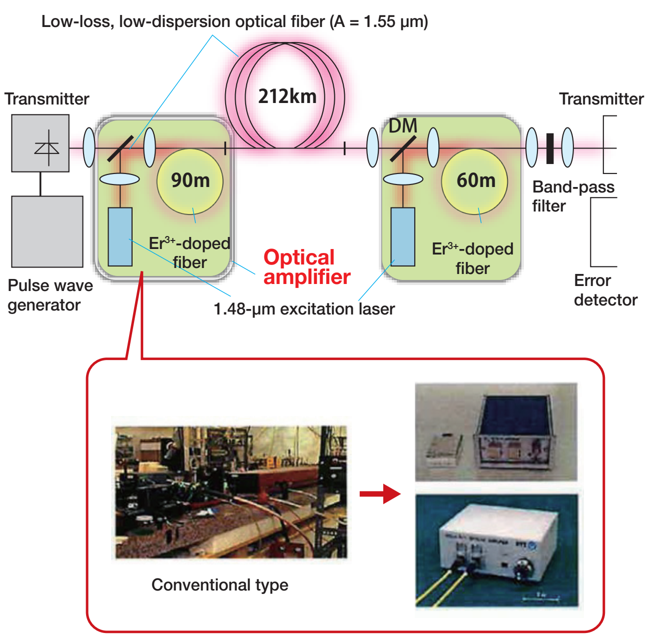
An urgent need for practical applications

Nakazawa's proposal showed that it was possible to build a battery-powered optical amplifier much more compact than existing amplifiers, which required light sources as big as 1.5 square meters. Moreover, they were broadband amplifiers capable of amplifying 1.5 µm signals over a 40 nm band, which illustrated their potential to help increase optical communication capacity.

Hagimoto learned of Nakazawa's proposal and immediately began building a practical optical communication system based on its principles. He used an EDFA measuring roughly 10 cm square, a device that had only recently been developed, and harnessed intensity modulation and direct detection to show that a 1.8 Gbit/s signal could be delivered over as long a distance as 212 km. This was the first successful demonstration of the practicality of optical amplifiers.

This technology was so exceptional that within only five years, it was being used in the long-distance transmission networks that connect the world.

Figure 3: Semiconductor laser pumped EDFAs and the 212km repeaterless transmission experiment at 1.8 Gbps



Source : https://www.youtube.com/watch?v=v_Xkn14XWcQ

Driving greater increases in capacity

After optical amplification was introduced in the 1990s, it became absolutely indispensable to optical communications. Other optical amplifiers have been developed, but EDFAs remain the most commonly used around the world. The work of Hagimoto and his fellow researchers in standardizing the technology internationally also helped demonstrate its superiority.

EDFAs are capable of amplifying multiple optical signals at different wavelengths simultaneously, so they can be combined with wavelength-division multiplexing, a technology that allows multiple signals at different wavelengths to be transmitted together and separated again at the detection end. Since the mid-1990s, that combination has driven greater increases in optical communication capacity, and opened the door to terabit-scale (10^{12} bit), large-capacity optical data transmission.

In addition, new technologies appear with regularity – technologies such as multi-level modulation transmission and digital coherent transmission – and both Nakazawa and Hagimoto continue to research these latest developments in transmission technology.

The world has entered the Data Era with the use of IoT, big data, and other developments, and the demand for increased communication capacity continues to rise. Experiments have shown that petabit-scale (10^{15} bit) transmission is possible, surpassing the 100 Tb physical limitations of single-mode fiber, thus illustrating that the evolution of optical communication – a technology that is interwoven into modern life – continues unabated.

Figure 4：Practical application of long-distance large-capacity optical fiber communication