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Temperature Dependence of Brillouin Gain Spectra in Erbium-Doped Optical Fibers with Different Concentrations

エルビウム添加光ファイバ中のブリルアン利得スペクトル
～温度とエルビウム濃度に対する依存性～

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1. Introduction

Brillouin scattering occurs when lightwave interacts with periodical refractive-index change caused by the acoustic wave in an optical fiber [1]. The frequency downshift from the incident light to the backscattered Stokes light is called the Brillouin frequency shift (BFS), which depends on the temperature and strain applied to the optical fiber. Based on this principle, to monitor the civil structures such as buildings, dams, bridges, tunnels, and dams, various kinds of fiber-optic distributed temperature/strain sensors have been developed, which include Brillouin optical time-domain reflectometry/analysis (BOTDR/A) [2], Brillouin frequency-domain analysis (BOFDA), and Brillouin optical correlation-domain reflectometry/analysis (BOCDR/A) [3].

One of the most important parameters in evaluating their performance is a measurement range, which is partially limited by the optical propagation loss in the sensing fiber. Up to now, a BOTDA system with a measurement range of as long as 150 km (2-m spatial resolution) has been achieved by employing frequency-division multiplexing (FDM) with in-line erbium-doped fiber amplifiers (EDFAs) [4], but its system was rather complicated. Another simple way to extend the measurement range of Brillouin sensors is to utilize the Brillouin scattering in fibers with optical amplification capability; for example, in pumped fibers doped with rare-earth ions, such as neodymium-doped fibers (NDFs), thulium-doped fibers (TDFs), ytterbium-doped fibers (YDFs), and EDFs. However, a detailed study on their Brillouin properties has not been reported yet.

In this work, as the first step to exploit the Brillouin scattering in rare-earth-doped optical fibers, we investigate the Brillouin gain spectra (BGS) in EDFs with three different erbium concentrations without pumping, and their dependence on temperature. We also compare these parameters with those of standard silica fibers.

2. Experimental setup

As the fibers under test (FUTs), we employed three 20-m-length EDFs with different erbium concentrations: 720 (low), 1200 (moderate), and 2280 wtppm (high). Each end of the EDFs was coupled to a silica single-mode fiber (SMF) with a fiber fusion splicer with < 0.1 dB loss.

Figure 1 depicts the experimental setup for investigating the BGS in the EDFs. The light from a laser diode (LD) at 1550 nm was split into two beams by a 50:50 optical coupler. After propagating a polarization controller (PC), one of the beams was used as the reference light for the self-heterodyne detection for measuring BFS with a high resolution. The other beam was amplified up to 18.7 dBm with an EDFA, and injected into the EDF. The Stokes light from the EDF was coupled to the reference light, and their beat signal was converted to electrical signal with a photodetector (PD) and monitored with an electrical spectrum analyzer (ESA). All the optical paths except for the EDF were composed of silica SMFs.

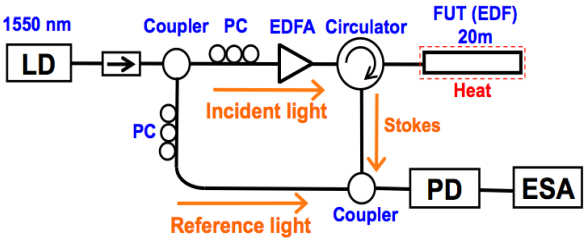

Fig. 1 Experimental setup.

3. Experimental results

We measured the temperature dependences of the BGS in the three EDFs. **Figure 2** is the data for the EDF with low erbium concentration. For all the three EDFs, with the increasing temperature, the BGS shifted toward higher frequency, and the Stokes power was increased. This behavior was the same as that of a silica SMF [5].

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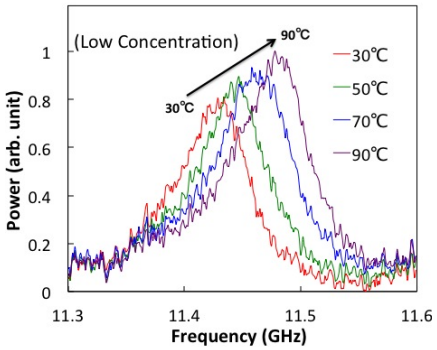

Fig. 2 Measured BGS dependence on temperature in EDF with low concentration.

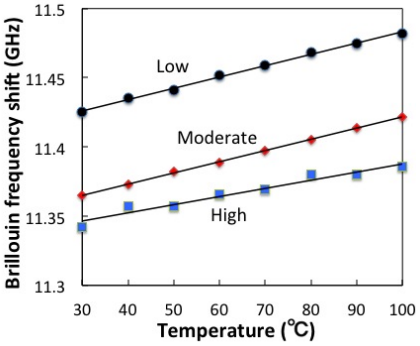

Fig. 4 Measured BFS dependence on temperature in EDFs with three different concentrations.

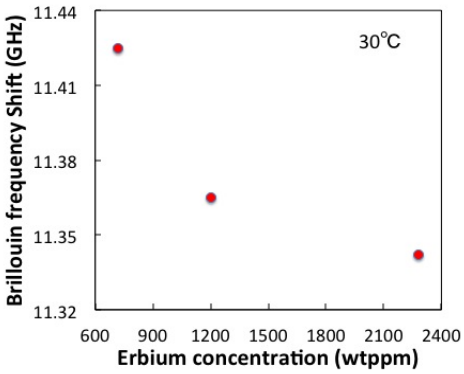

Fig. 3 BFS dependence on erbium concentration in EDF with low concentration at 30ºC.

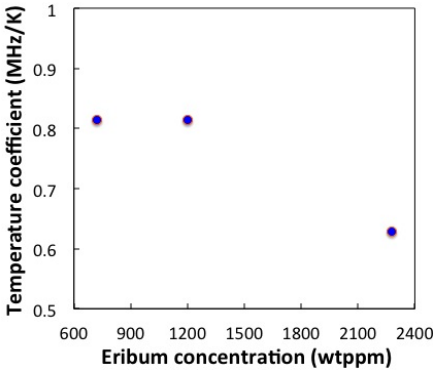

Fig. 5 Temperature conefficient of BFS in EDF as a function of erbium concentration.

Figure 3 shows the measured BFS at 30ºC as a function of erbium concentration. The BFS was approximately 500 MHz higher than that of silica SMFs. As the erbium concentration was increased, the BFS was reduced, which indicates that the BFS can be controlled by adjusting the erbium concentration.

Figure 4 shows the measured temperature dependence of the BFS in the EDFs with three erbium concentrations. Each BFS was obtained after Lorentzian fitting was performed to the BGS. The BFS in the EDFs shifted almost linearly toward higher frequency with the increasing temperature.

From **Fig. 4**, we can plot the slopes, i.e., the temperature coefficients as a function of erbium concentration, as shown in **Fig. 5**. The temperature coefficients of the EDFs (0.6−0.8 MHz/K) were lower than that of silica SMFs (1.18 [6] or 1.36 MHz/K [5]). Although the number of the EDF samples is not sufficient, the temperature coefficient seems to be reduced with the increasing erbium concentration, indicating that, by doping erbium to the fiber with much higher concentration, a strain sensor with a reduced temperature sensitivity might be feasible.

4. Conclusion

The BGS in EDFs with three different erbium concentrations and their temperature dependence were investigated without pumping. The BFS in the EDFs, which was higher than that of silica SMFs by ~500 MHz, was reduced with the increasing erbium concentration. As the temperature was increased, the BFS shifted toward higher frequency with coefficients of 0.6−0.8 MHz/K, which seemed to decrease with the increasing erbium concentration. We believe that these results will be a significant archive in developing practical sensing systems based on Brillouin scattering in pumped EDFs.

Acknowledgment

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References

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