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エルビウム添加光ファイバ中のブリルアン散乱特性の解明

Characterization of Brillouin Scattering Properties in Erbium-Doped Optical Fiber

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1. Introduction

Brillouin scattering occurs when light interacts with the acoustic waves in an optical fiber [1]. The frequency difference between the backscattered light and the incident light is called the Brillouin frequency shift (BFS), which is known to be dependent on strain and temperature change applied to the optical fiber [2,3]. This mechanism provides a feasible solution to the development of distributed fiber-optic sensors which monitor civil structures such as buildings, dams, bridges, tunnels, and aircraft wings. Among various sensing performances (spatial resolution, measurement time, etc.), measurement range is an extremely important parameter for such large-scale monitoring systems, which is partially limited by the optical propagation loss in the sensing fibers. One solution is to utilize the Brillouin scattering in fibers with optical amplification capability [4], such as rare-earth-doped fibers including neodymium-doped fibers (NDFs), ytterbium-doped fibers (YDFs), and erbium-doped fibers (EDFs). Although EDF amplifiers are most widely used in optical communication systems, no report on the Brillouin properties in EDFs has been provided so far.

In this work, as the first step toward the implementation of EDF-based sensing, we investigate the Brillouin properties in EDFs in detail without pumping, which includes BFS, Stokes power, Brillouin linewidth, and their dependence on strain, temperature, and erbium concentration.

2. Experimental setup and results

The 20-m-length EDFs with three different erbium concentrations (720, 1200 and 2280 wtppm; denoted below as low, moderate, and high concentrations, respectively) were used. The experimental setup is depicted in Fig. 1, which was almost the same as the previously-reported one [4], which employed self-heterodyne detection to monitor the Brillouin gain spectra (BGS) with high frequency resolution.

Figure 2 shows the BGS dependence on temperature in the low concentration EDF. The BFS at 20 ˚C was 11.42 GHz, which is ~600 MHz higher than ~10.8 GHz in standard silica single-mode fibers (SMFs) [1]. As the temperature was increased, the BGS shifted toward the higher frequency. The BFS dependences on temperature in the EDFs with three different erbium concentrations are shown in Fig. 3. Then, as shown in Fig. 4, we calculated the slopes, i.e., the temperature coefficients for each EDF to be approximately 0.8 MHz/K, which is 1.5 times as low as that in standard silica SMFs [3]. As the erbium concentration was increased, the temperature coefficient was reduced. As shown in Fig. 3, with increasing erbium concentration, the BFS was reduced and approached that in silica SMFs, which might be caused by the influence of alumina doping accompanied by erbium doping to the fiber.

Next, the strain dependences were investigated. As the applied strain was increased, the BGS also shifted to the higher frequency. Figures 5 and 6 show the BFS dependences on strain in three EDFs with different erbium concentrations and the dependence of the strain coefficient on erbium concentration, respectively. Regardless of the erbium concentration, the strain coefficient was approximately 490 MHz/%, which is lower than 580 MHz/% in silica SMFs [2]. The erbium concentration seems to have hardly any influence on the strain coefficient.

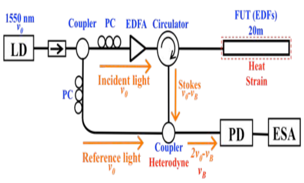

Figure 1. Experimental setup.

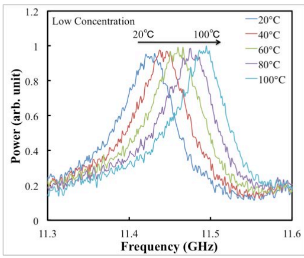

Figure 2. Measured BGS dependence on temperature in low concentration EDF.

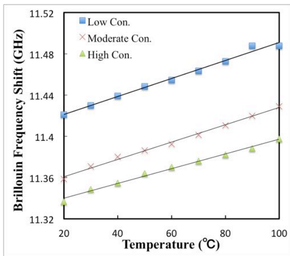

Figure 3. Measured BFS dependence on temperature in EDFs with three different concentrations.

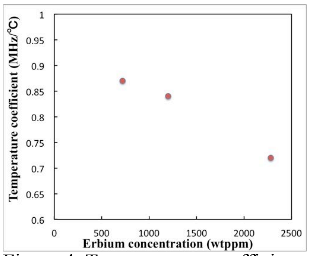

Figure 4. Temperature conefficient of BFS in EDF as a function of erbium concentration.

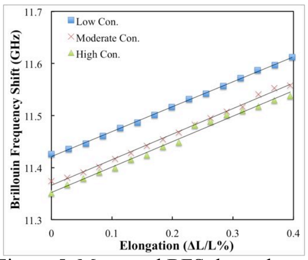

Figure 5. Measured BFS dependence on tstrain in EDFs with three different concentrations.

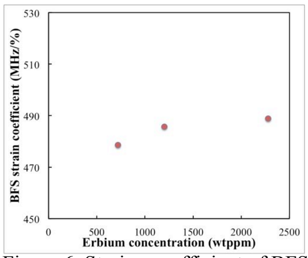

Figure 6. Strain coefficient of BFS in EDF as a function of erbium concentration.

References

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