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励起光入射によるエルビウム添加光ファイバ中のブリルアン散乱信号の増幅

Enhancement of Brillouin Scattering Signal in Pumped Erbium-Doped Optical Fiber

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1. Introduction

Brillouin scattering is one of the most significant nonlinear phenomena in optical fibers [1], and, by exploiting the dependences on Brillouin frequency shift (BFS) on temperature and strain [2, 3], it has been applied to distributed fiber-optic temperature/strain sensing for smart materials and structures. There are many parameters for evaluating the sensor performance, including spatial resolution, measurement range, measurement speed, and signal-to-noise ratio, which can be, in some cases, improved by enhancing the Brillouin signal [4].

One approach is to use pumped optical fibers doped with rare-earth ions, such as neodymium, thulium, and erbium ions. With their optical amplification capability, Brillouin signal is expected not only to be enhanced but also to be controlled at high speed by adjusting the pump light, which will be of great interest in other Brillouin application fields. Although fundamental Brillouin properties in neodymium-, thulium-, and erbium-doped fibers (NDF, TDF, and EDF) have already been investigated [5, 6], their pumping effects have not been reported yet.

In this work, we investigate the effect of 980-nm pump on the Brillouin signal in an EDF, which shows that the Brillouin Stokes power is enhanced with raising 980-nm pump power.

2. Experimental Setup

The EDF under test had a mode-field diameter of 7.2 μm, a core refractive index (RI) of ~1.47, a peak absorption at 1530 nm of 18 dB/km, and an erbium concentration of 0.72 wtppt. One end of the EDF was spliced to a silica single-mode fiber (SMF) by arc fusion, and the other end was immersed into RI matching oil to suppress the Fresnel reflection. The experimental setup based on self-heterodyne [7] is depicted in Fig. 1. The output light of a laser at 1550 nm was divided into two beams. One beam was amplified to 20 dBm with an optical amplifier, and was injected into the EDF under test. The Stokes light backscattered from the EDF was coupled with the other beam, i.e., the reference light, and was converted to an electrical signal with a photo-diode and observed with an electrical spectrum analyzer. Pump light at 980 nm was additionally injected to the EDF via a wavelength-division-multiplexing (WDM) coupler.

3. Experimental Results

Figure 2 shows the measured Brillouin gain spectra (BGS) in the EDF without and with pump light (pump power = 12, 18, and 24 dBm), and the peak power of the BGS as a function of pump power is shown in Fig. 3. The BFS without pump was 11.42 GHz, which agrees with the previous result [6]. Though the BFS kept unchanged by pumping the EDF, the Stokes power was enhanced by 1.36 dB. This amplification effect seems to be caused by three reasons: (1) the Stokes light itself

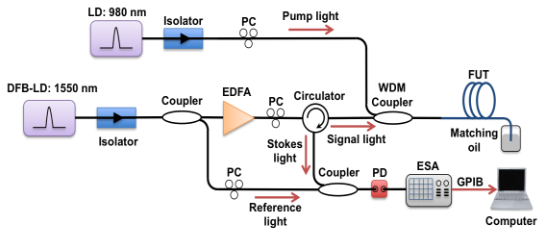

Fig. 1. Experimental setup.

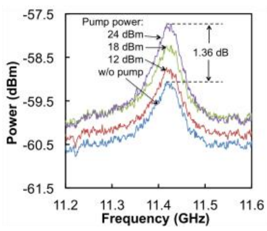

Fig. 2. Measured BGS in EDF.

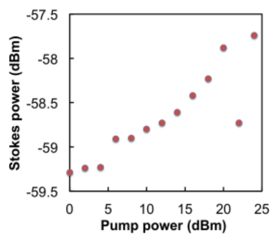

Fig. 3. Stokes power vs. 980-nm pump power.

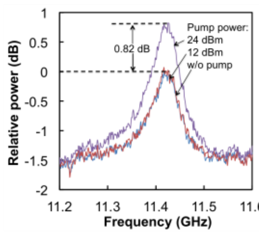

Fig. 4. Normalized BGS in EDF.

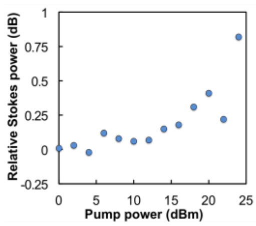

Fig. 5. Relative Stokes power vs. 980-nm pump power.

was amplified, (2) the incident light was amplified, leading to the enhancement of Brillouin signal, and (3) the enhanced amplified spontaneous emission (ASE) of EDF resulting in the raise of noise floor.

Since it is the net amplification effect of the Brillouin Stokes power that is important to Brillouin sensing, to exclude the influence of the enhanced ASE, we scaled each BGS so that the noise floor might be the same level, and set the Stokes power without pump to 0 dB, as shown in Fig. 4. When the pump power was 24 dBm, 0.82-dB amplification of the Stokes "height" was still observed. The Stokes height as a function of 980-nm pump power is shown in Fig. 5. The Stokes height was drastically enhanced when the pump power was higher than ~15 dBm. These results indicate that, if we employ a 980-nm pump laser with by far higher power than 24 dBm, much more drastic enhancement of the Stokes signal can be obtained.

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