傾斜利用ブリルアン光相関領域反射計による世界最短ホットスポットの検出

Detection of World's Shortest Hot Spots by Slope-Assisted Brillouin Optical Correlation-Domain Reflectometry

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1. Introduction

To achieve distributed strain and temperature measurements, optical fiber sensors based on Brillouin scattering have been extensively studied over a couple of decades. Many types of measurement schemes have been developed; above all, Brillouin optical correlation-domain reflectometry (BOCDR) [1] has been gathering a lot of attention since it is the only scheme with single-end accessibility and a high spatial resolution. Numerous BOCDR configurations have been implemented, for instance, to enlarge the measurement range and to increase the measurement speed.

Recently, we have developed a new high-speed BOCDR configuration, which we named slope-assisted (SA-) BOCDR [2]. By detecting a spectral power at a certain frequency on the Brillouin gain spectrum (BGS), SA-BOCDR deduces the information on Brillouin frequency shift (BFS). Note that standard BOCDR detects the BFS directly, which is relatively time-consuming due to the necessity of acquiring the whole BGS. The operation of SA-BOCDR has been demonstrated using not only silica single-mode fibers (SMFs) but also plastic optical fibers (POFs) [3]. The investigation of the relationship between the final system output (i.e., power-change distribution) and the actual BFS distribution has also been performed. Consequently, it has been theoretically proved that strained (or heated) sections even shorter than the nominal spatial resolution can be detected using SA-BOCDR [4]. Although this "beyond-nominal-resolution" effect is very attractive for practical applications, its experimental details have not been clarified yet.

In this work, we show the usefulness of the beyond-nominal-resolution effect of SA-BOCDR by experimentally detecting shortest-ever hot spots. To date, the world's shortest lengths of the hot spots (strained or heated sections) have been 3 mm for an SMF [5] and 100 mm for a POF [6]. Here, we demonstrate the detections of a 2-mm-long strained section in an SMF and a 5-mm-long heated section in a POF.

2. Experiments

The experimental setup shown in **Fig. 1(a)** was basically the same as that of Ref. [2]. The resolution bandwidth and the video bandwidth of the electrical spectrum analyzer were set to 10 MHz and 1 kHz, respectively. Averaging was performed 1024 times on an oscilloscope (OSC) to improve the signal-to-noise ratio. The room temperature was 26 °C. To begin with, a 2.0-m-long silica SMF was used as a fiber under test (FUT). Its BFS at room temperature was 10.85 GHz. We applied strains of 0.10, 0.15, and 0.20 % to a 2-mm-long section of the SMF (1.50 m from a circulator; see **Fig. 1(b)**). The modulation frequency f_m and the amplitude Δf were set to 13.45–13.54 MHz and 0.67 GHz, respectively, corresponding to the measurement range of 7.64 m and the nominal spatial resolution of 0.11 m (refer to the equations in Ref. [15]). The change in the spectral power at 10.89 GHz was observed using the OSC. Then, as an FUT, we employed a 2.0-m-long perfluorinated graded-index POF, which had a BFS of 2.75 GHz at room temperature. A 5-mm-long section of the POF (1.50 m from a circulator) was heated to 35, 45, and 55 °C. The measurement range and the nominal spatial resolution were set to 4.5 m (f_m: 24.70–24.84 MHz) and 0.21 m (Δf: 0.69 GHz). The spectral power-change at 2.78 GHz was observed.

First, we present the experimental results with the SMF. **Figure 1(c)** shows the power-change distributions measured at four strains: 0, 0.10, 0.15, and 0.20 %. The vertical axis was normalized so that the maximal value became 1 when the strain was 0.20 %. Abrupt power-changes were observed at the correct position along the SMF. The lengths of the power-changed sections appeared longer than 2 mm, which is valid and theoretically explicable (see Ref. [4]). The maximal normalized power-change (derived from each distribution) was plotted as a function of applied strain as shown in **Fig. 1(d)**. With increasing strain, the power-change increased almost linearly, which indicates the strain magnitude can be correctly measured in this strain range. Subsequently, we performed similar experiments using the POF. In the normalized power-changed distributions measured when the 5-mm-long section was heated to 26 (room temperature), 35, 45, and 55 °C (not shown here), the abrupt power-changes were observed at the correct position, and the magnitude of the power-change was in proportion to the temperature change, indicating the potential feasibility of distributed temperature sensing.

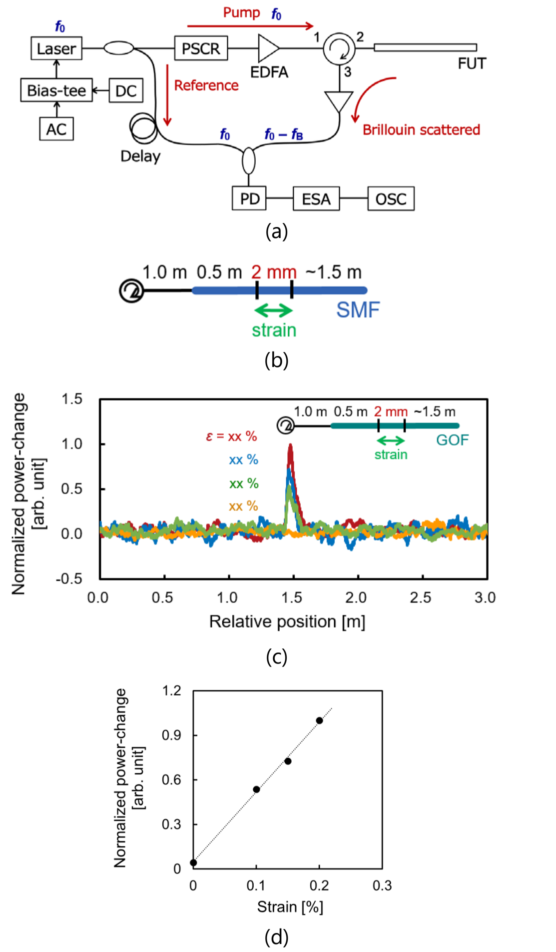

Fig. 1. **(a)** Experimental setup of SA-BOCDR. **(b)** Structure of the FUT. **(c)** Normalized power-change distributions measured at four strains. **(d)** Maximal power-change plotted as a function of applied strain.

References

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