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Large-Strain Dependence of Acoustic Velocity in Polymer Optical Fiber Estimated by Brillouin Measurement
ブリルアン測定によるポリマー光ファイバ中の音速推定 ～大歪依存性の検討～

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1. Introduction

To investigate the acoustic velocity in polymers under large strain is not only of significant physical interest but also of great importance in developing some useful devices and systems such as strain and temperature sensors [1-5]. Such investigation is, however, quite difficult because measurement of acoustic velocity with large strain applied using a bulk sample is not simple. One method to resolve the problem is to make use of Brillouin-scattered signal in fiber sample, the frequency shift of which (known as the Brillouin frequency shift (BFS)) depends on the acoustic velocity in the fibers. We have so far estimated the acoustic velocity in a perfluorinated graded-index polymer optical fiber (PFGI-POF) with no strain applied to be 1627 m/s [2]. The PFGI-POF was used because Brillouin measurement was not feasible for other POFs with much higher losses, including standard poly(methyl methacrylate)-based (PMMA-) POFs.

In this paper, based on Brillouin analysis of the PFGI-POF, we investigate the dependence of the acoustic velocity in polymers on large strain of up to 20%. The dependence is clarified to be nonlinear, which shows a unique feature of polymers.

2. Principle

When a light beam is propagating in an optical fiber, it interacts with acoustic phonons and generates a backscattered light beam called the Stokes light [6]. This phenomenon is known as Brillouin scattering, and the Stokes light spectrum is called the Brillouin gain spectrum (BGS). The center frequency of the BGS is known to be down-shifted from that of the incident light; the amount of this frequency shift ν_B, called the BFS, is given by $2\,n\,\nu_A/\,\lambda$, where n is the refractive index, ν_A is the acoustic velocity in the fiber, and λ is the wavelength of the incident light. Therefore, under the assumption that the refractive index n is constant, the acoustic velocity ν_A can be calculated from the measured BFS. It is well known that the BFS linearly changes with applied strain in glass optical fibers under small strain [6].

3. Experimental setup

We employed a 1.27-m-long PFGI-POF as a fiber under test, which had a numerical aperture (NA) of 0.185, a core diameter of 50 μm, a cladding diameter of 750 μm, a core refractive index of ~1.35, and a propagation loss of ~250 dB/km at 1.55 μm. Figure 1 shows a photo of the PFGI-POF sample. The experimental setup for investigating the BFS dependence on large strain in the PFGI-POF was shown in Fig. 2, which was basically the same as that previously reported in [2]. The BGS was observed with a high resolution by self-heterodyne detection. A distributed-feedback laser diode (DFB-LD) at 1.55 μm was used as a light source, and one end of the PFGI-POF was butt-coupled to a silica single-mode fiber (SMF). Polarization state was optimized for each measurement with polarization controllers (PCs). Different strains of up to 20% were applied to the whole length of the PFGI-POF fixed on two translation stages.

Fig. 1 Photo of PFGI-POF sample.

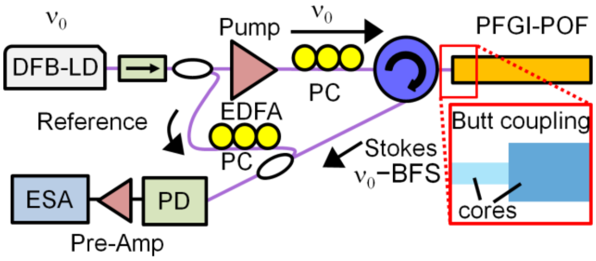

Fig. 2 Experimental setup for investigating the BFS (namely, acoustic velocity) dependence on large strain in the PFGI-POF: DAQ, data acquisition; DFB-LD, distributed-feedback laser diode (at frequency ν_0); EDFA, erbium-doped fiber amplifier; ESA, electrical spectrum analyzer; PC, polarization controller; PD, photo detector.

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4. Experimental results

First, we measured the fracture strain of the PFGI-POF. Figure 3 shows the measured stress-strain curve of a 0.1-m PFGI-POF of the identical type, which was obtained with the same method as in Ref. [5]. The cross-sectional area was assumed to be constant during the measurement. Fracture strain of the PFGI-POF was 71% and its elastic-plastic transition was apparently induced at several % strain [7].

The measured BGS dependence on large strain of up to 18.3% in the PFGI-POF is shown in Fig. 4. When the strain was 2.6%, a small peak was clearly observed at approximately 2.8 GHz. This peak was caused by a 6-cm portion of the PFGI-POF end connected to the silica SMF, to which proper strain was not applicable.

Using the data in Fig. 4, the dependence of the acoustic velocity on large strain in the PFGI-POF was calculated as shown in Fig. 5. The dependence was found to be nonlinear; with the increasing strain, the acoustic velocity shifted at first toward lower frequency (0-2.6%), then toward higher frequency (2.6-8.1%), and finally became almost constant (8.1-18.3%). This behavior seems to originate from the elastic-plastic transition.

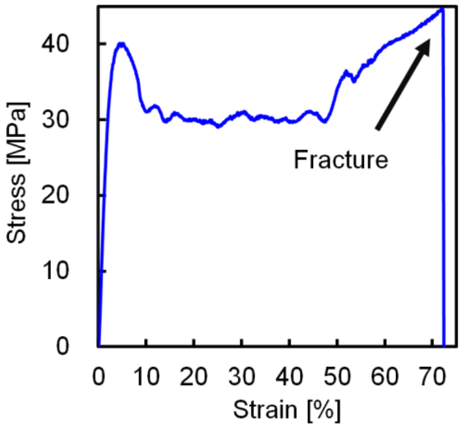

Fig. 3 Stress-strain curve of PFGI-POF.

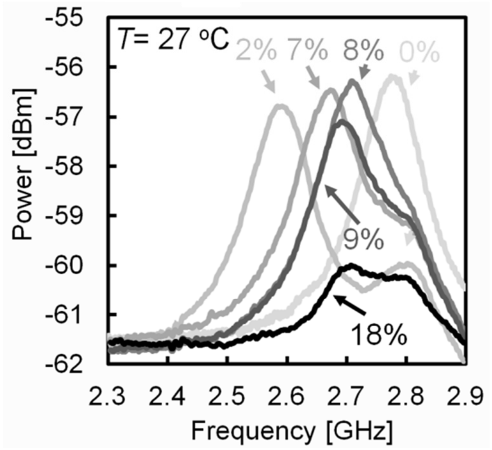

Fig. 4 Measured BGS dependence on large strain in the PFGI-POF.

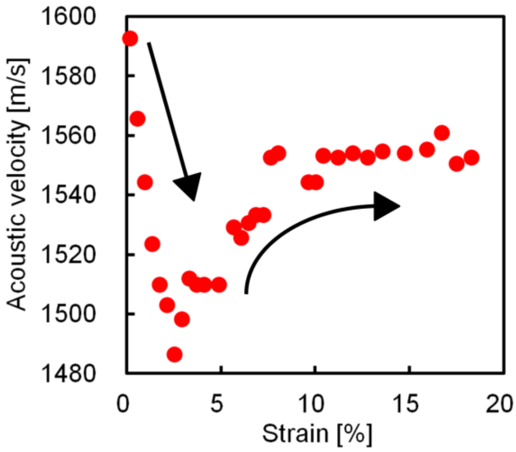

Fig. 5 Estimated large-strain dependences of acoustic velocity in the PFGI-POF.

5. Conclusion

The acoustic velocity dependence on large strain in the PFGI-POF was investigated by measuring the BFS, which was found to be nonlinear. This behavior, which has never been reported in glass fibers [6], should be a unique feature of polymers. We believe that these results are physically interesting and extremely important in developing large-strain sensors based on POFs.

Acknowledgment

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