Improved technique for etching overcladding layer of perfluorinated polymer optical fibre by chloroform and water

N. Hayashi, Y. Mizuno and K. Nakamura

A simple technique is developed for etching the overcladding layer of a perfluorinated graded-index polymer optical fibre by the combined use of chloroform and water. The boundary between the two liquids can mitigate the evaporation of chloroform, leading to a much lower loss than that of the conventional technique which does not employ water. The effectiveness of this method is verified by Brillouin signal measurement and infrared thermometry.

Introduction: Owing to their measurability of strain and temperature distribution along the fibres, fibre-optic sensors based on Brillouin scattering have been widely studied as a promising technique for health monitoring of civil structures, such as buildings, dams and aircraft wings [1–4]. Their sensor heads have been mainly composed of glass optical fibres, which are so fragile that they cannot withstand strains of over several percentages. To extend the measurable/endurable strain, we have been focusing on the use of Brillouin scattering in polymer optical fibres (POFs), which have extremely high flexibility and can withstand strains of $>50\%$ [5]. After succeeding in observing Brillouin scattering in perfluorinated graded-index (PFGI-) POFs at 1.55 µm [6], we have shown that it can be potentially applied to high-precision temperature sensing [7] as well as large-strain sensing [8]. The biggest problem that makes such practical applications difficult is, however, their extremely weak Brillouin signal because of their large core diameters and multimode nature.

One method for enhancing the Brillouin signal is to taper the PFGI-POFs. Heat-assisted tapering is one of the most major methods for tapering glass optical fibres [9], which has been shown to be also applicable to poly(methyl methacrylate)-based (PMMA-) POFs [10] (observing Brillouin scattering in PMMA-POFs is extremely difficult [11]). However, this method cannot be directly used to taper commercialised PFGI-POFs, because the glass-transition temperatures of the core/cladding layer (amorphous perfluorinated polymer) and the overcladding layer (polycarbonate) are different (<108 and 144 °C, respectively), resulting in the destruction of the wave-guiding structure of the core. The pressing need for the stable fabrication of tapered PFGI-POFs is to develop a technique for removing their overcladding layers. Chloroform has been conventionally used [12], but with a higher loss, which needs to be mitigated for Brillouin applications.

In this Letter, a simple technique for etching the overcladding layer of a PFGI-POF is demonstrated by using chloroform and water. A much lower loss is expected because the boundary between the two liquids suppresses the evaporation of chloroform. We experimentally show that, using this method, the Brillouin signal in a PFGI-POF without the overcladding layer can be clearly observed. We also prove the effectiveness of this method by infrared thermometry.

Experimental setup: We employed two 1.05 m-long PFGI-POFs as the fibres under test, which had a numerical aperture of 0.185, a core diameter of 50 µm, a cladding diameter of 100 µm, an overcladding diameter of 750 µm, a core refractive index of ~ 1.35 and a propagation loss of ~ 250 dB/km at 1.55 µm. The core/cladding layers and the overcladding layer were, respectively, composed of amorphous perfluorinated polymer (polymer fluorobutenylvinyl ether; commercially known as CYTOP) and polycarbonate [12].

Fig. 1*a* shows the schematic setup for etching the overcladding layer of the fibre under test (FUT) using chloroform only. A 0.9 m-long portion of the FUT was perpendicularly dipped into 500 ml of chloroform (Wako Pure Chemical Industries Ltd) in a container for 20 minutes (sufficiently long to remove its overcladding layer). Note that, during this process, the overcladding layer near the surface of the chloroform was partially damaged by the evaporated chloroform, resulting in a high optical loss. Then, the FUT was taken out, fixed perpendicularly and dried in air. The fibre end of the etched portion was angled-cut to suppress the possible Fresnel reflection; the fibre end of the unetched portion (~ 0.15 m) was butt-coupled to a silica single-mode fibre via an SC connector, from which 1.55 µm light was injected. In contrast, Fig. 1*b* shows the setup for etching the overcladding layer by using both chloroform and water. We added 500 ml of water (upper: specific gravity SG = 1.0) to 500 ml of chloroform (lower: SG = 1.46) in a container, and the same experimental procedures were followed. Next, the Brillouin gain spectra (BGSs) of the fibres under test [13] with the overcladding layers etched by the two different methods were compared. The experimental setup for measuring the BGSs, based on self-heterodyne detection, was basically the same as that previously reported [6]. The polarisation state was optimised for each measurement with the polarisation controllers so that the Stokes power might be maximal. The temperature was kept at 25 °C for all the measurements.

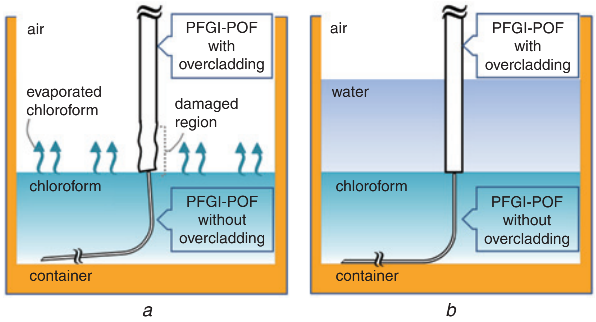

Fig. 1 *Schematic setups for etching overcladding layers of PFGI-POFs using chloroform only, and chloroform and water*

a Chloroform only
b Chloroform and water

Experimental results: Fig. 2*a* shows the BGSs measured (i) before etching the overcladding layer, (ii) after etching it by using chloroform and water and (iii) after etching it by using chloroform only. The pump power was fixed at 28.5 dBm. The Brillouin frequency shift was ~ 2.8 GHz, which is in good agreement with the previous results [6]. Although it is clear that the Stokes power was reduced by etching the overcladding layer, the Stokes power of (ii) was approximately 1.5 dB higher than that of (iii). The Stokes power of (iii) seems to be attributed to the ~ 0.15 m-long unetched portion, because the BGS of (iii) was almost the same as that measured using a 0.15 m-long unetched PFGI-POF sample shown, see Fig. 2*b*. These results indicate that, in (ii), the Brillouin signal in the PFGI-POF with its overcladding layer etched was successfully observed for the first time.

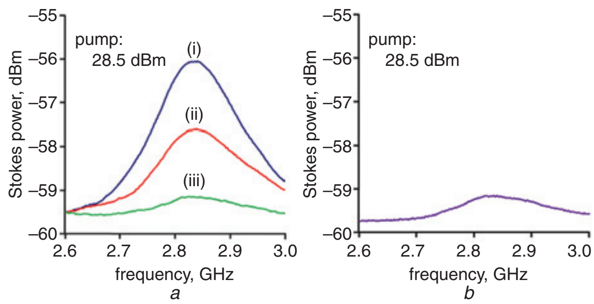

Fig. 2 *BGS measurements*

a BGSs measured (i) before etching, (ii) after etching using chloroform and water and (iii) after etching using chloroform only
b BGS measured in 0.15 m-long unetched PFGI-POF

Discussion: Fig. 3*a* is a photograph of the PFGI-POFs, along which 28.5 dBm light beams were propagating. The overcladding layer of the left fibre was etched using chloroform only, whereas that of the right fibre was etched using both chloroform and water. Scarcely any difference was found between their appearances. Then, to verify the location of the induced loss, we obtained the infrared thermal image [14] of the same PFGI-POFs, as shown in Fig. 3*b*. Almost no local increase in temperature was detected in the right fibre, while a clear bright spot was observed in the left fibre. Thus, we found that a considerable loss is induced at the etched/unetched boundary of a PFGI-POF when only chloroform is used to etch its overcladding layer, and that this loss can be greatly mitigated by the combined use of chloroform and water, which suppresses the evaporation of chloroform.

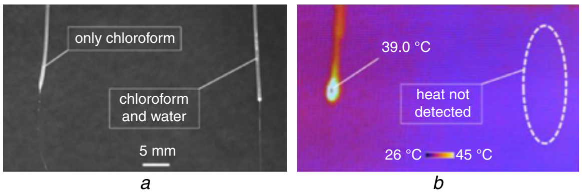

Fig. 3 *Photograph and infrared thermal image, of PFGI-POFs with overcladding layers etched using chloroform only (left), and chloroform and water (right)*

a Photograph
b Infrared thermal image

Conclusion: We have demonstrated a simple technique for etching the overcladding layer of a PFGI-POF by using chloroform and water. A much lower loss can be obtained than that in the conventional technique by employing chloroform only, because the boundary between the two liquids suppresses the evaporation of chloroform. On using this method, a Brillouin signal in the PFGI-POF with the overcladding layer etched was clearly observed for the first time. This method was verified to be effective also by infrared thermometry. We believe that this result will open the way for the development of new Brillouin devices and systems based on tapered PFGI-POFs.

Acknowledgments: This work was partially supported by a grant-in-aid for Young Scientists (A) (no. 25709032) from the Japan Society for the Promotion of Science (JSPS) and by research grants from the General Sekiyu Foundation, the Iwatani Naoji Foundation and the SCAT Foundation. N. Hayashi acknowledges a grant-in-aid for JSPS Fellows (no. 25007652).

15 October 2013
doi: 10.1049/el.2013.3267
One or more of the Figures in this Letter are available in colour online.

N. Hayashi, Y. Mizuno and K. Nakamura (*Precision and Intelligence Laboratory, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama 226-8503, Japan*)

E-mail: hayashi@sonic.pi.titech.ac.jp

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