Tensile strain dependence of Brillouin scattering in tapered optical fibers

***Adrien Godet*[1], *Abdoulaye Ndao*[1], *Thibaut Sylvestre*[1], *Sylvie Lebrun*[2], *Gilles Pauliat*[2], *Jean-Charles Beugnot*[1], *Kien Phan Huy*[1]**

1. *Institut FEMTO-ST, Université Bourgogne Franche-Comté, CNRS UMR 6174, Besançon 25030, France*
2. *Laboratoire Charles Fabry, Institut d'Optique, Université Paris-Sud, CNRS, Palaiseau 91127, France*

In the last few years, several authors have reported the observation of a new class of acoustic waves in sub-wavelength diameter tapered optical fibers (TOFs) through Brillouin scattering [1,2]. These include the observation of surface acoustic waves (SAW), hybrid shear and longitudinal acoustic waves (HAW) associated with anti-crossings (AC). It has also been suggested that these acoustic waves could be used to develop compact Brillouin optical sensors based on TOFs.
Here we report the first tensile strain measurement of TOFs using Brillouin spectroscopy. Because of the hybrid nature of the acoustic modes, we show that the backward Brillouin response to strain in those tiny waveguides is fundamentally different compared with that of conventional single-mode fibers (SMFs) [3,4]. More specifically, we measured a strain coefficient for SAWs two times lower than theoretically predicted.
Figures 1 (a) shows the experimental setup for measuring the Brillouin spectrum in the fiber taper schematically depicted in Fig. 1(b), and tapered using the heat-brush technique [1]. The backscattered Brillouin spectrum was measured using a heterodyne detection and an electrical spectrum analyzer. Strain was applied by further stretching the fiber taper using two programmable translation stages.

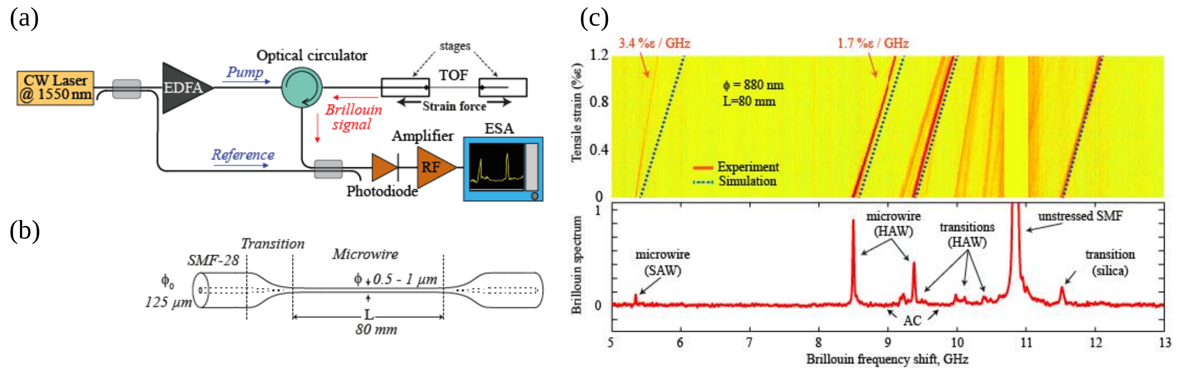

Fig. 1 (a) Experimental setup for measuring the tensile strain in TOFs. (b) Scheme of the TOF. (c) Top: Experimental (red lines) and numerical (blue dotted lines) Brillouin spectrum as a function of tensile strain. Bottom: Experimental Brillouin spectrum measured before applying strain.

Figure 1(c) shows the Brillouin spectrum without applying strain. We observe a set of Brillouin frequency shifts from 5 GHz up to 11.5 GHz, arising from surface and hybrid waves in the microwire, and also from transition and un-tapered sections (black arrows). 50 µm pulling steps up were then applied to the fiber taper up to 1.2% of its total length (microwires and transitions). Figure 1(c) illustrates the tensile strain dependence of all Brillouin resonances (red lines). The results have been compared to a numerical simulation (blue dotted lines) based on the elastodynamics equation [1]. As shown by the red arrows in Fig. 1(c), the surface wave has a steeper slope (3.4%ε/GHz) than the hybrid waves (1.7%ε/GHz), which is not predicted by the numerical simulation. For standard optical fiber, the Brillouin light induced by strain is explained by both an elastic contribution due to the longitudinal velocity variation and an optical contribution due to variation of the refractive index. In TOF, applying longitudinal strain modifies the microwire diameter and therefore a geometric contribution must be taken into account. For the first time, we probably separate shear and longitudinal stress in the same Brillouin measurement. This result is very promising for the conception of new class of tapered fiber strain sensor.

References

[1] J.C. Beugnot, S. Lebrun, G. Pauliat, H. Maillotte, V. Laude and T. Sylvestre, "Brillouin light scattering from surface acoustic waves in a subwavelength-diameter optical fiber", Nat. Commun. **5**, 5242 (2014).
[2] O. Florez, P.F. Jarschel, Y.A.V. Espinel, C.M.B. Cordeiro, T.P. Mayer Alegre, G.S. Wiederhecker and P. Dainese, "Brillouin scattering self-cancellation", Nat. Commun. **7**, 11759 (2016)
[3] T. Horiguchi, T. Kurashima, and M. Tateda, "Tensile Strain Dependence of Brillouin Frequency Shift in Silica Optical Fibers", IEEE Phot. Tech. Lett. **1**, 107 (1989)
[4] M. Nicklès, L. Thévenaz and P.A. Robert, "Brillouin Gain Spectrum Characterization in Single-Mode Optical Fibers", J. of Light. Tech. **15**, 1842 (1997)