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Novel Forward Brillouin Scattering measurement technique based on high-Q fiber ring resonator.

Ana I. Garrigues-Navarro[1], *Martina* Delgado-Pinar[1,2,*], *Antonio* Díez[1,2] and *Miguel* V. Andrés[1,2]

[1]Institut Universitari de Ciència dels Materials (ICMUV), Universitat de València, Burjassot, Spain.
[2]Departament de Física Aplicada i Electromagnetisme, Universitat de València, Burjassot, Spain.

Abstract. The conventional detection of Forward Brillouin Scattering (FBS) in optical fibers requires of interferometric techniques using lengths of tens of meters. In this paper, we demonstrate an alternative approach that provides efficient and high-resolution detection of FBS signals, while using just a 20 cm length section of bare fiber. It consists of a pump and probe scheme using a fiber ring resonator as the interrogation system of the mechanical vibration, which modulates the resonances. The result is an amplitude modulated optical trace which allows the detection of resonances $R_{0,m}$ and $TR_{2,m}$.

1 Introduction

In recent years, Forward Brillouin Scattering (FBS) has gained recognition for its applications in sensing and fiber characterization [1]. FBS consists in the non-linear interaction between two optical field components mediated by an acoustic wave propagating in a common waveguide. Since bare optical fibers can guide optical and acoustic modes at once, they are excellent platforms for FBS experiments. Bare fibers are, from an acoustic point of view, homogeneous cylinders that support solutions of the elastic wave equation. The phase-matching condition imposes that transversal acoustic resonant modes (TARMs) are the only solutions involved in this interaction [2]. Moreover, single mode optical fibers can guide intense pump pulses within the core that, by means of electrostriction, can generate mechanical vibration. Additional low-power co- or contra- propagating probe signals can be used to monitor the TARMs, all of them propagating along a single fiber.

In this work, we propose to nest the pump and probe system to detect mechanical modes generated by FBS in a high-Q fiber ring resonator that will play the role of the interrogator.

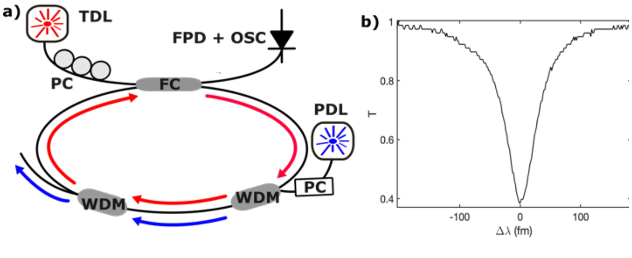

Fig. 1. a) Setup scheme of the pump and probe technique. Blue and red arrows mark the path of 1060 and 1550 nm light, respectively. b) Optical resonant notch of the passive ring.

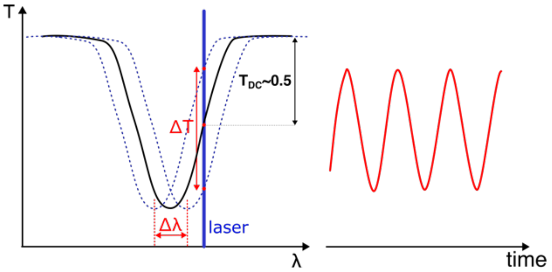

Fig. 2 Principle of operation. Resonance shifts are transduced into a power transmission modulation.

2 A fiber ring resonator as the interrogator of TARMs

The experimental setup for our pump-and-probe technique is shown in Fig. 1. Our optical ring resonator, constructed with SMF-28e fiber from Corning, includes a directional 90:10 coupler, with the 10% output arm spliced to the free input arm. A fiber polarization controller (PC) ensures optimal polarization alignment. A narrow linewidth (<100 Hz) tunable diode laser (TDL) centered at 1550 nm is used as the probe signal. The optical transmittance of the passive ring is a series of equidistant in wavelength, narrow transmission notches. A fast photodiode (FPD) and a 1 GHz bandwidth oscilloscope (OSC) is used for detection and analysis of the optical trace.

Figure 1 presents one of the resonant notches of a passive (that is, when there are not mechanical resonances) high Q-factor fiber ring ($Q = 3 \times 10^7$). The resonance wavelength of these notches is sensitive to changes in the effective index of the optical mode (n_{eff}) and the length of the ring (L):

$$\lambda_R = \frac{1}{m} n_{eff} L \quad (1)$$

When operating at a fixed wavelength (that is, the probe signal is tuned at the slope of one of the notches of

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[*] Corresponding author: martina.delgado@uv.es

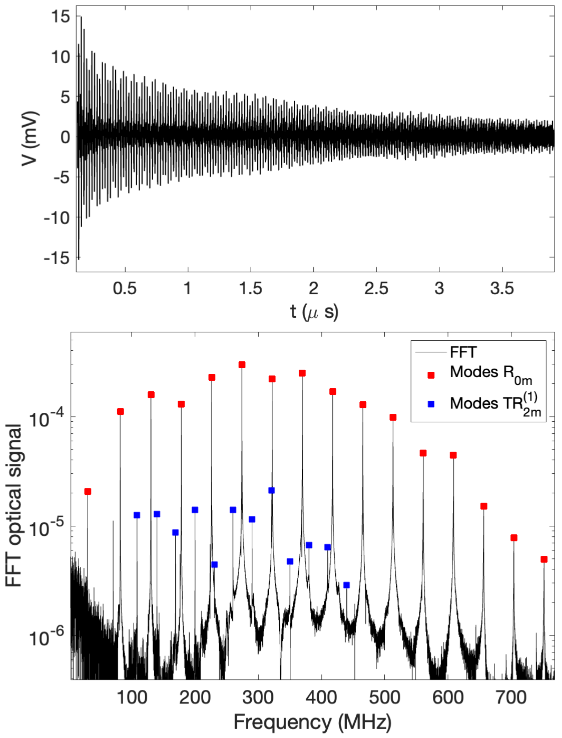

Fig.3 Output signal (up) and its FFT (down) of the trace registered in the experiments. TARMs families are denoted by red and blue circles.

the ring using a feedback loop), the power transmission is constant for the passive ring. The maximum sensitivity of the detection system is achieved when the working point is fixed at half the visibility of the notch, see Figure 2.

Once the pump source is turned on, the pump pulses generate TAMRs. Thus, the phase of the optical ring is modulated at the resonant acoustic frequency and, consequently, λ_R, sweeps in wavelength, accordingly, see Eq. 1. Thus, the optical trace shows an amplitude modulation at the same frequency, and a linear relation between amplitude-modulation and wavelength shift can be stablished. Ultimately, this will provide information about the frequency and amplitude of the TAMRs.

In our case, pump pulses emitted by a Q-switch microchip laser (700 ps pulse duration, 1064 nm wavelength, 19.9 kHz repetition rate) are launched into the bare fiber section of 20 cm in length, see Figure 1. These optical pulses present a few hundreds of MHz of frequency bandwidth. For our fiber, where the fundamental mode can be approximated by a Gaussian radial distribution, the only excitable families are $R_{0,m}$ and $TR_{2,m}$, [3].

A PC is used to adjust the polarization of the pump pulses to remove the family $TR_{2,m}$, which is achieved by using circular polarization for the pump signal.

3 Measurement and analysis of TARMs

Fig. 3 depicts an example of the registered optical trace and its Fast Fourier Transform (FFT). In this example, we can observe a series of resonances, up to hundreds of MHz. The signal-to-noise-ratio is higher than 20 dB for most of them, especially at intermediate frequencies. The dynamic character of the ring cavity leads to a response like that of a low-frequency band-pass filter [1]. This feature has direct consequences on the selection of the optimal resonator for future applications.

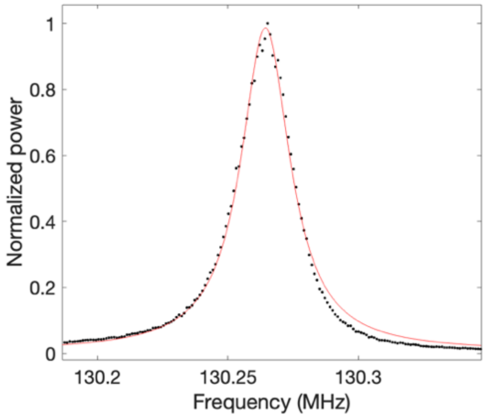

Fig.4 Normalized resonance amplitude for $R_{0,3}$. Experimental data (black points) and Lorentzian fitting (red line).

A high-resolution characterization of the acoustic resonances was performed using an electric signal analyzer with a resolution bandwidth of 1.8 kHz and a video bandwidth of 18 Hz. Fig. 4 shows the detail of the $R_{0,3}$ resonance with a Lorentzian fitting included. The bandwidth of the resonance is 22.89 ± 0.10 kHz, and the Q-factor is $(5.6\pm0.5)\times10^3$. The deviation from symmetry in the resonance is due to the interference with Kerr nonlinearities since temporal gating was not applied in these measurements. Given the short section of fiber employed, the contribution to the bandwidth of the acoustic resonances due to fiber inhomogeneities is reduced, which are crucial when using longer lengths. Thus, we can obtain high Q-factors for the acoustic resonances.

4 Conclusions

We demonstrated a novel technique for the accurate measurement of TARMs using a short fiber section (20 cm) and an optical fiber ring as the interrogator. We observed the $R_{0,m}$ family of resonances and studied in detail $R_{0,3}$, obtaining a Q-factor of $(5.6\pm0.5)\times10^3$. Such a high Q-factor is achieved because of the short section of bare fiber. Results were compared with theory, obtaining an excellent agreement.

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References

1. L.A Sánchez, et al., Adv. Optical Mater. **12**, 2301629 (2024).
2. A. Zadok, et al. *Forward Brillouin Scattering in Standard Optical Fibers,* (2022).
3. A.S. Biryukov, et al. Quantum Electron. **32,** 765 (2002).