Evaluation of the pressure sensing capabilities for pure radial acoustic mode exited by optomechanic interaction in SMF-28 optical fiber

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Given the critical need for precise pressure measurements in various fields like fossil fuel exploration, underwater environments, aerospace engineering, and industrial processes, fiber optic-based sensing techniques have emerged as a promising solution. These techniques offer inherent advantages such as small size, lightweight, and immunity to electromagnetic interference. A promising mechanism for fiber optic pressure sensing is forward-stimulated Brillouin scattering (FSBS). FSBS is an optomechanical interaction that involves two copropagating optical waves and nearly transverse acoustic mode resonances (TAMR's) supported by the optical fiber. Pure radial, $R_{0,m}$, acoustic mode resonances can be stimulated in single-mode optical fibers [1]. The frequency at which $R_{0,m}$ modes are excited can be approximated by $f_{0,m} \approx \frac{V_L}{2\pi a}\left(c_m - \frac{16\alpha^2-1}{8c_m}\right)$, where a is the radius of the fiber, V_L is the longitudinal acoustic velocity. The coefficient $c_m = (m\pi - \pi/4)$ being m $(m = 1, 2, 3 \ldots)$ an integer denoting the mode order order [2]. By analyzing the frequency shift of the FSBS spectrum, precise determination of environmental parameters becomes feasible. Presure applied to the fiber have an impact of the longitudinal acoustic velocity [3].

We investigated the response of FSBS in a telecom optical fiber to hydrostatic pressure. A short length of 30 cm of bare SMF-28 optical fiber segment was inserted into a sealed chamber and pressure was applied by connecting the chamber to a pressurized tank of N_2. Measurements were performed for pressure between 0.1 to 5.1 MPa with a step of 1 MPa. Figure 1 (a) shows the peak in the radio-frequency spectrum caused by the oscillation of acoustic mode $R_{0,4}$ for different pressure. Two effects can be noticed when pressure was applied. First, the peak shifted to shorter frequency as the pressure was increased. The origin of such a frequency shift is the reduction of acoustic velocity with pressure [3]. Figure 1 (b) shows the frequency shift as a function of pressure, showing a shift rate $\Delta f/\Delta P \approx 6.9\ kHz/MPa$. Moreover, a clear increase of the linewidth is observed for peak as a function of pressure. This effect has not been previously reported. Two contributions might be at the origin of linewidth increase with pressure. The impedance of the medium surrounding the fiber increases with pressure, thus acoustic surface dumping also does it. Additionally, the viscosity of glass is expected to increase as well. Both contribution increase the attenuation of the optical resonances leading to the line broadening.

Both effects, the frequency shift and the linewidth increase can be support the development of pressure measurement based on FSBS. A qualitatively similar response was observed for other radial acoustic modes.

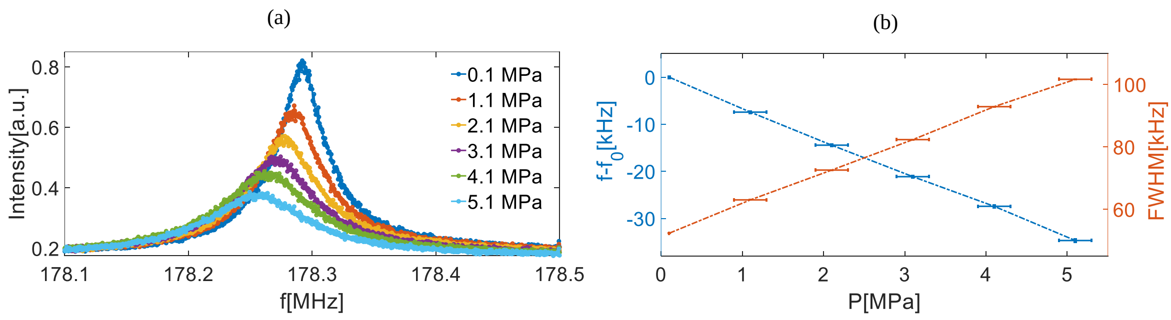

Fig. 1. (a) Spectrum of $R_{0,4}$ acoustic mode for different pressure. (b) Frequency shift and linewidth as a function of pressure.

References

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