Localized temperature and pressure measurements inside CS_2-filled fiber using stimulated Brillouin scattering

Alexandra Popp[1,2,3,†], Andreas Geilen[1,2,4,†], Daniel Walter[1,2], Mario Chemnitz[5], Saher Junaid[6,7], Christopher G. Poulton[8], Christoph Marquardt[1,2,3], Markus A. Schmidt[6,7], Birgit Stiller[1,2]

1. Max Planck Institute for the Science of Light, Staudtstr. 2, Erlangen, Germany
2. Department of Physics, University of Erlangen-Nuremberg, Staudtstr. 7, 91058 Erlangen, Germany
3. SAOT, Graduate School in Advanced Optical Technologies, Paul-Gordan-Str. 6, 91052 Erlangen, Germany
4. IMPRS, International Max Planck Research School - Physics of Light, Staudtstr. 2, Erlangen, Germany
5. INRS-EMT, 1650 Boulevard Lionel-Boulet, Varennes, Qubec, J3X 1S2, Canada
6. Leibniz Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany
7. Otto Schott Institute of Materials Research (OSIM), Fraunhoferstr. 6, 07743 Jena, Germany
8. School of Mathematical and Physical Sciences, University of Technology Sydney, NSW 2007, Australia
† authors contributed equally, alexandra.popp@mpl.mpg.de

Liquid-core fibers are a versatile platform for nonlinear light-matter interactions, combining highly nonlinear materials like carbon disulfide (CS_2) or nitrobenzene with the confinement and long interaction length of optical fibers. While there is only minor influence of strain inside the fiber core due to the liquid phase, pressure effects have a dominant role depending on the thermodynamic regime and filling of the fiber core [1]. In our experiments we use Brillouin Optical Correlation Domain Analysis (BOCDA) to create a localized Brillouin response [2]. Due to the associated refractive index change, this response is strain, pressure and temperature dependent. While the discrimination of strain and temperature effects in silica fibers is complicated due to the combined Brillouin response [3], CS_2 filled fibers have the advantage of thermo- and piezo-optical coefficients with different signs. While the thermo-optic coefficient is negative, resulting in a downshifted acoustic response for higher temperature, the piezo-optic coefficient is positive, resulting in an upshifted Brillouin frequency for increased pressure. To investigate the response of the CS_2, we heated different parts of the 60 cm liquid-core fiber on a hotplate up to a temperature of 135 °C while measuring the distributed Brillouin response with a resolution of 4 cm.

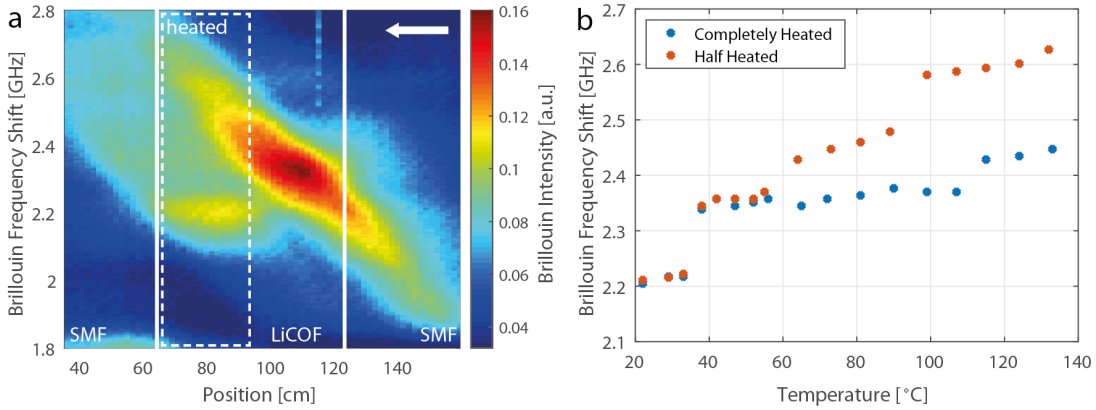

Fig. 1 a Color-coded Brillouin spectrum as function of position and frequency shift (BFS) in a liquid-core fiber (LiCOF) with one half heated up to 40 °C. The pump direction is denoted by a white arrow. The heated area of the fiber is denoted by a white box. Both, the steady and upshifted BFS responses are visible. Horizontal tilt of the BFS is artificial to the measurement. **b** Global maximum Brillouin frequency shift as function of temperature, for both, the fully (blue) and partially (red) heated fiber.

We find that the temperature change is localized inside the fiber while the pressure change due to the thermal expansion is present inside the entire liquid-core. This results in a positive Brillouin frequency shift of the non heated region and a steady, non-shifted Brillouin response of the heated region due to the local cancellation of the thermo-optic and piezo-optic coefficients. The observed Brillouin frequency shift is larger for smaller parts of the fiber heated, which is caused by the two coefficients compensating each other in the heated regions as well as a dominating pressure-induced shift for smaller heated regions. Thus, we have shown that our system is capable of measuring local changes in the Brillouin response of the liquid phase attributed to temperature as well as pressure changes. In the future, further measurements with a faster measurement rate will allow for a more detailed investigation of the pressure dynamics inside the fiber.

References

[1] Pumpe, S., Chemnitz, M., Kobelke, J., & Schmidt, M. A. (2017). "Monolithic optofluidic mode coupler for broadband thermo-and piezo-optical characterization of liquids." Optics express, 25(19), 22932-22946.
[2] Hotate, K., & Hasegawa, T. (2000). "Measurement of Brillouin Gain Spectrum Distribution along an Optical Fiber Using a Correlation-Based Technique–Proposal, Experiment and Simulation–." IEICE transactions on electronics, 83(3), 405-412.
[3] Zou, W., He, Z., & Hotate, K. (2009). "Complete discrimination of strain and temperature using Brillouin frequency shift and birefringence in a polarization-maintaining fiber." Optics express, 17(3), 1248-1255.