Characterization of axial non-uniformities in single-mode fibers at the subnanometer scale by edge-interrogated time-resolved acousto-optics

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Recently, a new technique based on time-resolved acousto-optics for the analysis and characterization of axial non-uniformities in single-mode optical fibers has been reported [1]. Measurement of fiber diameter variations in the nanometric scale with a spatial resolution of few cm was demonstrated [1]. Here, we show that the performance of this technique can be improved further by using an edge interrogation approach.

The time-resolved acousto-optic technique is based on the propagation of a short packet of a flexural elastic wave along the fiber. The elastic wave causes coupling between the core and a cladding mode. Since the elastic packet propagates along the fiber at its group velocity, the optical transmittance at a given instant is determined by the coupling at the specific fiber point where the elastic packet is located. Fluctuations of the fiber characteristics lead to fluctuations of the AO phase-matching wavelength. Fiber properties variations are analyzed by monitoring the transmittance vs. time of an optical probe laser. In [1], the probe laser wavelength was tuned to match the AO resonance (see Fig. 1(a)). This interrogation scheme presents two limitations. First, it cannot distinguish blueshift and redshift of the notch, and second, the sensitivity is small around the minimum of the notch. These are overcome by looking at the fluctuations of transmittance at the edge of the notch.

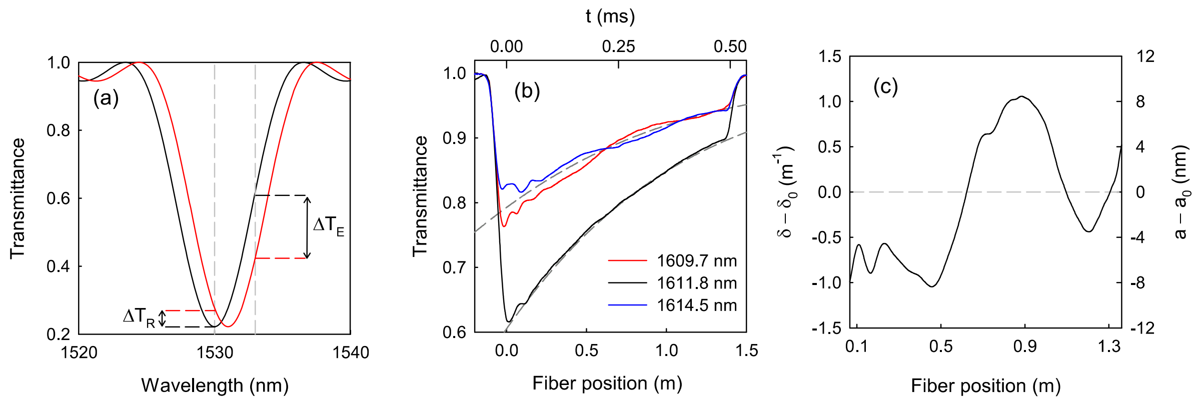

Fig. 1 (a) Diagram illustrating the sensitivity improvement by the edge interrogation scheme. ΔT_R and ΔT_E are the transmittance change at resonance, and at the edge, respectively. (b) Transmittance as a function of time/position for different optical wavelengths. Dashed lines are the transmittance for a perfectly uniform fiber. (c) Detuning and fiber radius fluctuations along the fiber section.

Packets of flexural elastic waves were generated by a piezoelectric disk and coupled to the fiber via a horn. The piezoelectric was driven with an electrical signal consisting of a burst of 20 periods of a sinusoidal waveform of frequency 2.1 MHz. Fig. 1(b) shows the transmittance recorded as the elastic wave packet propagated along a particularly uniform section of SMF-28 fiber of 1.45 m in length. The three traces are for different optical wavelengths: at resonance (as in [1]), at the short wavelength edge, and at the long wavelength edge. In all cases, one can observe small fluctuations of transmittance with respect to the transmittance of a perfectly uniform fiber. We must point out that the fluctuations are larger when the optical wavelength was tuned to the edges of the AO notch, as it corresponds to a larger sensitivity. Additionally, the fluctuations shown by the traces taken at the two edges are complementary, as expected since the slope at the edges of the notch have opposite sign.

Fig. 1 (c) shows the fluctuation along the fiber of the AO detuning parameter [1] obtained from the transmittance trace recorded when the optical wavelength was tuned to one edge of the notch. A feasible origin of the detuning fluctuation is the non-uniformity of fiber radius. In that case, the corresponding fluctuation of radius can be calculated taking into account the basic fiber properties, and it is included in Fig. 1 (c).

The sensitivity of the technique is determined by the characteristics of the fiber, the optical wavelength, and the modes involved in the AO coupling. Within the conditions of the present experiment, assuming that the smallest transmittance deviation able to be detected is 1×10^{-3}, a detuning change of 0.05 m^{-1} can be resolved. Such detection limit implies that a radius variation as small as 0.4 nm can be detected. If the transmittance deviations were caused by fluctuations of the core refractive index, then core refractive index variations of 4×10^{-8} could be resolved.

References

[1] E. P. Alcusa-Sáez, A. Díez, M. González-Herráez, and M. V. Andrés, "Time-resolved acousto-optic interaction in singlemode optical fibers: Characterization of axial non-uniformities at the nanometer scale", Opt. Lett. **39**, 1437-1440 (2014).