Investigation of Thermal Effects on Embedded Microcoil Resonators

G. Y. Chen, T. Lee, Y. Jung, M. Belal, G. Brambilla, N. Broderick, and T. P. Newson

ORC, University of Southampton, Southampton, SO17 1BJ, UK

Recently, there has been great interest in the use of microfiber resonators as optical sensors [1] and micro-optical devices [2] due to their compactness, robustness, high Q-factor and low-loss. In particular, temperature sensors exploiting the thermally-induced resonance wavelength shift have potentially high sensitivity, fine resolution and large operating temperature range. Here, we report on the theoretical and experimental analysis of such a sensor based on a microcoil resonator (MCR).

A 2 μm-diameter silica microfiber (MF), fabricated using a ceramic microheater, was wrapped around a 1 mm-diameter glass rod to form a 3-turn MCR, and subsequently embedded in EFIRON UV-373 polymer. The Q-factor and free spectral range (FSR) were 5.3×10^4 and 486 pm respectively. The temperature-dependent transmission spectrum of the MCR was simulated by solving the coupled mode equations [3] whilst considering the thermal effects due to the thermo-optic effect (dn/dT) and thermal-expansion (dL/dT) of both materials. A sensitivity of 150 pm/°C ($\pm$ 30%) and FSR of 0.5 nm were predicted.

To experimentally confirm this, the MCR was placed on a hotplate and heated to 42.8 °C. The hotplate was then switched off and the wavelength of a chosen resonance (λ_R) was tracked using an optical spectrum analyzer as the device was allowed to slowly cool down to 28 °C. The temperature of the MCR (T) was measured using a thermocouple. Fig. 1(a) shows a linear relationship between λ_R and T. The uncertainty of λ_R and T measurements are $\pm$ 60pm and $\pm$ 0.05 °C respectively. Heating the MCR to 66.7 °C produced a small but permanent sensitivity reduction (118.7 to 110.9 pm/°C), leading to change in λ_R when cooled to room temperature. This phenomenon is attributed to heat-induced changes in the physical arrangement of the microcoil within the polymer packaging. Nonetheless, the sensitivity remained similar and close to the theoretically simulated value.

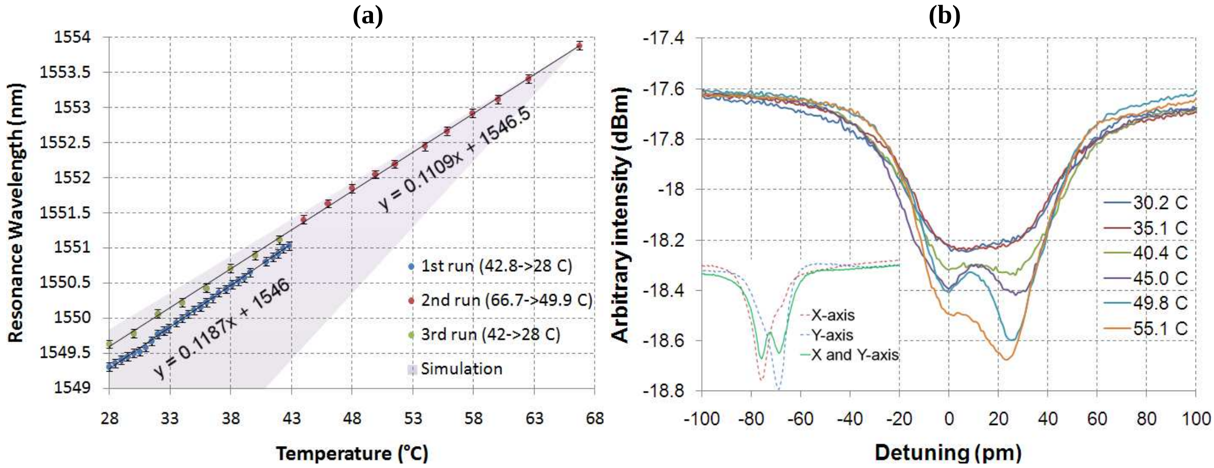

Fig. 1 **(a)** Resonance wavelength against temperature, showing a linear trend. **(b)** Transmission spectra showing resonances at different temperatures. Inset: X and Y polarized transmission components.

Note that birefringence, primarily caused by evanescent field penetration into the rod, produces two resonance dips as depicted in Fig. 1(b) corresponding to the separate resonances associated with the fast and slow axes (see inset). The extinction ratio of each resonance varies with T. This can be explained by the thermo-optic coefficient (10^{-4}/°C, [1]) of the polymer being significantly higher than that of silica (10^{-5}/°C); this slightly increases the modal area, and hence coupling, with increasing T. This effect is more pronounced for the polarization axis aligned with the axis of the fiber coil. The increase in coupling due to the increase in modal area is somewhat offset by the thermal expansion of the device which will increase the pitch and reduce the coupling. Although the operating temperature range of the MCR is limited by the degradation of the polymer coating for T>130 °C, it can be extended to 360 °C by using Teflon as the embedding material.

References

[1] X. Zeng, Y. Wu, C. Hou, J. Bai, and G. Yang, "A temperature sensor based on optical microfiber knot resonator", Opt. Commun. **282**, 3817-3819 (2009).
[2] G. Brambilla, "Optical fibre nanowires and microwires: a review", J. Opt. **12**, 9 (2010).
[3] M. Sumetsky, "Optical fiber microcoil resonator", Opt. Express **12**, 2303-2316 (2004).