In-fiber silicon microsphere as a hybrid Fabry-Pérot microcavity for temperature sensing

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Abstract: A silicon microsphere was fabricated inside a fiber forming a hybrid Fabry–Pérot microcavity. The large difference in indices and thermal-optic coefficients of the sphere and its silica cladding are exploited for high-sensitivity temperature sensing.

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Silicon (Si) microspheres are currently receiving significant attention for wide ranging applications spanning photonics, biology and green energy [1]. In particular, in-fiber microspheres fabricated from the Si optical fiber (SOF) platform offer a route to exploiting the unique properties of the microspheres in a robust and flexible geometry. Here we propose and demonstrate a unique structure in which a Si microsphere is fabricated into the end of a standard silica fiber as a hybrid Fabry-Pérot (FP) micro-cavity for high-sensitivity temperature sensing.

In-fiber FP micro-cavities have been investigated quite intensely for use as temperature sensors [2]. Generally the FP micro-cavities are formed from an air-gap structure, where the incident light is reflected off the air-silica interfaces. However, the low thermal expansion coefficient of silica limits the temperature response of these devices. Hybrid FP micro-cavities with improved temperature sensitivity have been demonstrated using polymer materials, though these are not suitable for high temperature applications. In contrast, Si has high refractive index (~3.5 at infrared wavelength range), large thermo-optic coefficient (2.3×10^{-4}/K) and a high melting point, making Si-based FP cavities excellent candidates for efficient sensors that can operate over a wide temperature range.

To fabricate the in-fiber Si microspherical sensors we have developed a 3 step approach. Firstly, a SOF with a polycrystalline core material was spliced to a conventional single mode fiber (SMF) using an Ericson splicer with optimized parameters to avoid overheating. Then the SOF was cleaved using a CO_2 laser so that only a short section of the SOF remains attached to the end of the SMF (Fig.1a). Finally the SOF segment was carefully heated by repeated arc discharges to produce the microsphere. During the process, the melted Si cylindrical-core collapses into a sphere and becomes entirely surrounded by the softened silica cladding. The fabricated Si sphere diameter in Fig.1b is 27.3 µm. To characterize the in-fiber microspherical cavity we used a reflective set-up similar to that in Ref. [2]. Fig.1c shows the measured spectrum, with a high interference fringe visibility of ~25 dB. The fringe spacing of 12.1 nm matches the Si cavity length. Finally, Fig.1d shows the temperature dependence of the resonant wavelength dip over the range 30-120 °C, though it is worth noting that measurements have been conducted up to 750 °C without damage to the device. From the temperature tuning we can estimate the sensitivity to be ~80 pm/°C, which is ~40 times more sensitive than the air-gap microcavity [2].

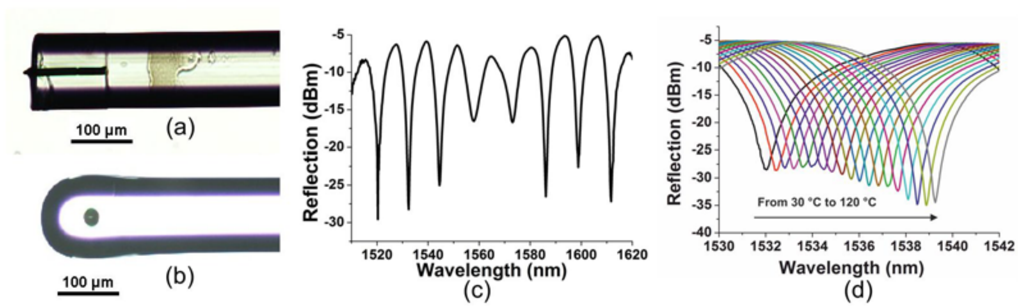

Figure 1. (a) The SOF (left) spliced to the SMF, and cleaved. (b) The fabricated silicon microsphere integrated at the end of the SMF. (c) The interference fringe of the silicon microsphere. (d) The wavelength dip of the interference fringe is shifted with the increase of the temperature from 30 °C to 120 °C with a step of 5 °C.

References

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