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Embedded Optical Microfiber Coil Resonator

Fei Xu and Gilberto Brambilla
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
e-mail: fex@orc.soton.ac.uk

Abstract — **The embedding of an optical microfiber coil resonator in Teflon is demonstrated. Resonances in excess of 9dB and Q-factors greater than 6000 have been observed. The device is compact, robust and portable.**

Index Terms—Microfibers, optical nanowire, optical fiber coupling, optical resonators, ring resonators

In recent years there has been a great deal of interest on microresonators based on sub-wavelength microfibers, mainly because of the development of new fiber fabrication methods that allow for low-loss evanescent wave guiding along microfibers [1,2]. Microfiber coil resonators (MCR) are powerful microoptical devices with a wide range of potential applications such as optical filter, slow light, sensing, and microlasers. Recently two kinds of MCR were reported in literature: self-touching loop resonator [3,4] and knot resonator [1,5]. Knot resonators have a long coupling region but they present severe drawbacks including the complexity of fabrication, the need for an additional coupler at the output or input of the resonator, the high loss and the presence of only one standard telecom fiber pigtail. The self-touching loop resonator is fabricated by bending a microfiber on itself and keeping two sections of a microfiber together by taking advantage of surface attraction forces (Wan der Waals and electrostatic). This approach is simple, can be fabricated from a single fiber, has two telecom fiber pigtails at the extremities and presents a lower loss that the knot resonator. The main challenge relates to the use of very thin microfibers to achieve strong self-coupling; common diameters of microfibers used for these devices are sub-micrometric. A major drawback of the self-touching loop resonator in air is its geometrical stability; coupling is strongly affected by the microcoil geometry and a small change in shape implies a great deal of change in transmission properties. Moreover, it has been shown [6] that sub-micrometric wires experience ageing when exposed to air for some days. The embedding of a MCR in a low refractive index medium can provide both protection from fast aging and geometrical and optical stability. In this paper the embedding of a MCR wrapped on a low index rod is experimentally demonstrated.

The microfiber was initially wrapped on a rod consisting of two layers: the inner core is a conventional silica optical fiber which provides rigidity to the structure while the outer layer consists of a coating polymer (Efiron UV373), manufactured by Luvantix, South Korea) which has a low refractive index (n~1.37 at wavelength λ~1.55μm) and limits the leakage of power from the microfiber. This structure is stable in air and preserves all the benefits of the self-touching loop resonator. Subsequently the whole arrangement was coated by Teflon fluoropolymer resin. This provides an extremely low-refractive-index embedding material (n~1.3 at λ~1.55μm). The coating method is very simple and the device is strong and portable. Additionally, coated MCR wrapped on a rod make the fabrication of 3D microcoils resonators [7] and high sensitivity biosensors possible [8].

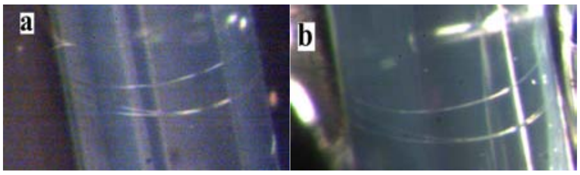
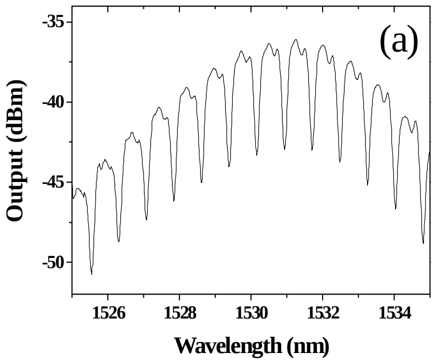


Fig. 1. Microscope pictures of an MCR wrapped on a rod before and after embedding. (a) in air; (b) in Teflon.

The microfiber used in the experiment was fabricated using the set-up presented in reference 9 and a microheater (NTT-AT, Japan). The microfiber radius and the length of the uniform waist region were ~1.5 μm and 3.5 mm respectively. The rod had a total diameter D~700mm, silica core with radius ~200μm and was additionally coated with Teflon AF to provide a uniform refractive index surrounding to the microfiber. The microfiber had its pigtails connected to an Erbium-doped fiber amplifier (EDFA) and an optical spectrum analyzer (OSA) to check in real time the resonator properties during fabrication and embedding. The embedded structure was manufactured as follows: at first, with the aid of a microscope the microfiber was wrapped on the rod while one of its ends was fixed on a 3D stage; then the other microfiber end was fixed to another 3D stage and both microfiber ends were tuned to find the optimum resonator spectrum. This methodology was similar to that theoretically predicted for the design optimization of 3D microcoil resonators [10-11]. Fig. 1a shows the three turns MCR: because the microfiber has relatively large radius, bending losses are negligible and the whole structure is stable in air. The transmission spectrum in the wavelength interval 1525-1535nm is shown in figure 2a: the overall resonances extinction ratio is about 7 dB.

The resonator embedding was carried out with the use of the 601S1-100-6 solution of Teflon @AF (DuPont, United

States). The structure was covered with Teflon solution and the solvent was let to evaporate. The coupling process is extremely challenging because the solution reduces the effect of surface forces and if the microfiber in not tightly wrapped around the rod the resonating conditions are lost. Moreover, because of the rapid solvent evaporation, Teflon particles in solution move rapidly and a collision with the microfiber can displace the microfiber and change the MCR transmission properties. Particular care has to be taken to avoid any particle contamination into the solution because it will eventually get in contact with the microfiber and significantly alter its overall loss. The picture of the MCR after its embedding in Teflon is shown in figure 1b.



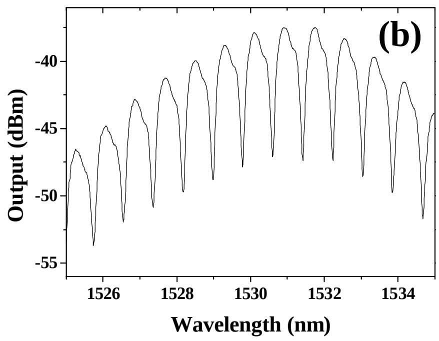


Fig. 2 Spectra of MCR before and after embedding: (a) in air, (b) in Teflon

The resonator spectrum is shown in figure 2b. Compared to the spectrum of the MCR before embedding, a small shift to longer wavelengths and an increase in the resonance attenuation (from ~7dB to ~9dB) has been observed. The increase of the extinction ratio as a consequence of the embedding process can be explained by an increase in coupling: Teflon has a refractive index closer to that of silica than air, implying that when the microfiber is embedded the mode propagating in the microfiber has a bigger fraction of intensity in the evanescent field, therefore the possibility to experience a stronger coupling.

FSR can be predicted using the simple resonator model:

$$FSR=\frac{\lambda^2}{n_{eff}L}$$

where λ is the wavelength, n_{eff} is the effective index of the mode propagating in the microfiber and L is the loop length. This model predicts FSR~0.8nm for both the microfiber in air and embedded in Teflon, in good agreement with the experimental results. It is important to note that the spectrum shape of the MCR in figure 2 is different with respect to that of a simple self-coupling loop resonator [7], because in this latter case the coupling is limited to a single point while MCR is a 3D microcoil resonator. Simplified, figure 2 can be taken as the combination of two simple resonators, one of which is dominating the spectrum.

The Q-factor of a resonator depends on the coupling coefficient, coupling length and loss. The embedded MCR has a Q-factor greater than 6000. The Q factor of this resonator is not extremely high because the wrapping has been performed by hand and the microfibers do not have a good positioning. By using precisely controllable rotation and translation stages all-coupling resonators with ultrahigh-Q factors should be obtainable.

In conclusion, the embedding in Teflon of microfiber coil resonators has been demonstrated. A resonance extinction ratio greater than 9dB, a free spectral range of 0.8nm and a Q-factor in excess of 6000 have been observed in the embedded resonator. The embedded resonator provides a solution to the stability and reliability problems observed in microfiber resonating structures.

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