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A simple, polymer-microfiber-assisted approach to fabricating the silica microfiber knot resonator

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ABSTRACT

With the assistance of the polymer microfiber, we propose a simple approach to fabricating silica-based optical microfiber knot resonators (MKRs) in this paper. A pre-fabricated knot ring made of the polymer microfiber can be readily driven to the silica microfiber owing to the intensive van der Waals and the electrostatic forces between the polymer and the silica microfibers. The fabrication process is introduced in detail. Several kinds of MKRs are fabricated and their optical performances are demonstrated accordingly.

1. Introduction

In recent years, miniature photonic devices assembled by microfibers with diameters of micrometer scale have attracted significant interest. Various structures of microfiber resonators, including loop, knot and coil, have been investigated [1–11]. Among them the optical microfiber knot resonator (MKR) [2], due to its high *Q* factor, tunable free spectral range, high stability and compact structure, has been extensively applied to optical filters [12], optical sensing [13–17], microfiber lasers [18], and nonlinear resonators [19]. Currently, most MKRs are fabricated based on the micromanipulation method proposed by Jiang et al. [2]. That is, the microfiber knot is assembled with the assistance of two tapered-drawing fiber probes under an optical microscope. Obviously, operating under an optical microscope increases the inconvenience of the fabrication. Recently, for the first time Xiao et al. proposed a new method to directly fabricate a MKR from a double-ended tapered fiber [20]. The merit of this fabrication method is that light can be coupled in and out of the resonator directly via integral full-size fiber ports, which benefits the high finesse. However, this method also has some other deficiencies for the fabrication. For example, one has to draw a longer microfiber with a high degree of uniformity. In fact, this is a challenging problem being addressed in several papers [21–23].

In this paper, we demonstrate an approach to fabricating the silica MKR under the assistance of a polymer microfiber. Several kinds of MKRs with different structures, such as those with a longer intertwisted overlap at the contact area, with a two-ring serial connection structure and with a two-ring parallel connection structure, have been fabricated by use of this technique. It is found that this technique is quite simple and is beneficial to fabricating multi-ring MKRs with more complicated structures.

2. Basic principle of fabrication

The schematically fabrication process is illustrated in Fig. 1, which can be divided into four steps. (1) Using the high-temperature tapered-drawing technique one fabricates a silica microfiber with a diameter of micrometer scale from the standard single mode fiber (SMF). As a result, there is a tapered-drawing region which connects the silica microfiber to the SMF at each end of the silica microfiber. Cutting one end of the silica microfiber makes it become a freestanding end. As shown in Fig. 1(a), a polymer microfiber with a diameter of tens micrometers, drawn from solvent polymers [24], is tailored to a suitable length. Then let's manually wind a knot ring with a diameter of several millimeters from the above polymer microfiber and adhere one end of the knot ring to the freestanding end of the silica microfiber. (2) The polymer microfiber knot ring is driven to the silica microfiber with the assistance of a tapered-drawing fiber probe until the polymer microfiber is completely drawn out of the knot ring. As shown in Fig. 1(b), in this case, the knot ring is only composed of the silica microfiber. (3) As shown in

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Fig. 1(c), continuously drawing the polymer microfiber thus finely tunes the diameter of the knot ring under an optical microscope. (4) Departing the polymer microfiber from the freestanding end of the silica microfiber and adhering the other silica microfiber produced in the step (1) to it, as shown in Fig. 1(d), one finally fabricates a silica MKR. Note that the zoom-in image in Fig. 1(d) is the intertwisted overlap at the contact area.

The key point of this approach is to take advantage of the strong van der Waals and electrostatic forces between the silica microfiber and the polymer microfiber. The van der Waals and electrostatic forces between two molecules have the following relationship

$$F = -\frac{2}{3}\frac{I_1 I_2}{I_1+I_2}\frac{\alpha_1\alpha_2}{r^6}\times\frac{1}{(4\pi\varepsilon_0)^2}, \quad (1)$$

where r is the interaction distance, ε_0 is the permittivity in vacuum. I_1 and I_2 are the ionization energy, α_1 and α_2 are the polarizabilities of the two molecules, respectively. It is easy to see that the van der Waals and electrostatic forces are inverse proportional to the sixth power of the interaction distance. And the interaction distance is usually limited less than ~0.165 nm [25]. The fabricated microfiber possesses such a high degree of diameter uniformity and surface smoothness [26,27] that, when two microfibers adhere together, most molecules located at the surfaces of them can contact firmly, which produces strong van der Waals and electrostatic forces between them. Moreover, the distance between molecules becomes shorter when the diameters of the microfibers become smaller, resulting in an increase of the van der Waals and electrostatic forces. Therefore, in principle, it is beneficial for us to drive the knot ring from the polymer microfiber to the silica microfiber when the diameters of these two microfibers are as small as possible. However, as far as the manual fabrication of the polymer microfiber knot ring is concerned, a polymer microfiber with a too small diameter inevitably increases the fabrication difficulties of the knot ring. Repeated experiments indicate that for silica microfibers with the diameters of 1–4 μm, it is better to select the diameters of the polymer microfibers to be 10–20 μm. The adhering length between the silica microfiber and the polymer microfiber should be longer than the circumference of the polymer microfiber knot ring.

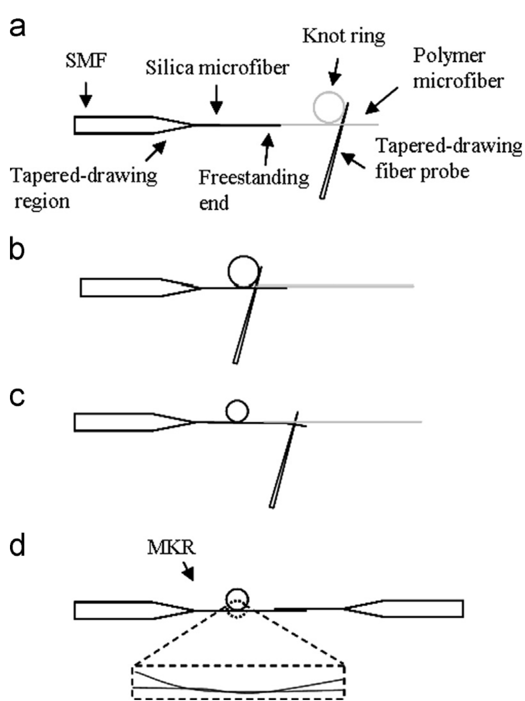

Fig. 1. (a)–(d) Schematic of the fabrication process.

3. Experimental results and discussions

Experimentally, we fabricated a MKR with this technique. Fig. 2 (a) shows an optical microscope image of the knot resonator, in which the polymer microfiber ring has being driven to the freestanding end of the silica microfiber. As one can see in Fig. 2(a), the

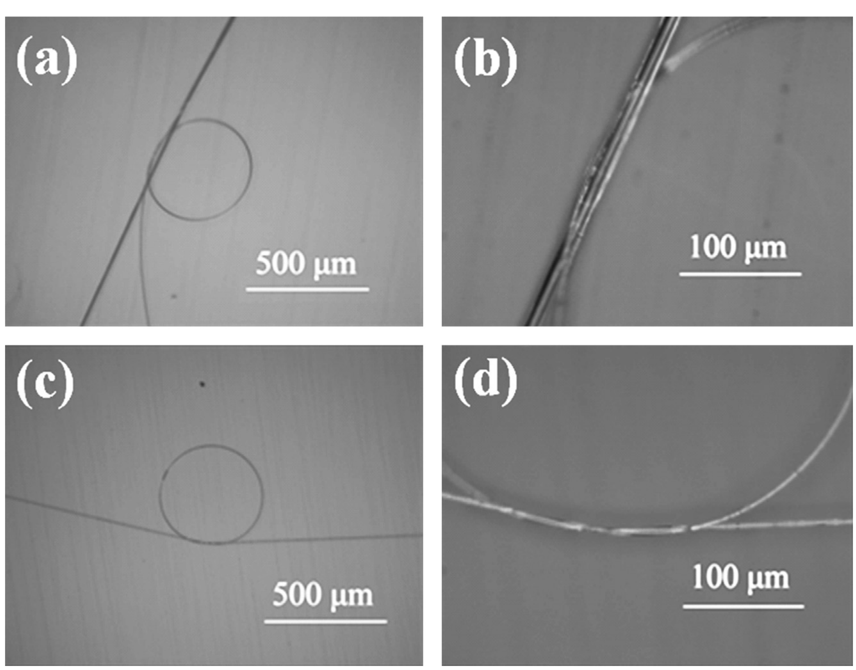

Fig. 2. Optical microscope images of (a) the MKR located in the adhered region between the polymer microfiber and the silica microfiber on an MgF_2 substrate, (b) the zoom-in knot region in (a), (c) the final fabricated MKR, (d) the zoom-in knot region in (c).