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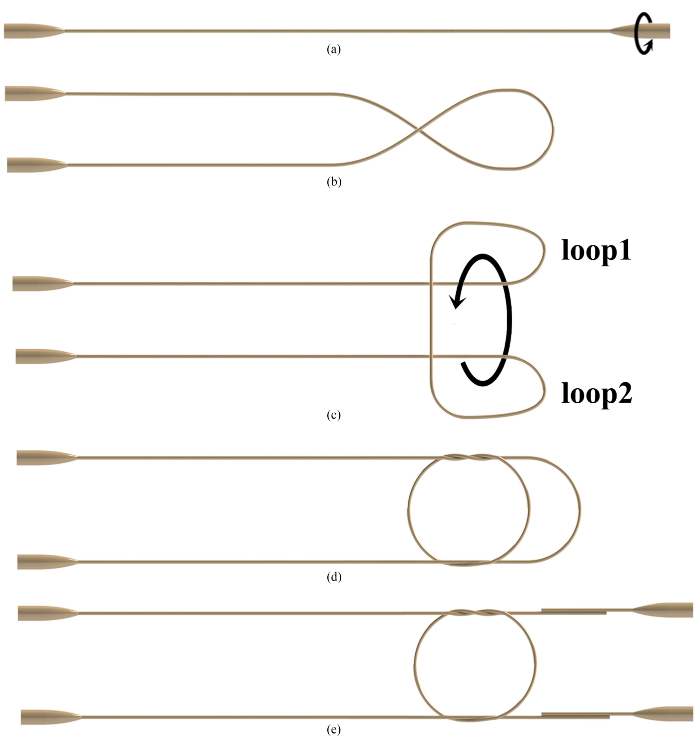

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Demonstration of a Microfiber-Based Add–Drop Filter Using One Tapered Fiber

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Abstract: We propose a novel approach to demonstrate an add–drop filter based on microfiber knot resonator (MFKR). The two coupled regions and four ports (including input port, through port, drop port, and add port) of this device are formed using the same one microfiber. By reconnecting the ends of the through and add ports with other two microfibers, this structure could serve as an add–drop filter, which is a key building block in the fields of optical networks and optical information processing system. The MFKR-based add–drop filter with the quality factor (Q-factor) of 21 000 and a diameter of 740 μm is demonstrated successfully. The intrinsic loss and extinction ratio are about –2 and 18.5 dB for the drop port, and –4.6 and 10.7 dB for the through port, respectively. The fabrication process also shows the feasibility and simplicity of this device.

Index Terms: Optical fiber filters, filters, optical resonators and optical fiber devices.

1. Introduction

Microfibers [1] are considered as the building blocks of optical fiber systems due to their intrinsic advantages of simple fabrication process and naturally low-loss coupling. With the development of optical microfiber transmission system, a growing number of optical devices based on microfiber including optical resonator [2], Mach-Zender interferometer [3], twisted coupler [4], polarizer [5], and micro-ring laser [6] have been demonstrated and reported. Owning to its small size and high quality factor, optical resonators are considered as key elements not only for integrated photonic devices [7]–[10] but also for fiber optics devices. Currently, various optical microfiber-based resonators have also been demonstrated in loop [11], knot [2] and coil [12] configuration. As an important function device, add-drop filter [13] consists of MFKR has attracted considerable interests due to their potential applications in optical information processing system. In fact, optical filters with different structures and fabrication processes such as microfiber knot resonator [14], microsphere resonator [15], reef knot microfiber resonator [16], microfiber racetrack ring resonator [17], hybrid optical fiber [18], hybrid optical filter between microfiber knot ring and Lithium-Niobate microwaveguide chip [19], add-drop filter based on an optical microfiber coupler and a microsphere [20], etc. have been proposed and demonstrated recently. However, for all of these schemes, a second microfiber or waveguide is always needed to couple with the MFKR or compose the resonant cavity in order to achieve the add-drop function of the filter. In those cases, the extra coupling losses induced by the insertion process and the mode mismatching between the taper and the resonant cavity would be generated, which can deteriorate the filtering performance of the device like increasing the insertion loss, reducing the extinction ratios or Q-factors. In this letter, we propose and demonstrate a new method to form an all-fiber add-drop filter using a single microfiber. By twisting and cutting a single tapered-fiber in certain sequences, optical filters with special merits such as extremely low loss, high extinction ratios, high Q-factors, perfect Lorentzian spectra can be built using a simple fabrication process.

2. Device Design, Fabrication, and Working Principle

2.1 Device's Design

In order to fabricate the tapered microfiber from standard optical fiber, a cleaned standard fiber with both ends fixed in the translation stages is heated by a hydrogen flame [2]. By pulling the ends symmetrically using the tapered drawing machine during the heating process, the fiber can be elongated, and the diameter of the fiber is reduced. A microfiber with a diameter of 2 μm and a length of 1 cm could be obtained using this flame-heated taper drawing method as shown in Fig. 1(a). Then we rotate the right end of this fiber counterclockwise by 180 degrees on its axis to ensure that the construction keeps the right shape and there's no cross between the input straight fiber and the drop straight fiber in the following step as shown in Fig. 1(d). Then the right part of this fiber is shifted to the left stage, the tapered section would intersect due to inner stress as shown in Fig. 1(b). Moving the two sides of the loop in Fig. 1(b) by probes, the microfiber is formed to the structure as shown in Fig. 1(c). After leading loop 2 pass through loop 1 from bottom to up, a steady construction consists of a micro-knot and a bent section is formed as shown in Fig. 1(d). The add-drop function area of the proposed device including two coupled regions and four ports can be obtained by cutting off the bent section in the middle, and this filter is finally assembled by coupling the ends of the Through port and the Add port through electrostatic and Van der Waals forces using two microfibers which are cut off from another microfiber as shown in Fig. 1(e). Comparing to the filter with a similar structure reported recently [21], our fabrication approach and function are truly different since the microfiber knot resonator in our work is formed when the whole microfiber is unbroken. However, it is required to cut the tapered microfiber into two parts before forming the filter in that paper.

2.2 Device's Fabrication

Fig. 2(b) and (c) show the photographs of the complete device with different diameters. Fig. 2(c) and (d) show the photographs of the device with a diameter of 740 μm under the light and in the dark, respectively. Visible red light is launched into the Input port for a clear visual effect.

Fig. 3 shows the detail of this proposed add-drop filter. As the figure shows, this device consists of the add-drop filtering function area and the complementary part which is used to reconnect the broken fibers to standard fibers and collect the light transmitted out of the knot on the right side. Comparing to previous work [14], this fabrication process doesn't require additional insertion operation to place the dropping taper since those coupling zone are formed spontaneously once we cut off the bent section. Made from one standard fiber in one tapered drawing process, this structure also shows a great uniformity in the diameter of microfiber. Thus extra coupling losses caused by the insertion process and the mismatching between the dropping taper and the MFKR or the mismatching of the two microfibers could be avoided. Considering that the performance of the filter is mainly determined by the coupling and losses at the filter function area since the bending loss of the microfiber knot with the diameter around 1 mm is relatively low and the extra coupling losses mentioned above could be avoided [22], our work owns superior performances thanks to the tight coupling and uniform structure of the microfiber knot.

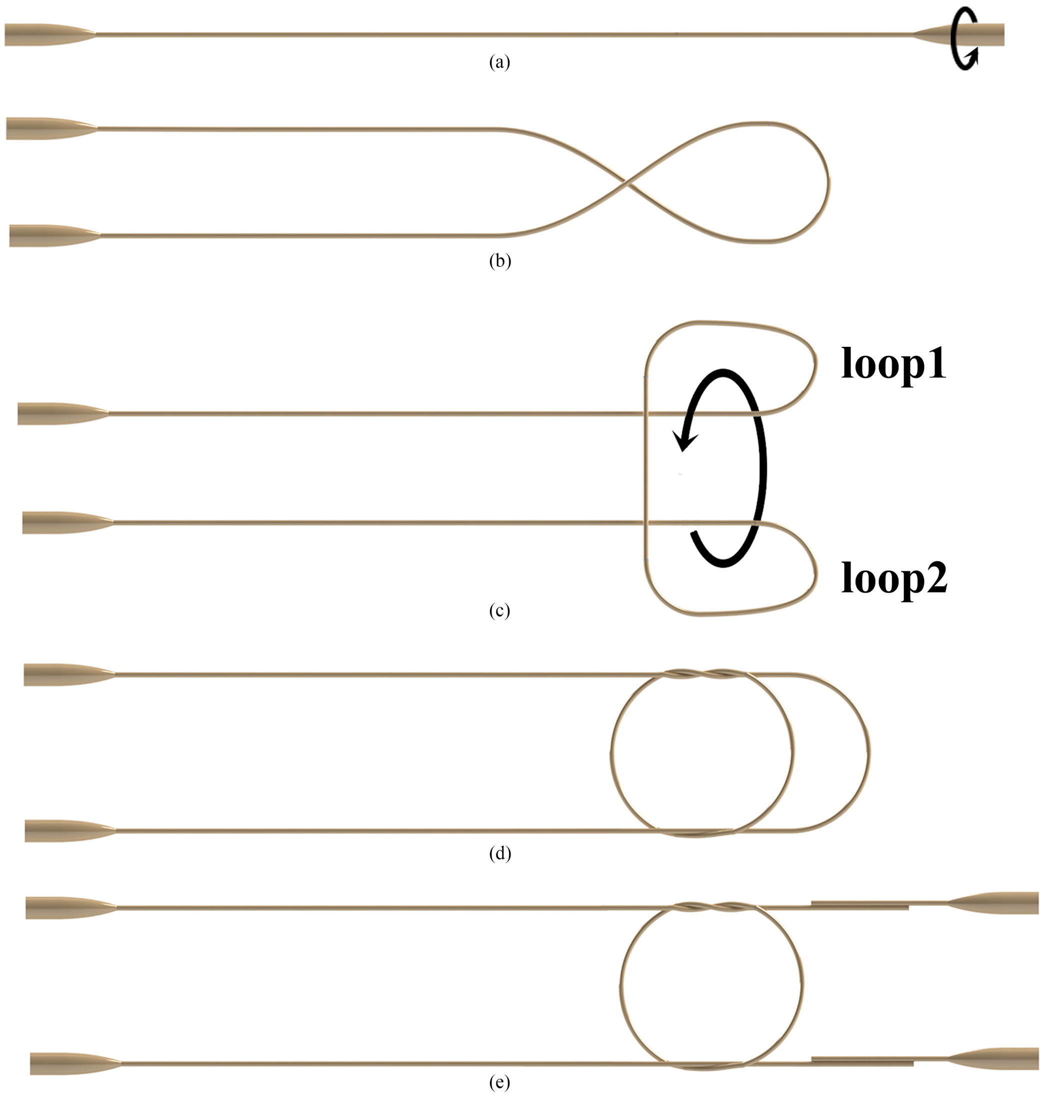

Fig. 1. Schematic of the fabrication process made of a single microfiber.

3. Experimental Results

In our experiment, transmission was monitored using an amplified spontaneous emission (ASE) and an optical spectrum analyzer (OSA) with a resolution of 0.02 nm. This add-drop filter was fabricated following the steps mentioned above, and the diameter of micro-knot could be controlled by pulling the fiber ends. A wide spectrum light was input into this device by an ASE and the output power was monitored by an OSA. We connect the ASE and a piece of normal single mode fiber and the OSA with two fiber flanges, the value of the spectrum of the proposed filter recorded at the OSA was then subtract the value of the spectrum measured in this situation in order to get the transmission spectrum. The information of intrinsic loss and extinction ratio could be obtained from the spectrum. As shown in Fig. 4, the blue line and the red line represent the transmission spectral measured at the through port and drop port respectively. By pulling the fiber gradually, two filters with different diameter were formed and tested in our experiment. As Fig. 4(a) shows, the free spectrum range (FSR) of this MFKR is 0.58 nm, corresponds to the microfiber knot with a diameter of about 1 mm as shown in Fig. 2(b). The intrinsic losses of the through port and drop port are −6.7 dB and

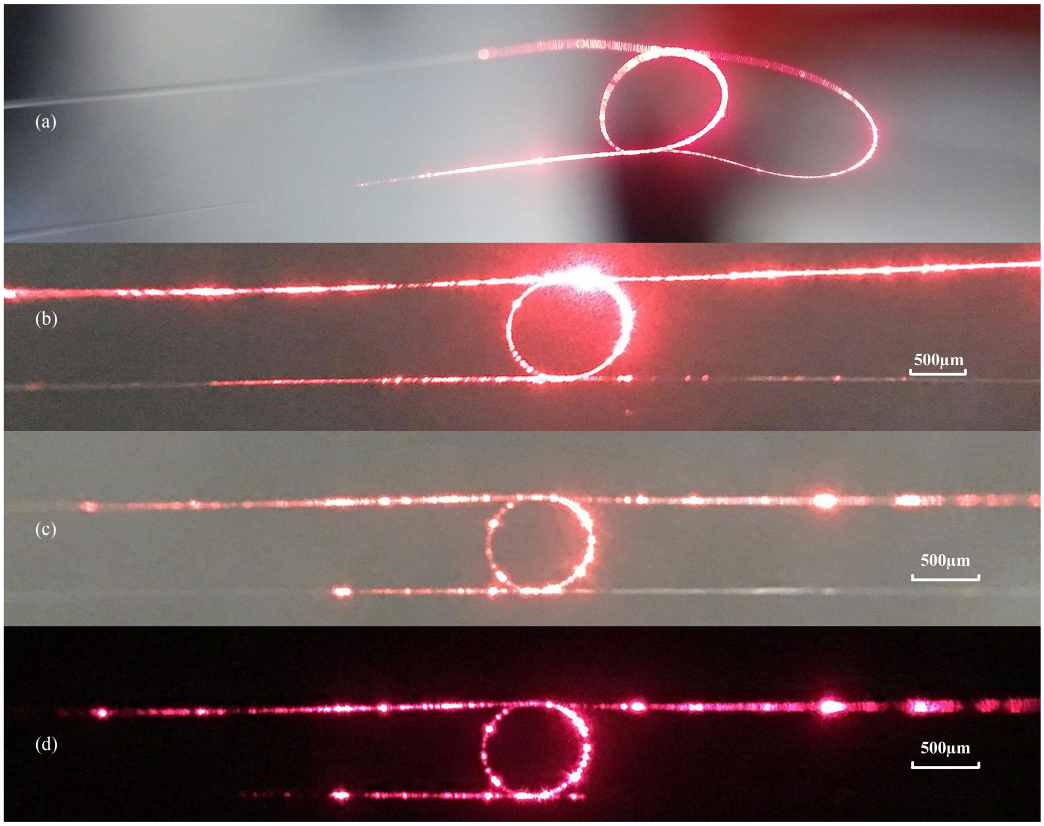

Fig. 2. (a) Graphs of visible red light transmitting through the proposed construction in Fig. 1(d). Graphs of visible red light transmitting through the microfiber knot with the diameter of (b) 1 mm and (c) (under the light), (d) (in the dark) 740 μm.

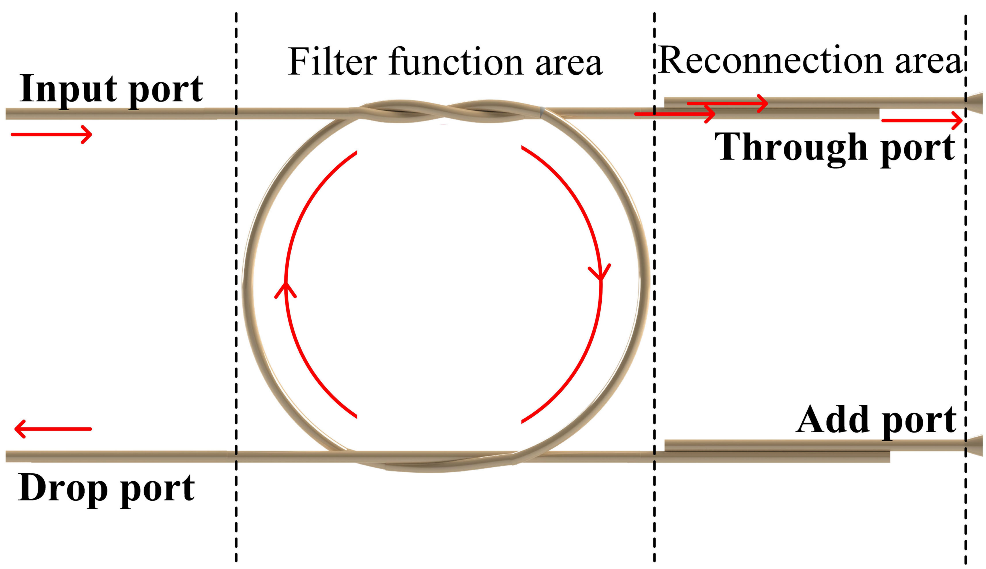

Fig. 3. Schematic diagram of the add-drop filter. The light is input in the filter through the Input port and output at the Through port and Drop port.

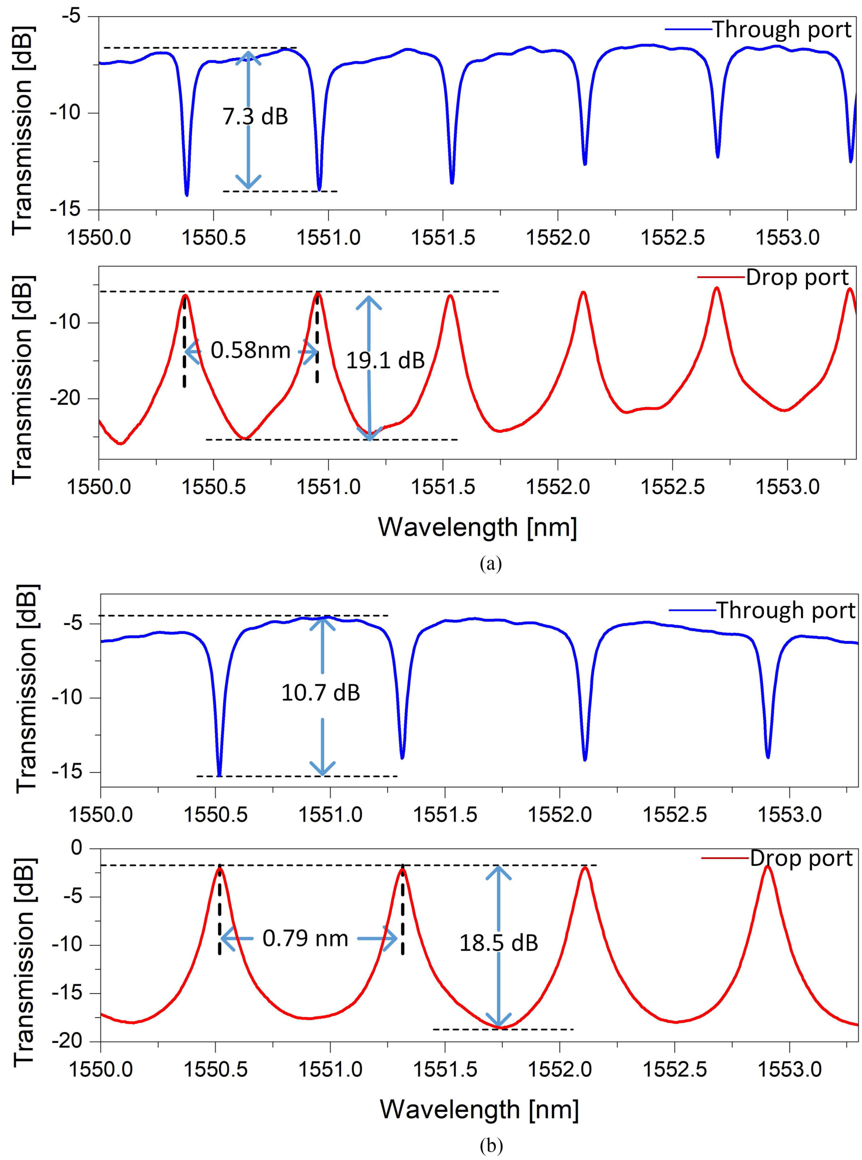

Fig. 4. Transmission spectra for the drop port and through port of the microfiber knot shown in Fig. 2(b) and (c) with the diameters of (a) 1 mm and (b) 740 μm.

-6.1 dB, and the extinction ratios of the two ports are 7.3 dB and 19.1 dB, respectively. Comparing with Fig. 4(a) and (b) shows lower intrinsic losses and more standard Loretzian type spectral. The main cause of this phenomenon is the MFKR shown in Fig. 2(c) owning a more uniform rotundity shape than the one in Fig. 2(b) since a smaller diameter leads to a stronger inner stress.

Comparing to previous works [16], [17], the intrinsic losses of this device are much lower, especially the one with a diameter of 740 μm. As we can see, the intrinsic loss at the drop port is as low as -2 dB since the two coupling zones and the micro-knot were fabricated by a single standard fiber in one taper drawing process, which means the uniformity of the microfiber could be well guaranteed and what's more, extra coupling losses caused by the insertion process and the mismatching between the dropping taper and the MFKR could be avoided. Considering the inevitable coupling loss in the MFKR area and reconnection area shown in Fig. 3 simultaneously, the intrinsic loss of the through port reaches -4.6 dB. While guaranteeing low losses, the extinction ratios of the two ports are 18.5 dB and 10.7 dB, respectively, which shows a great filtering and switching ability. In addition, the Q-factor measured at the through port is close to 21000, which is higher than previous works [14], [16].

In addition, the position and the shape of the MFKR could be adjusted by probes, which means the coupling zone, the diameter and the uniformity could be tuned, and thus the extinction ratio, bandwidth and resonance wavelength could be well controlled.

4. Conclusion

In conclusion, we have demonstrated an all-fiber add-drop filter from one microfiber using a novel method. The intrinsic loss and extinction ratio are about −2 dB and 18.5 dB for the drop port, and −4.6 dB and 10.7 dB for the through port, respectively. And the measured Q-factor is about 21000, shows a strong ability of storing energy. We believe that this scheme will provide an ideal platform for several applications including dense wavelength division multiplexing (DWDM), sensors, ultra-small optical tunable filters and integrated micro-lasers.

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