All-fiber add–drop filters based on microfiber knot resonators

Xiaoshun Jiang, Yuan Chen, Guillaume Vienne, and Limin Tong*

Department of Optical Engineering, State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou 310027, China

Corresponding author: phytong@zju.edu.cn

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We demonstrate an all-fiber add–drop filter composed of a microfiber knot (working as a resonator) and a fiber taper (working as a dropping fiber). The dropping taper can be either parallel or perpendicular to the input port of the filter. A quality factor (Q factor) of 13,000 is obtained from a parallel-coupling 308 μm diameter microknot add–drop filter with a free spectral range (FSR) of 1.8 nm. A Q factor of ~3300 is obtained from a cross-coupling 65 μm diameter microknot add–drop filter with a FSR of 8.1 nm. This device is particularly easy to fabricate and to connect to fiber systems. © 2007 Optical Society of America

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Optical microresonators are essential components for optical communications [1,2], enabling a variety of functions. A particularly important function in modern wavelength division multiplexing (WDM) networks is add–drop filtering. This key function has already been implemented in various forms of resonators including microrings [3–7], microdisks [4,8], microspheres [9,10], microtoroids [11], and photonic crystal resonators [12]. Recently, optical microfiber loop or knot resonators have been given considerable attention as building blocks for optical devices [13–17]. Owning to their high Q factors, easy fabrication, and small sizes, these fiber-based microloop or micro-knot resonators have been developed into compact optical devices such as sensors [15] and lasers [17]. In this Letter, using microfiber knot structures, we demonstrate all-fiber four-port passive add–drop filters. Previously fiber-based add–drop filters were constructed either by combining a fiber Bragg grating with a polarization splitter [18] or with a Mach–Zehnder interferometer [19], or by recording a Bragg grating in the merged region of two adiabatically tapered and fused fibers [20]. The work described here offers a new approach to add–drop filter construction with special advantages, including simple fabrication, easy connection to fiber systems, compact size, and compatibility with miniaturized microfiber devices.

Figure 1(a) shows a typical add–drop filter geometry including a microfiber-knot resonator and two evanescently coupled microfibers (the collection fibers). The microfiber-knot resonators are fabricated by assembling the freestanding end of the microfiber under an optical microscope, as described in [16]. When the knot is tightened to the desired size, a second microfiber (collection fiber 1) is used to collect the transmitted power by means of evanescent coupling [16], while the third microfiber (collection fiber 2) placed tangentially to the microfiber knot is used to drop the resonant signal. The dropping microfiber can be placed in parallel [Fig. 1(b)] or perpendicularly [Fig. 1(c)] to the input port and is joined together with the microfiber knot through van der Waals and electrostatic attractive force. The resonant power can be transferred from the input port (port 1) to the drop port (port 3), while the nonresonant power is transferred from the through port (port 2) without being significantly affected.

In the measurement setup, a tunable laser (Agilent 81642 A) with a linewidth of 100 kHz is used as the light source. The optical power at the through and drop ports is measured using an optical power meter. Figure 2 shows a typical spectral response from a 308 μm diameter add–drop filter at the through port [Fig. 2(a)] and the drop port [Fig. 2(b)]. During the measurement, the dropping taper is placed parallel to the input port of the filter [see Fig. 1(b)]. The knot is assembled with a 2.7 μm diameter microfiber, showing a Q factor of ~13,000 and a finesse of ~14.6 with a free spectral range (FSR) of ~1.8 nm.

Similar to the vertically coupled microring resonator add–drop filter composed of a ring resonator stacked above a cross-grid node [6], the microfiber-knot-resonator-based add–drop filter also works when the dropping taper is placed perpendicularly to the input port. As shown in Fig. 1(c), the distal end of the dropping taper crosses the through port of the fil-

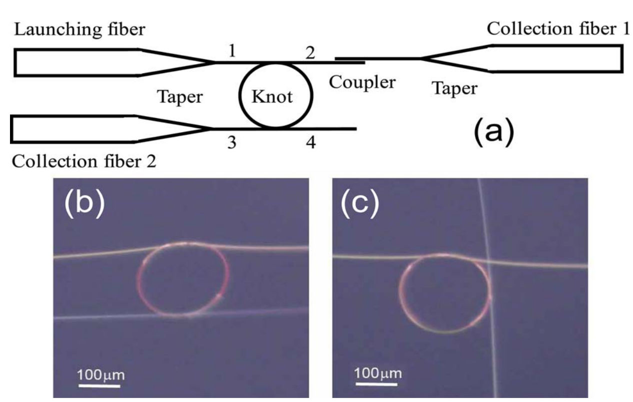

Fig. 1. (Color online) (a) Schematic of the microfiber-knot-resonators-based add–drop filter. (b), (c) Optical microscope image of a ~200 μm diameter microknot add–drop filter with the dropping taper placed (b) parallel or (c) perpendicular to the input port of the filter.

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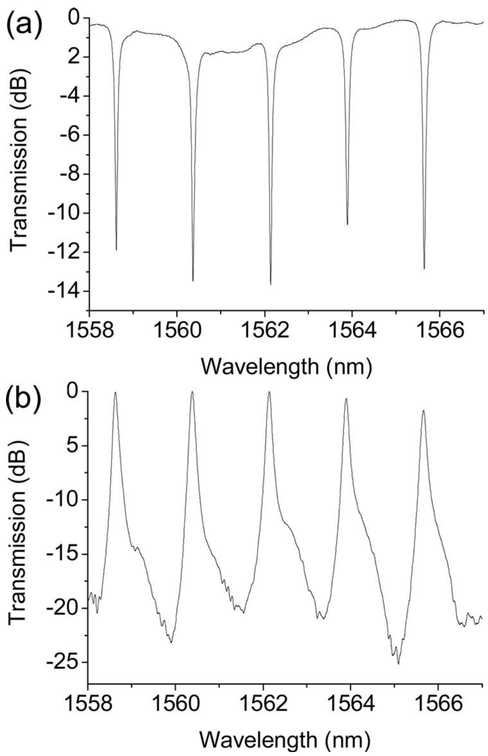

Fig. 2. Transmission spectra of a 308 μm diameter add–drop filter with the dropping taper placed parallel to the input port of the filter at the (a) through port and (b) drop port. The knot resonator is assembled using a 2.7 μm diameter microfiber.

ter. Thanks to the low magnitude of the cross talk [6,21], the resonant signal in this structure is well retrieved. On the other end, in the parallel dropping configuration unintended contact between the dropping taper and the through port leads to high cross talk, and should therefore be avoided. When the knot becomes small, avoiding this contact becomes difficult and the perpendicular dropping configuration is preferred. A typical response from the drop port of a 65 μm diameter microfiber knot is shown in Fig. 3, in which a 1.8 μm diameter microfiber is used to assemble the knot resonator. The measured FSR is ~8.1 nm with the resonator Q factor and the finesse of ~3300 and 17.3, respectively.

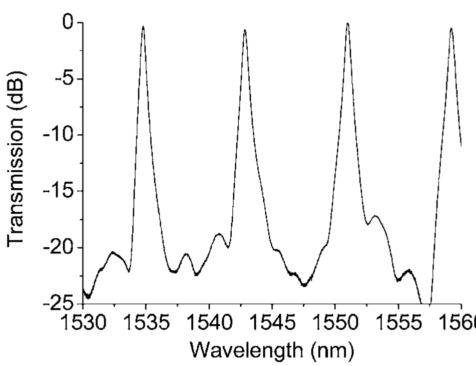

Fig. 3. Transmission spectrum of a 65 μm diameter add–drop filter with the dropping taper placed perpendicularly to the input port of the filter at the drop port. The knot resonator is assembled using a 1.8 μm diameter microfiber.

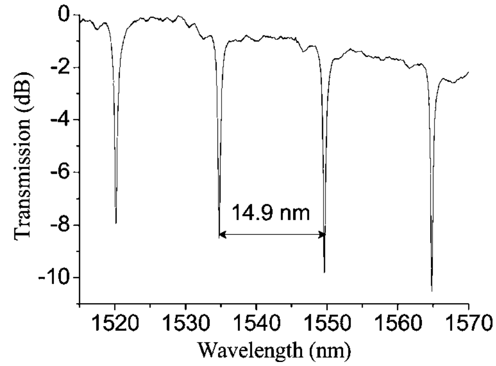

Fig. 4. Transmission spectrum of a 35 μm diameter microfiber knot resonator (without dropping taper). The knot resonator is assembled using a 1.0 μm diameter microfiber.

To investigate the possibility of achieving larger FSR that may be desired in certain applications, we have fabricated a smaller knot with thinner microfibers. Figure 4 shows the transmission spectra of a 35 μm diameter microfiber knot resonator assembled with a 1.0 μm diameter microfiber. The diameter of this microfiber knot is much smaller than reported previously [16], leading to a FSR as large as 14.9 nm. The full width at half-maximum (FWHM) of the resonance peak at 1549.6 nm is ~0.57 nm, resulting in a Q factor of ~2700 and a finesse of ~28. Considering that Q factors as large as 4×10^8 have been demonstrated in silica toroid microcavities with similar diameters [22] and that the bending loss of the microfiber is very low [23], we expect that the Q factor can be greatly increased by further improvements, such as finely tuning the coupling strength at the twisted region and decreasing the scattering loss along the fiber.

In conclusion, we have experimentally demonstrated all-fiber add–drop filters based on microfiber knots, which are tens to hundreds of micrometers in diameter. The add–drop filter works well with either a parallel or a perpendicular dropping fiber. The possibility of obtaining larger FSR (e.g., ~15 nm) from a smaller knot resonator is also demonstrated. Since this kind of add–drop filter is constructed solely with microfibers, it may show special advantages, such as simple fabrication, easy connection to fiber systems, compact size, and compatibility with miniaturized microfiber devices. For practical applications, the device can be embedded in a low-index matrix for achieving high stability [24]. In addition, with the advent of high-index low-loss microfibers or nanofibers (e.g., tellurite nanofibers [25]), much more compact filters with larger FSR may be achieved based on the scheme shown here.

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