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Whispering gallery mode microsphere resonator with microsphere-microsphere coupling

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ABSTRACT

We demonstrate a new type of whispering gallery mode microsphere resonator with microsphere-microsphere coupling. The device is based on two cascaded microspheres glued on a single mode fiber tip. The incident light from the fiber core diverges in the first microsphere and part of light is coupled to the surface of the second microsphere, exciting whispering gallery mode resonance when the angle between the connection line of the two microsphere centers and the fiber axis is appropriate. Such a whispering gallery mode microsphere resonator is robust in structure, compact in size, easy in fabrication and stable in operation.

1. Introduction

Whispering gallery mode (WGM) microsphere resonator on the fiber tip was demonstrated in only 1990s. For example, L. Collot et al. reported fused silica microspheres with optical Q factors above 109 by fusing the end of a silica fiber tip in 1993. This topic has attracted a lot of research interests since then [18]. WGMs has some unique features such as high quality factor (Q), small mode volume, long photon life time and high potential for a variety of photonic and biochemical sensing applications [1–3]. To excite WGM resonance in microsphere, efficiently coupling light into and out of microsphere is critically important. A number of approaches have been developed such as the use of prism, planar or ridge waveguide, side polished or angle polished fiber and fiber taper [4–14]. A prism coupler is flexible and efficient for free space optical operation while it is bulky and needs a careful alignment.

The waveguide coupler is robust and compact however, it requires high precision and complicated fabrication technique, is not compatible with optical fiber and needs additional component for light coupling into optical fibers. The coupling efficiency of side polished or angle polished fiber is low. Although high efficiency can be achieved for fiber taper-microsphere coupling, the system needs careful alignment, has poor robustness and subject to environmental perturbation, hence it cannot support stable WGM operation. Moreover, critical refractive index (RI) requirement imposed by silica fiber prevents the use of microsphere with high RI.

Here we propose and demonstrate a new type of microsphere WGM resonator with microsphere-microsphere coupling. The coupler consists of a microsphere glued to a single mode fiber (SMF) tip by use of UV adhesive. The incident light from fiber core at the fiber end diverges and arrives at the surface of microsphere with different angles. Part of diverged light beam is picked up by the second microsphere, which is glued to the first microsphere at the fiber tip. When the second microsphere is positioned properly or in other words, the angle between the connection line of the two microsphere centers and the fiber axis is appropriate, WGM resonance is excited. The WGM microsphere resonator structure is then fixed by employing UV light to solidify the UV adhesive. Such a microsphere-microsphere coupling system is robust in structure, compact in size, easy in fabrication and stable in operation.

2. Device fabrication

In the device fabrication, the end face of SMF with a core diameter of 8 µm and a nominal effective RI of 1.4682 (at 1550 nm) is glued to two cascaded microspheres by use of UV adhesive (Norland, NOA68) (Norland, NOA68). The glass microsphere (Cospheric Inc, BTGMS-4.22) used have the nominal effective RI value of 1.9 (at 1550 nm), with the diameter ranging from 63 to 75 µm. The UV adhesive employed can sustain temperature change from −80 °C to 90 °C, and have the RI value of 1.54. The fabrication of the device is carried out in a fusion splicer and the process is illustrated in Fig. 1.

1. Initially, the cleaved end of a section of SMF is touched by UV adhesive, before contacting the cleaved end of another SMF. This

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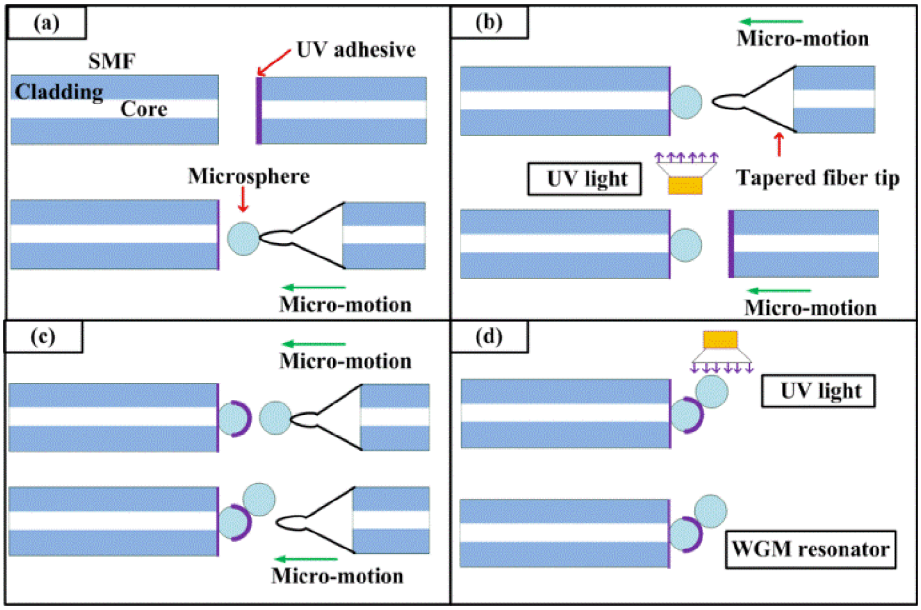

Fig. 1. Schematic diagram of the fabrication process of the WGM microsphere resonator.

allows a thin layer of UV adhesive be left on the fiber end to glue a microsphere with the help of a fiber taper, as shown in Fig. 1(a).

2. The location of the microsphere at the fiber end is adjusted to be positioned at the center of fiber core with the help of a fiber taper, before the UV adhesive is solidified by UV light illumination. Then, the surface of the first microsphere is covered with a small amount of UV adhesive, as demonstrated in Fig. 1(b).
3. The microsphere covered with UV adhesive on its surface sticks another (the second) microsphere with the help of a fiber taper, and the position of the second microsphere is continuously adjusted, while observing the reflection spectrum of the device, until the WGM resonance appears, as depicted in Fig. 1(c).
4. Finally, the UV adhesive is solidified by UV light illumination, to provide a robust structure of the WGM resonator device, as shown in Fig. 1(d).

The volume of the adhesive used has to meet the requirement to adhere the microspheres. In general, UV adhesive of 5 µm in thickness needs to cover 1/4 of the surface of the microspheres.

3. Operating principle

The microscope image of the sensor head is shown in Fig. 2, where the inset displays the propagation path of red light on the surface of

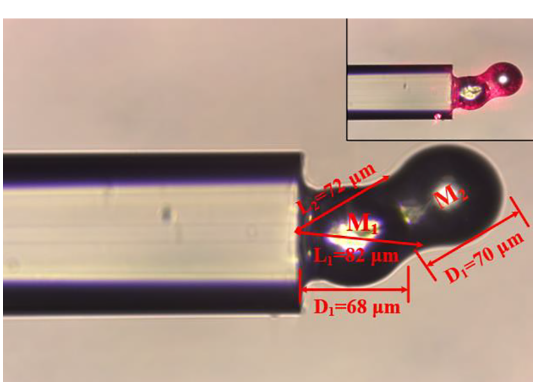

Fig. 2. The microscope image of the WGM microsphere resonator and the inset shows the propagation path of red light on the surface of microspheres.

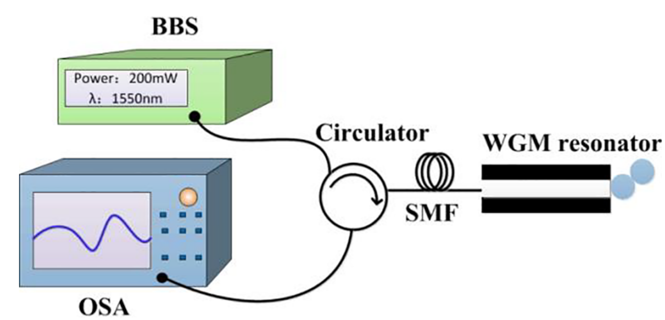

Fig. 3. Schematic diagram of experimental setup of the WGM device.

microspheres. The diameter of the first microsphere (M1) and the second one (M2) are 68 and 70 µm, respectively.

The experimental setup used to verify the operation of the WGM microsphere resonator proposed is shown in Fig. 3. Light output from a broadband light source (BBS) is introduced to the device via a circulator. The reflection output of the device is directed to an optical spectrum analyzer (OSA) with the resolution of 0.02 nm to monitor the reflection spectrum.

The reflection spectrum of the device sample S1 and its corresponding spatial frequency spectrum obtained by use of fast Fourier transform (FFT) are displayed in Fig. 4. It can be observed from the figure that there are two dominant peaks in the spatial frequency spectrum, located at ~0.422 nm^{-1} and ~0.438 nm^{-1}, respectively. Another side peak is situated at ~0.108 nm^{-1}.

The free spectral range (FSR) [15] is given by

$$FSR = \frac{\lambda^2}{OPD} \tag{1}$$

Where λ is the wavelength, OPD is the optical path difference introduce by the device.

For a WGM microsphere resonator,

$$OPD = n\pi D \tag{2}$$

where n is the RI of the microsphere, and D is the diameter of the glass microsphere.

For a Fabry-Perot (FP) cavity,

$$OPD = 2n_{FP}L \tag{3}$$