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Whispering gallery modes of dye-doped polymer microspheres in microtube

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ABSTRACT

A micro-system including a silica micro-tube (inner diameter ≈ 6.2 μm) and dye-doped microspheres (diameter ≈ 6 μm) was pumped by a 532 nm laser. The whispering gallery modes (WGMs) of fluorescence resonance were observed. Free Spectral Range (FSR) of single-sphere with diameters of 40 μm was 3.1 nm and with diameters of 6 μm was 5.4 nm. Two size-matched microspheres were coupled using a bi-sphere micro-system. Resonances from each sphere's evanescent field were coupled, which leads to resonance splitting. The measured resonance splitting in the spectra of the two coupled spheres is about $\Delta\lambda \approx 0.8$ nm. The scheme would be a promising component in future micro-photonic devices.

1. Introduction

When light propagates in a dielectric sphere, it will be trapped near the surface of the sphere by repeated total internal reflections [1–3]. Then, the resonances are generated and travel in a circle with virtually no loss except for residual absorption and scattering in the dielectric [4–6]. The natural frequencies of these resonances are described as whispering gallery modes (WGMs), which will confine photons in this small volume with a long time by total internal reflections. Owning to their high optical quality, long cavity lifetime and strong field confinement, WGMs micro-resonators [7–10] are known as versatile elements in photonics with applications including optical filters [11], laser sources [12,13], and biological sensors [14,15].

Coupled microspheres can be used as a well-designed model system; the two spheres are coupled in such way that the evanescent field of WGM resonances of each separate sphere coherently add up together. We study these coupled microspheres to learn more about their fundamental properties [16]. The experimental demonstration of coherently coupled photon states in such microsphere resonators succeeded with the photonic molecules based on the mutual coupling of evanescent fields from WGMs of pairs of dye-doped microspheres [17,18]. The coherent coupling results in the corresponding WGMs splitting and is a manifestation of the well-known phenomena of the normal mode splitting in coupled harmonic oscillators. In this paper, we report dye-doped microspheres with diameter of 6 μm placed into a micro-tube with inner diameter of 6.2 μm by micro-manipulating with a fiber probe. Optical pumping the microspheres-micro-tube system, WGMs were generated and observed in the spectrum. WGMs resonance mode splitting of two spheres with nearly the same diameter in contact in the micro-tube was also demonstrated.

2. Experiment methods

The micro-tube used in our experiment was obtained from the silica capillary (outside diameter ∼162 μm, inner diameter ∼100 μm, refractive index 1.55, Polymicro Technologies, L.L.C.) by a flame-heated drawing method. The coating (about 12 μm in thickness) of the silica capillary was melt away by a Bunsen burner; by controlling the flame temperature and the speed stretching, we can get micro-tube with different diameters. Fig. 1a shows the scanning electron microscope (SEM) images of the micro-tube with well surface smoothness after drawing process, we obtained silica micro-tubes with outside diameters down to ∼8 μm; wall thickness down to ∼900 nm and lengths up to hundreds of microns.

In this paper, we adopt the Melamine-Formaldehyde Resin microsphere as the resonator. Its refractive index is 1.68 and diameter ranges from 2 μm to 20 μm. The sphere is doped with a fluorescent laser dye (Rhodamine B, fluorescence FWHM is about 50 nm) using the dispersion polymerization method [19]. Fig. 1b shows SEM images of the microspheres with high surface smooth. We can manipulate and select the microspheres by a fiber probe

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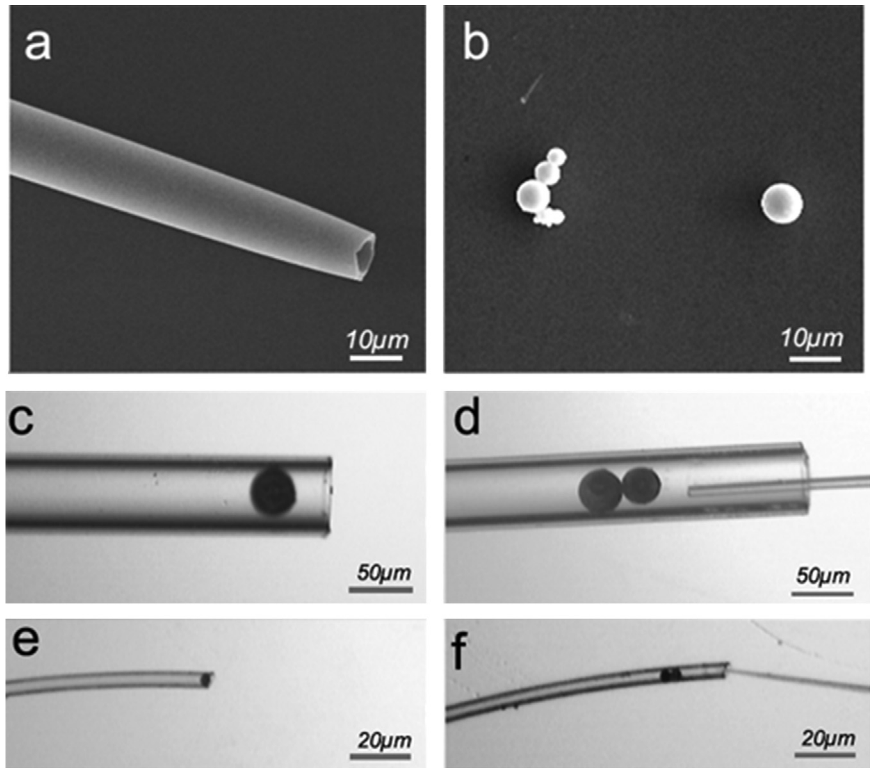

Fig. 1. (a) The SEM image of the micro-tube with outside diameters down to 8 μm; wall thickness down to 900 nm. (b) The SEM image of the Melamine-Formaldehyde Resin microspheres. (c) Micrograph of one single sphere with diameter of 40 μm in the micro-tube. (d) Another sphere with diameter of 35 μm was been manipulating into the micro-tube. (e) A microsphere with diameter of 6 μm in the micro-tube with inner diameter of 6.2 μm. (f) Another microsphere with the same diameter pulled into the same smaller micro-tube.

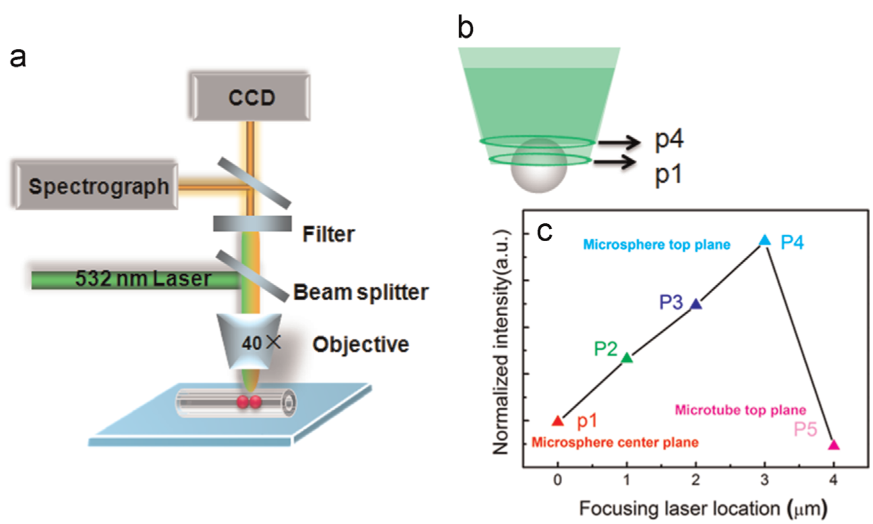

Fig. 2. (a) The schematic experimental configuration. (b) The schematic diagram of laser focal plane from the center of micro-system (P1) to the top (P5). (c) The relationship between emission intensity and focusing laser location on the micro-system.

which was fabricated by a flame-heated drawing from SMF128. An optical fiber probe with a tip diameter of ~10 μm is fixed on the XYZ translation stage with a resolution of 0.1 μm to manipulate the microspheres into micro-tube. Fig. 1c shows a single micro-sphere with diameter about 40 μm, which was manipulated into the micro-tube with inner diameter about 45 μm. Another sphere ~35 μm was manipulated into the same micro-tube by the fiber probe as shown in Fig. 1d. Fig. 1e given a smaller sphere ~6 μm in a smaller micro-tube (inner diameter ~6.2 μm). We choose the same size micro-sphere by measuring the diameter under micro-scope. Fig. 1f shows another microsphere pulled into the same smaller micro-tube.

Optical characterization of the microtube–microspheres system is carried out under an optical microscope using an experimental setup as schematically shown in Fig. 2(a). The micro-system was placed on a low-index MgF_2 crystal to reduce the loss. Light source is a frequency doubled CW Nd:YAG laser ($\lambda=532$ nm) which was focused to a spot size of ~100 μm through a 40× objective (NA=0.45). The measurement of fluorescence from the micro-system and laser power was at the same sample spot. The dye fluorescence is collected with the same objective, reflection of the excitation laser is removed by a 532 nm notch filter, emission of the spheres was split by a beam splitter and directed to a spec-trometer (spectral resolution=0.1 nm) and CCD. The microtube-