Tuning Optical Resonances of a Microsphere with Liquid Crystal

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ABSTRACT

Optical resonances are observed in the elastic light scattering from high refractive index glass microspheres placed on a single mode optical fiber coupler and in a liquid crystal. Placing the liquid crystal on the optical fiber coupler increases the non-resonant scattering, whereas placing the liquid crystal away from the optical coupler increases the resonant scattering. Optical resonances blue and red shift due to the placement and removal of the liquid crystal.

Keywords: morphology dependent resonance, whispering gallery mode, coupler, optical fiber, glass, microsphere, liquid crystal, tuning.

1. INTRODUCTION

Dielectric microspheres, with high quality factor optical resonances, are important for their potential use in photonic devices [1, 2]. In analogy with the whispering gallery modes (WGM's) of acoustic waves, light waves in an optical cavity also experience resonant modes, due to the total internal reflection inside a microcavity [3]. For our microspheres, the radius of the microsphere is much larger than the vacuum wavelength of the light ($a \gg \lambda$). The morphology dependent resonances (MDR's) occur for specific values of the size parameter $x=2\pi an/\lambda$, where n is the refractive index of the outside medium [4].

Additionally, nematic liquid crystals (NLC's) have optical anisotropy arising from their spatial arrangement. NLC molecules with rod-like geometries have a preferred orientation axis, i.e., a director. NLC's show interesting electro-optical features and have relatively high birefringence. The most common method used in NLC based devices is the reorientation of the director. Rod-like NLC's can be aligned along their long axis, by applying an external electric field. When the external electric field is switched off, NLC's tend to relax back to their original configuration [5, 6]. NLC's are extensively used in liquid crystal displays (LCD's), optical switches, and light modulators. Other applications, such as liquid crystal droplet microresonators and solid-state ring microresonators with a cladding of liquid crystal layers have been demonstrated [7, 8].

In this work, we report on the observation of MDR's in the elastic light scattering spectra of high refractive index glass microspheres placed on single mode optical fiber half couplers (OFHC's) and in NLC's.

2. EXPERIMENTAL SETUP AND RESULTS

Figure 1 shows the experimental setup. A Nd:YAG laser pumped dye laser is used to obtain the elastic light scattering spectra. The input laser light is focused to a single mode optical fiber (SMOF) at 630 nm. The laser light is coupled through the OFHC to the microsphere. The 90° elastic light scattering is detected by a photomultiplier tube (PMT). The transmission is monitored by a silicon photodiode (PD). There are no MDR associated dips in the transmission spectra, because of weak coupling to the MDR's. All the data are recorded using a digital storage oscilloscope (DSO). High refractive index glass microspheres with radii of 11.5 μm and 51.5 μm are used. The input polarization of light into the optical fiber is tuned by an achromatic half wave ($\lambda/2$) plate before the optical fiber coupling. A Glan polarizer is placed in the objective of the microscope for improved polarization selection of the 90° elastically scattered light. The glass microspheres are positioned by using a micropositioner with a tungsten tip with a diameter of 10 μm . The NLC used in the experiments is 4-cyano-4'-pentyl-biphenyl (5CB).

Figure 1. The schematic of the experimental setup.

Figure 2 shows the results of the preliminary experiments. First a high refractive index glass microsphere with a radius of $11.5 \mu\text{m}$ is placed on a single mode optical fiber half coupler (OFHC). The elastic scattering spectrum of the microsphere is measured in the range of 624 nm and 628 nm. The spectral mode spacing is measured as 2.532 nm. Then, a droplet of NLC 5CB is placed on the OFHC to surround the microsphere. After measuring the spectrum in the same range, a dramatic change in the spectrum is observed. The non-resonant background signal increased and the Q-factor of the resonances decreased excessively. This is caused by the high refractive indices of 5CB ($n_o = 1.53$ and $n_e = 1.71$), which are comparable to the refractive indices of the single mode optical fiber. The high refractive index NLC between the microsphere and the optical fiber causes light to escape and prevents efficient coupling to the microsphere MDR's.

Figure 2. Elastic light scattering spectra of the microsphere in (a) air and (b) 5CB LC.

The original geometry of the high refractive index glass microsphere, single mode optical fiber half coupler, and the NLC is shown in Fig. 3. In order to overcome the non-resonant scattering, an improved geometry is devised. As shown in figure 4, a high refractive index glass microsphere with a radius of $51.5 \mu\text{m}$ is placed on the single mode optical fiber half coupler (OFHC). A glass slab placed on top of the microsphere holds the NLC. The position of the glass slab is controlled by a micropositioner to place the NLC on top of the glass microsphere. A larger glass microsphere is used in order to prevent the contact of NLC with the OFHC.

Figure 3 The schematic of the original excitation geometry.

Figure 4. The schematic of the efficient excitation geometry.

First, the 90° elastic scattering spectrum of the glass microsphere is measured. Then, the NLC is placed by the glass slab over the glass microsphere and the 90° elastic scattering spectrum is measured again. Lastly, the NLC is removed by taking the glass slab away from the glass microsphere. The contact area of NLC to the glass slab is much larger than the contact area to the glass microsphere, so nearly all of the NLC molecules are removed.

Fig 5 shows a red shift of 0.24 nm for the optical resonances due to the 5CB NLC on the surface of the microsphere. The mode spacing is measured to be 0.75 nm. The red shift means an increase in the optical path, which is caused by the weaker confinement of the evanescent field, when the NLC coats the microsphere. The relative refractive index decrease and the optical path increase are competing effects, and the optical path increase dominates in this case.

In Fig. 6, the removal of the 5CB NLC shifted the optical resonances to blue again by 0.24 nm. The mode spacing is again measured to be 0.75 nm. However, the optical resonances do not appear the same even though the resonances are at the same wavelengths. This may be caused by a small amount of NLC, that could not be removed, or there might be surface contaminants. These two effects can decrease the quality factor of the resonator.

CONCLUSIONS

Placing the NLC on the OFHC increases the non-resonant scattering, whereas placing the NLC away from the OFHC increases the resonant scattering. The red/blue shift of the optical microsphere resonances is realized by placing/removing a coat of NLC on the surface of the microsphere. Instead of placing/removing NLC of the surface, electrically switching the NLC should result in the modulation of the elastically scattered signal.

Figure 5. 90° elastic light scattering spectrum, when there is (a) no NLC on the microsphere, and (b) NLC on the microsphere.

Figure 6. 90° elastic light scattering spectrum, when there is (a) NLC on the microsphere, and (b) NLC is removed from the microsphere.

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