WAVEGUIDE COUPLING TO SIZE-MISMATCHED BISPHERES

G. Senthil Murugan (1), James S. Wilkinson (1), Michalis N. Zervas (1,2)
(1) Optoelectronics Research Centre, University of Southampton, United Kingdom
(2) SPI Lasers Ltd, Southampton, United Kingdom

Abstract: *Coupling of whispering gallery resonances has been observed for two contacting glass microspheres of very different diameter. Whispering gallery modes were excited in one microsphere from the evanescent field of a planar waveguide, and wavelength-selective coupling of energy between spheres was demonstrated.*

1. Introduction

Over the last decade, there has been rapidly increasing interest in microsphere resonators [1,2], stemming from their very high quality (Q) factors and their potential integration in optical circuits for wavelength filtering, nonlinear switching, pulse shaping and lasing. Recently, much research activity has been focused on coupled microspheres, especially bispheres [3]. Understanding the optical behavior and spectral properties of bispheres is extremely important as these composite structures can be part of larger chains, such as coupled resonator optical waveguides (CROW) [4]. They can also be used for the selection of specific spectral lines of relatively large multi-line lasing spheres, through a Vernier-type effect. Finally, bispheres are ideal for studying the optical properties of "photonic molecules" of various sizes.

Among the various excitation methods, free space excitation of microsphere whispering gallery modes (WGM) is extremely inefficient due to the mismatch in the phase velocities of light in air and the WGMs. Efficient excitation can be achieved using evanescent coupling in the vicinity of a prism, angled fibre tip, polished or tapered fibre, or planar waveguide. We excite the microspheres by positioning them on planar (channel or rib) waveguides by chemical or topographical means [5]. The planar configuration offers robust construction, and photolithographic techniques permit multiple spheres to be placed in well-defined positions on a substrate to build up multifunctional optical circuits.

In this paper, we present for the first time results showing the spectral response of highly mismatched bispheres evanescently excited by a planar waveguide.

2. Microsphere preparation and measurement

The microspheres used in the present study were fabricated by annealing/softening glass particles. Erbium doped (≈ 2 wt% oxide) BK7 bulk glass was crushed into a fine powder and double filtered using sieves of closer (≤10µm) mesh size, providing glass particles within a specified range (30-40µm and 110-130 µm) of sizes. The particles were placed on non-wetting glassy carbon plates and were heat-treated near the softening point of the glass for one hour and cooled slowly under Ar atmosphere. Due to surface tension the softened mass attains a spherical shape that is retained during cooling. In some cases large spheres adhere to the glassy carbon and form flat bottomed spheres. Otherwise these are close to spherical and the flat region is less than one fifth of the diameter of the spheres. When excited from a waveguide these spheres showed undisturbed whispering gallery modes. The flat region proved useful for attaching the sphere to a tapered fibre stem facilitating the mechanical manipulation across the waveguide and the placement of one sphere on top of the other.

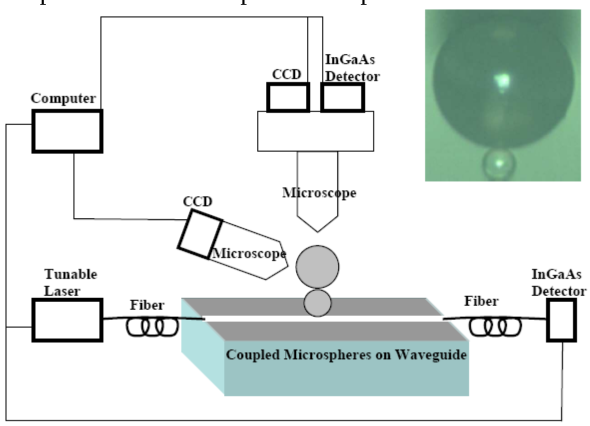

Fig. 1: Experimental apparatus used for whispering gallery resonance measurements; the inset shows the bisphere used.

The experimental apparatus used to observe the WGMs is shown in Fig. 1. A potassium ion-exchanged BK-7 glass waveguide, monomode at 1550nm [6], was used to evanescently couple the light into a microsphere. The single microspheres or bispheres ("photonic molecules"), are placed on top of the waveguide and are imaged through microscopes with CCD cameras from the front side to help align the waveguides and spheres and from the top, to image scattered light, as shown in Fig.1. The top microscope also houses an InGaAs detector to measure the scattered power directly. WGMs were excited using a narrow-line tunable laser source (1440-1640nm), coupled with a monomode fibre into the waveguide. The throughput of the waveguide was measured with another InGaAs detector. The inset in Fig. 1 shows a photograph (from the front) of bispheres used in the present investigation. The bottom of this image corresponds to the position of the waveguide. The diameters of the bottom and top microspheres are 30 µm and 125 µm, respectively. The bottom and top microspheres will be referred to below as sphere S (source) and R (receiver), respectively.

3. Results and Discussion

Figures 2(a) and (b) show top views of sphere R alone and of the bisphere, respectively, under optical excitation. The position of the waveguide and direction of excitation light are also marked. The wavelength of excitation (1556nm) was selected such that both the spheres are in resonance (see Fig. 3(a & c)). Also marked are regions I and II where light is scattered out of the single microsphere R in 2(a) and the bisphere in 2(b). In Fig. 2(a) light from the waveguide couples directly into a WGM that propagates clockwise into microsphere R. As a result it scatters predominantly on side I. The much dimmer scattering in region II is probably due to a counter-propagating WGM excited by the surface roughness [7]. In Fig. 2(b), on the other hand, sphere R is excited indirectly through sphere S (not visible), which is now in optical contact with the waveguide. In this case, top sphere R is excited so that the light propagates predominantly in the counter-clockwise direction. As a result spot II is brighter than spot I. This clearly indicates that sphere S is indeed the source and the sphere R the receiver in the bisphere configuration, according to the normal description of "photonic molecules" [8].

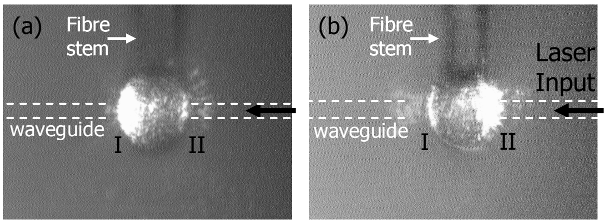

Fig. 2: Top views of (a) sphere R and (b) the biosphere on the waveguide, excited at a wavelength of 1556nm.

The WGM resonances of the individual spheres (S & R) and the bisphere are depicted in Fig. 3. The free spectral range calculated from the diameter and refractive index of the sphere at 1550nm for spheres S and R are about 17nm and 4nm, respectively, which accurately matches the measured values.

The spectral response of the evanescently excited highly mismatched bisphere shows several very interesting features. Firstly, there is significant excitation of the top sphere R (Fig. 3(b)) in the vicinity of the resonances of isolated sphere S (Fig. 3(c)) at wavelengths 1556.5nm and 1574.5nm (shaded regions). It should be noticed that at these wavelengths the isolated sphere R shows very weak excitation (Fig. 3(a)). The various bisphere peaks show signs of spectral splitting of WGMs, which is a common feature of strongly coupled microspheres [8]. Secondly, there is also some bisphere excitation, although of smaller magnitude, in the wavelength range between the sphere S resonances (Fig. 3(b)). These features correspond to the sphere R resonances (Fig. 3(a)). These peaks show signs of splitting and they are a consequence of the strong coupling between the dissimilar spheres. Work is underway to fully understand the rich features observed.

These results imply that the matching requirements in multiple cascaded coupled microspheres and CROW structures can be relaxed considerably and still result in appreciable transmission. In addition the proposed configuration can be used to study the coupling properties of "photonic molecules" and their "bonding" features. Work is continuing with the study of coupled microspheres of different sizes and intersphere separations, as well as different materials and further results will be reported at the conference.

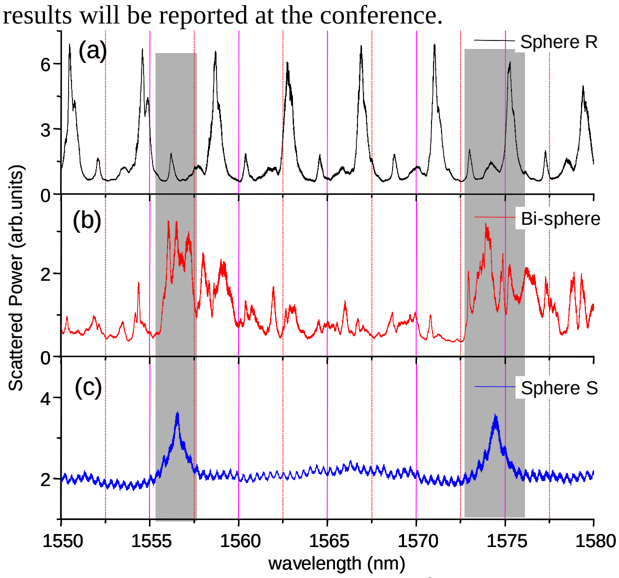

Fig. 3: Whispering gallery resonances of (a) isolated sphere R, (b) bisphere (sphere R on S) and (c) isolated sphere S.

4. Summary

Er-doped BK-7 glass microspheres have been fabricated by a heat-treatment method. A planar waveguide was used to evanescently excite the WGMs of coupled bispheres. Optical coupling between size-mismatched microspheres was observed in coupled bispheres with diameters of 30 µm and 125 µm. The resonance spectra of the coupled bispheres show mode splitting and the split modes have enhanced Q-factors.

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