Optoelectronic Applications of Sapphire Microspheres

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Abstract— The sphere with its highly symmetric geometrical shape enhances the efficiency of optical effects with its high quality factor morphology dependent resonances (MDRs). We report here on numerical studies of elastic light scattering in a sapphire microdisk coupled to slab waveguides, i.e., the 2D analog of a microsphere coupled to the 2D analog of an optical waveguide. The numerical electromagnetic simulations for the surface electric field strength are performed at 800 nm. The experimental elastic light scattering measurements are also proposed in the near-infrared from sapphire microspheres. 800 nm operation with sapphire microspheres is suitable for local area networks (LANs) applications such as channel dropping, filtering, switching, modulation, and monitoring.

1. INTRODUCTION

Over the past few decades light interaction with microspheres composed of various materials has been studied towards the observation of novel photonic effects. The whispering gallery modes (WGMs) are optical resonances excited in dielectric and semiconductor resonators [1]. The WGMs take advantage of 3-dimensional state of light trapped inside the resonator medium and offer very narrow optical linewidths, as well as specific resonance lineshapes, and high quality factors. WGMs can be used in various applications such as biosensing [2, 3], nano-particle sizing [4], optical switching [5], and optoelectronics [6]. WGMs of circular microresonators can be excited with an optical waveguide [7] using evanescent coupling [8, 9]. In this work, modeling and analysis of WGMs excited in a dielectric microsphere with a waveguide is studied. Here, we perform numerical simulation of the out of plane electric field strength of an evanescently coupled sapphire microdisk (the 2D analogue of the sapphire microsphere) and various slab waveguides (the 2D analogue of optical waveguide) [10]. We utilized finite difference time domain (FDTD) technique of the MIT electromagnetic equation propagation (MEEP) tool for the numerical simulations [11].

2. PROPOSED EXPERIMENTAL SETUP

The overall proposed experimental setup diagram is shown in Figure 1. A sapphire (refractive index 1.764) microsphere can be used as an optical resonator with radius $a = 1.5\,\mu\text{m}$. An optical waveguide with a width $w = 0.4\,\mu\text{m}$ can be used for the excitation of the sapphire sphere placed at an impact parameter of $b = 1.9\,\mu\text{m}$. A continuous wave (CW) tunable laser diode operating at 800 nm can be used for the excitation of the WGMs of the microsphere resonator. The evanescent coupling of the near-IR laser to the sapphire microsphere can be achieved with an optical waveguide [9]. The 0° transmission and 90° elastic scattering intensities from the microsphere can be measured with photodiodes (PD1 and PD2), which can be connected to a digital storage oscilloscope. The 90° elastic scattering can be collected with the optical microscope (L1, L2 and L3).

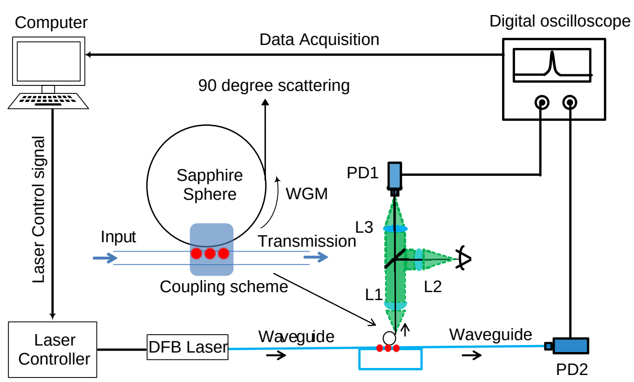
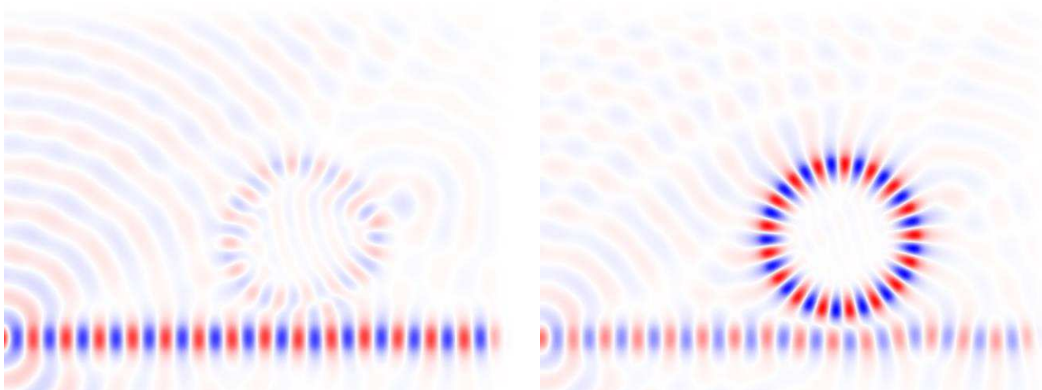


Figure 1: Proposed experimental setup with the inset showing the coupling region of the sphere.

3. SIMULATION GEOMETRY, RESULTS, AND DISCUSSION

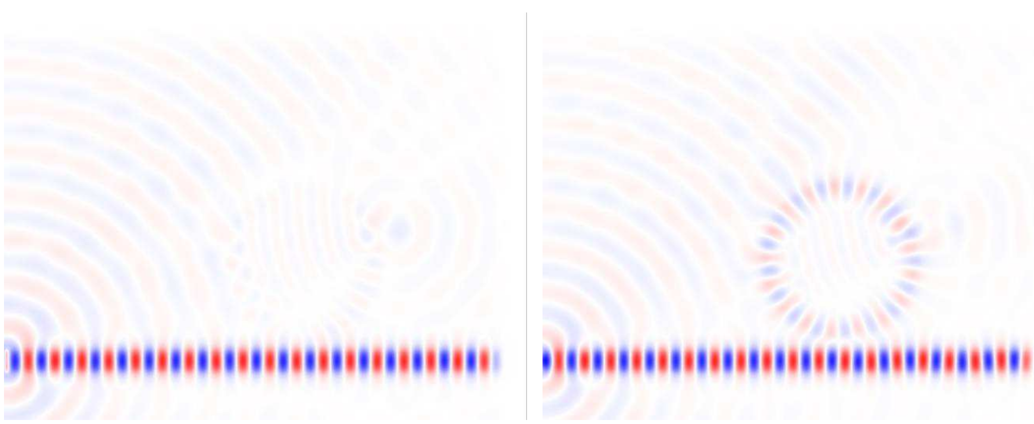
In the numerical electromagnetic simulations, we studied the effect of the waveguide material on the 'waveguide to sphere coupling' by changing the material of the slab waveguide, exciting the sapphire microdisk. The slab waveguide was coupled to a sapphire microdisk with a radius of $a = 1.5\,\mu\text{m}$ and refractive index 1.764. The excitation wavelegth was set in the near-IR region from 795 nm to 855 nm. Four different materials were used in the waveguide: glass with a refractive index of 1.455, sapphire with a refractive index of 1.764, diamond with a refractive index of 2.419, and silicon with a refractive index of 3.681. The excitation beam was placed at an impact parameter of $b = 1.9\,\mu\text{m}$. The width of the waveguide $w = 400$ nm was chosen such that, the waveguide would be single mode for operation at 800 nm for the case of glass, sapphire, and diamond. Ideally, the waveguide should have both a core and a cladding for evanescent coupling to the microdisk. The radial mode order l, and the angular mode number n will be specified for each numerical simulation. By changing the impact parameter b or the wavelength λ, it is possible to address various mode orders l or mode numbers n. The mode spacing is given by $\lambda^2/2a\pi m = 43.5$ nm at 850 nm and 38.5 nm at 800 nm. The excitation from the left port of the waveguide is in the z direction (perpendicular to the paper) and the following figures show the electric field (perpendicular to the paper) strength everywhere in the xy plane.

Figure 2 shows off/on resonance condition for sapphire microdisk coupled to a glass waveguide. The off-resonance wavelength is at 819 nm, while the on resonance wavelength is at 800 nm. For the on resonance case the angular mode number is $n = 17$ and radial mode order is $l = 1$. Figure 3 shows the off/on-resonance condition for sapphire microdisk coupled to a sapphire waveguide. The off-resonance wavelength is 820.6 nm, while the on-resonance wavelength is 795.6 nm. For the on-



(a) (b)

Figure 2: (a) The off-resonance at 819 nm and (b) on-resonance at 800 nm excitation for sapphire microdisc on glass slab waveguide.



(a) (b)

Figure 3: (a) The off-resonance at 820.6 nm and (b) on-resonance at 795.6 nm sapphire microdisk on sapphire slab waveguide excitation.

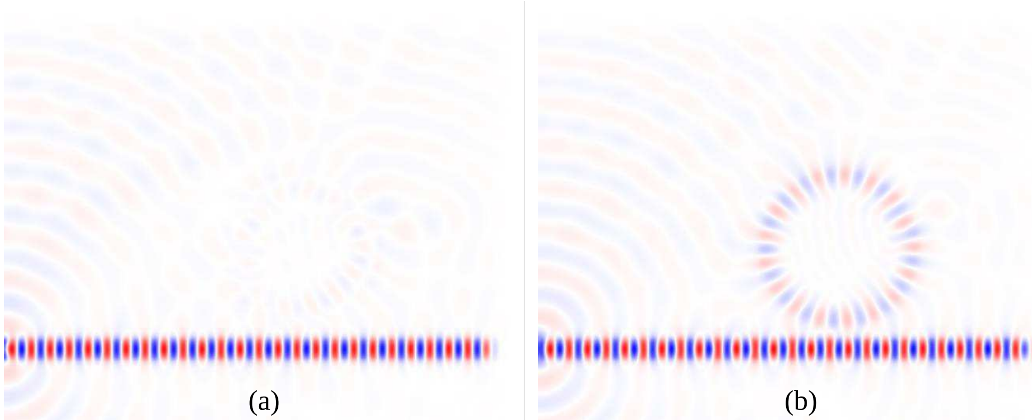


Figure 4: (a) The off-resonance at 820 nm and (b) on-resonance at 799.6 nm sapphire microdisk on diamond slab waveguide excitation.

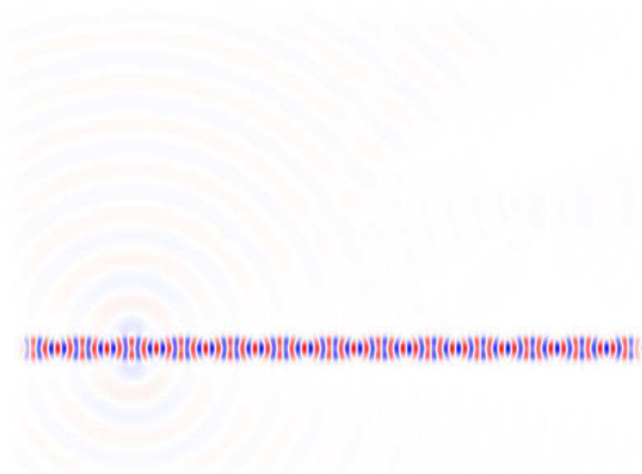


Figure 5: Sapphire microdisk on silicon slab waveguide at a wavelength of 800 nm. There is no evanescent excitation to the microdisk.

resonance case the angular mode number is $n = 17$ and radial mode order is $l = 1$. Figure 4 shows the off/on-resonance condition for sapphire microdisk on a diamond waveguide. The off-resonance wavelength is 820 nm, while the on-resonance wavelength is 799.6 nm. For the on-resonance case the angular mode number is again $n = 17$ and radial mode order is $l = 1$. Figure 5 shows the excitation of sapphire microdisk by a silicon slab waveguide excited with a wavelength of 800 nm. As the refractive index of silicon is bigger than sapphire, there is no appreciable evanescent coupling from the waveguide to the sapphire microdisk.

4. CONCLUSIONS

We have shown that the sapphire microdisks can be used as optical resonators, which eventually can be used for applications such as biosensing, and optical communication. We demonstrated our approach by numerically calculating the electric field strengths of an evanescently coupled sapphire microdisk (the 2D analogue of the sapphire microsphere) and various slab waveguides (the 2D analogue of the optical waveguide) of glass, sapphire, diamond, and silicon. As the refractive index of silicon is higher than sapphire, there is no significant evanescent coupling from the silicon waveguide to the sapphire microdisk.

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