Excitation of Silicon Microspheres Resonances with Femtosecond Laser Fabricated Glass Waveguides

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ABSTRACT

Optical waveguides were fabricated with femtosecond pulsed lasers on glass and characterized by transmission measurements. Glass waveguides were later used for excitation of the whispering gallery modes in a silicon microsphere. The coupling between the silicon microsphere and the femtosecond laser inscribed optical waveguide was simulated in both 90° elastic scattering and 0° transmission spectra. The silicon microsphere whispering gallery modes are available for both in the transverse electric and transverse magnetic polarizations with a spectral mode spacing of 0.25 nm. Optical resonances on silicon microsphere integrated with femtosecond laser written optical waveguides may lead to future quantum optical communication devices.

Keywords: femtosecond laser written optical waveguide, generalized Lorenz-Mie theory, microsphere, optical microcavities, silicon photonics, whispering gallery mode.

1. INTRODUCTION

Whispering gallery modes (WGMs) are morphology dependent resonances (MDRs), which occur on the surface of circular cavities such as microspheres.¹ Optical properties of the WGMs, such as high quality factors in relatively small volumes, resulted in the integration of WGMs in various photonics applications.² Excitation of WGMs in microspheres depend on total internal reflection (TIR) and has been performed using prisms,³ tapered fibers,⁴ and optical fiber half couplers (OFHCs).⁵ Moreover, thriving femtosecond laser micromachining techniques^{6,7} opens the way for more efficient, stable, and controllable excitation in more compact, and robust geometries such as femtosecond laser inscribed glass optical waveguides.^{8,9,10} Here, we present results for the characterization of the femtosecond laser inscribed optical waveguides in glass. We also performed the analysis of the excitation of a 500 μm radius silicon ($n = 3.48$) microsphere WGMs at 90° elastic scattering and 0° transmission spectra excited by using femtosecond laser inscribed glass waveguides in the near-infrared optical communication bands.

2. FEMTOSECOND LASER INSCRIBED OPTICAL WAVEGUIDE IN GLASS

The femtosecond laser inscribed optical waveguide are fabricated on glass using a commercial laser with a fundamental wavelength of 1030 nm, a pulse width of 300 fs, and a repetition rate of 500 kHz. The waveguides are written with 350 mW laser with a numerical aperture of 0.42 at a glass depth of 25 μm , and 2 mm/s inscription speed. The mode field diameter (MFD) of the glass optical waveguide at 1550 nm is measured to be 17 $\mu\text{m} \times 22 \mu\text{m}$, as shown in Figure 1.

Figure 1. Mode field diameter of 17 $\mu\text{m} \times 22 \mu\text{m}$ for the femtosecond laser inscribed glass optical waveguide at 1550 nm.

3. ELASTIC SCATTERING SPECTRA FROM THE SILICON MICROSPHERE

Figure 2. 90° elastic scattering and 0° transmission transverse electric (TE) polarization spectra from the silicon sphere.

Figure 3. 90° elastic scattering and 0° transmission transverse magnetic (TM) polarization spectra from the silicon sphere.

The 90° elastic scattering and 0° transmission spectra from the silicon microsphere excited with a Gaussian beam in the near-infrared telecommunication band are analyzed using the generalized Lorenz-Mie theory (GLMT).¹¹ For a silicon sphere with a radius $a = 500 \text{ } \mu\text{m}$ and the glass optical waveguide at a depth of $25 \text{ } \mu\text{m}$, the impact parameter of the excitation beam is selected as $b = 525 \text{ } \mu\text{m}$. Due to numerical limitations, the half-width at half-maximum (HWHM) of the Gaussian beam is assumed to be $54 \text{ } \mu\text{m}$, which is larger than the measured MFD ($17 \text{ } \mu\text{m} \times 22 \text{ } \mu\text{m}$) of the glass optical waveguide. The near-infrared excitation laser beam is chosen to be in telecommunication band with a wavelength ranging between $1426 \text{ nm} - 1428 \text{ nm}$. Figure 2 and Figure 3 show the numerically simulated 90° elastic scattering and 0° transmission spectra of the silicon microsphere for TE and TM polarizations, respectively. WGMs, observed as peaks in the 90° elastic scattering spectra, correlate well with the dips of the 0° transmission spectra. The 90° elastic scattering and 0° transmission spectra exhibit a 0.25 nm spectral mode spacing between two WGMs with consecutive polar mode numbers for the same radial mode order. The quality factors of the WGMs are on the order of 10^5 .

4. CONCLUSIONS

The excitation of WGMs of a silicon microsphere by using a femtosecond laser inscribed glass optical waveguide was presented. WGMs were observed in the 90° elastic scattering and the 0° transmission spectra for TE and TM polarizations. WGMs of the silicon microsphere with quality factors of the order of 10^5 can be used in various applications such as photonic computing, sensing,

or communication. Moreover, femtosecond laser written optical waveguides in glass are shown to facilitate the resonant excitation of circular cavities such as silicon microspheres.

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