Silicon Microspheres for Mid Infrared Photonics

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ABSTRACT

Microspheres possess high quality factor morphology-dependent resonances, i.e., whispering gallery modes. These whispering gallery modes can be used in resonant cavity enhanced applications of optoelectronic devices such as, filters, detector, modulators and switches. Feasibility of silicon microsphere device at Mid-IR frequencies is studied. The high quality factor morphology dependent resonances have repetitive channel separations of 0.124 μm in silicon microspheres with a radius of 50 μm at wavelengths between 9.8 μm and 10.6 μm .

Keywords: channel dropping, detector, frequency selective, microsphere, morphology dependent resonance, light coupling, optical fiber coupler, whispering gallery mode.

1. INTRODUCTION

Dielectric microspheres have found various photonic applications in the ultraviolet (UV), visible and near-infrared (IR) communication bands [1]. Morphology dependent resonances (MDR's) or alternatively whispering gallery modes (WGM's) of dielectric microspheres provide the necessary optical feedback for applications in spectroscopy, laser science, and optical communications. Among these applications, we can find novel microlasers, optical couplers, and optical filters. Low threshold lasing from rare earth doped silica microspheres [2], polymer microsphere lasers [3] and Raman lasers have been demonstrated. Strain tunable microsphere oscillators [4], add-drop filters [5], and thermo-optical switching [6] have been realized for the frequency control in optical communications. Microsphere resonators are uniquely applicable in compact optoelectronic devices in wavelength division multiplexing (WDM) applications [7]. Recently, we have observed elastic light scattering in silicon microspheres in the near-IR [8]. In this paper, we are investigating the mid IR communication applications of silicon microspheres. Since there is no atmospheric absorption in the mid-IR band, this communication band can be used in atmospheric communication applications. The system can easily be red or blue shifted by adjusting the size of the silicon microsphere and the operation frequency.

2. MORPHOLOGY DEPENDENT RESONANCES

The MDR's of the microsphere can be understood using geometrical optics. As the light propagates around the microsphere, it is confined by almost total internal reflection (TIR) [9]. After circumnavigating the microsphere, the light wave returns to the original starting point in phase to interfere constructively with itself. This constructive interference can occur only at certain discrete MDR wavelengths [10]. Each MDR is characterized by a mode number (n) and a mode order (l). Physically, (n) indicates the number of nodes in the internal intensity distribution as the polar angle is varied from 0° to 180° . The mode order (l) indicates the number of nodes in the internal intensity distribution in the radial direction. For each set of mode number (n) and mode order (l), there is a transverse electric

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(TE) and transverse magnetic (TM) MDR. The mode spacing $\Delta\lambda = (\lambda^2 \arctan(m^2 - 1)^{1/2}) / (2\pi a(m^2 - 1)^{1/2})$, i.e. wavelength difference between consecutive mode numbers n in the same mode order l , gives information about the size of the microsphere [11]. The Q-factor of a MDR, ($Q = \lambda/\delta\lambda$), gives information about the lifetime and linewidth ($\delta\lambda$) of the resonance [12]. For a given microsphere, the MDR occurs at specific value of the size parameter, $x_{n,l}$, which is given by $2\pi a/\lambda_{n,l}$, where $\lambda_{n,l}$ is the light wavelength in vacuum and a is the radius of the microsphere. These MDR's have been verified experimentally at optical wavelengths with micrometer sized spheres.

3. SILICON MICROSPHERES

Fig. 1. SEM of the silicon microsphere.

Silicon has been the material of choice for the electronics industry for more than half-a-century. It is a relatively inexpensive, plentiful, and well understood material for producing electronic devices [13]. Additionally, the need for low cost photonic devices has stimulated a significant amount of research in silicon photonics [14]. Although silicon photonics is less well developed as compared to III-V technologies; it is poised to make a serious impact on the telecommunications industry, as well as in many other photonic applications. Recent studies show that the silicon will be widely used, as in electronics, in the photonics industry [15]. Silicon microspheres with their morphology dependent resonances (MDR's) can also be used in Mid-IR communication applications, where silicon is transparent. This makes silicon the material of choice for micro-electro-photonic-integration (MEPI) and future electro-photonic integrated circuits (EPICs). The high purity single crystal silicon microspheres are produced by the solidification of molten silicon melt [16]. The silicon microspheres are then mechanically lapped and polished to make mirror-like finish with no surface defects and damages [17]. In order to investigate the sphericity of our microresonators, we have obtained SEM images of the microspheres [18]. Fig. 1 shows a scanning electron microgram (SEM) of the silicon microsphere.

4. ELASTIC SCATTERING CALCULATIONS

Fig. 2. Geometry of the elastic scattering calculations.

We have investigated the feasibility of Mid-IR communication filters using silicon microspheres. Elastic scattering calculations are performed between the wavelengths of 9.8 μ m to 10.6 μ m. 0° (forward), 90°, and 180° (backward) elastic scattering spectra from a silicon microsphere of radius 50 μ m are calculated. Figure 2 shows the geometry of

the elastic scattering calculations. Figure 3 shows the results of the calculations for backward (180°) scattering from a microsphere of radius $a = 500 \text{ nm}$. The mode spacing, i.e., the separation between the adjacent MDRs of the same mode number (l) with consecutive mode numbers (n) is estimated and calculated to be 0.124 nm . Note that because of symmetry, the TE and TM components give the same results for 180° scattering. There is no background in the backward direction.

Fig 3. 180° normalized scattering intensity from a silicon microsphere.

Note that because of symmetry, the TE and TM components give the same results for 0° scattering as well. For the calculations for 90° scattering from a microsphere of radius $a = 50 \text{ nm}$ for TE and TM polarizations, the spacing between the adjacent MDR peaks is 0.248 nm . This mode spacing value is twice the calculated mode spacing of 0.124 nm . That is due to the fact that, only even mode number resonances are observed at 90° scattering [14]. There is no background in the 90° direction.

5. CONCLUSIONS

We have calculated the elastic scattering spectra of silicon microspheres in the mid-IR band. The mode spacing $\Delta\lambda$, i.e. wavelength difference between consecutive mode numbers (n) in the same mode order (l), is estimated and calculated to be 0.124 nm . The 90° elastic scattering occurs only for even mode number MDRs, as a consequence, the mode spacing is two times bigger than any other angle. The linewidths $\delta\lambda$ of the highest mode order MDR's are measured to be 0.1 nm , which results in a quality factor ($Q = \lambda/\delta\lambda$) of approximately 10^5 . With the proper system design, it would be possible to use silicon microspheres for atmospheric communication applications. The silicon microsphere shows promise as a building block for future microoptoelectronic integration.

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7. REFERENCES

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