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Silicon Microspheres for Optoelectronic Applications

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Abstract. Having high quality factors, optical microsphere resonators are shown to be ideal circuit elements for wavelength division multiplexing. Silicon, as a common semiconductor and thus being a building block in the integrated circuits, also is a very important material with its optical properties. We have experimentally observed the shifts in resonance wavelengths of an electrically driven silicon microsphere of 500 microns in radius, in the near-IR. We have used a DFB laser at 1475nm, and applied voltages ranging from 0V to 9V to the microsphere and observed the respected shifts in the resonance wavelengths around 0.005 nm to 0.050 nm, and respective shifts in the refractive index are 10^{-5} to 10^{-4} .

Keywords: Channel dropping filter, microsphere, resonator, morphology-dependent resonance, whispering gallery mode, wavelength division multiplexing.

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With the development of optoelectronics, metal interconnections are no longer limiting factor for the performance of electronic systems. Replacing the metal interconnections by optical interconnections could provide low power dissipation, low latencies and high-bandwidths. Such optical interconnections rely on the development of integration of microphotonics with microelectronics. Microsphere resonators are ideal microphotonic building blocks due to their small volumes and high quality factors. There have been various photonic applications in the ultraviolet (UV), visible and near-infrared (IR) communication bands [1]. Morphology dependent resonances (MDRs) of dielectric microspheres provide the necessary optical feedback for applications in spectroscopy, laser science, and optical communications. Microlasers, optical couplers, and optical filters are some of the applications of microspheres. Microsphere resonators are uniquely applicable in compact optoelectronic devices in wavelength division multiplexing (WDM) applications [2]. In these planar lightwave circuits, microspheres can be used as compact channel dropping filters. Recently, we have observed elastic light scattering in silicon microspheres in the near-IR [3]. In this paper, we are investigating the change in the near-IR resonant wavelengths of the silicon microsphere by an applied potential. At resonant wavelengths, the interference is constructive and the elastically scattered light from the microsphere reaches to peak intensities. Respective to the peaks in elastically scattered light, the intensity of transmitted light through fiber experiences associated dips in intensity. [4] In practice, the greatest impediment to the use of microsphere resonators has been the

difficulty of coupling the light into and out of the microspheres efficiently. Light can be coupled into the microsphere by side-polished optical fibers [5]. The principle of this device is based on providing efficient energy transfer to the resonant circular TIR guided wave in the microsphere resonator through the evanescent field. There two main conditions to be satisfied to achieve efficient coupling: phase synchronism and significant overlap of the two waves modeling the MDR mode and the coupler mode. The coupling is based on the fact that the modal field of the guided mode extends beyond the core-cladding interface. Light is coupled to the silicon microsphere by using an optical fiber half coupler (OFHC). The details of the experimental setup are given elsewhere. [6] The microsphere was held in position by electrical probes from the poles, which were also used for electrical modulation.

FIGURE 1. microsphere over the OFHC.

Electro-optical excitation experiments are based on the optical setup shown in Fig. 1. A silicon microsphere is placed on an optical fiber half coupler (OFHC) and is held in position by a pair of electrical probes which are used for electrical input. The scattered signals at respective potential differences are detected. Figure 2 shows the elastic scattering spectrum at a scattering angle of 90° from the silicon microsphere, when a positive potential difference is applied at the poles of the microsphere. There is a background due to OFHC surface imperfections. The width and magnitude of the MDR peaks are highly sensitive functions of the size parameter ($2\pi a/\lambda$) and refractive index (m) of the microsphere. The mode spacing ($\Delta\lambda$), i.e., the wavelength difference between MDR's with consecutive mode numbers (n) with the same mode order (l), is measured to be 0.280 nm. Potential difference of 3, 6, 9 Volts were applied to the microsphere by a DC power supply and elastically scattered light has been measured with respect to the wavelength of the incident light. In both positive and the negative (not shown) potential differences, the scattered signal had a blue shift which was proportional to the magnitude of the applied potential difference. In the presence of free carriers in silicon, both the refractive index and the absorption of silicon can be changed using carrier injection or depletion. The refractive index changes due to free carrier accumulation is given by the Kramers-Kronig analysis: [7], $\Delta n_e = -8.8 \times 10^{-22} \Delta N_e$, $\Delta n_h = -8.5 \times 10^{-18} (\Delta N_h)^{0.8}$, where Δn_e and Δn_h are the changes in the refractive index resulting from change in the free electron carrier concentrations and change in the free hole concentrations. ΔN_e and ΔN_h are the free electron and free hole concentrations, respectively.

FIGURE 2. The elastic scattering spectra of silicon microsphere when the applied potential is positive.

For an applied voltage of 0V to 9V, the shifts in the resonance wavelengths range from 0.005 to 0.050 nm, which corresponds to a refractive index shift of 10^{-5} to 10^{-4} . In conclusion, we have experimentally observed the elastic scattered signal from a silicon microsphere in the near-IR at a wavelength of 1475 nm. The mode spacing ($\Delta\lambda$), i.e. wavelength difference between consecutive mode numbers (n) with the same mode order (l), is measured to be 0.27 nm. Moreover, we have observed the shifts in the resonant wavelengths of silicon microsphere with respect to the applied potential. The shifts in the resonance wavelengths were observed as blue shifts and were proportional to the applied potential difference. The observation heralds novel active optoelectronic device applications. Possible wavelength division multiplexing (WDM) applications include optoelectronic devices for filtering, modulation, and switching. We would like to acknowledge the partial support of this research by the European Commission Grant No: FP6-IST-511616 PHOREMOST and FP6-IST-003887 NEMO.

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