# Add-drop filter based on silicon spherical microcavities

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Optical microcavities are very relevant structures for optical processing of light, because they can trap and confine electromagnetic energy during long times in very reduced volumes, enhancing this way light-matter interaction [1]. Among the different technological platforms on which microcavities can be produced, silicon is of uttermost importance because it can combine electronics and photonics at the same time in a single device [2]. Recently, some of us reported on the synthesis of silicon microspheres also called silicon colloids [3]. They are highly spherical particles with diameter from 0.5 to 5 μm and with a very smooth surface. This allows them working as photonic microcavities, with well defined Mie modes [3]. Here, we report on the coupling of silicon microspheres to Silicon-On-Insulator (SOI) waveguides at telecom wavelengths (C-band). For this purpose, devices consisting of SOI waveguides with microspheres deposited onto them are developed and their transmitted signal is measured. These measurements are compared with theoretical calculations of Mie modes of the microspheres. Previous reports about similar devices include 2D photonic crystal nanocavities coupled to photonic crystal waveguides [4], ring shaped cavities coupled to SOI waveguides [5], and half millimeter diameter silicon spheres coupled to optical fiber half couplers [6].

Silicon microspheres are obtained by chemical vapor deposition techniques, using di-silane as a precursor gas [3]. The as-grown samples consist of a substrate with many isolated and clustered spheres being the spheres poly-disperse with sizes from 0.5 to 5 μm. The size of the sphere determines which resonant modes posses a frequency within the transmission wavelength range of the silicon waveguide and can therefore be coupled to it. For this reason, we performed a selection of spheres (within the limited resolution of the optical microscope at 1000x magnification) having a diameter from 2.0 to 2.5 μm approximately. For the precise determination of the diameter of the microsphere, optical transmittance measurements were performed on each of the selected microspheres for the wavelength range from 1 to 4 μm. We used a Fourier Transform Infrared Spectrometer Bruker IF 66/S for that purpose. This allows identifying the resonant modes and precisely determining the sphere diameter by fitting the measured signal to Mie theory [3]. Only those microspheres having resonant modes within the transmission range of the waveguides were considered as candidates to build up the devices.

The accurate placement of the microspheres on top of the silicon waveguides was performed using a micromanipulation technique we have developed. Different needle-shaped tools were fabricated for the pick and place operation and for the fine positioning of the spheres on the waveguides. Figure 1 shows an optical microscopy image (top view) of a silicon microsphere on top of a waveguide. The diameter of the sphere shown in Fig. 1 is 2.49 μm, determined using the process described above.

The silicon waveguides used for this device were produced on a standard SOITEC wafer by deep UV lithography in an ePIXfab platform. They have a cross section of 500x220 $nm^2$ and their length is about 3 mm, finishing at their both ends by a grating coupler so that light can be easily in/out coupled to/from the waveguides [7]. Both, waveguides and couplers were designed for transmitting only TE polarized light around 1550 nm.

Light from an ASE source was coupled to the waveguide and the transmitted signal was measured by a spectrum analyzer. The direction and the polarization of light for the waveguide-microsphere device can be observed in the inset of Fig. 1. Figure 2 shows the light transmitted through the waveguide with the microsphere placed on it (solid line, left axis), as well as the calculation by Mie theory of the light transmitted through that microsphere when being isolated, i.e. without being placed on any substrate (dashed line, right axis). The deeps in transmission for the isolated sphere case correspond to whispering gallery modes, indicated in the figure by letters ‘a’ and ‘b’ for TM an TE modes respectively and followed by two sub-indexes that account for the mode order [3]. We have associated the deeps in the transmitted signal through the waveguide to the coupling of light to the resonances of the microsphere. This way, the pronounced deep placed around 1535 nm would be originated from $b_{10,1}$ mode, the less marked deep around 1543 nm from $a_{9,1}$ mode and the much wider deep placed around 1580 nm from $a_{6,2}$ mode. However, some discrepancies between theory and experiment are observed. Mode $b_{7,2}$ does not give rise to a coupling effect and the coupled modes ($b_{10,1}$, $a_{9,1}$ and $a_{6,2}$) split into two deeps. Several reasons may explain these discrepancies. Firstly, while in the calculation the sphere is considered to be isolated, in the experiment it is placed on the silicon waveguide, therefore mode degeneracy would be broken due to the waveguide coupling. Secondly the control on the position of the microsphere is limited in the direction perpendicular to the waveguide, thus different coupling effects can be produced depending on this position. Thirdly, the microsphere may have some defects that could not be detected by optical microscopy and some type of absorption could be present. This would decrease the quality factor of the resonances. Nevertheless, it should be stressed the strong and peaked attenuation of the signal, of about 25 dB, achieved around 1535 nm.

We have demonstrated the coupling between a silicon waveguide and a silicon microsphere. The light transmitted through the waveguide has been attenuated up to 25 dB for a wavelength corresponding to one of the microsphere resonating modes. A splitting effect of the modes has also been observed.

## References


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## Figures

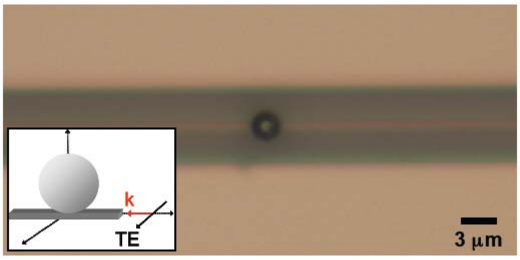


Figure 1. Optical microscopy image at 1000x magnification of a silicon microsphere placed on top of a silicon waveguide. Inset, schematic of the sphere and the waveguide showing the polarization of the transmitted light.

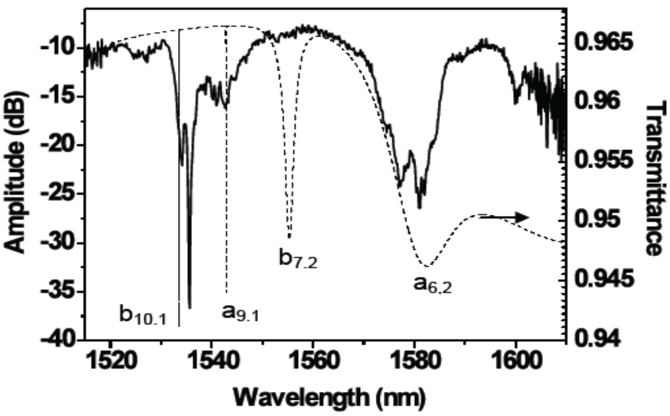


Figure 2. Measured light transmittance through a silicon waveguide with a silicon microsphere positioned on it (solid line, left axis). And simulation of the transmittance of the same silicon microsphere being isolated (dashed line, right axis).