Silicon Colloids with a strong magnetic response below 1.5 micrometers region

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Abstract

It is generally accepted that the magnetic response of materials at optical frequency values is completely negligible. The recent discovery of Metamaterials (MMs) has broken this traditional understanding, since both the electric and the magnetic field are key ingredients in MMs [1]. Although, MMs have shown their potential for molding light matter interaction, unsolved problems remain that prevent their use in practical applications. One challenge concerns the intrinsic losses in the optical range of noble metals used for MMs processing [2]. Also the top-down technology used so far is not amenable to large area 3 dimensional (3D) MMs working in both the near infrared (NIR) and the visible (VIS) regions [3]. One potential way to circumvent this obstacle concerns using high refractive index value dielectric structures, which may show strong magnetic and electric resonances [4]. Particularly, Mie resonances of high refractive index optical nanocavities may open a new route to realize low loss isotropic metamaterials. Mie theory of high refractive index spherical cavities predicts well defined magnetic and electric resonances, with huge scattering cross section values. Furthermore, the fundamental magnetic dipole and electric dipole resonances appear at wavelength values much larger than nanocavity size (i.e.: in the subwavelength region), in a similar manner as occurs for metallic metamaterials. Here we report on the synthesis and the optical properties of silicon colloids based nanocavities with strong magnetic response in the NIR region. The transmission and reflection properties of single silicon colloids with size values between 250 nm and 700 nm are reported. Both, experiments and theoretical calculations (Mie theory and the finite difference time domain (FDTD) simulations) clearly show that single submicron silicon nanocavities support well defined magnetic resonances in NIR region at wavelength values up to six times larger than the cavity radius.

The method for obtaining isolated submicron silicon colloids is based on chemical vapor deposition (CVD) techniques with the disilane (Si_2H_6) as a precursor gas, as it has been described elsewhere [5]. Figures 1 (a) and (b) show both optical microscope and SEM images respectively of the same area where small size colloids are located. Small size silicon colloids, of about 300-500 nm, show huge values of the extinction cross section in the visible region. Therefore, as the apparent size of optical images are several times larger than the real size, we can see, and also manipulate, nanoparticles, as small as 250 nm, with the help of a simple optical microscope. Figures 1 (c)-(d) show high magnification SEM images of the blue, green and red areas shown in Figures 1 (a) and (b). In blue and green areas, the colloid sizes are as small as 250 nm and 350 nm respectively. We have performed optical transmission and reflection experiments on single particles with the help of a home-made confocal microscope attached to a spectrometer combined with an InGaAs detector. Figure 2 shows the transmission spectra of single submicron silicon colloids with different sizes. The dips correspond to Mie resonances. As the particle size increases transmission dips are red shifted, and more transmission dips emerge in the short wavelength side of the detection window. By varying the size of silicon colloids, we can tune the wavelength position of intrinsic modes freely. The fundamental magnetic mode, $b_{1,1}$ and electric dipole mode $a_{1,1}$, as well as $b_{2,1}$ mode have been indicated in the figure. Theoretical modeling, showed a good agreement with the experiments. Therefore, we can conclude that submicrometric size silicon colloids might be useful as potential metamaterial building blocks [6]. Moreover, we are currently working on a new route to achieve monodisperse silicon colloids and to measure their collective signal [7]. This is a very important step towards the realization of large area 3 dimensional MM structures.

References

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Figures

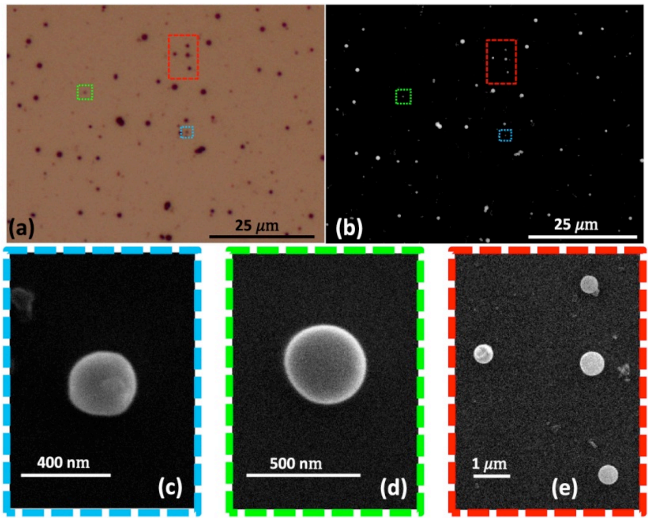

Figure 1. (a) Optical microscopy image at 1000X magnification of silicon colloids. (b) SEM images of silicon colloids located at the same area as shown in (a). (c-e) High-magnification SEM images of silicon colloids located at blue, green, and red areas as shown in (a) and (b).

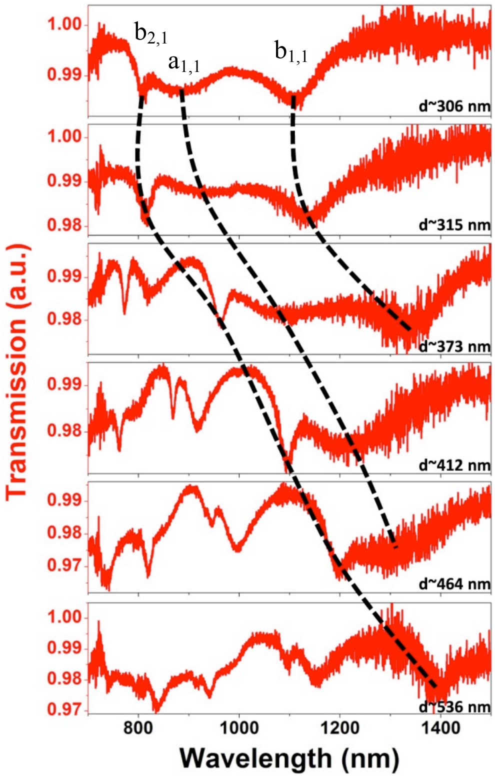

Figure 2. Transmission spectra of submicrometer-size silicon colloids with different diameter values (shown in the figure). The position for modes $b_{1,1}$, $a_{1,1}$ and $b_{2,1}$ is indicated on its corresponding dip in the top spectrum. The dotted lines connect the same modes for different nanocavities.