誘電体メタ液体の実現へ向けたコロイド状シリコンナノ粒子の開発

Colloidal Solution of Silicon Nanospheres for All Dielectric Metafluid

神戸大院工, °(DC)雛本 樹生, 堀田 慎之介, 杉本 泰, 藤井 稔

Kobe Univ., °(DC)Tatsuki Hinamoto, Shinnosuke Hotta, Hiroshi Sugimoto, Minoru Fujii

E-mail: fujii@eedept.kobe-u.ac.jp

Meta-atoms that support magnetic and electric dipoles at visible frequencies are key building-blocks for optical metamaterials. Recently liquid-type metamaterials, solutions in which meta-atoms are dispersed, are proposed as metafluids.[1,2] In contrast to solid-state metamaterials, the liquid metamaterials can be applied to solution-phase spectroscopy and optofluidic devices to enhance signals and/or offer advanced functionalities. As a component of liquid metamaterials, a plasmonic meta-atom composed of silica core decorated with metal nanoparticles have been studied so far; however, the magnitude of the magnetic dipole (MD) is weaker than that of the electric dipole (ED) on the plasmonic meta-atom. Here we propose silicon nanospheres as a novel meta-atom that can be dispersed in solution with moderate concentration and stability. The silicon nanoparticle possesses Mie-type resonances whose amplitudes of electric and magnetic dipoles (Figure 1a) are comparable. The strong optical magnetism of the silicon nanoparticle in the form of colloidal solution is experimentally proven by selectively measuring scattering spectra of ED and MD with orthogonal polarizations and angular dependence as shown in Figure 1b and its angular profiles (Figure 1c). We also show that, thanks to strong optical magnetism, the silicon nanoparticle colloid can control effective refractive index from high value (>4) to near-zero or even negative by calculation including the effective medium approximation (Figure 1d,e). This meta-atom is an excellent candidate for the metafluid and may pave the way for optofluidic metamaterial devices.

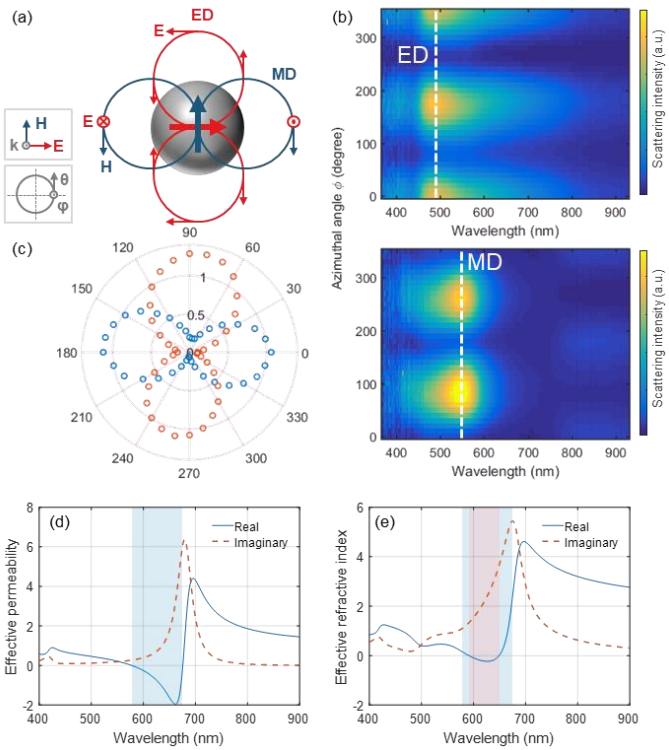

Figure 1. (a) Electric dipole (ED) and magnetic dipole (MD) modes of the Mie resonance and their scattered fields. (b) Measured angle-resolved scattering spectra of the silicon nanoparticle colloid. The top and bottom panels were measured with the analyzer corresponds to θ and φ polarization, respectively. (c) Polar plots correspond to profiles of (b) at peak wavelengths of ED (θ, blue) and MD (φ, orange). (d,e) Complex effective permeability and refractive index calculated for a silicon nanoparticle dispersion (radius: 80 nm, filling fraction: 0.65) by the extended Maxwell-Garnett effective medium approximation incorporating the Mie theory.

[1] Y.A. Urzhumov et al., Opt Express. 15 14129 (2007)
[2] S.N. Sheikholeslami et al., Nano Lett. 13 4137 (2013)