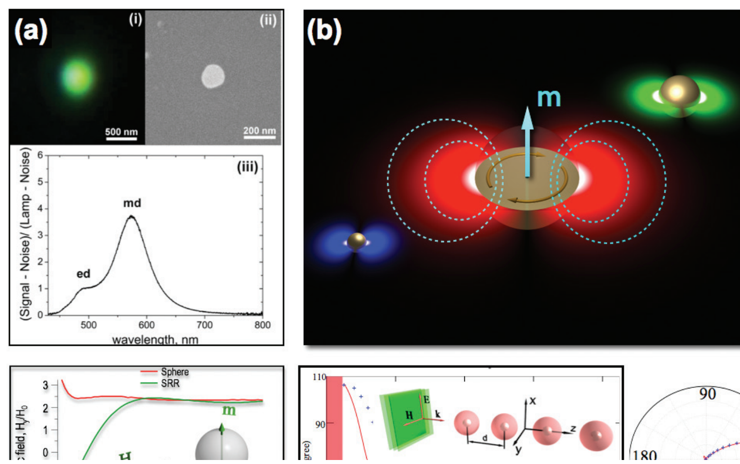
METAMATERIALS

Magnetic Light: Optical Magnetism of Dielectric Nanoparticles

A split-ring resonator (SRR) is an inductive metallic ring with a gap that can support an oscillating current, giving rise to an optically induced magnetic moment. Unfortunately, metal intrinsic loss sets the limit for using SRRs at optical frequencies. But according to our work, spherical silicon nanoparticles can make an attractive alternative.

Dielectric nanoparticles exhibit strong magnetic resonances in the visible. Their excitation is similar to SRRs, but our work shows that silicon nanoparticles have lower losses. Magnetic resonance originates from exciting an electromagnetic mode inside the nanoparticle with a circular displacement current of the electric field. This mode is excited when the wavelength is comparable to the particle's diameter. We observed antiparallel polarization at opposite ends of the particle while the magnetic field is oscillating up and down in the middle. We saw this fundamental phenomenon of strong magnetic resonances throughout the whole visible spectral range for silicon nanoparticles from 100 to 270 nm. We published similar results in the red and infrared.[1,2]

These dielectric nanoparticles could be used to explore nanoscale interactions. Coupling silicon nanoparticles and SRRs allows researchers to control the magnetic interaction between optically induced dipole moments. If the spacing between a nanoparticle and SRR becomes smaller than a critical value, the induced magnetization can be inverted. This leads to a staggered pattern of magnetic moments, with the potential for light-induced artificial antiferromagnetism at optical frequencies.[3] This approach can be generalized to create hybrid structures supporting and controlling optically induced spin waves.



(a) Close-view dark-field microscope (i) and SEM (ii) images of a silicon nanoparticle with dark-field scattering spectra (iii) exhibiting magnetic dipole (md) resonance. (b) Electric (yellow) and magnetic (blue) field distributions inside a high-refractive index dielectric nanoparticle at the magnetic resonance. (c) Dependence of the dielectric sphere and SRR optically induced magnetization on the separation distance at the magnetic resonance frequency. Below the critical distance, the optically induced ferromagnetic-like magnetization is replaced by an antiferromagnetic pattern. (d) Beam width of the radiation of core-shell nanoparticles vs. separation distance d. (e) Far-field scattering diagram showing zero backscattering and strong directivity.

The interaction between magnetic and electric dipoles may lead to new scattering properties. An interference between two optically induced dipole resonances results in azimuthally symmetric unidirectional scattering that can be realized in layered nanoparticles with metal cores and dielectric shells.[4] A superposition of electric and magnetic resonances of a single core-shell nanoparticle may give way to the suppression of backward scattering and unidirectional emission by a single subwavelength element.[4] Directivity can be enhanced by forming a chain of such nanoparticles. This work suggests a novel principle of optical nanoantennas made of dielectric nanoparticles.[5] These structures exhibit higher radiation efficiency than their plasmonic counterparts, allowing more compact designs. OPN

Researchers

Andrey E. Miroshnichenko (aem124@rsphysse.anu.edu.au), **Wei Liu**, **Dragomir Neshev** and **Yuri S. Kivshar**
Australian National University, Canberra

Arseniy I. Kuznetsov, **Yuan Hsing Fu** and **Boris Luk'yanchuk**
Data Storage Institute, Singapore

References

1. A.I. Kuznetsov et al. Sci. Rep. **2**, 492 (2012).
2. A.B. Evlyukhin et al. Nano. Lett. **12**, 3749 (2012).
3. A.E. Miroshnichenko et al. ACS Nano. **6**, 837 (2012).
4. W. Liu et al. ACS Nano **6**, 5489 (2012).
5. A.E. Krasnok et al. Opt. Exp. **20**, 20599 (2012).