Full vector field imaging of light in near field by probes with nanoparticles

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Light is an electromagnetic wave composed of both electric and magnetic fields. Light-matter interaction results in complicated and vectorial field distribution of light in nanoscale. Hence, imaging the vector field of light in near field has become very important for both fundamental science and applications in nanophotonics and optofluidics. This paper reports a new design of near-field probe with silicon nanoparticle(SiNP) and gold nanoparticle(GNP) that is respectively sensitive to magnetic and electric components of light, and full vector field imaging of light in near field would be achieved by this kind of probe with nanoparticles.

Electric vector field imaging in near field was first reported by a GNP probe [1], but the GNP has no response to the weak magnetic components of light. In order to achieve full vector field imaging of light, probes that are both sensitive to the in-plane magnetic components(Hx and Hy) and out-of-plane magnetic components(Hz) should be designed and fabricated. Recently, several novel probes [2,3] have been demonstrated with SNOM/NSOM system for near-field optical magnetism detection; However, magnetic vector imaging still remains several challenges, such as complexity of design and fabrication, limitation of sensitivity for only one magnetic component(either in-plane or out-of-plane) and weak response for visible light. On the other hand, according to Mie theory, silicon nanopariticles have strong magnetic dipole resonance in visible band. Hence, our research utilizes SiNP probes for magnetic vector imaging, in association with GNP probes for electric vector imaging, and our method differs from previous study in the design and working principles.

The design of probes with nanoparticles is illustrated in Fig. 1. Parabolic bare fibers by heat-pull and HF etching procedure are used for support and distance control in near field; GNPs with size about 50nm are prepared by chemical synthesis, and SiNPs with size almost from 100nm to 200nm are prepared by laser ablation method [4]; SiNP and GNP are attached to the fiber probe by APTES/APTMS. In the fabrication of SiNP probes, the most important procedure is the particle selection with a specific size. Therefore, dark-field microscopy and spectrometry are utilized for this selection, and Fig.2 shows the dark-field spectrum of SiNP and GNP that are used for 633nm laser. In this research, an evanescent standing wave with TE mode is generated by total internal reflection of a prism, and the SiNP and GNP probe are used for full vector field imaging of this distribution in near field. Furthermore, FDTD simulations were conducted in combination with reciprocity theory in near field [5,6], to interpret the electromagnetic response of the SiNP and GNP probes. The results in Fig. 3 concludes that the GNP is sensitive to the electric vector field (projection of Ey), and the SiNP is sensitive to the magnetic vector field (Hx and Hz).

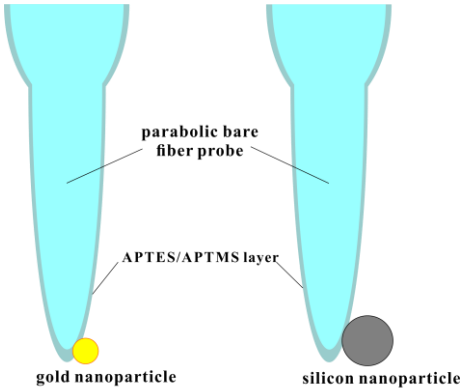

Fig.1 Schematic diagram of the probes with gold nanoparticle and silicon nanoparticle..

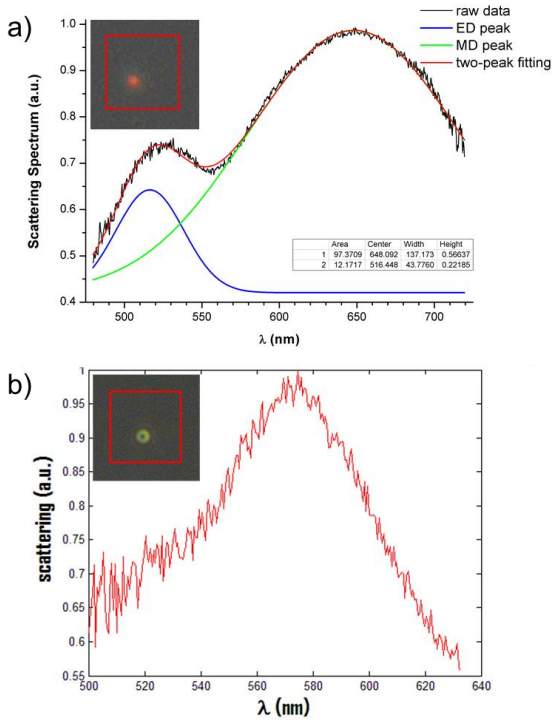

Fig. 2 Dark-field images and scattering spectrums of nanoparticles used for near-field measurement. a) silicon nanoparticle on silicon substrate; b) gold nanoparticle on silicon substrate. The size of red rectangular in both images is 4μm×4μm.

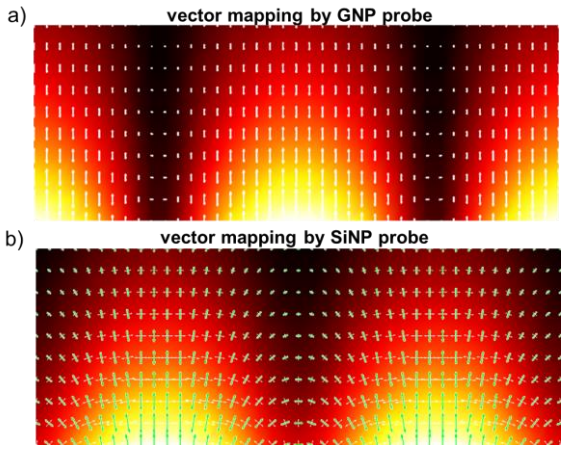

Fig. 3 FDTD simulations of the near-field vector mapping with the reciprocity. a) electric polarization mapping(white arrow) by GNP probe; b) magnetic polarization mapping(green arrow) by SiNP probe. The spatial period of near-field intensity distribution in both figures is about 300nm.

REFERENCES:

[1] K. G. Lee, H. W. Kihm, *et al.*, "Vector field microscopic imaging of light," Nature Photonics. **2007**, 1, 53-56.

[2] M. Burresi, D. van Oosten, *et al.*, "Probing the magnetic field of light at optical frequencies," Science. **2009**, 326, 5952.

[3] D. Denkova, N. Verellen, *et al.*, "Mapping magnetic near-field distributions of plasmonic nanoantennas," ACS Nano, **2013**, 7(4), 3168-3176.

[4] A. Kuznetsov, A. Miroshnichenko, *et al.*, "Magnetic light," Sci. Rep. **2012**, 2, 249.

[5] J. A. Porto, R. Carminati and J.-J. Greffet, "Theory of electromagnetic field imaging and spectroscopy in scanning near-field optical microscopy," J. Appl. Phys. **2000**, 88(8), 4845-4850.

[6] B. le Feber, N. Rotenberg, D. Beggs and L. Kuipers, "Simultaneous measurement of nanoscale electric and magnetic optical fields," Nature Photonics. **2014**, 8(1), 43-46