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Analysis on near field scattering spectra around nanoparticles by using parametric indirect microscopic imaging

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ABSTRACT

We report the simulation and measurement results of near field spatial scattering spectra around nanoparticles. Our measurement and simulations results have indicated that Parametric Indirect Microscopic Imaging can image the near field spatial scattering to a much larger distance from the scattering source of the particle under measurement whereas this part of spatial scattering was lost in the conventional microscopy. Both FDTD modeling and measurement provided evidence that parameters of indirect optical wave vector have higher sensitivity to near field scattering.

1. Introduction

In the 1870s, a German Physicist Ernst Abbe found the resolution of the imaging system is limited by the diffraction of the beam [1]. This result declared that the resolution of the imaging system not only lies on the quality of lens but also on the wavelength of beam and the size of aperture. In other words, a conventional microscope can not measure two objects located as the distance is shorter than $\lambda/2\mathrm{NA}$. Here λ is the wavelength of the light and NA is the numerical aperture of the lens. To shrink the light spot of point spread function of the system, the lens of shorter wavelength and smaller numerical aperture are needed imminently. However, these lens are either high-cost or have low transmission. And to reduce the wavelength of the beam is nearly impossible. What is worse, NA of extant lens is close to diffraction limit [2].

The remarkable optical response of matter to the light varies with size, shape and environment [3]. Both propagation and evanescent waves are produced in the result of such interaction of light with small particles. These evanescent waves produced at the boundary of two media and are undamped but when they go away from the boundary then decay exponentially whereas propagating waves can be detected many wavelength distances from the object. This free propagation of the electromagnetic waves to far field is strongly related to the physical nature of the diffraction limit, so the careful study of the near field is essential in the field of super resolution [4].

Due to the diffraction limit, the electromagnetic field near the scattering source produce high frequency scattering i.e. evanescent scattering, that hold on more information for image resolving but lost in shorter distance around the particle while using conventional microscopy [5]. Some methods were tried to solve these difficulty, such as scanning near-field optical microscopy (SNOM) where the subwavelength-scale information hidden in the evanescent waves can be revealed by bringing a small nanometer scale object, a nano probe, into the region where the evanescent field dominates [6]. But using the nano probe cannot obtain all the information of the scattering center. The near field high frequency region of SNOM is not big enough to meet the requirement of super resolution. In this paper we have reported the Polarization parameters indirect microscopic imaging which modulates the field variations to the atomic arrangement, the particle composite structure and the shape of the particle by filtering of the irrelevant scattering from neighboring source points in the sample under the test to reach sub-100 nm super-resolution. Compared with spherical particle, non-sphericity plays an important role in scattering processes, because it can cause a different absorption of scattering light.

2. Theory

We usually use Mei scattering theory for a sphere particle whose size is comparable with the incident wavelength like water

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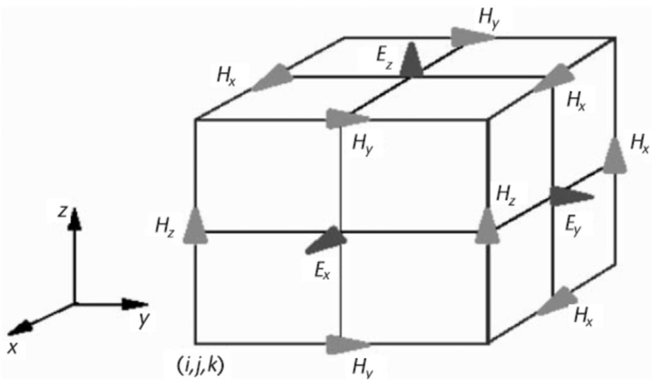

Fig. 1. Yee cell.

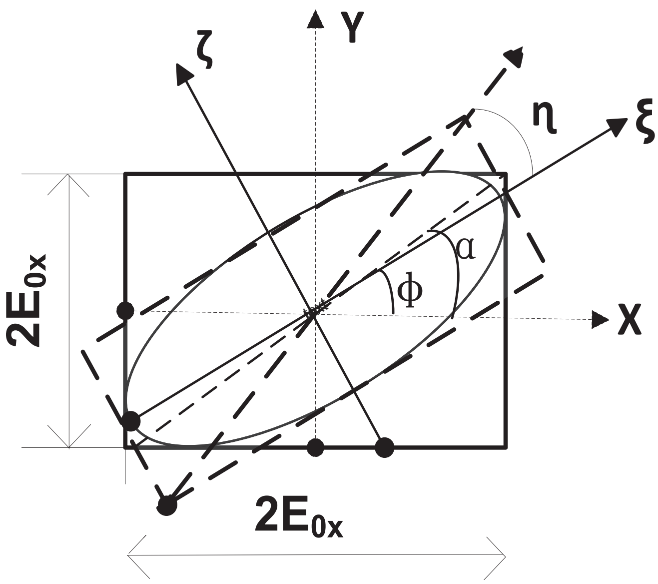

Fig. 2. Shows polarization ellipse where α is the auxiliary angle, ϕ is the crystal indicatrix orientation angle or slow axis vibration angle and η is the ratio of the ellipse semi axis.

droplet in the atmosphere and latex particle in paint, but for the particle which is much smaller or bigger and with non-spherical shape, Mei solution needs a lot of modifications [7]. Most of non-spherical particles are composite particles. They consist of many smaller particles which cause multiple scattering. Scattering from composite particle can be studied by using various methods like T-matrix method, discrete dipole approximation, generalized multiple Mie solution, effective medium theory combined with Mie solution and Finite difference time domain (FDTD) etc. [8].

The foundation of FDTD was laid by Yee in 1966 [9]. Yee chose a geometric relationship for the spatial sampling of the vector components of the electric and magnetic fields which representing both differential and integral form of Maxwell equation in a robust manner (Fig. 1).

FDTD scheme discretizes Maxwell's curl equations by approximating the time and space first order partial derivative with central differences and then solve the resulting equation by using a leapfrog scheme [10–12]. As we make the smallest array of the simulation area by using small cubic cells more accurate will be the solution of Maxwell's equation that's why in our simulations we take mesh grid size of 5 nm but it took a large time and memory. We have taken the mesh size as 5 nm for high accuracy. In our simulations we used the Gaussian illumination source and used reflection monitor at different distance from the particle under study according to our measurement system setup.

In this paper, we apply a new theoretical method to study the near field scattering spectra, by finding the change in polarized light after scattering to a nanoparticle, we can express that change in terms of near field distribution. If $Ex(x, z)$ and $Ey(x,z)$ describe the sinusoidal oscillations in x–z and y–z plane separately (Fig. 2), after an arithmetical operation we get the Eq. (1):

$$Ex(z,t)\text{^}2/Eox\text{^}2 + Ey(z,t)\text{^}2/Eoy\text{^}2 - 2Ex(z,t)Ey(z,t)\cos\delta/EoxEoy = \sin\text{^}2\delta \quad (1)$$

where δ is phase difference between two orthogonal polarization status.

We can find out the ellipticity angle (x) and orientation angle (φ) in terms of polarization parameters of ellipse:

$$\tan\ 2\varphi = 2EoxEoy\ \cos\ \delta/Eox\text{^}2 - Eoy\text{^}2,\quad 0 \le \varphi \le \pi \quad (2)$$

$$\sin\ 2x = 2EoxEoy\ \sin\ \delta/Eox\text{^}2 + Eoy\text{^}2,\quad -\pi/4 \le x \le \pi/4 \quad (3)$$

If we apply time average definition to the polarization ellipse then we get the following equations:

$$S_0 = S_1 + S_2 + S_3 \quad (4)$$

$$S_0 = E^2ox + E^2oy \quad (5)$$

$$S_1 = E^2ox - E^2oy \quad (6)$$

$$S_2 = 2EoxEoy\ \cos\ \delta \quad (7)$$

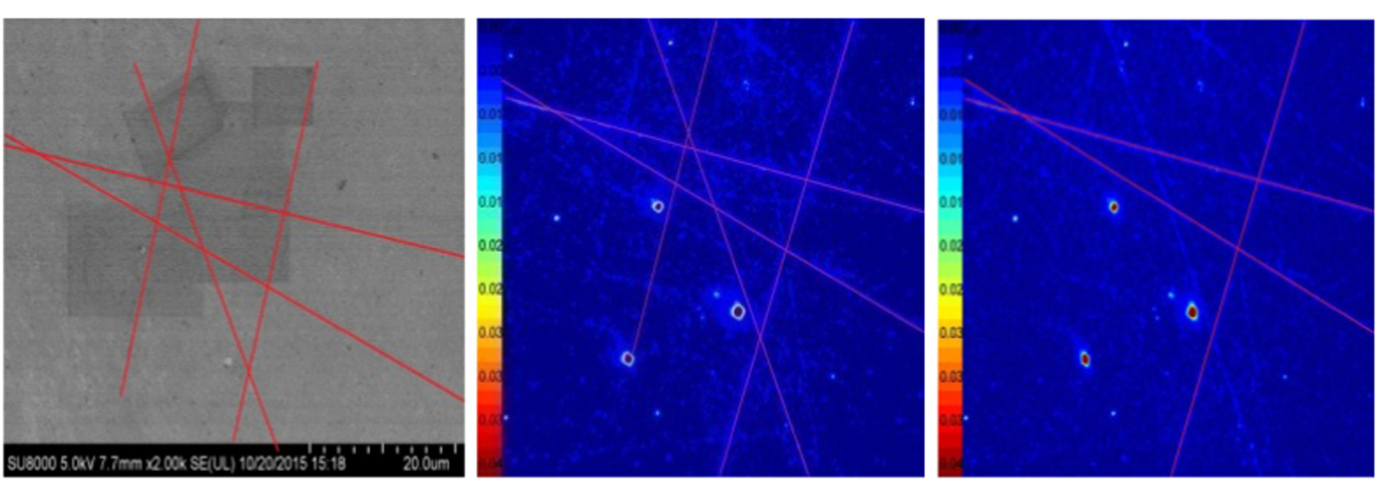

Fig. 3. From left to right (1) SEM measurement with magnification 2 K (2) Idp (Depolarized Intensity) (3) Direct field Intensity.