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Analysis of Electromagnetic Fields near Nanoparticles by Using BIEM in Static Approximation

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Abstract : It has been the focus of attention in developing ultra high density recording and microfabrication technologies to analyze electromagnetic fields near nanoparticles. Recently, nano antennas to achieve an ultra high speed and high density magnetic recording have been investigated by using a boundary integral equation method. In this report, we investigate the computational accuracy of the method due to the static approximation.

1. Introduction

It is important for developing ultra high density recording to analyze the electromagnetic fields near nanoparticles.

Recently, we designed nano antennas to achieve an ultra high speed and high density magnetic recording using a boundary integral equation method (BIEM) in the static approximation [1]. We can easily find some plasmon modes which are related to the shapes of objects by using this method [2]. However, the computational error due to the static approximation is still under investigation.

In this report, we analyze the electromagnetic fields near the nanoparticles by using the BIEM and investigate the computational accuracy.

2. Formulation

The normal component of the electric fields satisfies the following boundary condition [1-3]:

$$\mathbf{n}\cdot\varepsilon(\mathbf{E}_0^{+}+\mathbf{E}^{i})=\mathbf{n}\cdot\varepsilon_0(\mathbf{E}_0^{-}+\mathbf{E}^{i}), \qquad (1)$$

where $\mathbf{n}$ is a unit vector of normal to the surface, $\mathbf{E}^{i}$ is the incident electric field, $\mathbf{E}_0^{+}$ is the electric field inside the object, and $\mathbf{E}_0^{-}$ is the scattered electric field.

When the free-space wavelength is much larger than the scale of the object, the normal components of the electric field on the surface are given in terms of the static approximation, such as

$$\mathbf{n}_Q\cdot\mathbf{E}_0^{\pm}(Q)=\mp\frac{\sigma(Q)}{2\varepsilon_0}+\frac{1}{4\pi\varepsilon_0}\oint_S\sigma(M)\frac{\mathbf{r}_{MQ}\cdot\mathbf{n}_Q}{r_{MQ}^3}dS_M, \qquad (2)$$

where σ indicates the electric charge density on the surface.

By substituting Eq. (1) into Eq. (2), we obtain the expression

$$\sigma(Q)-\frac{\lambda}{2\pi}\oint_S\sigma(M)\frac{\mathbf{r}_{MQ}\cdot\mathbf{n}_Q}{r_{MQ}^3}dS_M=2\varepsilon_0\lambda\mathbf{n}_Q\cdot\mathbf{E}^{i}, \qquad (3)$$

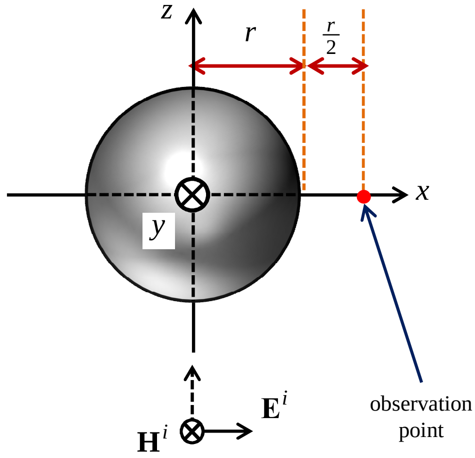

Figure 1. Geometry of a nano sphere.

where

$$\lambda=\frac{\varepsilon-\varepsilon_0}{\varepsilon+\varepsilon_0}. \qquad (4)$$

Calculating a matrix equation which is obtained by discretizing Eq. (3), we can find the surface electric charge density σ .

3. Computational Results

We analyze the electric fields of a nano sphere as shown in Figure 1. The incident wave is a sinusoidal plane wave with the amplitude of 1.0 V/m. The incident wave propagates to the positive *z*-direction and has the *x*-component of the electric field.

Figure 2 shows the relative error between the computational result and exact solution for varying the wavelength. The radius *r* is equal to 3 nm and the dielectric permittivity $\varepsilon=2\varepsilon_0$. As the wavelength becomes longer, the relative error becomes small due to the approximation. The error is of the order of 10^{-4} when the wavelength is longer than 580 nm.

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Next we analyze the electric fields of a gold sphere with radius r = 3 nm. The observation point is at $y = z = 0$ and x = 4.5 nm. The dielectric permittivity of the gold sphere in the frequency domain $\varepsilon(\omega)$ is defined by the Lorentz-Drude model as [4]

$$\varepsilon(\omega) = \left(1 - \frac{A_0\omega_p^2}{\omega(\omega + j\gamma_0)} + \sum_{l=1}^{K} \frac{A_l\omega_p^2}{(\omega_l^2 - \omega^2) - j\omega\gamma_l}\right)\varepsilon_0, \quad (5)$$

where ω_p is the plasma frequency, K is the number of oscillators with the frequency ω_l, γ_0 and γ_k are collision frequencies, and A_0 and A_l are constants which depend on the material.

Figure 3 shows the wavelength response of the electric field intensity. Both the computational result and the exact solution are in a good agreement.

Figure 4 shows the relative error for varying the number of unknowns N when the wavelength is 200 and 800 nm. Increasing the number of unknowns N, the relative error converges. In spite of the number of unknowns, the relative error for 800 nm is always smaller than that for 200 nm.

4. Conclusions

In this report, we analyzed the electromagnetic fields near nanoparticles by using the BIEM in the static approximation. We clarified the relation between the computational accuracy and the wavelength by comparison of the exact solutions.

5. Acknowledgements

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6. References

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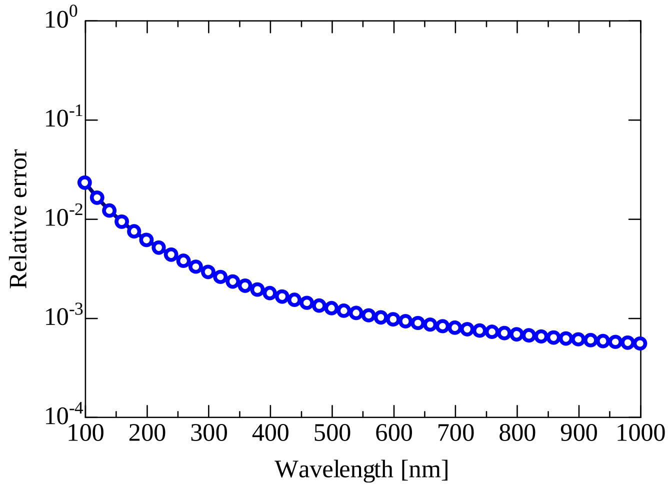

Figure 2. Relative error for varying the wavelength.

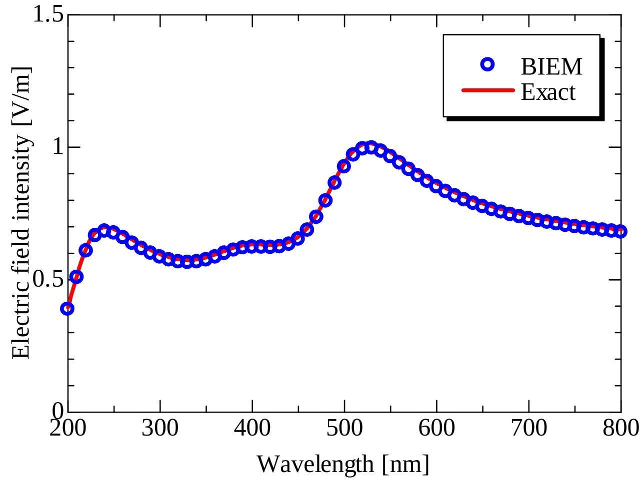

Figure 3. Wavelength responses of the electric field intensity for a gold sphere when r = 3 nm.

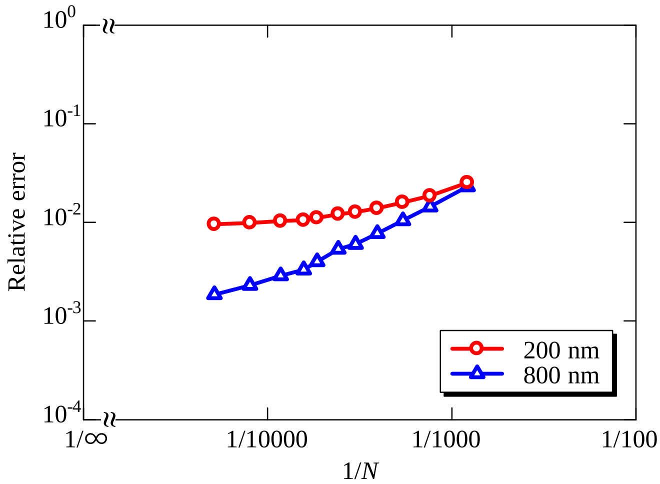

Figure 4. Relative error for varying the number of unknowns N.