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Transmission of shaped beam through a rotationally uniaxial anisotropic sphere

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ABSTRACT

We proposed a semi-analytical solution to the arbitrarily shaped beam scattering by a rotationally uniaxial anisotropic sphere. The scattered and internal fields are expanded in terms of appropr- iate spherical vector wave functions, and the unknown expansion coefficients are determined by virtue of the boundary conditions and the method of moments procedure. For incidence of a Gaussian beam, zero-order Bessel beam and Hertzian electric dipole radiation, numerical results are given for the normalized internal and near-surface field intensity distributions, and then their properties are discussed concisely.

1. Introduction

The electromagnetic (EM) scattering process from a spherical particle has been an attractive subject both from a fundamental point of view and from the point of view of practical applications such as optical tweezers, particle sizing, laser beam aerosol penetration, and so on. It is well- known that the classic Lorenz-Mie theory provides a rigorous solution for the problem of EM plane wave scattering by a dielectric sphere [1]. Over the past few decades, Gouesbet et al. have developed the generalized Lorenz-Mie theory (GLMT) which is effective in dealing with the case of an incident shaped beam [2,3]. The EM scattering by an anisotropic sphere (uniaxial, gyrotr- opic), illuminated by the plane wave or shaped beam, has also been extensively investigated [4–8]. In these studies, it is necessary to have the incident EM fields expanded in the form of an infinite series of spherical vector wave functions (SVWFs). However, it is usually a very difficult problem to obtain such an expansion for quite a few shaped beams. In this paper, following the method of moments (MoM) scheme we present a theoretical procedure for calculating the scattered fields of an arbitrarily shaped beam striking a rotationally uniaxial anisotropic sphere, for which what we need is the explicit description of the incident EM fields.

The body of this paper is organized as follows. In section 2, a theoretical procedure is given for the determination of the scattered fields by a rotationally uniaxial anisotropic sphere illuminated with an arbitrarily shaped beam. In section 3, numerical results of the normalized internal and near-surface field intensity distributions are presented for a Gaussian beam, zero-order Bessel beam (ZOBB) and Hertzian electric dipole (HED) radiation. The present work is concluded in section 4.

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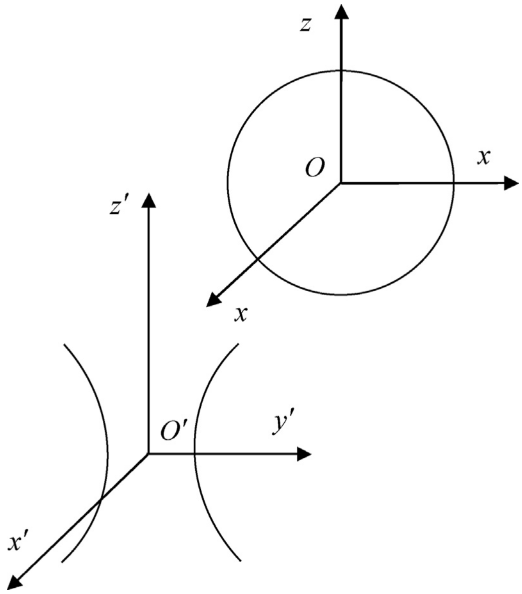

Fig. 1. A rotationally uniaxial anisotropic sphere illuminated by an EM beam.

2. Formulation

As schematically illustrated in Fig. 1, an EM beam propagates in free space and from the negative z' to the positive z' axis of the Cartesian coordinate system $O'x'y'z'$ (EM beam coordinate system). A rotationally uniaxial anisotropic sphere is natural to the system $Oxyz$ (parallel to $O'x'y'z'$), with its origin O having the Cartesian coordinates (x_0, y_0, z_0) in $O'x'y'z'$. In this paper, the time-dependent part of the EM fields is assumed to be $\exp(-i\omega t)$.

According to the radiation condition, the scattered fields (outgoing wave) by the sphere can be expanded in terms of the SVWFs of the third kind with respect to the system $Oxyz$, as follows:

$$\mathbf{E}^s = E_0 \sum_{n=1}^{\infty} \sum_{m=-n}^{n} [a_{mn}\mathbf{M}_{mn}^{r(3)}(k) + b_{mn}\mathbf{N}_{mn}^{r(3)}(k)] \tag{1}$$

$$\mathbf{H}^s = -iE_0 \frac{1}{\eta} \sum_{n=1}^{\infty} \sum_{m=-n}^{n} [a_{mn}\mathbf{N}_{mn}^{r(3)}(k) + b_{mn}\mathbf{M}_{mn}^{r(3)}(k)] \tag{2}$$

where $k = \omega\sqrt{\mu_0\varepsilon_0}$ and $\eta = \sqrt{\mu_0/\varepsilon_0}$ are respectively the free space wave number and wave impedance, and a_{mn}, b_{mn} are the unknown expansion coefficients to be determined.

The constitutive relations of a rotationally uniaxial anisotropic medium are described by the following permittivity and permeability tensors

$$\bar{\bar{\varepsilon}} = (\varepsilon_r\hat{r}\hat{r} + \varepsilon_t\hat{\theta}\hat{\theta} + \varepsilon_t\hat{\varphi}\hat{\varphi}) \tag{3}$$

$$\bar{\bar{\mu}} = (\mu_r\hat{r}\hat{r} + \mu_t\hat{\theta}\hat{\theta} + \mu_t\hat{\varphi}\hat{\varphi}) \tag{4}$$

As discussed in [7] and [8], the EM fields within the rotationally uniaxial anisotropic sphere (internal fields) can be decomposed into the TE and TM modes (with respect to the unit vector $\hat{r}$), and then the expansion representations of the internal fields are obtained in terms of the SVWFs of the first kind, in the following form

$$\mathbf{E}^w = E_0 \sum_{n=1}^{\infty} \sum_{m=-n}^{n} [c_{mn}\mathbf{M}_{m\nu_{TE}(n)}^{r(1)}(k_t) + d_{mn}\frac{k_t}{\omega}\bar{\bar{\varepsilon}}^{-1} \cdot \mathbf{N}_{m\nu_{TM}(n)}^{r(1)}(k_t)] \tag{5}$$

$$\mathbf{H}^w = -iE_0 \sum_{n=1}^{\infty} \sum_{m=-n}^{n} [c_{mn}\frac{k_t}{\omega}\bar{\bar{\mu}}^{-1} \cdot \mathbf{N}_{m\nu_{TE}(n)}^{r(1)}(k_t) + d_{mn}\mathbf{M}_{m\nu_{TM}(n)}^{r(1)}(k_t)] \tag{6}$$

where $\nu_{TE,TM}(n) = \frac{-1+\sqrt{1+4R_{TE,TM}n(n+1)}}{2}$, $R_{TE} = \mu_t/\mu_r$, $R_{TM} = \varepsilon_t/\varepsilon_r$, and $k_t = \omega\sqrt{\mu_t\varepsilon_t}$.