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Light scattering by a cluster consisting of homogeneous axisymmetric particles illuminated with an arbitrarily focused electromagnetic Gaussian beam

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ABSTRACT

Scattering of an arbitrarily focused electromagnetic Gaussian beam by a chain cluster consisting of axisymmetric particles is presented. The illustrated technique in this paper combines the plane-waves spectrum method and the cluster *T*-matrix calculation technique. This combination provides a powerful mathematical and numerical tool to solve such types of scattering problems. Computed results are shown for different particles shapes in the cluster and for different beam focusing.

1. Introduction

Cluster characteristics and their formation is important in many aspects in every day of life. Generally micro and nano clusters consist of two or more particles formed through a particles aggregation processes. There are numerous developed techniques to study particle aggregation that are important in many applications such as material processing, drug and chemical industries, and medical diagnostics [1]. Also clusters and their performance are important to understand many physical phenomena. To enhance such applications many ways were developed to study the performance of clusters and their characteristics. Among these ways is electromagnetic wave scattering by clusters [2–8]. Over 40 years have passed since Liang [9] and Brunning [10] first developed an exact analytical solution to the time-harmonic Maxwell's equations for multiple-sphere systems. Their theory is based on expansion of the incident field into spherical vector wave functions. Much of work is focused on the mathematical and computational aspects of multiple sphere scattering. However, many natural and artificial small particles have overall nonspherical shape or lack a spherically symmetric structure. Examples of such clusters of nonspherical particles are mineral and soot aerosols, particles forming planetary and asteroid surfaces, biological microorganisms, and more.

Many theories are developed and presented in the literature to illustrate and explain the interaction of an electromagnetic waves with clusters. Among these theories is the *T*-matrix method which is the most powerful and widely used theoretical technique for scattering of an incident field by a single, or composite spherical or nonspherical particle. In this method the incident and scattered electric fields are expanded in series of suitable vector spherical wave functions through satisfying boundary conditions. The *T*-matrix formalism developed

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by Waterman [11] for a single particle is extended to deal with clusters by Peterson and Ström [2] to compute scattering of a plane wave by two spheroids. Mackowski and Mishchenko [12] introduced a cluster *T*-matrix method for clusters consisting of more than two spherical particles. Recently Ibrahim and Khaled [3,6,7] modified the cluster *T*-matrix method to apply to clusters consisting of different homogeneous axisymmetric objects ensembles of spheres adhering to spheroids [3], and clusters consist of homogeneous or nonhomogeneous coated axisymmetric particles illuminated with a plane wave [6,7]. The modified method is cited in a research of comprehensive database of *T*-matrix publications [8].

All the above mentioned work are for clusters illuminated with a plane wave. But in many applications the incident light is a shaped laser beam; more specifically the incident light is a focused Gaussian beam (GB) [13]. Furthermore in many cases the incident beam has a focusing waist smaller than the average cross-section of the whole cluster or even less than the diameter of one element in the cluster. Among these applications is a focused GB light-scattering spectroscopy that is used extensively in recent years to study the diffusion motions of macromolecules, sperm mobility, and bacterial movement [14]. In other applications a cluster illuminated with a focused GB is important to investigate the characteristics of non-destructive measurements in optical diagnostic to record either reflected or transmitted light through a part of a sample of blood [15], human dermis, or soil particles. In such applications the object is represented by a collection of particles (a cluster). The scattering analysis of all these applications, which are presented in the current literature, simplify the processes to a cluster of different particles illuminated with a plane wave. The main aim of this paper is to study the scattering of a focused laser beam by a cluster of different shaped particles. To the best of our knowledge no attempts are published in the literature to tackle such type of problem and its application. Our solution depends on the combination of the plane wave spectrum method with the cluster *T*-matrix method to provide a powerful technique to calculate the scattered field intensities of any incident electromagnetic field illuminating a cluster of different shaped particles. To check the validity of our technique the calculated results for some cases are contrasted with the available results in the literature for a cluster of spheres [12], homogeneous spheroids [16] illuminated with a plane wave. No differences were noticed in all cases.

The method used here and the mathematical analysis are outlined in Section 2. Computed results of the scattering matrix elements and the angular scattering for different cases of clusters consisting of spheres and spheroids illuminated with an arbitrary focused beam are presented in Section 3. Conclusions are given in Section 4.

2. Theoretical analysis

In this paper we investigate the scattering of a lowest order (TEM_{00}) monochromatic Gaussian beam by a chain cluster consisting of homogeneous axisymmetric dielectric particles. The incident beam propagates in the *z*-direction of a right handed Cartesian coordinate system (*x*,*y*,*z*) as shown in Fig. 1. The beam is polarized in the *xz*-plane with a focal point at the origin of the coordinates. The beam can be focused into an arbitrarily spot size, even, smaller than

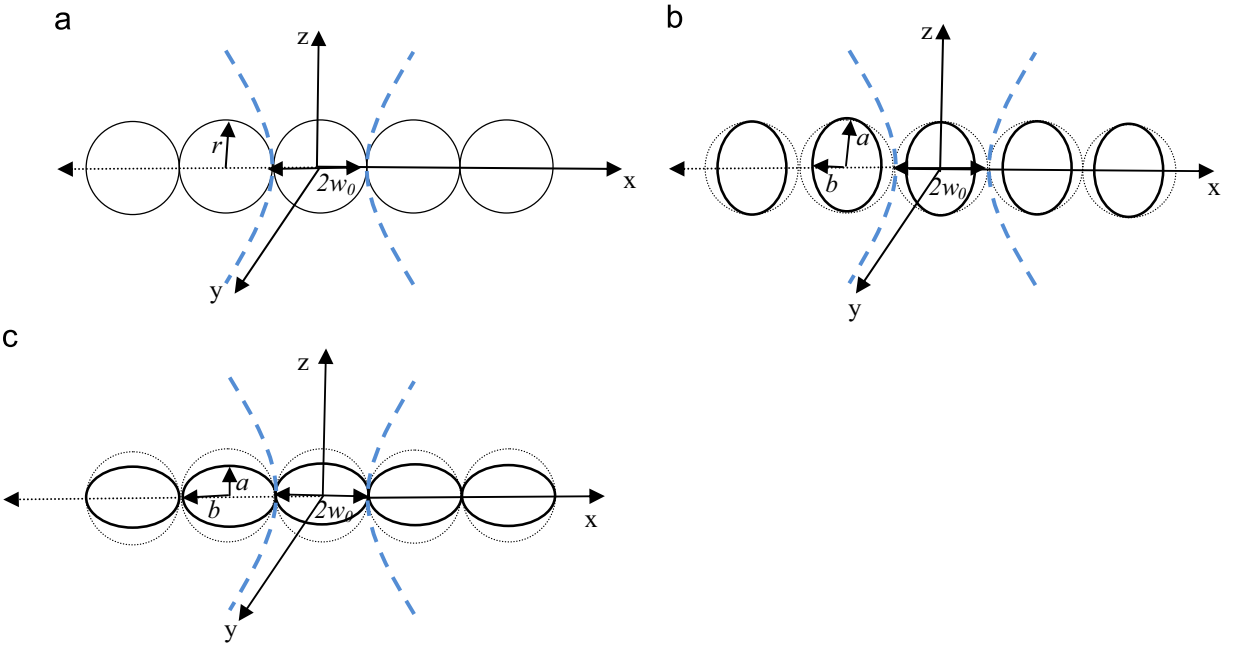

Fig. 1. A chain cluster of axisymmetric particles arranged along the *x*-axis and centered at the origin of a Cartesian coordinate system (*x*, *y*, *z*). The cluster is illuminated with a focused Gaussian beam of a spot size w_0 propagating in the *z*-direction, and polarized in the *x*–*z* plane. The cluster consists of five identical; (a) spherical particles, (b) prolate particles, and (c) oblate particles. The smallest circumscribing spheres of the component spheroidal particles do not overlap.