Scattering simulations for Bessel beams near a plane substrate in the framework of the discrete dipole approximation

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We report the simulations of vector Bessel beam scattering by particles near a substrate using the discrete dipole approximation. To implement it, we decompose Bessel beams into a weighted sum of plane waves using the angular spectrum decomposition method. This allowed us to use the previous realization of plane-wave scattering near a plane substrate in the ADDA code. We also extended existing angular spectrum decompositions of several Bessel beam types to all other types. The beta version of the code for the simulation shows good computational speed and accuracy. It enables the simulation of a wide range of experiments with Bessel beams involving the presence of a substrate.

INTRODUCTION

Bessel beams are prominent examples of structured light possessing features valuable in diverse areas of photonics and medical science. First, ideal Bessel beams are diffraction-free, so they can propagate without intensity divergence along the propagation axis [1]. Next, Bessel beams have a helical phase proportional to orbital angular momentum. Both qualities make Bessel beams a versatile tool for optical manipulation, holography, material processing, and many other applications [2–4]. Various applications of such beams require the consideration of their scattering by particles and the contribution of a substrate. The aim of the work is to create a robust tool for the simulation of such scenarios, including the consideration of all existing types of Bessel beams [5].

VECTOR BESSEL BEAMS NEAR A PLANE SUBSTRATE

The most straightforward and effective way to calculate the reflection and transmission of Bessel beams on the interface of two media is to represent the beam as a superposition of plane waves using the angular spectrum decomposition (ASD) method [6] and then apply Fresnel equations to these plane components.
In contrast to a simple scalar Bessel beam obtained in paraxial approximation, vector Bessel beams are more complicated and can be described as various types and polarizations such as beams with circularly symmetric energy density (CS and CS' types), with transverse electric and magnetic fields – TE and TM types and their linear components TEL and TML, respectively, and with linear polarizations of electric and magnetic fields – LE and LM beams, respectively [5]. The energy density profiles of some of these types are shown on Fig. 1. Unfortunately, the ASD expressions are known only for some vector Bessel beam types (TE, TM, and CS). Thus, we derived a common expression for a generalized vector Bessel beam using our classification from Ref. [5]. Now, understanding how to decompose any vector Bessel beam into a sum of plane waves we can easily implement scattering simulations using existing methods.

SCATTERING SIMULATIONS

To simulate electromagnetic scattering by arbitrary particles we use the discrete dipole approximation (DDA) and its open-source implementation ADDA [7]. We combined the ASD of a generalized vector Bessel beam and existing implementation of plane wave scattering by particles near a plane substrate in ADDA code in a separate fork of ADDA: https://github.com/stefaniagl/adda/tree/besselASD. Apart from the main functionality of the code to calculate a wide range of scattering quantities, such as scattering intensities (Fig. 2), it can also be used for the visualization of the incident field near a plane substrate (Fig. 3).
Fig. 2. Convergence of the scattering intensities of 0-order CS Bessel beam, normally incident on a cube on a plane substrate, to the same results for a plane wave.

Fig. 3. The incident field of a Bessel beam reflected and transmitted near a plane substrate, generated with ADDA.

One of the ways to validate our code is to show the convergency of results for Bessel beams to the plane wave limit scattering on a particle near a plane substrate to the analogous results for the previously implemented plane wave near a substrate in ADDA (see Fig. 2). The capability of the code also allows us to demonstrate various cases of vector Bessel beams reflection and transmission on a plane substrate including the total internal reflection in Fig. 3.

The presented code might be valuable for the simulation of a wide range of experiments with Bessel beams involving the presence of a substrate. Its further development for the calculation of optical forces for vector Bessel beams will allow to consider such interesting phenomena as micromanipulations near a substrate.

REFERENCES


