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Trapping and alignment of a microfibre using the discrete dipole approximation

T. A. Nieminen, H. Rubinsztein-Dunlop,
and N. R. Heckenberg
Centre for Laser Science, Department of Physics,
The University of Queensland, Brisbane QLD 4072, Australia
phone +617-3365 3405, fax +617-3365 1242
`timo@physics.uq.edu.au`

Abstract

Optical tweezers can be used to trap, move, and rotate or align microscopic particles. Elongated particles are ideal candidates for alignment and controlled rotation; the behaviour of microfibres within an optical trap is investigated.

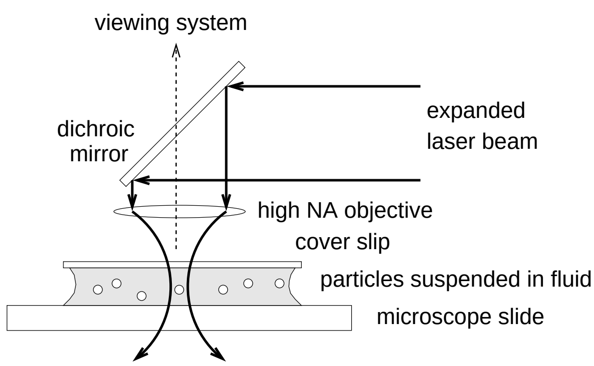

Figure 1: Schematic diagram of a typical optical tweezers setup

1 Introduction

Optical trapping, which is the trapping and manipulation of microscopic particles by a focussed laser beam or beams, is a widely used and powerful tool. The most common optical trap, commonly called *optical tweezers*, consists of a laser beam strongly focussed by a lens, typically a high numerical aperture microscope objective (see figure 1).

Applications of optical trapping are numerous, and steadily growing in number and sophistication. The increasing number of quantitative applications require accurate calculation of the optical trapping forces; a calculation from first principles is important since it allows absolute calibration.

The force and torque acting on a

particle in a laser trap can be found from the momentum and angular momentum of the total electromagnetic field (the sum of the incident field and the scattered field) [1]. The fields can be found using electromagnetic scattering theory, avoiding the common approximations of geometric optics and Rayleigh approximations which are only valid in limited regimes.

2 The discrete dipole approximation

A number of different methods can be, and have been, used to calculate optical forces: finite element (FEM) and finite difference time domain (FDTD) methods [2], which are computationally intensive, required the discretisation of the particle and surrounding space, and special boundary conditions; the T-matrix method [1, 3], which is fast and efficient, but fails for particles of very large aspect ratio and cannot be used for anisotropic particles; and the discrete dipole approximation (DDA), which allows calculation of forces on extreme aspect ratio particles and anisotropic materials, while only requiring discretisation of the particle.

In the discrete dipole approximation, the scatterer is represented as a collection of small polarisable particles, each much smaller than the wavelength of the illumination [4, 5]. The response of each dipole to the surrounding field can be readily calculated. The field at any dipole is the sum of the incident field and the field produced by all other dipoles; an iterative procedure can be used to find the total field. Fourier methods can be used for rapid convergence.

Once the field has been calculated, and the polarisation in each dipole is known, the force and torque acting on each individual dipole can be simply found – a known dipole moment in an applied field. Thus, the total force and torque can be calculated.

The advantages offered by DDA are that while the particle must be discretised, the surrounding space is not. Thus, the computational difficulty varies with the volume of the particle only, and the method is suitable for large aspect ratio particles. As an additional benefit, the stresses within the scatterer can be readily found.

3 Microfibres

Torques acting to align homogeneous particles due to their shape are of particular interest. Extremely elongated particles – microfibres – provide us with an ideal test case for investigating these effects.

The discrete dipole approximation is ideal for calculating the force and torque acting on a microfibre, with a relatively small volume, and extreme aspect ratio. A very thin fibre can be approximated as a single chain of dipoles, while a thicker fibre will have a number of elements across the width (see figure 2).

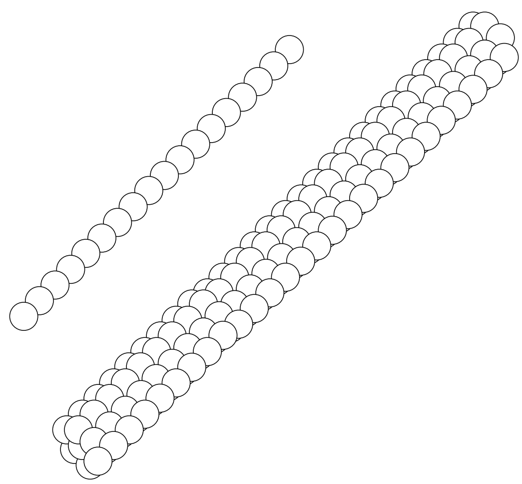

Figure 2: Discrete dipole representations of thin and thick microfibres

We present calculations of the scattered fields and optical force and torque for microfibres of a wide range of lengths and widths.

References

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