Optical trapping and manipulation of nanostructures

O. M. Maragó1,2, M. G. Donato1, A. Magazzù1,2, A. Iarrera1, C. D’Andrea1,2, E. Messina1, B. Fazio1, M. A. Iati1, P. H. Jones2, and P. G. Gucciardi1

1CNR-IPCF, Istituto per i Processi Chimici-Fisici, Messina, Italy
2Dottorato in Fisica, Università di Messina, Messina, Italy
3Matis CNR-IMM and Dipartimento di Fisica, Università di Catania, Catania, Italy
4Department of Physics and Astronomy, University College London, London, UK

*Corresponding author: marago@me.cnr.it

Abstract

Optical trapping (OT) of nanostructures has acquired tremendous momentum in the last few years. Manipulating nanoparticles with standard OT is generally difficult because radiation forces scale approximately with particle volume and thermal fluctuations easily overwhelm trapping forces at the nanoscale. However carbon nanotubes, graphene, polymer nanofibers, plasmonic nanoparticles, and semiconductor nanowires, have been stably trapped thanks either to their highly anisotropic geometry or to their intrinsic resonant behavior. Here we discuss our recent results on OT of nanostructures with a focus on the role of shape on optical forces, spectroscopy measurements in optical traps, and implications in force and spectroscopic sensing at the nanoscale.

1 Introduction

Optical trapping and manipulation of micrometre-sized particles was first reported in 1970 [1]. Since then, it has been successfully implemented in two size ranges: the subnanometre scale, where light–matter mechanical coupling enables cooling of atoms [2], and the micrometre scale, where the momentum transfer resulting from light scattering allows manipulation of microscopic objects such as cells [3]. But it has been difficult to apply these techniques to the intermediate, nanoscale, range that includes structures such as quantum dots, nanowires, nanotubes, graphene and two-dimensional crystals, all of crucial importance for nanomaterials-based applications [4]. Recently, however, several new approaches have been developed and demonstrated for trapping plasmonic nanoparticles, semiconductor nanowires and carbon nanotubes [4]. Here we describe our experimental and theoretical efforts in the understanding and the exploitation of optical forces as applied to nanostructures.

2 Optical trapping of nanostructures

We have trapped and manipulated different type of nanostructures (Fig. 1) with a first goal to investigate optical forces through their accurate measure in the optical trap [3-8]. We have used nanostructures as probes for light-driven rotations [9-10], as well as accurately measure forces with resolution at the level of femto–Newtons [5] crucial for photonic force microscopy applications [4] combining the outstanding force-sensing capabilities of OT with increased nanometric precision and bridging the gap between micro and nanoscale in fluidic environments (Fig. 1). In this context the role of shape [5-8,13] and size-scaling [6,13] is crucial for understanding the interplay between optical forces and hydrodynamic interactions that change dramatically with size, hence much affecting both force-sensing and spatial resolution in precision applications [4,5].

Furthermore the integration of OT with Raman and SERS spectroscopy (Fig. 2) allowed us to perform ultra-sensitive chemical-physical analysis of trapped nanoparticles [8,11,12]. The use of optical forces to trap and manipulate metal nanoparticles and aggregates permits exploitation of the field-enhancement properties of these nanostructures for surface-enhanced Raman spectroscopy of molecules adsorbed on aggregates optically trapped in a Raman tweezers setup [11,12] (Fig. 2). Moreover, we also demonstrated the operation of a SERS sensor in liquid environment obtained by optical force induced aggregation of colloidal gold nanorods.
This is the result of an interplay between thermal and radiation pressure effects. The creation of highly efficient hot spot regions enables the Raman detection of proteins dissolved in a buffer solution at very low concentration (up to $10^{-7}$ M).

Figure 2 Optical trapping of plasmonic nanoaggregates and SERS [8,11,12]. Fano-Doppler laser cooling of hybrid nanostructures [18].

3 Conclusions

In conclusion, optical trapping of nanostructures offers a unique opportunity to trap, manipulate, probe, characterize, individual nanostructures with well defined optical, mechanical, thermal properties. The range of applications is huge and spans from photonic force microscopy with femtonewton resolution, Raman and SERS spectroscopy in liquid, to novel approaches in laser cooling [14] and optomechanics of levitated particles [4].

4 References