Optical Trapping of Nanostructures: Femtonewton Force Sensing and Ultra-Sensitive Spectroscopy

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Abstract Optical trapping[1-3] (OT) of nanostructures[3-16] have acquired tremendous momentum in the last few years. Manipulating nanoparticles with standard OT is generally difficult because radiation forces scale approximately with particle volume[1-3,6,8] and thermal fluctuations easily overwhelm trapping forces at the nanoscale. However carbon nanotubes,[4,5,7] (Fig. 1) graphene,[9] (Fig. 2) polymer nanofibers,[6,10] plasmonic nanoparticles,[11,12] and semiconductor nanowires,[6,13,15,16] (Fig. 3) have been stably trapped thanks either to their highly anisotropic geometry[4-7,10,13,15,16] or to their intrinsic resonant behavior.[7,8,11,12]

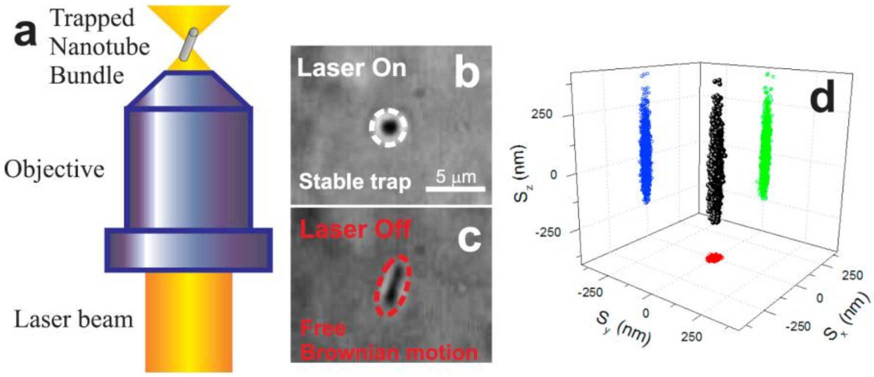

Fig. 1: Optical trapping of nanotubes. (a) Optical trapping geometry. (b) Image of a trapped nanotube bundle oriented by radiation torque along the optical axis. (c) Image of the same bundle un-trapped (laser is off) and randomly oriented by Brownian motion. (d) Tracking of a trapped nanotube bundle Brownian motion. The calibration of the trap allows force sensing with femtonewton resolution in liquid environment.

Nanostructures have been trapped and manipulated to build nano-assemblies,[15,16] used as probes for light-driven rotations,[7] as well as accurately measure forces with resolution at the level of few femto-newtons crucial for photonic force microscopy applications[3,5,13] combining the outstanding force-sensing capabilities of OT with increased nanometric precision and bridge the gap between micro and nanoscale in fluidic environments (Fig. 1 & 4).

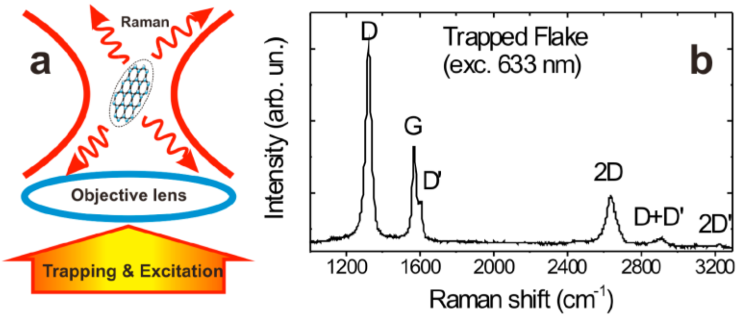

Fig. 2: Optical trapping of graphene. (a) Sketch of the Raman Tweezers setup. Trapping and excitation is performed with the same laser beam at 633nm. Collection of the Raman signal is guided through the same objective used for trapping. (b) Typical Raman spectrum for single layered graphene in the optical trap.

Furthermore the integration of OT with Raman and SERS spectroscopy (Fig. 2 & 3) allowed for ultra-sensitive chemical-physical analysis of trapped nanoparticles.[9,12,14] In this context the role of shape[5,6,9,10] and size-scaling[13] is crucial for understanding the interplay between optical forces and hydrodynamic interactions[17] that change dramatically with size, hence much affecting both force-sensing and spatial resolution in precision applications (Fig. 3).[3,5]

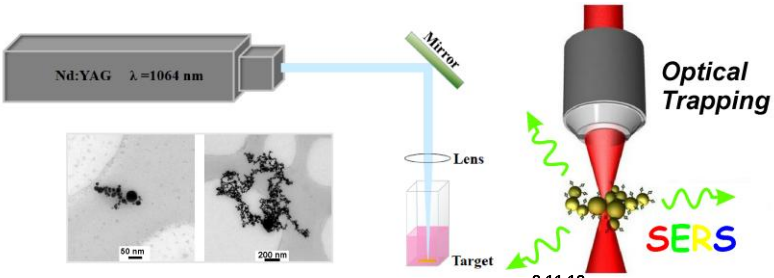

Fig. 3: Optical trapping of plasmonic nanoaggregates and SERS.[8,11,12] (from left to right) Sketch of the laser ablation set-up and SEM image of the plasmonic nanoaggregates with controlled optical properties. Sketch of the SERS optical tweezers: a nanoaggregate is held within the trapped while a SERS spectrum is collected with the same optics.

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, quantum optics, and ion trapping.[18-20]

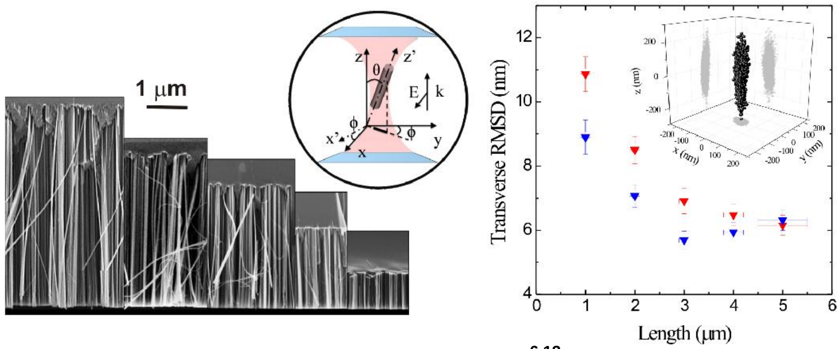

Fig. 4: Size-scaling in the optical forces on Silicon nanowires.[6,13] (from left to right) SEM image of the Silicon nanowires with length in the range 1-5 μm and diameter 10 nm. Geometry. Transverse Root-Mean-Squared-Displacement as a function of nanowire length and Brownian motion in the trap.

References

[1] A. Ashkin, J. M. Dziedzic, J. E. Bjorkholm, S. Chu. Opt. Lett., **11** (1986) 288; See also Special Issue in Nature Photon., **5,** Issue 6 (2011).
[2] F. Borghese, P. Denti, R. Saija, M. A. Iatì. Opt. Express, **15** (2007) 11984.
[3] O. M. Maragò, P. H. Jones, P. G. Gucciardi, *"Photonic Force Microscopy: From Femtonewton Force Sensing to Ultrasensitive Spectroscopy"*, in Scanning Probe Microsc. in Nanoscience & Nanotech.; B. Bushan Ed.; Springer-Verlag: Berlin (2010).
[4] O. M. Maragò, et al. Physica E, **8** (2008) 2347.
[5] O. M. Maragò, et al. Nano Lett., **8** (2008) 3211.
[6] F. Borghese, et al. Phys. Rev. Lett., **100** (2008), 163903.
[7] P. H. Jones, et al. ACS Nano, **3** (2009) 3077.
[8] R. Saija R., et al. Opt. Express, **17** (2009) 10231.
[9] O. M. Maragò, et al., ACS Nano, **4** (2010) 7515.
[10] A. A. R. Neves, et al., Opt. Express, **18** (2010) 822.
[11] E. Messina, et al. ACS Nano, **5** (2011) 905.
[12] E. Messina, et al. J. Phys. Chem C, **115** (2011) 5115.
[13] A. Irrera, et al. Nano Lett., **11** (2011) 4879.
[14] M. G. Donato, et al. Nanotechnology, **22** (2011), 505704.
[15] R. Agarwal, et al. Opt. Express **13** (2005) 8906.
[16] P. J. Pauzauskie, et al. Nat. Mater. **5** (2006) 97.
[17] R. Di Leonardo, et al. Phys. Rev. Lett. **107** (2011) 044501.
[18] A. Ridolfo, et al. ACS Nano **5** (2011) 7354.
[19] P. F. Barker, M. N. Shneider, Phys. Rev. A, **81** (2010) 023826.
[20] O. Romero-Isart, A. C. Pflanzer,M. L. Juan, R. Quidant, N. Kiesel, M. Aspelmeyer, J. I. Cirac. Phys. Rev. A, **83** (2011) 013803.
[21] B. E. Kane, Phys. Rev. B, **82** (2010) 115441.