Optical Nano-tweezers to Manipulate and Control Nano-objects

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ECE 695 Presentation
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1. Introduction
2. Optical Tweezers
3. Optical Manipulation of Nanoparticles
4. Applications of Optical Nano-tweezers
5. Summary
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Normal Tweezers

Marago et al., *Nature Nanotech.* 2013

Being able to manipulate and control nanoparticles has become important
Mechanical manipulation and interrogation of polystyrene nanoclusters (~ 500 nm)

Nanotweezers can have problems in releasing the nanostructures when opened due to the dominance of van der Waals force and electrostatic forces.
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Measurement of radiation pressure using light sources and a torsion balance

“A very short experience in attempting to measure these forces is sufficient to make one realize their extreme minuteness, a minuteness which appears to put them beyond consideration in terrestrial affairs.”

Nichols, E.F. & Hull G. F, Phys. Rev. 1901

J. H. Poynting’s presidential address to British Physical Society in 1905
Arthur Askin
Father of optical trapping

Observation of optical scattering and gradient forces decoupling thermal effects

First optical tweezer: Tightly focused beam of light holding particles in 3 dimensions

[ Basic Experimental Design ]

Sample in aqueous solution
Damps Brownian motion (normally ~ 10 μL)

Objective lens with high NA
Diffraction limited focus spot is produced

Camera imaging of particle
Bright-field or Dark-field imaging,
Interferometric position detection with QPD

[ The Physics of Optical Tweezers ]

Ray Optics
\( (D >> \lambda) \)

Rayleigh Regime
\( (D << \lambda) \)

Coffey, V., *Optics and Photonics News* 2013
Optical Forces on Nanostructures

- Gradient Force: $F_{grad} = \frac{-n^3 r^3}{2} \left( \frac{N^2 - 1}{N^2 + 2} \right) \nabla |E|^2$

Rayleigh Regime $(D << \lambda)$

- Gradient Force — electric dipole interaction scales down with particle volume

- Brownian motion from thermal fluctuations may be large enough to overcome the trapping forces at the nanoscale
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Solutions using geometry

Alternative trapping geometry
(Counter-propagating beams)
- Stronger gradient force

Alternative Particle Geometry
- Larger trapping volume

Woerdemann et al., *Opt. Express* 2010

Pauzauskie et al., *Nature Mater.* 2006
Capacitive effect leads to an intense "hot-spot"

Drawback: **Heating** from the plasmonic nanostructures
Integrated heat sink

~100 fold reduction in heating

Wang et. al., *Nature Commun.* 2011
Fast delivery of single particles to nanoantenna without agglomeration

AC field bias + Photo-induced heating $\rightarrow$ Electrical body Force

[ Hybrid Electrothermoplasmonnic Nanotweezer ]

Particle trapping and immobilization sequence

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Power Spectral Density

Microscopic spring

$f_0$: Roll-off frequency

$\kappa = f_0 2\pi \gamma$: Trap Stiffness

Biological Applications

Measurement of RNA hairpin undergoing conformational transitions

Dienerowitz et al., *J. Nanophoton.* 2008

Moffitt et al., *Annu. Rev. Biochem.* 2008
[ Spectroscopic Optical Tweezers ]

Marago et al., *Physica E*. 2008

Marago et al., *Nature Nanotech*. 2013

Marago et al., *ACS Nano*. 2010
[ Optomechanics with Levitated Nanoparticles ]

Study of mechanical motion induced by optical forces
Ultra-sensitive torque measurements may be achieved with laser cooling

Torsional Motion of Nonspherical Nanoparticles

Laser cooling of nanoparticles

Li et al., *Nature Phys.* 2011
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Non-invasive characteristics and its ability to control and manipulate nanoparticles. Gradient force from tightly focused laser beam to hold particles in all 3 dimensions.

Various techniques are introduced to overcome the decrease in gradient force for nanoscale particles.

Applications in diverse fields – Manipulation of nanostructures, force measurement, spectroscopy, optomechanics
Thank you
[ References ]