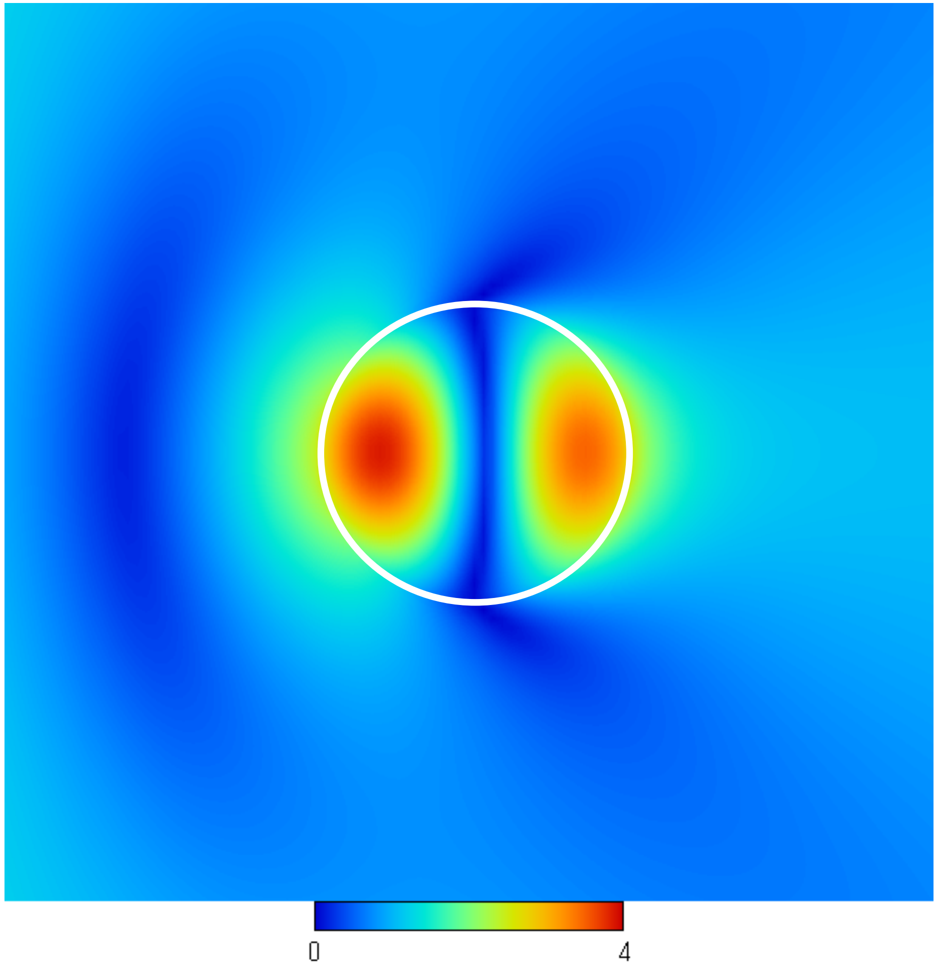
共鳴による力の増大

散乱電場の様子(ナノ、共鳴)

光の方向

共鳴条件



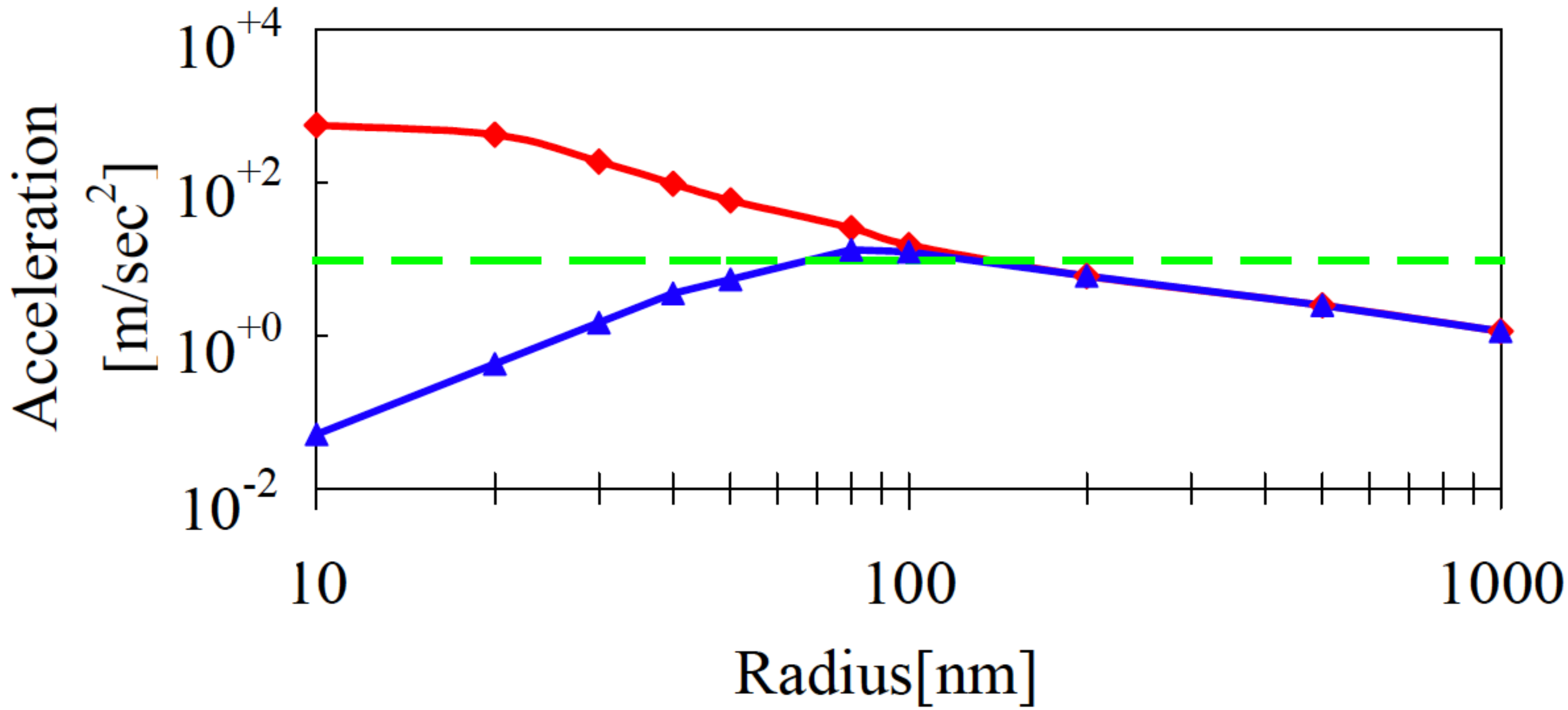
強い光散乱

半径50ナノメートル (波長387.85nm)

ナノ微粒子を動かす？

T. Iida & H. Ishihara, Phys. Rev. Lett. **90,** 057403 (2003)

For a CuCl nano-particle (50μW/100μm^2 Γ=0.06 meV)



共鳴光学応答を用いることの面白さ

T. Iida & H. Ishihara, *Phys. Rev. Lett*. **90**, 057403 (2003)

Size-selective sort and manipulation

Physical Review Focus

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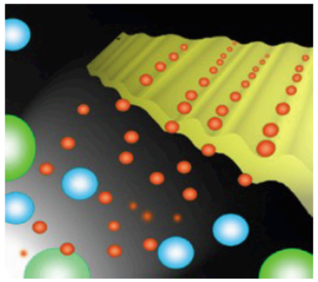
Phys. Rev. Lett. 90, 057403
(issue of 7 February 2003)
Title and Authors

11 February 2003

Manipulating Nanoparticles

Focused light beams called optical tweezers excel at trapping and moving micron-sized objects, but nanometer-scale particles generally slip through their grasp. Now researchers calculate that a laser tuned to resonate with the internal energy levels of semiconductor nanoparticles could strengthen its grip up to 100,000 times. A previous study had suggested a similar but much less drastic enhancement. The paper, appearing in the 7 February print issue of *PRL*, points the way toward size- and shape-selective sorting of building blocks for efficient nano-patterned materials.



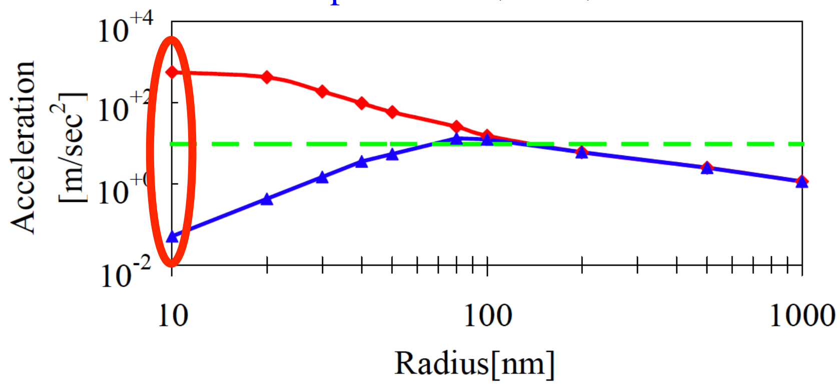
H. Ishihara/Osaka University

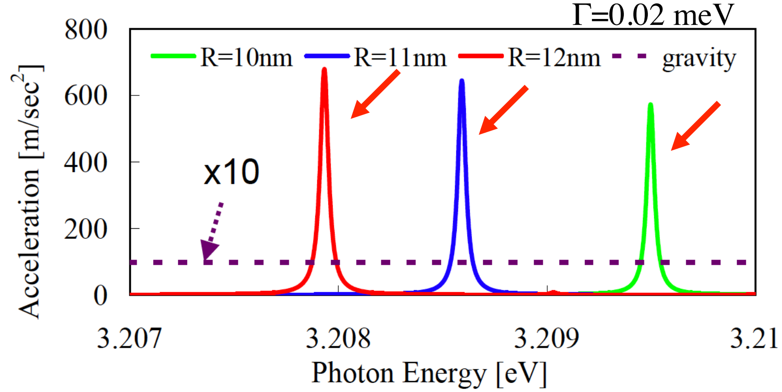
Light selection. Laser light tuned to match an object's internal energy levels could allow effective optical trapping and size-selective sorting of nanoparticles. Here a beam selectively pushes one size of particles toward a standing light wave, which directs the particles toward its nodes.

Separating minuscule objects by size and shape is a surprisingly important task. The speed with which fragments of chopped-up DNA molecules can be sorted determines the speed of genetic sequencing. In materials science, the ability to precisely select and orient particles would allow researchers to fashion substances that respond to a narrow range of light frequencies. Aside from some success trapping metallic particles, researchers have yet to master the manipulation of objects that are tens of nanometers across.

Phys. Rev. Focus. 11, Story 6, 11 Feb. (2003)

For a CuCl nano-particle (50μW/100μm² Γ=0.06 meV)

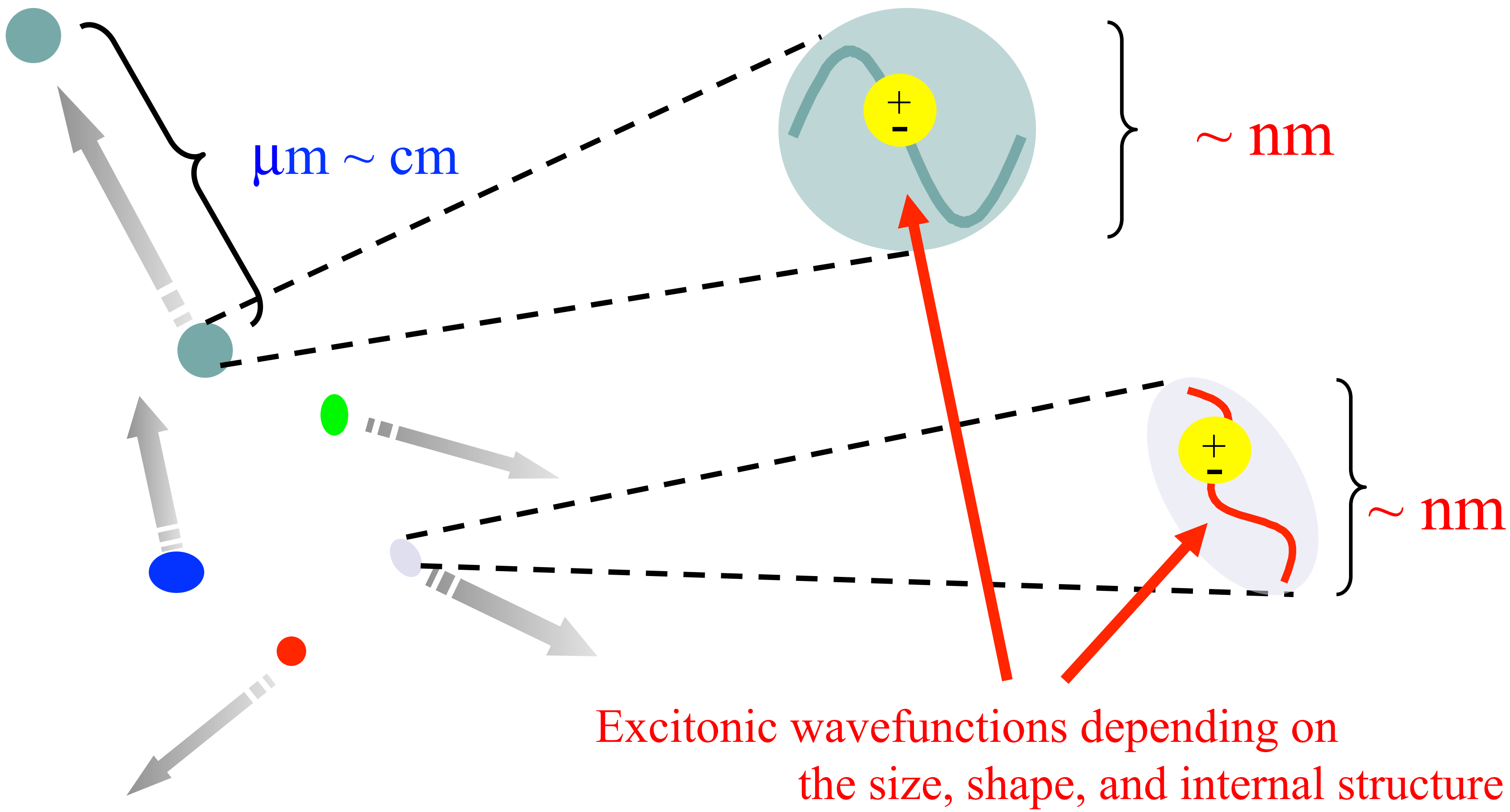




ナノ物質におけるミクロ自由度とマクロ自由度

Macroscopic (mechanical) degrees of freedom of nanoparticles

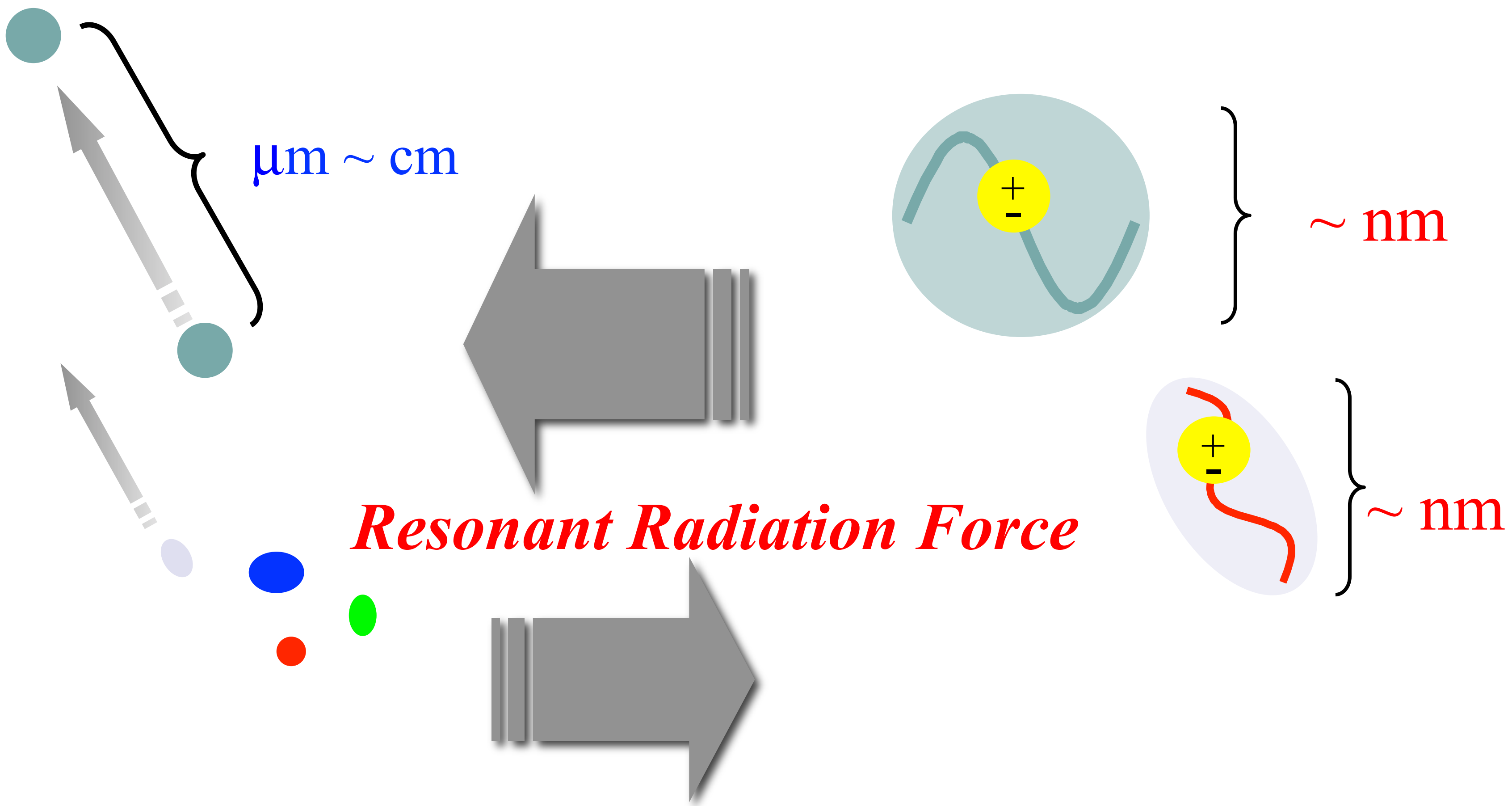
Microscopic (quantum) degrees of freedom of nanoparticles



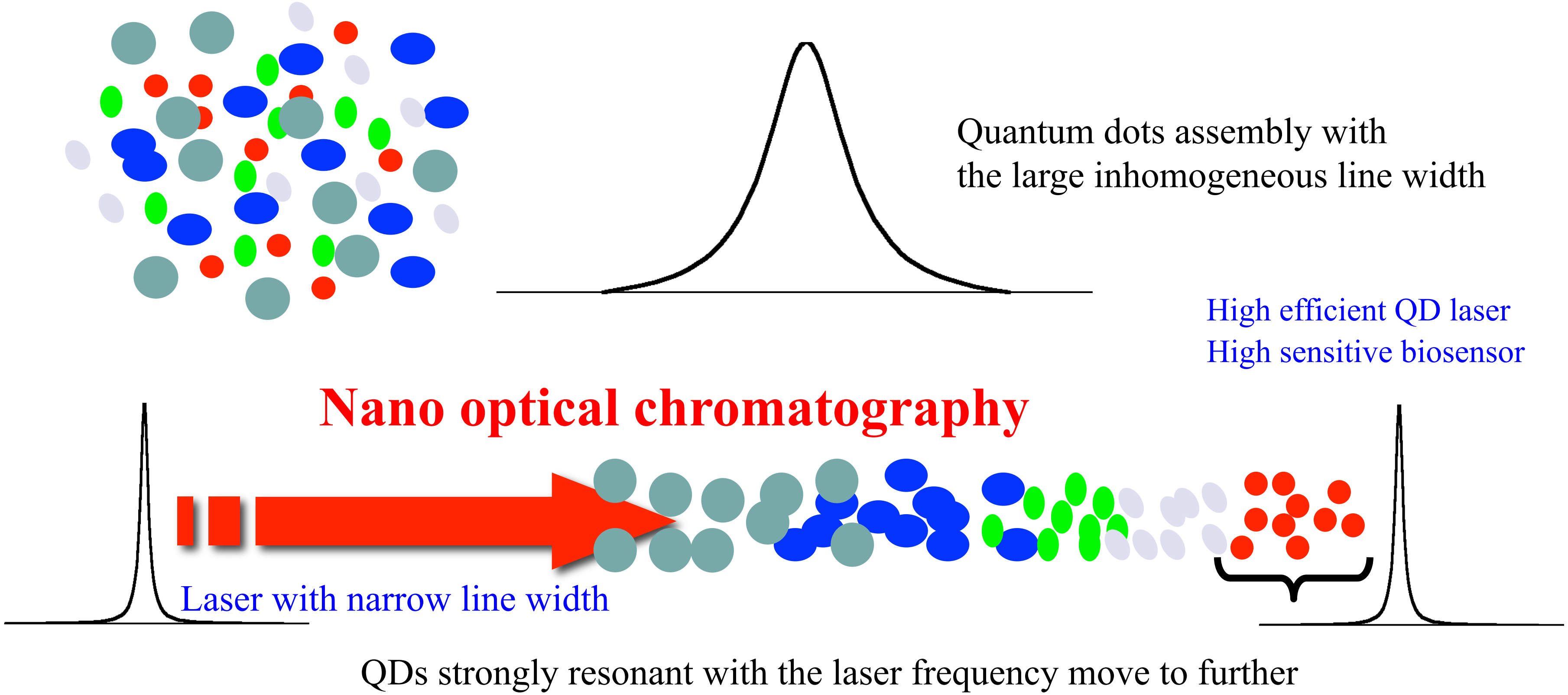
共鳴光学応答を通した
ミクロ自由度とマクロ自由度のインタープレイ

Macroscopic (mechanical) **degrees of freedom of nanoparticles**

Microscopic (quantum) **degrees of freedom of nanoparticles**



吸収線の揃ったナノ微粒子を選別するには？



共鳴輻射力により個々のナノ構造の量子力学特性を
非接触かつ直接的に選別！

ナノ領域での共鳴光マニピュレーション

Laser Tweezers
in μm regime

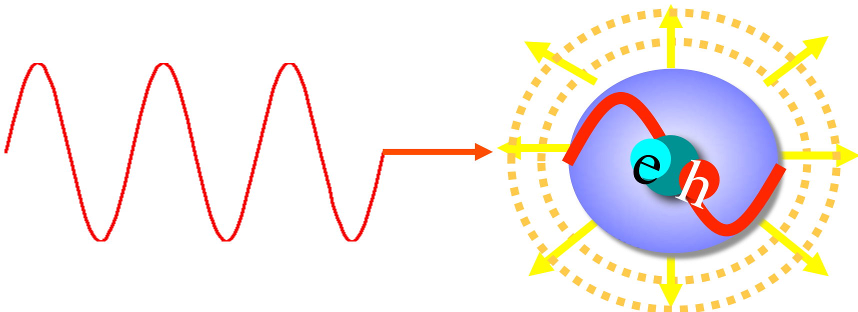
Nanoscale regime

Atom cooling
in atomic regime

nm

μm
non resonance
classical treatment

Atomic scale
resonance
quantum mechanical



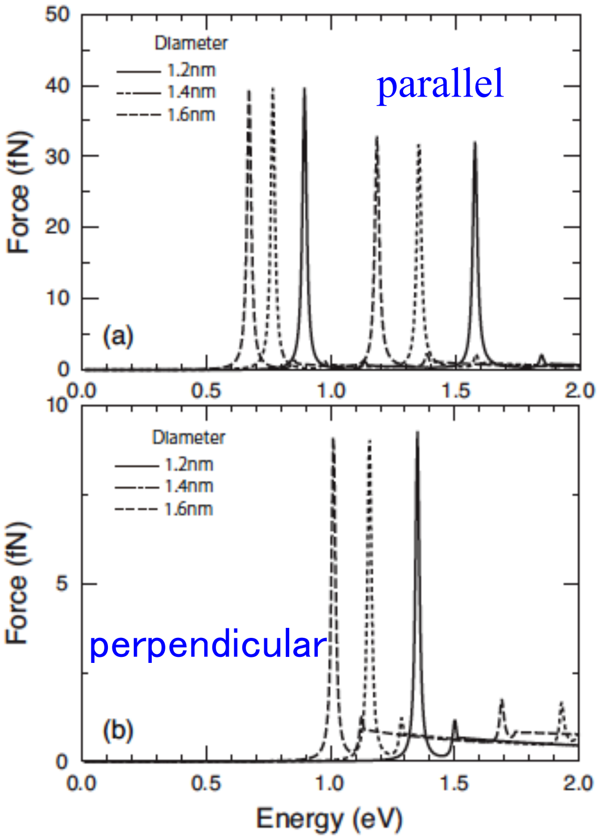
ナノ構造の「個々の量子力学的個性」を反映した輻射力による運動

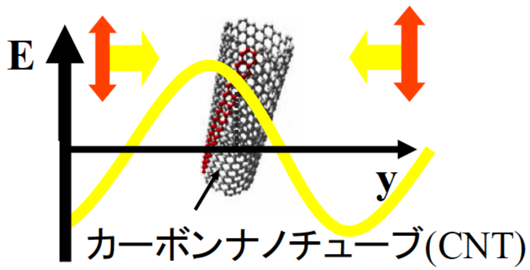
輻射力による単一CNTの選択的運動操作

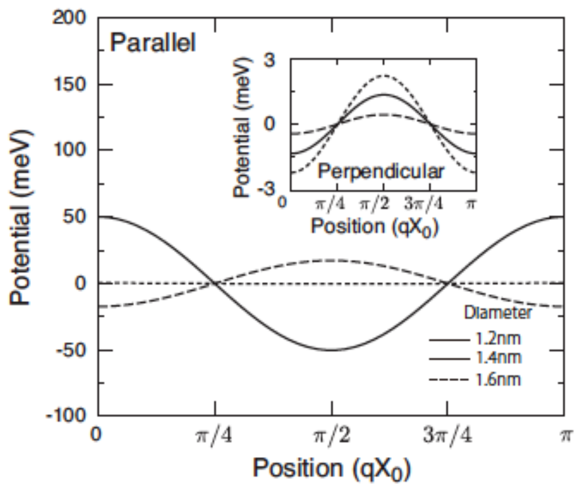
H. Ajiki, et al.: *Phys. Rev.* B**80**, 115437 (2009)

共鳴輻射力による単層カーボンナノチューブの常温選択的トラップ

散逸力によるサイズ選別　　勾配力による選択的トラップ　　Warping選択的トラップ







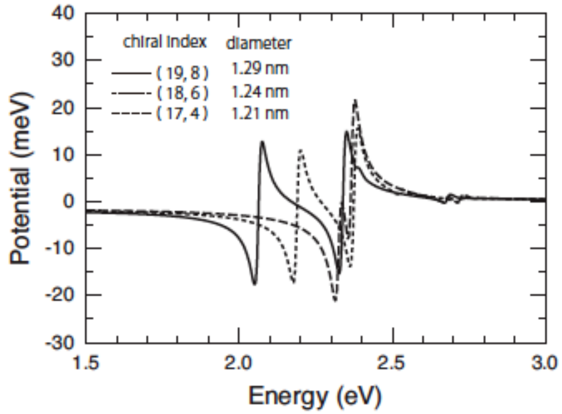
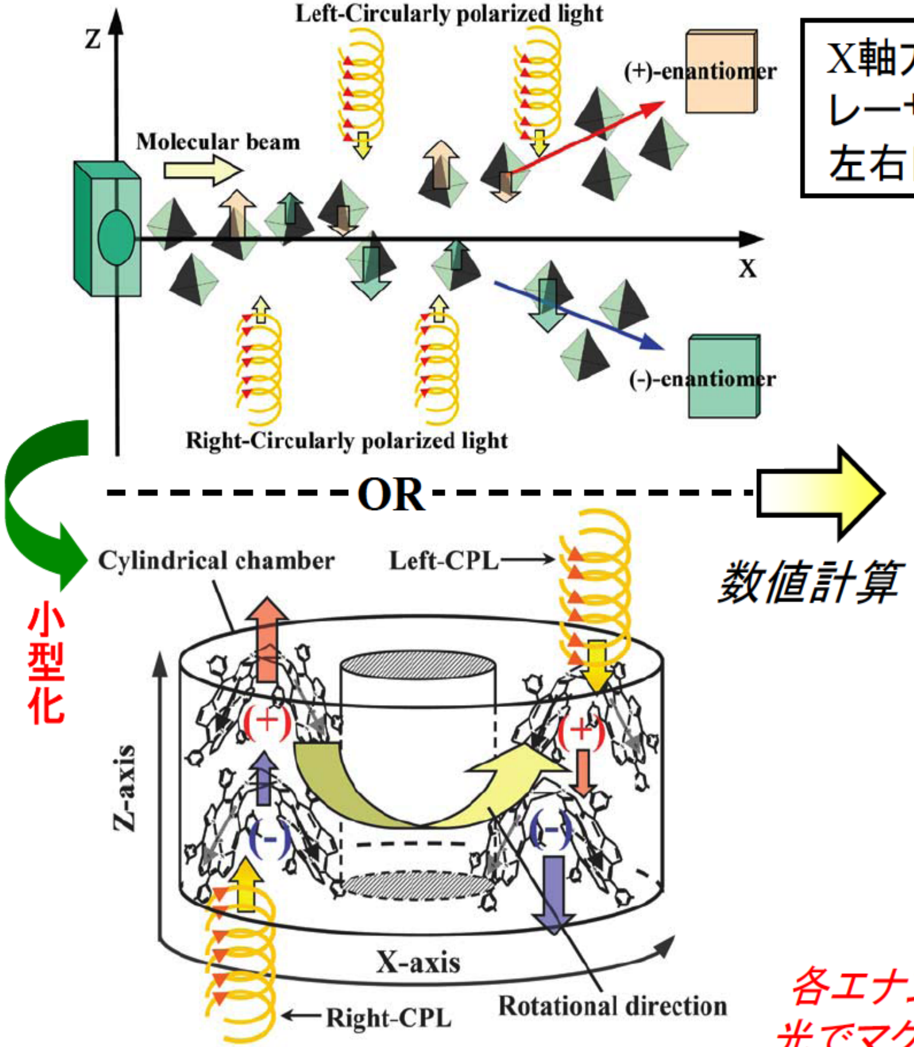


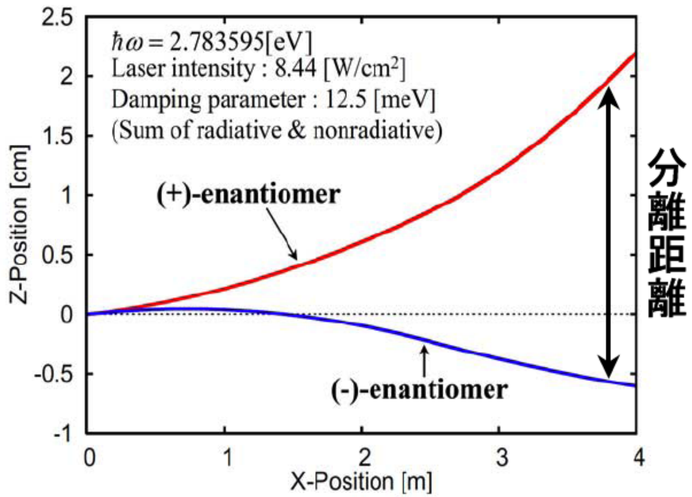
FIG. 7: Potential due to gradient force for parallel polarization. Warping effect is included by using higher-order $\mathbf{k}\cdot\mathbf{p}$ equation. SWCNs with chiral vectors (19,8), (18,6), and (17,4) are all metallic.

共鳴円偏光によるエナンチオマー分離



エナンチオマー分離装置の原理

X軸方向初速度 : 10m/s
レーザーのスポット直径 : 1mm
左右円偏光を交互に等間隔で250回/m照射



ポルフィリンダイマーを対象として想定した
各エナンチオマーの空間位置の軌跡
（X軸位置の関数としてZ軸位置をプロット）

※摩擦や拡散の効果は無視している

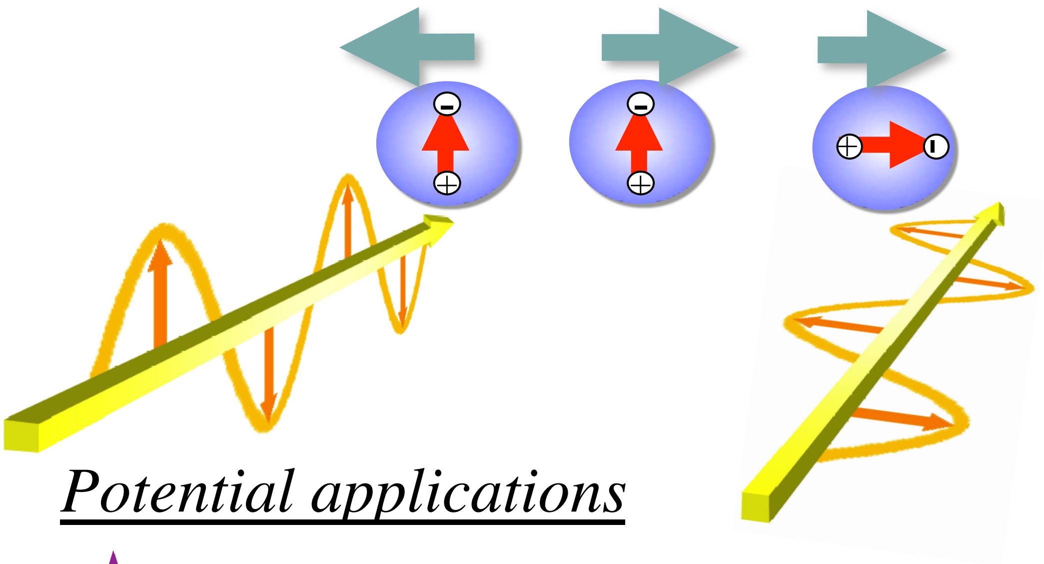
各エナンチオマーの僅かな光学応答の差異を
光でマクロな位置依存性に転写し選択的に分離

光誘起ドット間相互作用

T. Iida and H. Ishihara: *Phys. Rev. Lett.* **97**, 117402 (2006)

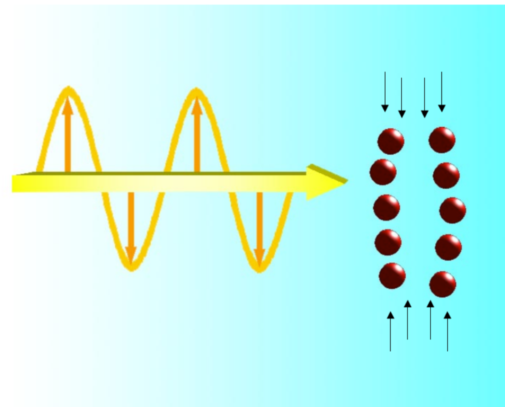
Control of the inter-particle force by laser irradiation

Switching of attractive and repulsive forces by polarization

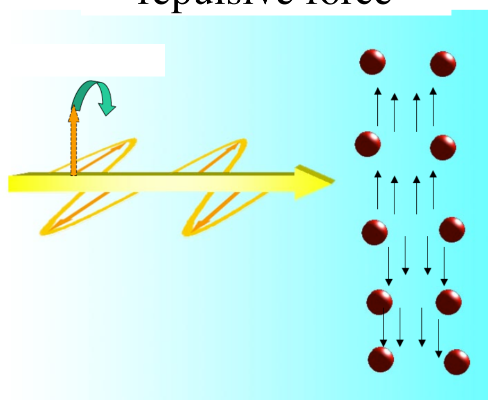


Manipulation of collective motion of a particle assembly

attractive force



repulsive force



Potential applications

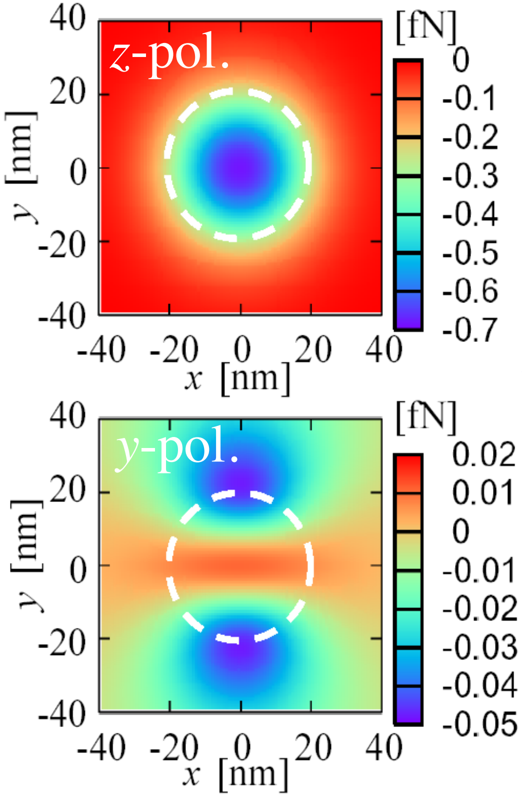
- ★ Control of inter-particle distance
- ★ Manipulation of cluster shape
- ★ Arrangement of particles
- ★ Control of aggregation and dispersion

輻射力顕微鏡の可能性

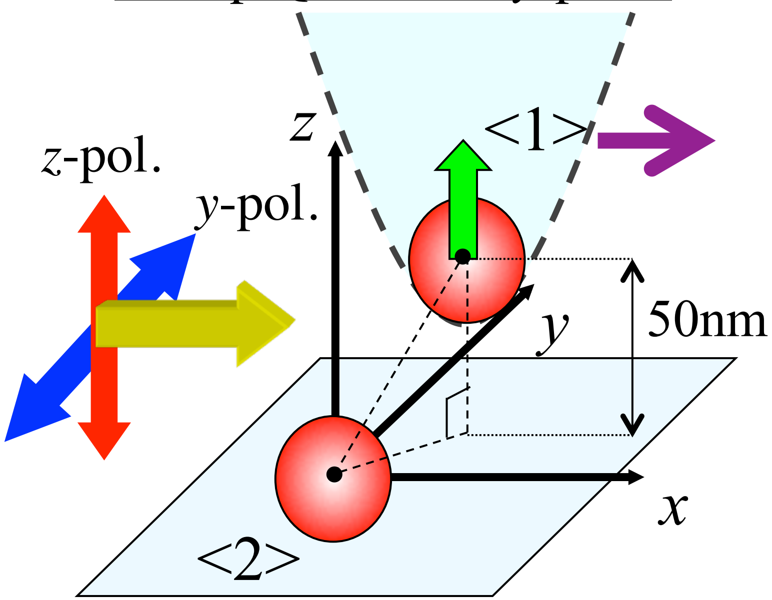
T. Iida, H. Ishihara, Nanotechnology **18**, 084018 (2007)

Dipole allowed bonding state

$\hbar\omega = 3.2042$[eV]

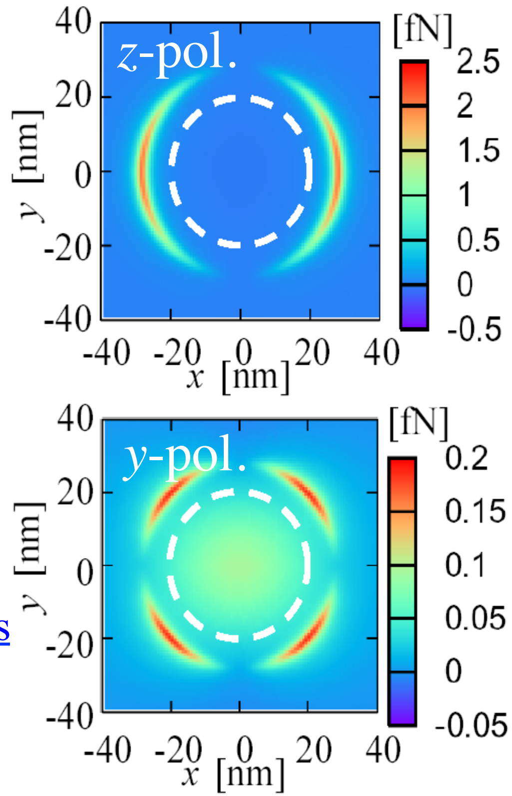


Sweep QD<1> // *xy*-plane



Dipole forbidden anti-bonding state

$\hbar\omega = 3.20452$[eV]



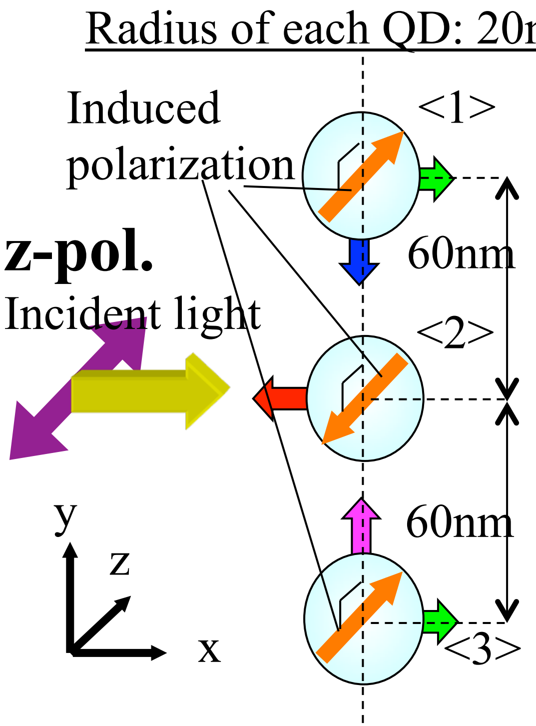
Different images for the different polarizations even for the same frequency

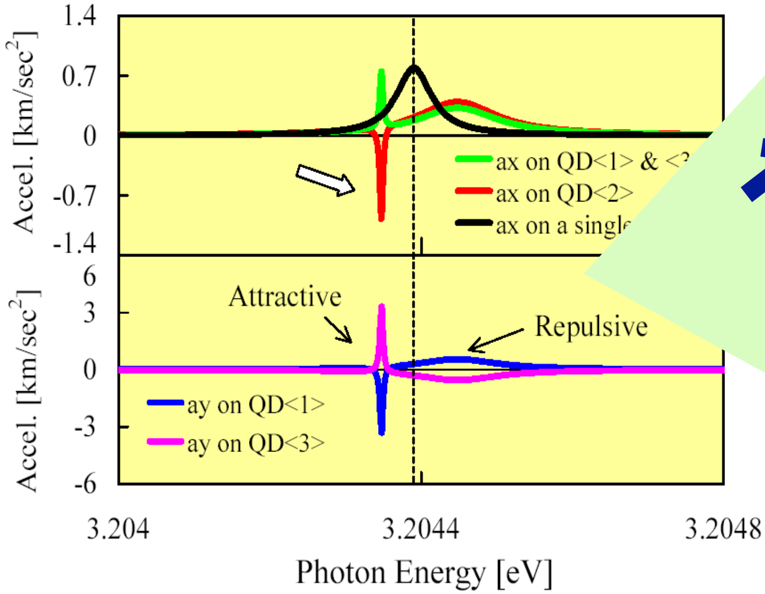
No need to detect scattering light

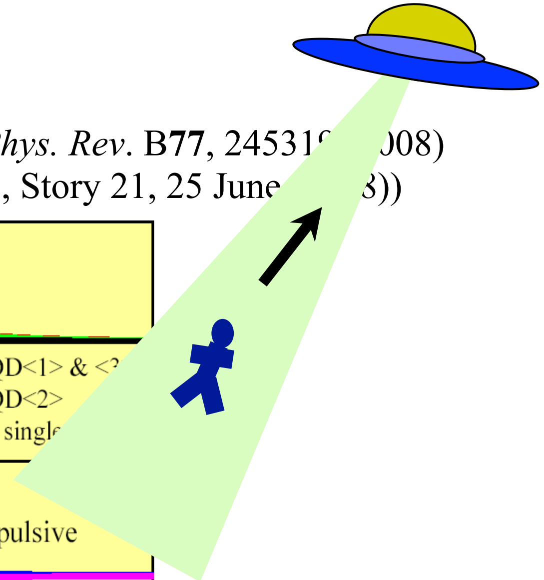
It will be possible to prove the electronic wavefunctions by utilizing the degrees of freedom of the frequency, incident direction and polarization

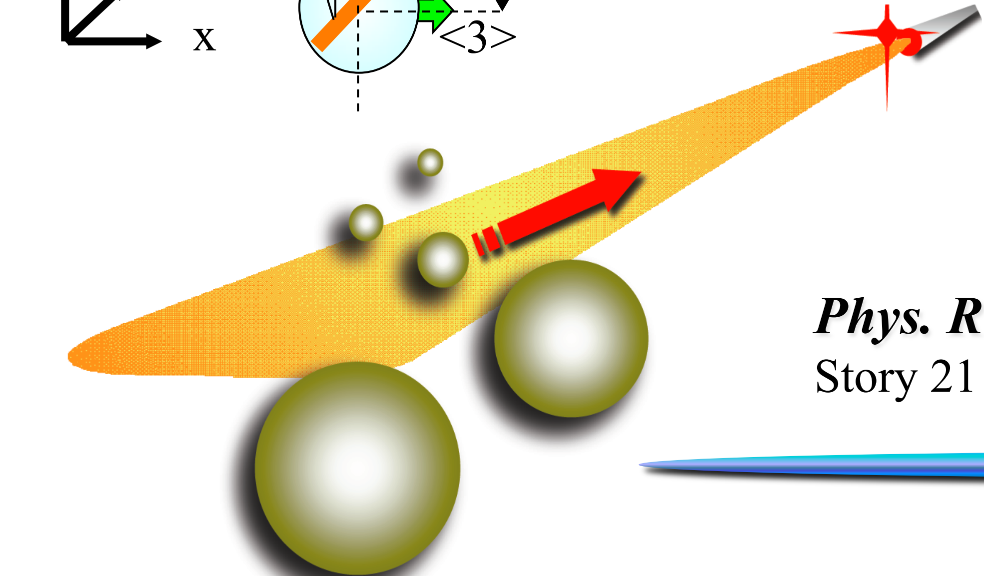
負の散逸力

T. Iida and H. Ishihara: *Phys. Rev.* B**77**, 24531… …008)
(*Phys. Rev. Focus* 21, Story 21, 25 June … …8))

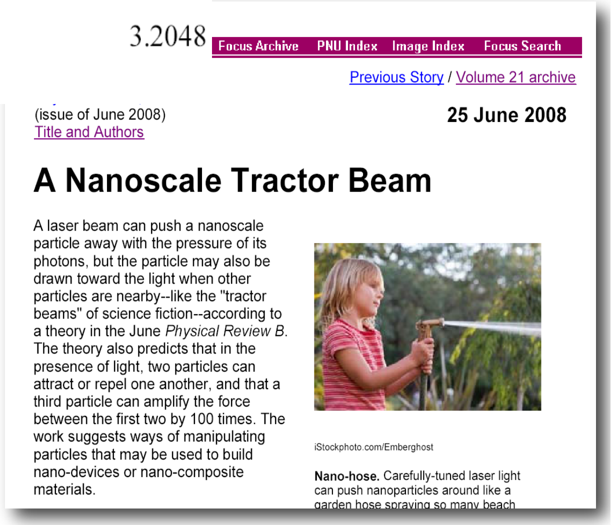








Phys. Rev. Focus
Story 21 (2008)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Previous Story / Volume 21 archive

(issue of June 2008)
Title and Authors

25 June 2008

A Nanoscale Tractor Beam

A laser beam can push a nanoscale particle away with the pressure of its photons, but the particle may also be drawn toward the light when other particles are nearby--like the "tractor beams" of science fiction--according to a theory in the June *Physical Review B*. The theory also predicts that in the presence of light, two particles can attract or repel one another, and that a third particle can amplify the force between the first two by 100 times. The work suggests ways of manipulating particles that may be used to build nano-devices or nano-composite materials.

iStockphoto.com/Emberghost

Nano-hose. Carefully-tuned laser light can push nanoparticles around like a

実験例(有機分子)

色素への共鳴光を用い選択的な分子捕捉

有機分子微粒子にドープした色素への
共鳴光をアシストしてトラップ時間を増大

C. Hosokawa et al., Jpn. J. Apl. Phys. **45,** L452 (2006)

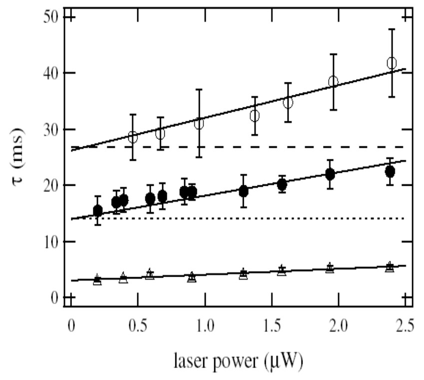
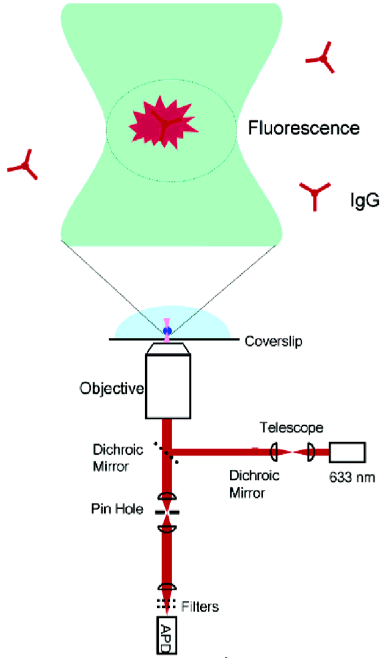


Fig. 2. ACF decay time τ of 40-nm-sized particle suspension plotted as a function of green laser power. A YAG laser beam was no irradiated (open triangles), and irradiated at 300 mW (closed circles) and 600 mW (open circles). The dotted and broken lines indicate the offset transit times in the case of a single-beam irradiation with the YAG laser. The solid lines are drawn by the least-squares fitting of transit time using eq. (3) as described in the text.

色素でラベルした抗体を色素に
共鳴する光で選択的にトラップ

Resonance trapping of individual multiple fluorophore-labeled antibodies

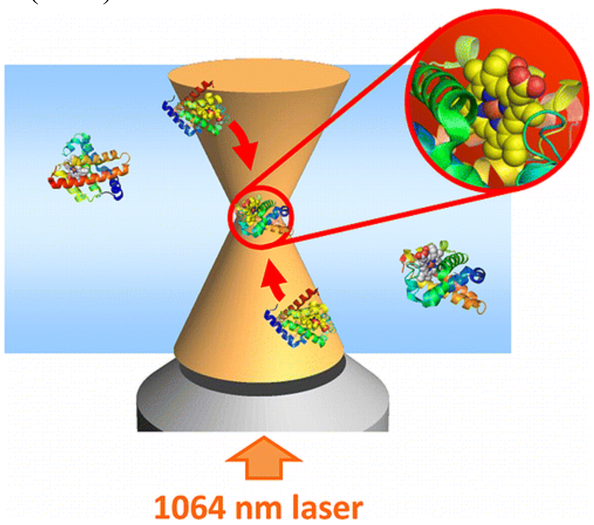
H. Li et al., J. AM. CHEM. SOC **128**, 5711 (2006)



Selective resonance trapping
to sort and manipulate fluorophore-labeled
biomolecules and complexes may be possible.

ヘムを導入したタンパク質分子
の共鳴トラッピング

T. Shoji et al., J. Phys. Chem. C **117**, 117 (2013)



Transport of selected semiconductor quantum dots

phys. stat. sol. (b) **243**, No. 14, 3829 – 3833 (2006) / **DOI** 10.1002/pssb.200672125

Editor's Choice

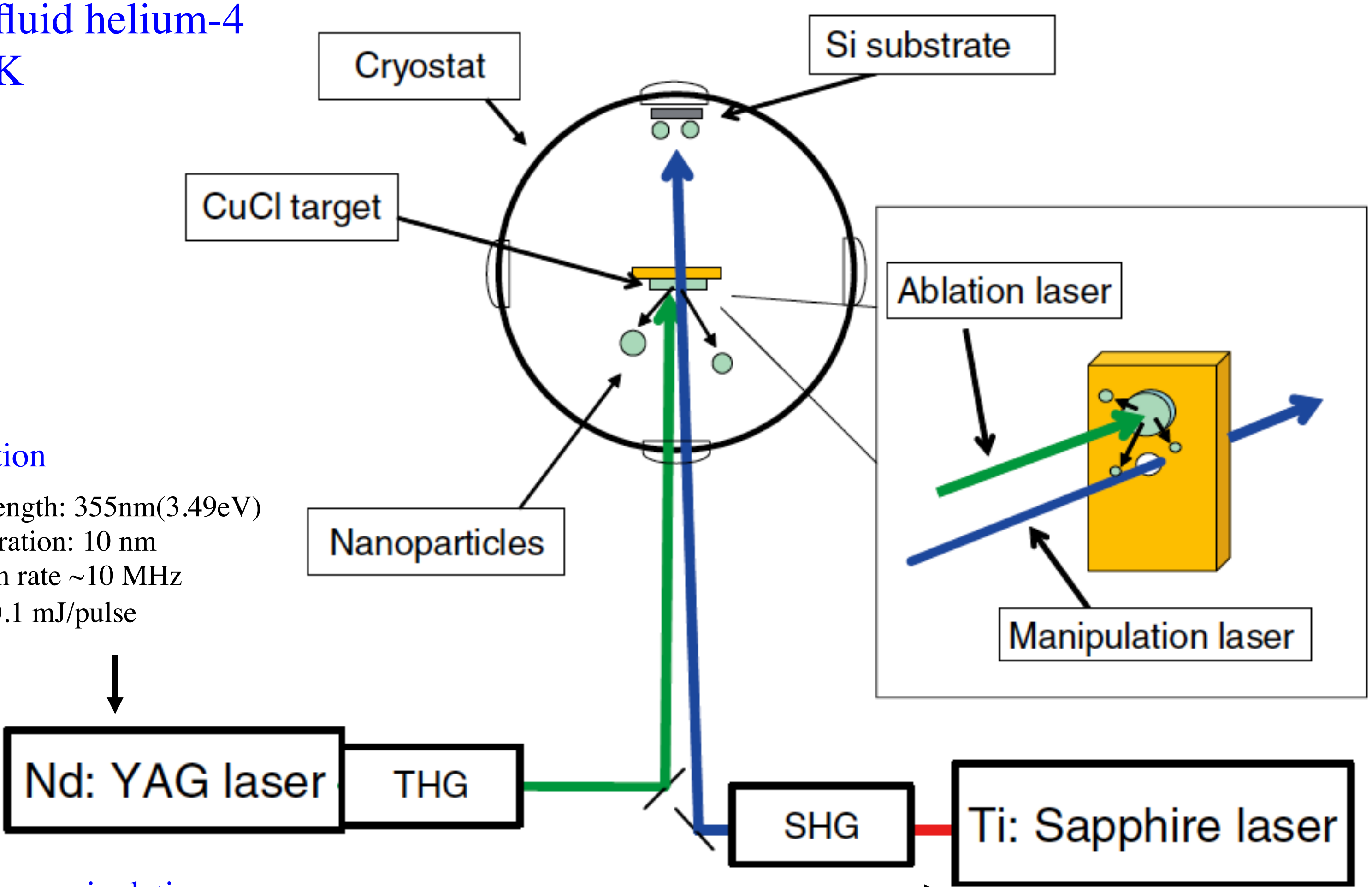
Optical manipulation of CuCl nanoparticles under an excitonic resonance condition in superfluid helium

K. Inaba[*,1], **K. Imaizumi**[1], **K. Katayama**[1], **M. Ichimiya**[1,2], **M. Ashida**[1,2], **T. Iida**[2,3], **H. Ishihara**[2,3], and **T. Itoh**[1,2]

[1] Graduate School of Engineering Science, Osaka University, 1-3 Machikaneyama-cho, Toyonaka, Osaka 560-8531, Japan
[2] CREST, Japan Science and Technology Agency, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan
[3] Department of Physics and Electronics, Osaka Prefecture University, 1-1 Gakuencho, Sakai, Osaka 599-8531, Japan

Schematic diagram of experimental setup

superfluid helium-4
T = 2K



For ablation

Wavelength: 355nm(3.49eV)
Pulse duration: 10 nm
repetition rate ~10 MHz
Power: 0.1 mJ/pulse

For manipulation

Wavelength: 387nm(3.20eV)
Pulse duration: 100 fs
repetition rate ~80 MHz
Power: 50mW

Schematic diagram of experimental setup