光渦レーザーが拓く新しい
ナノプロセッシング

千葉大学大学院融合科学研究科
尾松　孝茂

第4回光材料･応用技術研究会,森戸記念館, 1 March 2013

Outline

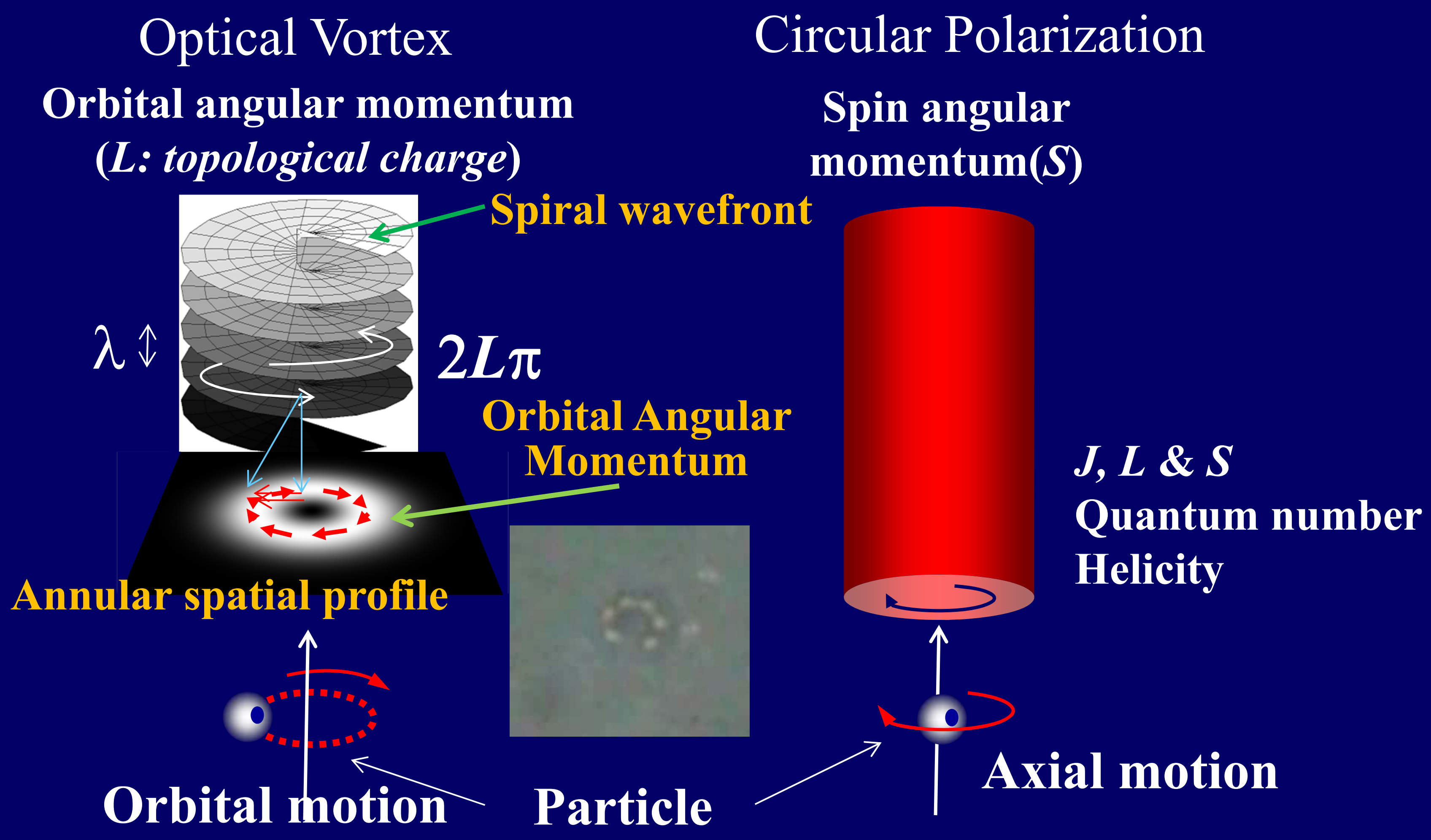
What's optical vortex laser?

Optical Vortex Laser Ablation
Chiral 'Nano'needle fabrication

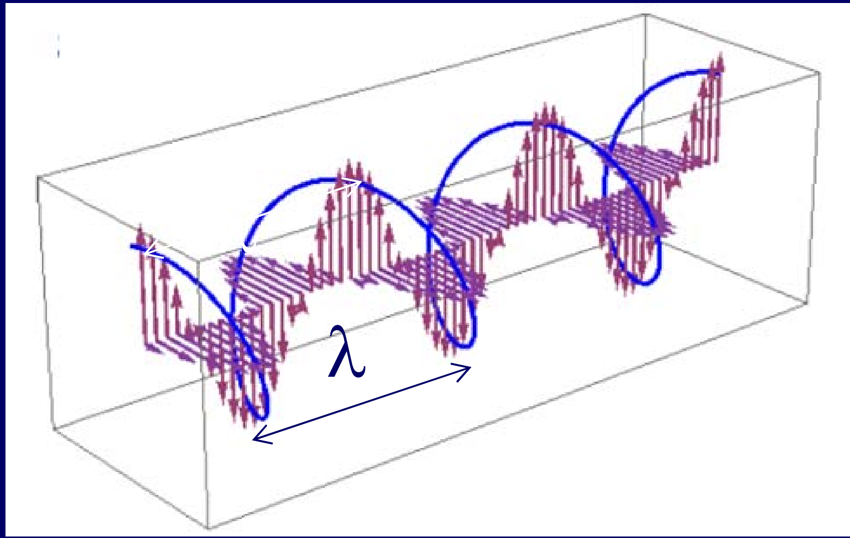
High power vortex laser technologies
Frequency extension of vortex laser

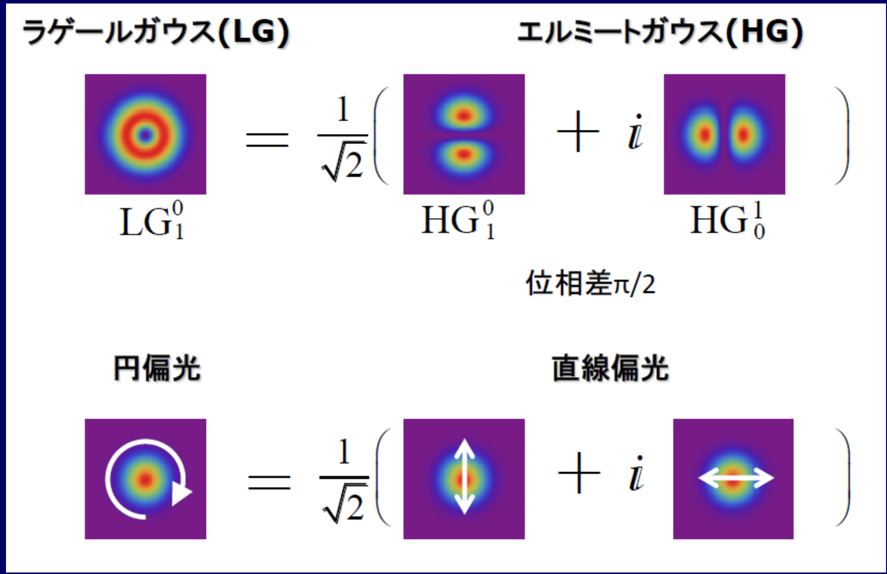
Summary

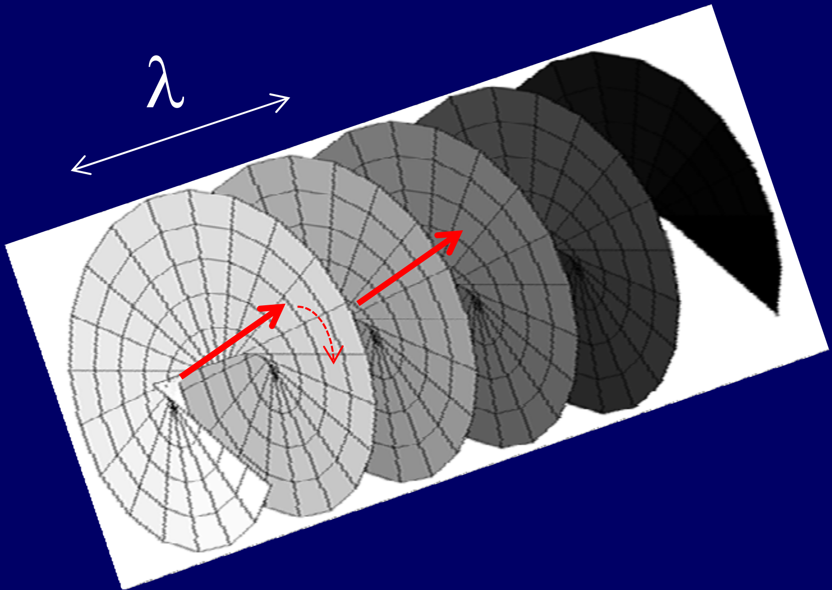
Optical Vortex



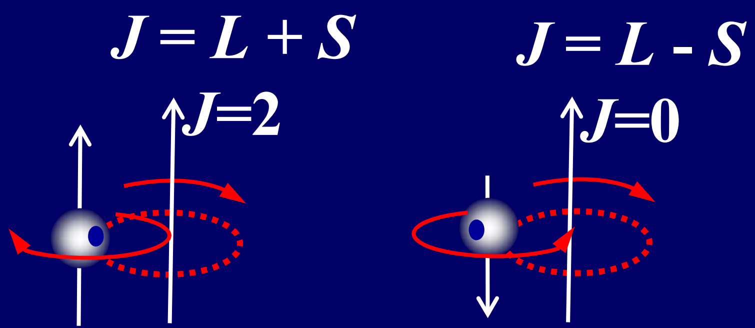
Orbital and spin angular momenta





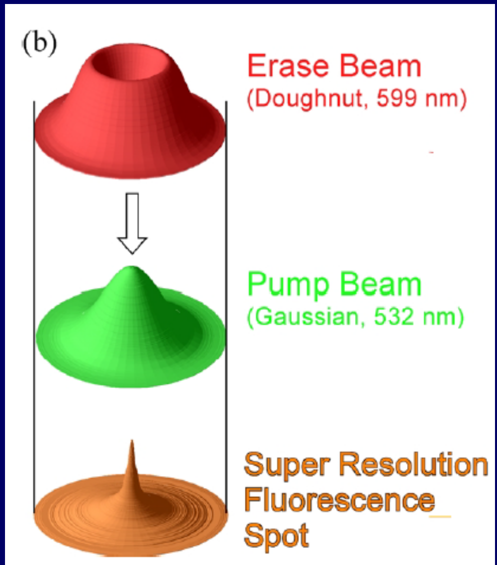


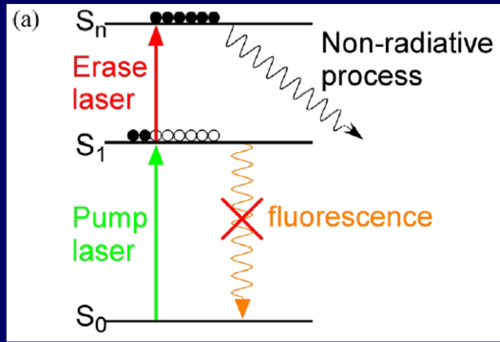
Total angular momentum *J*

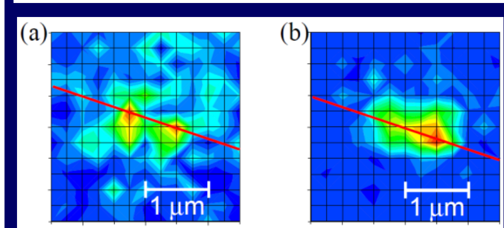


Orbital + axial

Super resolution microscope







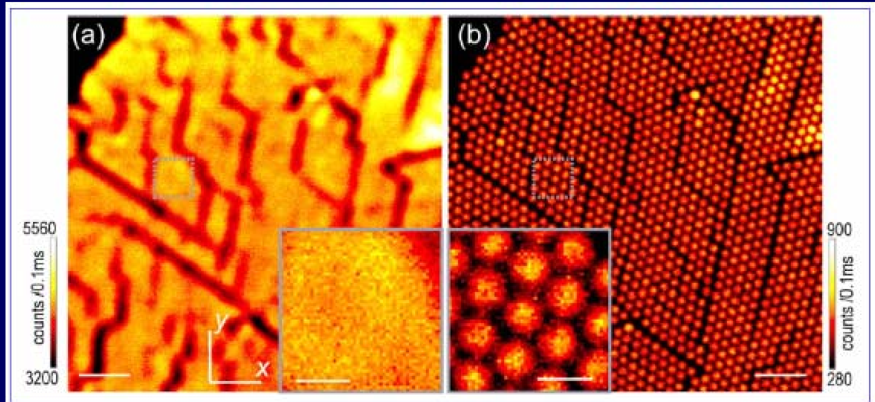


Fig. 5. Imaging of 200 nm self assembled colloidals: (a) confocal image with the STED counterpart. (b). Scale bar 1μm, in insets scale bar 250 nm (movie2, avi, 2.8 MB). All images are raw data.

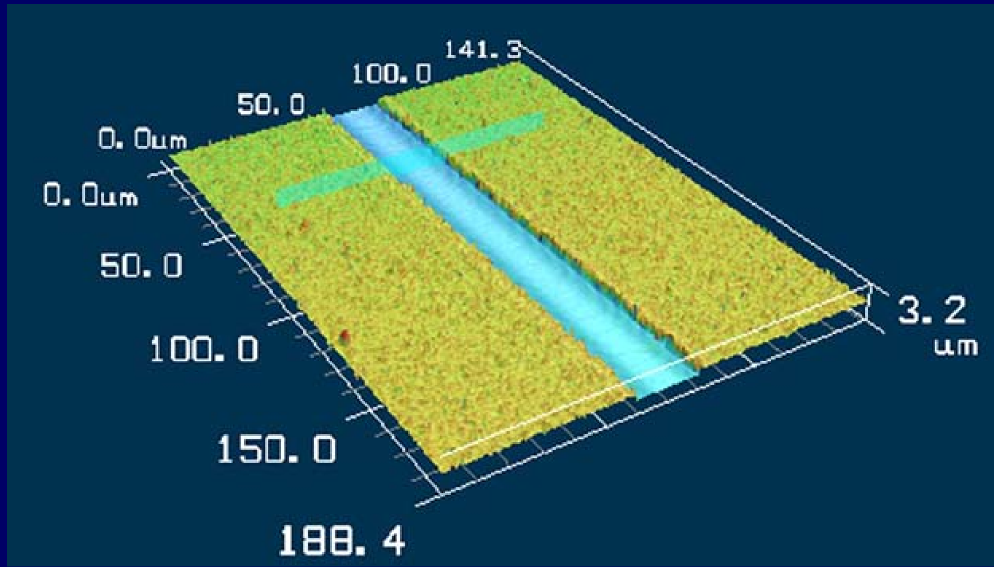
T. Watanabe,, T. Omatsu,,,
Optics Express 11 (2003) 3271-3276

S. Hell's group
Optics Express, 16 (2008)
4154-4162
Spatial resolution ~20nm

Laser ablation

Pulse shaping (Ultra-fast laser technology)

- 3dimensional micro fabrication
- multi-photon ionization

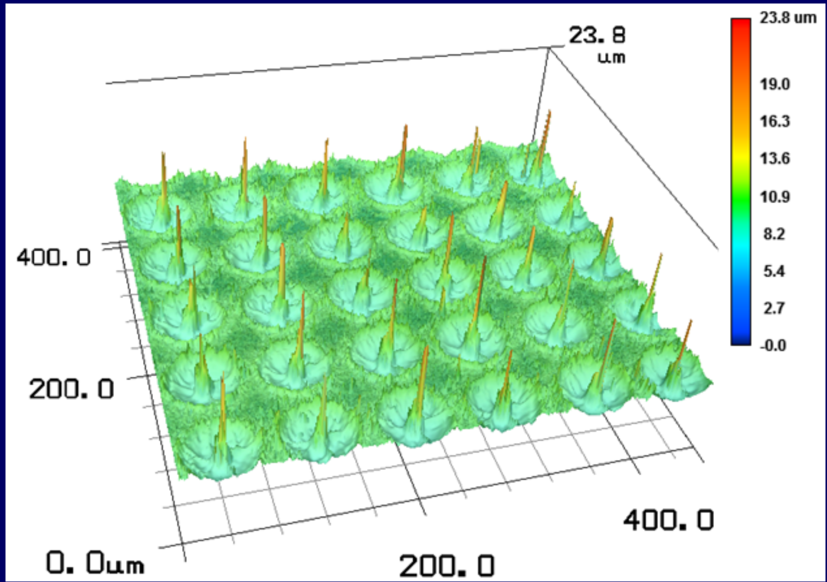


New parameter

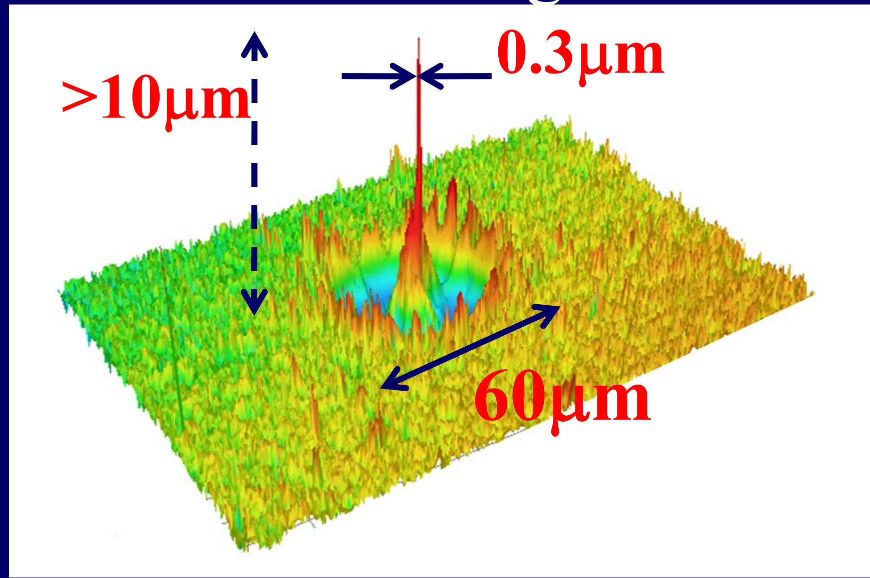
Angular momentum

Dynamics control of melted (or vaporized) matters

1 μm nanosecond vortex laser ablation



LSM image



Average height 11μm, Average diameter 0.3μm

100kHz PRF ⇒ 25,000 needles / second

Ultrahigh-speed fabrication

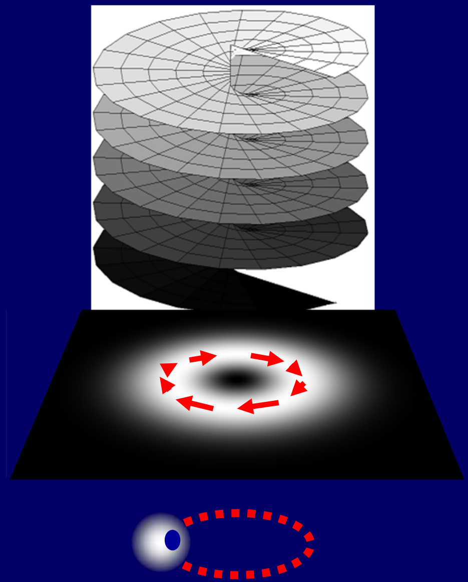
STM, AFM, Plasmonics, Metamaterials, Bio-MEMS

Hamazaki, Morita,, Omatsu, Optics Express, **18** (2010) 2144-2151.

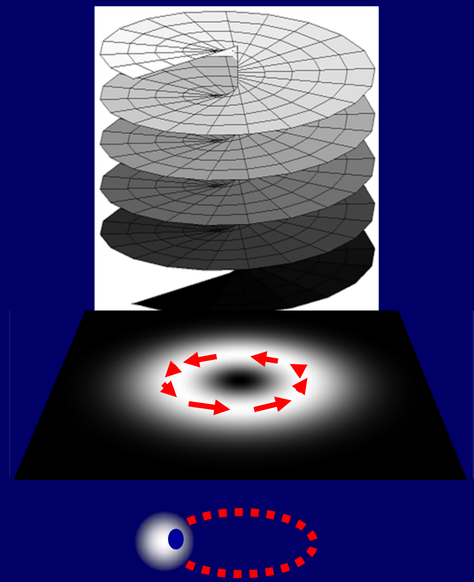
Omatsu et al., Optics Express, **18** (2010) 17967-17973

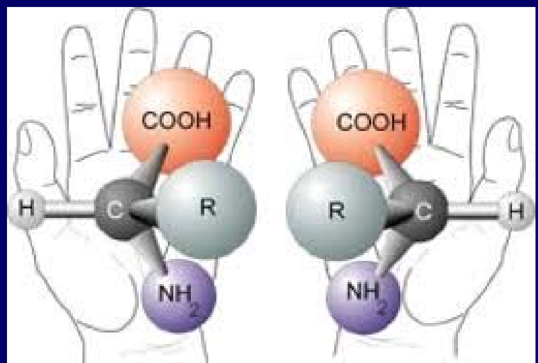
Helicity of optical vortex

Clockwise



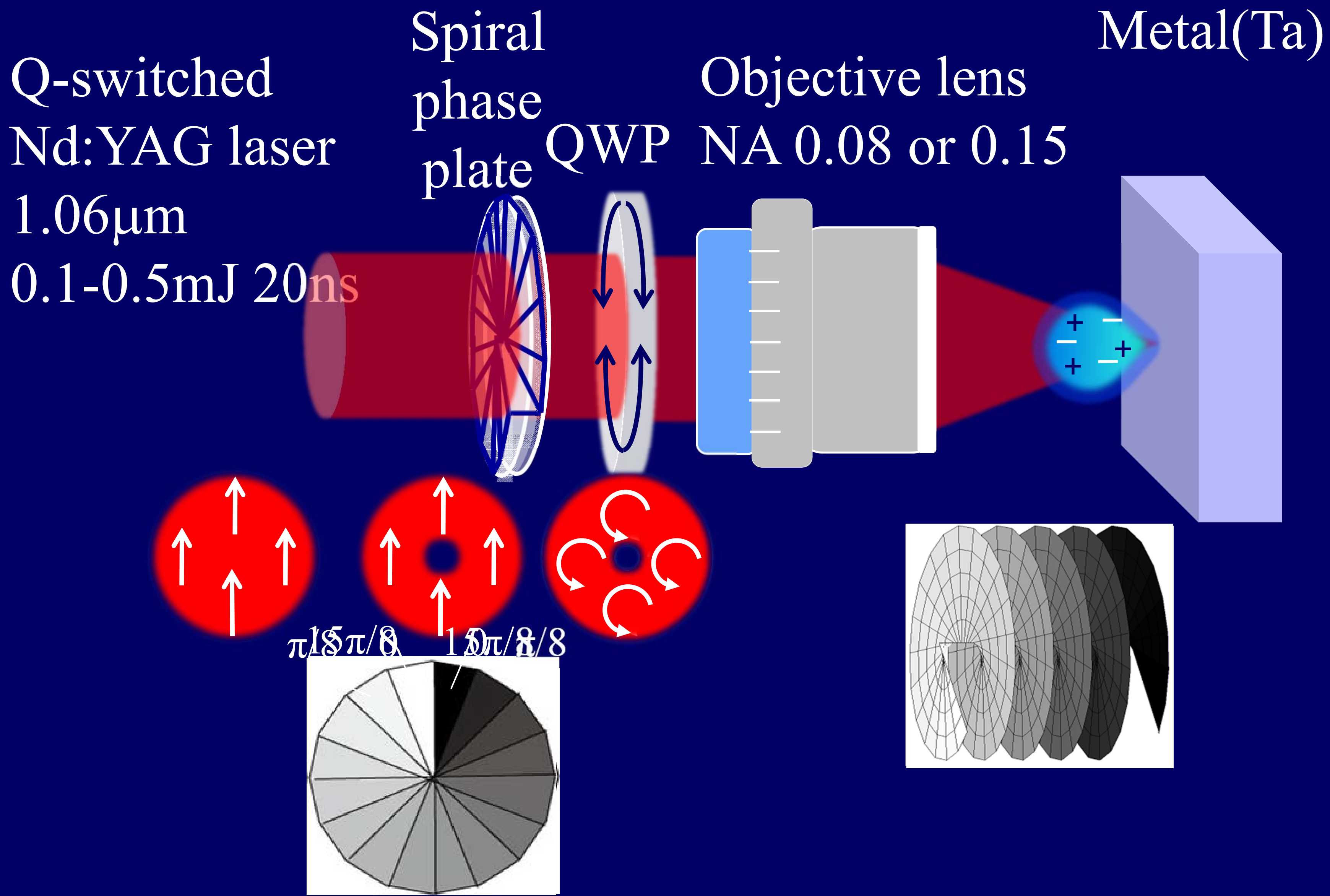
Anti-clockwise



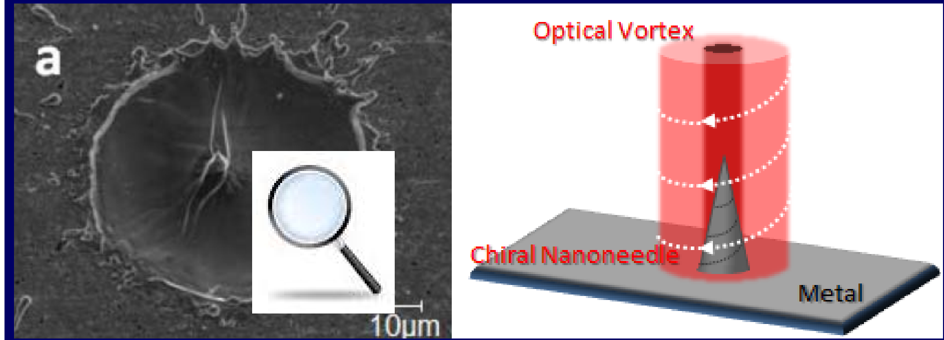


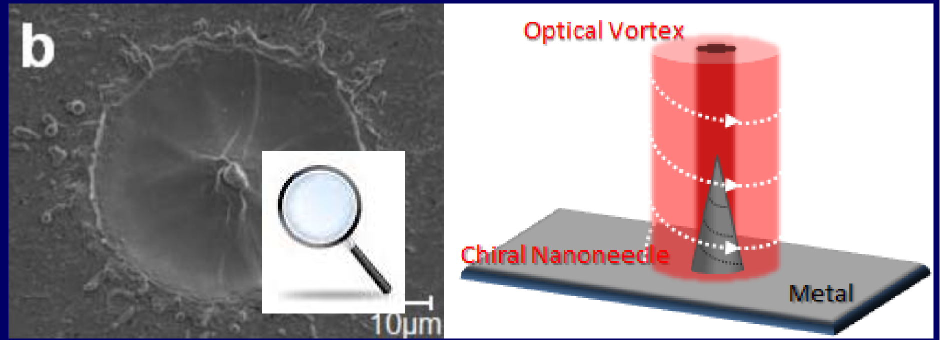
Chemistry, Physics, Material Science,,,,

Basic setup for optical vortex laser ablation

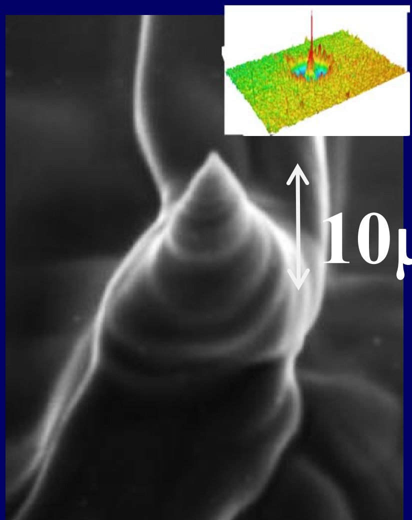


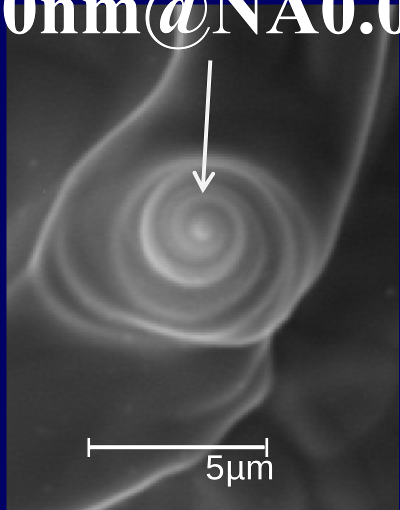
Chiral Metal Nanoneedle

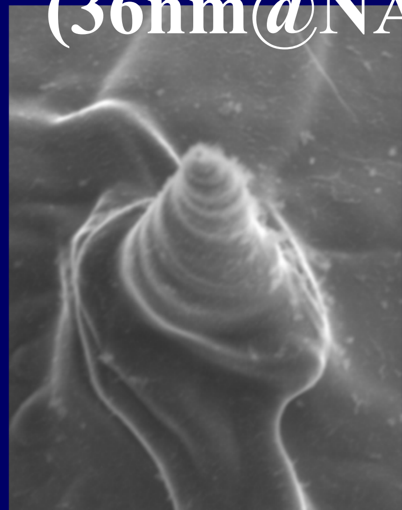


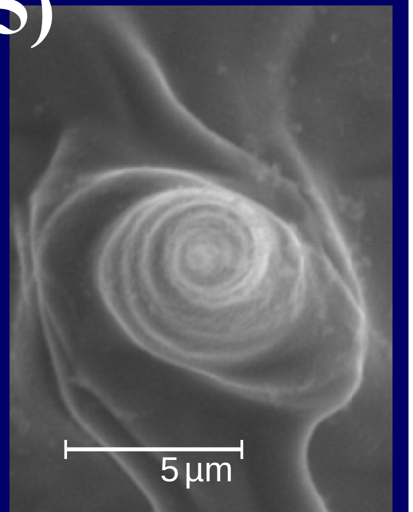


70nm@NA0.08 (36nm@NA0.15)





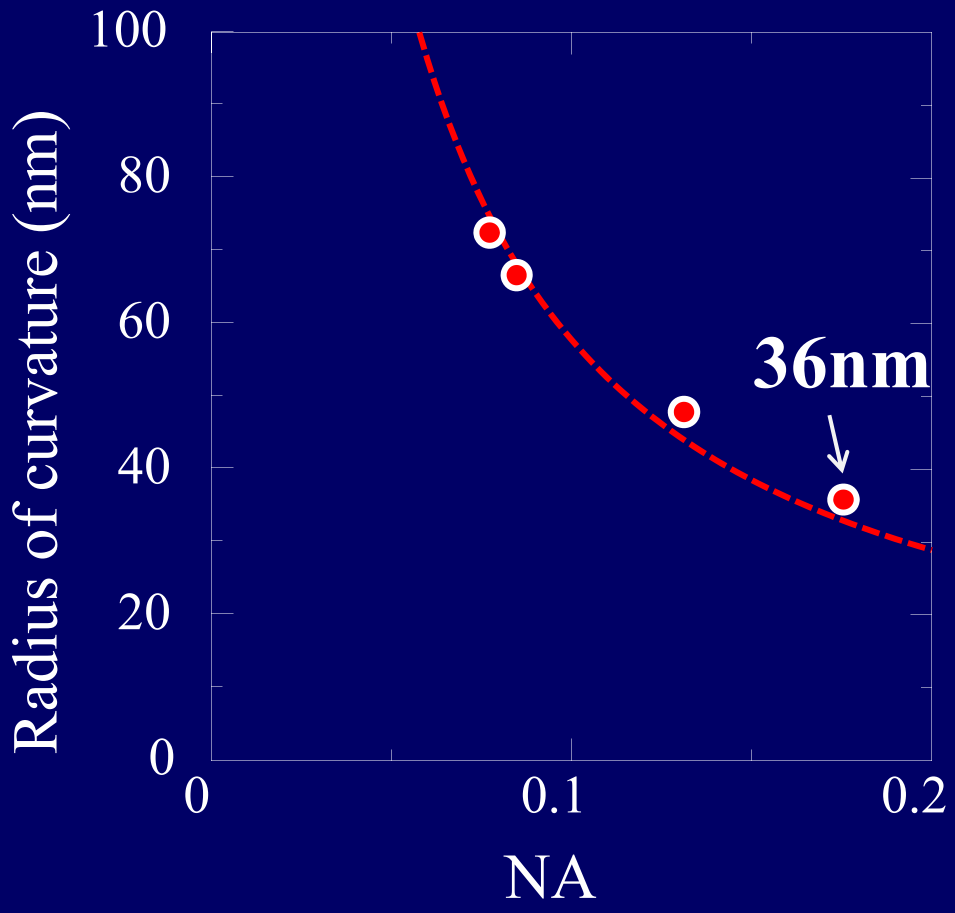


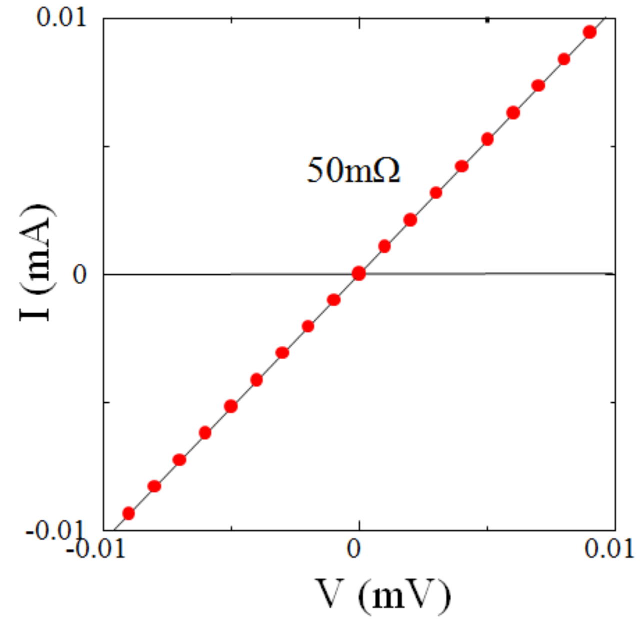


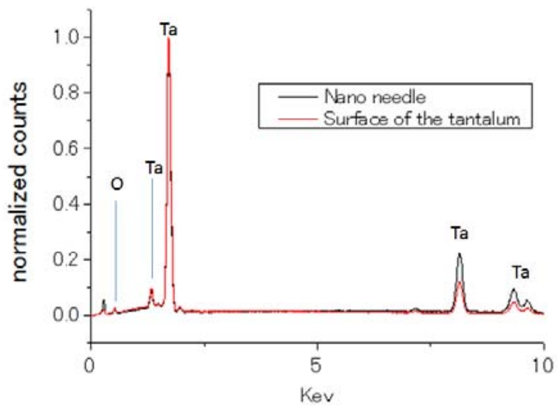
field emission electrode･nanocoil･metamaterials･plasmonics ･bio-MEMS

Toyoda, Miyamoto, Aoki, Morita, Omatsu, **Nano Letters 12**, 3645−3649 (2012)

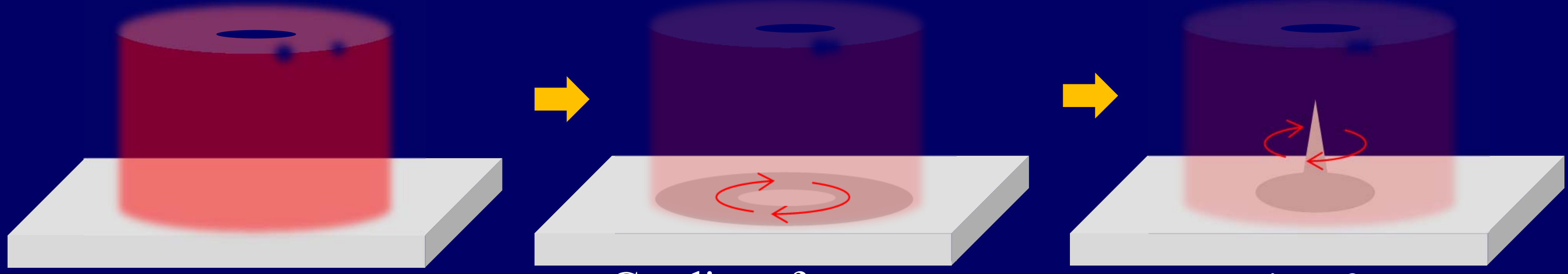
Electric properties



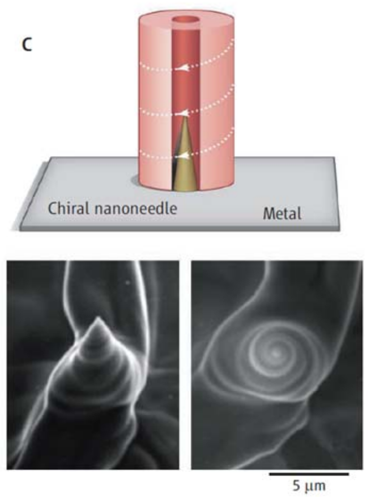




Modeling



Science
AAAS
Structured Light Meets Structured Matter
Natalia M. Litchinitser
Science **337**, 1054 (2012);
DOI: 10.1126/science.1226204



possibilities for nonlinear singular optics, trapping and optomechanical micromanipulation, as well as potential for applications in optical signal processing.

References and Notes

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2. Y. Gorodetski, A. Niv, V. Kleiner, E. Hasman, *Phys. Rev. Lett.* **101**, 043903 (2008).
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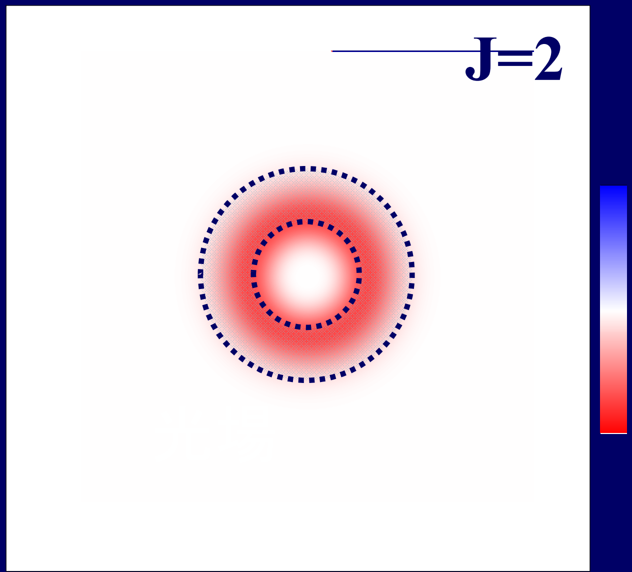
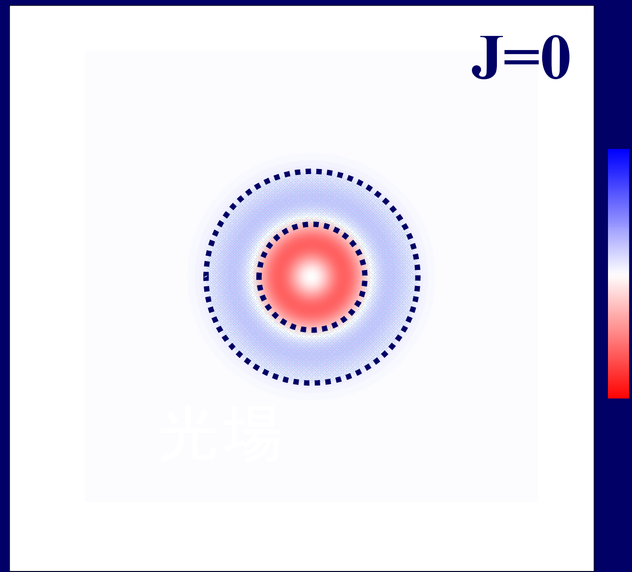
Angular momentum density

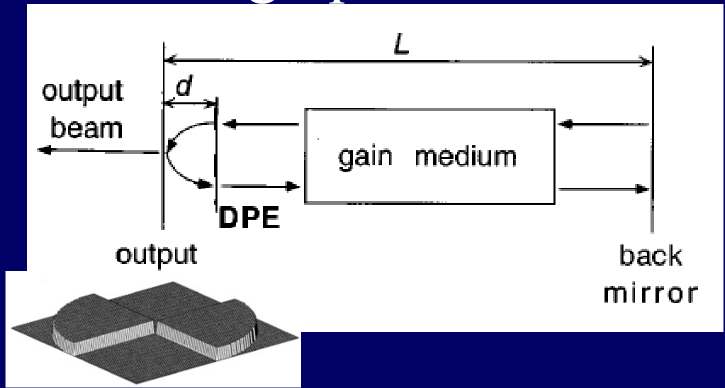
$$J_{L,S} = \varepsilon_0 \left\{ \omega L I - \frac{1}{2} \omega S r \frac{\partial I}{\partial r} \right\} \qquad I(r) = r^2 \exp\left(-\frac{r^2}{\omega_0^2} \right)$$





Review of vortex lasers

Holographic elements



Oron et.al. APL **74** (2001) 1373. LG(???)

Annular beam pumping

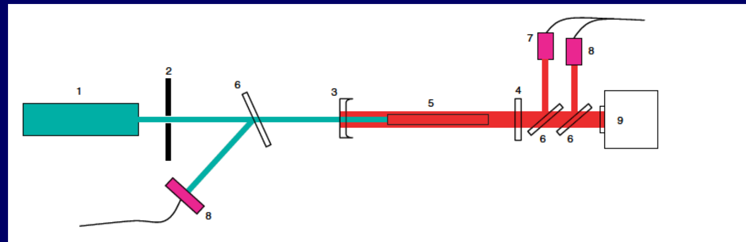
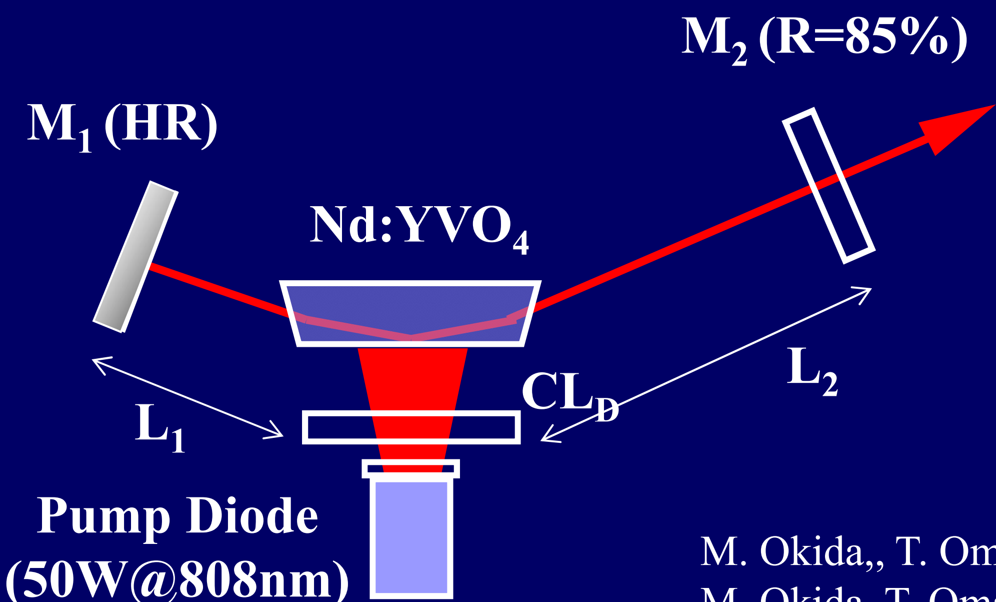
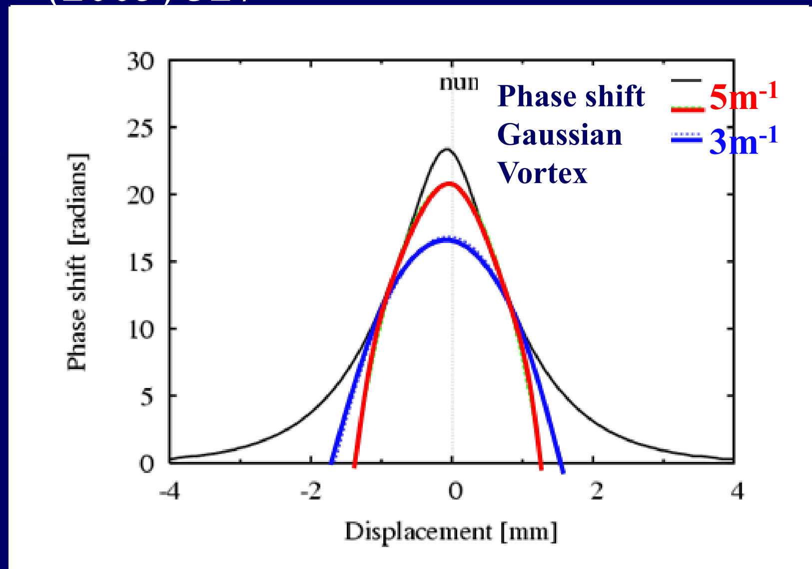


Figure 2 (online color at www.lphys.org) Scheme of the experiment on mode selection by diffractive optical pumping of an active medium: 1 - frequency-doubled 0.532 μm Nd:YAG pump laser; 2 - circular "pumping" diaphragm; 3,4 - resonator mirrors; 5 - Nd:YAG rod; 6 - beamsplitters; 7 - photodetector; 8 - powermeters; 9 - CCD camera with filters

J.-F. Bisson et.al. Laser Phys. Lett. **2**, (2005) 327

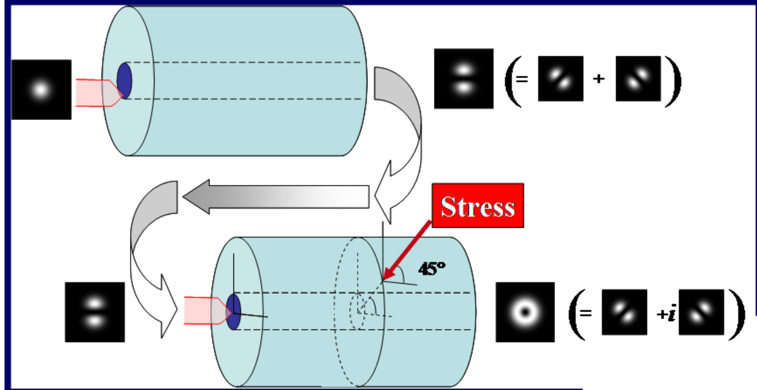


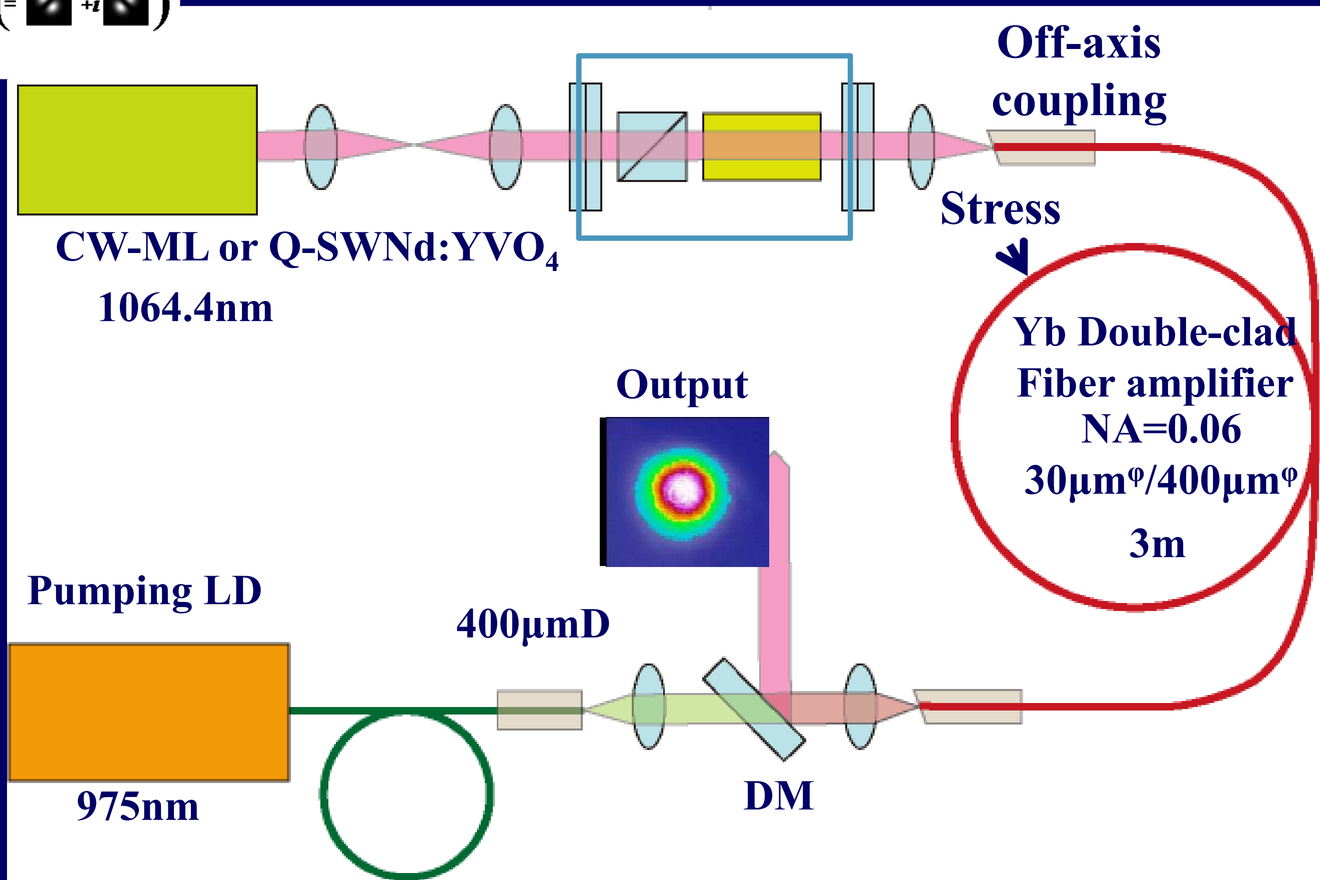


M. Okida,, T. Omatsu, Opt. Express, **15**, (2007) 7616

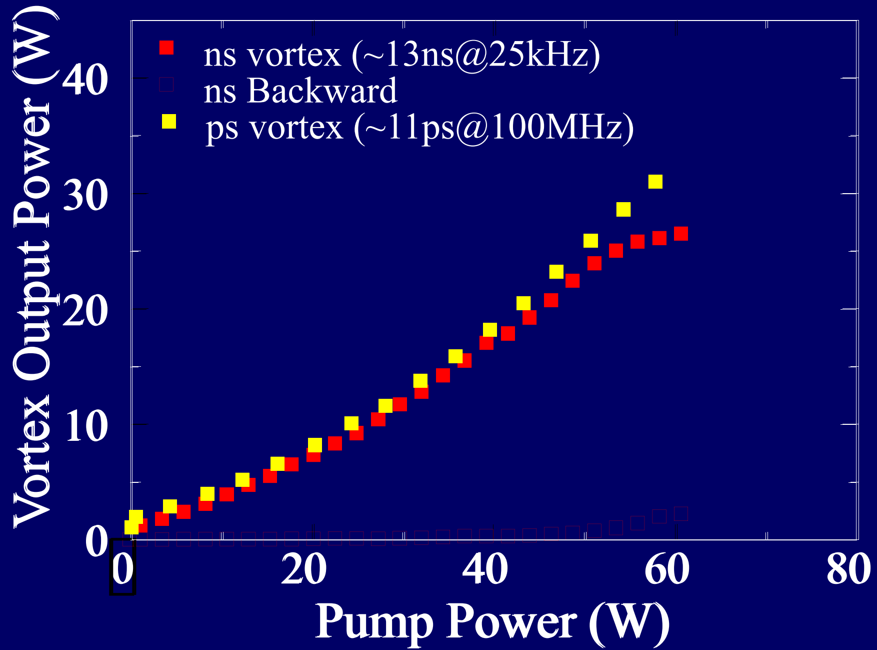
M. Okida, T. Omatsu,, R. Morita, Applied Physics B (2009) 69

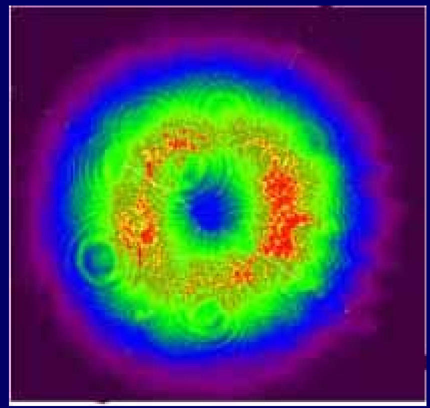
High power vortex fiber laser

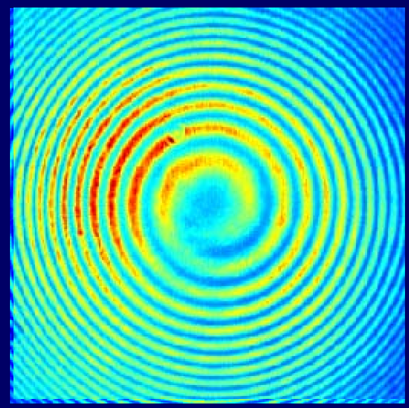




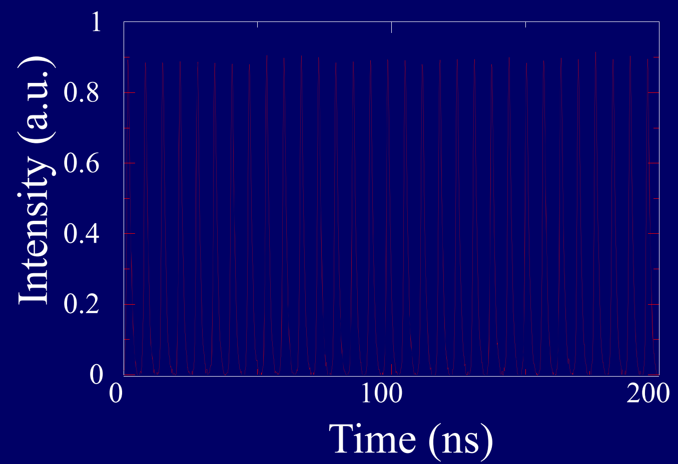
Laser performances







M^2=2.2



Tanaka,, Omatsu,
Opt. Express **17** (2009) 14362–14366.
Koyama,,, Omatsu,
Opt. Express **19** (2011) 14420-14425.
Koyama,,, Omatsu,
Opt. Express **19** (2011) 2994-2999.

Optical parametric down conversion

How to divide a topological charge of pump photon into two photons?

Charge shearing

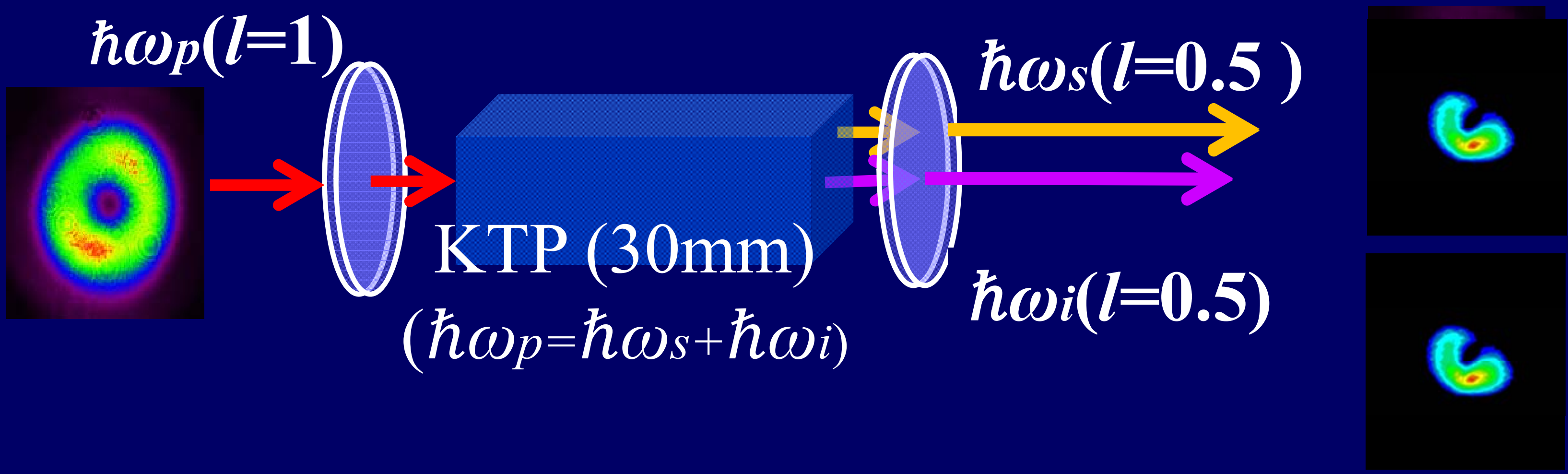
Selective charge transfer

$$\frac{dE_s}{dz} \propto dE_p E_i^*$$

$$E_p \propto e^{iL\phi} e^{i\omega t} \Rightarrow E_s \propto e^{iL_s\phi} e^{i\omega_s t} \qquad E_i \propto e^{iL_i\phi} e^{i\omega_i t}$$

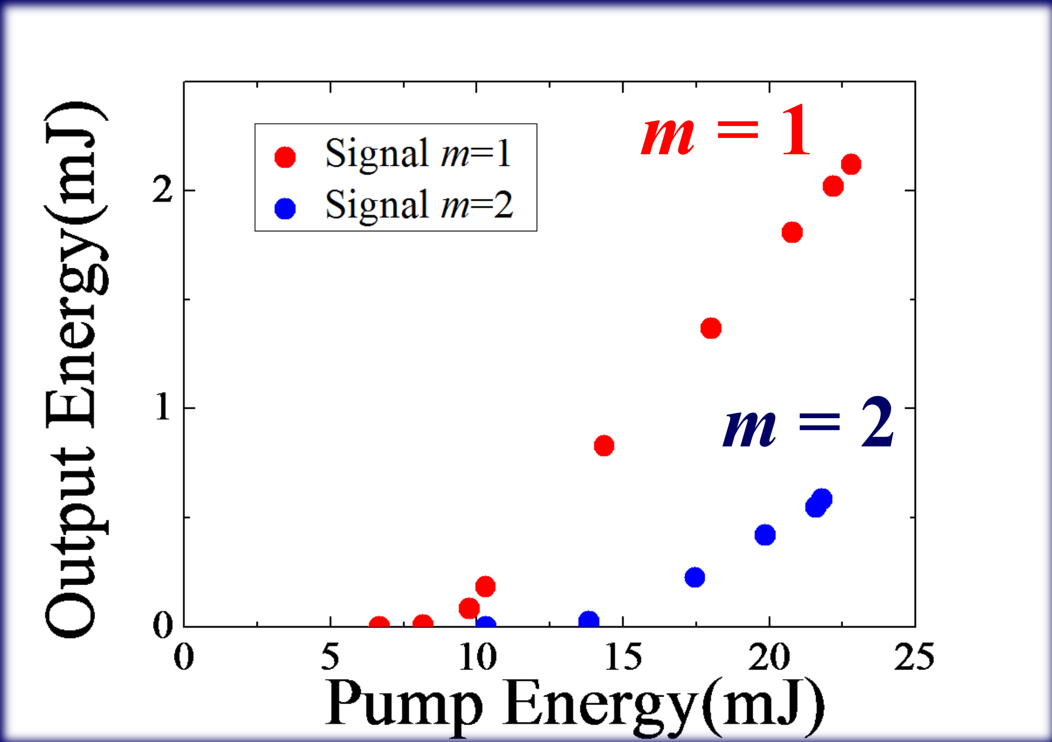
$$\omega_p = \omega_s + \omega_i \qquad L_p = L_s + L_i \;\; ???$$

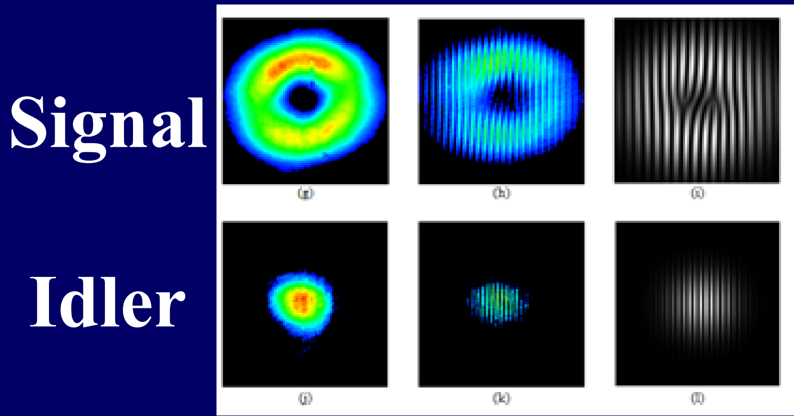
1μm Q-sw Nd:YAG 40ns

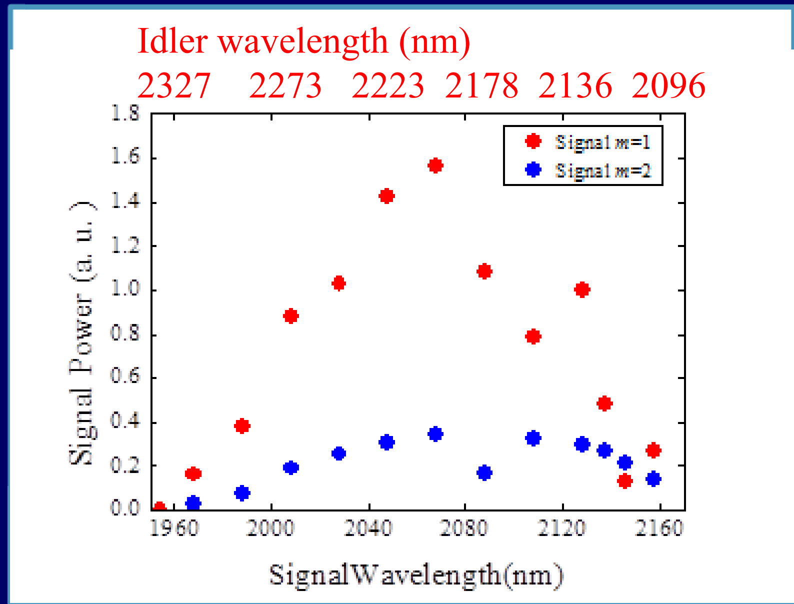


Miyamoto,,,,,, Omatsu, Optics Express, 19, (2011) 12220-12226.
Yusufu,,, Miyamoto, Omatsu, Optics Express, 20, (2012) 23666-23675

Vortex pumped OPO







Summary

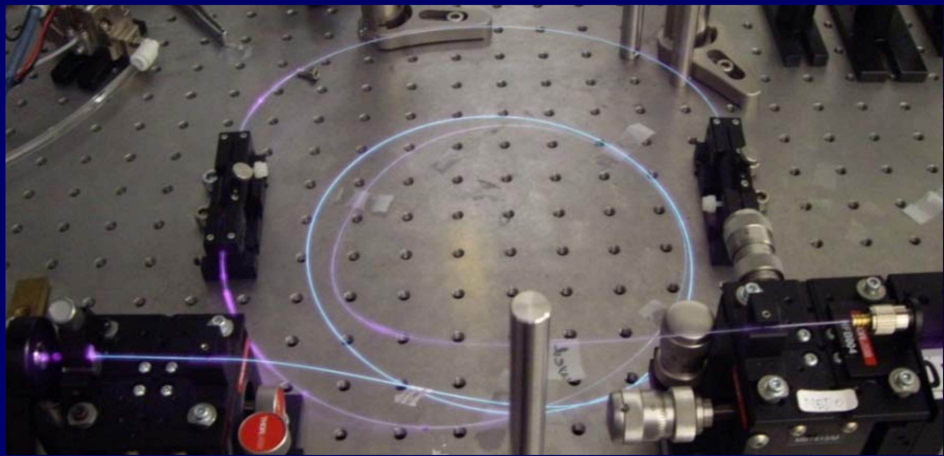
'Nano'-processing based on optical vortex laser ablation

Chiral nano-needle diameter <50nm Height >10μm

2 dimensional nano-needle array

AFM, STM, Bio-MEMS, Plasmonics, Metamaterials

New aspect of photonics & laser physics



Vortex solid-state lasers

15W (CW, Q-switched)

Vortex fiber lasers

40W (ps), 25W (ns)

SHG 1.5W, 2μm ~2mJ

Further power scaling up to 100W

Further frequency extension to UV and MIR regions