COMSOL 2011年中国区用户年会

Chiral surface plasmon polaritons on metallic nanowires

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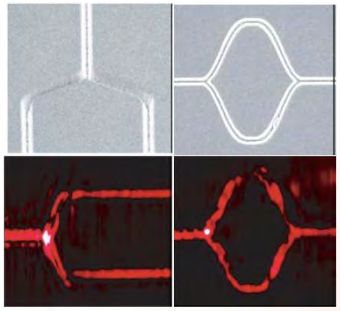
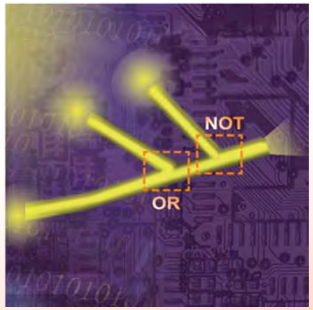
Surface Plasmon Polaritons

Waveguides



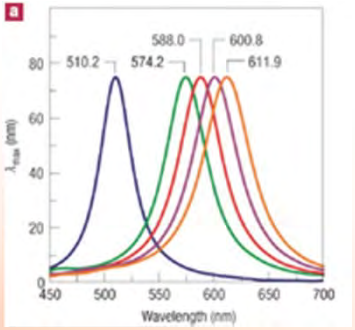
Nature, 440(23), 508-511(2006)

Optical computing



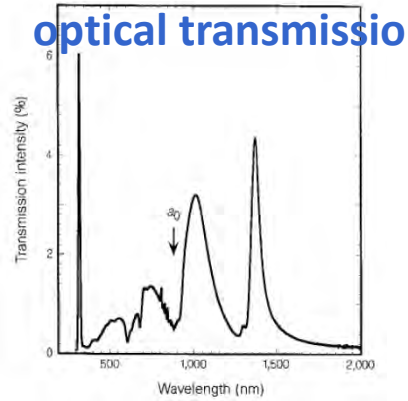
Nat. Commun. 2, 387 (2011)

Chemical bio-sensing



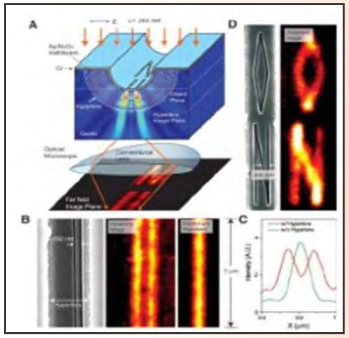
Nano Lett. 3, 1057-1062 (2003)

Extraordinary optical transmission

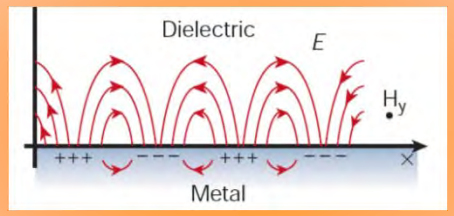


Nature 391, 667-669 (1998)

Imaging



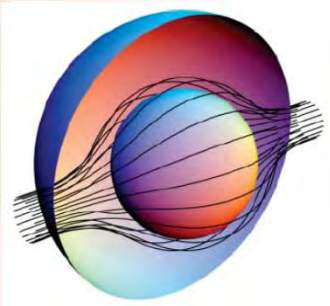
Science 315, 1686 (2007)



Nature, 424, 824 (2003)

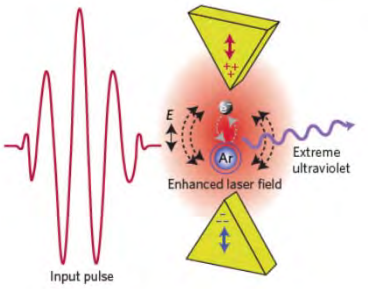
And also THz, Infrared detection, LED, enhanced optical catalysis, optical force …

Metamaterials



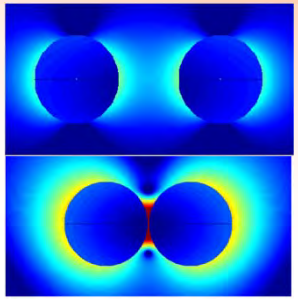
Science 312, 1780 (2006)

Nonlinear optics



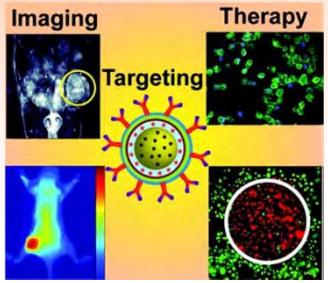
Nature 453, 757-760 (2008)

SERS



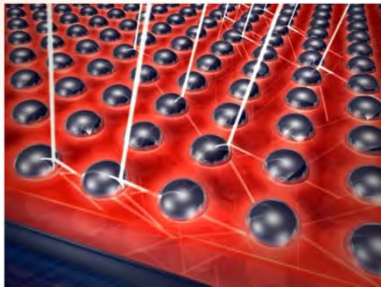
Phys. Rev. Lett. 83(21), 4357 (1999)

Cancer therapy



Acc. Chem. Rev. DOI: 10.1021/ar200023x

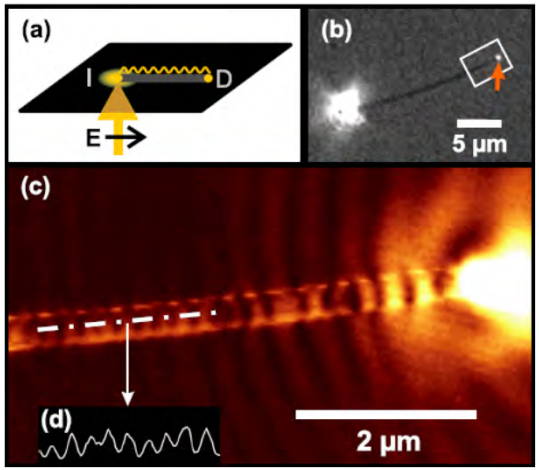
Solar cell



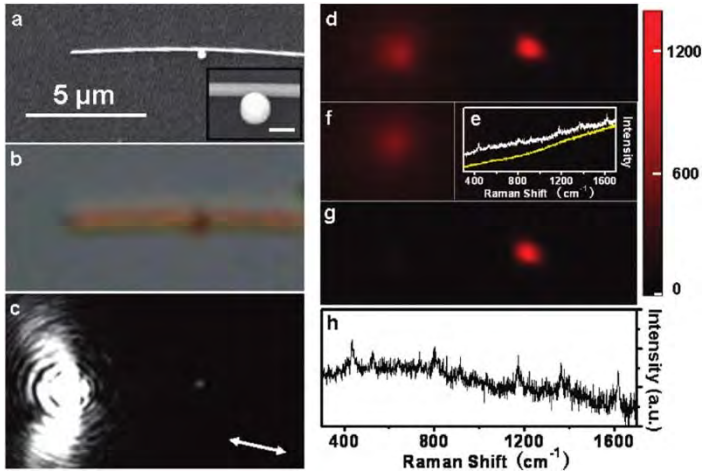
Nat. Mater., 9, 205-213 (2010)

Ag nanowires as plasmonic fibers

- Crystallized structures
- Small SPPs mode volumes
- Low intrinsic loss compared to other metals
- Ease access for manipulators

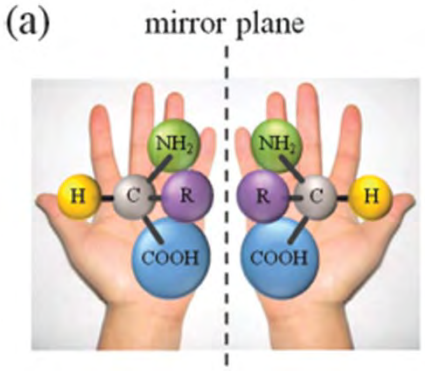


H. Ditlbacher, et al. ***Phys. Rev. Lett.***, 95, 257403 (2005)



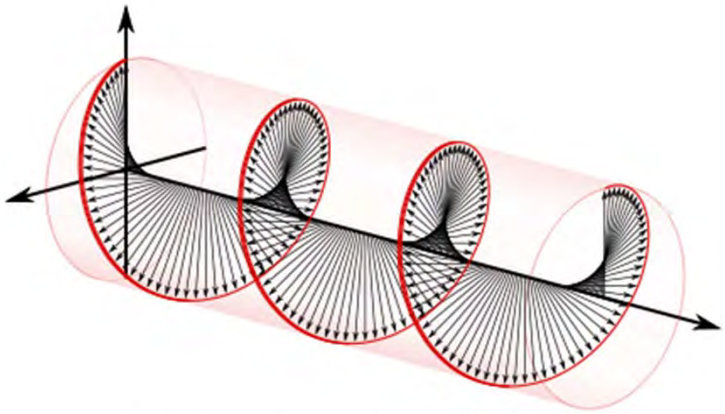
Y. R. Fang & H. Wei, et al. ***Nano Lett.*** 9, 2049-2053 (2009)

What's chiral?



Y. Liu, X. Zhang, Chem. Soc. Rev.
DOI:10.1039/c0cs00184h

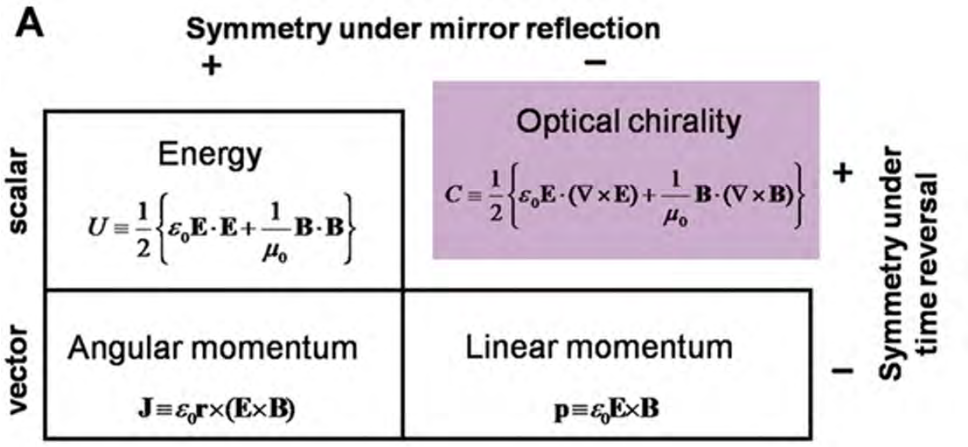
Chiral objects



From Wikipedia: circular polarization

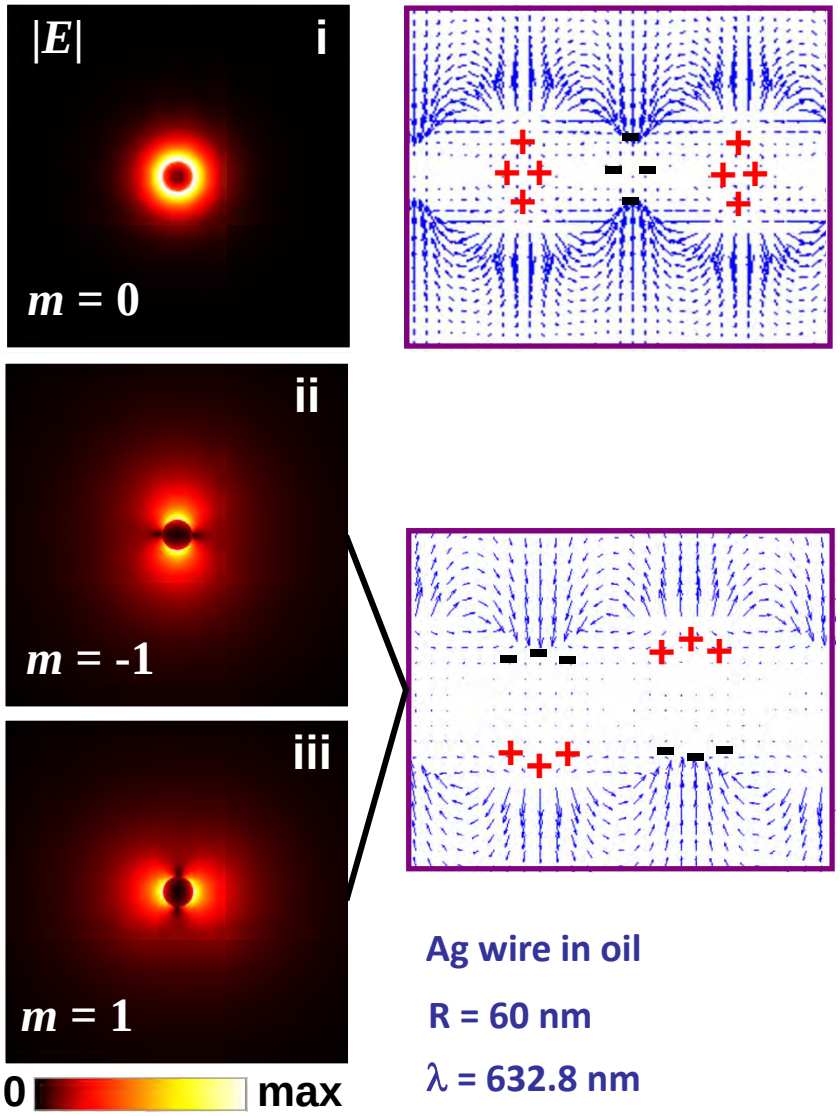
Chiral electromagnetic waves

Chirality is one fundamental aspect of an optical field.



Y.Q. Tang, A. E. Cohen. ***Science*** 332:333-336 (2011)

Excitation of nanowire SPPs

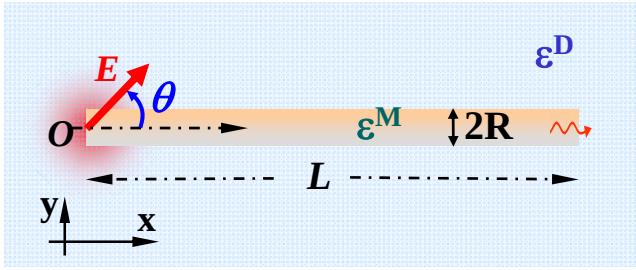


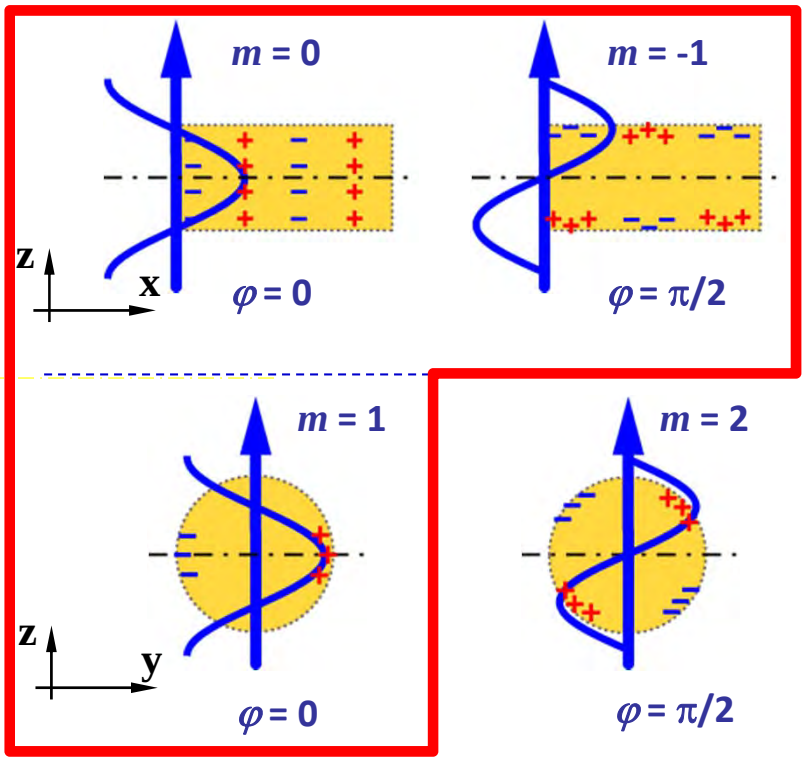
Ag wire in oil

R = 60 nm

λ = 632.8 nm

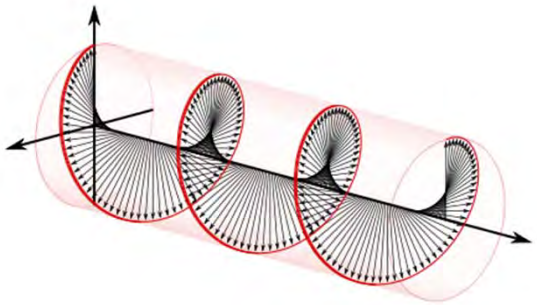
COMSOL 3.5a, 2D, RF module > Perpendicular wave > Hybrid-Mode Waves > Mode analysis



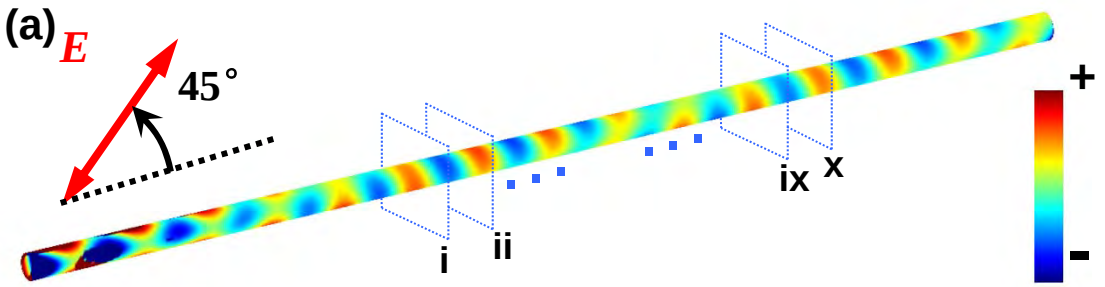


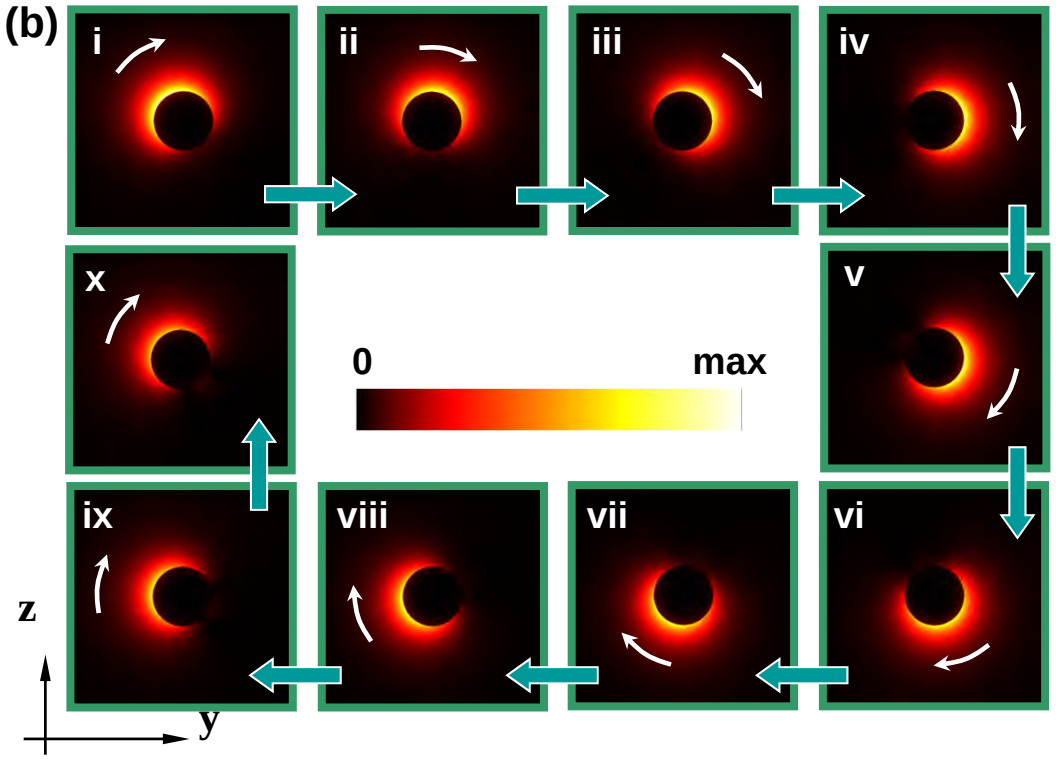
A π/2 phase delay between m = -1 and 1 modes!

Superposition of different modes forms chiral SPPs



From Wikipedia: circular polarization





Ag nanowire in oil

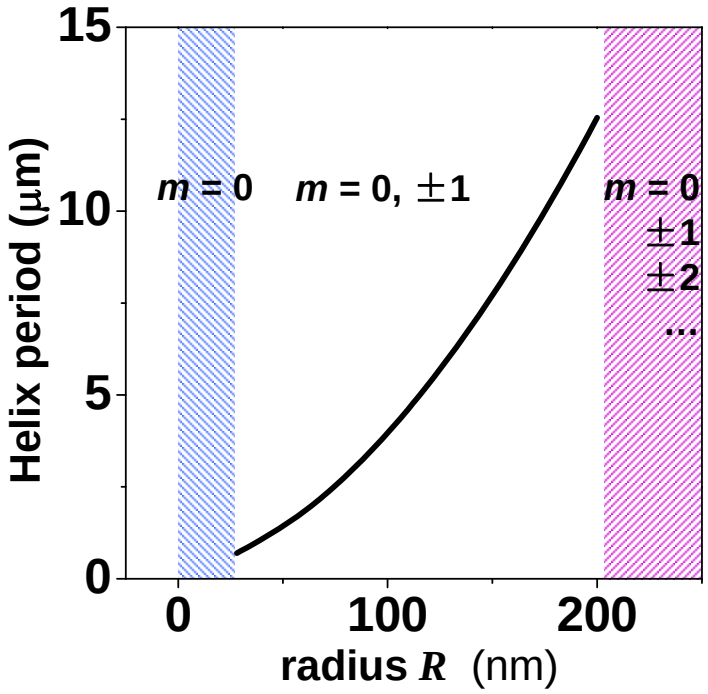
R = 60 nm, L = 5 μm

The period of the helix is 1.86 μm.

COMSOL 3.5a, 3D, RF module > Electromagnetic Waves > Scattered harmonic propagation

S. P. Zhang, et al. Phys. Rev. Lett., 107, 096801 (2011)

Tunable helix period



The period of the plasmon helix :

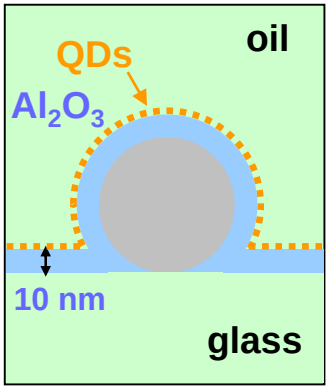
$$\Lambda_{mm'} = 2\pi\left(\Delta k_{mm'}\right)^{-1}$$

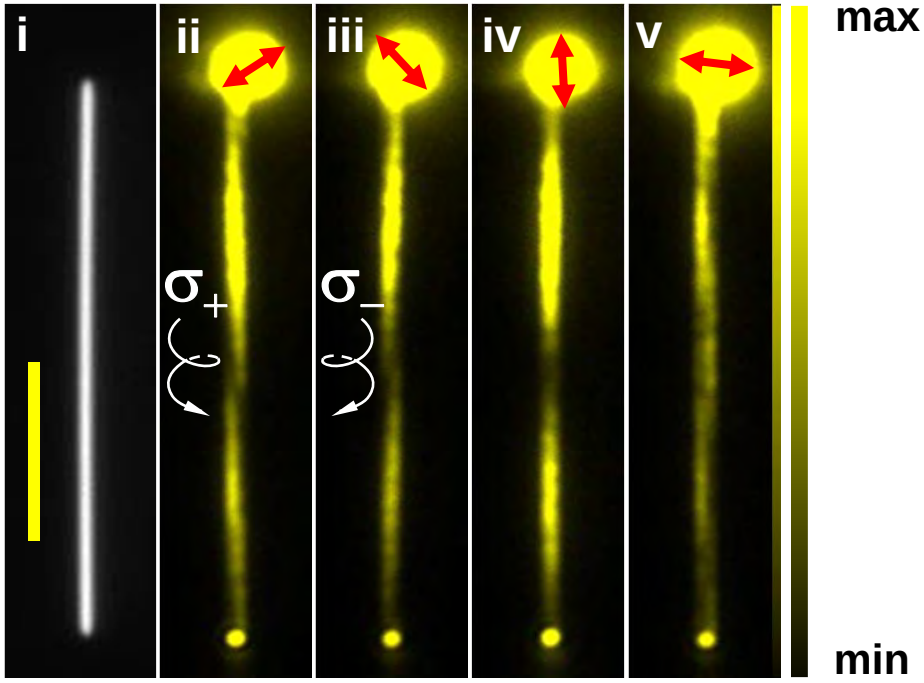
$$\Delta k_{mm'} = \left| k_{m,\square} - k_{m',\square} \right|$$

The helix period depends on the size, material, dielectric medium and excitation wavelength

S. P. Zhang, et al. Phys. Rev. Lett., 107, 096801 (2011)

Quantum dots fluorescence imaging reveals the chirality of the SPPs





Scale bar: 5 μm

Phys. Rev. Lett., 107, 096801 (2011)

Chiral SPPs generate circularly polarized light

The degree of circular polarization:

$$C = \frac{2\left\langle E_y(t)E_z(t)\sin(\delta_y - \delta_z)\right\rangle}{\left\langle E_x^2(t)\right\rangle + \left\langle E_y^2(t)\right\rangle + \left\langle E_z^2(t)\right\rangle}$$

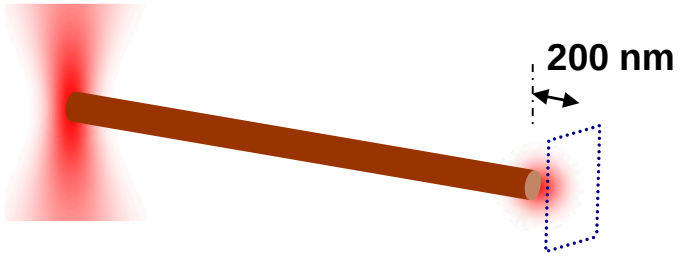


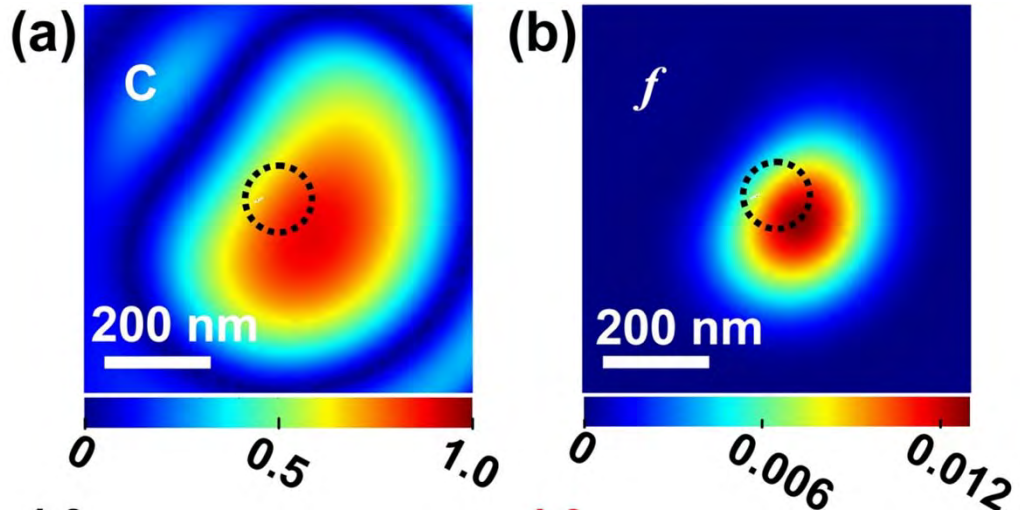
Figure of merit:

$$f = I \times C^2$$

$$I = \left|\boldsymbol{E}(\boldsymbol{r})\right|^2 \Big/ \left|\boldsymbol{E}_0(0)\right|^2$$

R = 60 nm, L = 5 μm

Polarization angle θ = 45°



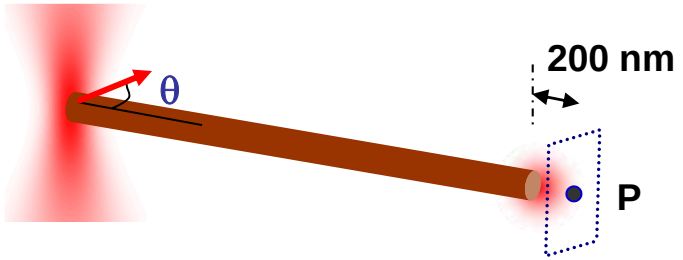
A subwavelength circularly polarized light convertor (¼ wave plate)

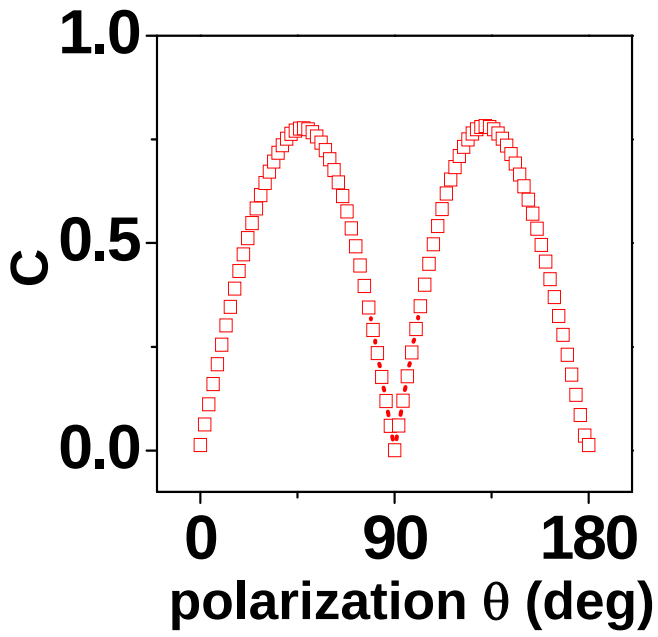
Phys. Rev. Lett., 107, 096801 (2011)

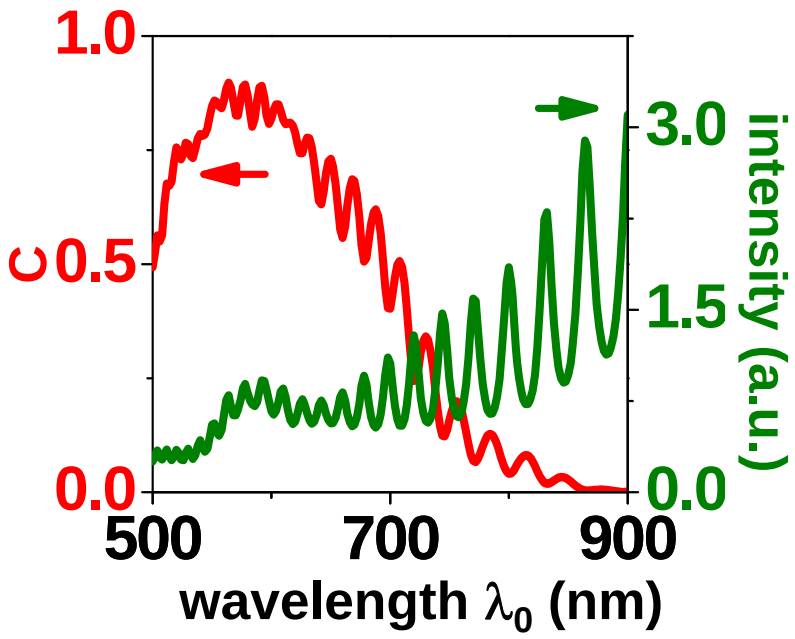
Broadband tunable nanoprobes

The degree of circular polarization:

$$C = \frac{2\left\langle E_y(t)E_z(t)\sin(\delta_y - \delta_z)\right\rangle}{\left\langle E_x^2(t)\right\rangle + \left\langle E_y^2(t)\right\rangle + \left\langle E_z^2(t)\right\rangle}$$



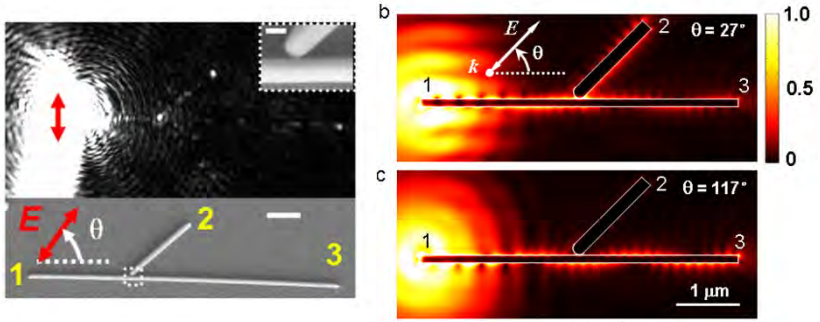




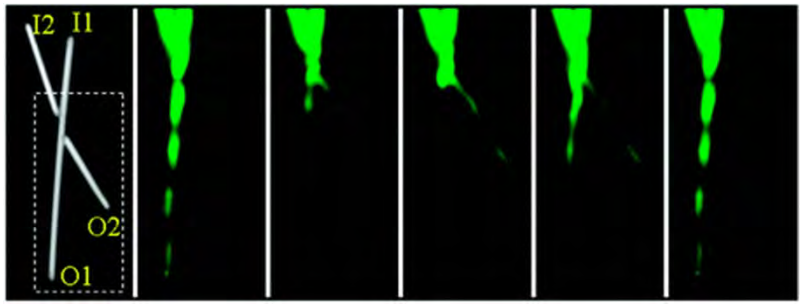
Phys. Rev. Lett., 107, 096801 (2011)

Applications

I. Metallic nanowires-based circuits



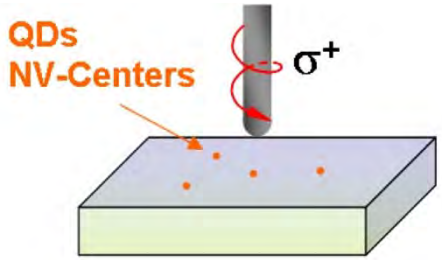
Yurui Fang, et al. *Nano Lett.*, *10*, 1950–1954 (2010)



Hong Wei, et al. *Nano Lett*., 11, 471–475 (2011)

II. Subwavelength circular polarized light source

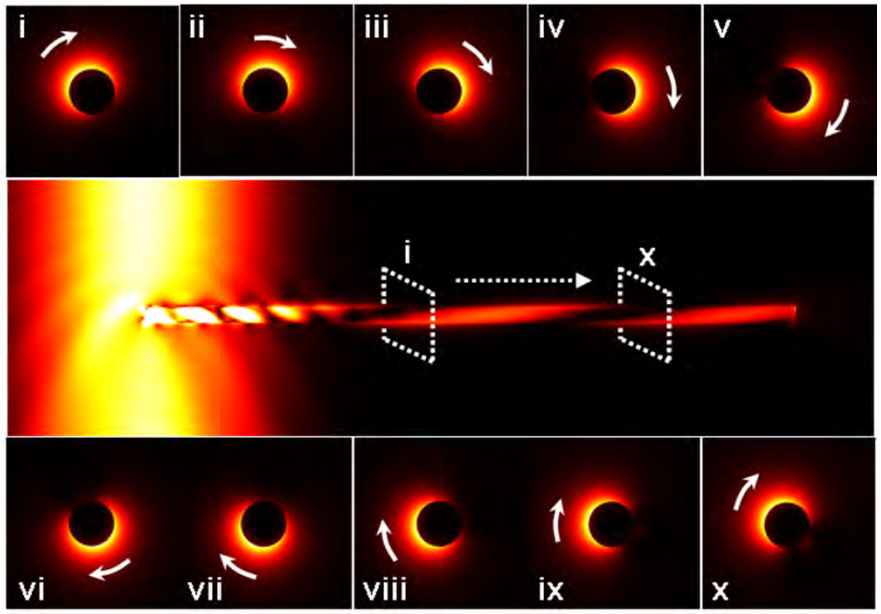
- SPPs-chiral molecule interactions
- Ag nanowires as scanning probes in aSNOM / TERS tip?
- All-optical magnetic recording and Spintronics



Conclusions

- Chiral SPPs can be generated by linearly polarized light incident at the end of a nanowire, exciting a coherent superposition of three specific nanowire waveguide modes.

- Chirality is preserved in the emitted photons, creating a subwavelength ¼ wave plate.



Publications using COMSOL (2010-2011)

(1) S. P. Zhang, et al. Phys. Rev. Lett., 107, 096801 (2011)

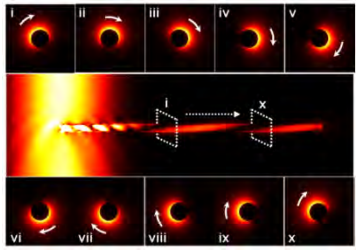
(2) S. P. Zhang, et al. Nano Lett., 11, 1657-1663 (2011)

(3) Z. P. Li, et al. Small, 7(5), 593-596 (2011)

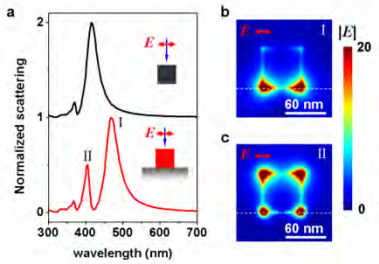
(4) Y. R. Fang, et al. Nano Lett., 10, 1950-1954 (2010)

(5) K. D. Alexander, et al. Nano Lett., 10, 4488-4493 (2010)

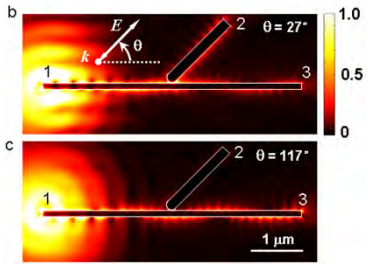
Chiral SPPs



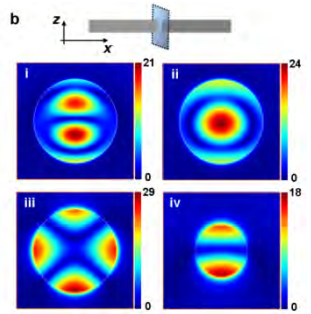
Fanocube



SPP routers



Controllable SERS



Acknowledgement

Thanks

Prof. Hongxing Xu, Peter Nordlander, Naomi Halas

Dr. Hong Wei, Kui Bao and Ulf Håkanson

Thanks COMSOL, for a open and friendly simulation platform.

Thank you !