



Nanjing University

等离子元光子学

(物理效应与应用)

李 涛

2012.5.29

taoli@nju.edu.cn

□ Nat. Lab. of Solid State Microstructures
College of Engineering and Applied Sciences
Nanjing University

Dielectric **S**uperlattice **L**aboratory

Nat. Lab. Microstructures

Dr. Tao Li taoli@nju.edu.cn



内容纲要

- ◆ 背景
- ◆ 基本原理
- ◆ 物理效应+相关应用
- ◆ 结论与展望



SPP激发对光透射偏振调控
SPP色散、态密度和场增强效应
SPP亚波长约束和纳米光子集成
SPP的面内传播与操控
SPP的量子特性
超构材料 (metamaterial)



热点起源

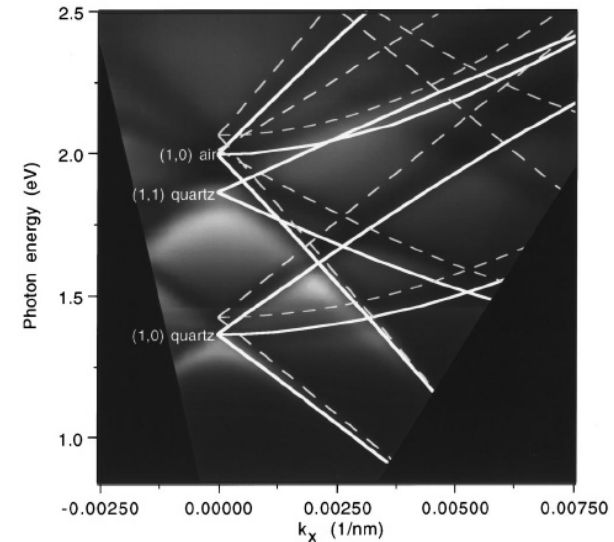
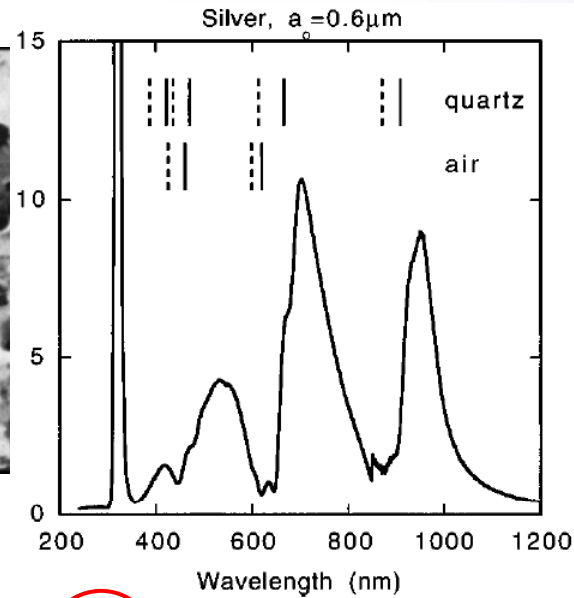
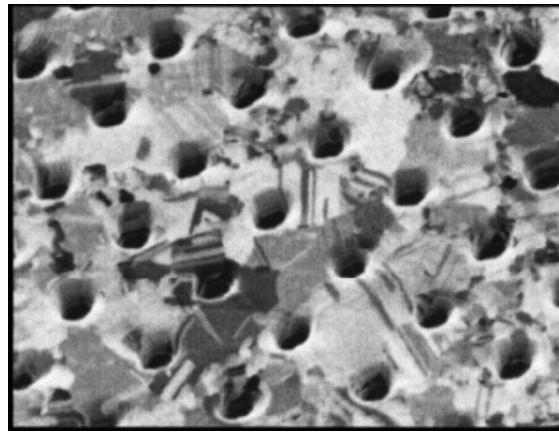
Extraordinary Optical Transmission (EOT) (T. W. Ebbesen 1998)

结构调控的SPP激发以及光学特性



穿孔金属膜的异常光学透射现象

(T. W. Ebbesen 1998)



Ebbesen et al,
Nature, PRB, (1998)

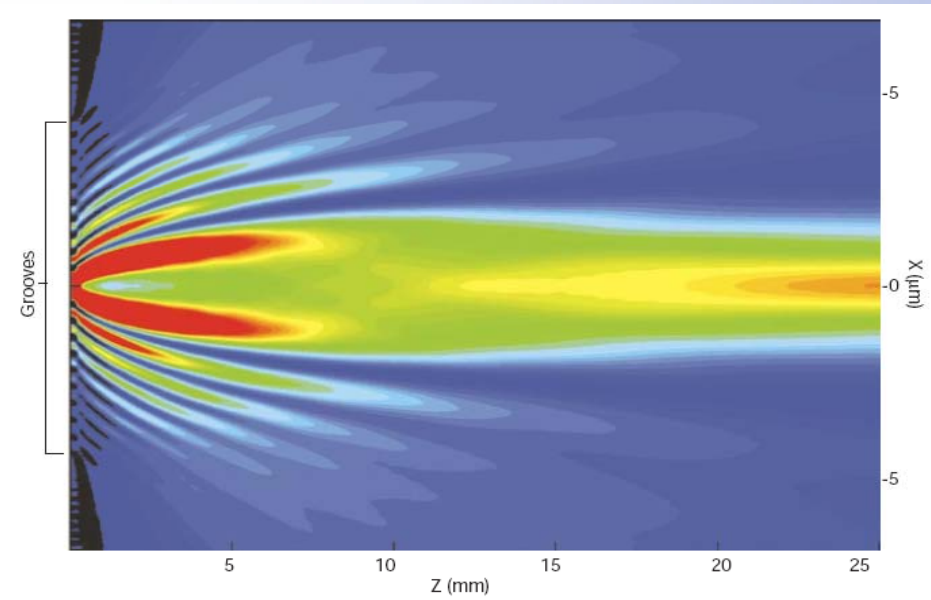
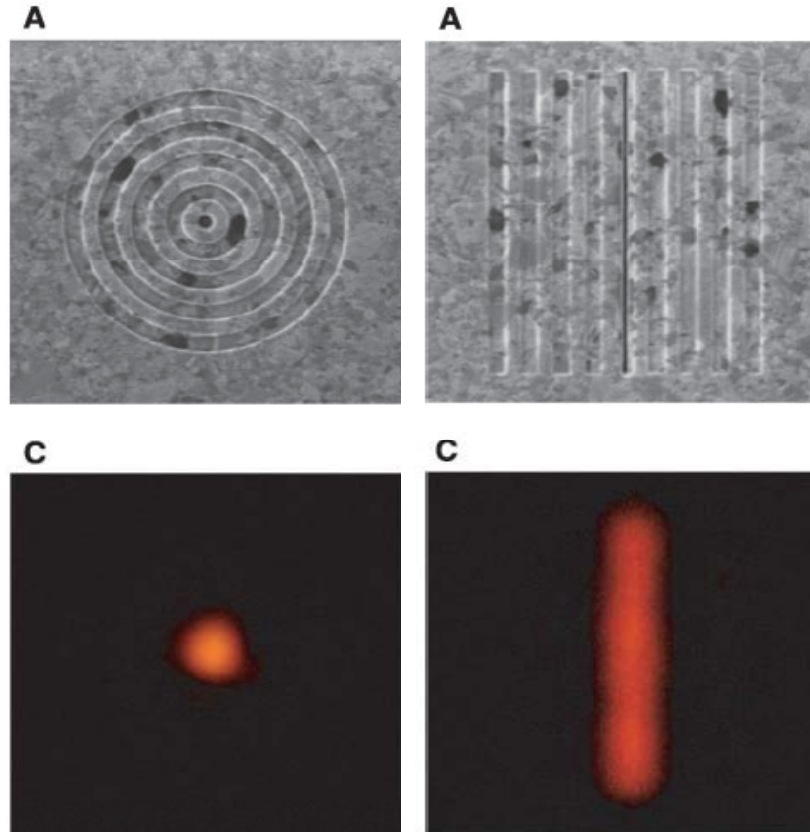
$$\vec{k}_{sp} = \vec{k}_x \pm i\vec{G}_x \pm j\vec{G}_y$$

$$(i^2 + j^2)^{1/2} \lambda = a_0 \left(\frac{\epsilon_1 \epsilon_2}{\epsilon_1 + \epsilon_2} \right)^{1/2}$$

角度色散



准直光束的发射 Directional Beam Light

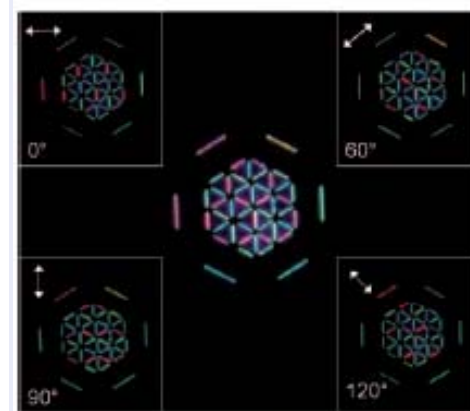
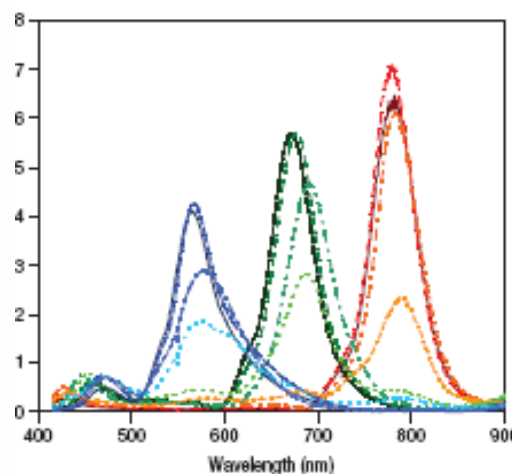
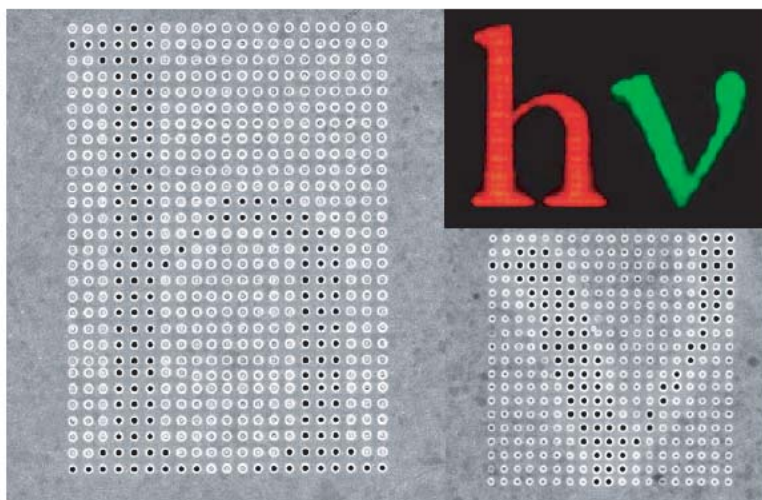
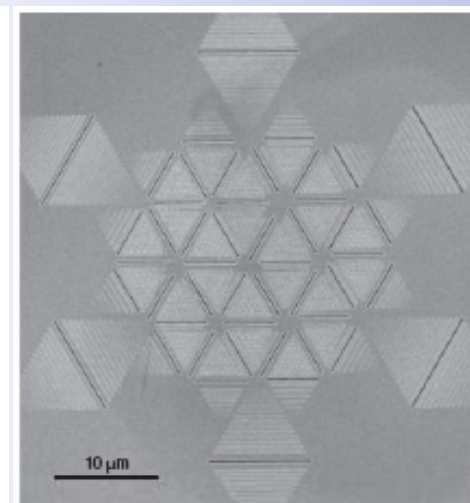
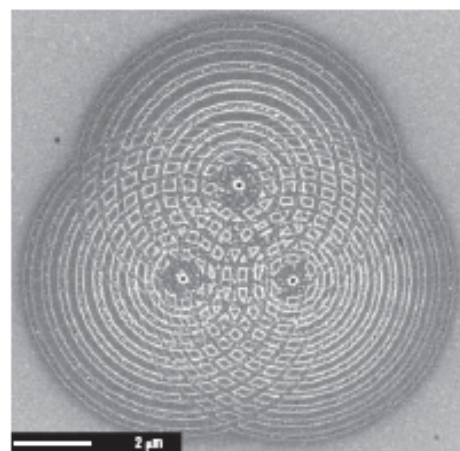
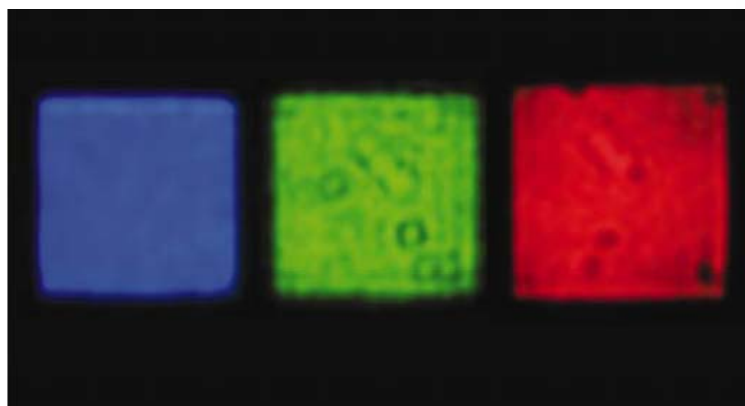


Lezec et al, Nature (2002)

通过精心设计的金属纳米结构可以实现对等离激元的激发调控，进而控制光的透射选频、辐射方向和偏振特性等！

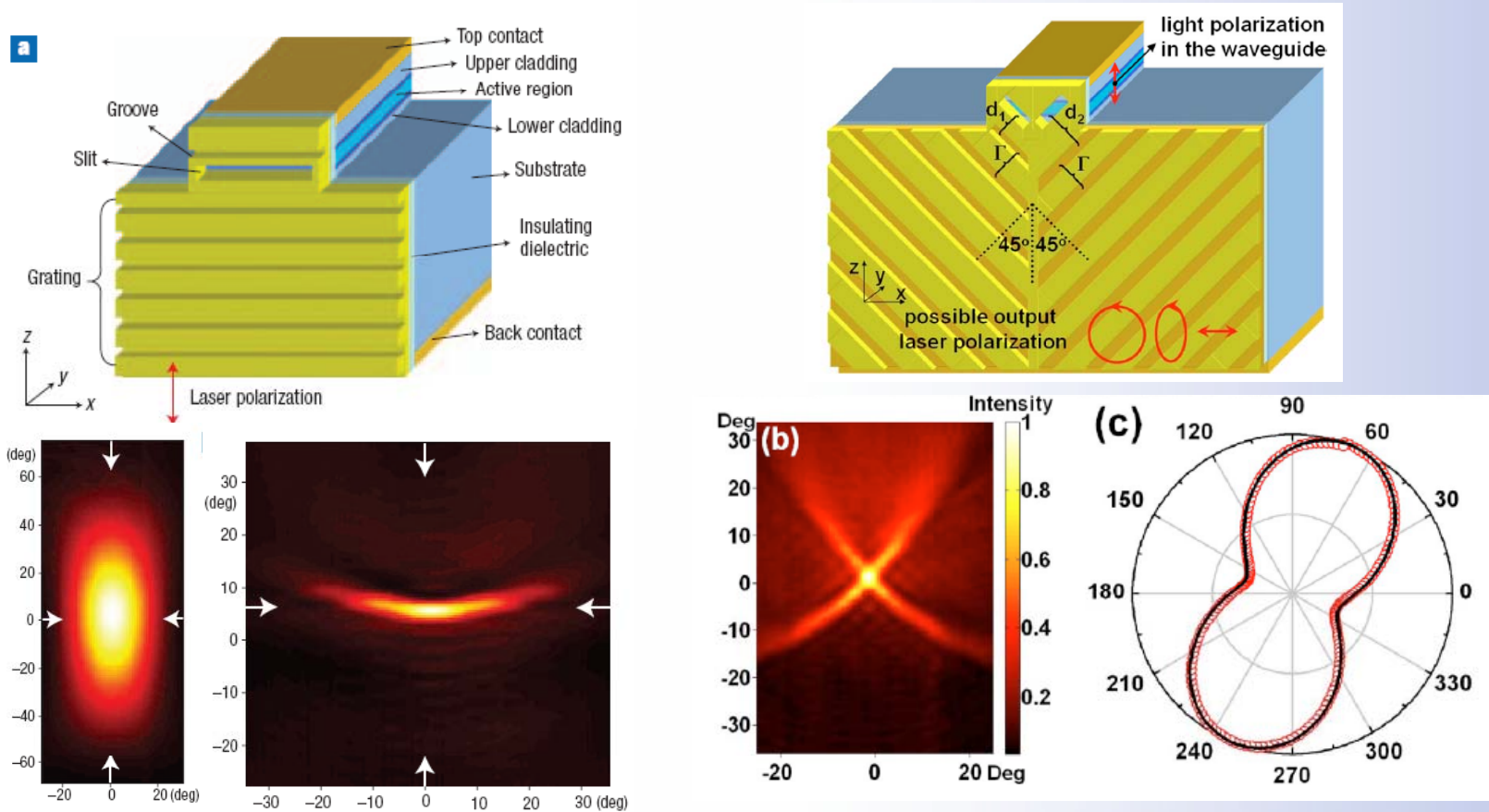


分色显示与成像





激光束的形状与偏振的调整



光束压窄

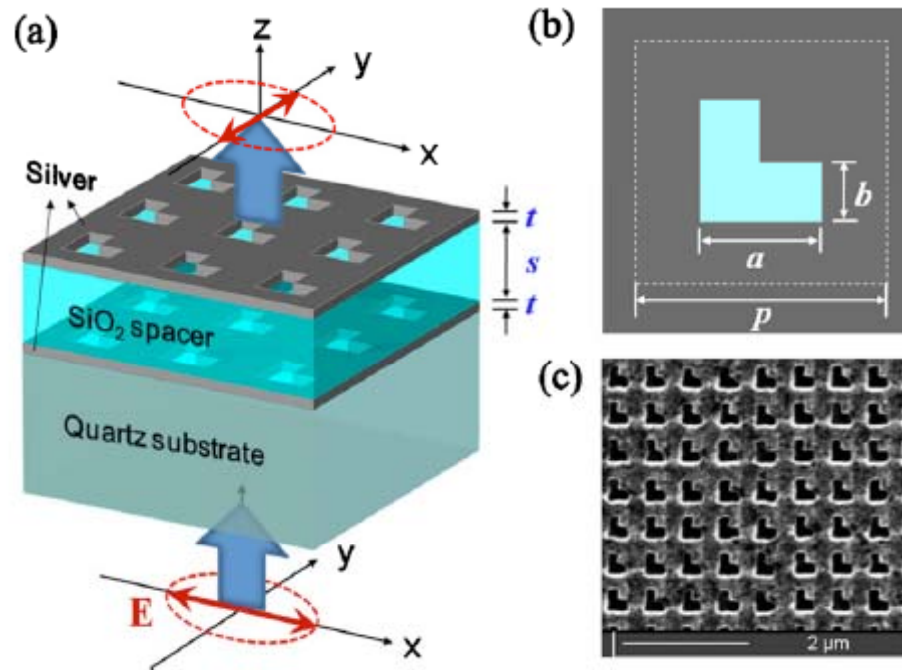
偏振调制

APL 94, 151101 (2009), Nat. Mater. 9, 730 (2010)

Capasso group, Harvard Univ.



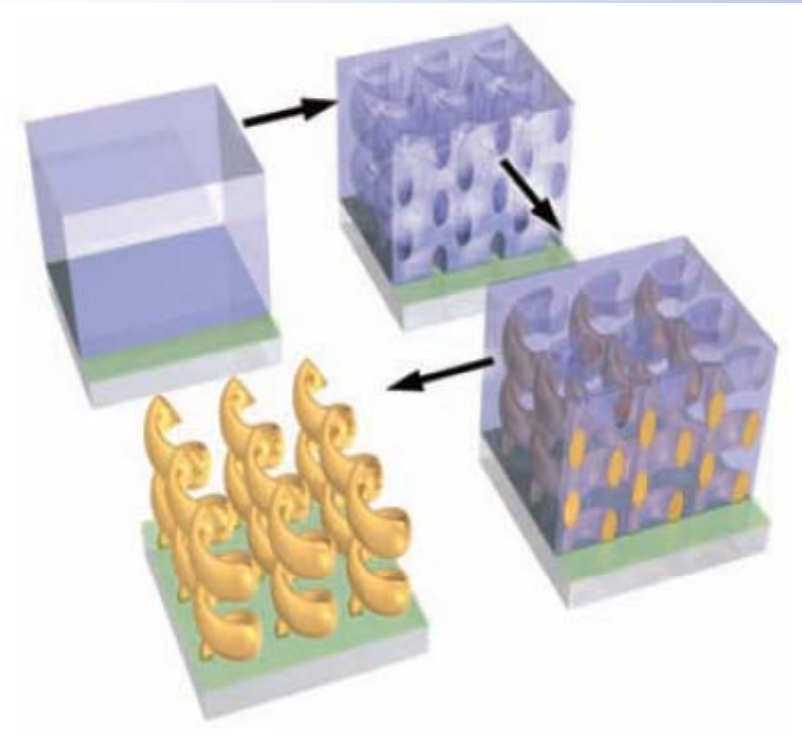
操控偏振与旋光性质



Plasmonic mode

T. Li, et al., APL 97, 261113 (2010)

D_{ielectric} S_{uperlattice} L_{aboratory}

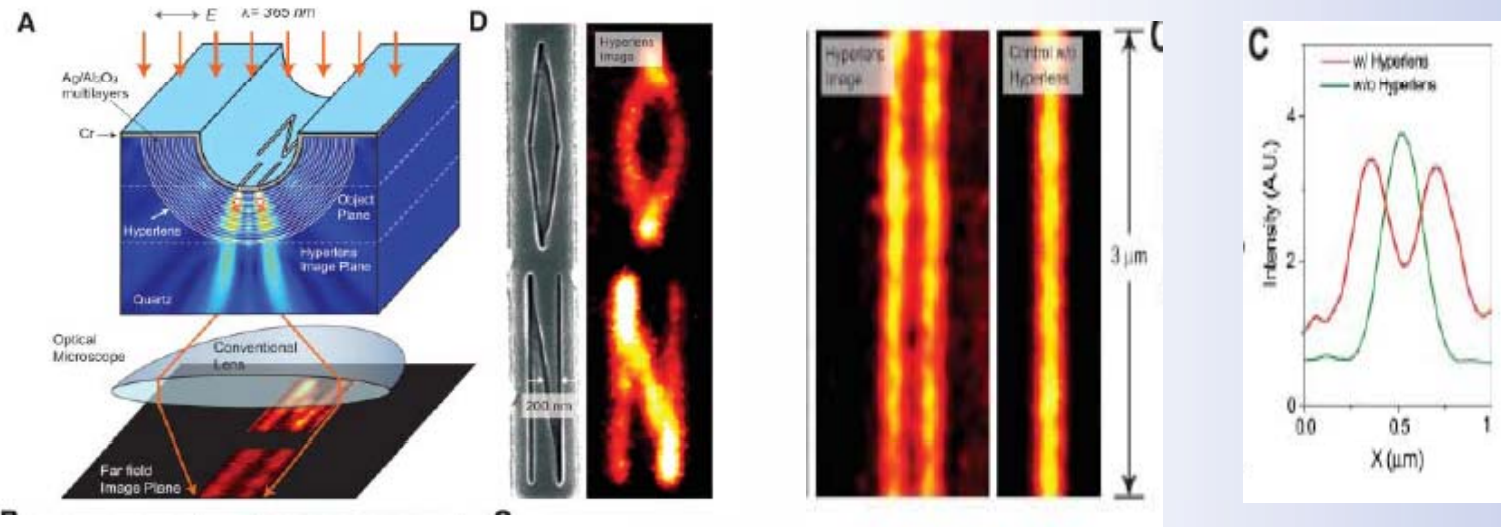
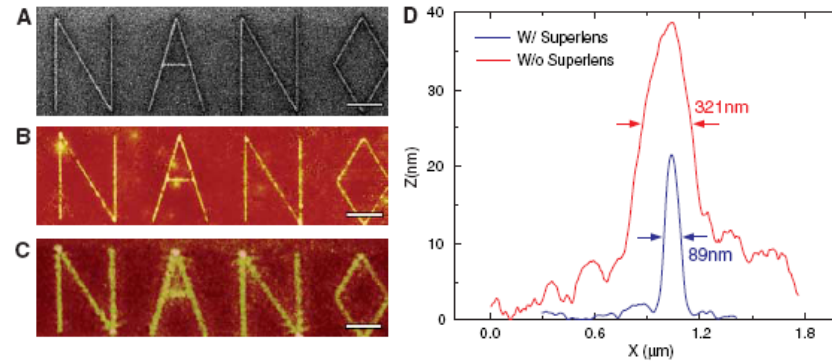
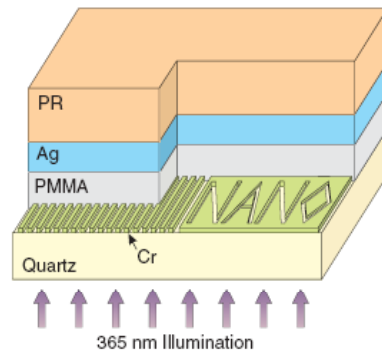


Chiral metamaterial

Science 325, 1513 (2009)



超透镜成像 (突破衍射极限)



Science 308, 534 (2005), Science 315, 1686 (2007)
 Xiang Zhang group, UC Berkeley.



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独特的色散关系、态密度 及场增强效应

Dielectric **S**uperlattice **L**aboratory

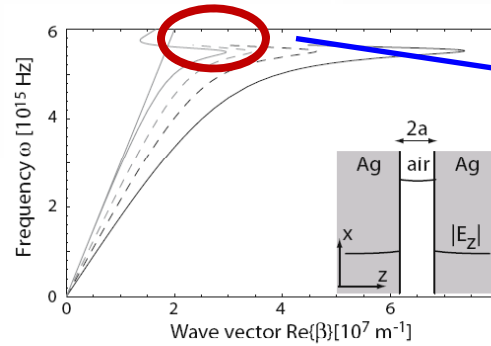
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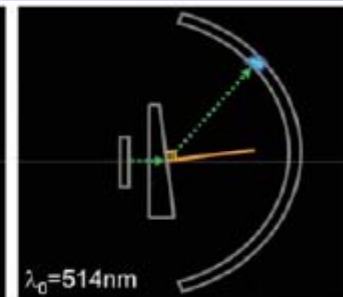
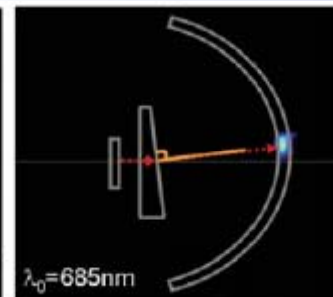
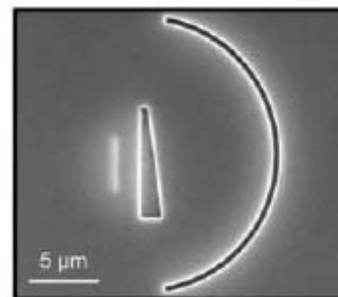
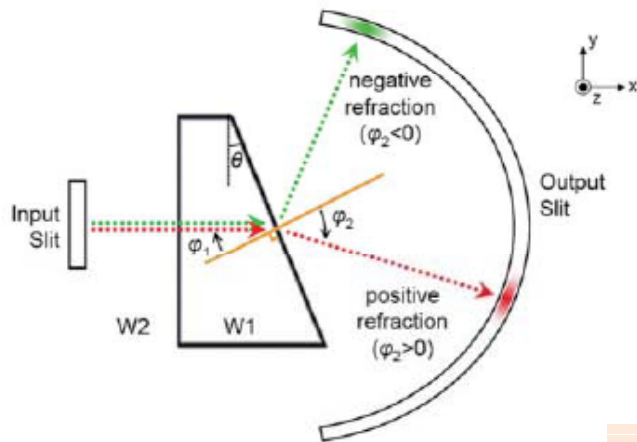
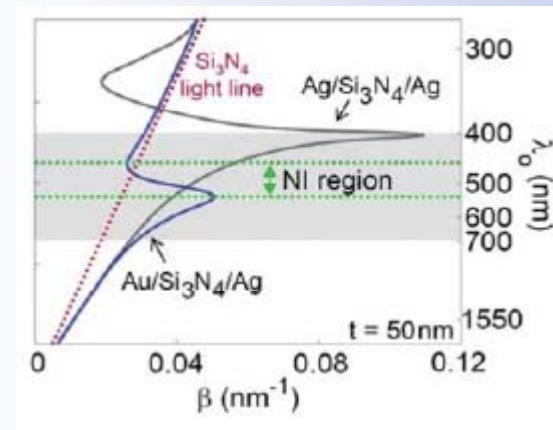
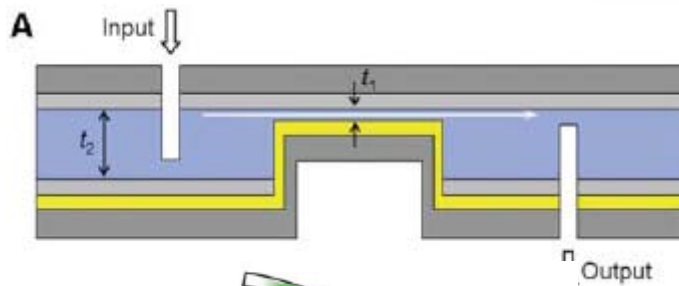


反常色散实现负折射

MIM结构

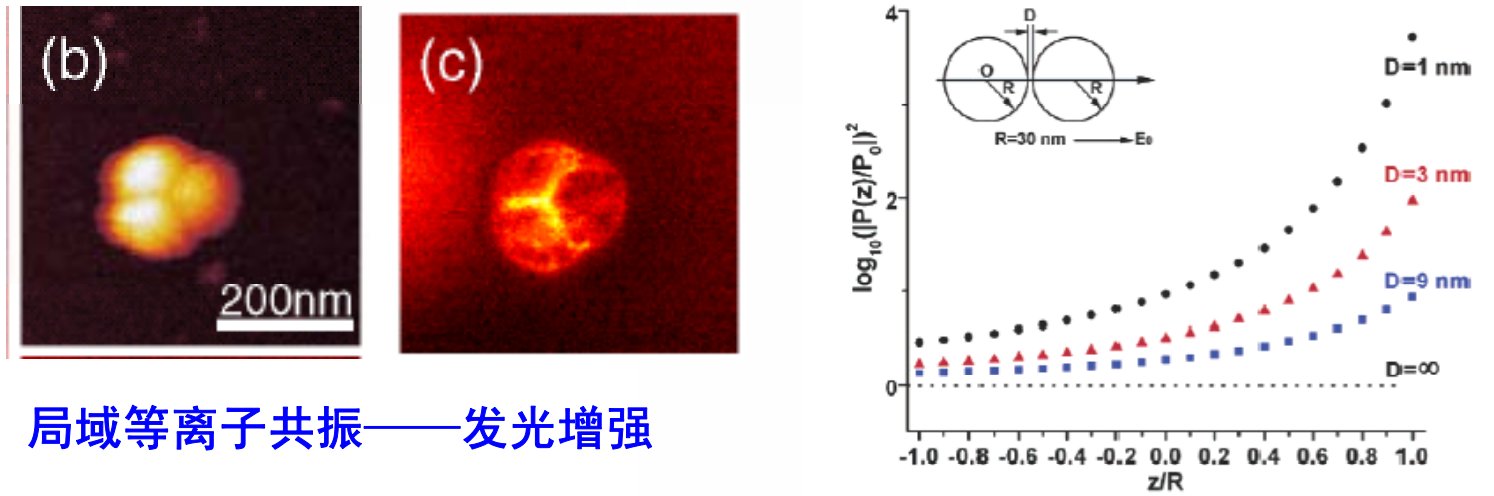


$$v_p = \frac{\omega}{k} > 0, \quad v_g = \frac{\partial \omega}{\partial k} < 0$$

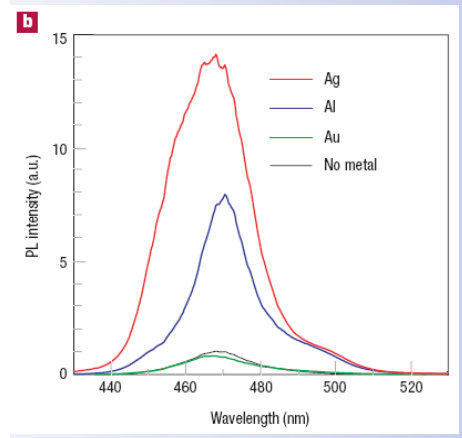
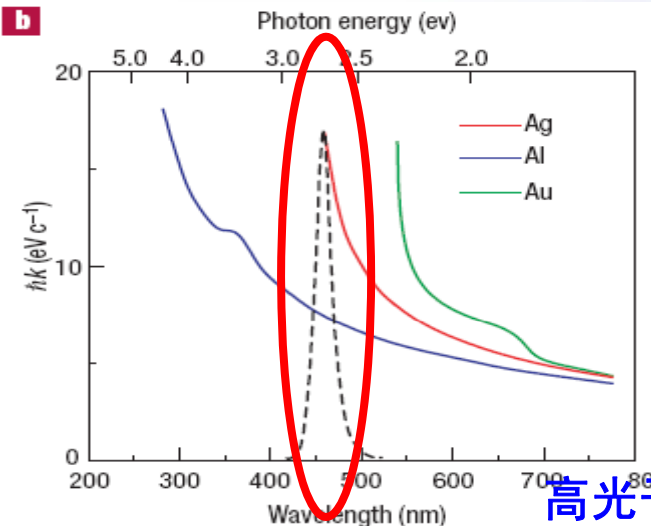
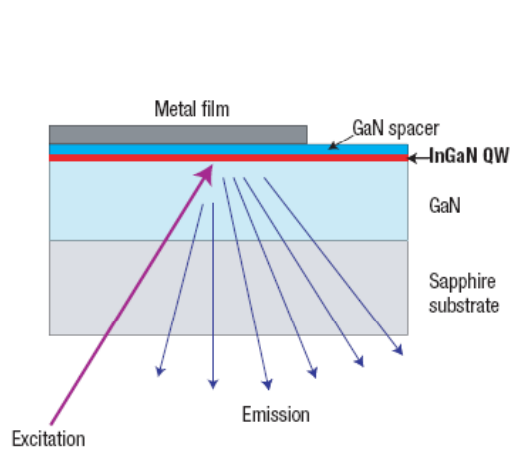




高局域场和高光子态密度



局域等离子共振——发光增强

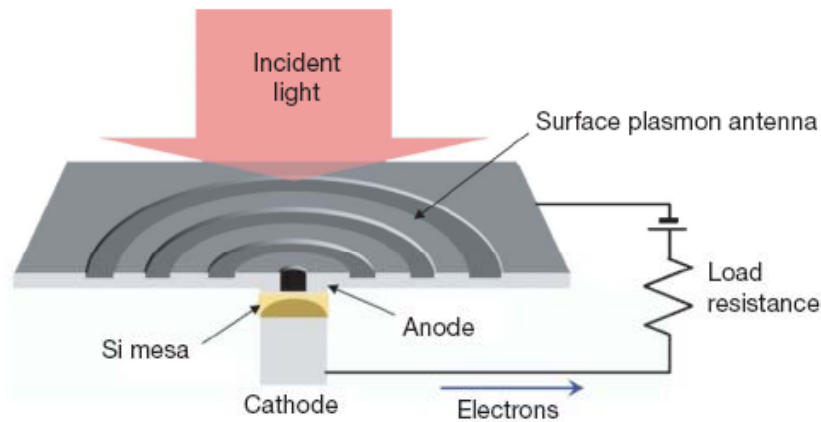


高光子态密度提高光的自发辐射效率

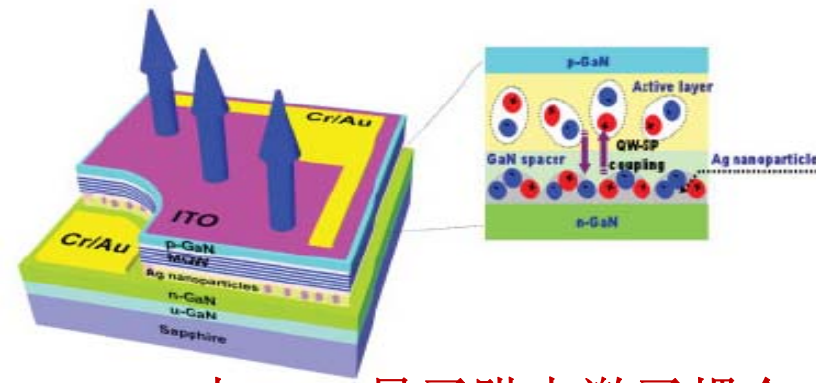
Nat. Mater. 3, 601 (2004)



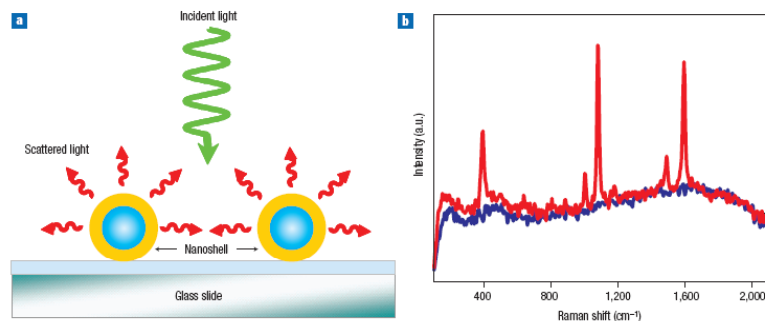
局域相互作用增强与应用



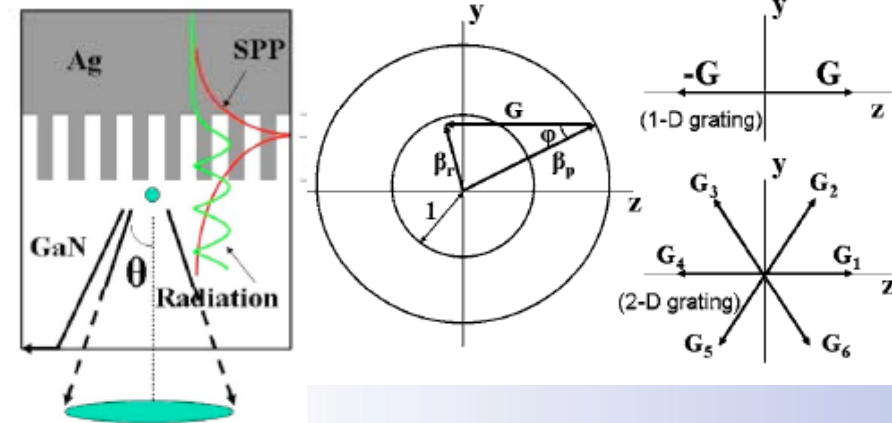
增强吸收与光电探测



SPP与LED量子阱中激子耦合
提高发光的量子转换效率



增强拉曼散射



周期结构中SPP提高LED光提取效率



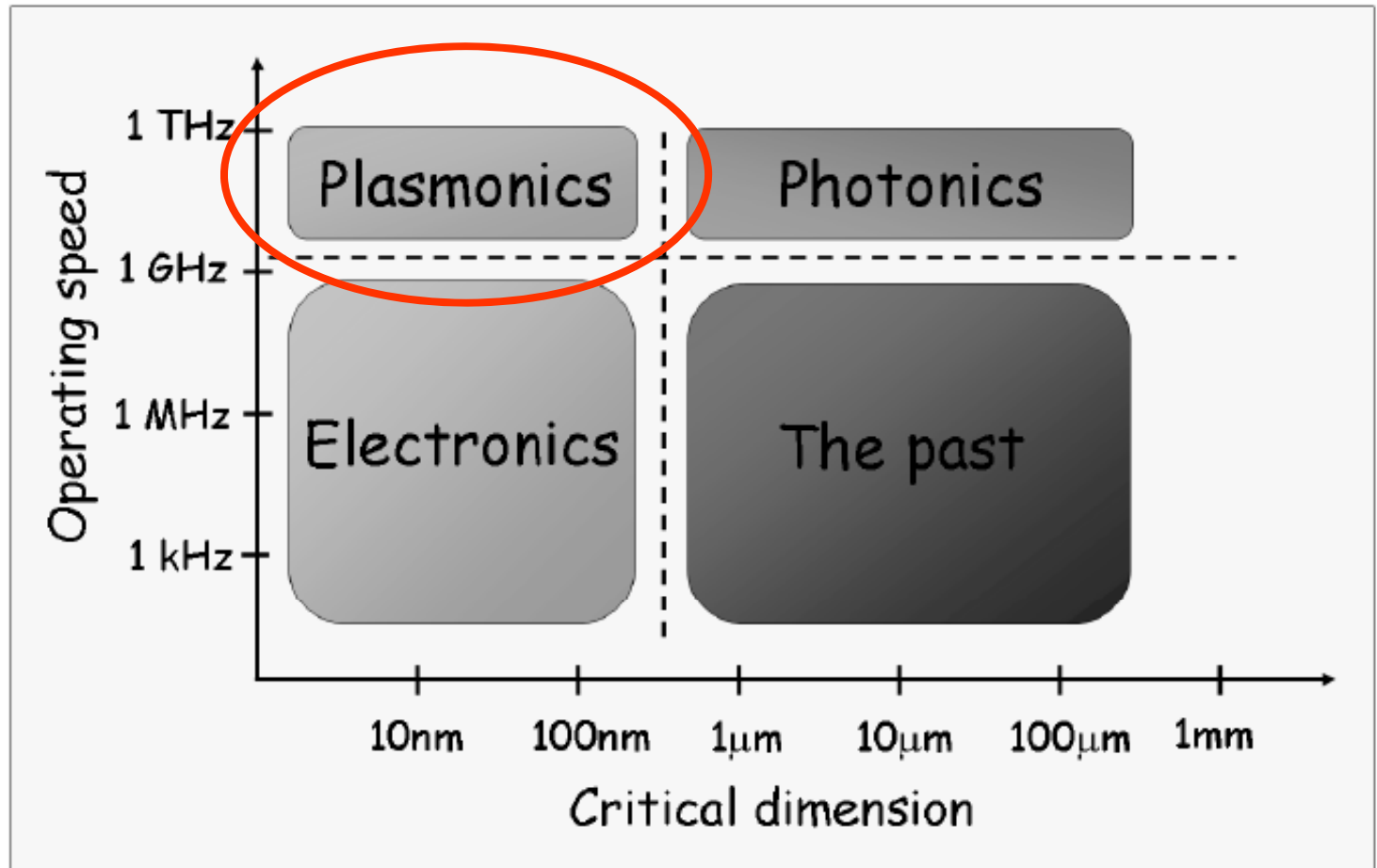
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亚波长光约束效应 纳米光子学集成

Dielectric **S**uperlattice **L**aboratory

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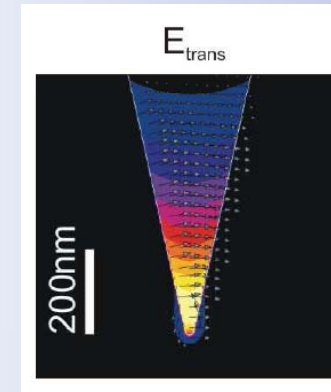
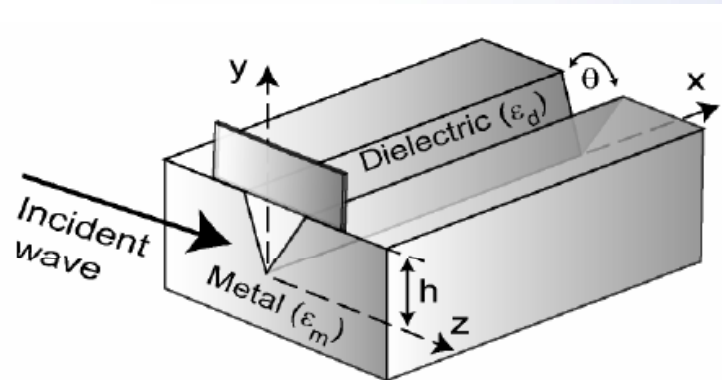
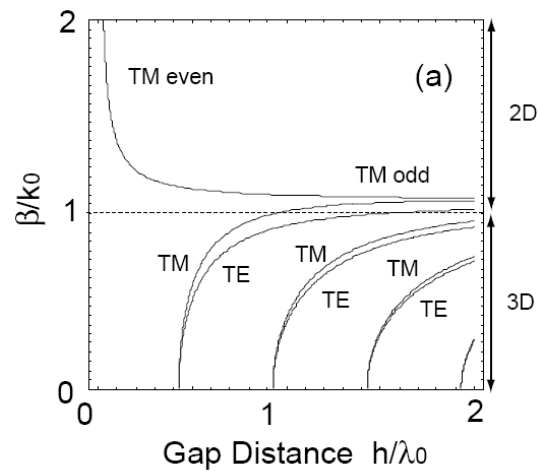
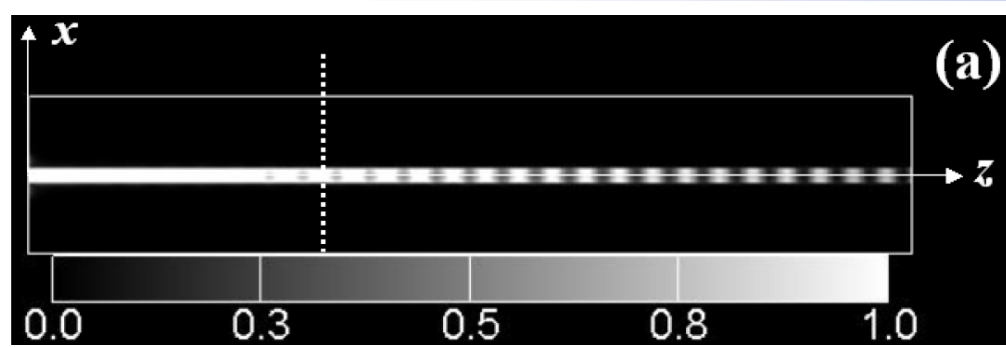


亚波长光波导

Sub-Wavelength Waveguide

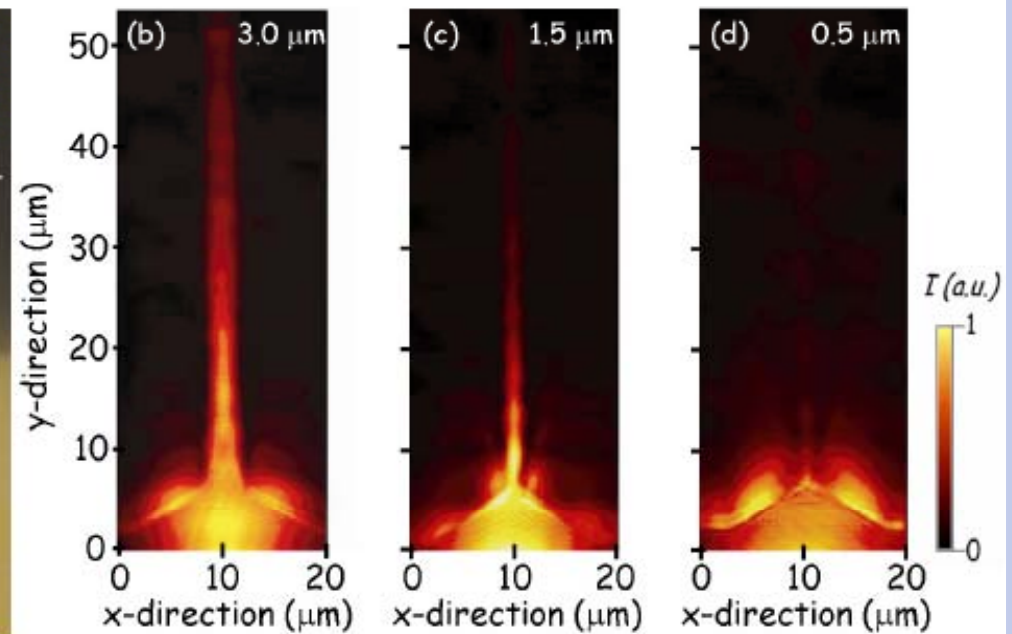
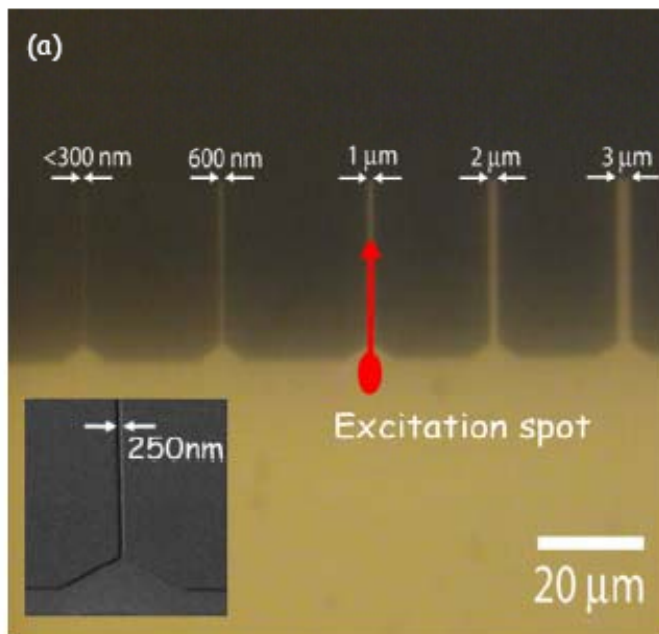
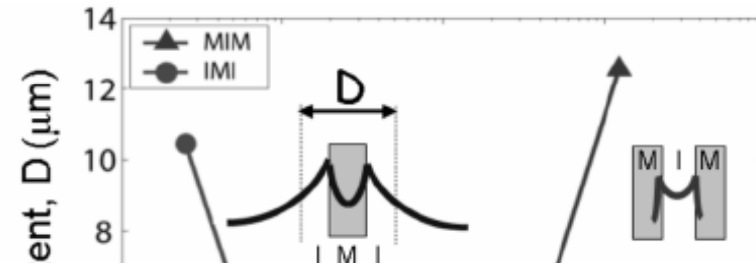
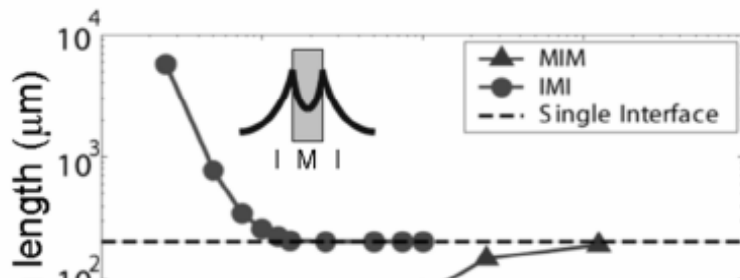


ND	$\epsilon_{ND} < 0$
D	$\epsilon > 0$
ND	$\epsilon_{ND} < 0$





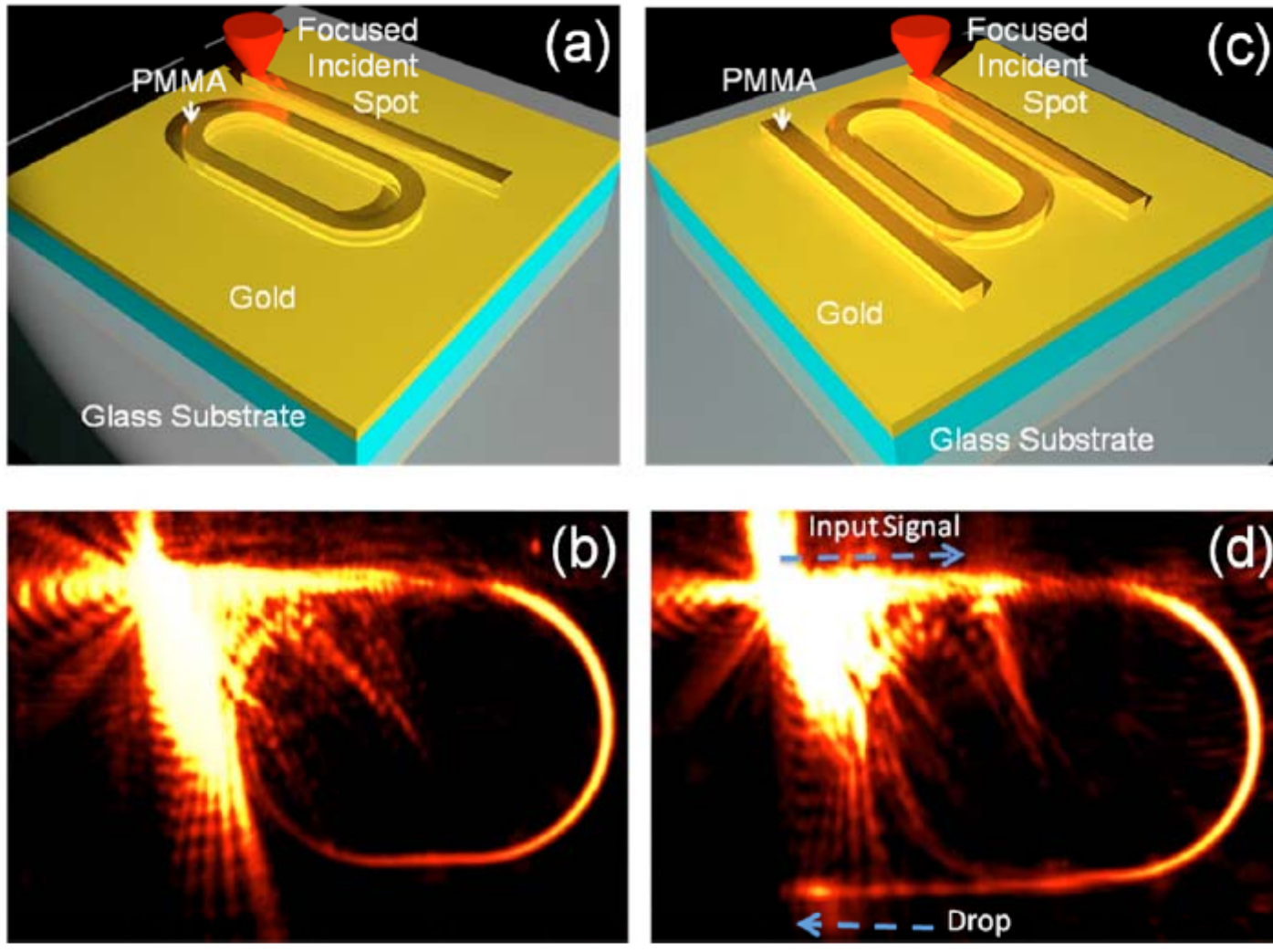
亚波长波导



$\lambda = 785 \text{ nm}$

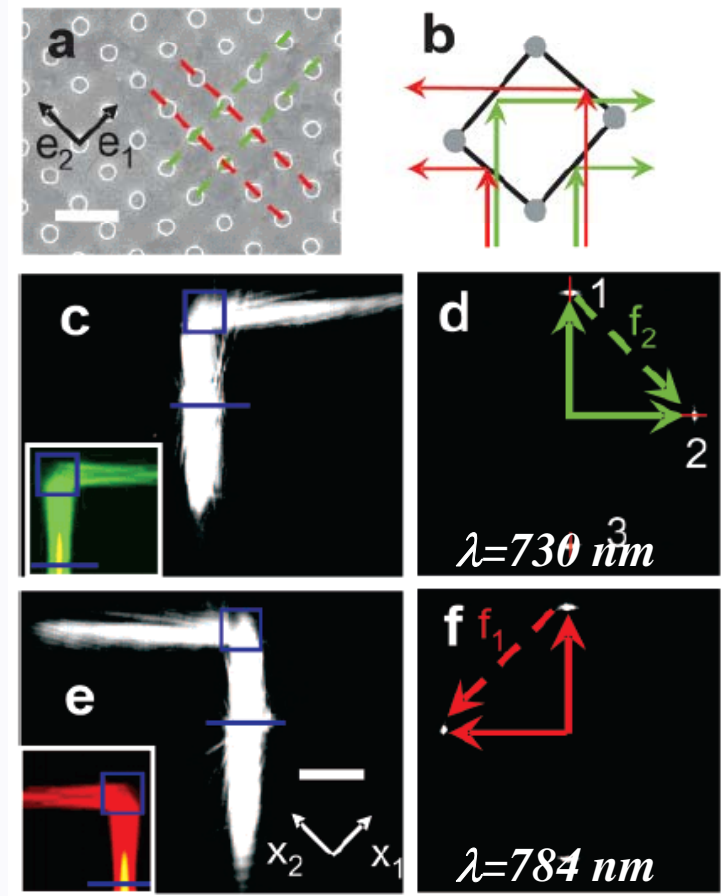
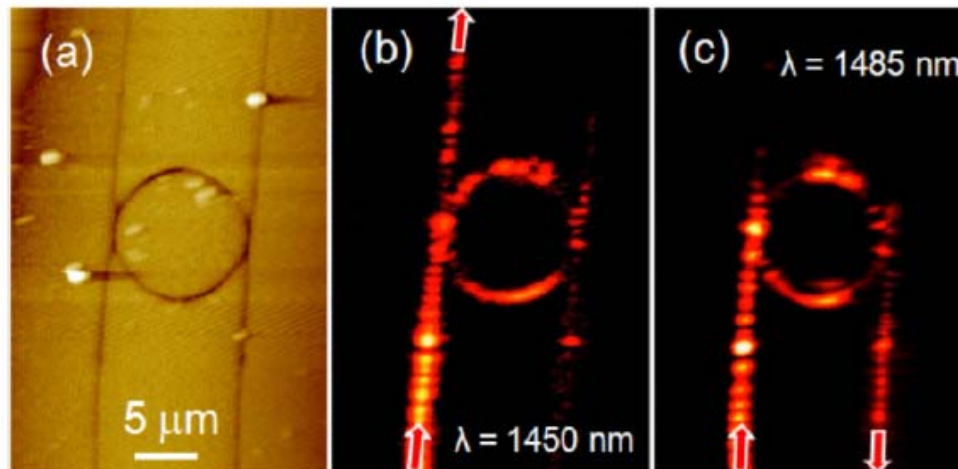
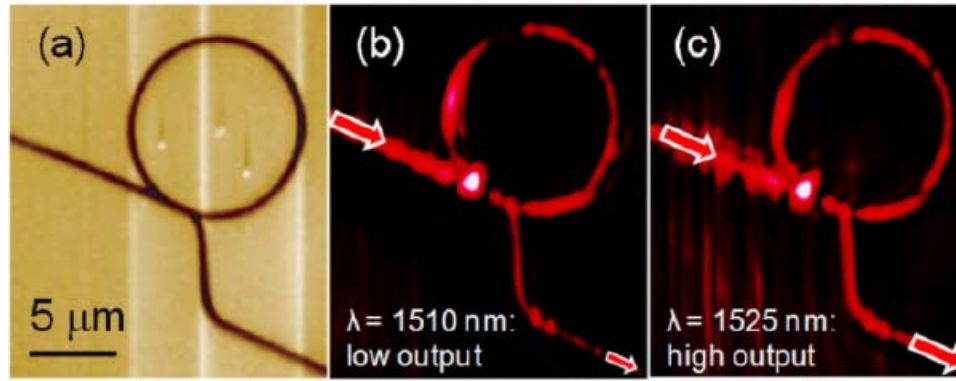


定向耦合器



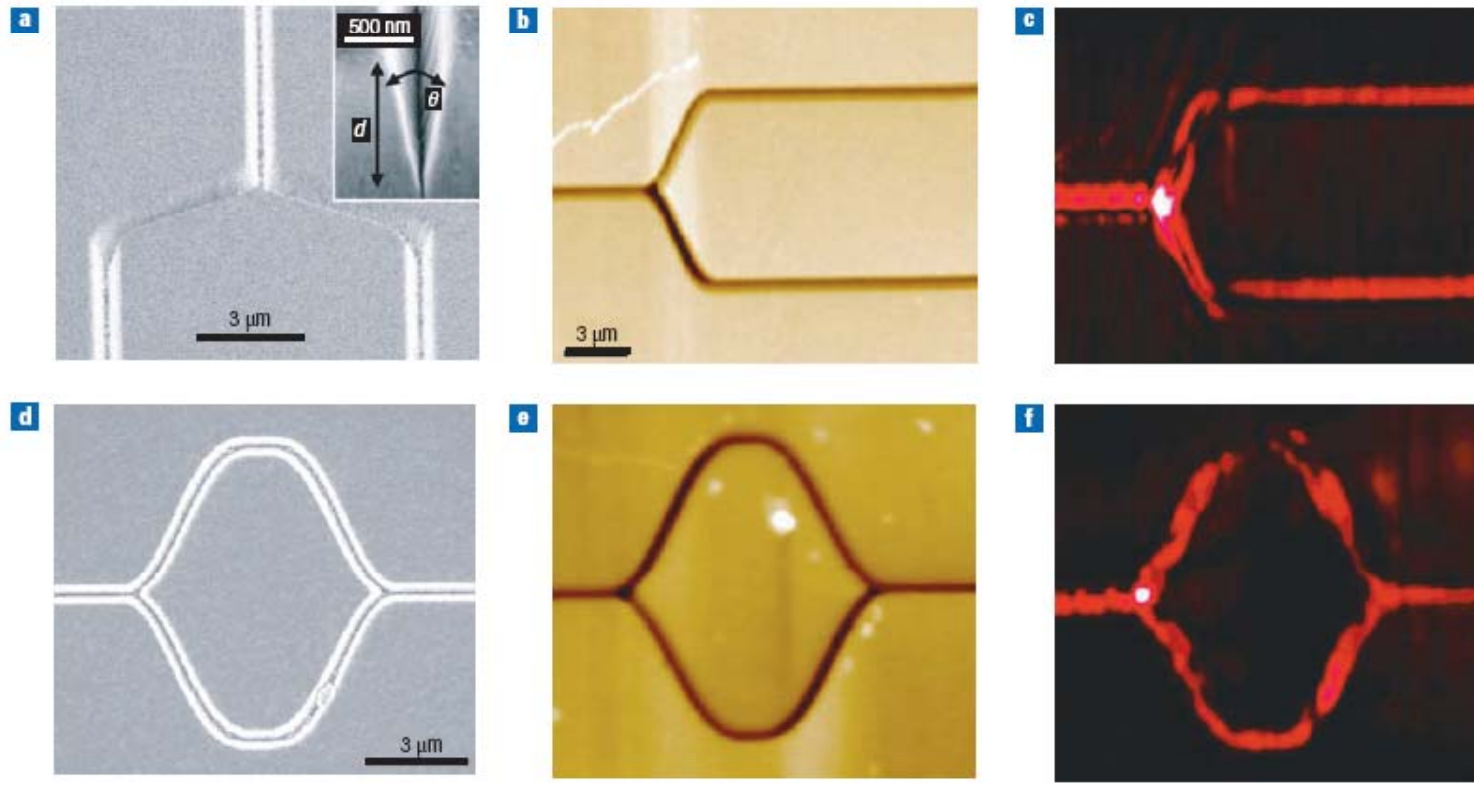


分插复用与波分复用



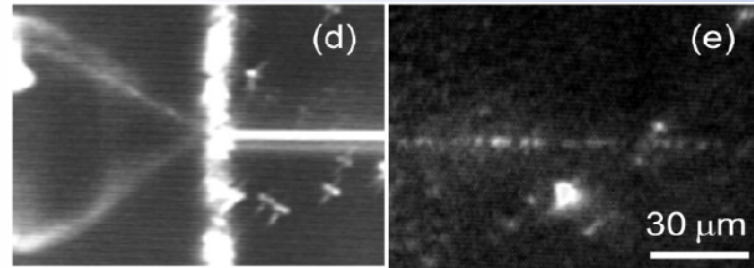
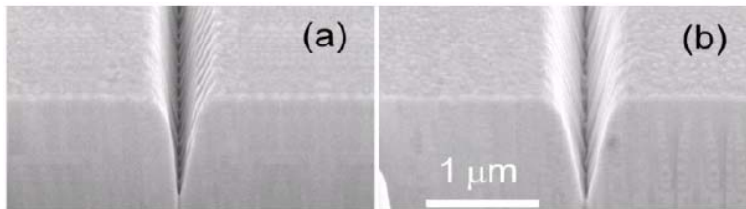
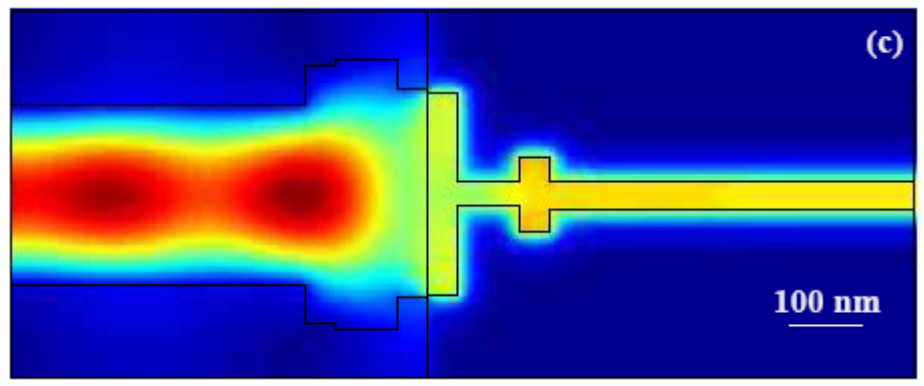
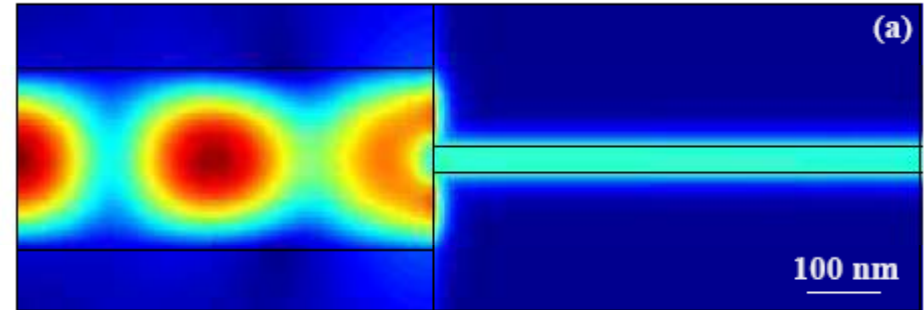
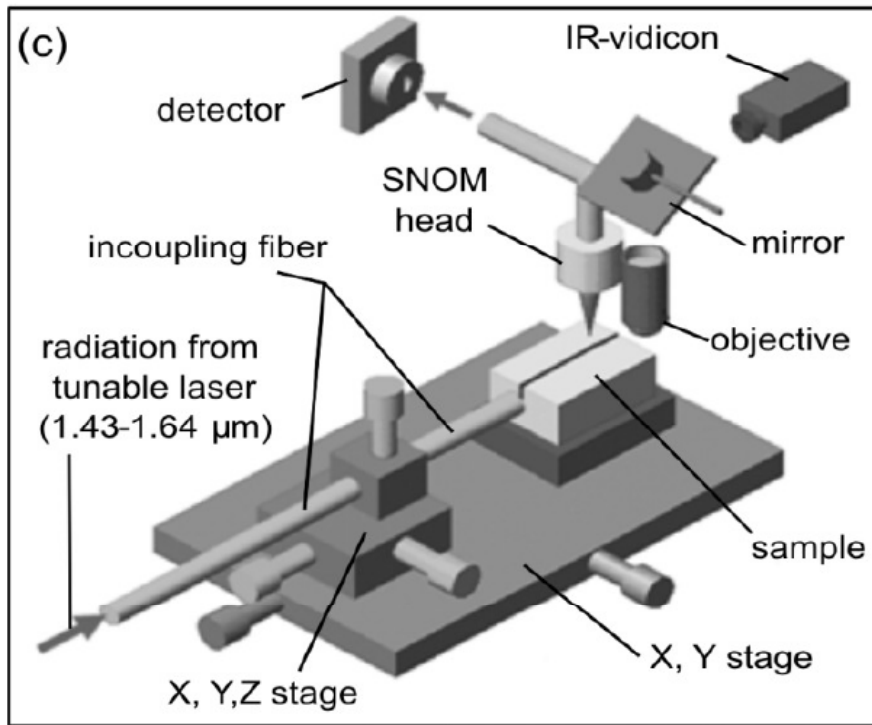


波导分束与MZ干涉



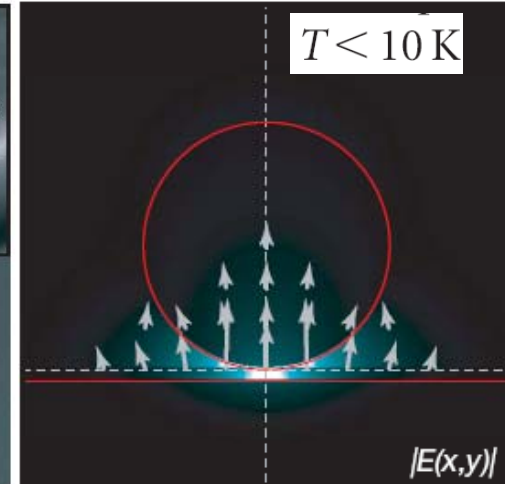
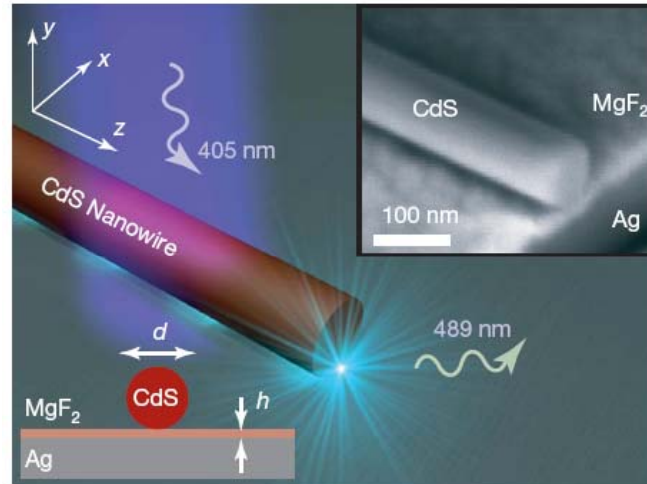
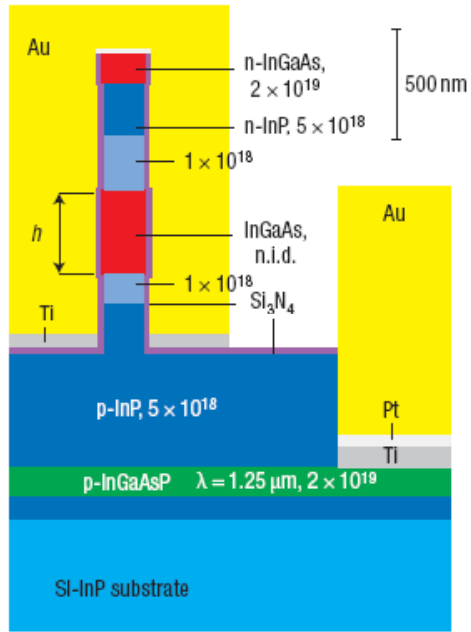


波导与光纤的对接

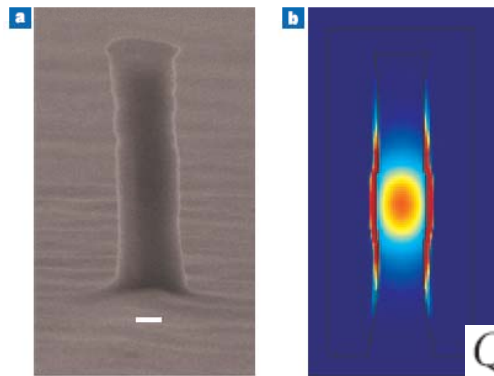




Plasmonic 纳米激光器

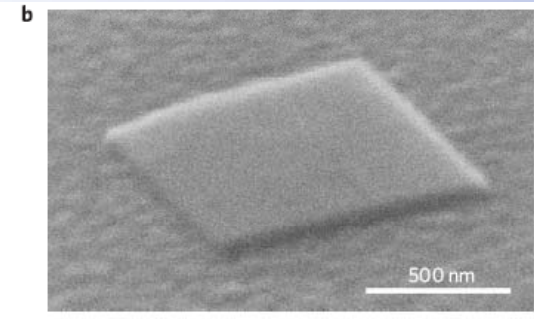
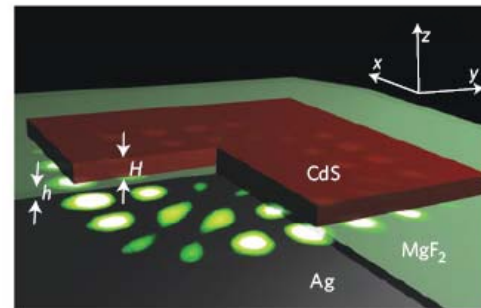


Deep subwavelength plasmon laser



$D_{\text{dielectric}}$ Golden Finger

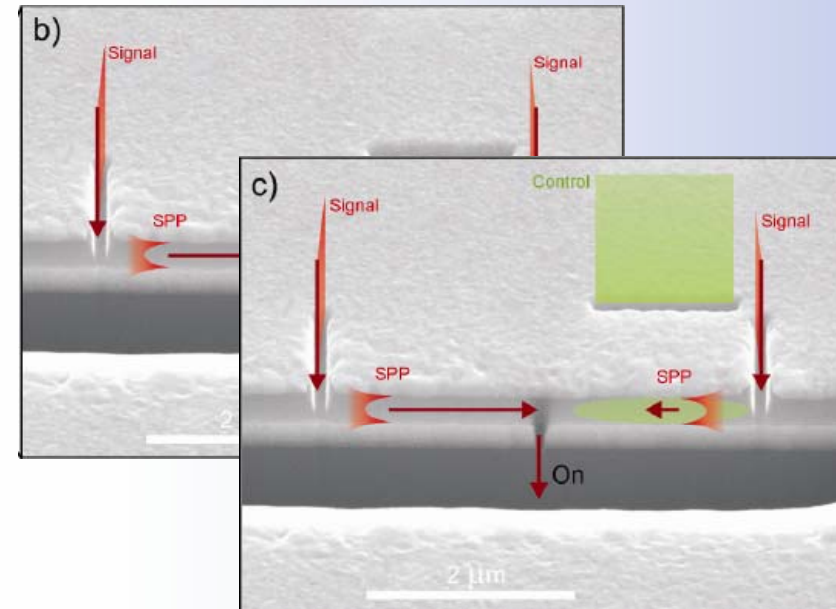
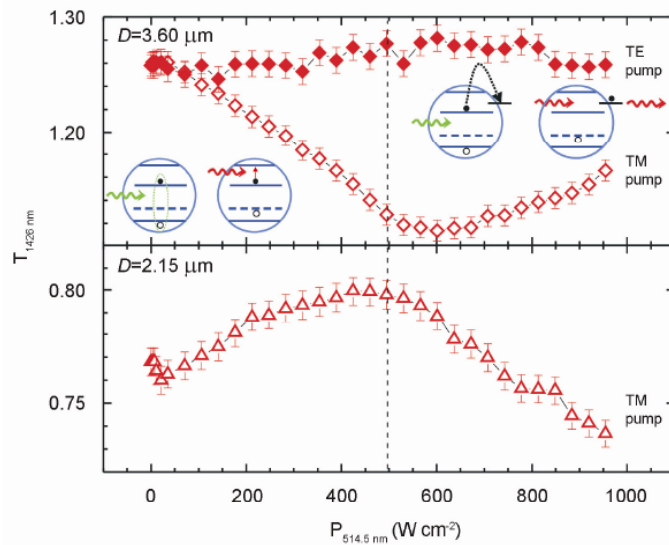
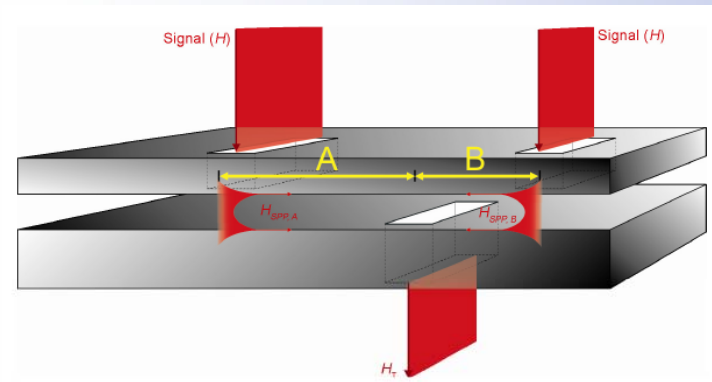
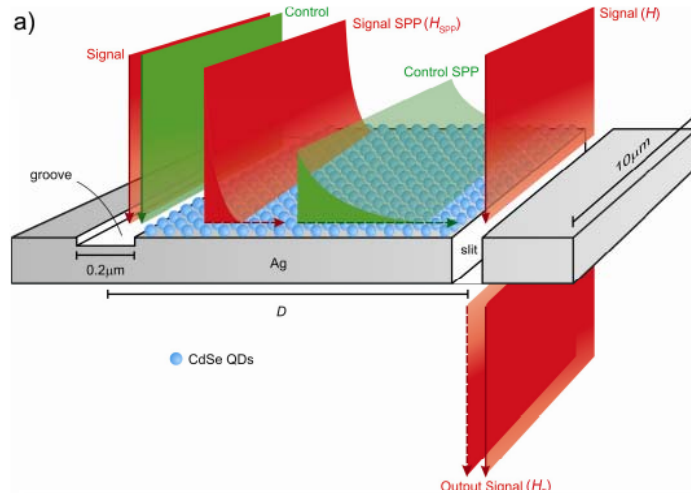
$Q = 268$ for 10 K,
 $Q = 144$ for 77 K,



Room temperature plasmon laser

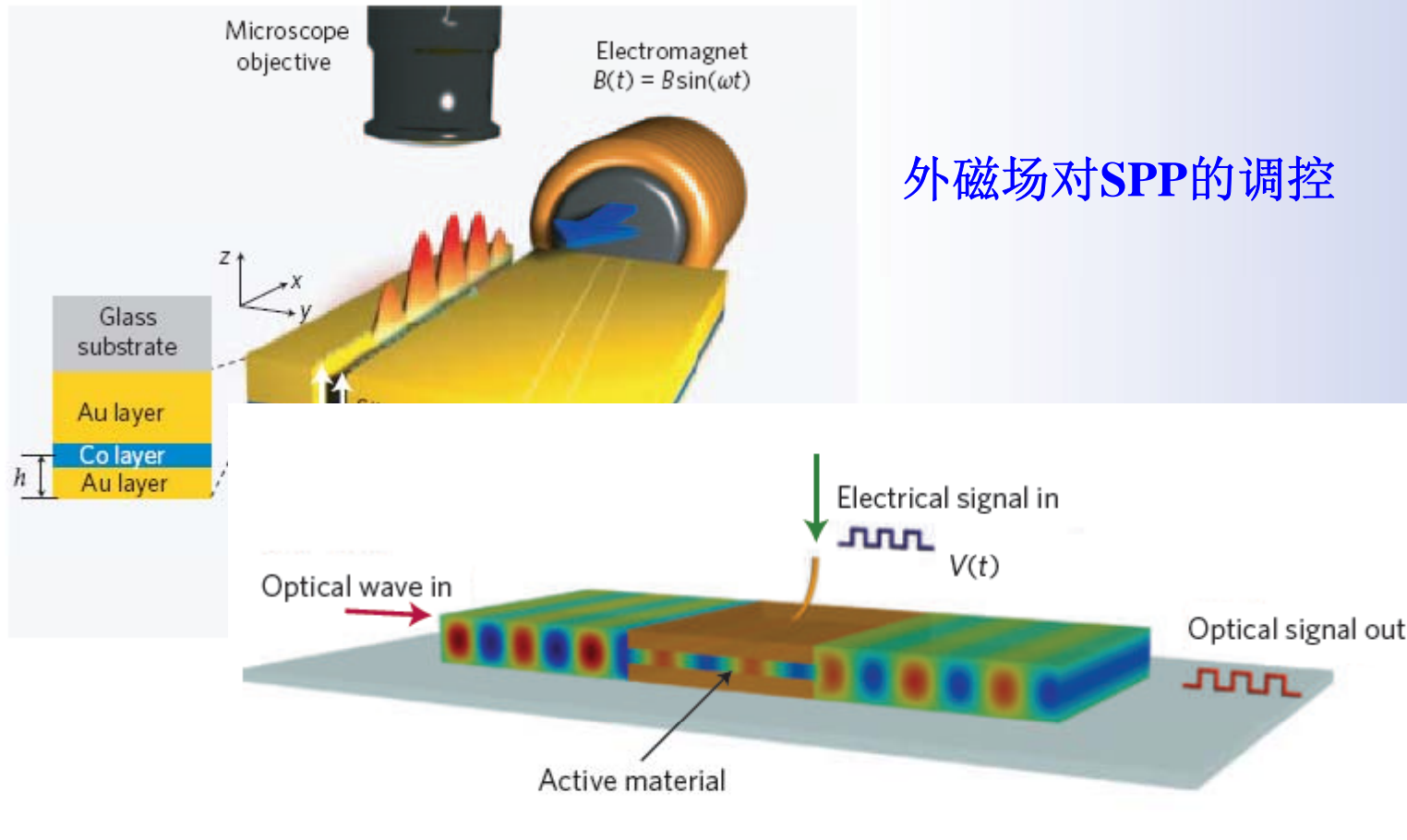


SPP动态调控





SPP动态调控

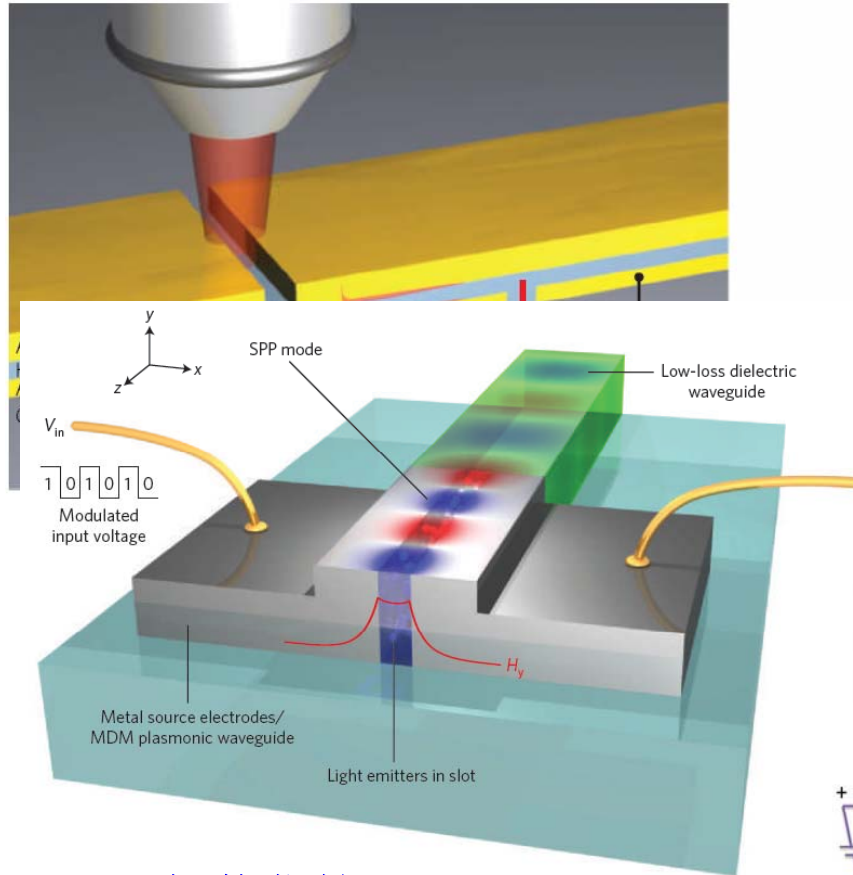


外磁场对SPP的调控

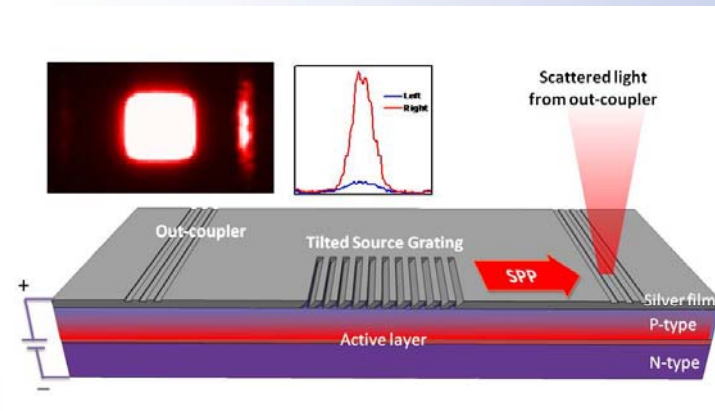
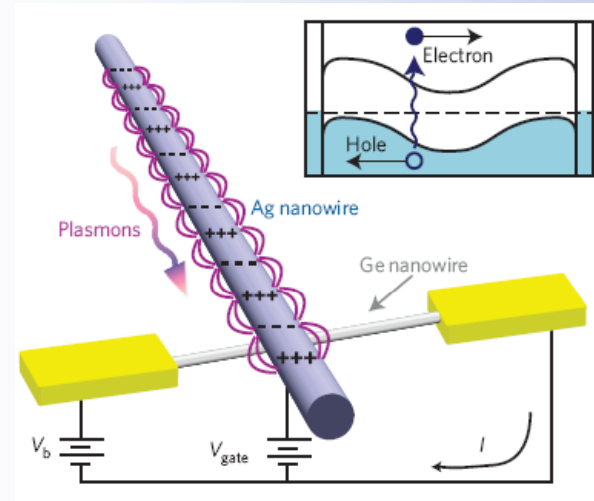
电场信号加载到SPP模式中



SPP的光电集成



电激发的plasmon



L. Wang, T. Li, et al.
OE 20, 8710 (2012)



Nanjing University

传统光学在二维平面的 拓展与应用

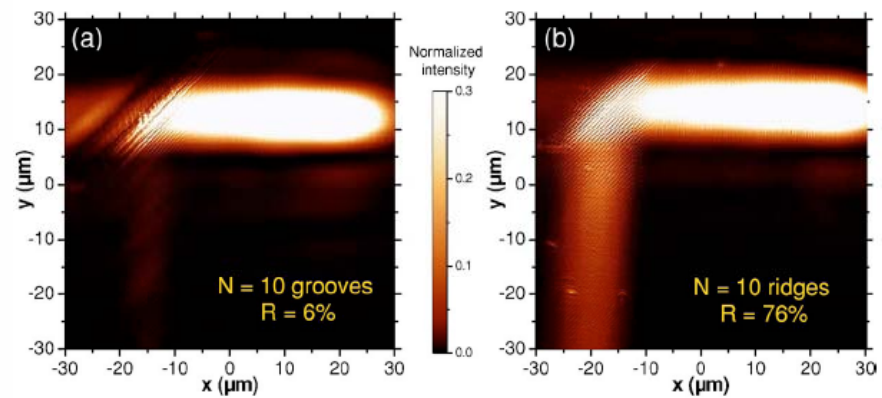
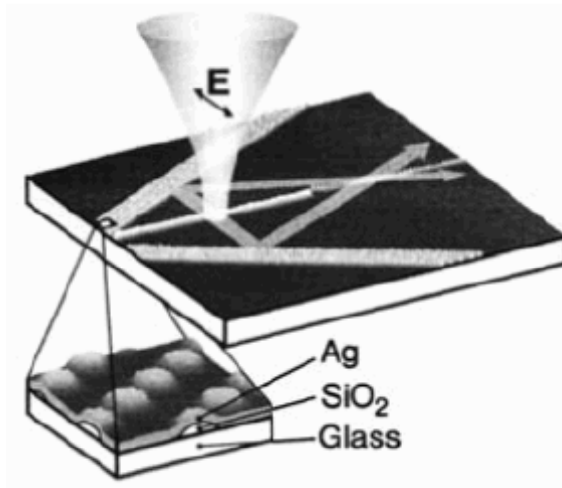
Dielectric **S**uperlattice **L**aboratory

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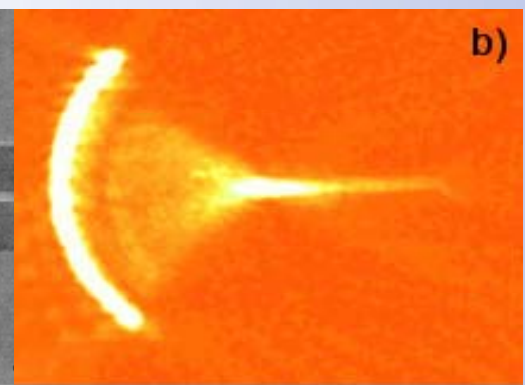
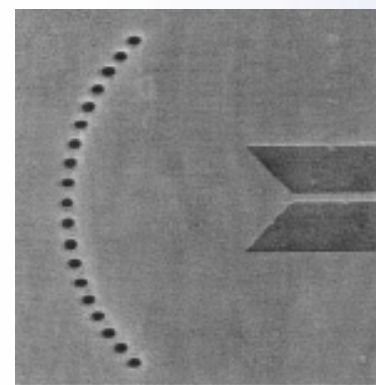
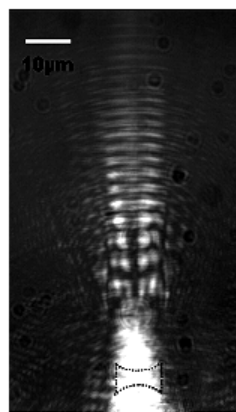
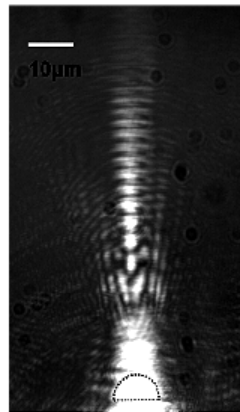
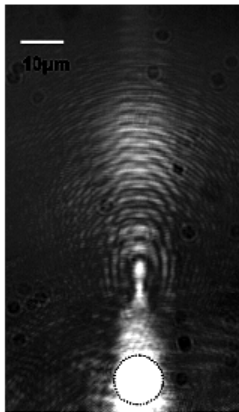
Dr. Tao Li taoli@nju.edu.cn



二维SPP光学元件



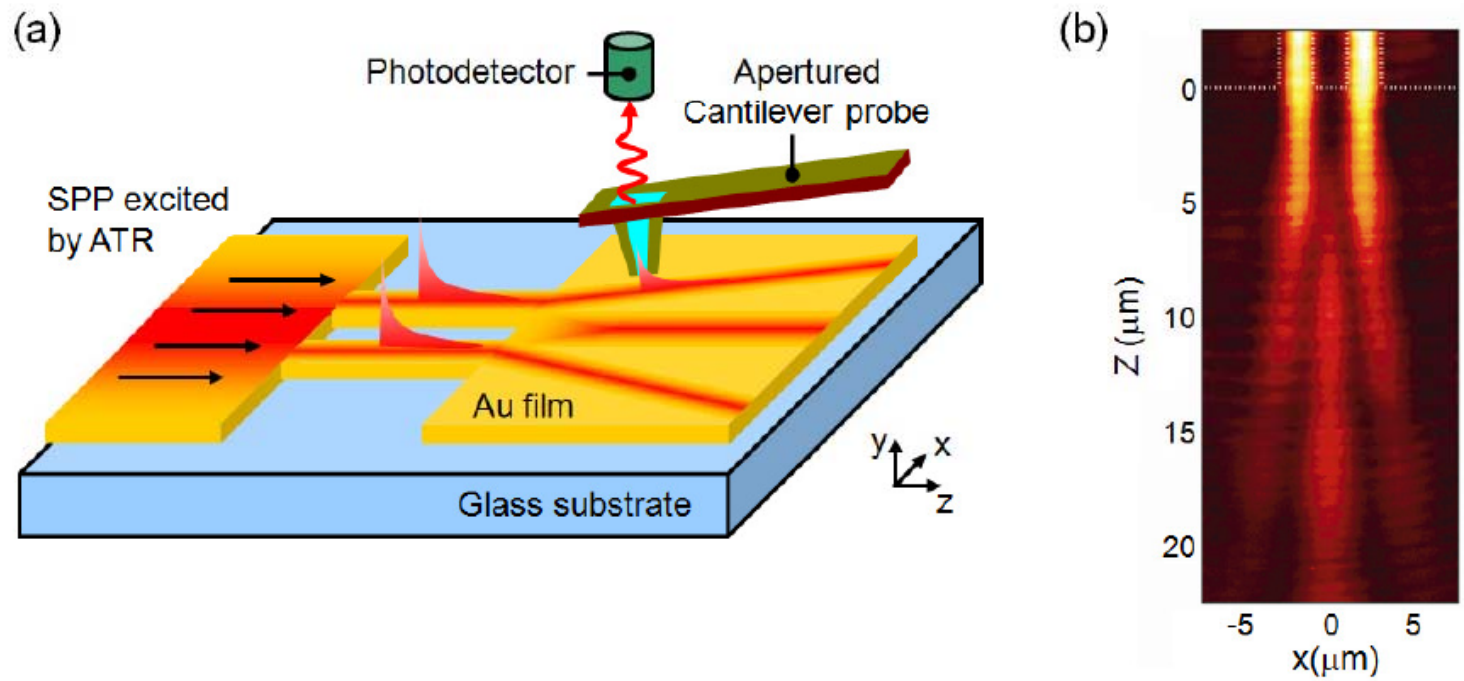
SPP Bragg反射镜



SPP透镜与聚焦



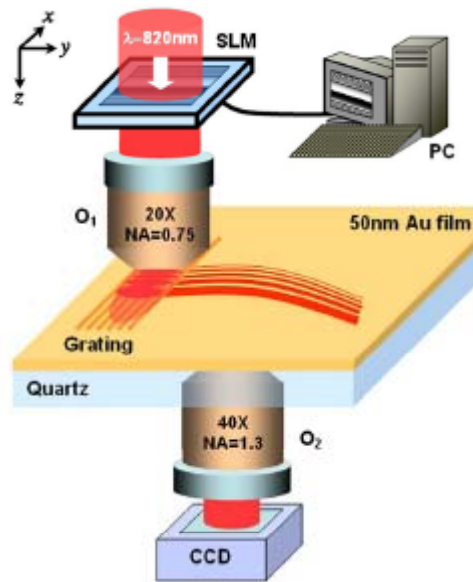
表面等离子激元的“双缝衍射”



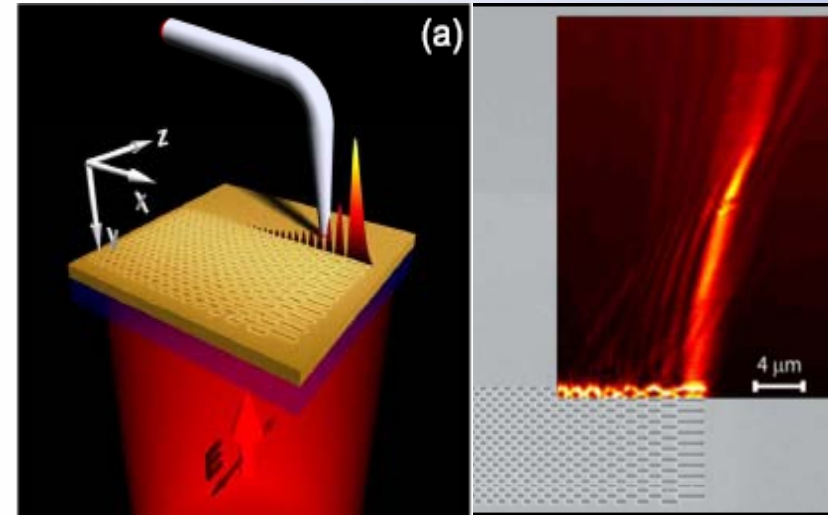
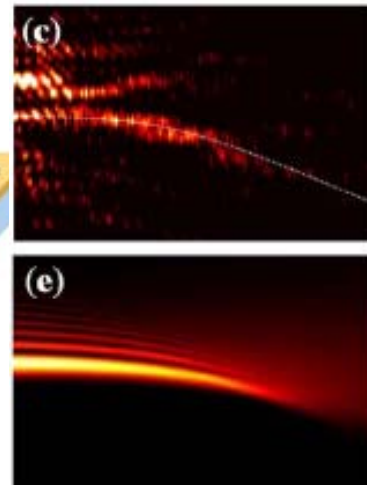
Nat. Nano. 2, 426 (2007)



表面等离子激元 Airy光束



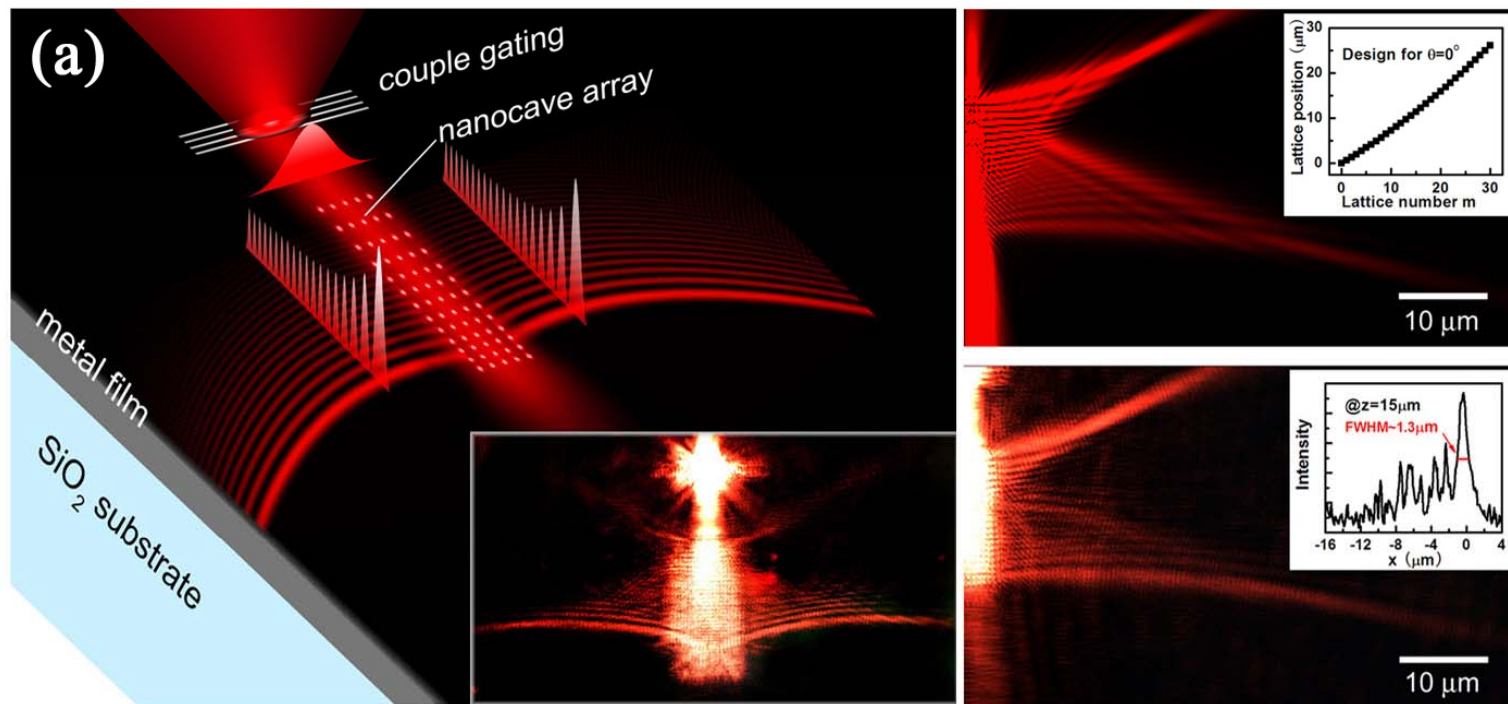
*X Zhang's group,
OL 36, 3191 (2011), August*



*Kivshar's group,
PRL 73, 155416 (2011), September, 9*



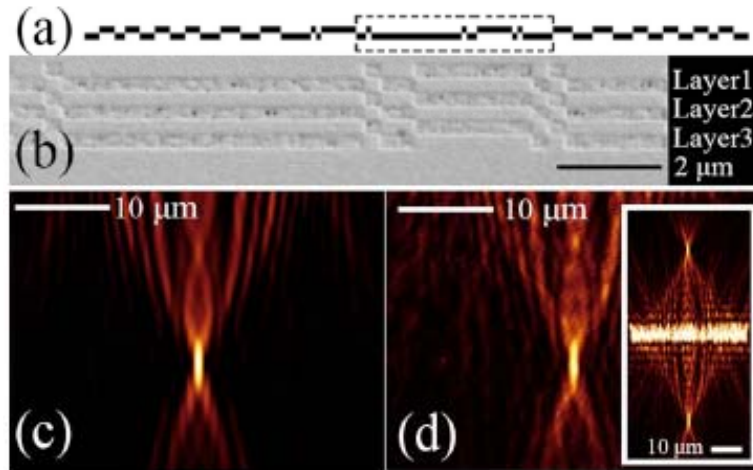
表面等离子激元 Airy光束



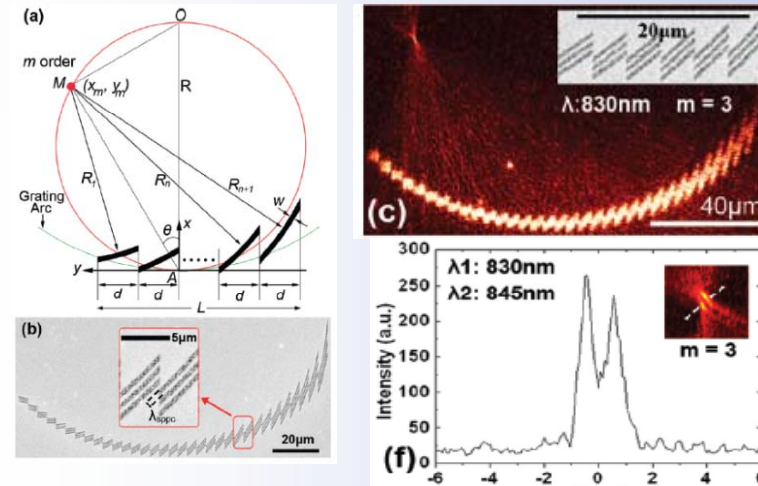
L. Li, T. Li, et. al.
PRL 107, 126804 (2011), September, 16



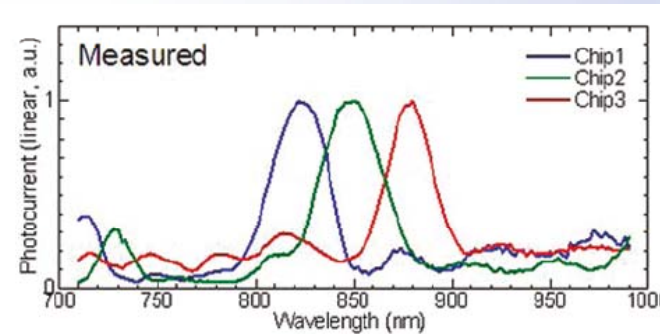
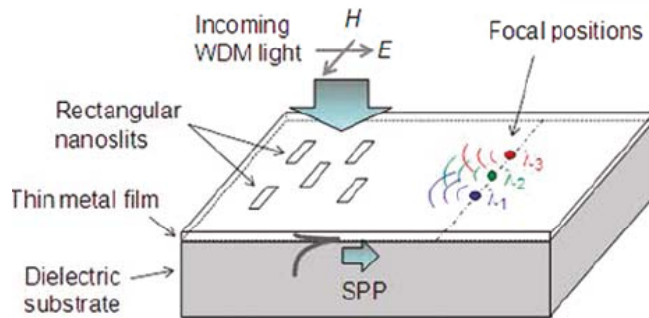
SPP平面内聚焦和波分复用



OL 16, 2417, APL 94, 081116 (2009)



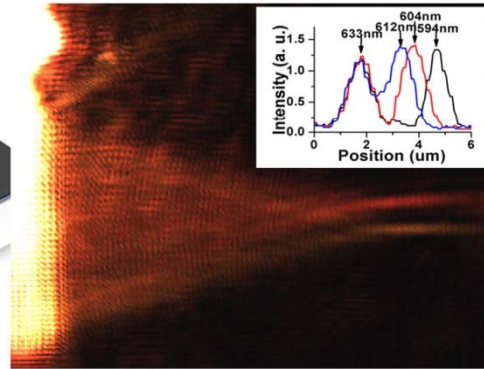
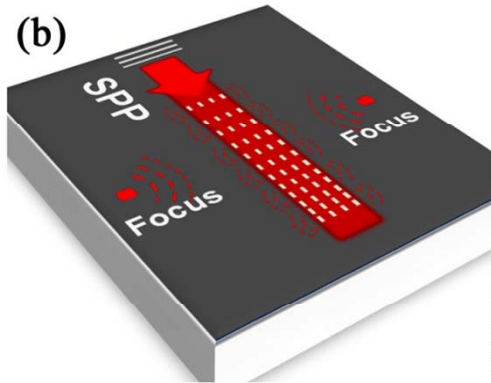
ACS Nano 11, 6433 (2010)



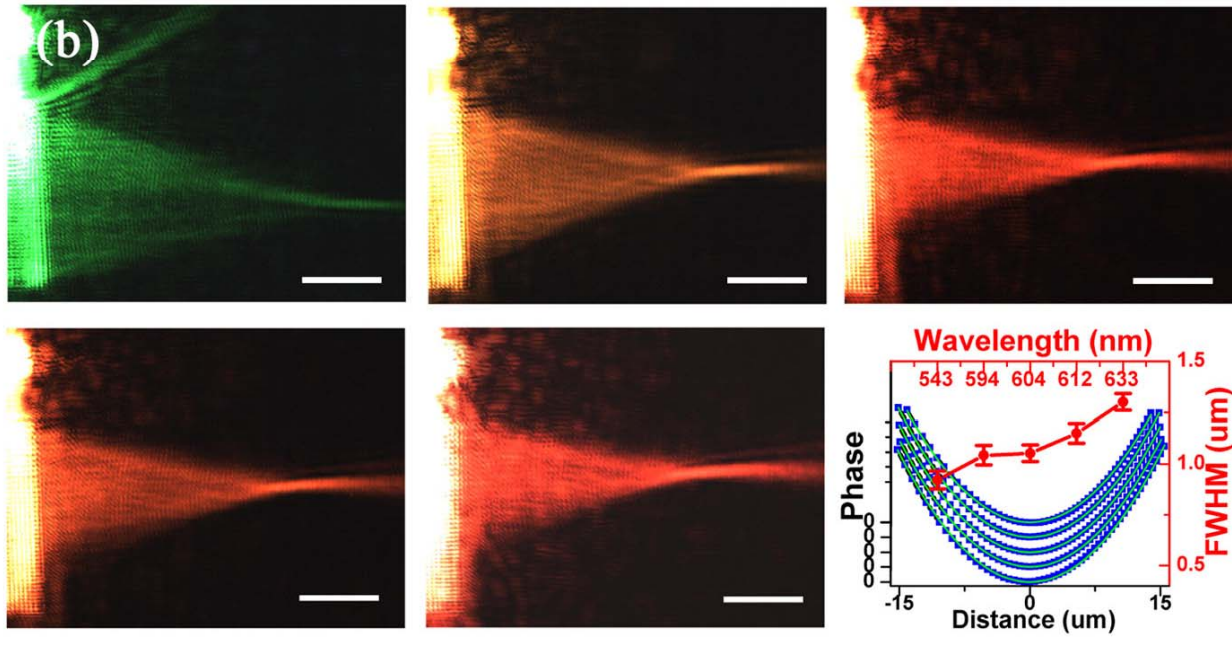
Nano Lett. 11, 2693 (2011)



SPP平面内聚焦和波分复用



L. Li, T. Li, et al.
Nano Lett. 11, 4357 (2011)





Nanjing University

SPP量子特性的研究

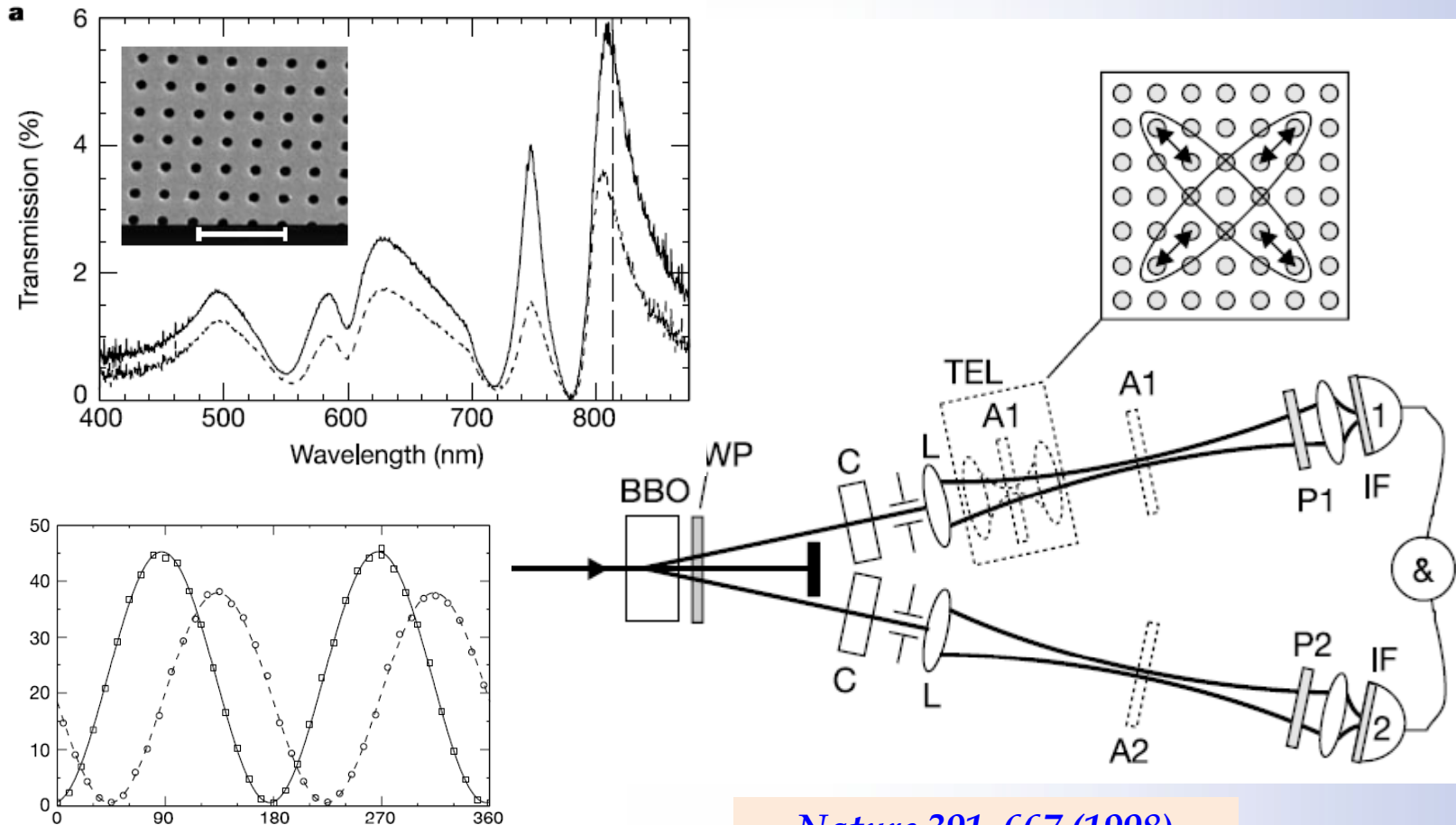
Dielectric **S**uperlattice **L**aboratory

Nat. Lab. Microstructures

Dr. Tao Li taoli@nju.edu.cn



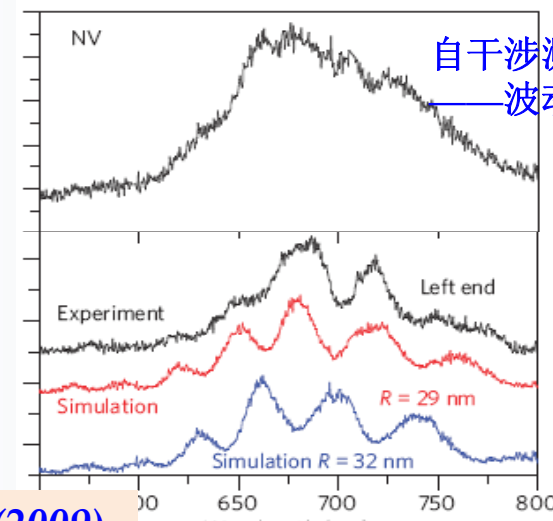
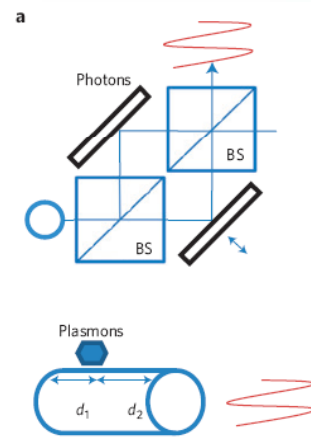
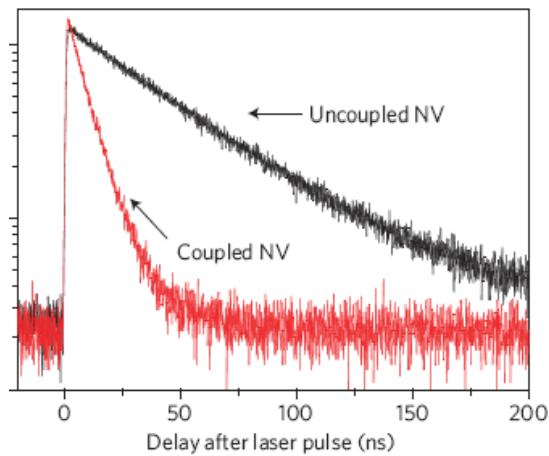
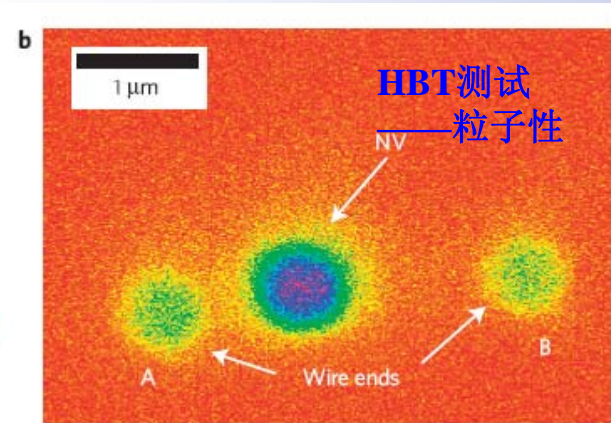
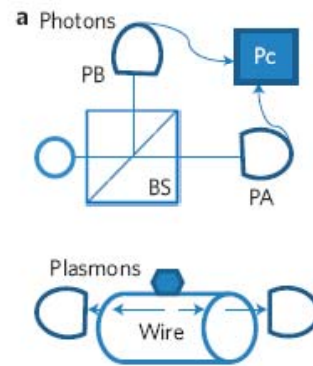
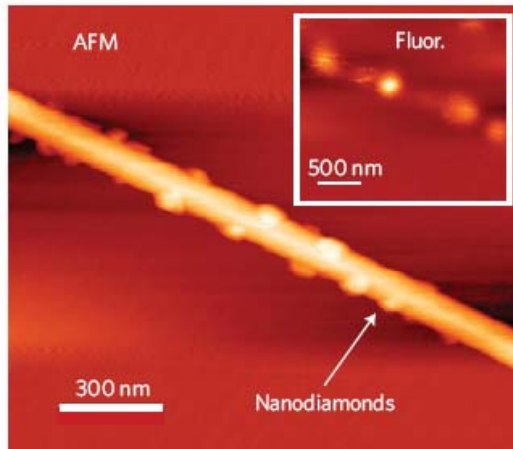
SPP对光子纠缠性质的保持



Nature 391, 667 (1998)



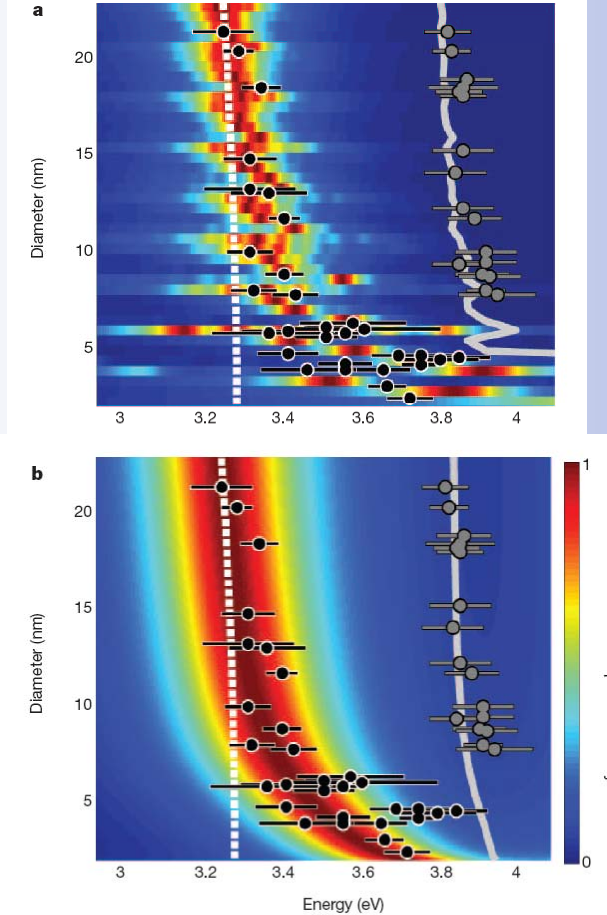
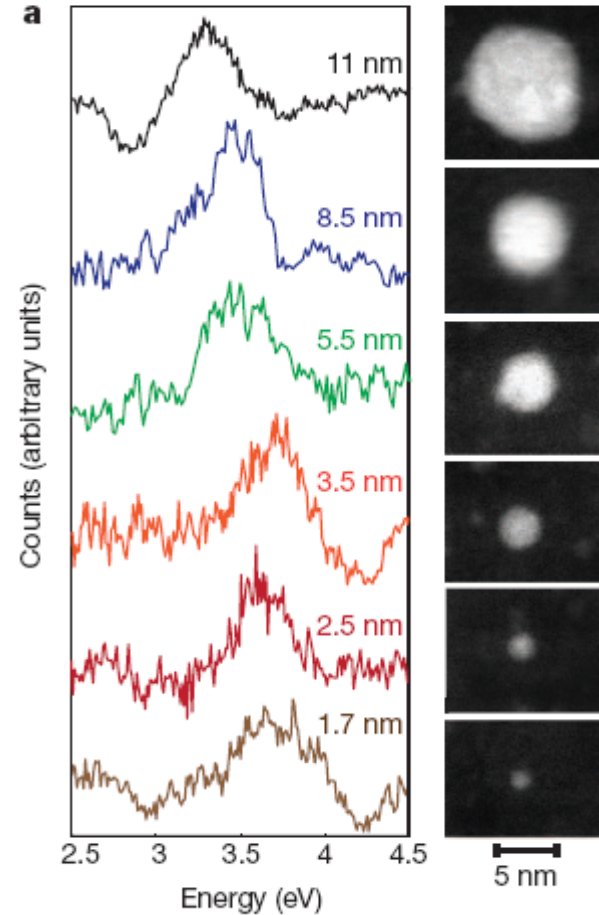
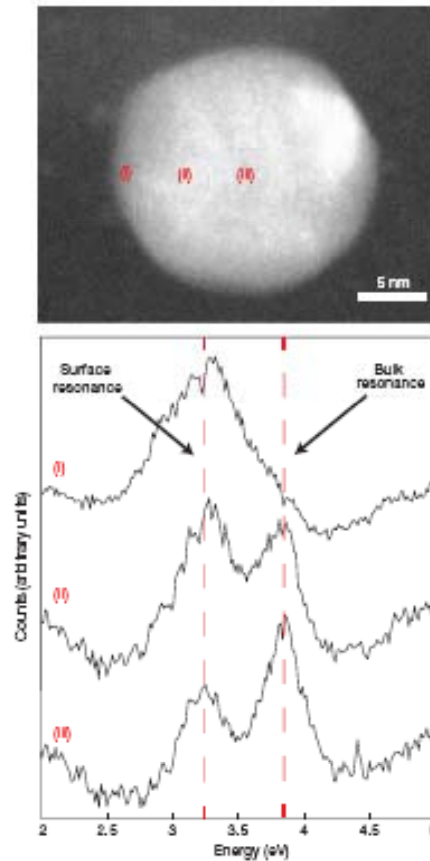
SPP的波粒二象性



Nat. Physics 5, 470 (2009)



小颗粒中的SPP量子效应



Nature 483, 421 (2012)



Nanjing University

超构材料研究 (metamaterial)

Dielectric **S**uperlattice **L**aboratory

Nat. Lab. Microstructures

Dr. Tao Li taoli@nju.edu.cn



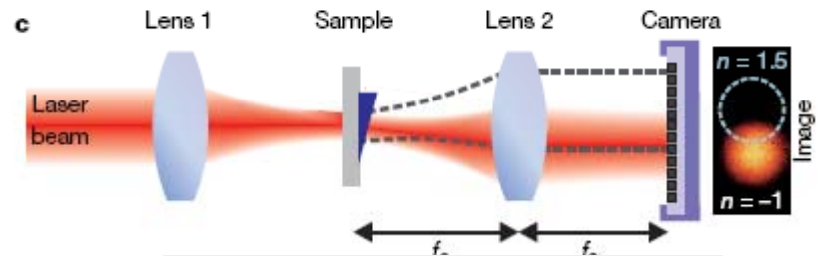
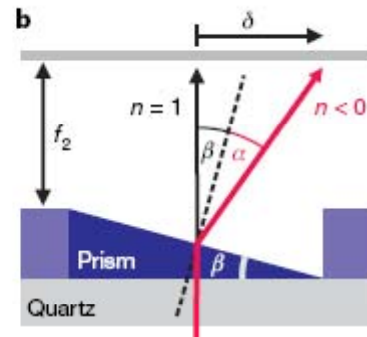
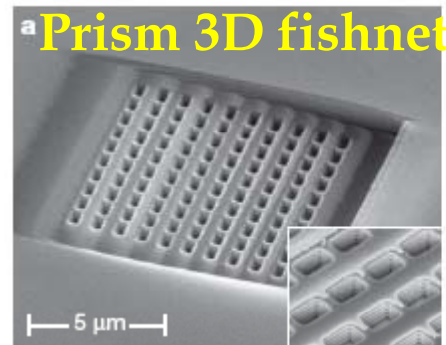
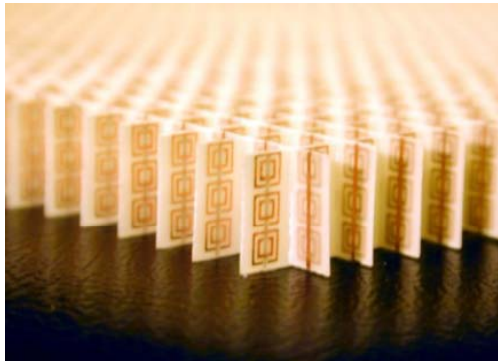
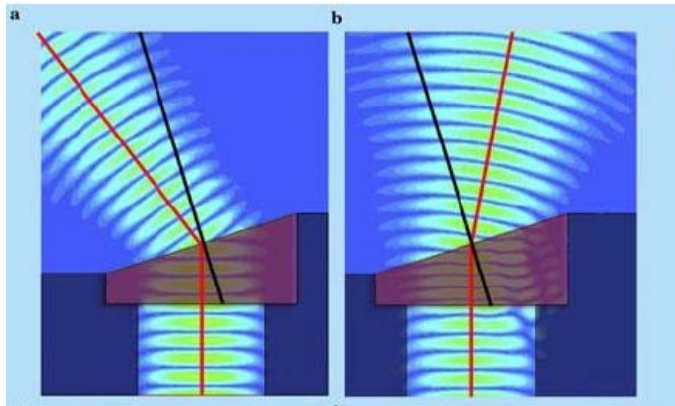
超构材料 - 负折射效应

负折射现象

metamaterial

$$n = \sqrt{\epsilon} \cdot \sqrt{\mu}$$

$$\epsilon < 0, \mu < 0 \Rightarrow n < 0$$



Science 292, 77 (2001)

Nature 455, 379 (2008)

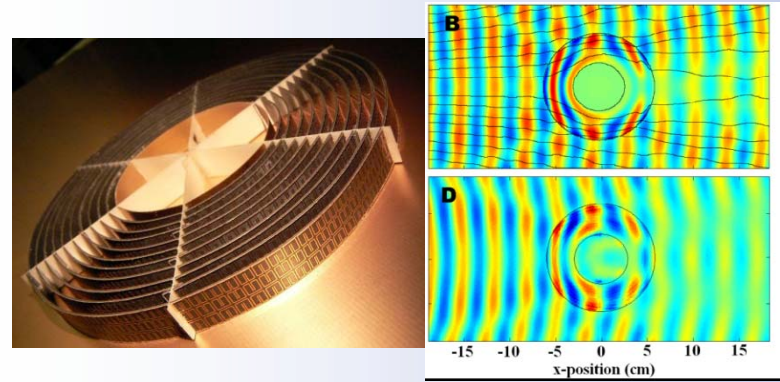
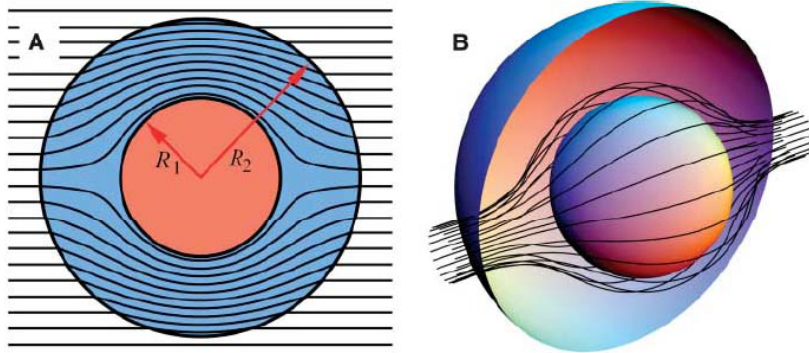
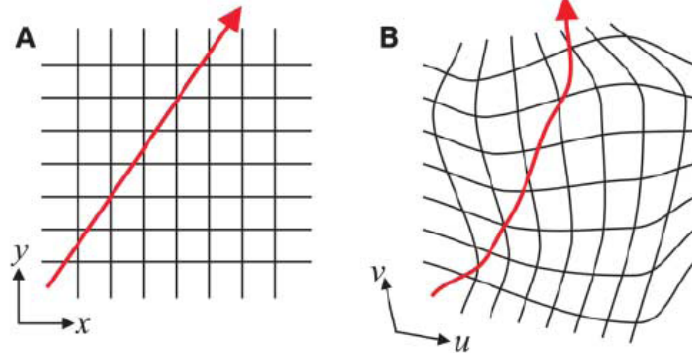


光学隐身衣 (超构材料变换光学) metamaterial

Cloaking隐身

在有效介质条件下，空间任意区域的 ϵ, μ 可以人为确定， n 也就可以人为确定

人们就可以设计材料按照自己意愿让光进行传播



Pendry

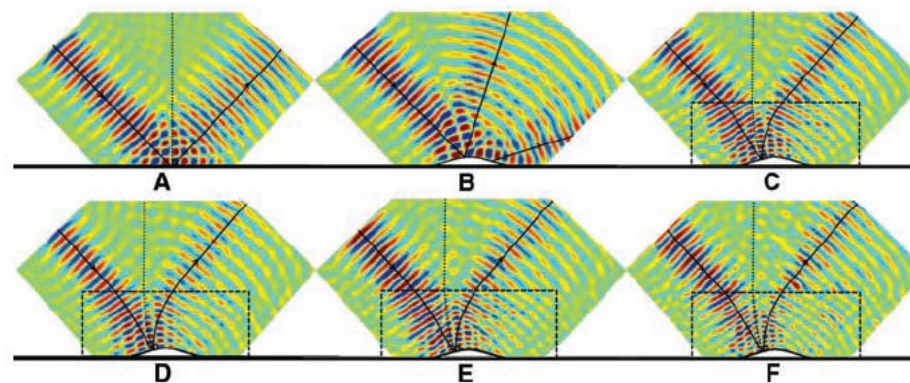
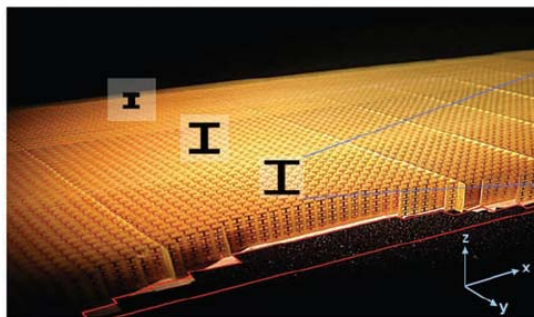
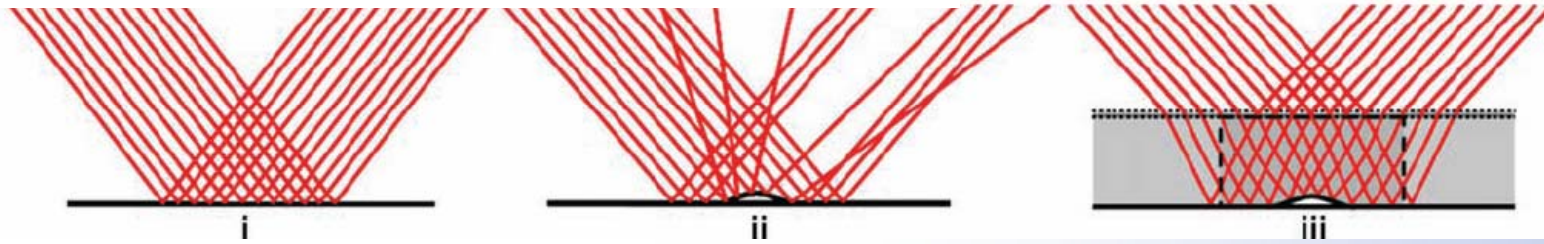
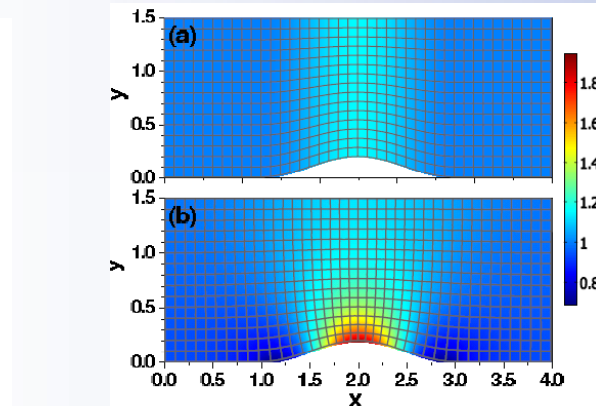
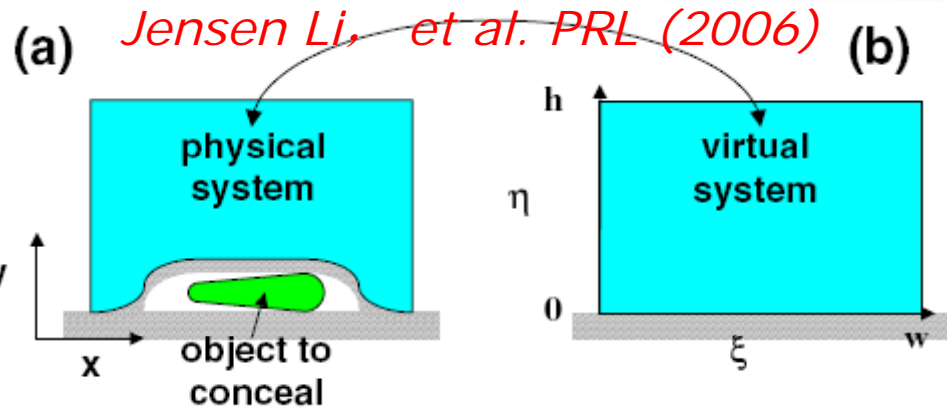
rlattice]

Science 312, 1780 (2006)

D. R. Smith, et al, Science (2006)



隐身地毯 (及微波波段实现)

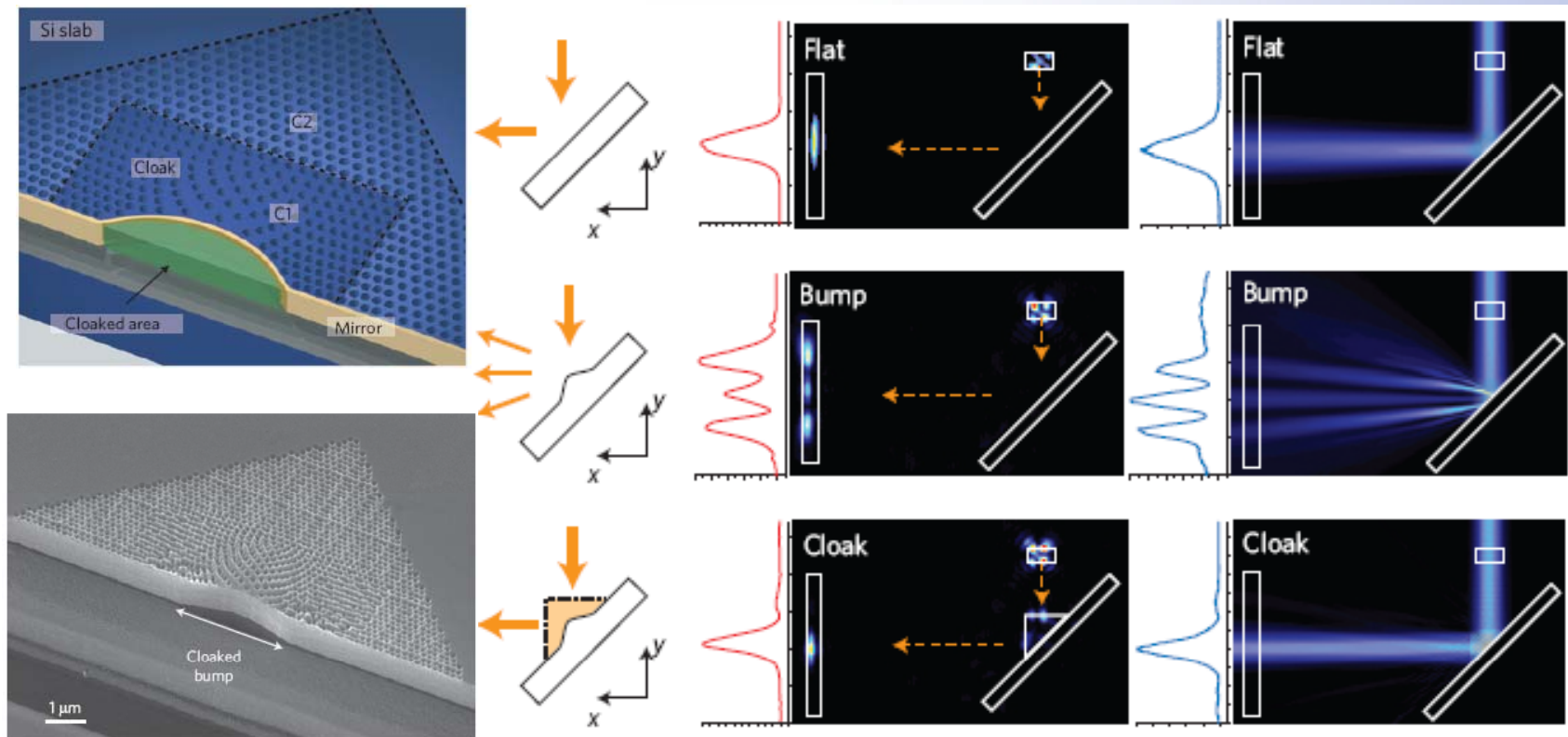


I *Science* 323, 366 (2009)

Microwave region, by D. R. Smith group



隐身地毯 (光波段实现)



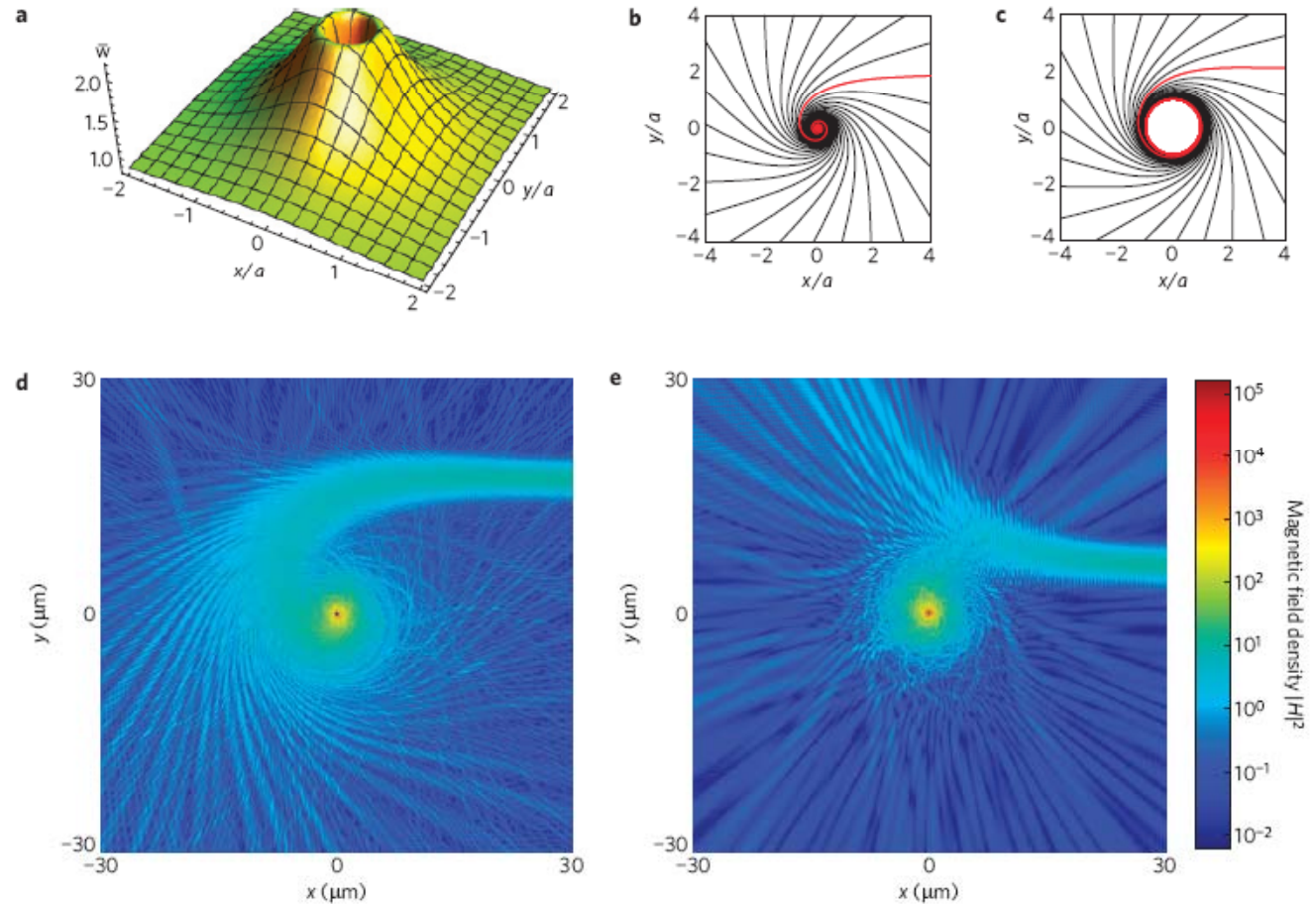
Nat. Mater. 8, 568 (2009)

1550 nm, By Xiang Zhang group (2009)

D_ielectric S_uperlattice L_aboratory



人造黑洞 (变换光学)



Nat. Physics 5, 687 (2009)

Dielectric Superlattice Laboratory

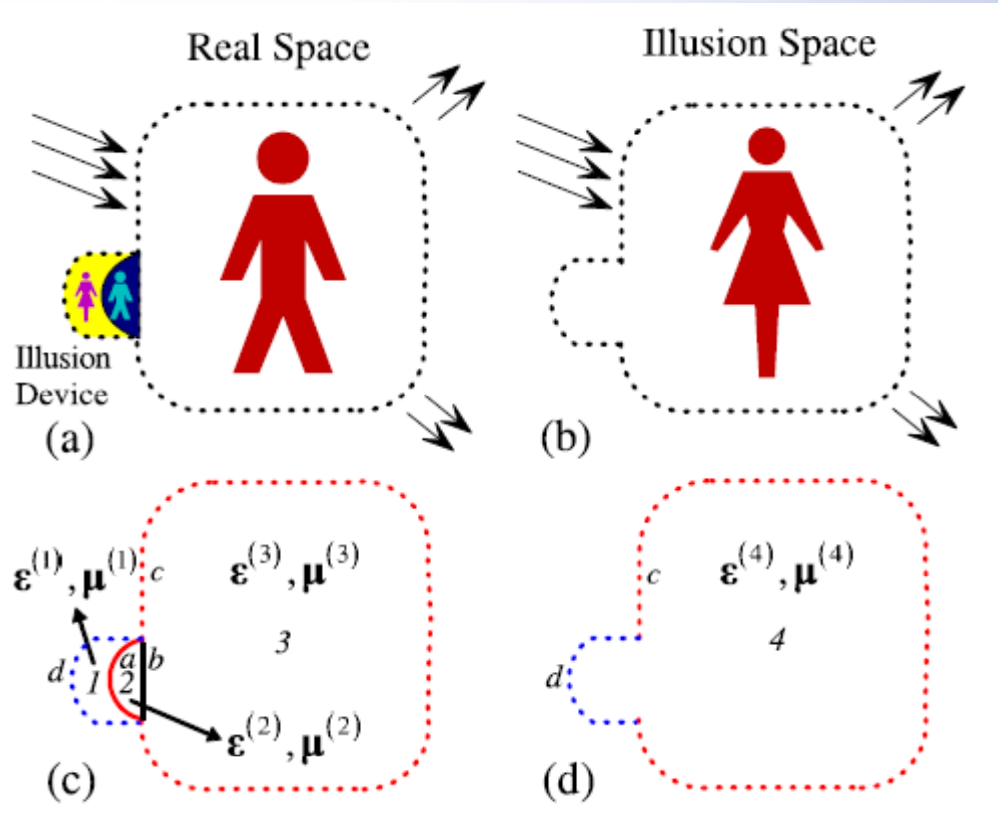
By Xiang Zhang group (2009)



幻象光学 (*Illumination Optics*)

Illusion Optics:
The Optical Transformation of an Object into Another Object

A further development of Transformation Optics



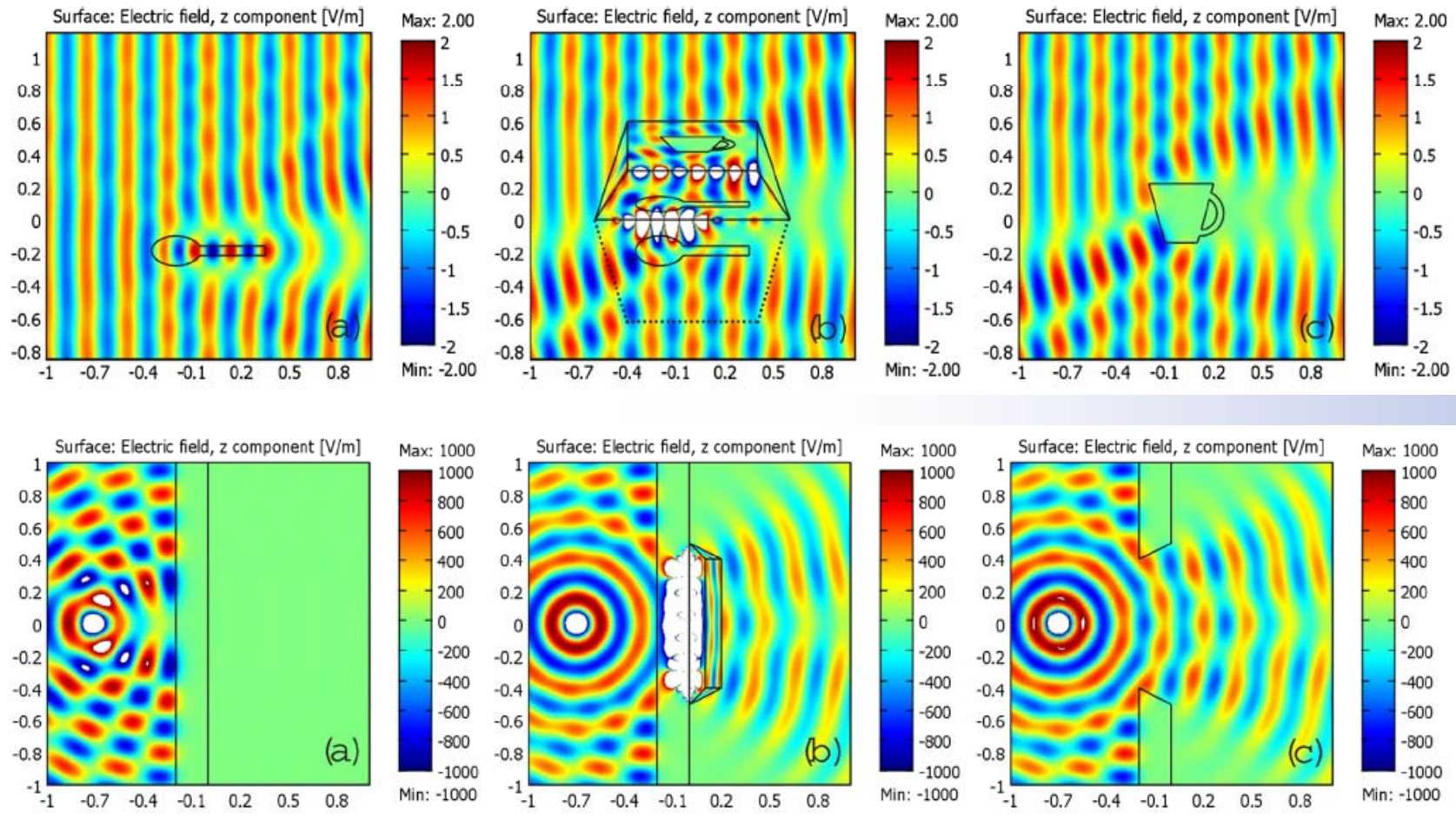
PRL 102, 253902 (2009)

Dielectric Superlattice Laboratory

By C.T. Chen group (2009)



幻象光学 (*Illumination Optics*)



By C.T. Chen group (2009)



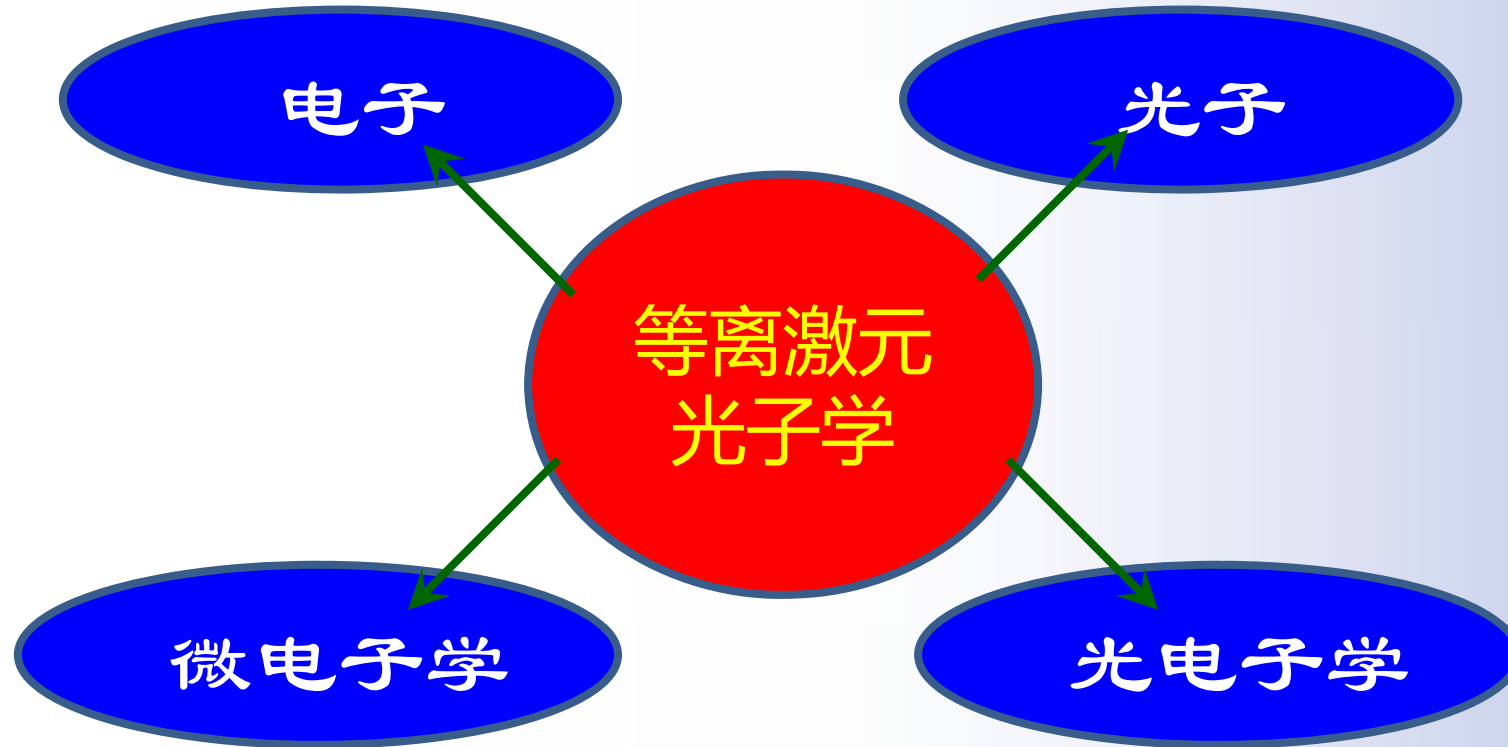
结论与展望

By using metallic nanostructures as a bridge between photonics and electronics, one plays to the strengths of the metallic nanostructures (concentrating fields and subwavelength guiding), the dielectric waveguides (low loss information transport) and the nanoscale electronic components (high speed information processing).

——Mark L. Brongersma



结论与展望



充满希望，充满机遇！



Nanjing University

谢谢大家!

相关资料请登陆
<http://dsl.nju.edu.cn/litao/res/>

Dielectric **S**uperlattice **L**aboratory

Nat. Lab. Microstructures

Dr. Tao Li taoli@nju.edu.cn