第五章 量子微纳光学

5.1 分子荧光

5.2 纳米结构近场区域偶极子弛豫系数

5.3 SPP增强分子荧光的前沿进展

5.4 SPP 的量子性

5.5 基于超构表面的量子性质

5.6 基于拓扑光子结构的量子性质

5.7 微纳尺度腔量子电动力学及应用

古英 ygu@pku.edu.cn

第五章 量子微纳光学

5.5 基于超构表面的量子性质

5.5.1 量子干涉和量子关联

5.5.2 量子光源

5.5.3 量子态操控

5.5.4 其它

量子光学和量子信息关注的部分核心问题：

光和量子体系作用、量子干涉和量子关联、量子光源、量子态操控及其过程中的损耗、效率、制备等

超构表面的特色：

有特定功能的周期或准周期人工微（亚波长）结构薄层

a. 微结构单元有共振时，近场增益 → 产生和调控量子光源和量子体系 （如SPP结构中情况）

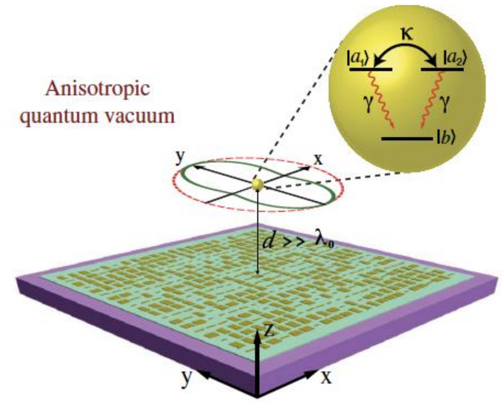
b. 超构表面特定功能包括（但不限于）相位跃变、偏振和振幅调控 → 调控量子光源和量子体系 的相位、方向和角动量等

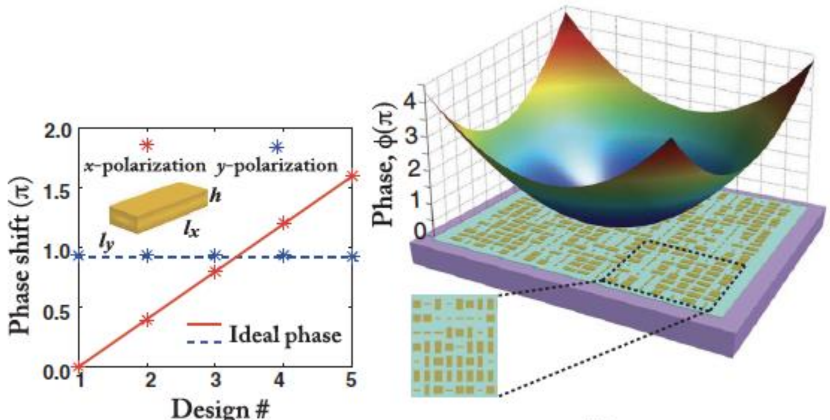
c. 周期或准周期的薄层→ 独特的优越于三维超材料的性质

5.5.1 量子干涉和量子关联

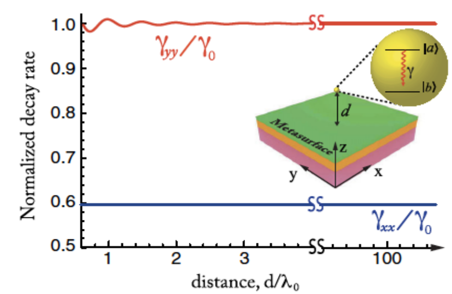
利用超构表面造成的相位和振幅可控的各向异性真空调控量子干涉

damping term takes the form $\kappa = (\gamma_{xx} - \gamma_{yy})/2$. From Fig. (4) we obtain $\gamma_{xx} = 0.6, \gamma_{yy} = 1$ which yields $\kappa = -0.2$. If we consider $d = 20\lambda_0$ where $\lambda_0 = 894$ nm, we obtain a significant cross damping at a distance of ~ 18 μm from the metasurface. It is worth mentioning that





(a) (b)



PRL **115,** 025501 (2015) PHYSICAL REVIEW LETTERS week ending 10 JULY 2015

Metasurface-Enabled Remote Quantum Interference

Pankaj K. Jha,[1] Xingjie Ni,[1] Chihhui Wu,[1] Yuan Wang,[1] and Xiang Zhang[1,2,*]

利用超构表面的各向异性真空（珀塞尔系数）增强量子干涉

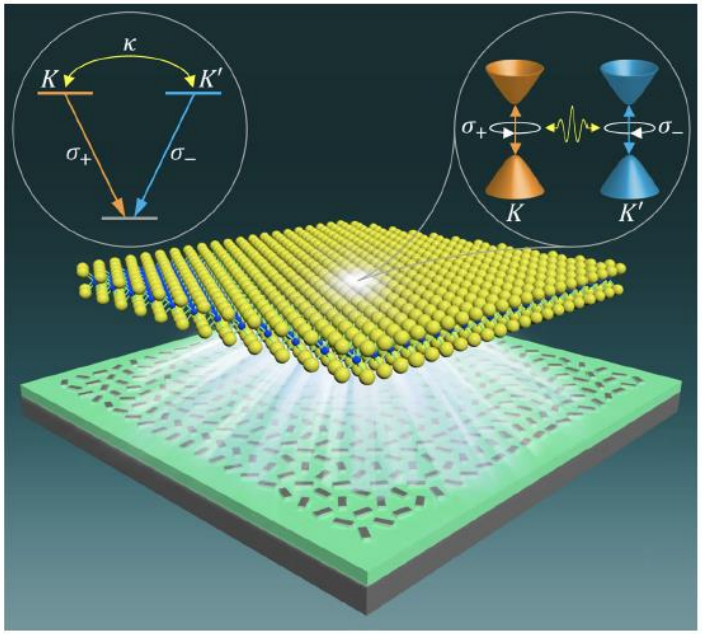
Transition metal dichalcogenides (TMDCs) of the form MX2 (M . Mo,W;X . S, Se, Te)

原理与上页同

不同之处：

emitter由原子换成TMDC

超构表面重新设计

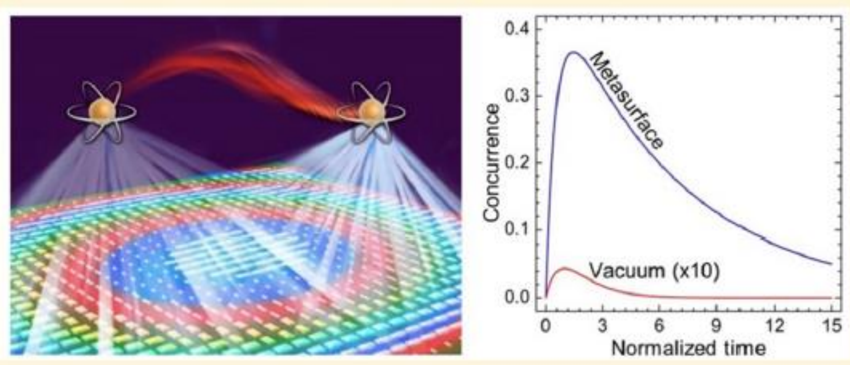


Spontaneous Exciton Valley Coherence in Transition Metal Dichalcogenide Monolayers Interfaced with an Anisotropic Metasurface

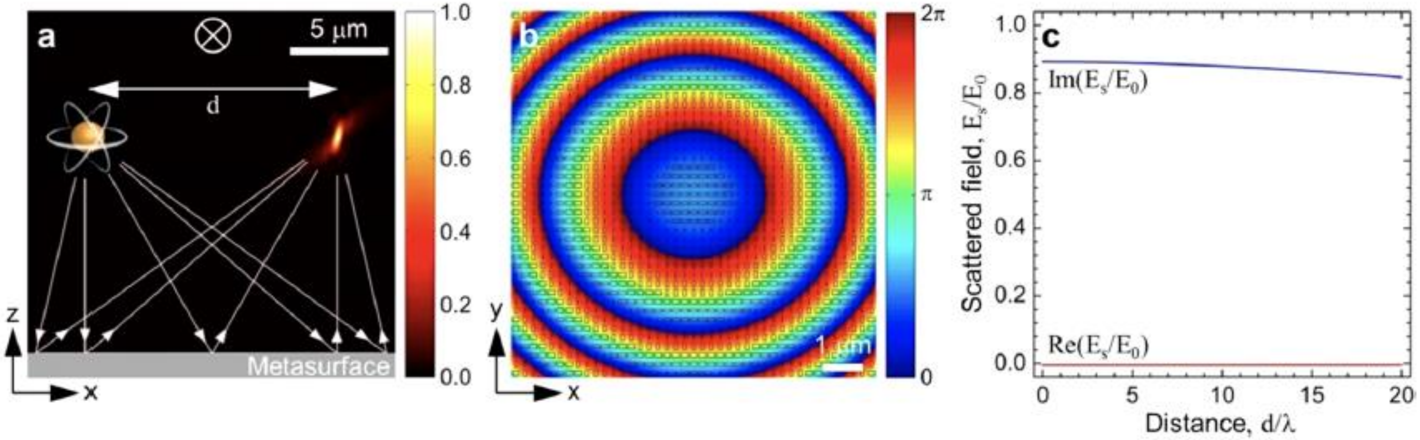
Pankaj K. Jha,[1,†] Nir Shitrit,[1,†] Xuexin Ren,[1] Yuan Wang,[1] and Xiang Zhang[1,2,*]

PHYSICAL REVIEW LETTERS **121,** 116102 (2018)

利用超构表面增强量子比特间的纠缠



原理：第一个比特发出的光通过超构表面聚焦在第二个量子比特上，可达90%



Metasurface-Mediated Quantum Entanglement

Pankaj K. Jha,[†,§] Nir Shitrit,[†,§] Jeongmin Kim,[†] Xuexin Ren,[†] Yuan Wang,[†] and Xiang Zhang[*,†,‡]

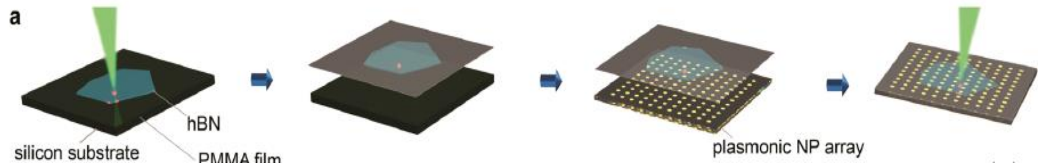
ACS Photonics 2018, 5, 971–976

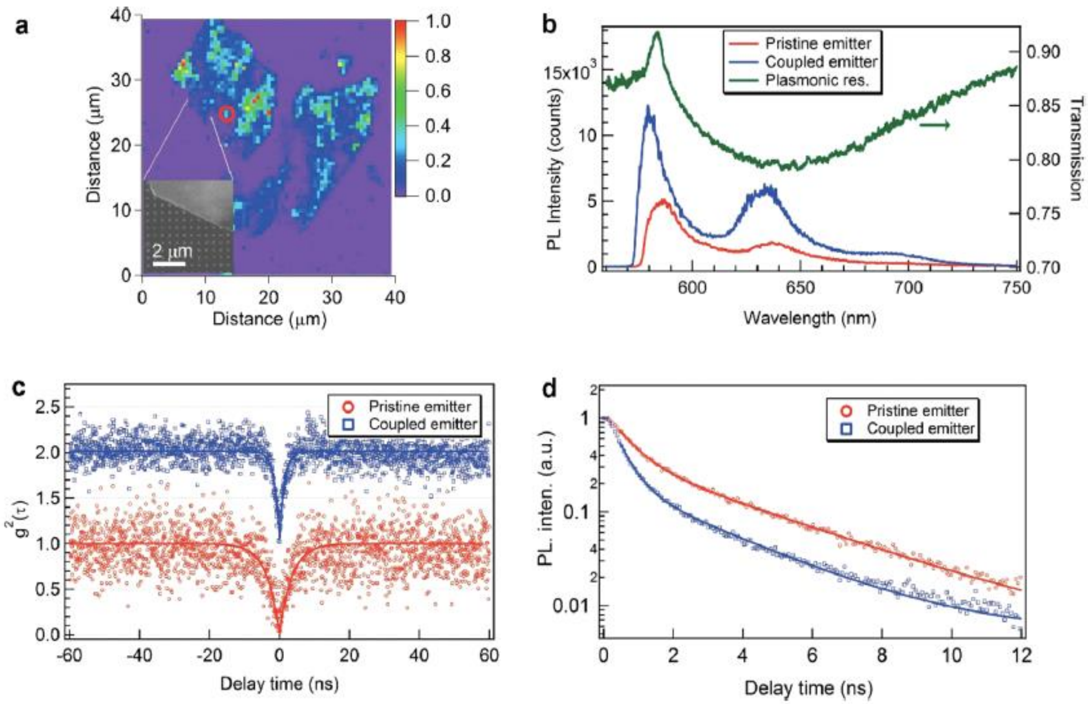
5.5.2 量子光源

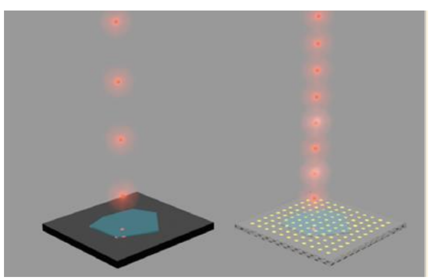
超构表面上的Purcell 效应

quantum emitters in 2D hexagonal boron nitride (hBN) （六角氮化硼）

可以看到：正常的和耦合的emitters荧光谱线不同







Deterministic Coupling of Quantum Emitters in 2D Materials to Plasmonic Nanocavity Arrays

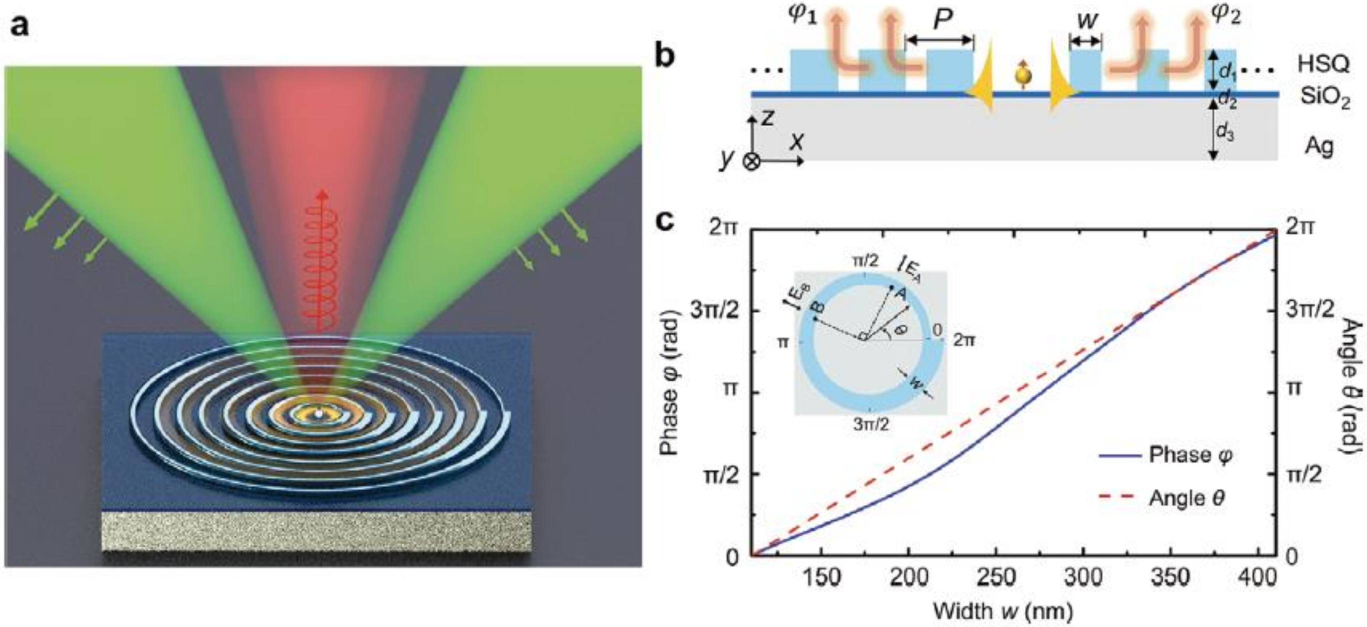
Toan Trong Tran,[†] Danqing Wang,[‡] Zai-Quan Xu,[†] Ankun Yang,[§] Milos Toth,[†] Teri W. Odom,[‡,§,∥] and Igor Aharonovich*[,†]

Nano Lett. 2017, 17, 2634−2639

通过超构表面产生圆偏振的高方向性的单光子

hydrogen silsesquioxane (HSQ) 氢硅酸盐类

超构表面设计 + linear polarized NV center



150 nm thick HSQ width-varying nanoridges with the period $P = 550$ nm
20 nm thin SiO_2 spacer and a 200 nm thick Ag substrate

Metasurface-Enabled Generation of Circularly Polarized Single Photons

Adv. Mater. **2020**, *32*, 1907832

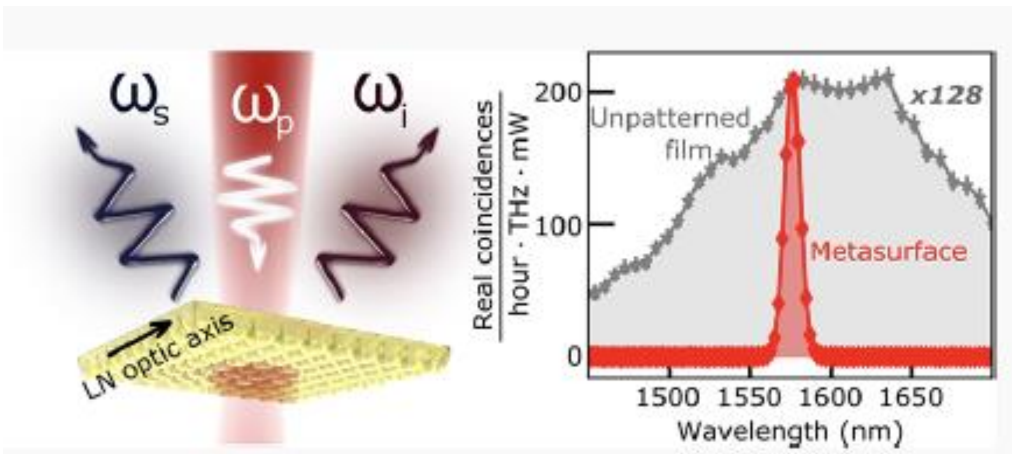
Yinhui Kan, Sebastian K. H. Andersen, Fei Ding, Shailesh Kumar, Changying Zhao, and Sergey I. Bozhevolnyi**

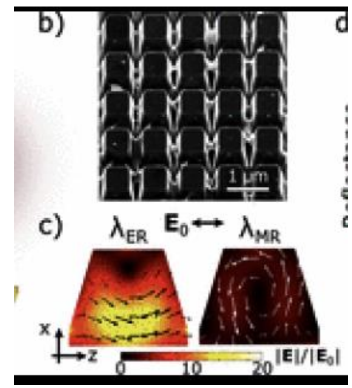
用共振超构表面的SPDC过程上产生窄线宽光子对

Spontaneous degenerate conversion

原理：在铌酸锂衬底上*设计超构表面*的电共振和磁共振，利用共振模式的局域场增强提高光子对的产率和线宽变窄

lithium niobate (LN) and gallium phosphide (GaP).



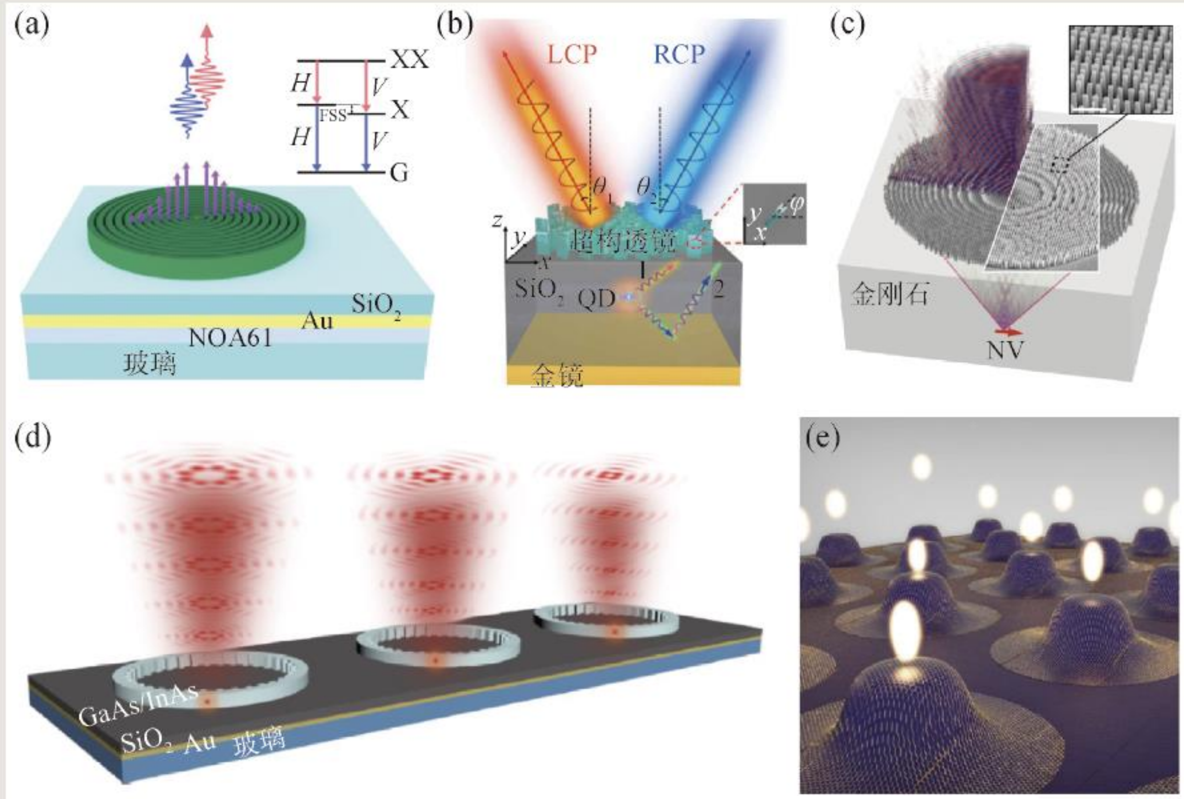


Photon Pairs from Resonant Metasurfaces

Nano Lett. 2021, 21, 4423–4429

Tomás Santiago-Cruz,*,▽ Anna Fedotova,▽ Vitaliy Sultanov, Maximilian A. Weissflog, Dennis Arslan, Mohammadreza Younesi, Thomas Pertsch, Isabelle Staude, Frank Setzpfandt, and Maria Chekhova

其它超构表面中的量子光源



布拉格环(CBR-HBR)结构

图1 基于超构表面的量子发光体光源 (a)基于CBR-HBR的量子点纠缠光源[13]；(b)自旋按需调控的双焦点超构透镜量子点辐射[14]；(c)超构透镜对单NV色心单光子源的辐射调控[15]；(d)嵌入量子点的微环谐振腔产生携带OAM量子叠加态的单光子源[18]；(e)超构表面诱发二维hBN单光子辐射[20]

浅谈超构表面在量子光学中的应用

李 林[1,†] 程 亚[1,2,††] 祝世宁[3,†] 物理 · 50卷 (2021年) 5期 308

and references therein.

5.5.3 量子态操控

Stav *et al.*, *Science* **361**, 1101–1104 (2018)

利用介质超构表面

操控纠缠光子对

Si-based geometric phase metasurface (GPM)

Quantum entanglement of the spin and orbital angular momentum of photons using metamaterials

Tomer Stav[1]*, Arkady Faerman[2]*, Elhanan Maguid[2], Dikla Oren[1], Vladimir Kleiner[2], Erez Hasman[2]†, Mordechai Segev[1]†

原理：单光子的自旋和轨道角动量纠缠

$$|H\rangle|\ell=0\rangle=\frac{1}{\sqrt{2}}(|\sigma_+\rangle+|\sigma_-\rangle)|\ell=0\rangle$$

$$|V\rangle|\ell=0\rangle=\frac{1}{\sqrt{2}i}(|\sigma_+\rangle-|\sigma_-\rangle)|\ell=0\rangle$$

$$|\sigma_\pm\rangle|\ell\rangle \overset{\text{GPM}}{\rightleftarrows} |\sigma_\mp\rangle|\ell\pm\Delta\ell\rangle$$

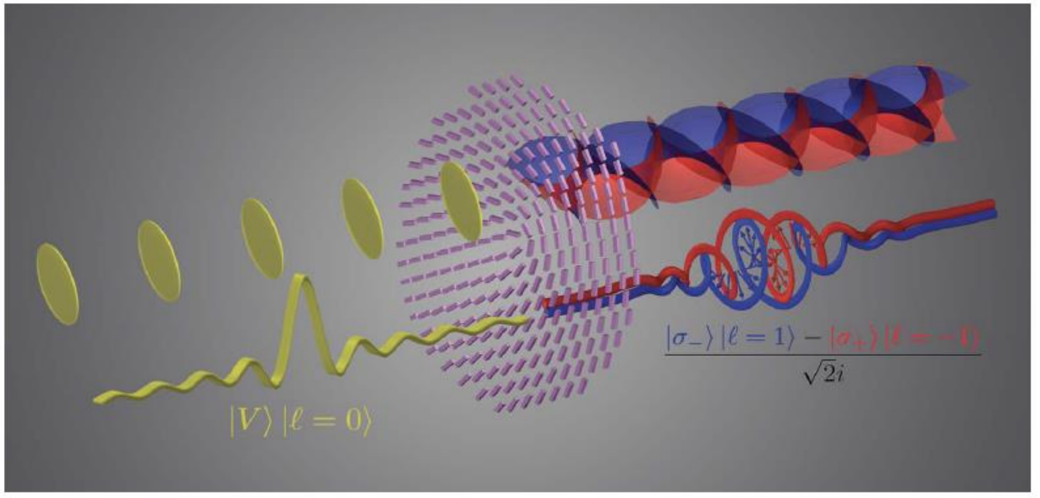


Fig. 1. Entanglement between spin and OAM on a single photon. A single photon vertically polarized is arriving from the left, as illustrated by the yellow wave packet representing the electric field amplitude. This photon carries zero OAM, as illustrated by the yellow flat phase fronts. The single photon passes through the metasurface nanoantennas (purple) and exits as a single-particle entangled state, depicted as a superposition of the red and blue electric field amplitudes, with the corresponding vortex phase fronts opposite to one another.

利用介质超构表面进行量子态重构和多光子干涉

Wang *et al.*, *Science* **361**, 1104–1108 (2018)

Quantum metasurface for multiphoton interference and state reconstruction

Kai Wang[1], James G. Titchener[1,2], Sergey S. Kruk[1], Lei Xu[1,3], Hung-Pin Chung[1,4], Matthew Parry[1], Ivan I. Kravchenko[5], Yen-Hung Chen[4,6], Alexander S. Solntsev[1,7], Yuri S. Kivshar[1], Dragomir N. Neshev[1], Andrey A. Sukhorukov[1*]

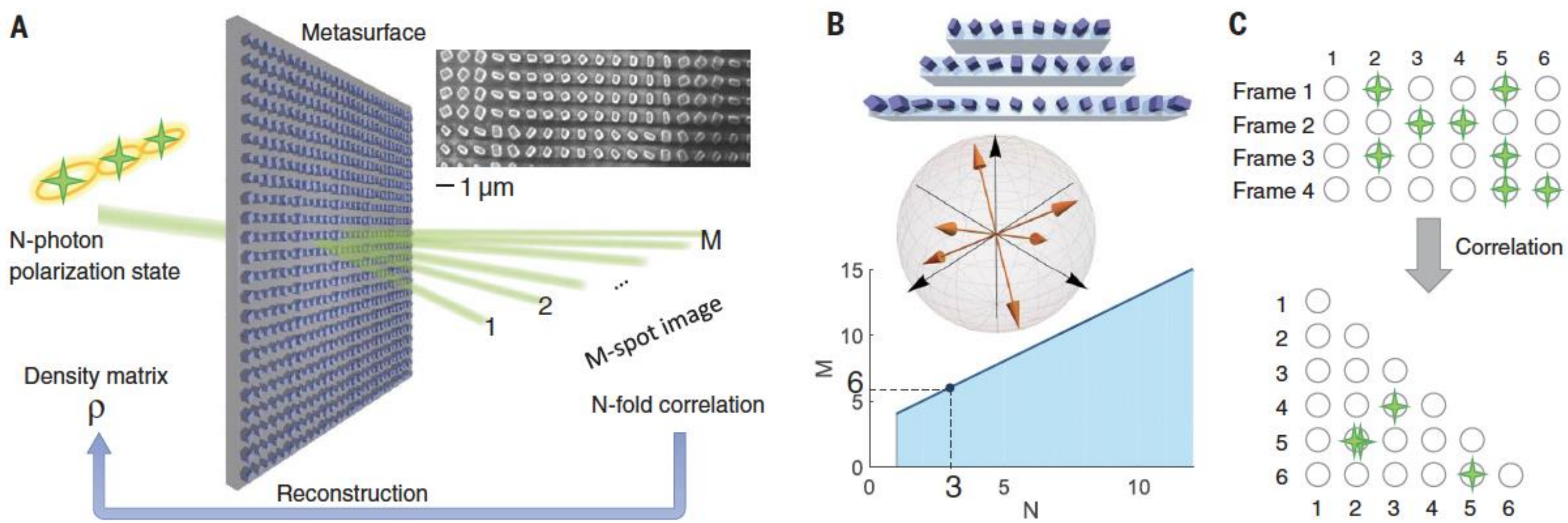


Fig. 1. Concept of quantum state imaging via nanostructured flat optics. (**A**) Sketch of a metasurface being used to image an input *N*-photon polarization state into an *M*-spot image. At the top right is a scanning electron microscopy image of the fabricated all-dielectric metasurface. Green crosses represent photons; purple blocks on the metasurface represent nanoresonators. (**B**) The top image is a sketch of three interleaved gratings for *M* = 6. The middle image shows, with orange arrows, the corresponding projective bases as vectors on the Poincaré sphere; black arrows indicate the coordinate axes. Shown at the bottom are the minimum number of required spots to fully reconstruct the initial quantum state for different numbers of photons *N*, where optimal-frame choice of projective bases exists for *M* = 6, 8, 12, 20, … . (**C**) An example of correlation measurement with *N* = 2 and *M* = 6, with several time-frame measurements combined into a two-dimensional correlation image.

利用介质超构表面调控光子纠缠

$$\hat{a}_L^\dagger = \frac{1}{\sqrt{2}}\left(\hat{a}_H^\dagger + i\cdot\hat{a}_V^\dagger\right)$$

$$\hat{a}_R^\dagger = \frac{1}{\sqrt{2}}\left(\hat{a}_H^\dagger - i\cdot\hat{a}_V^\dagger\right)$$

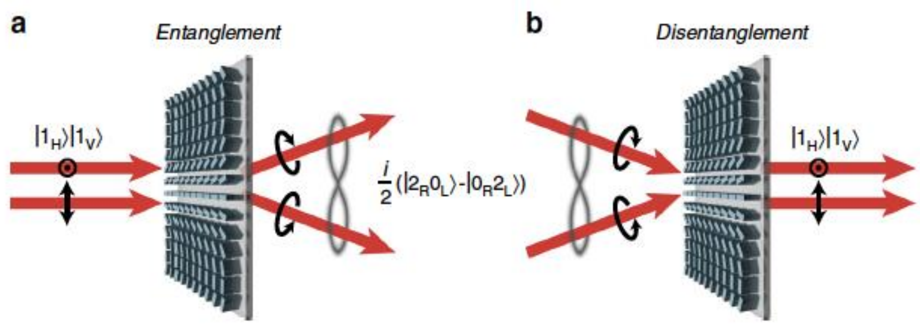


Fig. 1 Spatial entanglement and disentanglement of a two-photon state at a metasurface

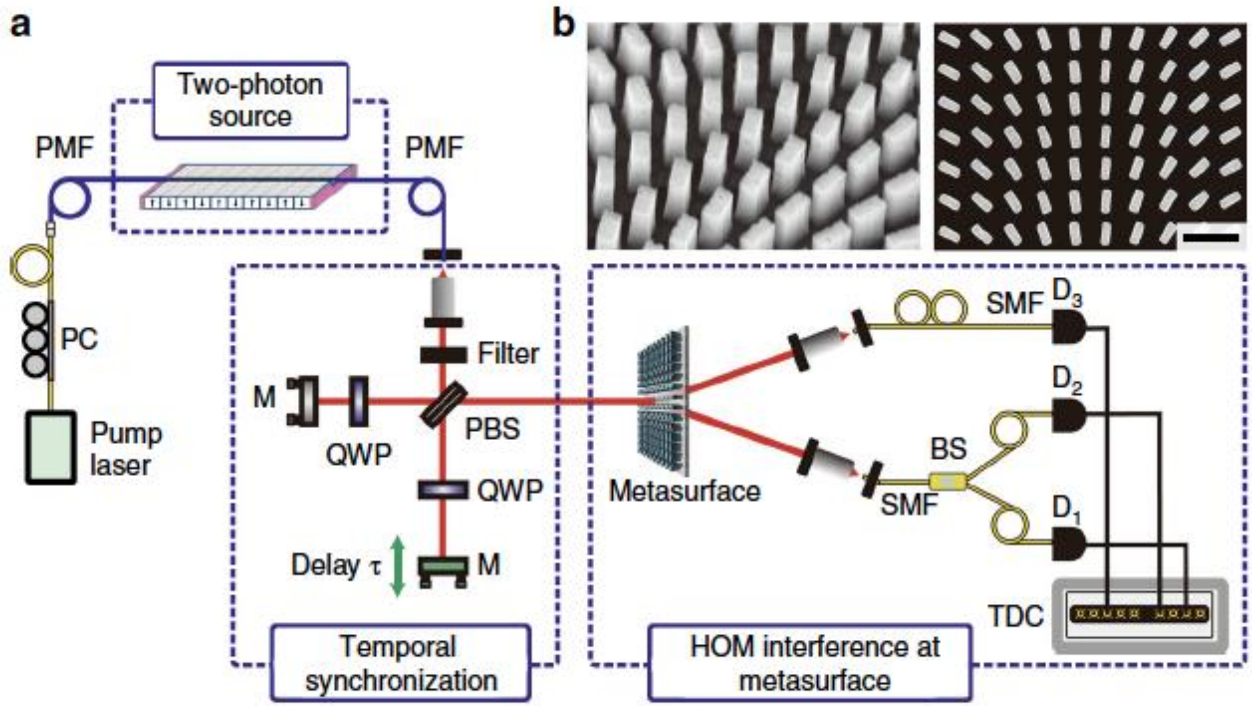
通过超构表面后，得到双光子NOON态

$$|\Psi\rangle = \hat{a}_H^\dagger\hat{a}_V^\dagger|0\rangle = -\frac{i}{2}\left(\hat{a}_L^\dagger\hat{a}_L^\dagger - \hat{a}_R^\dagger\hat{a}_R^\dagger\right)|0\rangle$$

Metasurface interferometry toward quantum sensors

Georgi et al. *Light: Science & Applications* (2019)8:70

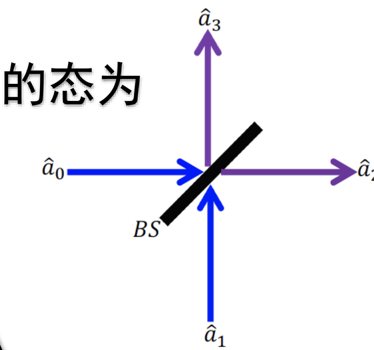
Philip Georgi[1], Marcello Massaro[1], Kai-Hong Luo[1], Basudeb Sain[1], Nicola Montaut[1], Harald Herrmann[1], Thomas Weiss[2], Guixin Li[3], Christine Silberhorn[1] and Thomas Zentgraf[1]


a
b
Two-photon source
PMF
PMF
PC
Pump laser
M
QWP
Filter
PBS
QWP
Delay τ
M
Temporal synchronization
Metasurface
SMF
D_3
D_2
BS
SMF
D_1
TDC
HOM interference at metasurface

文献与上页同

$$U=\begin{pmatrix} t & r \\ -r^* & t^* \end{pmatrix} \qquad U=\begin{pmatrix} \cos\theta & \sin\theta\, e^{-i\phi} \\ -\sin\theta\, e^{i\phi} & \cos\theta \end{pmatrix}$$

② 若初态为$|1\rangle_0|1\rangle_1=\hat{a}_0^\dagger\hat{a}_1^\dagger|0\rangle_0|0\rangle_1$，经过分束器变换后的态为



$$\hat{a}_0^\dagger\hat{a}_1^\dagger|0\rangle_0|0\rangle_1 \xrightarrow{BS}$$

$$(\cos\theta\,\hat{a}_2^\dagger-\sin\theta\,\hat{a}_3^\dagger)(\sin\theta\,\hat{a}_2^\dagger+\cos\theta\,\hat{a}_3^\dagger)|0\rangle_2|0\rangle_3$$

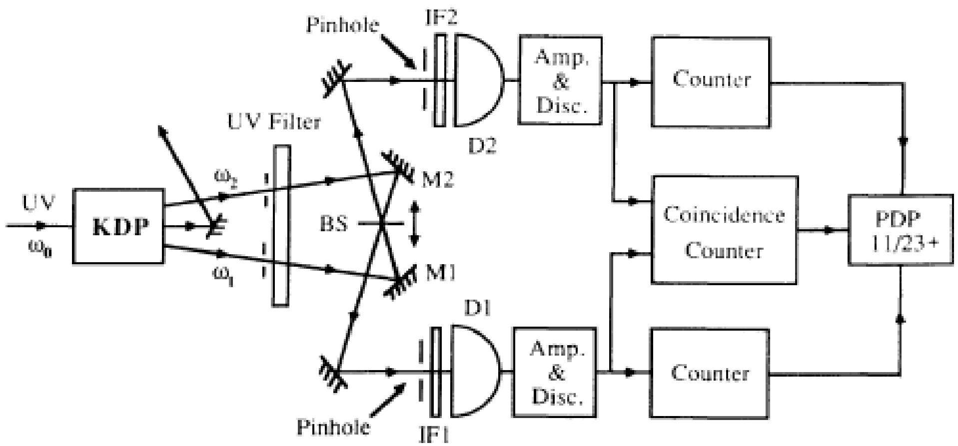
$$=\left(\cos\theta\sin\theta\,\hat{a}_2^\dagger\hat{a}_2^\dagger+(\cos^2\theta-\sin^2\theta)\hat{a}_2^\dagger\hat{a}_3^\dagger-\cos\theta\sin\theta\,\hat{a}_3^\dagger\hat{a}_3^\dagger\right)|0\rangle_2|0\rangle_3$$

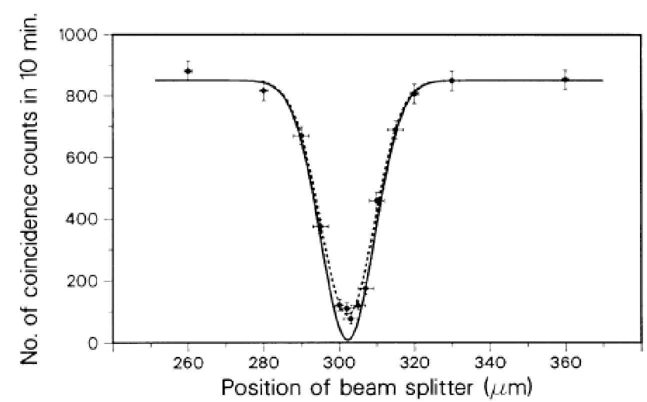
$$=\cos\theta\sin\theta\,|2\rangle_2|0\rangle_3+(\cos^2\theta-\sin^2\theta)|1\rangle_2|1\rangle_3-\cos\theta\sin\theta\,|0\rangle_2|2\rangle_3$$

若$\theta=\frac{\pi}{4}$，则制备的输出态为$\frac{1}{\sqrt{2}}(|2\rangle_2|0\rangle_3-|0\rangle_2|2\rangle_3)$，即2端口输出双光子及3端口输出双光子的叠加态。此时，对该态进行测量，总是在同一个端口探测到两个光子（*著名的Hong_Ou_mandel实验*），不违背光子数守恒条件的$|1\rangle_2|1\rangle_3$态却不能被探测到，这是一种量子干涉现象(*Quantum interference effect*)

Hong-Ou-Mandel实验

相当于 $g^{(2)}(\tau)$





$$|\psi_{\text{out}}\rangle=(R-T)|1_1,1_2\rangle+i(2RT)^{1/2}|2_1,0_2\rangle+i(2RT)^{1/2}|0_1,2_2\rangle, \qquad R/T=0.95$$

where R and T are the reflectivity and transmissivity of the beam splitter, with $R+T=1$.

HONG, CK (HONG, CK) OU, ZY (OU, ZY) MANDEL, L (MANDEL, L），
MEASUREMENT OF SUBPICOSECOND TIME INTERVALS BETWEEN 2 PHOTONS BY INTERFERENCE，Phys. Rev. Lett. **59**, 2044 – Published 2 November 1987，**引用2700余次，原理性实验**

通过超构表面的量子分束

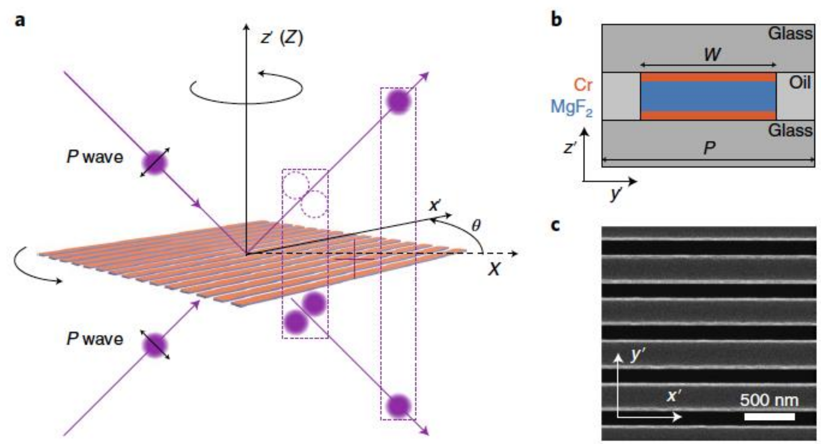
A non-unitary metasurface enables continuous control of quantum photon-photon interactions from bosonic to fermionic

Quanwei Li[1,2], Wei Bao[1,2], Zhaoyu Nie[1], Yang Xia[1], Yahui Xue[1], Yuan Wang[1], Sui Yang[1] and Xiang Zhang[1]

NATURE PHOTONICS | VOL 15 | APRIL 2021 | 267–271 |

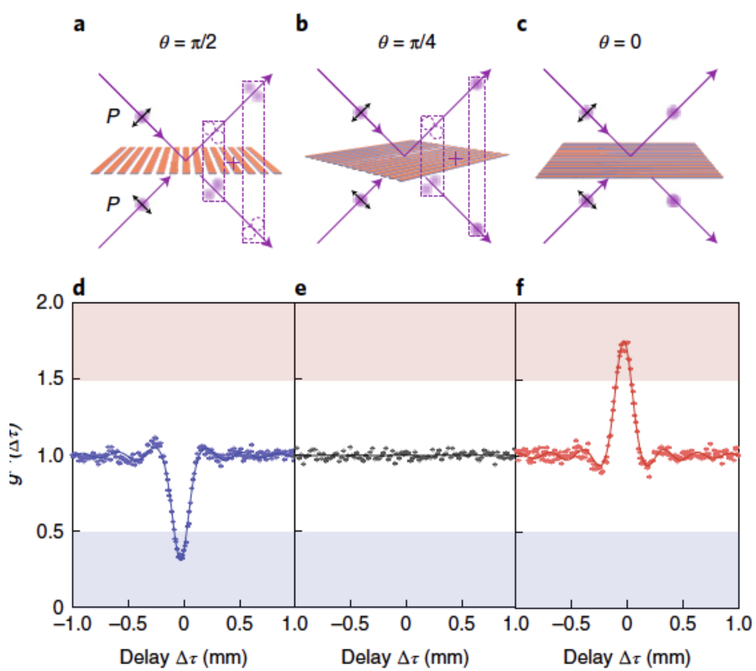
$$\phi_{rt} \equiv \phi_r - \phi_t$$

Measurement condition	$\|r\|$	$\|t\|$	$2\phi_{rt}/\pi$
$\theta = 0$	0.305 (0.342)	0.324 (0.338)	0.008 (0.048)
$\theta = \pi/2$	0.336 (0.346)	0.345 (0.364)	0.950 (1.061)



Cr/MgF$_2$/Cr (18/59/18 nm)

W=240nm, P=395nm, λ =710 nm



相当于一个旋转的HOM实验

5.5.4 其它

利用超构表面芯片实现冷原子源

通过超构表面出射多束光

反射后聚焦并囚禁原子

10^7个Rb原子备囚禁几个ms

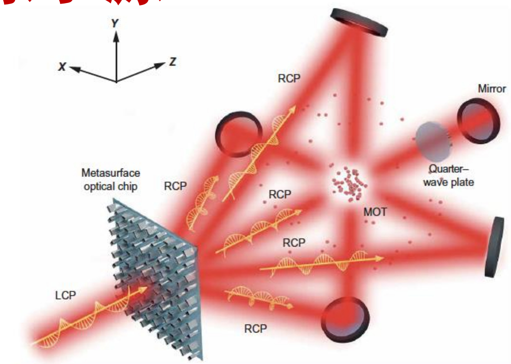
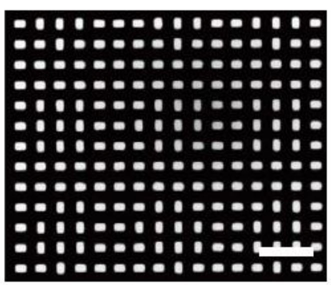
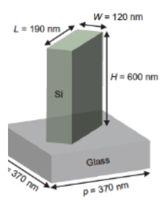
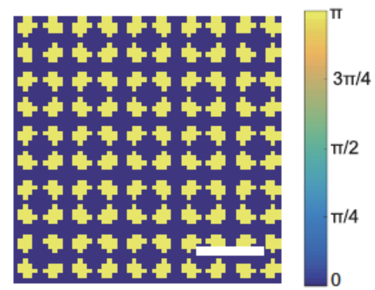


Fig. 1. Schematic of the cold atom device with the dielectric metasurface optical chip. An LCP light passing through the medium is diffracted into five RCP beams, respectively. After the reflection on the mirrors, all the beams are overlapped with





Scale bar, 1 µm



A dielectric metasurface optical chip for the generation of cold atoms

Zhu *et al.*, *Sci. Adv.* 2020; **6** : eabb6667

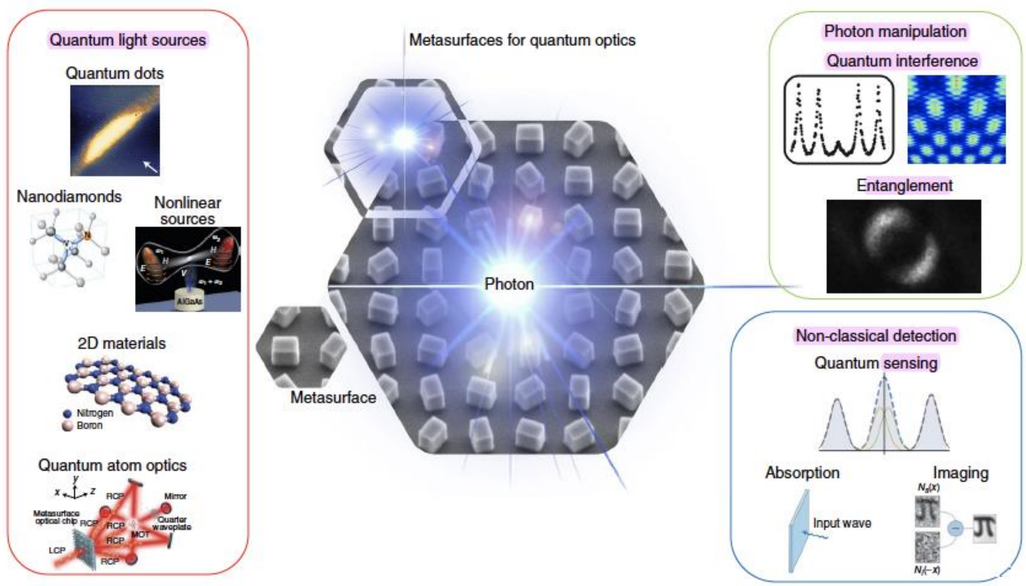
Lingxiao Zhu[1,2]*, Xuan Liu[3,4]*, Basudeb Sain[5]*, Mengyao Wang[1]*, Christian Schlickriede[5], Yutao Tang[3], Junhong Deng[3,4], Kingfai Li[3], Jun Yang[2], Michael Holynski[1], Shuang Zhang[1], Thomas Zentgraf[5], Kai Bongs[1], Yu-Hung Lien[1†], Guixin Li[3,4†]

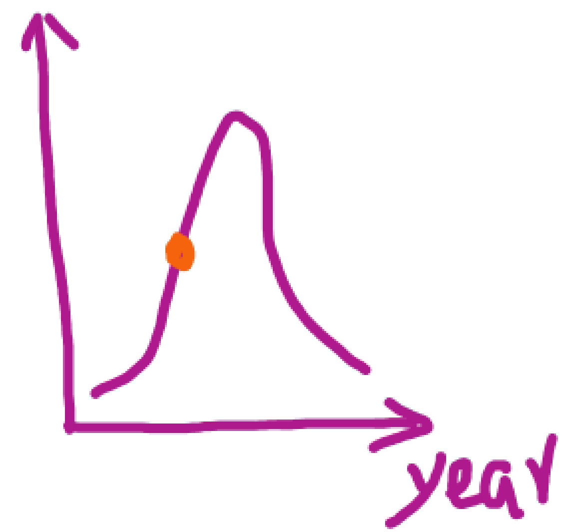
Metasurfaces for quantum photonics

PERSPECTIVE
https://doi.org/10.1038/s41566-021-00793-z

Alexander S. Solntsev[1]✉, Girish S. Agarwal[2] and Yuri Yuri Kivshar[3]✉

NATURE PHOTONICS | VOL 15 | MAY 2021 | 327–336 |





总之，如以上perspective文章所说，超构表面和量子光学与量子信息的结合，带来了新的*量子干涉现象*，正在*量子光源*、*量子态操控*以及*应用方面*展现出独特的魅力，而且处在*起始阶段*

第五章 量子微纳光学

5.1 分子荧光

5.2 纳米结构近场区域偶极子弛豫系数

5.3 SPP增强分子荧光的前沿进展

5.4 SPP 的量子性

5.5 基于超构表面的量子性质

5.6 基于拓扑光子结构的量子性质

5.7 微纳尺度腔量子电动力学及应用

第五章 量子微纳光学

5.6 基于拓扑光子结构的量子性质

主要内容如下：

拓扑保护下的量子纠缠、量子光源

（如单光子源、量子纠缠源、非经典光源）

及 量子态操控等

量子光学和量子信息关注的部分核心问题（用过）：

光和量子体系作用、量子干涉和量子关联、量子光源、量子态操控及其过程中的损耗、效率、制备等

拓扑光子学的特色：

周期性光子结构的体-边界对应所形成的具有拓扑保护性的模式

a. 1D、2D和3D拓扑结构→ edge state、角态

b. 拓扑模式（edge states）→ 增强光和量子体系相互作用，如单光子源和强耦合等（如SPP结构中情况）

c. 拓扑保护 → 量子纠缠、量子光源、量子态操控

拓扑保护下的路径量子纠缠

Topological protection of photonic path entanglement

Vol. 3, No. 9 / September 2016 / *Optica* 925

MIKAEL C. RECHTSMAN,[1,*] YAAKOV LUMER,[2] YONATAN PLOTNIK,[2] ARMANDO PEREZ-LEIJA,[3] ALEXANDER SZAMEIT,[3] AND MORDECHAI SEGEV[2]

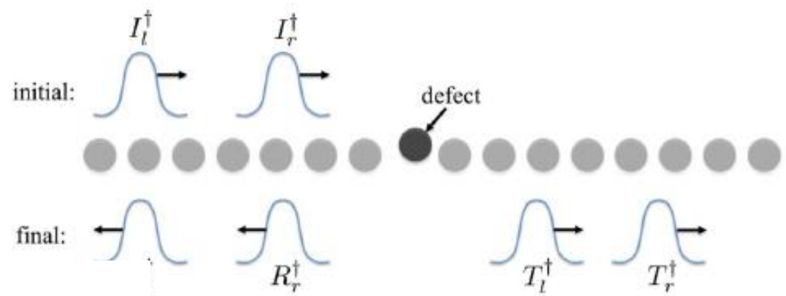
原理：

以NOON态为例

如果遇到defect，则有

$$I_l^\dagger \to \mathcal{U} I_l^\dagger \mathcal{U}^\dagger = rR_r^\dagger + tT_l^\dagger \quad \text{and}$$

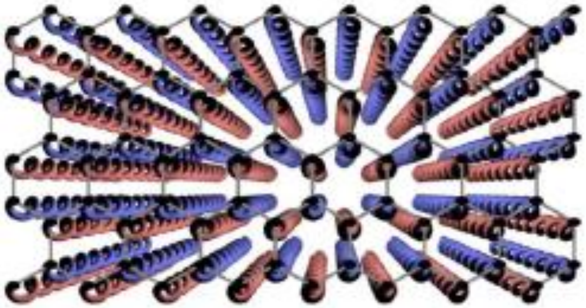
$$I_r^\dagger \to \mathcal{U} I_r^\dagger \mathcal{U}^\dagger = rR_l^\dagger + tT_r^\dagger,$$

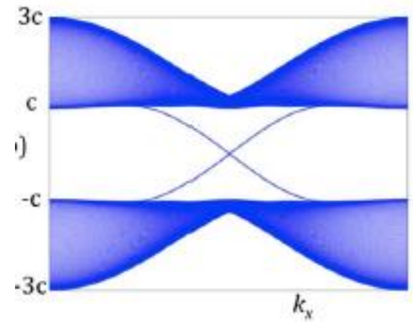


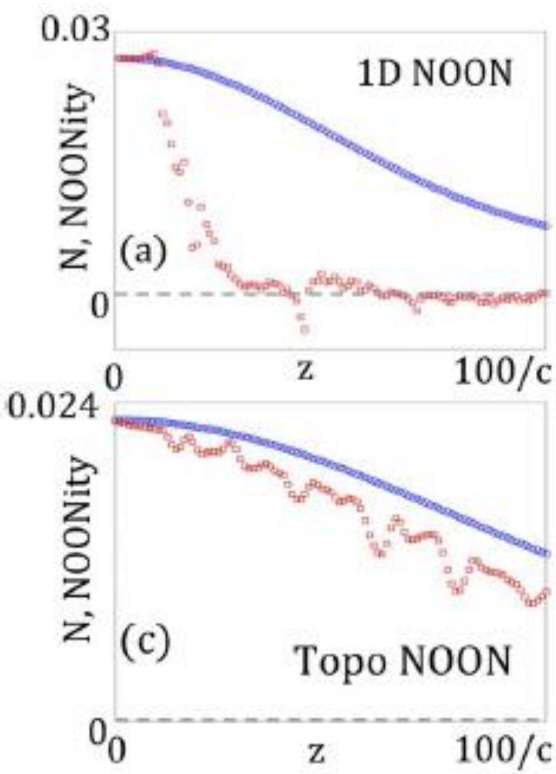
$$|\psi(0)\rangle = \tfrac{1}{2}(I_l^\dagger I_l^\dagger + I_r^\dagger I_r^\dagger)|0\rangle$$

$$|\psi(0)\rangle \to |\psi(t)\rangle = \frac{1}{2}\mathcal{U}(I_l^\dagger I_l^\dagger + I_r^\dagger I_r^\dagger)\mathcal{U}^\dagger |0\rangle$$
$$= \frac{1}{2}[(\mathcal{U} I_l^\dagger \mathcal{U}^\dagger)(\mathcal{U} I_l^\dagger \mathcal{U}^\dagger) + (\mathcal{U} I_r^\dagger \mathcal{U}^\dagger)(\mathcal{U} I_r^\dagger \mathcal{U}^\dagger)]|0\rangle.$$
$$= \frac{1}{2}[(rR_r^\dagger + tT_l^\dagger)(rR_r^\dagger + tT_l^\dagger) + (rR_l^\dagger + tT_r^\dagger)(rR_l^\dagger + tT_r^\dagger)]|0\rangle$$
$$= \frac{1}{2}[r^2 R_r^\dagger R_r^\dagger + t^2 T_l^\dagger T_l^\dagger + 2trT_l^\dagger R_r^\dagger + r^2 R_l^\dagger R_l^\dagger$$
$$+ t^2 T_r^\dagger T_r^\dagger + 2trT_r^\dagger R_l^\dagger]|0\rangle.$$

在拓扑结构中，单向传输（即 r=0），只有紫色的项存在，很好的保持了NOON态







结论：

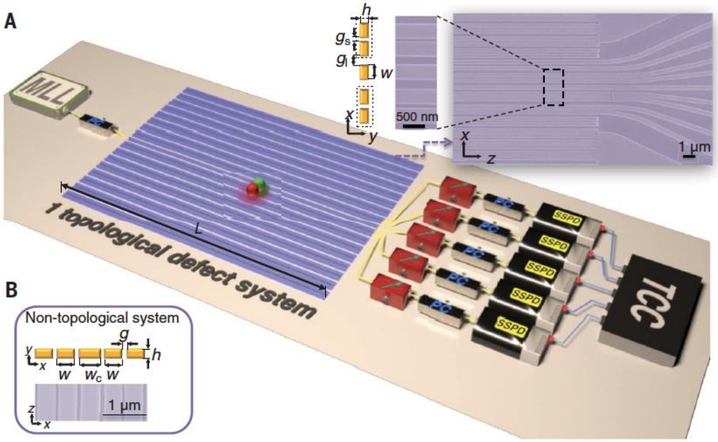
存在disorder时，由于拓扑保护性，路径纠缠的NOON态的保持得很好

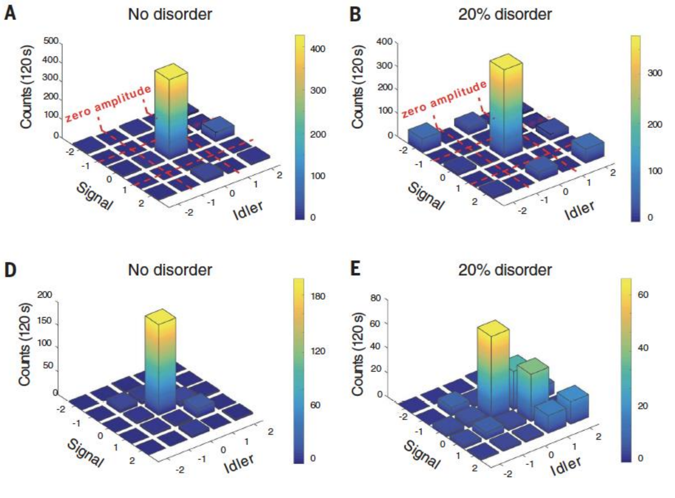
文献与上页同

拓扑保护下的纠缠光子源 1

1D硅波导下的SSH model

打入1550光，通过四波混频产生1545和1555nm的光





拓扑保护（左上）

无拓扑（左下）

Topological protection of biphoton states *Science* **362**, 568–571 (2018)

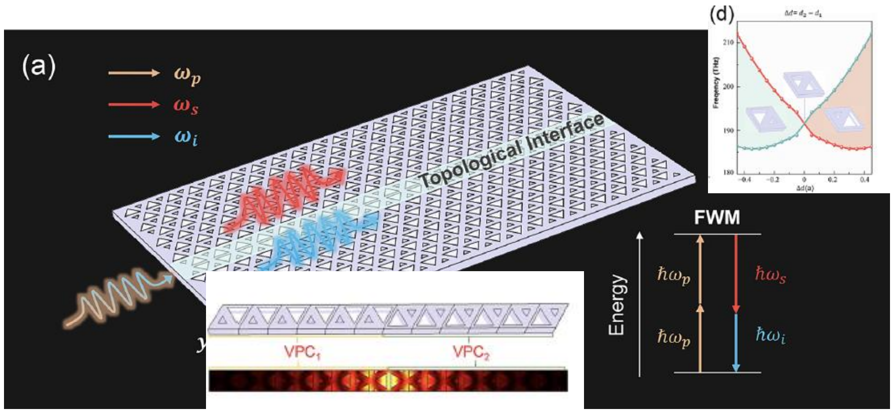
Andrea Blanco-RedondoBryn BellDikla OrenBenjamin J. EggletonMordechai Segev

拓扑保护下的纠缠光子源 2

谷光子晶体

四波混频

弯曲波导的鲁棒性



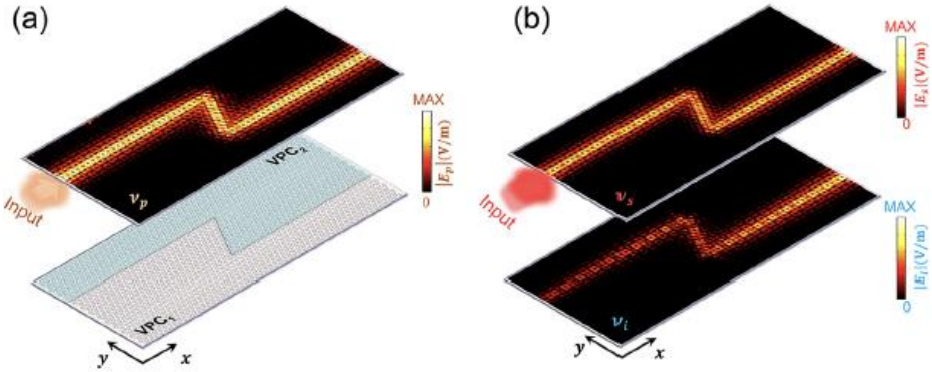


Figure 6: FWM interactions in VPCs with different interfaces. (a) Field profiles of the pump (ν_p = 190.8 THz) along a "Z" shaped interface between the VPC_2 and VPC_1. (b) Field profiles of the signal (ν_s = 190.9 THz) and idler (ν_i = 190.7 THz) in the VPCs.

Topological protection of continuous frequency entangled biphoton states

Nanophotonics 2021; 10(16): 4019–4026

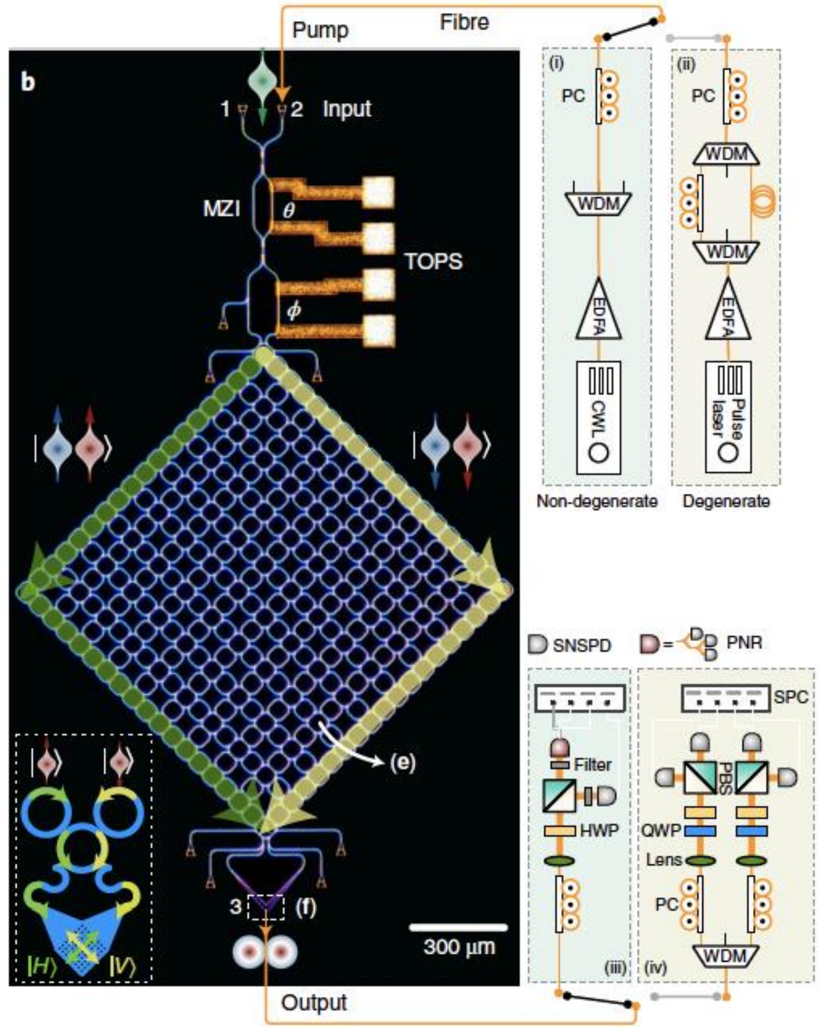
Zhen Jiang, Yizhou Ding, Chaoxiang Xi, Guangqiang He* and Chun Jiang*

拓扑保护下的SPDC双光子量子纠缠源 3

Spontaneous degenerate conversion

原理：

将连续或脉冲光input，通过干涉后进入两个边界态，传输中发生SPDC过程，从而产生纠缠态



Topologically protected quantum entanglement emitters

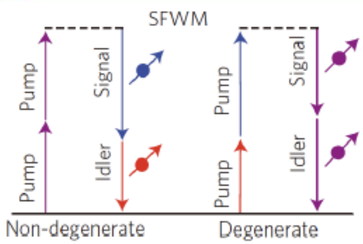
Tianxiang Dai[1,10], Yutian Ao[1,10], Jueming Bao[1,10], Jun Mao[1,10], Yulin Chi[1,10] et al.

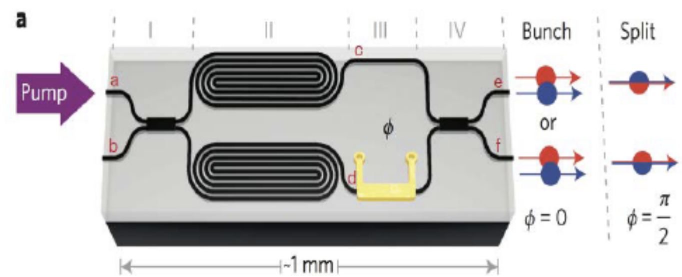
NATURE PHOTONICS | VOL 16 | MARCH 2022 | 248–257 248

以上过程的纠缠原理与下文类似

不同的是，edge state替代了光波导

片上量子纠缠光源





$$|\psi_{\mathrm{II}}\rangle = \frac{1}{\sqrt{2}}\left(\hat{a}_s^\dagger \hat{a}_i^\dagger + \hat{b}_s^\dagger \hat{b}_i^\dagger\right)|0\rangle$$

$$|\psi_{\mathrm{III}}\rangle = \frac{1}{\sqrt{2}}\left(\hat{a}_s^\dagger \hat{a}_i^\dagger + e^{i2\phi}\hat{b}_s^\dagger \hat{b}_i^\dagger\right)|0\rangle$$

$$|\psi_{\mathrm{IV}}\rangle = \frac{1}{\sqrt{2}}\left(\frac{\left(\hat{a}_s^\dagger + i\hat{b}_s^\dagger\right)}{\sqrt{2}}\frac{\left(\hat{a}_i^\dagger + i\hat{b}_i^\dagger\right)}{\sqrt{2}} + e^{i2\phi}\frac{\left(i\hat{a}_s^\dagger + \hat{b}_s^\dagger\right)}{\sqrt{2}}\frac{\left(i\hat{a}_i^\dagger + \hat{b}_i^\dagger\right)}{\sqrt{2}}\right)|0\rangle$$

$$\begin{cases} |\psi_{bunch}\rangle = \left(\hat{a}_s^\dagger \hat{a}_i^\dagger - \hat{b}_s^\dagger \hat{b}_i^\dagger\right)|0\rangle \\ |\psi_{anti-bunch}\rangle = \left(\hat{a}_s^\dagger \hat{b}_i^\dagger + \hat{b}_s^\dagger \hat{a}_i^\dagger\right)|0\rangle \end{cases}$$

$$|\psi_{\mathrm{IV}}\rangle = \frac{1 - e^{i2\phi}}{2\sqrt{2}}|\psi_{bunch}\rangle + \frac{i\left(1 + e^{i2\phi}\right)}{2\sqrt{2}}|\psi_{anti-bunch}\rangle$$

$$|\psi_{\mathrm{IV}}\rangle = \begin{cases} i|\psi_{anti-bunch}\rangle & \phi = 0 \\ |\psi_{bunch}\rangle & \phi = \dfrac{\pi}{2} \end{cases}$$

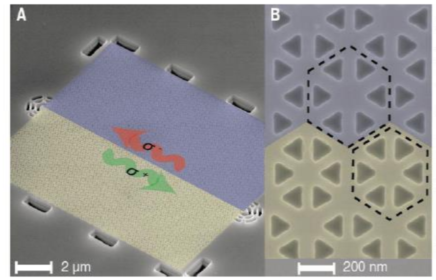
Silverstone J W, Bonneau D, Ohira K, et al. On-chip quantum interference between silicon photon-pair sources[J]. *Nature Photonics*, 2014, 8(2): 104-108.

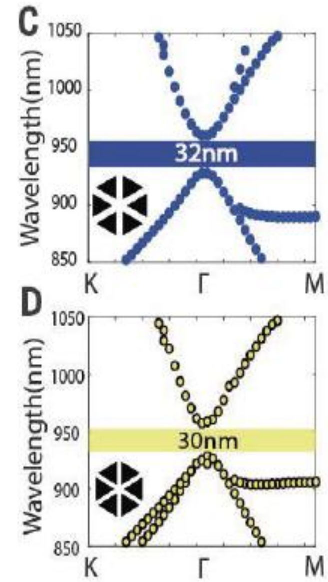
摘自戴天祥专题课PPT

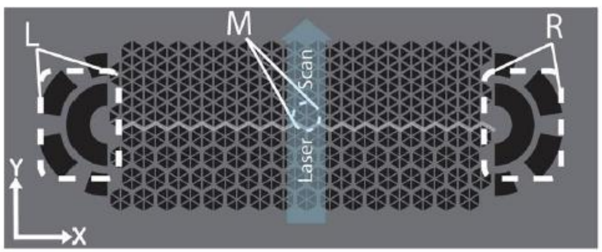
拓扑保护下的手性单光子源

设计拓扑结构

砷化镓薄膜上打空气孔

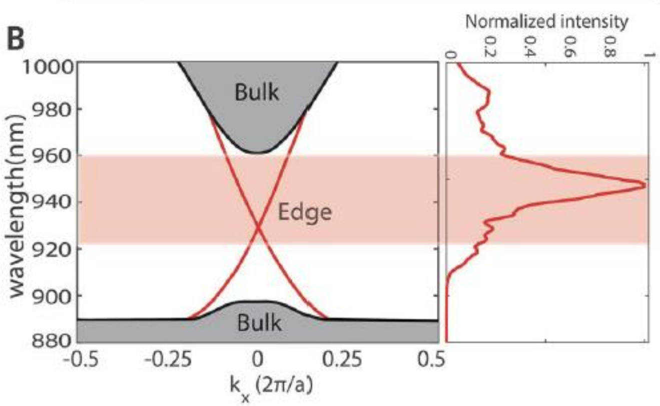


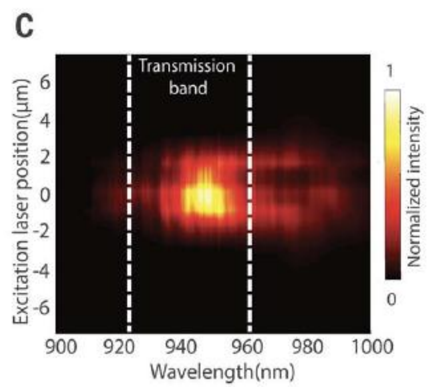


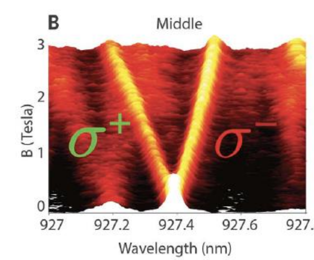


带隙设计（右）

edge state（下）

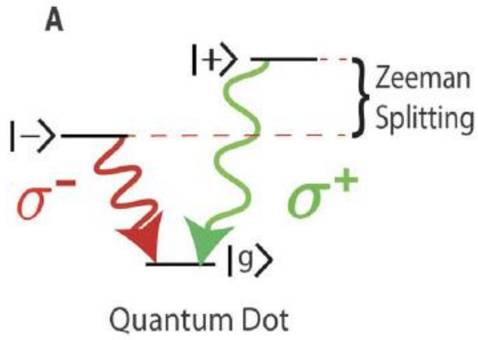


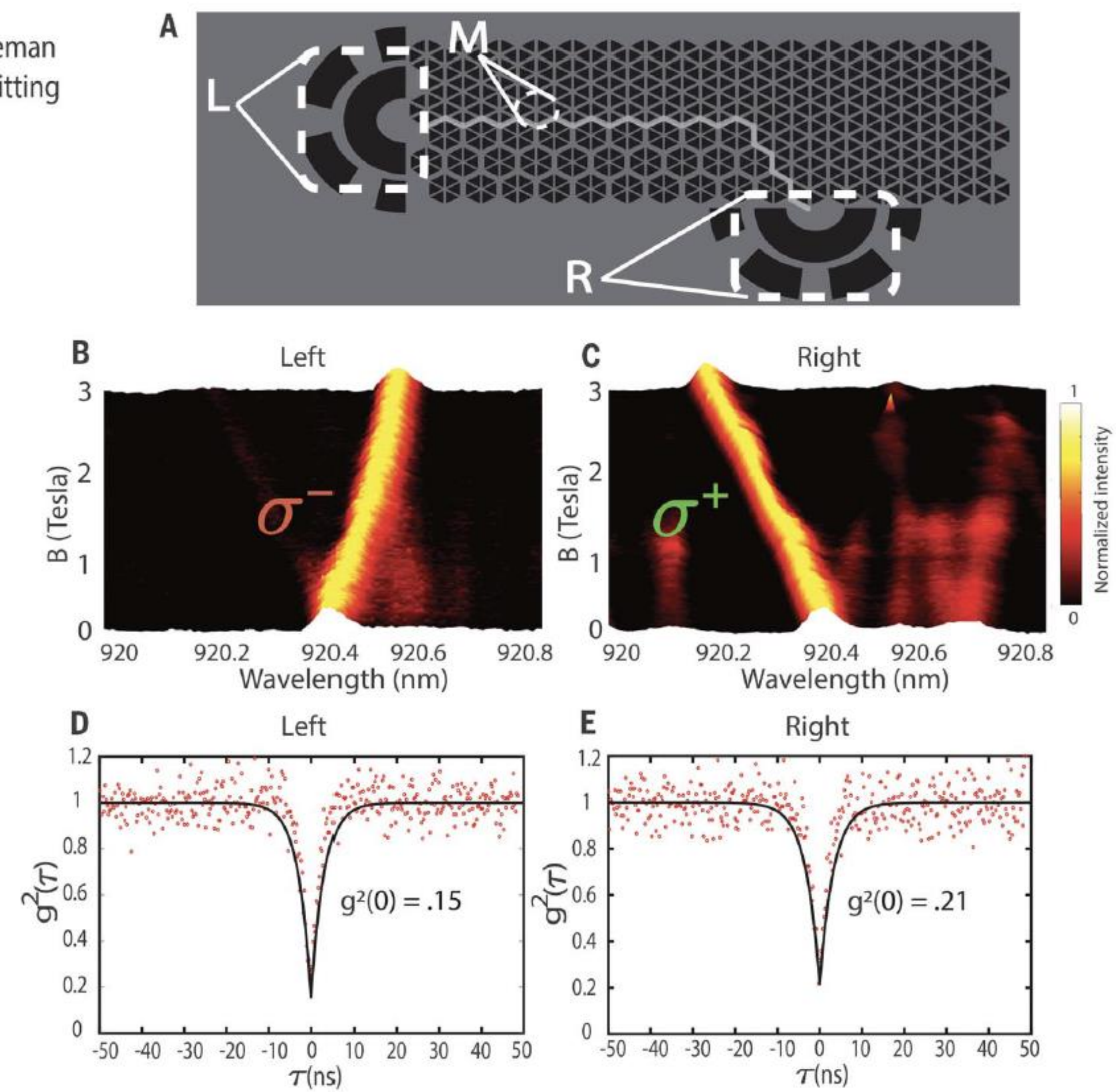




A topological quantum optics interface *Science* **359**, 666–668 (2018)

Sabyasachi BarikAziz KarasahinChristopher FlowerTao CaiHirokazu MiyakeWade DeGottardiMohammad HafeziEdo Waks





弯曲波导

手性传输

单光子性

鲁棒性

文献与上页同

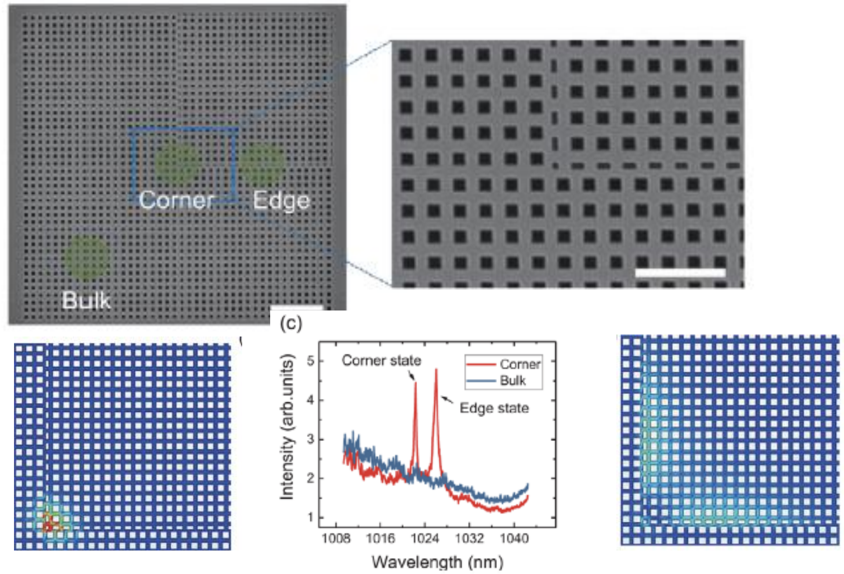
拓扑角态珀塞尔效应的实验实现

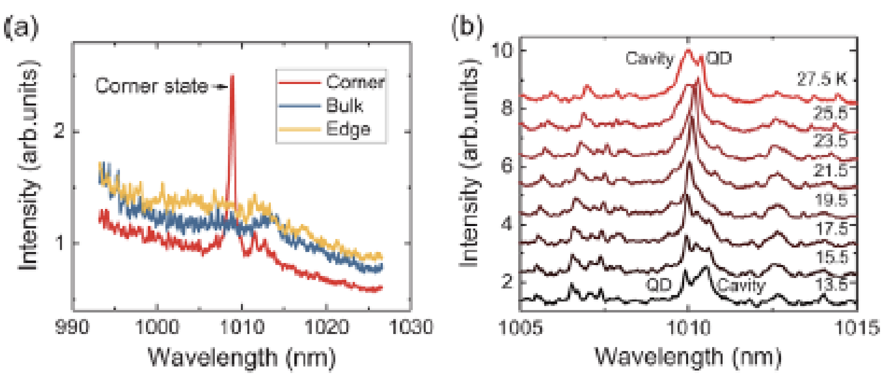
设计拓扑结构

砷化镓薄膜上打孔

方形结构

量子点放在corner





随量子点温度变化，

看到了谱线的移动及

微弱的荧光增强

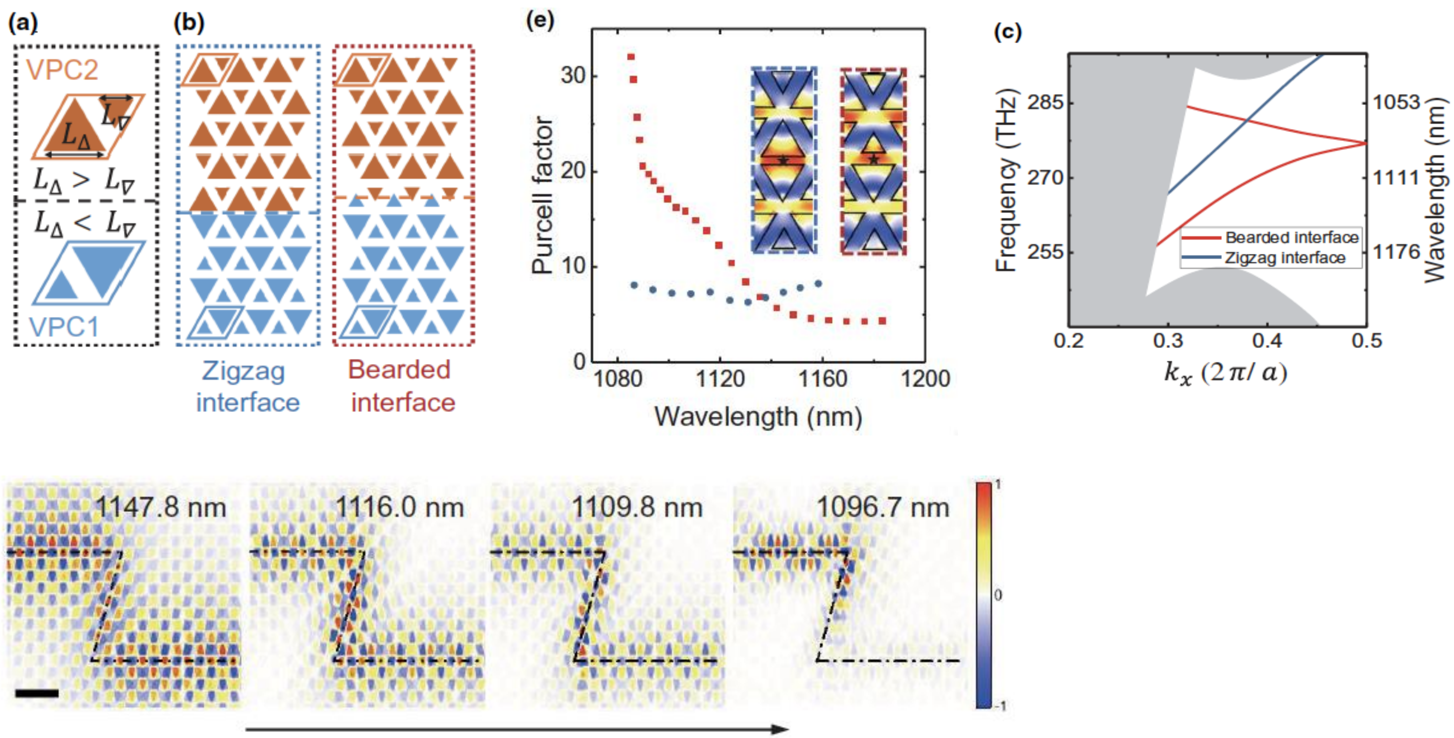
Cavity Quantum Electrodynamics with Second-Order Topological Corner State

Xin Xie, Weixuan Zhang, Xiaowu He, Shiyao Wu, Jianchen Dang, Kai Peng, Feilong Song, Longlong Yang, Haiqiao Ni, Zhichuan Niu, Can Wang, Kuijuan Jin, Xiangdong Zhang, and Xiulai Xu**

Laser Photonics Rev. **2020**, *14*, 1900425

拓扑谷光子晶体中群速度减慢下的珀塞尔增强

P ∝ 1/Vg, 1096nm处 群速度减慢

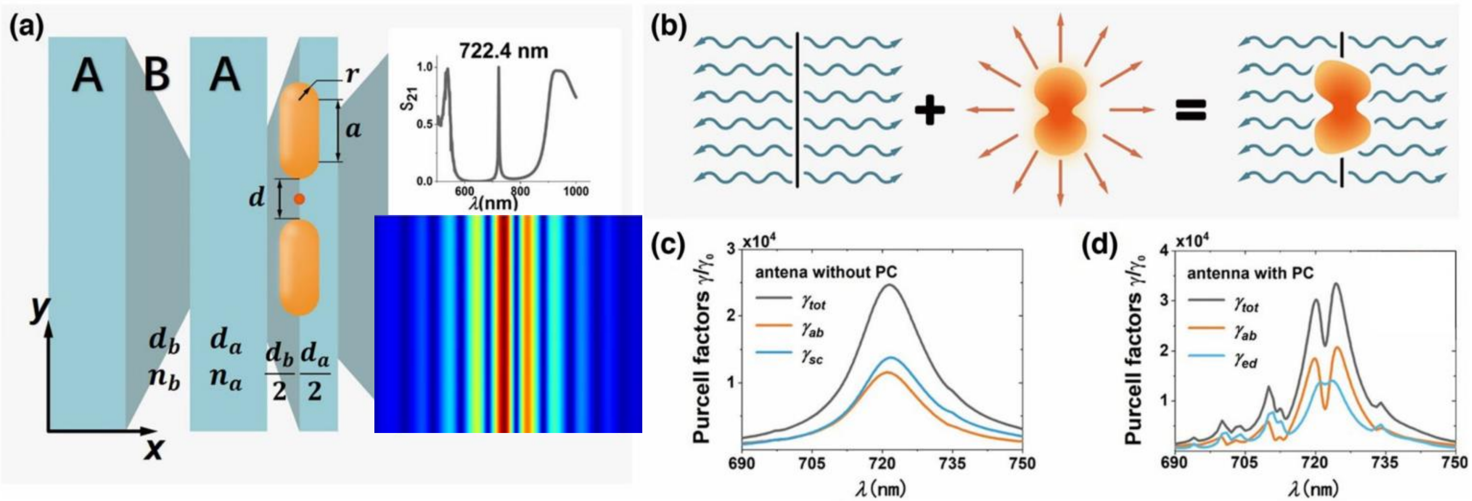


Topological Cavity Based on Slow-Light Topological Edge Mode for Broadband Purcell Enhancement

Xin Xie and Xiulai Xu el al. PHYSICAL REVIEW APPLIED **16,** 014036 (2021)

拓扑保护下的珀塞尔效应
（这里略讲，仅强调拓扑保护性）

Introducing topological protection into the Purcell enhancement

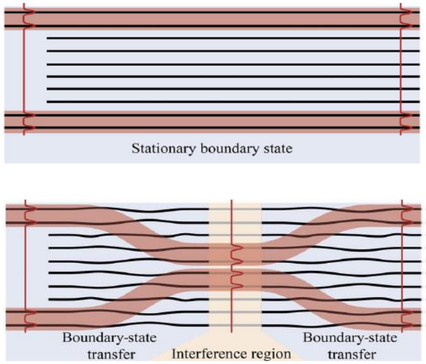


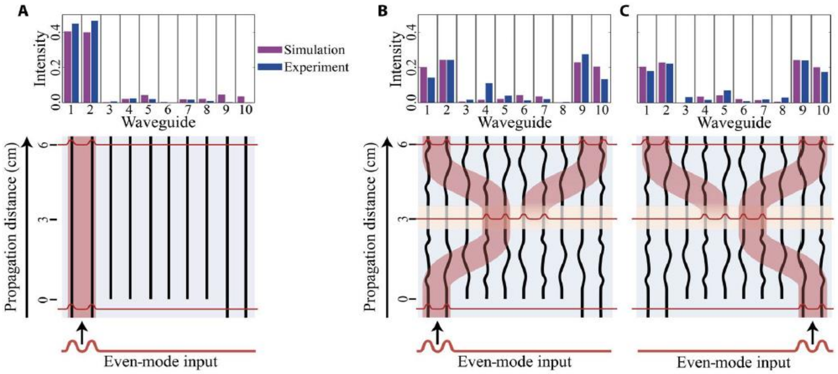
New Mode Coupling Mechanism， Absorption Reduction

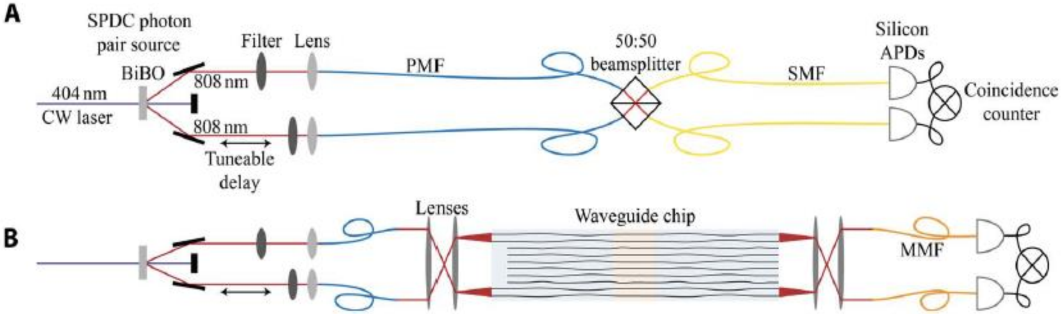
Zhiyuan Qian and Ying Gu et al., Absorption Reduction of Large Purcell Enhancement Enabled by Topological State-Led Mode CouplingPRL 126,023901(2021)

基于拓扑boundary state的Hong-Ou-Mandel实验

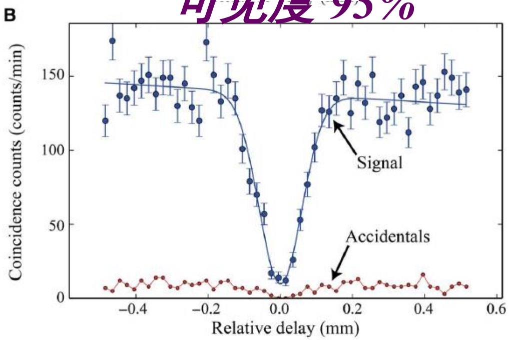
设计原理：通过调控波导间的耦合系数 κ 设计具有拓扑boundary state的准晶 $\kappa_n(t) = \kappa_0\left[1 + \Lambda(t)\cos(2\pi \bar{b} n + \phi(t))\right]$







可见度 93%



Quantum interference of topological states of light

Jean-Luc Tambasco[1], Giacomo Corrielli[2,3], Robert J. Chapman[1], Andrea Crespi[2,3], Oded Zilberberg[4], Roberto Osellame[2,3], Alberto Peruzzo[1]*

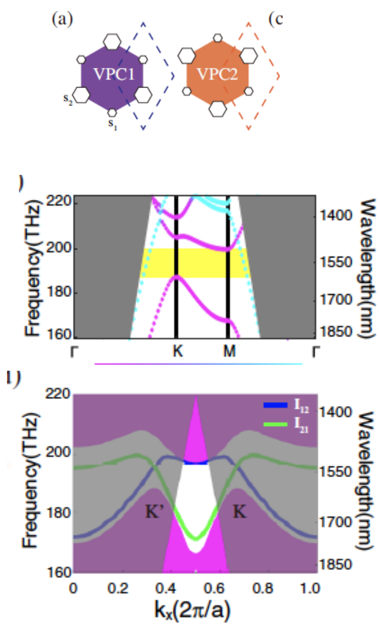
Sci. Adv. 2018; **4**: eaat3187

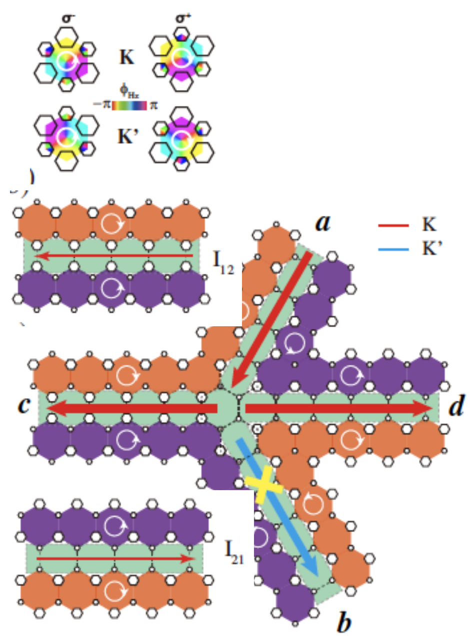
基于谷拓扑光子晶体的Hong-Ou-Mandel实验

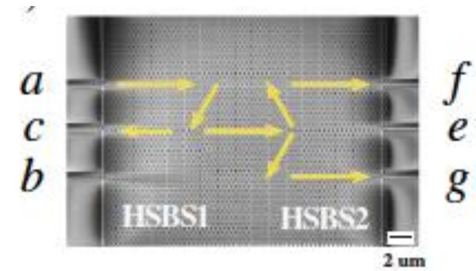
设计原理： **先打开VPC的带隙，找到edge state**

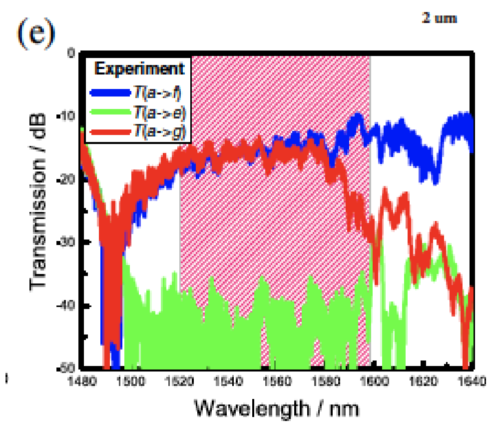
再通过phase vertex，确定不同圆偏振的单向传输方向

最后设计了双W结构的偏振分束器







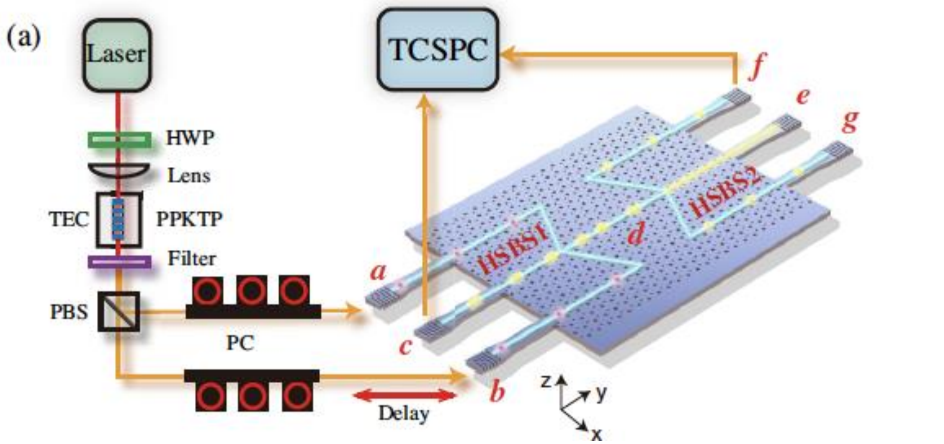


PHYSICAL REVIEW LETTERS **126,** 230503 (2021)

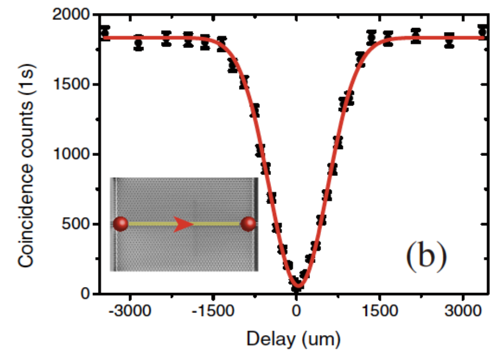
Topologically Protected Valley-Dependent Quantum Photonic Circuits

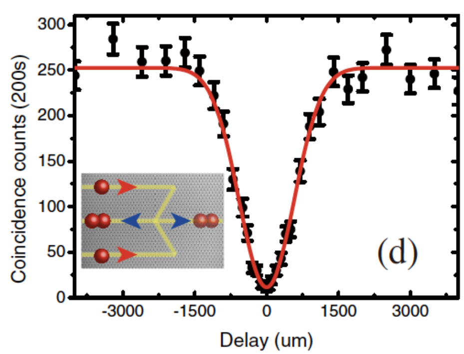
Yang Chen,[1,2,*] Xin-Tao He,[3,*] Yu-Jie Cheng,[1,2] Hao-Yang Qiu,[3] Lan-Tian Feng,[1,2] Ming Zhang,[4,5]
Dao-Xin Dai,[4,5] Guang-Can Guo,[1,2] Jian-Wen Dong,[3,†] and Xi-Feng Ren[1,2,‡]

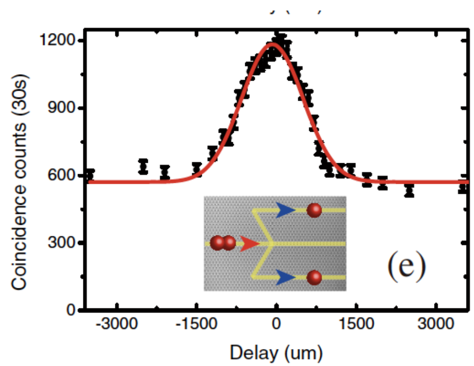
基于谷拓扑光子晶体的HOM线路

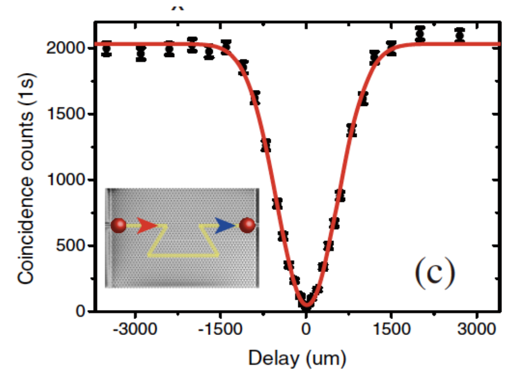


下面两张图：
单光子输入









上面两张图：双光子输入

文献与上页同

可以看到：

拓扑光子学和量子体系结合后的光学性质还处在一个*蓬勃发展的阶段*。各种新的思想和尝试层出不穷，充满了*挑战和机遇*，是微纳光学的*重要前沿*