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本期推荐报道 2022 年 5 月 Nature、Science 期刊上材料科学领域的部分最新论文。

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材料科学 5 月 Science 论文

[1]Ferroelectricity in untwisted heterobilayers of transition metal dichalcogenides

过渡金属二卤族化合物未扭曲异双层中的铁电性

出版信息：Science,27 MAY 2022, Volume 376 Issue 6596

作者：LUKAS ROGÉE, LVJIN WANG, YI ZHANG, SONGHUA CAI et al.

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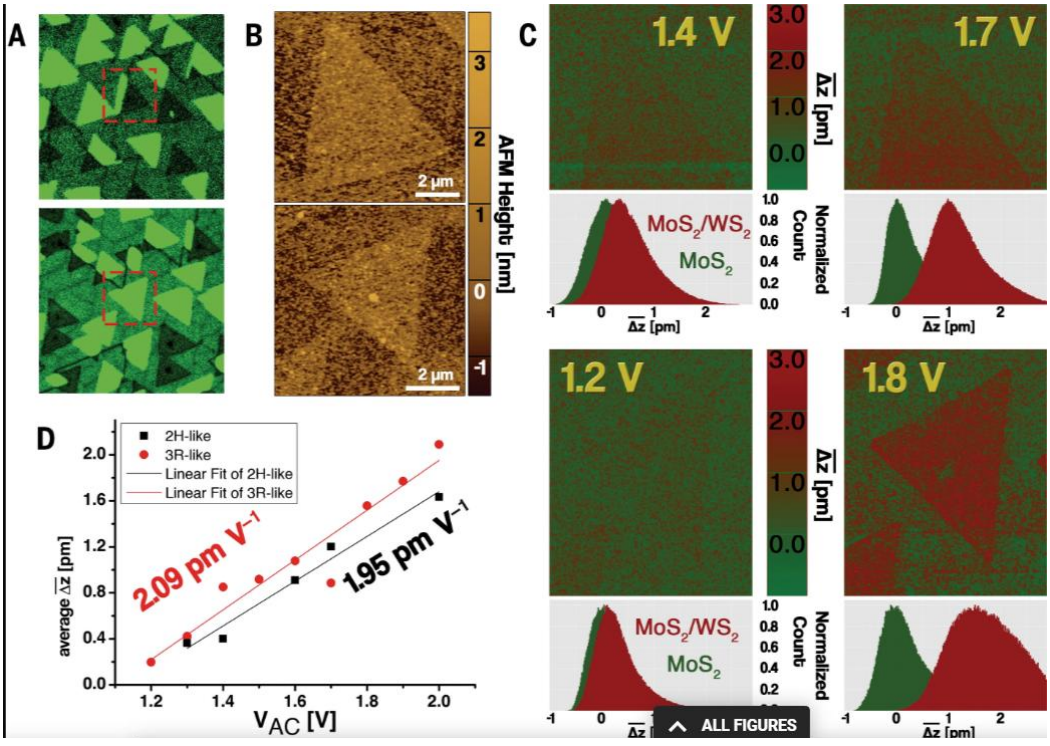
全文链接：https://www.science.org/doi/10.1126/science.abm5734

Abstract：Two-dimensional materials with out-of-plane (OOP) ferroelectric and piezoelectric properties are highly desirable for the realization of ultrathin ferro- and piezoelectronic devices. We demonstrate unexpected OOP ferroelectricity and piezoelectricity in untwisted, commensurate, and epitaxial MoS2/WS2 heterobilayers synthesized by scalable one-step chemical vapor deposition. We show d33 piezoelectric constants of 1.95 to 2.09 picometers per volt that are larger than the natural OOP piezoelectric constant of monolayer In2Se3 by a factor of ~6. We demonstrate the modulation of tunneling current by about three orders of magnitude in ferroelectric tunnel junction devices by changing the polarization state of MoS2/WS2 heterobilayers. Our results are consistent with density functional theory, which shows that both symmetry breaking and interlayer sliding give rise to the unexpected properties without the need for invoking twist angles or moiré domains.

摘要翻译：具有面外铁电和压电特性的二维材料是实现超薄铁和压电电子器件的理想材料。我们通过一步化学气相沉积法合成了未扭曲、相称和外延的 MoS2/WS2 异质双层材料，意外证明了 OOP 铁电性和压电性。我们得到的 d33 压电常数为 1.95～2.09 皮米/伏，比单层 In2Se3 的自然 OOP 压电常数大 6 倍。通过改变 MoS2/WS2 异质双层的极化状态，我们证明了相应铁电隧道结器件中隧穿电流可进行约三个数量级调制。我们的结果与密度泛函理论是一致的，这表明对称性破缺和层间滑动都产生了意想不到的性质，而不需要调用扭曲角或摩尔畴。

文中插图：



[2]**Highly enhanced ferroelectricity in HfO2-based ferroelectric thin film by light ion bombardment**

轻离子轰击增强 HfO2 基铁电薄膜的铁电性

出版信息：Science, 13 MAY 2022, VOL 376, ISSUE 6594

作者：SEUNGHUN KANG, WOO-SUNG JANG, ANNA N. MOROZOVSKA, OWOONG KWON, YEONGROK JIN, YOUNG-HOON KIM, et al.

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全文链接：https://www.science.org/doi/10.1126/science.abk3195

Abstract：Continuous advancement in nonvolatile and morphotropic beyond-Moore electronic devices requires integration of ferroelectric and semiconductor materials. The emergence of hafnium oxide (HfO2)–based ferroelectrics that are compatible with atomic-layer deposition has opened interesting and promising avenues of research. However, the origins of ferroelectricity and pathways to controlling it in HfO2 are still mysterious. We demonstrate that local helium (He) implantation can activate ferroelectricity in these materials. The possible competing mechanisms, including He ion–induced molar volume changes, vacancy redistribution, vacancy generation, and activation of vacancy mobility, are analyzed. These findings both reveal the origins of ferroelectricity in this system and open pathways for nanoengineered binary ferroelectrics.

摘要翻译：非易失和准同型的后摩尔电子器件的不断发展需要集成铁电材料和半导体材料。与原子层沉积兼容的氧化铪（HfO2）基铁电体的出现开辟了有趣且颇有前景的研究途径。然而，HfO2 中铁电性的起源和控制途径仍然是个谜。研究组证明了局部氦（He）注入可以激活这些材料中的铁电性。他们还分析了可能的竞争机制，包括 He 离子引发的摩尔体积变化、空位再分布、空位生成和空位迁移率的激活。这些发现既揭示了该系统中铁电性的起源，也为纳米工程二元铁电体开辟了新途径。

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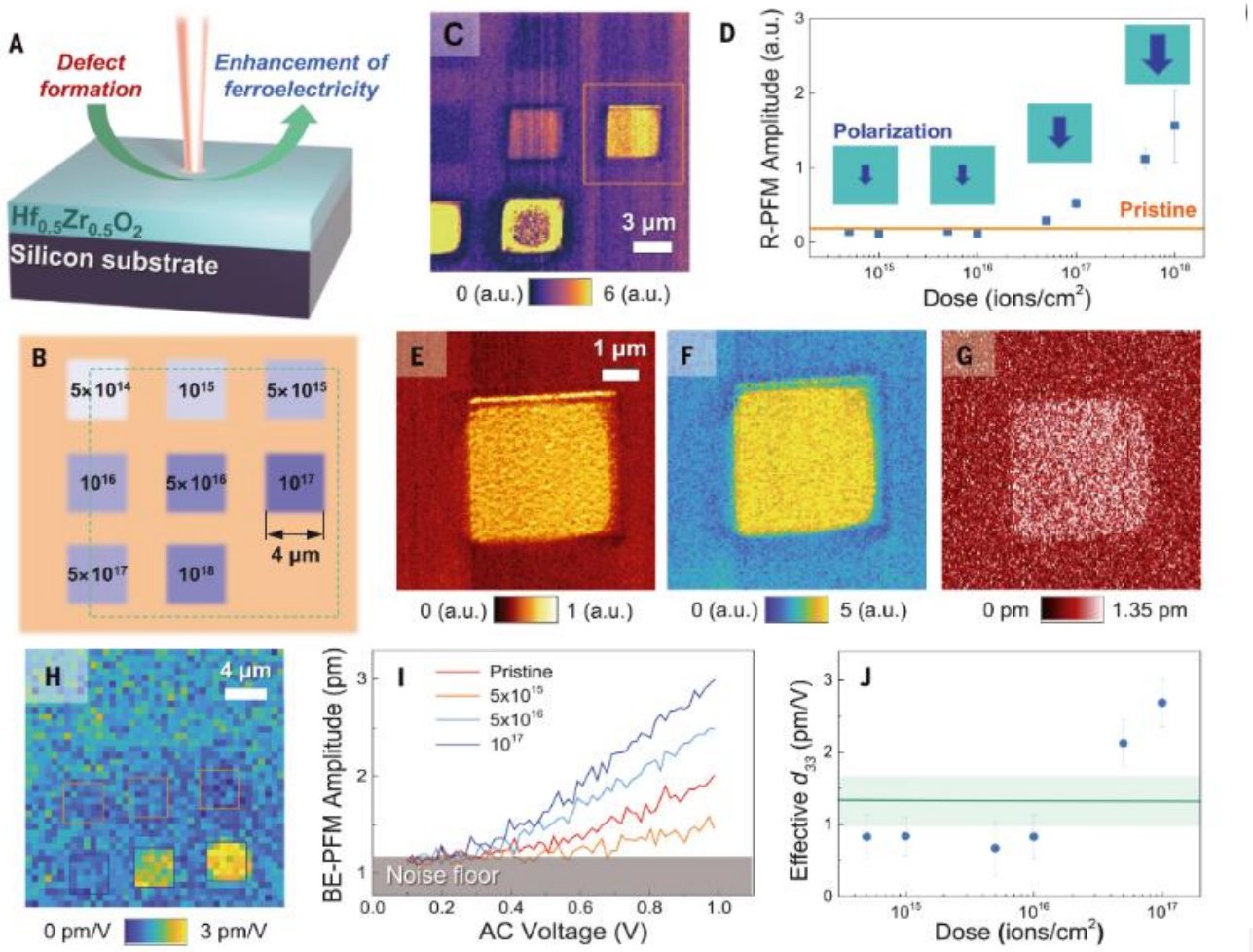

[3]Ultrafast water permeation through nanochannels with a densely fluorous interior surface

内表面致密氟纳米通道可超快渗透水

出版信息：Science, 13 MAY 2022, VOL 376, ISSUE 6594

作者：YOSHIMITSU ITOH, SHUO CHEN, RYOTA HIRAHARA, TAKESHI KONDA, TSUBASA AOKI, TAKUMI UEDA, ET AL.

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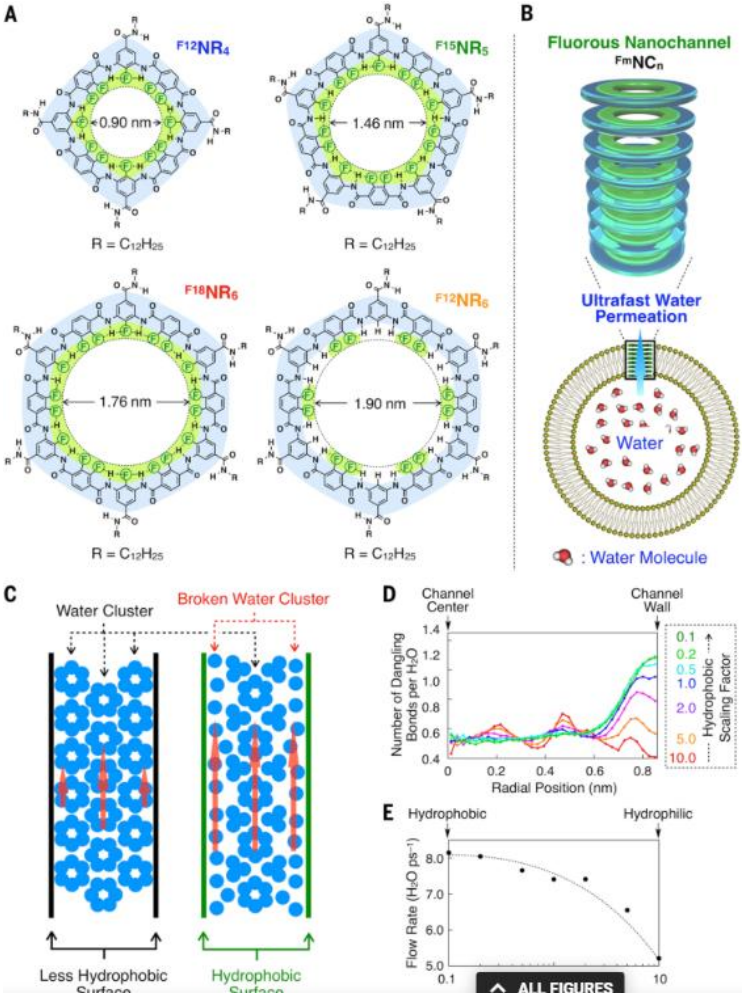
全文链接：https://www.science.org/doi/10.1126/science.abd0966

Abstract：Ultrafast water permeation in aquaporins is promoted by their hydrophobic interior surface. Polytetrafluoroethylene has a dense fluorine surface, leading to its strong water repellence. We report a series of fluorous oligoamide nanorings with interior diameters ranging from 0.9 to 1.9 nanometers. These nanorings undergo supramolecular polymerization in phospholipid bilayer membranes to form fluorous nanochannels, the interior walls of which are densely covered with fluorine atoms. The nanochannel with the smallest diameter exhibits a water permeation flux that is two orders of magnitude greater than those of aquaporins and carbon nanotubes. The proposed nanochannel exhibits negligible chloride ion (Cl-) permeability caused by a powerful electrostatic barrier provided by the electrostatically negative fluorous interior surface. Thus, this nanochannel is expected to show nearly perfect salt reflectance for desalination.

摘要翻译：水通道蛋白的疏水性内表面促进了水在其中的超快渗透。聚四氟乙烯有着致密的氟面，因此具有很强的防水性。研究组报道了一系列内径为 0.9-1.9 纳米的含氟低聚酰胺纳米环。这些纳米环在磷脂双层膜中进行超分子聚合，形成含氟纳米通道，其内壁被氟原子密集覆盖。直径最小的纳米通道的水渗透通量比水通道蛋白和碳纳米管的水渗透通量大两个数量级。该研究所提出的纳米通道具有可忽略的氯离子（Cl-）渗透性，这是由静电负氟内表面提供的强大静电屏障造成的。因此，这种纳米通道有望在脱盐过程中显示出近乎完美的阻盐。

文中插图：



[4]Emergent ferroelectricity in subnanometer binary oxide films on silicon

硅上集成的亚纳米二元氧化物薄膜中的铁电性

出版信息：Science, 6 MAY 2022, VOLUME 376 ISSUE 6593

作者：SURAJ S. CHEEMA, NIRMAAN SHANKER, HANG-LIN HSU et al.

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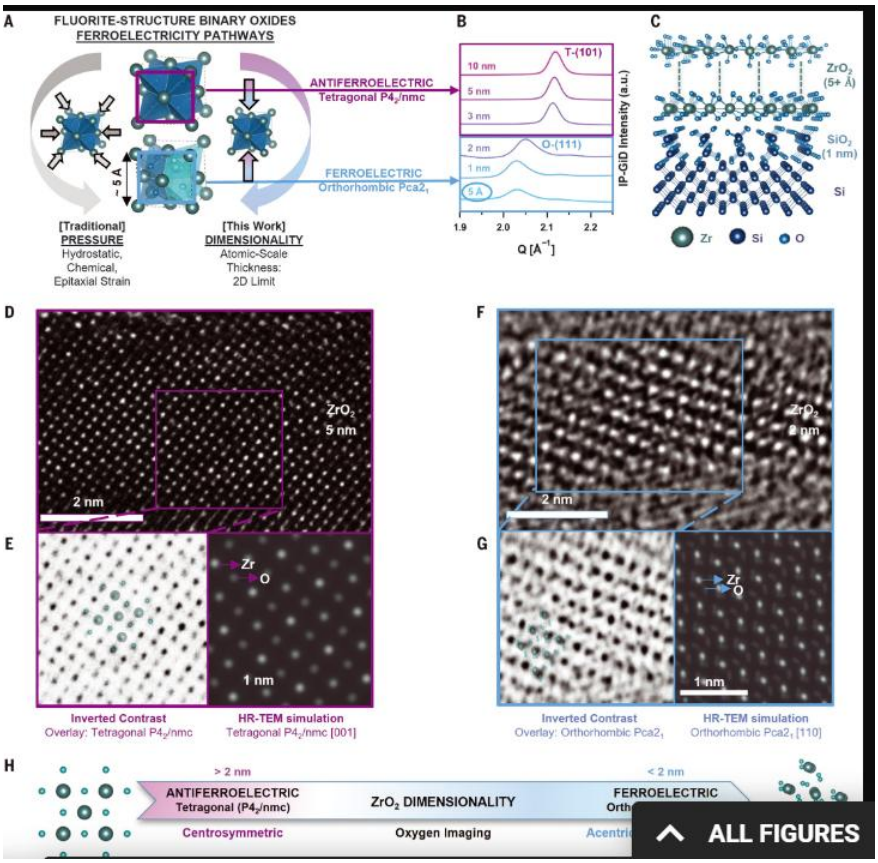
全文链接：https://www.science.org/doi/10.1126/science.abm8642

Abstract：The critical size limit of voltage-switchable electric dipoles has extensive implications for energy-efficient electronics, underlying the importance of ferroelectric order stabilized at reduced dimensionality. We report on the thickness-dependent antiferroelectric-to-ferroelectric phase transition in zirconium dioxide (ZrO2) thin films on silicon. The emergent ferroelectricity and hysteretic polarization switching in ultrathin ZrO2, conventionally a paraelectric material, notably persists down to a film thickness of 5 angstroms, the fluorite-structure unit-cell size. This approach to exploit three-dimensional centrosymmetric materials deposited down to the two-dimensional thickness limit, particularly within this model fluorite-structure system that possesses unconventional ferroelectric size effects, offers substantial promise for electronics, demonstrated by proof-of-principle atomic-scale nonvolatile ferroelectric memory on silicon. Additionally, it is also indicative of hidden electronic phenomena that are achievable across a wide class of simple binary materials.

摘要翻译：电压可切换电偶极子的临界尺寸限制对节能电子器件有着广泛的影响，强调了在降维下稳定铁电序的重要性。在此，我们报告硅上集成二氧化锆薄膜中与厚度相关的反铁电-铁电相变反应。超薄二氧化锆（通常是一种顺电材料）中出现的铁电性和迟滞极化开关，能在薄膜厚度低至 5 埃时依旧持续。这种利用三维中心对称材料沉积到二维厚度极限的方法，特别是在这种具有非常规铁电尺寸效应的结构系统模型中，为电子技术提供了巨大的前景。这一点可由硅上集成原子尺度非易失性铁电存储器证明。此外，它还表明隐藏的电子现象可以在广泛的简单二元材料中实现。

文中插图：



[1]**Cilia metasurfaces for electronically programmable microfluidic manipulation**

电子可编程微流控操作的纤毛超表面

出版信息：Nature,26 May 2022, VOL 605, ISSUE 7911

作者：Wei Wang, Qingkun Liu, Ivan Tanasijevic, Michael F. Reynolds, Alejandro J. Cortese, Marc Z. Miskin, et al.

第一作者单位：Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, NY, USA

全文链接：https://www.nature.com/articles/s41586-022-04459-w

Abstract：Cilial pumping is a powerful strategy used by biological organisms to control and manipulate fluids at the microscale. However, despite numerous recent advances in optically, magnetically and electrically driven actuation, development of an engineered cilial platform with the potential for applications has remained difficult to realize. Here we report on active metasurfaces of electronically actuated artificial cilia that can create arbitrary flow patterns in liquids near a surface. We first create voltage-actuated cilia that generate non-reciprocal motions to drive surface flows at tens of microns per second at actuation voltages of 1 volt. We then show that a cilia unit cell can locally create a range of elemental flow geometries. By combining these unit cells, we create an active cilia metasurface that can generate and switch between any desired surface flow pattern. Finally, we integrate the cilia with a light-powered complementary metal‐oxide‐semiconductor (CMOS) clock circuit to demonstrate wireless operation. As a proof of concept, we use this circuit to output voltage pulses with various phase delays to demonstrate improved pumping efficiency using metachronal waves. These powerful results, demonstrated experimentally and confirmed using theoretical computations, illustrate a pathway towards fine-scale microfluidic manipulation, with applications from microfluidic pumping to microrobotic locomotion.

摘要翻译：纤毛泵送是生物有机体在微尺度上控制和操纵流体的一种强有力策略。然而，尽管最近在光、磁和电驱动致动方面取得了许多进展，但开发具有应用潜力的人工纤毛平台仍然很难实现。研究组报道了电子驱动人工纤毛的主动超表面，它可以在表面附近的液体中创建任意流动模式。首先创建了电压驱动的纤毛，在1V 的驱动电压下产生非互易运动，以每秒数十微米的速度驱动表面流动。然后展示了纤毛晶胞可以局部创建一系列基本流动几何形状。通过组合这些晶胞，研究组创建了一个主动纤毛超表面，可以产生和切换任何所需的表面流动模式。最后将纤毛与光驱动互补金属氧化物半导体（CMOS）时钟电路集成，以演示无线操作。作为概念证明，研究组使用该电路输出不同相位延迟的电压脉冲，以证明利用异时波提高了泵浦效率。实验和理论计算证实了这些强有力的结果，该研究开辟了一条精细尺度微流控操作的新途径，其应用范围从微流控泵到微机器人运动。

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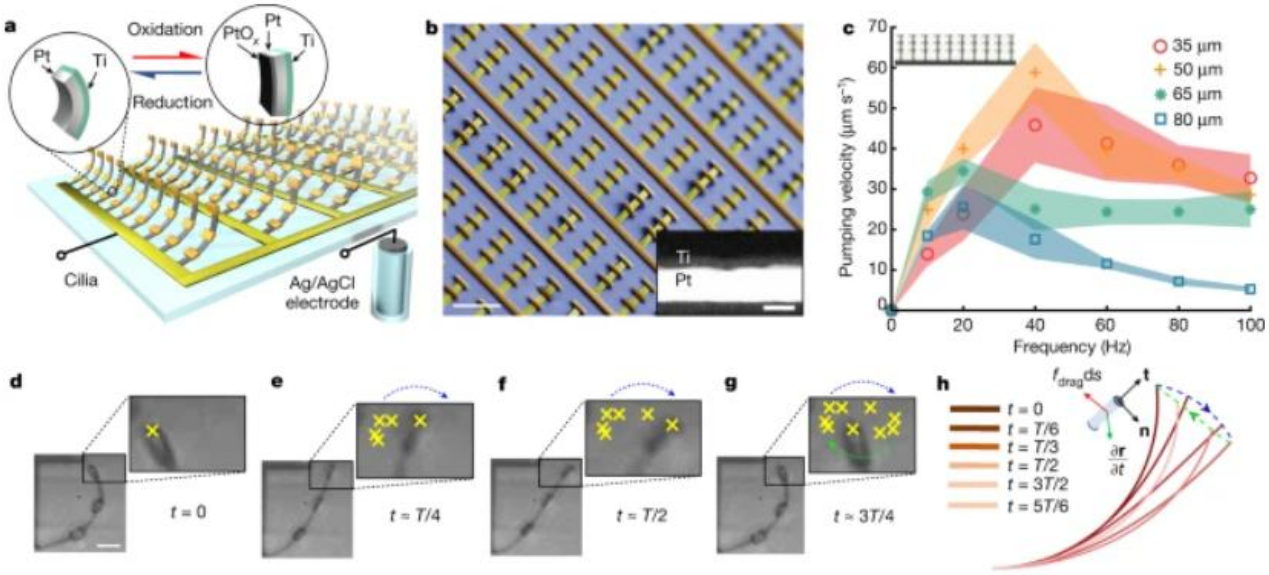


[2]**Observation of chiral and slow plasmons in twisted bilayer graphene**

扭曲双层石墨烯中手性和慢等离子体的观测

出版信息：Nature, 5 May 2022, VOL 605, ISSUE 7908

作者：Tianye Huang, Xuecou Tu, Changqing Shen, Binjie Zheng, Junzhuan Wang, Hao Wang, et al.

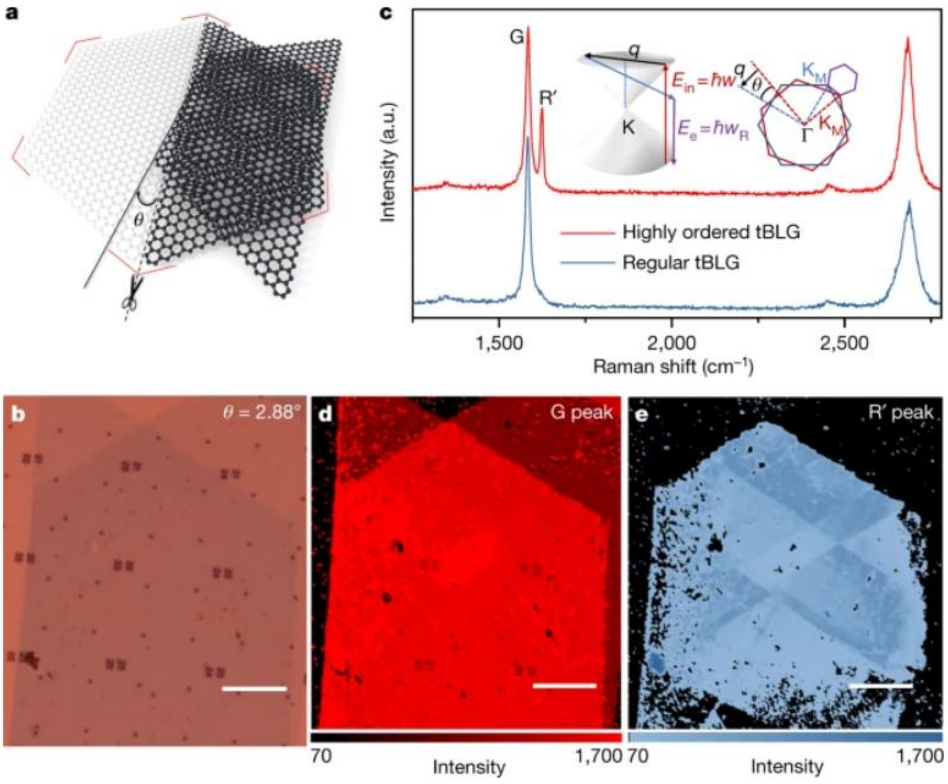
第一作者单位：School of Electronic Science and Engineering, Nanjing University, Nanjing, China

全文链接：https://www.nature.com/articles/s41586-022-04520-8

Abstract：Moiré superlattices have led to observations of exotic emergent electronic properties such as superconductivity and strong correlated states in small-rotation-angle twisted bilayer graphene (tBLG). Recently, these findings have inspired the search for new properties in moiré plasmons. Although plasmon propagation in the tBLG basal plane has been studied by near-field nano-imaging techniques, the general electromagnetic character and properties of these plasmons remain elusive. Here we report the direct observation of two new plasmon modes in macroscopic tBLG with a highly ordered moiré superlattice. Using spiral structured nanoribbons of tBLG, we identify signatures of chiral plasmons that arise owing to the uncompensated Berry flux of the electron gas under optical pumping. The salient features of these chiral plasmons are shown through their dependence on optical pumping intensity and electron fillings, in conjunction with distinct resonance splitting and Faraday rotation coinciding with the spectral window of maximal Berry flux. Moreover, we also identify a slow plasmonic mode around 0.4 electronvolts, which stems from the interband transitions between the nested subbands in lattice-relaxed AB-stacked domains. This mode may open up opportunities for strong light–matter interactions within the highly sought after mid-wave infrared spectral window. Our results unveil the new electromagnetic dynamics of small-angle tBLG and exemplify it as a unique quantum optical platform.

摘要翻译：莫尔超晶格已引发对奇异涌现电子特性的观测，例如小旋转角扭曲双层石墨烯（tBLG）中的超导性和强关联态。最近，这些发现激发了人们对莫尔等离子体新特性的探索。虽然近场纳米成像技术已经研究了等离子体在 tBLG 基面中的传播，但这些等离子体的一般电磁特性和性质仍不清楚。研究组报道了在一个高度有序莫尔超晶格的宏观 tBLG 中直接观测到两种新的等离子体模式。利用 tBLG 的螺旋结构纳米带，研究组确定了因光泵浦下电子气未补偿 Berry 通量而产生的手性等离子体特征。这些手性等离子体的显著特征表现在它们对光泵浦强度和电子填充的依赖，以及与最大 Berry 通量光谱窗口相一致的明显共振分裂和法拉第旋转。此外，研究组还发现了 0.4 电子伏特左右的慢等离子体模式，这源于晶格-弛豫 AB-堆叠畴中嵌套子带之间的带间跃迁。这种模式有望在常用的中波红外光谱窗口内为强光-物质相互作用提供机会。该研究结果揭示了小角度 tBLG 的新电磁动力学特性，证明其可作为一个独特的量子光学平台。

文中插图：



[3]Self-regulated non-reciprocal motions in single-material microstructures

单一材料微结构中的自调节非互易运动

出版信息：Nature, 7 April 2022, Volume 604 Issue 7904

作者：Shucong Li, Michael M. Lerch, James T. Waters, Bolei Deng, Reese S. Martens, Yuxing Yao, et al.

第一作者单位：Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA, USA

全文链接：https://www.nature.com/articles/s41586-022-04561-z

Abstract：Living cilia stir, sweep and steer via swirling strokes of complex bending and twisting, paired with distinct reverse arcs. Efforts to mimic such dynamics synthetically rely on multimaterial designs but face limits to programming arbitrary motions or diverse behaviours in one structure. Here we show how diverse, complex, non-reciprocal, stroke-like trajectories emerge in a single-material system through self-regulation. When a micropost composed of photoresponsive liquid crystal elastomer with mesogens aligned oblique to the structure axis is exposed to a static light source, dynamic dances evolve as light initiates a travelling order-to-disorder transition front, transiently turning the structure into a complex evolving bimorph that twists and bends via multilevel opto-chemo-mechanical feedback. As captured by our theoretical model, the travelling front continuously reorients the molecular, geometric and illumination axes relative to each other, yielding pathways composed from series of twisting, bending, photophobic and phototropic motions. Guided by the model, here we choreograph a wide range of trajectories by tailoring parameters, including illumination angle, light intensity, molecular anisotropy, microstructure geometry, temperature and irradiation intervals and duration. We further show how this opto-chemo-mechanical self-regulation serves as a foundation for creating self-organizing deformation patterns in closely spaced microstructure arrays via light-mediated interpost communication, as well as complex motions of jointed microstructures, with broad implications for autonomous multimodal actuators in areas such as soft robotics, biomedical devices and energy transduction materials, and for fundamental understanding of self-regulated systems.

摘要翻译：活纤毛通过复杂弯曲和扭曲的旋转冲程进行搅动、扫掠和转向，并伴有明显的反向弧线。综合模拟此类动力学常依赖于多材料设计，但在规划任意运动或同一结构的不同行为时面临限制。研究组展示了如何通过自我调节，在单一材料系统中出现多样、复杂、非互易、类似冲程的轨迹。当一个由基元-结构轴倾斜排列的光响应液晶弹性体组成的微柱暴露在静态光源下时，动态舞蹈随着光启动一个有序到无序的运动过渡前沿而演变，通过多级光-化学-机械反馈，瞬间将结构转变为复杂的、不断演变的、扭转和弯曲的双晶片。正如该理论模型所捕捉到的，运动前沿不断地改变分子轴、几何轴和照明轴的方向，从而产生由一系列扭转、弯曲、避光和向光运动组成的路径。在该模型的指导下，研究组通过调整参数，包括照明角度、光强、分子各向异性、微结构几何形状、温度和辐照间隔以及持续时间，设计了一系列的广泛轨迹。研究组进一步展示了这种光-化学-机械自我调节如何通过光介导的干预通信，以及连接微结构的复杂运动，在紧密间隔的微结构阵列中创建自组织变形模式。这对软体机器人、生物医学设备和能量转换材料等领域的自主多模态致动器，以及对自我调节系统的基本认知具有广泛意义。

文中插图：