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简  介

一. 光学与工程

1. 研究人员演示了可以在纳米级操作的“随机，晶体管”激光器

简介：研究人员研究发现通过施加外部电压，能够控制激光输出光束方向，可以克服第二代激光器物理限制。这项研究结果使随机激光更接近光谱学实际应用，可应用于各种形式的扫描和生物医学程序中。

2. 开创性的新技术可以通过利用扭曲的光束使互联网速度提高 100 倍

简介：研究人员研发出了纳米光子器件，该器件以螺旋形式传输光波数据，传输速度更快，传输带宽更大。纳米光子器件可接收通过扭曲光发送的量子信息，可应用于各种尖端量子通信和量子计算研究。

3. 研究人员开发出可以弯曲光线以产生新辐射的小型设备

简介：研究人员使用激光产生“超短”脉冲或光脉冲，持续时间为万亿分之一秒。天线阵列使光脉冲沿晶体内弯曲轨迹加速，从而发射同步辐射。该研究可用于研究固体，液体或气体中原子或分子行为和生物医学科成像中。

4. 神经网络可以学习量子计算机的纠错策略

简介：研究人员提出了一种能够通过人工智能学习的量子纠错系统。人工神经网络是模拟相互连接的神经细胞（神经元）行为的计算机程序，它可以识别视觉模式，可用于量子计算机中开发纠错学习。

5. K 核心作为共生生态系统结构崩溃的预测指标

简介：研究人员研究发现网络 K 核心可以预测共生生态系统结构的崩溃。K 核心可预测哪些物种首先面临灭绝，气候变化等全球性冲击，以及生态系统因外部力量而崩溃等情况。该理论不仅可以监测生态系统健康状况，还可以影响金融市场。

6. 旋转灯：世界上最亮的光学陀螺仪

简介：研究人员采用“相互灵敏度增强”新技术研发出了一种新型光学陀螺仪，可以改善系统信噪比，体积比目前最先进的设备小 500 倍，但该系统可以检测到相移比其他系统小 30 倍。

7. 团队研究打破了福斯特共振能量转移（FRET）距离限制

简介：研究人员采用工程纳米复合材料结构，打破了 Förster 共振能量转移（FRET）距离限制 10~20nm，将能量转移距离显著增加至 160 nm。这项成果可用于测量更大分子组件，以及研发新型药物。

8. 光弯曲技术使千米级的辐射系统缩小到毫米级

简介：研究人员使用激光产生可见光脉冲，持续时间为万亿分之一秒。天线阵列使光脉冲沿晶体内弯曲轨迹加速，释放电磁能量。这项研究能够在太赫兹应用范围内产生较低光频率，例如识别伪钞或区分癌症和健康组织。

9. 一种更有效的微波激光焊接方法

简介：研究人员研发出了一种新型光纤激光器，通过调整激光频率，消除焊接过程中出现的黑边现象。这种激光器采用空气代替水进行节能，工作更加一致，更紧凑，而且成本更低。

二. 光子学

10. 声子色散合理化：晶格热导率高效精确的预测

简介：晶格热导率强烈影响了热功率材料的应用，例如热管理、热障涂层和热电学。大多数模型都是依据 Debye 提出的声弹性波假设的线性声子色散，但是当这些声子卷入到声子输运时，使声学和光学子都为晶格热导率做出贡献，由此 Debye 色散会导致晶格热导率高估和晶格热导率下界现象。Debye-Snyde 模型充分考虑了 BVK 边界条件，使声光色散产生了正弦函数。因此优
化了声子色散，更有利于晶格导电高效和运算。

11. 叠合式光学产品用新的方法操纵光

    简介：Faraon group 科研小组通过折叠式曲面光学技术研发出新型光谱仪，具体解释为一种将多种类型的元曲面打印到基板两侧的方法（如玻璃），基板由此成为光的传播空间。此光谱仪厚度为 1 毫米，包括 3 个分光反色光反射曲面。这种紧凑型光谱仪涵盖无创血糖测量系统等光学产品。

12. 晶体把可见光与红外连接起来的方法打开了近红外传感技术之门

    简介：近红外光谱可用于医疗、材料、历史文物等检测，可见波长则可用于手机及激光照射技术。基于两种技术相结合的目的，A*STAR 数据储存研究所研发出一种将激光光束转换成两个联接的低能光束，两个光束的连接允许近红外波长在一个光束中得到测量，而第二个则测可见光。科学家们通过上述设计，基于光学相干断层成像术可以从事近红外传感技术。

13. 量子边缘：量子技术的新途径

    简介：澳大利亚科学家通过物理拓扑概念，首次展示了双光子之间相关态的保护—光能包。此技术为建构新型量子点—量子计算机材料奠定了基础，利用受保护的光子为逻辑门构建出光子纠缠态。他们在以色列科学家合作下，将此研发成果发表在《科学》期刊上。

三. 电子工程

14. 科学家开发计算模型来预测人类行为

    简介：美国陆军研究实验室科学家研发出了一种个体行为动态模型，该模型用非整数（分数）来表示波动观点来模拟群体动力学。这项研究可以定量分析个体结合群体的动态行为，打开了通向网络科学和分数微积分新研究领域的大门。

15. 新的充气纤维束可以使内窥镜更小

    简介：研究人员研发出了一种新型充气光纤束，采用蜂窝结构将玻璃和空气结合在一起，其波长范围是商用光纤两倍，分辨率高。这种新型光纤可用于制造体积更小、分辨率更高的内窥镜，用于微创手术或支气管镜检查，还可应用于监测危险机器内部或对油和矿物钻头内部进行成像。

16. 使用材料信息学发现新的超导材料

    简介：NIMS-Ehime 大学联合研究小组利用材料信息学（MI）方法在高压下合成 SnBi2Se4 和 PbBi2Te4 两种材料，新材料具有超导性和热电性能。该研究证明 MI 方法可适用开发于各种功能材料，例如室温超导材料等。

17. 物理学家展示了使用量子效应和机器学习的磁力计

    简介：研究人员研发出了一种使用量子效应和机器学习来测量磁场的原型设备，该设备测量精度高，可以低温环境下工作，可以用于寻找矿物沉积物，观察天文物体以及诊断脑部疾病等。

18. 用于节能数据存储的新材料达到计算机工作温度

    简介：研究人员研发出了一种新型材料，该材料同时包含小磁铁和正负电荷，晶格中原子距离缩小，通过施加电器产生磁场，能够消除传统磁数据存储的缺点。这种新型材料的温度稳定性可以达到 100 摄氏度，可适应计算机工作温度。

19. 快速流动的电子可能模仿天体物理发电机

    简介：联合量子研究所（JQI）研究人员研究发现韦尔半金属材料能够承载以每秒一公里速度流动的电子流体，能够快以产生引导发电机所需的湍流。这种方法比传统方法更简单安全。

20. 电子显微镜显示以前看不见的电子活动

    简介：研究人员将扫描透射电子显微镜或 STEM 与电子束感应电流成像配对，称为 EBIC 成像。EBIC 成像使用放大器来测量暴露于显微镜电子束样品中的电流，科学家和工程师可以通过这种方式观察工作设备内部电子活动，并最终改善其功能。
21. 原子尺度结温差引起的电子噪声

**简介：**研究人员研究发现当在两个电极之间施加温差时，电子噪声与相同温度下电极相比更加剧烈。这种噪声被称为“Δ-T 噪声”，它源于介导热传输电荷载体的离散性。该研究可应用于纳米级系统中温度差异的探针以及可变尺寸导体。

22. 更新的高分辨率 MR

**简介：**研究人员认为采用微带贴片天线（MPA）射频探头可提高高频 MRI 机器分辨率。MPA 由平面金属片制成，成本低廉且易于制造，可在更高微波范围内提供高质量性能，同时降低辐射损耗。研究人员下一步计划继续应用电气工程来修改这些探头以使其更好工作，并进一步扩展高频 MRI 机器及其创建图像的可能性。

23. 科学家首次详细测量了与高温超导相关的关键因

**简介：**研究人员研究发现高温超导体中铜和氧原子协调运动形成声学等离子体，可以提高电子对超导强度，使材料在更高温度下导电。这项研究为未来用光控制声波奠定了基础，也可以用于开发等离子体技术。

四. 人工智能

24. 下一代无人驾驶汽车正在走进你

**简介：**无人驾驶汽车在雨雾天气由于散射光的关系而难以区分前方物体。Jayakanth Ravichandran 教授和他的博士生等研发出新型电子和光学材料——一种化学式为 BaTiS 3 的成分，通过近红外技术来提高无人驾驶技术。此研发成果发表在《自然光子学》期刊上。

25. 应用深度学习方法的空气过敏原辨别移动设备

**简介：**传统空气过敏原辨别方法费时费力。UCLA 研究者研发出空气过敏原辨别便携式设备，它利用全息图和机器学习来识别和测量空气中的生物粒子（来源于菌类或生物体），这是一种由神经网络驱动的人工智能来清理图像，把它切换成描述生物粒子的部分。此方法使通过花粉、孢子、毒素和微生物等生物粒子确定率达到百分之 94，从而极大避免了过敏、哮喘和其他疾病的发生。

26. 材料科学家将研发出更佳记忆制备

**简介：**未来人工智能功能将培育出密集阵列中使用高度并行计算神经网络，例如相变记忆比图形处理单元（GPU）更快捷、更节能。此种神经网络包含多个制备功能：如有负责长期记忆功能的制备；有负责图式更新的制备；有负责图式转换成长期记忆的制备。此研发的关键在于基于模拟存储器的节能人工智能硬件加速器。

五. 纳米物理与材料

27. 适用于可穿戴设备高性能，灵活且透明的力接触传感器

**简介：**研究人员通过开发薄、柔软、透明的分层纳米复合材料（HNC）薄膜，成功合成了高性能的透明纳米触摸传感器。该国际研究团队表示，他们的传感器具备工业级应用的所有必要特性，包括高灵敏度、透明度、弯曲不敏感性和可制造性。这种能识别外部刺激位置和压力的力触摸传感器已经受到多种应用的关注，例如可穿戴设备、柔性显示器和类人机器人。

28. 探索新型二维材料剥离特性挑战

**简介：**曼彻斯特大学研究人员剥离单层碳（称为石墨烯）以来，科学家们一直致力于将其在二维材料中进行创造和应用。Barraza-Lopez 实验室研究人员通过模拟新型单层材料与水分子相互作用，发现产生巨大动能积累的吸引力，有望用于二维材料剥离，但是仍然需要许多额外的研究来实现。

29. 分子半导体或将成为电子产品未来，新技术发现提供量产可能

**简介：**Nanosystems 研究团队最近测试了一种技术，成功形成了数百万个纳米级分子结，并获得极小电极对，其中的纳米级间隙可以被捕获和探测分子。这种通过间隙定义新方法，打破分
子结构半导体量产僵局，有朝一日有望用于单分子电子设备。
30. 走向不可破解的通信：光单粒子有望带来“量子互联网” .........................................................27

简介：量子通信的出现可以在很大程度上防止黑客攻击。普渡大学的研究人员创造了一种新光源，每秒产生至少3500万个光子，从而提高了量子通信的速度。研究人员修改了激光束发出的光脉冲，激发晶格缺陷中的电子，改变局部扰动的方式，从而实现量子通信，利用光子来保护信息而不是可破解的代码。

31. 探索石墨烯异质结构中新自旋电子器件功能 ........................................................................28

简介：石墨烯首席研究人员在《科学进展》上发表的一篇论文中表明，由石墨烯和拓扑绝缘体构成的异质结构具有强大的、接近诱导的自旋轨道耦合，通过这种方式组合石墨烯，可以使用可调的状态密度来开启或关闭传导自旋和不传导自旋。这项研究打开了主动旋转装置操控场，这种耦合是形成信息处理新技术的基础。

32. 实验室和计算机中的纳米笼：基于DNA的树状大分子如何传输纳米颗粒................................ 28

简介：维也纳大学、维也纳技术大学、德国Jülich研究中心和美国康奈尔大学的物理学家们联合，研究在实验室合成基于DNA的树状大分子的方法，通过可编程的粘端内聚力实现了卓越的控制性和亚纳米精度，并利用详细的计算机模拟来预测它们的行为。该研究为进一步研究纳米笼的功能性和智能纳米载体铺平了道路。

33. 新研究为纳米粒子与生物系统相互作用提供新思路 ................................................................. 29

简介：国家可持续纳米技术中心研究小组发现，当某些涂层纳米粒子与生物体相互作用时，会产生新特性，导致纳米粒子变粘。在颗粒上形成碎片状的脂质冠状物，它们粘在一起形成卷曲状，具有5纳米直径的纳米颗粒在溶液中形成具有微米尺寸长结构。这项研究提供了纳米粒子与生物系统相互作用的新见解，可以将现有的纳米材料生产模式推向具有可持续性的模式。

34. 纳米铁电体成为现实 ........................................................................................................................ 30

简介：德国德累斯顿纳米电子材料实验室宣布了一项突破，通过在基板上生长氧化铪单相薄膜，利用X射线散射和高分辨率电子显微镜技术，观察到低于10纳米的薄膜以完全意想不到和未知的极性结构生长，这是铁电体所必需的。将这些观察与高精度测量相结合，证实了该材料确实是铁电体，这将开启许多关于铁电体的新研究。

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简介：马萨诸塞州阿默斯特大学科学家团队已经开发出一类新电子材料，将蛋白质纳米线与非导电聚合物混合以产生导电复合材料，具有耐用、易于加工成新材料的优势，而且蛋白质纳米线是一种真正的绿色可持续性材料。这项研究具有极高生物医学意义，并可以结合到可穿戴传感装置或其他柔性基质中。

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简介：LMU实验物理学研究小组负责人Monikar博士提出，使用困在光学晶格中的超冷镱原子来模拟浓缩物质中量子行为，从而研究量子多体现象。这个实验将有助于研究人员模拟晶格规范理论，从而为研究量子动力学实验研究铺平道路。

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简介：芝加哥大学量子科学设计实验通过基于物质量子态的通信网络的构建，计划在30英里距离范围内传送信息。这个项目提供安全发送信息的全新方式，可以防止黑客和安全漏洞造成的信息泄露。通过使用量子物理定律，将建立一个真正不可攻击的网络。

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简介：康斯坦茨大学Guido教授和他的物理学家团队合作，开发了在短时间内能够屏蔽电磁噪声的方法，这将用作增益量子计算机存储器。研究人员通过延长安相干时间，在短时间内屏蔽噪
声，从而进行高效计算机操作，为量子计算机研究提供了新思路。

39. 测试表明集成量子芯片或将取得成功
简介：澳大利亚研究团队已经在硅芯片上实验性地实现了集成连接数百万个量子比特的方法，并能够纠正脆弱量子系统中不可避免的错误。他们展示了一个集成硅量子比特平台，不仅具备结合单自旋可寻址能力，并且在单个自旋量子比特上写入信息而不会干扰其相邻位，这一发现使通用量子计算机的梦实现更接近现实。

40. 计算机理论家展示优于经典验证量子新方法
简介：量子至上理论是描述量子计算机解决计算任务能力的术语，难以通过任何经典算法验证。加州大学伯克利分校的研究人员刚刚给出了一个领先的实用方案，利用随机电路采样（RCS），证明它是否优于传统计算机芯片，提出了验证量子至上理论的新方法，它被认为是量子计算的一个重要里程碑。

41. 科学家们“驯服”量子计算机造成的破坏性影响
简介：苏塞克斯大学离子量子技术小组已经成功地减少了被困离子影响，通过复杂射频和微波信号，控制各个带电原子（离子）固有的量子效应，优化了量子计算机的环境“噪音”问题。这意味着该团队提高了大型量子计算机克服现实环境中干扰的能力，距离成功构建量子计算机更近了一步。

42. 量子鼓的有源噪声控制
简介：哥本哈根大学 Schliesser 实验室的研究人员展示了解决量子物理学核心问题的新方法：在量子尺度上，任何测量都会干扰测量对象，这种干扰限制了跟踪运动物体的精度。在振动的毫米级薄膜中，研究人员已设法用激光精确地监测运动，并通过测量来消除量子干扰，这允许他们在量子水平上控制膜的运动。实验结果将用于在位置、速度和力的超精确传感器，以及未来量子计算机开发中。

43. 新方法或将产生更强大量子传感器
简介：芝加哥大学分子工程研究所正在尝试，将量子环境中的光学系统调谐到特殊点，或将两种以上的光模式以特定频率聚集，目标是解释光波动性和颗粒性带来的量子噪声波动。这项科学研究可能对量子传感和量子技术产生令人兴奋的影响，并大幅超越光学经典传感器性能。

44. 超导现象中的新量子临界
简介：美国能源部艾姆斯实验室的科学家利用固态核磁共振技术，在超导材料中发现了一种新的量子临界性，从而更好地理解了磁性与非常规超导性之间的联系。这一重大发现推进了高温超导性研究，研究人员认为这种近乎量子临界的反铁磁转变或将成为新的突破点。

七. 技术与应用

45. 推动超导科学的超冷前沿
简介：测量绝对零度超导材料量子性质十分重要，Prozorov 和他的研究团队研发出测量超导和磁性材料的新方法，即在稀释冰箱中放置一个隧道二极管谐振器，这是一种精确的射频测量磁性的仪器。科学家们在低温高磁条件下展示了这些材料的性质（包括材料的量子临界行为、超导电性、磁阻抗扰和相变机制）。

46. 电子大脑的建构材料
简介：计算机位是二进制的（0 或 1），而大脑中的神经元可以有许多内部状态，因而大脑方式更节能。格罗宁根大学物理学家正在研发记忆电阻（铌掺杂钛酸锶），用以模仿神经元功能。此类记忆器，就像大脑中的突触一样，可以削弱和加强它们的传递能力。他们的科研成果发表在《应用物理学》期刊上。

47. 大型强子对撞机实验室通过机器学习提高了粒子辨认精度
简介：以往科学家预测大爆炸后物质相对于反物质的数量优势原因在于：CP 破坏（粒子间的
相互破坏) 造成了物质与反物质的不平衡。大型强子对撞机实验室科学家展示了不稳定粒子-B 介子的衰败过程，他们采纳人工神经网络与梯度增强（五乘五矩阵方法），利用能量计区分了初级光子和高能 π 介子衰变光子。此方法拥有高于传统方法四倍质量指标和 0.97区分质量（以往 0.89）。
Researchers demonstrate 'random, transistor' laser that can be manipulated at nanoscale

In the last half-century, laser technology has grown into a multi-billion-dollar global industry and has been used in everything from optical-disk drives and barcode scanners to surgical and welding equipment.

Not to mention those laser pointers that entertain and confound your cat.

Now, lasers are poised to take another step forward: Researchers at Case Western Reserve University, in collaboration with partners around the world, have been able to control the direction of a laser's output beam by applying external voltage.

It is a historic first among scientists who have been experimenting with what they call "random lasers" over the last 15 years or so.

"There's still a lot of work to do, but this is a clear first proof of a transistor random laser, where the laser emission can be routed and steered by applying an external voltage," said Giuseppe Strangi, professor and Ohio Research Scholar in Surfaces of Advanced Materials at Case Western Reserve University.

Strangi, who led the research, and his collaborators recently outlined their findings in a paper published in the journal Nature Communications. The project, funded by the National Academy of Sciences of Finland, was aimed at overcoming certain physical limitations intrinsic to that second generations of lasers.

Laser successes, laser limitations The history of laser technology has been fast-paced as the unique source of light has revolutionized virtually all areas of modern life, including telecommunications, biomedicine and measurement technology.

But laser technology has also been hampered by significant shortcomings: Not only do users have to physically manipulate the device projecting the light to move a laser, but to function, they require a precise alignment of components, making them expensive to produce.

Those limitations could soon be eliminated: Strangi and research partners in Italy, Finland and the United Kingdom have recently demonstrated a new way to both generate and manipulate random laser light, including at nano-scale.

Eventually, this could lead to a medical procedure being conducted more accurately and less invasively or re-routing a fiber optic communication line with the flip of a dial, Strangi said.

'Random' lasers made better So how do lasers actually work?

Conventional lasers consist of an optical cavity, or opening, in a given device. Inside that cavity is a photoluminescent material which emits and amplifies light and a pair of mirrors. The mirrors force the photons, or light particles, to bounce back and forth at a specific frequency to produce the red laser beam we see emitting from the laser.

"But what if we wanted to miniaturize it and get rid of the mirrors and make a laser with no cavity and go down to the nanoscale?" he asked. "That was a problem in the real world and why we could not go further until the turn of this century with random lasers."

So random lasers, which have been researched in earnest for about the last 15 years, differ from the original technology first unveiled in 1960 mostly in that they do not rely on that mirrored cavity.

In random lasers, the photons emitted in many directions are instead wrangled by shining light into a liquid-crystal medium, guiding the resulting particles with that beam of light. Therefore, there is no need for the large, mirrored structure required in traditional applications. In random lasers, the photons emitted in many directions are instead wrangled by shining light into a liquid-crystal medium, guiding the resulting particles with that beam of light. Therefore, there is no need for the large, mirrored structure required in traditional applications.

The resulting wave—called a "soliton" by Strangi and the researchers—functions as a channel for the scattered photons to follow out, now in an orderly, concentrated path.

One way to understand how this works is by envisioning a light-particle version of the "solitary waves" that surfers (and freshwater-bound fish) can ride when rivers and ocean tide collide in certain estuaries, Strangi said.

Finally, the researchers hit the liquid crystal with an
electrical signal, which allows the user to "steer" the laser with a dial, as opposed to moving the entire structure.

That's the big development by this team, Strangi said. "That's why we call it 'transistor,' because a weak signal (the soliton), controls a strong one—the laser output." Strangi said. "Lasers and transistors have been the two leading technologies that have revolutionized the last century, and we have discovered that they are both intertwined in the same physical system"

The researchers believe that their results will bring random lasers closer to practical applications in spectroscopy (used in physical and analytical chemistry as well as in astronomy and remote sensing), various forms of scanning and biomedical procedures.


2. **Groundbreaking new technology could allow 100-times-faster internet by harnessing twisted light beams**

The miniature OAM nano-electronic detector decodes twisted light.

Broadband fiber-optics carry information on pulses of light, at the speed of light, through optical fibers. But the way the light is encoded at one end and processed at the other affects data speeds.

This world-first nanophotonic device, just unveiled in *Nature Communications*, encodes more data and processes it much faster than conventional fiber optics by using a special form of 'twisted' light.

Dr. Haoran Ren from RMIT's School of Science, who was co-lead author of the paper, said the tiny nanophotonic device they have built for reading twisted light is the missing key required to unlock super-fast, ultra-broadband communications.

"Present-day optical communications are heading towards a 'capacity crunch' as they fail to keep up with the ever-increasing demands of Big Data," Ren said.

"What we've managed to do is accurately transmit data via light at its highest capacity in a way that will allow us to massively increase our bandwidth."

Current state-of-the-art fiber-optic communications, like those used in Australia's National Broadband Network (NBN), use only a fraction of light's actual capacity by carrying data on the colour spectrum.

New broadband technologies under development use the oscillation, or shape, of light waves to encode data, increasing bandwidth by also making use of the light we cannot see.

This latest technology, at the cutting edge of optical communications, carries data on light waves that have been twisted into a spiral to increase their capacity further still. This is known as light in a state of orbital angular momentum, or OAM.

In 2016 the same group from RMIT’s Laboratory of Artificial-Intelligence Nanophotonics (LAIN) published a disruptive research paper in *Science* journal describing how they'd managed to decode a small range of this twisted light on a nanophotonic chip. But technology to detect a wide range of OAM light for optical communications was still not viable, until now.

"Our miniature OAM nano-electronic detector is designed to separate different OAM light states in a continuous order and to decode the information carried by twisted light," Ren said.

"To do this previously would require a machine the size of a table, which is completely impractical for telecommunications. By using ultrathin topological nanosheets measuring a fraction of a millimeter, our invention does this job better and fits on the end of an optical fiber."

LAIN Director and Associate Deputy Vice-Chancellor for Research Innovation and Entrepreneurship at RMIT, Professor Min Gu, said the materials used in the device were compatible with silicon-based materials used in most technology, making it easy to scale up for industry applications.

"Our OAM nano-electronic detector is like an 'eye' that can 'see' information carried by twisted light and decode it to be understood by electronics. This technology's high performance, low cost and tiny size makes it a viable application for the next generation of broadband optical communications," he said.

"It fits the scale of existing fiber technology and could be applied to increase the bandwidth, or potentially the processing speed, of that fiber by over 100 times within the next couple of years. This easy scalability and the massive impact it will have on telecommunications is what's so exciting."

Gu said the detector can also be used to receive quantum information sent via twisting light, meaning it could have applications in a whole range of cutting edge quantum communications and quantum computing research.

"Our nano-electronic device will unlock the full potential of twisted light for future optical and quantum communications," Gu said.


3. **Researchers develop small device that bends light to generate new radiation**
A research team led by University of Michigan physicists have developed a way to generate synchrotron using a device the size of a match head. Typically, synchrotron radiation is generated at facilities the size of several football fields.

University of Michigan physicists have led the development of a device the size of a match head that can bend light inside a crystal to generate synchrotron radiation in a lab.

When physicists bend very intense beams of charged particles in circular orbits near the speed of light, this bending throws off bits of light, or X-rays, called synchrotron radiation. The U-M-led researchers used their device to bend visible light to produce light with a wavelength in the terahertz range. This range of wavelength is considerably larger than that of visible light, but much smaller than the waves your microwave produces—and can penetrate clothing.

Synchrotron radiation is usually generated at large-scale facilities, which are typically the size of several football stadiums. Instead, U-M researchers Roberto Merlin and Meredith Henstridge's team developed a way to produce synchrotron radiation by printing a pattern of microscopic gold antennae on the polished face of a lithium tantalate crystal, called a metasurface. The U-M team, which also included researchers from Purdue University, used a laser to pulse light through the pattern of antennae, which bent the light and produced synchrotron radiation.

"Instead of using lenses and spatial light modulators to perform this kind of experiment, we figured out by simply patterning a surface with a metasurface, you can achieve a similar end," said Merlin, professor of physics and electrical engineering and computer science. "In order to get light to curve, you have to sculpt every piece of the light beam to a particular intensity and phase, and now we can do this in an extremely surgical way."

Anthony Grbic, U-M professor of electrical engineering and computer science, led the team that designed the metasurface with former doctoral student Carl Pfeiffer developing the metasurface.

The metasurface is composed of roughly 10 million tiny boomerang-shaped antennae. Each antenna is considerably smaller than the wavelength of the impinging light, said Henstridge, lead author of the study. The researchers use a laser that produces "ultrashort" bursts or pulses of light which last for one trillionth of a second. The array of antennae causes the light pulse to accelerate along a curved trajectory inside the crystal.

Microscopic device that bends light.

The light pulse creates a collection of electric dipoles—or, a group of positive and negative charge pairs. This dipole collection accelerates along the curved trajectory of the light pulse, resulting in the emission of synchrotron radiation, according to Henstridge, who earned her doctoral degree at U-M and is now a postdoctoral scientist at the Max Planck Institute for the Structure and Dynamics of Matter in Hamburg, Germany.

The researchers' device produces synchrotron radiation that contains many terahertz frequencies because the light pulses travel just a fraction of a circle. But they hope to refine their device so that the light pulse revolves continuously along a circular path, producing synchrotron radiation at a single terahertz frequency.

The scientific community uses single-frequency terahertz sources to study the behavior of atoms or molecules within a given solid, liquid or gas. Commercially, terahertz sources are used to scan items hidden in clothing and packaging crates. Drugs, explosive and toxic gases all have unique "fingerprints" in the terahertz range that could be identified using terahertz spectroscopy.

The device's uses aren't limited to the security industry. "Terahertz radiation is useful for imaging in the biomedical sciences," Henstridge said. "For instance, it has been used to distinguish between cancerous and healthy tissue. An on-chip, single-frequency terahertz source, such as a tiny light-driven synchrotron such as our device, can allow for new advancements in all of these applications."


4. Neural networks enable learning of error correction strategies for quantum computers

Learning quantum error correction: the image visualizes the activity of artificial neurons in the Erlangen researchers' neural network while it is solving its task. Quantum computers could solve complex tasks that are beyond the capabilities of conventional computers. However, the quantum states are extremely sensitive to constant interference from their environment. The plan is to combat this using active protection based on quantum
error correction. Florian Marquardt, Director at the Max Planck Institute for the Science of Light, and his team have now presented a quantum error correction system that is capable of learning thanks to artificial intelligence.

In 2016, the computer program AlphaGo won four out of five games of Go against the world's best human player. Given that a game of Go has more combinations of moves than there are estimated to be atoms in the universe, this required more than just sheer processing power. Rather, AlphaGo used artificial neural networks, which can recognize visual patterns and are even capable of learning. Unlike a human, the program was able to practise hundreds of thousands of games in a short time, eventually surpassing the best human player. Now, the Erlangen-based researchers are using neural networks of this kind to develop error-correction learning for a quantum computer.

Artificial neural networks are computer programs that mimic the behaviour of interconnected nerve cells (neurons) - in the case of the research in Erlangen, around two thousand artificial neurons are connected with one another. "We take the latest ideas from computer science and apply them to physical systems," explains Florian Marquardt. "By doing so, we profit from rapid progress in the area of artificial intelligence."

Artificial neural networks could outstrip other error-correction strategies The first area of application are quantum computers, as shown by the recent paper, which includes a significant contribution by Thomas Fösel, a doctoral student at the Max Planck Institute in Erlangen. In the paper, the team demonstrates that artificial neural networks with an AlphaGo-inspired architecture are capable of learning—for themselves—how to perform a task that will be essential for the operation of future quantum computers: quantum error correction. There is even the prospect that, with sufficient training, this approach will outstrip other error-correction strategies.

To understand what it involves, you need to look at the way quantum computers work. The basis for quantum information is the quantum bit, or qubit. Unlike conventional digital bits, a qubit can adopt not only the two states zero and one, but also superpositions of both states. In a quantum computer's processor, there are even multiple qubits superimposed as part of a joint state. This entanglement explains the tremendous processing power of quantum computers when it comes to solving certain complex tasks at which conventional computers are doomed to fail. The downside is that quantum information is highly sensitive to noise from its environment. This and other peculiarities of the quantum world mean that quantum information needs regular repairs—that is, quantum error correction. However, the operations that this requires are not only complex but must also leave the quantum information itself intact.

Quantum error-correction is like a game of Go with strange rules "You can imagine the elements of a quantum computer as being just like a Go board," says Marquardt, getting to the core idea behind his project. The qubits are distributed across the board like pieces. However, there are certain key differences from a conventional game of Go: all the pieces are already distributed around the board, and each of them is white on one side and black on the other. One colour corresponds to the state zero, the other to one, and a move in a game of quantum Go involves turning pieces over. According to the rules of the quantum world, the pieces can also adopt grey mixed colours, which represent the superposition and entanglement of quantum states.

When it comes to playing the game, a player—we'll call her Alice—makes moves that are intended to preserve a pattern representing a certain quantum state. These are the quantum error correction operations. In the meantime, her opponent does everything they can to destroy the pattern. This represents the constant noise from the plethora of interference that real qubits experience from their environment. In addition, a game of quantum Go is made especially difficult by a peculiar quantum rule: Alice is not allowed to look at the board during the game. Any glimpse that reveals the state of the qubit pieces to her destroys the sensitive quantum state that the game is currently occupying. The question is: how can she make the right moves despite this?

Auxiliary qubits reveal defects in the quantum computer In quantum computers, this problem is solved by positioning additional qubits between the qubits that store the actual quantum information. Occasional measurements can be taken to monitor the state of these auxiliary qubits, allowing the quantum computer's controller to identify where faults lie and to perform correction operations on the information-carrying qubits in those areas. In our game of quantum Go, the auxiliary qubits would be represented by additional pieces distributed between the actual game pieces. Alice is allowed to look occasionally, but only at these auxiliary pieces.

In the Erlangen researchers' work, Alice's role is performed by artificial neural networks. The idea is that, through training, the networks will become so good at this role that they can even outstrip correction strategies devised by intelligent human minds. However, when the team studied an example involving five simulated qubits, a number that is still manageable for conventional computers, they were able to show that one artificial neural network alone is not enough. As the network can only gather small amounts of information about the state of the quantum bits, or rather the game of quantum Go, it never gets beyond the stage of random trial and error. Ultimately, these attempts destroy the quantum state instead of restoring it.

One neural network uses its prior knowledge to train another. The solution comes in the form of an additional neural network that acts as a teacher to the first network. With its prior knowledge of the quantum computer that is
to be controlled, this teacher network is able to train the other network—its student—and thus to guide its attempts towards successful quantum correction. First, however, the teacher network itself needs to learn enough about the quantum computer or the component of it that is to be controlled.

In principle, artificial neural networks are trained using a reward system, just like their natural models. The actual reward is provided for successfully restoring the original quantum state by quantum error correction. "However, if only the achievement of this long-term aim gave a reward, it would come at too late a stage in the numerous correction attempts," Marquardt explains. The Erlangen-based researchers have therefore developed a reward system that, even at the training stage, incentivizes the teacher neural network to adopt a promising strategy. In the game of quantum Go, this reward system would provide Alice with an indication of the general state of the game at a given time without giving away the details.

The student network can surpass its teacher through its own actions

"Our first aim was for the teacher network to learn to perform successful quantum error correction operations without further human assistance," says Marquardt. Unlike the school student network, the teacher network can do this based not only on measurement results but also on the overall quantum state of the computer. The student network trained by the teacher network will then be equally good at first, but can become even better through its own actions.

In addition to error correction in quantum computers, Florian Marquardt envisages other applications for artificial intelligence. In his opinion, physics offers many systems that could benefit from the use of pattern recognition by artificial neural networks.


5. The K-core as a predictor of structural collapse in mutualistic ecosystems

A network metric called the K-core could predict structural collapse in mutualistic ecosystems, according to research by physicists at The City College of New York. The K-core appears able to forecast which species is likely to face extinction first, by global shocks such as climate change, and when an ecosystem could collapse due to external forces.

Led by Flaviano Morone and Hernán A. Makse, the physicists from CCNY’s Division of Science used state of the art network theory to predict the tipping point of an ecosystem under severe external shocks like a global increase of temperature. They determined that a network metric termed the K-core of the network can predict the terrifying tipping point of climate Armageddon.

The idea applies to any network—from species interacting in ecosystems, like plant-pollinators or predator-prey—to financial markets where brokers interact in a financial network to determine the prices of stocks and products.

In all these networks a hierarchical structure emerges: each species in the ecosystem belong to a given shell in the network: the so called K-shells. In the periphery of the network is where the commensalists live. These are species that mainly receive the benefits from the core of the network but give nothing back (not to be confused with parasites which benefit from but at the same time harm the network core).

"Amazingly, these peripheral shells are highly populated, indeed, there are many commensalist species in most ecosystems and markets," noted Makse. "These species are predicted to go extinct first and much before the entire ecosystem collapses."

Fortunately, the CCNY theory provides early warning signals that can be monitored to predict this collapse well in advance. Indeed, monitoring the health of the vital inner K-core of the network is the clear marker to anticipate the ecosystem collapse.

"The theory has enormous implications for not only monitoring ecosystem's health but also financial markets," said Makse.

The study, whose other co-author is research associate Gino Del Ferraro, appears in the current issue of Nature Physics.


6. Spinning the light: The world's smallest optical gyroscope

The optical gyroscope developed in Ali Hajimiri's lab, resting on grains of rice.

Gyroscopes are devices that help vehicles, drones, and wearable and handheld electronic devices know their orientation in three-dimensional space. They are commonplace in just about every bit of technology we rely on every day. Originally, gyroscopes were sets of nested wheels, each spinning on a different axis. But open up a cell phone today, and you will find a
microelectromechanical sensor (MEMS), the modern-day equivalent, which measures changes in the forces acting on two identical masses that are oscillating and moving in opposite directions. These MEMS gyroscopes are limited in their sensitivity, so optical gyroscopes have been developed to perform the same function but with no moving parts and a greater degree of accuracy using a phenomenon called the Sagnac effect.

The Sagnac effect, named after French physicist Georges Sagnac, is an optical phenomenon rooted in Einstein's theory of special relativity. To create it, a beam of light is split into two, and the twin beams travel in opposite directions along a circular pathway, then meet at the same light detector. Light travels at a constant speed, so rotating the device—and with it the pathway that the light travels—causes one of the two beams to arrive at the detector before the other. With a loop on each axis of orientation, this phase shift, known as the Sagnac effect, can be used to calculate orientation.

The smallest high-performance optical gyroscopes available today are bigger than a golf ball and are not suitable for many portable applications. As optical gyroscopes are built smaller and smaller, so too is the signal that captures the Sagnac effect, which makes it more and more difficult for the gyroscope to detect movement. Up to now, this has prevented the miniaturization of optical gyroscopes.

Caltech engineers led by Ali Hajimiri, Bren Professor of Electrical Engineering and Medical Engineering in the Division of Engineering and Applied Science, developed a new optical gyroscope that is 500 times smaller than the current state-of-the-art device, yet they can detect phase shifts that are 30 times smaller than those systems. The new device is described in a paper published in the November issue of Nature Photonics.

How it works

The new gyroscope from Hajimiri's lab achieves this improved performance by using a new technique called "reciprocal sensitivity enhancement." In this case, "reciprocal" means that it affects both beams of the light inside the gyroscope in the same way. Since the Sagnac effect relies on detecting a difference between the two beams as they travel in opposite directions, it is considered nonreciprocal. Inside the gyroscope, light travels through miniaturized optical waveguides (small conduits that carry light, that perform the same function as wires do for electricity). Imperfections in the optical path that might affect the beams (for example, thermal fluctuations or light scattering) and any outside interference will affect both beams similarly.

Hajimiri's team found a way to weed out this reciprocal noise while leaving signals from the Sagnac effect intact. Reciprocal sensitivity enhancement thus improves the signal-to-noise ratio in the system and enables the integration of the optical gyro onto a chip smaller than a grain of rice.

The paper is titled "Nanophotonic optical gyroscope with reciprocal sensitivity enhancement."

7. Team study breaks Forster resonant energy transfer (FRET) distance limit

Schematic of the long-range energy transfer between donor and acceptor molecules enhanced by the metamaterial. Using engineered nanocomposite structures called metamaterials, a City College of New York-led research team reports the ability to measure a significant increase in the energy transfer between molecules. Reported in the journal ACS Photonics, this breakthrough breaks the Förster resonance energy transfer (FRET) distance limit of ~10-20 nanometers, and leads to the possibility of measuring larger molecular assemblies.

And since FRET is a staple technique in many biological and biophysical fields, this new development could benefit pharmaceuticals, for instance.

"Energy transfer between molecules plays a central role in phenomena such as photosynthesis and is also used as a spectroscopic ruler for identifying structural changes of molecules," said Vinod Menon, professor of physics in City College's Division of Science. "However, the process of energy transfer is usually limited in the distance over which it occurs, typically reaching 10 to 20 nm."

But in the study reported by Menon's research group in ACS Photonics, the authors demonstrate significant increase in the energy transfer distance (> 15x) - reaching ~ 160 nm. This is accomplished by using a metamaterial that undergoes a topological transition.

The present work sets the stage for the use of spectroscopic rulers for studying a wide array of larger molecular systems which has not been previously possible using standard FRET technique.

8. Light-bending tech shrinks kilometers-long radiation system to millimeter scale

A new device bends visible light inside a crystal to produce...
"synchrotron" radiation (blue and green) via an accelerating light pulse (red) on a scale a thousand times smaller than massive facilities around the world.

The DESY accelerator facility in Hamburg, Germany, goes on for miles to host a particle making kilometer-long laps at almost the speed of light. Now researchers have shrunk such a facility to the size of a computer chip.

A University of Michigan team in collaboration with Purdue University created a new device that still accommodates speed along circular paths, but for producing lower light frequencies in the terahertz range of applications such as identifying counterfeit dollar bills or distinguishing between cancerous and healthy tissue.

"In order to get light to curve, you have to sculpt every piece of the light beam to a particular intensity and phase, and now we can do this in an extremely surgical way," said Roberto Merlin, the University of Michigan's Peter A. Franken Collegiate Professor of Physics.

The work is published in the journal Science. Ultimately, this device could be conveniently adapted for a computer chip.

"The more terahertz sources we have, the better. This new source is also exceptionally more efficient, let alone that it's a massive system created at the millimeter scale," said Vlad Shalaev, Purdue's Bob and Anne Burnett Distinguished Professor of Electrical and Computer Engineering.

The device that Michigan and Purdue researchers built generates so-called "synchrotron" radiation, which is electromagnetic energy given off by charged particles, such as electrons and ions, that are moving close to the speed of light when magnetic fields bend their paths.

Several facilities around the world, like DESY, generate synchrotron radiation to study a broad range of problems from biology to materials science.

This accelerating light pulse (left) met expectations (right) that it would follow a curved trajectory and emit radiation at the terahertz frequencies of security technology and other sensing applications.

But past efforts to bend light to follow a circular path have come in the form of lenses or spatial light modulators too bulky for on-chip technology.

A team led by Merlin and Meredith Henstridge, now a postdoctoral researcher at the Max Planck Institute for the Structure and Dynamics of Matter, substituted these bulkier forms with about 10 million tiny antennae printed on a lithium tantalite crystal, called a "metasurface," designed by the Michigan team of Anthony Grbic and built by Purdue researchers.

The researchers used a laser to produce a pulse of visible light that lasts for one trillionth of a second. The array of antennae causes the light pulse to accelerate along a curved trajectory inside the crystal.

Instead of a charged particle spiraling for kilometers on end, the light pulse displaced electrons from their equilibrium positions to create "dipole moments." These dipole moments accelerated along the curved trajectory of the light pulse, resulting in the emission of synchrotron radiation much more efficiently at the terahertz range.

"This isn't being built for a computer chip yet, but this work demonstrates that synchrotron radiation could eventually help develop on-chip terahertz sources," Shalaev said.


9. A fine-tuned laser welds more effectively

Cardiac pacemakers are usually housed in a titanium housing that is welded together from two parts. Empa has optimized the frequency of the working laser so that no black edges appear during welding, which would reduce the value of the medical product.

Using laser technology Empa scientists optimized a technique to weld the electronics of implantable pacemakers and defibrillators into a titanium case. The medtech company Medtronic is now using the method worldwide to produce these devices.

In Tolochenaz (Canton of Vaud) the US medtech company Medtronic produces one out of five heart pacemakers available on the global market and one out of four defibrillators. The electronics of these implantable devices are housed in titanium cases, which thus far were welded hermetically with a solid state flash laser. However, the lasers are high-maintenance and often the source of irregularities. Moreover, they require water cooling and take up a lot of space.

A new type of laser launched in 2015 by US company IPG Photonics came to the rescue: This fiber laser is cooled energy-efficiently using air instead of water, requires less maintenance, works more consistently and is more compact. Initial tests conducted by Medtronic, however, revealed that the weld seams now have black edges that look a lot like soot – extremely problematic for implants. Therefore, Medtronic's Sébastien Favre approached Empa materials specialists Patrik Hoffmann and Marc Leparoux from the Advanced Materials Processing Laboratory at the Thun site, who initiated a project to optimize the new laser for usage with titanium. The project was funded by Innosuisse, the former Commission for Technology and Innovation (CTI).

Titanium nanoparticles look black, In order to simulate production processes at Medtronic, Empa built its own "plant" to precisely analyze the behavior of the laser in a controlled environment. The results revealed that an interaction with the titanium vapor interferes with the
process: The black edge on the seams turned out to be titanium nanoparticles. In follow-up experiments, the Empa researchers demonstrated that the black edge disappears if the laser is operated at a different wavelength. Laser manufacturer IPG Photonics subsequently built a fiber laser tailored towards the Empa researchers’ specifications and offered it for further tests. As these experiments confirmed, adjusting the laser frequency indeed solved the problem.

Meanwhile, Empa, Medtronic and IPG Photonics jointly hold a patent for the optimized fiber laser. Medtronic benefits from improved production processes for its implants – at considerably lower costs. And Switzerland could confirm its status as a leading technology hub within the globally operating US multinational. After all, the special lasers "made in Switzerland" are now being used at Medtronic factories in Puerto Rico, Singapore and the US.


二．光子学

10. Rationalizing phonon dispersion: an efficient and precise prediction of lattice thermal conductivity

(a) linear phonon dispersion based on acoustic-elastic-wave assumption, (b) sine phonon dispersion considering the periodic boundary condition, (c) lattice standing wave (top) and traveling wave (bottom).

Lattice thermal conductivity strongly affects the applications of materials related to thermal functionality, such as thermal management, thermal barrier coatings and thermoelectrics. In order to understand lattice thermal conductivity more quantitatively and in a time- and cost-effective way, many researchers have devoted their efforts and developed a few physical models using approximated phonon dispersions over the past century.

Most of these models use a linear phonon dispersion, proposed by Debye in 1912 based on an acoustic-elastic-wave assumption (Fig. 1a), while other models either involve fitting parameters on phonon dispersion or lack detailed equations for phonon transport properties. The linear phonon dispersion of Debye offers many simplifications on phonon transport properties, and was the most common approximation in the past century. The linear dispersion of Debye successfully predicts the T3 dependence of the heat capacity at very low temperatures, and heat capacity approaches the Dulong-Petit limit at high temperatures. However, the nature of periodicity on atomic arrangements leads to a periodic boundary condition for lattice vibrations in solids (Fig. 1b), which actually creates lattice standing waves at Brillouin boundaries (Fig. 1c). This does not satisfy the acoustic-elastic-wave assumption of Debye, as proposed by Born and von Karman (BvK) in 1912—the same year that Debye proposed the linear dispersion.

This results in a significant deviation of Debye dispersion for periodic crystalline materials when phonons with wave vectors are close to the Brillouin boundaries (high frequency phonons). When these phonons are involved for phonon transport (i.e. at not extremely low temperatures), Debye dispersion leads to an overestimation of lattice thermal conductivity due to the overestimation of group velocity for these high-frequency phonons, as observed in materials with hundreds of known measured lattice thermal conductivity and necessary details for a time- and cost-effective model prediction to our best knowledge (Fig. 2g and h showing a mean absolute deviation of ~+40%). In addition, Debye dispersion overestimates the theoretically available lower bound of lattice thermal conductivity as well, leading the violations of the measured lattice thermal conductivity to be even lower than the current theoretical minimum predicted (based on the Debye-Cahill model) as observed in tens of materials.

Comparison on phonon dispersion (a, b and c), measured lattice thermal conductivity versus prediction (d, e and f) and the corresponding error analyses (g, h and i) for Debye-Slack model (a, d and g), Debye-Snyder model (b, e and h) and the one developed in this work considering the periodic boundary condition (c, g and i) for crystalline solids.

This work takes into account the BvK boundary condition, and reveals that the product of acoustic and optical dispersions yields a sine function. In the case of which the mass (or the force constant) contrast between atoms is large, the acoustic dispersion tends to be a sine-function. This sine type dispersion indeed exists in both the simplest and the most complex materials. Approximating the acoustic dispersion to be sine, the BvK boundary condition subsequently reduces the remaining optical branches to be a series of localized modes with a series of constant frequencies. While first-principles calculations enable a more detailed phonon dispersion, a development of rationalized phonon dispersion for a time- and cost-effective prediction
of phonon transport is significant due to the time-consuming and computationally expensive for first-principles calculations.

This work utilizes the above-mentioned rationalization of phonon dispersions, which enables both contributions to lattice thermal conductivity of acoustic and optical phonons to be included. This improvement in phonon dispersions significantly improves the accuracy of a time- and cost-effective prediction on lattice thermal conductivity of solids without any fitting parameters (Fig. 2c, showing a mean absolute deviation of only -2.5%), and therefore offers a more precise design of solids with expected lattice thermal conductivity. Furthermore, this work successfully removes the contradiction of the measured lattice thermal conductivity being even lower than the theoretical minimum predicted based on a linear dispersion of Debye (Debye-Cahill model) and opening further opportunities for advancing thermally resistive materials for applications, including thermoelectrics.

Comparison on measured minimal lattice thermal conductivity ($\kappa_{\text{L,min}}$) and predictions based on a dispersion developed according to the periodic boundary condition or on a linear dispersion of Debye (Debye-Cahill model)


11. 'Folded' optical devices manipulate light in a new way

An array of 11 metasurface-based optical spectrometers, pictured here before the final fabrication step. Each spectrometer is composed of three metasurfaces that disperse and focus light with different wavelengths to different points.

The next generation of electronic devices, ranging from personal health monitors and augmented reality headsets to sensitive scientific instruments that would only be found in a laboratory, will likely incorporate components that use metasurface optics, according to Andrei Faraon, professor of applied physics in Caltech's Division of Engineering and Applied Science. Metasurface optics manipulate light similarly to how a lens might—bending, focusing, or reflecting it—but do so in a finely controllable way using carefully designed microscopic structures on an otherwise flat surface. That makes them both compact and finely tunable, attractive qualities for electronic devices. However, engineers will need to overcome several challenges to make them widespread.

Most optical systems require more than a single metasurface to function properly. In metasurface-based optical systems, most of the total volume inside the device is just free space through which light propagates between different elements. The need for this free space makes the overall device difficult to scale down, while integrating and aligning multiple metasurfaces into a single device can be complicated and expensive.

To overcome this limitation, the Faraon group has introduced a technology called "folded metasurface optics," which is a way of printing multiple types of metasurfaces onto either side of a substrate, like glass. In this way, the substrate itself becomes the propagation space for the light. As a proof of concept, the team used the technique to build a spectrometer, which is a scientific instrument for splitting light into different colors, or wavelengths, and measuring their corresponding intensities. (Spectrometers are used in a variety of fields; for example, in astronomy they are used to determine the chemical makeup of stars based on the light they emit.)

The spectrometer built by Faraon's team is 1 millimeter thick and is composed of three reflective metasurfaces placed next to each other that split and reflect light, and ultimately focus it onto a detector array. The design is described in a paper published by *Nature Communications* on October 10.

A compact spectrometer like the one developed by Faraon's group has a variety of uses, including as a noninvasive blood-glucose measuring system that could be invaluable for diabetes patients. The platform uses multiple metasurface elements that are fabricated in a single step, so, in general, it provides a potential path toward complex but inexpensive optical systems.


12. Using a crystal to link visible light to infrared opens a window on infrared sensing
A cheap, compact technique for analyzing samples at infrared wavelengths using visible-wavelength components could revolutionize medical and material testing.

Infrared spectroscopy is used for material analysis, in forensics and in the identification of historical artifacts, for example—but scanners are bulky and expensive. Visible-wavelength technology is cheap and accessible in items such as smartphone cameras and laser pointers.

This led Leonid Krivitsky and colleagues at the A*STAR Data Storage Institute to develop a method in which a laser beam was converted into two linked lower energy beams: The link between the two beams allowed experiments using one beam at infrared wavelengths to be detected in the second beam, at visible wavelengths.

"It's a very simple setup, uses simple components, and is very compact, and we've hit a resolution comparable with conventional infrared systems," Krivitsky said.

The team fed laser light into a lithium niobate crystal that split some of the laser photons into two quantum-linked photons of lower energies, one in the infrared, and one in the visible parts of the spectrum, through a nonlinear process known as parametric down-conversion.

In a setup similar to a Michelson interferometer, the three beams were separated and were sent to mirrors that reflected them back into the crystal.

When the original laser beam re-entered the crystal, it created a new pair of down-converted beams that interfered with the light created in the first pass.

It was this interference that the team exploited: a sample placed in the infrared beam affected the interference between first-pass and second-pass beams, which could be detected in both the infrared and visible beams, because they are quantum linked.

Not only does the method allow changes in the infrared beam to be analyzed via the visible beam, it provides more information than conventional spectroscopy. "Because this is an interferometric scheme, you can independently measure absorption and refractive index, which you cannot measure in conventional infrared spectroscopy," Krivitsky said.

The team were able to gain more information about the sample by systematically changing its position in the beam. With these measurements they were able to construct a three-dimensional image using a technique known as optical coherence tomography.

"It's a very powerful concept. It's a nice combination of spectroscopy, imaging and the ability to widely tune the wavelength," said Krivitsky.

The team analyzed samples at four wavelengths between 1.5 microns and 3 microns, wavelengths that previously required sophisticated lasers and detectors.

The range of the technique can be extended to the near and far infrared by judicious choice of components.

"To the best of our knowledge there is no commercially-available optical coherence tomography system that operates beyond 1.5 microns," Krivitsky said.


13. Quantum on the edge: Light shines on new pathway for quantum technology

Scientists in Australia have for the first time demonstrated the protection of correlated states between paired photons—packets of light energy—using the intriguing physical concept of topology. This experimental breakthrough opens a pathway to build a new type of quantum bit, the building blocks for quantum computers.

The research, developed in close collaboration with Israeli colleagues, is published today in the prestigious journal, Science, a recognition of the foundational importance of this work.

"We can now propose a pathway to build robust entangled states for logic gates using protected pairs of photons," said lead author Dr. Andrea Blanco-Redondo at the University of Sydney Nano Institute.

Logic gates are the switches needed to operate algorithms written for quantum computers. Classical computational switches are in simple binary forms of zero or one. Quantum switches exist in a state of 'superposition' that combine zero and one.

Protecting quantum information long enough so that quantum machines can perform useful calculations is one of the biggest challenges in modern physics. Useful quantum computers will require millions or billions of qubits to process information. So far, the best experimental devices have about 20 qubits.

To unleash the potential of quantum technology, scientists need to find a way to protect the entangled superposition of quantum bits—or qubits—at the nanoscale. Attempts to achieve this using superconductors and trapped ions have shown promise, but they are highly susceptible to electromagnetic interference, making them devilishly difficult to scale up into useful machines.

The use of photons—packets of light energy—rather than electrons has been one proposed alternative upon which to build logic gates that can calculate quantum algorithms.

Photons, unlike electrons, are well isolated from the thermal and electromagnetic environment. However, scaling quantum devices based on photonic qubits has been limited due to scattering loss and other errors; until
protected modes attached to the boundary of a fundamental level because it shows the existence of said: "Dr. Blanco-Redondo's result is exciting at a physicist at Sydney Nano who is unconnected to the study, the photon development." highlighting the importance of this discovery for further information systems will rely on multiphoton states, demonstrated for single photons.

superconductors and semiconducting metals. electron states induced through the interaction of protected via the knotting of quasiparticles known as qubits where quantum information Sydney, are pursuing the development of electron-based atoms. electromagnetism, condensed matter, acoustics and cold matter. These topological features offer protection for discoveries in the past decade on topological states of the 2018 Nobel Prize in Physics Donna Strickland and Gerard Mourou were awarded laser pulses, the same underlying technology for which now at the University of Oxford.

Dr. Blanco-Redondo designed and performed the experiment in the Sydney Nanoscience Hub with Dr. Bryn Bell, previously at the University of Sydney and now at the University of Oxford.

The photons were created by high-intensity, ultra-short laser pulses, the same underlying technology for which Donna Strickland and Gerard Mourou were awarded the 2018 Nobel Prize in Physics. This research is the latest in the flourishing of discoveries in the past decade on topological states of matter. These topological features offer protection for classical and quantum information in fields as diverse as electromagnetism, condensed matter, acoustics and cold atoms.

Microsoft Quantum Laboratories, including the one in Sydney, are pursuing the development of electron-based qubits where quantum information is topologically protected via the knotting of quasiparticles known as Majorana fermions. This is a bit like braiding half electron states induced through the interaction of superconductors and semiconducting metals.

Topologically protected states have previously been demonstrated for single photons. However, Dr. Blanco-Redondo said: "Quantum information systems will rely on multiphoton states, highlighting the importance of this discovery for further development."

She said the next step will be to improve protection of the photon entanglement to create robust, scalable quantum logic gates.

Professor Stephen Bartlett, a theoretical quantum physicist at Sydney Nano who is unconnected to the study, said: "Dr. Blanco-Redondo's result is exciting at a fundamental level because it shows the existence of protected modes attached to the boundary of a topologically ordered material. "What it means for quantum computing is unclear as it is still early days. But the hope is that the protection offered by these edge modes could be used to protect photons from the types of noise that are problematic for quantum applications."


三．电子工程
14. Scientists develop computational model to predict human behavior

Army researchers have developed for the first time an analytic model to show how groups of people influence individual behavior.

Technically speaking, this had never been done before: No one had taken the computational information from a collective model (numerical solutions of, say, thousands of equations) and used it to exactly determine an individual's behavior (reduced to one equation). Scientists from the U.S. Army Research Laboratory report their findings ("Fractional Dynamics of Individuals in Complex Networks") in the October edition of Frontiers in Physics.

This discovery was the product of ongoing research to model how an individual adapts to group behavior. ARL's program in network science seeks to determine collective group behavior emerging from the dynamic behavior of individuals. In the past, the collaborative work of Drs. Bruce West a senior scientist at the Army Research Office, and Malgorzata Turalska, a post-doctoral researcher at ARL, focused on constructing and interpreting the output of large-scale computer models of complex dynamic networks from which collective properties such as swarming, collective intelligence and decision making could be determined.

"Dr. Turalska and I had developed and explored a network model of decision-making for a number of years," West said. "But recently it occurred to us to change the question from 'How does the individual change group behavior?' to 'How does the group change individual behavior?' Turning the question on its head allowed us to pursue the holy grail of social science for the Army, which has been to find a way to predict the sensitivity of individuals to persuasion, propaganda and outright deception. Models developed for this purpose have evolved to the point that they require large-scale calculations that are as complex and as difficult to interpret as the results of psychological experiments involving humans. Consequently, the present study suggests a way to bypass these time-consuming calculations and represent the sought-for sensitivity in a single parameter."

Psychologists and sociologists have intensely studied and debated how individuals' values and attitudes change when they join an organization, West said. Likewise, the
In their article, Turalska and West derive and successfully test a new kind of dynamic model of individual behavior that quantitatively incorporates the dynamic behavior of the group. The test shows that the analytic solution to this new kind of equation coincides with the predictions of the large-scale computer simulation of the group dynamics.

The model consists of many interacting individuals that have a yes/no decision to make e.g., is it Election Day, and they must vote either R or D. Suppose when alone the individuals cannot make up their minds, they quickly switch back and forth between the two options, so they begin talking with their neighbors. Because of this information exchange, the numerical calculation using the computer model finds that people now hold their opinions for a significantly longer time.

To model the group dynamics, the test used a new kind of equation, with a non-integer (fractional), rather than an integer, derivative, to represent fluctuating opinions. In a group of 10,000 people, the influence of 9,999 people to disrupt an individual is condensed into a single parameter, which is the index for the fractional derivative. West said that whatever the behavior of the individual before joining the group, the change in behavior is dramatic after joining. The strength of the influence of the group on an individual's behavior is compressed into a single number, the non-integer derivative.

Consequently, an individual's simple random behavior in deciding how to vote, or in making any other decision, when isolated, is replaced with behavior that might serve a more adaptive role in social networks. The authors conjecture that this behavior may be generic, but it remains to determine just how robust the behavior of the individual is relative to control signals that might be driving the network.

The fractional calculus has, only in the past decade, been applied to complex physical problems such as turbulence, the behavior of non-Newtonian fluids, and the relaxation of disturbances in viscoelastic materials; however, no one had previously applied fractional operators to the description and interpretation of social/psychological dynamic phenomena. The idea of collapsing the effect of the interactions between members of a social group into a single parameter that determines the level of influence of the collective on the individual has never previously been accomplished mathematically.

West said this research opens the door to a new area of study dovetailing network science and fractional calculus, where the large-scale numerical calculations of the dynamics of complex networks can be represented through the non-integer indices of derivatives. This may even suggest a new approach to artificial intelligence in which memory is incorporated into the dynamic structure of neural networks.


15. New air-filled fiber bundle could make endoscopes smaller

Researchers have fabricated a new kind of air-filled optical fiber bundle that could greatly improve endoscopes used for medical procedures like minimally invasive surgeries or bronchoscopies. The new technology might also lead to endoscopes that produce images using infrared wavelengths, which would allow diagnostic procedures that are not possible with endoscopes today.

Endoscopes use bundles of optical fibers to transmit images from inside the body. Light falling on one end of the fiber bundle travels through each fiber to the far end, allowing a picture to be carried in the form of thousands of spots that are much like the pixels that make up a digital picture.

Optical fibers consist of an inner core and an outer cladding with different optical properties, which traps the light inside and allows it to travel down the fiber. Rather than using cores and claddings made of two types of glass like most fiber bundles, the new bundles use an array of glass cores surrounded by hollow glass capillaries filled with air that act as the cladding.

In The Optical Society (OSA) journal Optics Letters, researchers show that their new fiber bundles, which they call air-clad imaging fibers, maintain the resolution of the best commercial imaging fibers at double the wavelength range that the commercial fibers can be used. The new fiber could be used to create endoscopes that are smaller or have higher resolutions than those available today.

"Higher resolution is always helpful to clinicians carrying out endoscopic procedures, but the most sensitive jobs, such as those in the brain, usually require the thinnest instruments," said the paper's first author, Harry Wood of the University of Bath. "These instruments are usually so narrow that the imaging fiber contains too few cores to make a clear image. Our air-clad bundles allow more fibers to be packed into a smaller diameter and so will likely be particularly useful in these situations."

In addition to applications in medical diagnostics and treatment, the new fiber could prove useful for industrial applications such as monitoring the contents of hazardous machines or imaging the inside of oil and mineral drills.

Combining air and glass

When a bundle of fibers contains a greater number of cores within a given cross section area, it will produce
more detailed images in the same way that a camera with more pixels creates higher resolution images. However, if the cores are too small and close together, light can leak from one to another and the image becomes blurry.

"The honeycomb structure we developed combines glass and air to contain light far more tightly in the cores than traditional imaging fibers that use two types of glass," said Wood. "This allows us to bring the cores closer together than ever before possible, or squeeze in longer wavelengths of light, without the blurring that would be seen with conventional approaches."

The fact that the new fibers work well with wavelengths further into the infrared portion of the spectrum could allow the development of endoscopes that image fluorescent markers that emit at these wavelengths. Infrared light also can be used to image cells that are embedded more deeply within tissue than can be imaged with visible wavelengths.

"There are fluorescent marker probes that emit light of specific wavelengths in response to certain bacteria or immune cells," said Wood. "These could be very effective at highlighting disease in the lung, for example, but we can currently use only one or two such probes in the wavelength range that is offered by today's endoscope technology."

Comparing fiber performance
To test the imaging fibers, the researchers made an air-clad fiber bundle that matched the resolution of a leading commercial fiber because it had the same spacing between cores. They were able to incorporate more than 11,000 cores into the fiber by stacking multiple smaller honeycomb structures together.

The researchers point out that the principle behind the new fibers has been known for years but that fabrication approaches, especially for fibers with air gaps, have just recently advanced to the point where these fibers could be made.

The researchers used their new air-clad fiber bundle and the commercial fiber to image a standard test target image. "We were delighted to find that the air-clad fiber functioned well beyond the wavelength range our visible camera could detect," said Wood. "When we changed to an infrared camera, we saw that the fiber created a clear image at double the wavelength that the commercial fiber reached."


16. Discovery of new superconducting materials using materials informatics

Superconductor search process concept: Candidate materials are selected from a database by means of calculation and subjected to high pressure to determine their superconducting properties.

A NIMS-Ehime University joint research team succeeded in discovering new materials that exhibit superconductivity under high pressure using materials informatics (MI) approaches (data science-based material search techniques). This study experimentally demonstrated that MI enables efficient exploration of new superconducting materials. MI approaches may be applicable to the development of various functional materials, including superconductors.

Superconducting materials that enable long-distance electricity transmission without energy loss in the absence of electrical resistance are considered to be a key technology in solving environmental and energy issues. The conventional approach by researchers searching for new superconducting materials or other materials has been to rely on published information on material properties, such as crystalline structures and valence numbers, and their own experience and intuition. However, this approach is time-consuming, costly and very difficult because it requires extensive and exhaustive synthesis of related materials. As such, demand has been high for the development of new methods enabling more efficient exploration of new materials with desirable properties.

This joint research team took advantage of the AtomWork database, which contains more than 100,000 pieces of data on inorganic crystal structures. The team first selected approximately 1,500 candidate material groups whose electronic states could be determined through calculation. The team then narrowed this list to 27 materials with desirable superconducting properties by actually performing electronic state calculations. From these 27, two materials SnBi2Se4 and PbBi2Te4 were ultimately chosen because they were relatively easy to synthesize.

The team synthesized these two materials and confirmed that they exhibit superconductivity under high pressures using an electrical resistivity measuring device. The team also found that the superconducting transition temperatures of these materials increase with increasing pressure. This data science-based approach, which is completely different from the conventional approaches, enabled identification and efficient and precise development of superconducting materials.

Experiments revealed that these newly discovered materials may have superb thermoelectric properties in addition to superconductivity. The method we developed may be applicable to the development of various functional materials, including superconductors. In future studies, we hope to discover innovative functional materials, such as room-temperature superconducting materials, by including a wider range of materials in our studies and increasing the accuracy of the parameters.
relevant to desirable properties.


17. Physicists demonstrate magnetometer that uses quantum effects and machine learning

Researchers from the Moscow Institute of Physics and Technology (MIPT), Aalto University in Finland, and ETH Zurich have demonstrated a prototype device that uses quantum effects and machine learning to measure magnetic fields more accurately than its classical analogues. Such measurements are needed to seek mineral deposits, discover distant astronomical objects, diagnose brain disorders, and create better radars.

"When you study nature, whether you investigate the human brain or a supernova explosion, you always deal with some sort of electromagnetic signals," explains Andrey Lebedev, a co-author of the paper describing the new device in npj Quantum Information. "So measuring magnetic fields is necessary across diverse areas of science and technology, and one would want to do this as accurately as possible."

Quantum magnetometer offers more precision

A magnetometer is an instrument that measures magnetic fields. A compass is an example of a primitive magnetometer. In an electronics store, one can find more advanced devices of this kind used by archaeologists. Military mine detectors and metal detectors at airports are also magnetometers.

There is a fundamental limitation on the accuracy of such instruments, known as the standard quantum limit. Basically, it says that to double the precision, a measurement has to last four times as long. This rule applies to any classical device, which is to say one that does not utilize the bizarre effects of quantum physics.

"It may seem insignificant, but to gain 1,000 times in precision, you would have to run the experiment 1 million times longer. Considering that some measurements take weeks to begin with, chances are you will experience a power cut or run out of funds before the experiment is over," says Lebedev, who is a leading researcher at the Laboratory of the Physics of Quantum Information Technology, MIPT.

Achieving a higher accuracy, and therefore shorter measurement times, is crucial when fragile samples or living tissue is examined. For example, when a patient undergoes positron emission tomography, also known as a PET scan, radioactive tracers are introduced into the bloodstream, and the more sensitive the detector is, the smaller the necessary dose.

In theory, quantum technology enables a measurement's accuracy to be increased twofold by repeating it twice instead of four times as in the case of a classical magnetometer. The paper reported in this story details the first successful attempt to put this principle into practice using a superconducting qubit as the measuring device.

![Figure 1. Magnetometer fingerprint. The colors indicate the probability to detect the qubit in the excited state right after the second microwave pulse. Yellow means that the excited state is highly likely, while blue means it is unlikely. This probability depends on the delay between the two pulses (horizontal axis) and the external magnetic field (vertical axis). Each magnetometer is characterized by a unique fingerprint: No two instruments are alike. Credit: S. Danilin, A. Lebedev et al./npj Quantum Information](image)

Qubits measure magnetic fields

A qubit is a particle that obeys the laws of quantum physics and can occupy two discrete basis states simultaneously in what is known as a superposition. This notion refers to a multitude of "intermediate" states, each of which collapses into one of the two basis states as soon as it is measured. An example of a qubit is a hydrogen atom whose two basis states are the ground and the excited state.

In the study by Lebedev and co-authors, the qubit was realized as a superconducting artificial atom, a microscopic structure made of thin aluminum films and deposited on a silicon chip held in a powerful refrigerator. At temperatures close to the absolute zero, this device behaves as an atom. In particular, by absorbing a specific portion of microwave radiation fed to the qubit via a cable, it can enter a balanced superposition of the two basis states. If the state of the device is then checked, the measurement will detect the ground and the excited state with an equal 50 percent probability.

Superconducting qubits are distinguished by their sensitivity to magnetic fields, which can be used for making measurements. Once a suitable microwave radiation pulse is used to drive the device into a balanced superposition of the ground and excited states, this new state begins to change predictably with time. To track this state change, which is a function of the external magnetic field, the researchers sent a second microwave pulse to the device after a brief delay and measured the
probability of finding the qubit in the excited state. This probability, which was calculated over many identical experiments performed in quick succession, indicates the strength of the magnetic field. The precision of this quantum technology surpasses the standard quantum limit.

Qubit training

An actual physical qubit is imperfect. It is a manmade device, rather than a mathematical abstraction. So instead of using a theoretical formula, we train the qubit before making real measurements," says Lebedev. "This is the first time machine learning has been applied to a quantum magnetometer," he adds.

Qubit training consists of making many preliminary measurements under controlled conditions with predetermined delays between pulses and in a range of known magnetic fields. The authors thereby determined the probability of detecting the excited state following the sequence of two pulses for an arbitrary field and pulse delay. The researchers plotted their findings on a diagram, which serves as a fingerprint for the individual device used in the study, accounting for all its imperfections.

The point of the sample fingerprint is that the delay times between pulses can be optimized during repeated measurements. "We perform adaptive measurements," says Lebedev. "At the first step, we take a measurement given a certain delay between the microwave pulses. Then, depending on the result, we let our pattern recognition algorithm decide how to set the delay for the next iteration. This results in a higher precision over fewer measurements."

"Engineers are working on increasing the operating temperature of such devices to 4 kelvins [269 C]. This would make cooling by liquid helium feasible, making the technology commercially viable."

The prototype has been tested on a static magnetic field, but time-varying or transient fields can be measured in the same way. The research team is already conducting experiments with variable fields, expanding the potential range of applications of their device.

For example, a quantum magnetometer could be mounted on a satellite to observe astronomical phenomena too faint for classical instruments. Conveniently, the frigid space conditions make cooling somewhat less of an issue. Besides, a system of quantum magnetometers could work as an ultrasensitive radar. Further applications of such nonclassical instruments include MRI scans, mineral prospecting, and research into biomolecule structure and inorganic materials.

How to extract information about the external field from a qubit

Once the first microwave pulse is absorbed by the magnetometer, it enters a superposition of the ground and excited states. This can be visualized by picturing the two basis states of the qubit as the two poles of a sphere, where each other point on the sphere represents some state of superposition. In this analogy, the first pulse drives the state of the qubit from the north pole—the ground state—to some point on the equator (figure 2a). A direct measurement of this state of balanced superposition would result in the ground or excited state being detected with even odds.

Following the first pulse, the qubit becomes sensitive to the external field. This is manifested as a predictable change of the device's quantum state. It can be pictured as a point rotating along the equator of a sphere (figure 2b). How fast this point rotates, depends on the strength of the external field. This means that by finding a way to measure the angle of rotation X over a known period of time, the field can be quantified.

The main challenge is to distinguish between the different states on the equator: Unless some trick is used, the measurement would return the excited state exactly 50 percent of the time. This is why the physicists sent a second microwave pulse to the qubit and only then checked its state. The idea behind the second pulse is that it predictably shifts the state of the device off the equator, into one of the hemispheres. Now, the odds of measuring an excited state depend on how much the state has rotated since the first pulse, that is, angle X. By repeating the sequence of two pulses and a measurement many times, the authors calculated the probability of an excited state, and thus the angle X and the strength of the magnetic field. This principle underlies the operation of their magnetometer.

18. A new material for energy-efficient data storage reaches computer operating temperature

The matt grey pellet is a so-called layered copper-iron perovskite, a crystal. It can be placed on a fingertip.

Multiferroics are considered miraculous materials for future data storage – as long as their special properties can be preserved at computer operating temperatures. This task has now been accomplished by researchers at the Paul Scherrer Institute PSI, with colleagues from Institut Laue-Langevin ILL in Grenoble. With this, they have taken these materials one step closer to practical applications. The use of multiferroics holds promise for more energy-efficient computers because an electric field would suffice for magnetic data storage. To produce this, much less power and cooling are required than with conventional magnetic storage. Multiferroics combine magnetic and electrical properties to form a material that is extremely rare. Most such materials only exhibit these two properties at temperatures well below the freezing point. In order to keep the magnetic properties stable even at one hundred degrees, the researchers have employed a trick. They used atoms smaller than those employed in previous investigations, making the material more compact. This was enough to make its structure resistant to heat and preserve its crucial magnetic properties. The researchers published their results today in the journal Science Advances.

Computers often run continuously, consuming many kilowatts hour of electricity per year. Most of them are used for data storage. The data are written onto hard disks as magnetic bits in a 0 or 1 state, a process which requires a continuous reversal of polarity from plus to minus and vice versa. This magnetic pole reversal consumes a lot of energy, and leads to severe heat release. That is why computers have to be cooled intensively while they are operating. This requires a lot of electricity, high costs and is not environmentally friendly. Scientists have for a long time been searching for a material which eliminates this disadvantage of conventional magnetic data storage.

For some years, the so-called magneto-electric multiferroics have attracted the interest of researchers as a possible alternative. With these materials, the necessary magnetic functionality is achievable by applying an electrical instead of a magnetic field, because these two physical properties are coupled together in the material. This state usually occurs at very low temperatures, typically below minus 173 degrees Celsius, and is lost again at everyday temperatures.

Two years ago, a working group at PSI succeeded in shifting the temperature limit up to 37 degrees Celsius. This was a big step forward, but still was not enough to think about using it in laptops and other strongly heated data storage systems. Now, PSI researchers Marisa Medarde and Tian Shang have succeeded in stabilizing a magneto-electric, multiferroic material that retains the required magnetic properties even at 100 degrees Celsius. "This temperature is more than 60 degrees Celsius higher than in the past," Medarde says delightedly. "Although a lot of further research is still needed, we are now a bit closer to a possible use of these materials in computers."

Two in one. The relatively new class of magneto-electric multiferroics includes various mixtures of chemical elements. These have one thing in common: they simultaneously contain small magnets and a combination of positive and negative electrical charges, the so-called electric dipoles. Electrical dipoles can usually be influenced by applying an electric field and small magnets by applying a magnetic field. For a multiferroic material, an electric field is sufficient for both. In practice, electric fields are much easier and cheaper to produce. They consume much less electricity. This is what makes magneto-electric multiferroics so interesting from an economic perspective. But how can one achieve the impossible?

In his laboratory at PSI, the physicist Shang shows different grey, white and yellow crystal powders, which he heats up in a laboratory oven to prepare the multiferroic materials for his experiments: "Here, we use barium, copper, iron and rare earths, and we heat them up to over 1,100 degrees Celsius for two days. Then we slowly cool the powders down to room temperature, press them into pellets, and then heat them up again for 50 hours. They are then abruptly quenched in liquid nitrogen." The dull grey material in the pellet that results from this procedure is a so-called layered copper-iron perovskite, a crystal. It is small enough to fit on a fingertip and at first sight does not seem very spectacular.

Marisa Medarde and Tian Shang at the neutron diffractometer DMC. With this device Shang found out where the atoms are located in the crystal lattice and how far apart they are from each other. The special features of the material are found on the non-visible level of the atoms, more precisely: in its crystal lattice structure. This can be pictured as consisting of several stacked lattice cages with barium and yttrium atoms at their corners. Inside the cages, small magnets
made of copper and iron are located. Electromagnetic forces act between the individual magnets, determining their relative orientation. Normally, two magnets are aligned parallel or opposite to each other. But it can also happen that the magnetic forces act from very different directions. Then the magnets oscillate like little compass needles. The technical term for such a material is a frustrated magnet. In order to avoid this unstable state while preserving the magnetism, the copper-iron magnets arrange into a spiral. Enlarged, this looks like many superimposed compass needles, each subsequent one twisted by a small angle. "This spiral arrangement can cause electrical polarisation and thus be responsible for the ferroelectric properties in the material," explains Medarde.

Thus, when the magnets are spirally arranged, they induce electric dipoles in the lattice and the material gets both coupled properties – electrical and magnetic. At normal temperatures, the compass needles lose their helical arrangement, which also makes the coupled multiferroic properties disappear. The fact that the magnetic spirals in the material can be "frozen" by very rapid cooling had already been shown Medarde and her group in an earlier work. In their latest investigation, Medarde and Shang have now fine-tuned the multiferroic crystal lattice. With microscopically small adjustments, they have succeeded in raising its temperature stability up to 100 degrees Celsius.

Proximity creates strength

Additionally to cooling the material extremely fast, Shang used a trick which chemists have known about for a long time: he simply reduced the distances between some atoms in the crystal lattice, bringing them closer to each other. As a result of the new, more compact design, the electromagnetic forces in the crystal changed in such a way that the spiral structure of the copper-iron magnets remained stable even at higher temperatures.

Shang achieved this by replacing some barium atoms in the crystal lattice with the smaller atoms of the element strontium. He added the strontium during the production of the material in the reaction furnace before finally cooling the material down again in the established way.

Next, the physicist wanted to know if the combination of the two methods had really had the desired effect. Shang studied the grey-black material using various measurement methods, including investigations at the Swiss Spallation Neutron Source SINQ, a large-scale research facility at PSI. With the help of special instruments, he succeeded in identifying the fingerprint of the magnetic spirals. Of particular importance to the researcher was an instrument with the complicated name of the magnetic spirals. Of particular importance to the researcher was an instrument with the complicated name of a neutron diffractometer. With this device, which Shang used at both SINQ and the Institut Laue-Langevin ILL in Grenoble, he found out where the atoms are located in the crystal lattice and how far apart they are from each other.

"The effect of rapid material cooling plus that of decreasing the distance between the atoms sum up together. The stability range of the magnetic spiral is now much higher than before," said Shang. He has thus reached the temperature range needed for use in computers. However, according to the physicists, it will take a while for the material to actually be used for storing data in the future. For this, it will also have to perform in thin-film layers, where much less material is used. Medarde and Shang are already working on this. And they are attempting to squeeze the perovskite crystal even further by incorporating atoms that are even smaller than strontium. If both strategies are successful, there is good a chance that the multiferroic material will one day be the basis for revolutionising data storage technology.


19. Fast-flowing electrons may mimic astrophysical dynamos

Certain materials may host an electron fluid that flows fast enough to generate turbulence and bootstrap a dynamo.

A powerful engine roils deep beneath our feet, converting energy in the Earth's core into magnetic fields that shield us from the solar wind. Similar engines drive the magnetic activity of the sun, other stars and even other planets—all of which create magnetic fields that reinforce themselves and feed back into the engines to keep them running.

Much about these engines, which scientists refer to as dynamos, remains unknown. That's partly because the math behind them is doubly difficult, combining the complex equations of fluid motion with the equations that govern how electric and magnetic fields bend, twist, interact and propagate. But it's also because lab-bound dynamos, which attempt to mimic the astrophysical versions, are expensive, dangerous and do not yet reliably produce the signature self-sustaining magnetic fields of real dynamos.

Now, Victor Galitski, a Fellow of the Joint Quantum Institute (JQI), in collaboration with two other scientists, has proposed a radical new approach to studying dynamos, one that could be simpler and safer. The proposal, which was published Oct. 25 in Physical Review Letters, suggests harnessing the electrons in a centimeter-sized chunk of solid matter to emulate the fluid flows in ordinary dynamos.

If such an experiment is successful, it might be possible
for researchers in the future to study the Earth's dynamo more closely—and maybe even learn more about the magnetic field flips that happen every 100,000 years or so. "The dynamics of the Earth's dynamo is not well understood, and neither are the dynamics of these flips," says Galitski, who is also a physics professor at the University of Maryland. "If we had experiments that could reproduce some aspects of that dynamo, that would be very important."

Such experiments wouldn't be possible but for the fact that electrons, which carry current through a material, can sometimes be thought of as a fluid. They flow from high potential to low potential, just like water down a hill, and they can flow at different speeds. The trick to spotting the dynamo effect in an electron fluid is getting them to flow fast enough without melting the material.

"People haven't really thought about doing these experiments in solids with electron fluids," Galitski says. "In this work we don't imagine having a huge system, but we do think it's possible to induce very fast flows."

Those fast flows would be interesting in their own right, Galitski says, but they are especially important for realizing the dynamo effect in the lab. Despite the many lingering unknowns about dynamos, it seems that turbulence plays a crucial role in their creation. This is likely because turbulence, which leads to chaotic fluid motion, can jostle the magnetic field loose from the rest of the fluid, causing it to twist and bend on top of itself and increase its strength.

But turbulence only arises for very fast flows—like the air rushing over the wing of an airplane—or for flows over very large scales—like the liquid metal in the Earth's core or the plasma shell of the sun. To create a dynamo using a small piece of solid matter, the electrons would need to move at speeds never before seen, even in materials known for having highly mobile electrons.

Galitski and his collaborators think that a material called a Weyl semimetal may be able to host an electron fluid flowing at more than a kilometer per second—potentially fast enough to generate the turbulence necessary to bootstrap a dynamo. These materials have received broad attention in recent years due to their unusual characteristics, including anomalous currents that arise in the presence of magnetic fields and that may reduce the speed required for turbulence to emerge.

"It might seem that turbulence isn't particularly extraordinary," says Sergey Syzranov, a co-author and former JQI postdoctoral researcher who is now an assistant professor of physics at the University of California, Santa Cruz. "But in solids it has never been demonstrated to our knowledge. A major achievement of our work is that turbulence is realistic in some solid-state materials."

The authors say that it's not yet clear how best to kickstart a dynamo on a small sliver of Weyl semimetal. It may be as simple as physically rotating the material. Or it could require pulsing an electric or magnetic field. Either way, Galitski says, the experimental signature would show a totally nonmagnetic system spontaneously form a magnetic field. "Controlled experiments like these with turbulence in electrons are totally unheard of," Galitski says. "I can't really say what will come out of it, but it could be really interesting."


20. Electronic activity previously invisible to electron microscopes revealed

The chips that drive everyday electronic gadgets such as personal computers and smartphones are made in semiconductor fabrication plants. These plants employ powerful transmission electron microscopes. While they can see physical structures smaller than a billionth of a meter, these microscopes have no way of seeing the electronic activity that makes the devices function.

That may soon change, thanks to a new imaging technique developed by UCLA and University of Southern California researchers. This advance may enable scientists and engineers to watch and understand the electronic activity inside working devices, and ultimately improve their functionality.

The study, which was published online in Physical Review Applied, was led by Chris Regan, UCLA professor of physics and astronomy and a member of the California NanoSystems Institute.

The new method shows details that traditional approaches with electron microscopes do not capture, while also revealing electronic states within a sample—previously impossible using such microscopes. "Of course you'd rather look at live devices," Regan said. "We want to see what makes a device alive in an electronic sense, and standard techniques can't."

An electronic device can be compared to the human brain. The brain is commonly photographed via X-rays, which give a precise picture of its physical structure.

"There's a lot of very subtle physics and chemistry happening in your brain, and if you took a picture, you wouldn't see any of it," Regan said. "The picture misses some very dramatic things that make your brain an interesting place."

The technique that he and his team created is less like X-ray imaging, and more like the functional MRI—or fMRI—tests that neuroscientists use to track blood flow within the brain.
"With the fMRI, you can see the parts light up that are being used," Regan said. "That gives you some insight into how the brain is working. Similarly, our technique allows you to see things that change as an electronic device functions."

Electron microscopes use beams of electrons to help scientists "see" an object. In this study, the researchers paired a scanning transmission electron microscope, or STEM, and electron-beam induced current imaging, known as EBIC imaging.

EBIC imaging uses an amplifier to measure the electrical current in a sample exposed to a microscope's electron beam. This technique, first demonstrated in the 1960s, is useful for showing the electric field built into certain devices like solar cells. But in this case, the researchers looked at devices that lacked built-in electrical fields.

Acquiring both the standard scanning microscope images and EBIC images, the researchers examined a simple pair of electrodes. The EBIC images produced previously unseen resolution and contrast. This method showed which electrode was receiving current, and even produced a detailed map of the electrodes' conductivity.

"When we started developing this technique, we were looking at samples where there's a very subtle physical change but a huge electronic change," said William Hubbard, a postdoctoral fellow in Regan's lab and first author of the study. "We saw really interesting contrast that you can't get any other way."

To understand the mechanism at work, the team used two amplifiers to record two EBIC measurements—another innovation—and found that EBIC imaging was picking up weak signals from secondary electrons. This sensitivity allowed them to visualize not just where electrons are, but where they are not—fundamental elements of the flow of current in a chip.

The richness of the data surprised even the researchers when they first applied the technique.

"We saw something very unexpected that made us incredibly excited," Hubbard said. "So I'd say it worked better than we expected."

Producing sample slices thin enough for imaging with transmission electron microscopy makes contemporary chips inoperable. But, as components become smaller and thinner over time, this research may open up new possibilities for understanding what happens inside the consumer devices of the future.


21. Electronic noise due to temperature difference in atomic-scale junctions
A single-quantum mechanical transport channel constituted the resulting junctions wherein electrons could be transmitted from one electrode to the other. The probability of electron transfer could be adjusted by varying the openness of the channel. An ideal test bed setup was thus provided to explore the properties of noise contribution so far overlooked. When a temperature difference was applied between the two electrodes, the authors observed a strong increase in electronic noise compared with electrodes at the same temperature. The new noise, termed 'delta-T noise,' scaled with the square of the temperature difference, exhibiting similar dependence on electrical conductance as shot noise.

The findings of the study were explained via the quantum theory of charge transport known as Landauer theory, developed in the past few decades. The theory accurately described many experimental observations when working entirely in thermal equilibrium or when applying small voltages. On closer inspection of the theory, the authors observed that inclusion of a noise component only occurred when a temperature difference was solely applied across a junction as experimentally observed with delta-T noise. In the absence of an applied voltage, an electric current can arise due to a temperature difference via a phenomenon termed the Seebeck effect. According to the study, the delta-T noise arose from the discreteness of the charge carriers mediating the heat transport.

Although the Landauer theory is widely used, surprisingly, delta-T noise was not previously observed. The present work therefore conveyed a key message that careful experimental design and rigorous analysis are required to study the details of quantum transport. In practice, quantum-transport experiments that weren't entirely in thermal equilibrium could show strongly enhanced noise, which could be mistaken for noise arising from interactions between charge carriers or due to subtle effects. Unexpectedly high noise in electric-current measurements could be due to unintentional temperature gradients in experimental setups. In practice, the authors' work can potentially be used to detect undesirable hot spots in electrical circuits.

Future experimental focus will explore the relationship between delta-T noise and shot noise, with a nonlinear dependence on applied voltage. This phenomenon was recently observed in high-voltage experiments at atomic junctions. In combination with thermal noise, delta-T noise can be used as a probe for temperature differences in nanoscale systems. Delta-T noise is a versatile probe compared to physical sensors, not limited to a particular setup range, and that can be applied to conductors of variable sizes, including those at the atomic scale. The versatility allows delta-T noise to become an attractive tool for heat management, which includes thermoelectricity, heat pumping, and heat dissipation, important for energy saving and sustainable energy production. Since temperature gradients are often unintentionally produced in electronic circuits, to prevent performance-limiting effects of delta-T noise, the temperature gradients should be minimized. The sensitivity of delta-T noise on the properties and interactions of charge carriers could become a valuable tool in quantum-transport.


22. Updating high-resolution MRI

Cylindrical patches are one alternative to the current tech used in MRI machines. How can you make a high-frequency MRI machine more precise? By taking an electrical engineering approach to creating a better, uniform magnetic field.

In a new study published in Transactions on Microwave Theory and Techniques, researchers discovered that radio frequency probes with structures inspired by microstrip patch antennas increase MRI resolution in high-frequency MRI machines, when compared to conventional surface coils used now.

"When frequencies become higher, wavelengths become shorter, and your magnetic field loses uniformity," says Elena Semouchkina, an associate professor of electrical and computer engineering at Michigan Technological University. "Uniformity is important for high-resolution images, so we proposed a..."
new approach to developing these probes."

A Common Design, Tuned with Optics

Semouchkina explains that the type of antenna you see on the top of a building isn't quite the same thing used here, but instead, the team's design was inspired by microstrip patch antenna (MPA). The design is relatively simple: MPAs are made of a flat piece of metal grounded by a larger piece of metal. They're cheap, simple and easy to make, which is why they're often used in telecommunications.

MRIs work by issuing radio frequency pulses in a magnetic field via probes with coils or bird-cage like structures. That's then used to create an image.

Proposed radio frequency probes to create homogeneous magnetic field within a phantom under study: single multi dielectric patch surface probe (upper left), volume probe composed of two vis-à-vis placed dielectric patch probes (lower left), volume probe composed of two cylindrical patches (upper right) and cosine-profiled patches (lower right).

But those conventional coils have frequency limits: too high and they can't create uniformed magnetic fields at the volume researchers need.

MPAs are an alternative where waves oscillate in the cavity formed between the patch and ground plane electrodes, which are accompanied by currents in the patch electrode and, respectively, oscillating magnetic fields around the patch, providing a magnetic field that is both even and strong.

"While the complexity of birdcage coils increases with the increase in operation frequency, patch-based probes can provide quality performance in the higher microwave range while still having a relatively simple structure," Semouchkina says. They also showed smaller radiation losses, making them competitive with, and even better, than conventional coils.

High Frequency MRI Machines – and Invisibility Cloaks

Because of the damage high-frequency radio waves cause to humans, the study was limited to high frequency machines—not the metal tube that we're used to seeing in hospitals and medical centers. Humans can only sustain strengths up to seven Teslas, but ultrahigh fields up to 21.1 Teslas can be used in testing on animal models, and in tissue samples.

Semouchkina is already known for her work involving invisibility cloaks, which involve redirecting electromagnetic waves around an area to hide an object. 

"We use some of the same approaches that we developed in cloaking devices here, like making antenna smaller," she said.

This study was conducted with Navid P. Gandji and George Semouchkin of Michigan Tech, and Gangchea Lee, Thomas Neubereger and Micheal Lanagan of Pennsylvania State University. The team's next step is to keep applying electrical engineering to modify those probes to make them work better, and to further expand the possibilities for high-frequency MRI machines and the images they create.


23. Scientists make first detailed measurements of key factors related to high-temperature superconductivity

A new study reveals how coordinated motions of copper (red) and oxygen (grey) atoms in a high-temperature superconductor boost the superconducting strength of pairs of electrons (white glow), allowing the material to conduct electricity without any loss at much higher temperatures. The discovery opens a new path to engineering higher-temperature superconductors.

In superconducting materials, electrons pair up and condense into a quantum state that carries electrical current with no loss. This usually happens at very low temperatures. Scientists have mounted an all-out effort to develop new types of superconductors that work at close to room temperature, which would save huge amounts of energy and open a new route for designing quantum electronics. To get there, they need to figure out what triggers this high-temperature form of superconductivity and how to make it happen on demand.

Now, in independent studies reported in Science and Nature, scientists from the Department of Energy's SLAC National Accelerator Laboratory and Stanford University report two important advances: They measured collective vibrations of electrons for the first time and showed how collective interactions of the electrons with other factors appear to boost superconductivity.

Carried out with different copper-based materials and with different cutting-edge techniques, the experiments lay out new approaches for investigating how unconventional superconductors operate.
"Basically, what we're trying to do is understand what makes a good superconductor," said co-author Thomas Devereaux, a professor at SLAC and Stanford and director of SIMES, the Stanford Institute for Materials and Energy Sciences, whose investigators led both studies.

"What are the ingredients that could give rise to superconductivity at temperatures well above what they are today?" he said. "These and other recent studies indicate that the atomic lattice plays an important role, giving us hope that we are gaining ground in answering that question."

The high-temperature puzzle

Conventional superconductors were discovered in 1911, and scientists know how they work: Free-floating electrons are attracted to a material's lattice of atoms, which has a positive charge, in a way that lets them pair up and flow as electric current with 100 percent efficiency. Today, superconducting technology is used in MRI machines, maglev trains and particle accelerators.

But these superconductors work only when chilled to temperatures as cold as outer space. So when scientists discovered in 1986 that a family of copper-based materials known as cuprates can superconduct at much higher, although still quite chilly, temperatures, they were elated.

The operating temperature of cuprates has been inching up ever since – the current record is about 120 degrees Celsius below the freezing point of water – as scientists explore a number of factors that could either boost or interfere with their superconductivity. But there's still no consensus about how the cuprates function.

"The key question is how can we make all these electrons, which very much behave as individuals and do not want to cooperate with others, condense into a collective state where all the parties participate and give rise to this remarkable collective behavior?" said Zhi-Xun Shen, a SLAC/Stanford professor and SIMES investigator who participated in both studies.

Behind-the-scenes boost

One of the new studies, at SLAC's Stanford Synchrotron Radiation Lightsource (SSRL), took a systematic look at how "doping" – adding a chemical that changes the density of electrons in a material – affects the superconductivity and other properties of a cuprate called Bi2212.

Collaborating researchers at the National Institute of Advanced Industrial Science and Technology (AIST) in Japan prepared samples of the material with slightly different levels of doping. Then a team led by SIMES researcher Yu He and SSRL staff scientist Makoto Hashimoto examined the samples at SSRL with angle-resolved photoemission spectroscopy, or ARPES. It uses a powerful beam of X-ray light to kick individual electrons out of a sample material so their momentum and energy can be measured. This reveals what the electrons in the material are doing.

"One popular theory has been that rather than the atomic lattice being the source of the electron pairing, as in conventional superconductors, the electrons in high-temperature superconductors form some kind of conspiracy by themselves. This is called electronic correlation," Yu He said. "For instance, if you had a room full of electrons, they would spread out. But if some of them demand more individual space, others will have to squeeze closer to accommodate them."

In this study, He said, "What we find is that the lattice has a behind-the-scenes role after all, and we may have overlooked an important ingredient for high-temperature superconductivity for the past three decades," a conclusion that ties into the results of earlier research by the SIMES group.

Electron 'Sound Waves'

The other study, performed at the European Synchrotron Radiation Facility (ESRF) in France, used a technique called resonant inelastic X-ray scattering, or RIXS, to observe the collective behavior of electrons in layered cuprates known as LCCO and NCCO.

RIXS excites electrons deep inside atoms with X-rays, and then measures the light they give off as they settle back down into their original spots.
In the past, most studies have focused only on the behavior of electrons within a single layer of cuprate material, where electrons are known to be much more mobile than they are between layers, said SIMES staff scientist Wei-Sheng Lee. He led the study with Matthias Hepting, who is now at the Max Planck Institute for Solid State Research in Germany.

But in this case, the team wanted to test an idea raised by theorists – that the energy generated by electrons in one layer repelling electrons in the next one plays a critical role in forming the superconducting state.

When excited by light, this repulsion energy leads electrons to form a distinctive sound wave known as an acoustic plasmon, which theorists predict could account for as much as 20 percent of the increase in superconducting temperature seen in cuprates.

With the latest in RIXS technology, the SIMES team was able to observe and measure those acoustic plasmons.

"Here we see for the first time how acoustic plasmons propagate through the whole lattice," Lee said. "While this doesn't settle the question of where the energy needed to form the superconducting state comes from, it does tell us that the layered structure itself affects how the electrons behave in a very profound way."

This observation sets the stage for future studies that manipulate the sound waves with light, for instance, in a way that enhances superconductivity, Lee said. The results are also relevant for developing future plasmonic technology, he said, with a range of applications from sensors to photonic and electronic devices for communications.


四．人工智能

24. Next-generation technology is coming to a self-driving car near you

Professor Jayakanth Ravichandran and PhD student Shanyuan Niu in the lab where they develop next generation technologies.

Typically, navigation systems for autonomous cars use visible light to identify foreign objects. This works most of the time. But in misty, foggy, or rainy conditions, self-driving cars become a deer in headlights, largely unaware of upcoming obstacles. Scattered light confuses the car's system, thus blurring the distinction between real objects and reflections from the scattered light itself. Under these conditions, autonomous cars cannot recognize upcoming obstacles that would be easily identifiable to the human eye.

To see through hazardous conditions, sensors within the cars need technology that can predict obstacles not immediately evident. Fortunately, Jayakanth Ravichandran, an assistant professor in the Mork Family Department of Chemical Engineering and Materials Science at USC Viterbi, wants to develop new electronic and optical materials that enable what he calls "next generation technologies" to improve the technology that surrounds people in their everyday lives, including self-driving cars.

"Look at the smartphones, computers and LED TVs around you," Ravichandran said. "None of these existed, at least in the current form, 10 to 20 years ago. These are possible because of research on materials used in these technologies. My group is looking at developing materials that will be used in technologies in the next ten to twenty years."

Ravichandran's latest research, conducted with doctoral students Shanyuan Niu, Boyang Zhao, and master's student Yucheng Zhou, found materials that might fundamentally change the way autonomous cars operate. Ravichandran's group closely collaborated with Han Wang, an assistant professor in the Ming Hsieh Department of Electrical Engineering at USC Viterbi and Mikhail Kats, an assistant professor at the University of Wisconsin, Madison and this work was recently published in Nature Photonics.

Though the visible light typically used by autonomous cars to identify obstacles cannot function in fog, smoke or rain, infrared light can see through such conditions. Consequently, developing new infrared devices to function in these hazy viewing conditions could vastly improve the safety of self-driving cars, Ravichandran said.

His lab has just discovered a material which could work in such infrared devices.

The material – a composition with the chemical formula, BaTiS3 – could become functional in thermal imaging systems, one type of infrared device.

Thermal imaging systems can recognize changes in an object's temperature by tracking the amount of radiation emitted from that object. By following the temperature changes of particular objects, thermal imaging systems can identify movement even in the absence of visibility – a crucial function for self-driving cars.

For an effective thermal imaging system, there must be a detector to sense the heat radiation and to provide a readable response, as well as a system for filtering and manipulating incoming radiation.

BaTiS3 currently works as a filter for the incoming radiation. It may soon work as a detector as well.

"We are exploring that now," Ravichandran noted. "Most importantly, there are subtle connections between the performance of the device and the material properties. Our job is to identify that and look for the right type of
materials based on this understanding."

Though his lab's project is still in its early stages, Ravichandran said that his team's next step is to make a functioning device out of the material so that they can take it to market. He also hopes to find other compositions that may work in thermal imaging systems even better than BaTiS3.

The implications of the lab's findings are exciting for uses outside of autonomous vehicle sensors as well.

"There are possibilities of using these materials to sense environmental pollutants, and biological agents in the air," Ravichandran said. "If there is some sort of airborne disease, identifying those biological particles can become very easy with this technology.

"There are so many applications which can happen."


25. New mobile device identifies airborne allergens using deep learning

The device weighs less than 600 grams.

UCLA researchers invented a portable device that uses holograms and machine learning to identify and measure airborne biological particles, or bioaerosols, that originate from living organisms such as plants or fungi. Trained to recognize five common allergens—pollen from Bermuda grass, oak, ragweed and spores from two types of mold—the system classified samples with an accuracy of 94 percent using deep learning.

Each minute, human adults typically breathe in between 100 and 1,000 bioaerosols—including pollens, spores, toxins and microbes—and an even greater number, 1 million or more, in highly contaminated areas. These tiny biological particles can trigger allergies, asthma and other diseases.

Quantifying exposure to those biological particles is difficult and can be time consuming and expensive. The current methods for identifying bioaerosols rely on 50-year-old technology: Researchers collect samples using filters or spore traps, and then transport them to labs, where they are stained and inspected under microscopes by scientists. Another challenge is that there are only a small number of air-sampling stations worldwide that have bioaerosol sensing or measurement capabilities.

The device pulls in air and traps particles on a sticky surface that is lit up by a laser, which generates a hologram. An image sensor chip scans the hologram and sends that data to a remote server.

There, a type of artificial intelligence powered by a neural network cleans up the image, which is then run through an algorithm that crops it down to the sections that depict the biological particles. A second neural network classifies those particles from among a set of preloaded allergen types.

The device can be made from parts costing about $200. It weighs less than 600 grams—approximately the same as three smartphones—and measures about 14 centimeters wide, 17 centimeters long and 6 centimeters thick.

The device is the first cost-effective portable device that senses and classifies airborne biological particles automatically and without needing to label using stains. Because the device is controlled wirelessly, it could potentially be carried by unmanned vehicles such as drones, which would allow scientists to monitor sites that would otherwise be dangerous or difficult for humans to reach. The technology could also be used in a network of sensors covering a wide area, which would enable scientists to create maps of pollen, spore and microbe density.


26. memory devices

Graphical representation of a crossbar array, where different memory devices serve in different roles.

Ideally, next-generation AI technologies should understand all our requests and commands, extracting them from a huge background of irrelevant information, in order to rapidly provide relevant answers and solutions to our everyday needs. Making these "smart" AI technologies pervasive—in our smartphones, our homes, and our cars—will require energy-efficient AI hardware, which we at IBM Research plan to build around novel and highly capable analog memory devices.

In a recent paper published in Journal of Applied Physics, our IBM Research AI team established a detailed set of guidelines that emerging nano-scaled analog memory devices will need to satisfy in order to enable such energy-efficient AI hardware accelerators.

We had previously shown, in a Nature paper published in June 2018, that training a neural network using highly parallel computation within dense arrays of memory devices such as phase-change memory is faster and consumes less power than using a graphic...
The advantage of our approach comes from implementing each neural network weight with multiple devices, each serving in a different role. Some devices are mainly tasked with memorizing long-term information. Other devices are updated very rapidly, changing as training images (such as pictures of trees, cats, ships, etc.) are shown, and then occasionally transferring their learning to the long-term information devices. Although we introduced this concept in our Nature paper using existing devices (phase change memory and conventional capacitors), we felt there should be an opportunity for new memory devices to perform even better, if we could just identify the requirements for these devices.

In our follow-up paper, just published in Journal of Applied Physics, we were able to quantify the device properties that these "long-term information" and "fast-update" devices would need to exhibit. Because our scheme divides tasks across the two categories of devices, these device requirements are much less stringent—and thus much more achievable—than before. Our work provides a clear path for material scientists to develop novel devices for energy-efficient AI hardware accelerators based on analog memory.


27. High-performance, flexible, transparent force touch sensor for wearable devices

Researchers have reported a high-performance and transparent nanoforce touch sensor by developing a thin, flexible, and transparent hierarchical nanocomposite (HNC) film. The research team says their sensor simultaneously features all the necessary characters for industrial-grade application: high sensitivity, transparency, bending insensitivity, and manufacturability.

Force touch sensors that recognize the location and pressure of external stimuli have received considerable attention for various applications, such as wearable devices, flexible displays, and humanoid robots. For decades, huge amounts of research and development have been devoted to improving pressure sensitivity to realize industrial-grade sensing devices. However, it remains a challenge to apply force touch sensors in flexible applications because sensing performance is subject to change and degraded by induced mechanical stress and deformation when the device is bent.

To overcome these issues, the research team focused on the development of non-air gap sensors to break away from the conventional technology where force touch sensors need to have air-gaps between electrodes for high sensitivity and flexibility.

The proposed non-air-gap force touch sensor is based on a transparent nanocomposite insulator containing metal nanoparticles which can maximize the capacitance change in dielectrics according to the pressure, and a nanograting substrate which can increase transparency as well as sensitivity by concentrating pressure. As a result, the team succeeded in fabricating a highly sensitive, transparent, flexible force touch sensor that is mechanically stable against repetitive pressure.

Furthermore, by placing the sensing electrodes on the same plane as the neutral plane, the force touch sensor can operate, even when bending to the radius of the ballpoint pen, without changes in performance levels.

The proposed force touch has also satisfied commercial considerations in mass production such as large-area uniformity, production reproducibility, and reliability according to temperature and long-term use.

Finally, the research team applied the developed sensor to a pulse-monitoring capable healthcare wearable device and detected a real-time human pulse. In addition, the research team confirmed with HiDeep, Inc. that a seven-inch large-area sensor can be integrated into a commercial smartphone.


28. Exploring the challenges of exfoliating novel two-dimensional materials

This image shows a water molecule breaking apart as it encounters a 2D material.

Ever since researchers at the University of Manchester used a piece of tape to isolate, or "exfoliate," a single layer of carbon, known as graphene, scientists have been
investigating the creation of and applications for two-dimensional materials in order to advance technology in new ways. Scientists have theorized about many different kinds of two-dimensional materials, but producing them, by isolating one layer at a time from a layered three dimensional source, often presents a challenge.

Salvador Barraza-Lopez, associate professor of physics, and his research group are studying 2-D materials called group IV monochalcogenides, which includes tin selenide, germanium sulfide, tin(II) sulfide, tin telluride and tin selenide, among others.

In 3-D form, these materials have many useful properties. For example, they are currently used in solar cells. Some group IV monochalcogenides are also ferroelectric when exfoliated down to the 2-D limit, which means that they contain pairs of positive and negative charges that create a macroscopic dipole moment.

While some of these two-dimensional materials have been grown, no one has successfully peeled off a stable two-dimensional layer from a group IV monochalcogenide. In a recent manuscript titled "Water Splits to Degrade Two-Dimensional Group-IV Monochalcogenides in Nanoseconds" and published in the Journal ACS Central Science, Barraza-Lopez explained a possible reason for this.

Barraza-Lopez said that, even under the strictest experimental conditions, ambient water molecules can be found near these materials. And just like these materials, water carries an electric dipole too. Barraza Lopez explained that the interaction of dipoles can be observed in commonplace circumstances: "The pull of small pieces of paper with a comb that was recently used on dry hair can be explained as the effect of an inhomogeneous electric field in the comb accelerating macroscopic electric dipoles in that piece of paper nearby," he said.

Taneshwor Kaloni, a former postdoctoral associate in Barraza-Lopez's lab, performed computer calculations that emulate monolayers of these materials interacting with water molecules at room temperature and ambient pressure. The team demonstrated that when water molecules are close to these materials, they are attracted to them. This attraction creates an enormous build-up of kinetic energy, which leads to the splitting of the water molecules, and destablizes the 2-D materials as a result of this chemical reaction. Barraza-Lopez explained that he was surprised to learn that this process created enough energy to split water molecules, because the kinetic energy required exceeds 70,000 degree Celsius.

In a way, the difficulty in exfoliating these materials may lead to a new technology for hydrogen production off two dimensional materials, though many additional studies are required to achieve such goal.


29. Molecular semiconductors could be the future of electronics, and this new technique offers a way to mass produce them

Visions for what we can do with future electronics depend on finding ways to go beyond the capabilities of silicon conductors. The experimental field of molecular electronics is thought to represent a way forward, and recent work at KTH may enable scalable production of the nanoscale electrodes that are needed in order to explore molecules and exploit their behavior as potentially valuable electronic materials.

A team from the Department of Micro and Nanosystems at KTH recently tested a technique to form millions of viable nanoscale molecular junctions – extremely small pairs of electrodes with a nanometer-sized gap between them, where molecules can be trapped and probed. The findings were published in Nature Communications.

The KTH researchers reported that with a 100 mm diameter wafer of thin materials, they can produce as many as 20 million such electrodes in five hours' time, using gold film on top of a brittle material that forms cracks. In addition, working with the van der Zant Lab at TU Delft, the team trapped and studied a widely-used reference molecule in the nanometer-wide space between the electrodes to ensure that the fabrication method didn't hinder the formation of molecular junctions.

Shyamprasad Natarajan Raja, one of the co-authors, says this "crack-defined break junction" method offers a breakthrough to the impasse of scalable production of structures that could one day enable electronic devices made of single molecules.

The key is to produce gaps that enable a phenomenon called tunneling, in which electrons overcome the break in a circuit. A break junction has a gap the size of a few atoms, which breaks the flow of electrons through it. However, because the gap is so small, electrons with sufficient energy can still jump across this expance. Tunneling electrons sustain a small but measurable current that is extremely sensitive to the size of the gap – and to the presence of nano-objects inside it.

"Break junctions are the best means available to make single molecules part of a larger electronic circuit that can probe molecules," Raja says. They could also one day enable ultra-sensitive high-speed detectors using quantum tunneling, he says.
However, tunneling break junctions are produced one gap at a time, which has been a major roadblock in developing any application involving tunneling junctions outside a research laboratory, Raja says.

The method begins with using photo lithography to pattern a stack of gold on titanium nitride (TiN). This stack is set on a silicon wafer, and the notched structures that are formed then concentrate stress. So, when the silicon directly underneath the stack is removed (a process called release etching), tiny cracks form at the pre-determined locations in the TiN to release the stress. This in turn deforms the gold, stretching it into atomically thin wires running across these cracks, which upon breaking form gaps as small as a molecule.

Raja says that the method can be used for other conductive materials, besides gold, which offer interesting electrical, chemical and plasmonic properties for applications in molecular electronics and spintronics, nanoplasmonics and biosensing.


30. Toward unhackable communication: Single particles of light could bring the 'quantum internet'

Purdue researchers have created a new light source that generates at least 35 million photons per second, increasing the speed of quantum communication.

Hacker attacks on everything from social media accounts to government files could be largely prevented by the advent of quantum communication, which would use particles of light called "photons" to secure information rather than a crackable code.

The problem is that quantum communication is currently limited by how much information single photons can help send securely, called a "secret bit rate." Purdue University researchers created a new technique that would increase the secret bit rate 100-fold, to over 35 million photons per second.

"Increasing the bit rate allows us to use single photons for sending not just a sentence a second, but rather a relatively large piece of information with extreme security, like a megabyte-sized file," said Simeon Bogdanov, a Purdue postdoctoral researcher in electrical and computer engineering.

Eventually, a high bit rate will enable an ultra-secure "quantum internet," a network of channels called "waveguides" that will transmit single photons between devices, chips, places or parties capable of processing quantum information.

"No matter how computationally advanced a hacker is, it would be basically impossible by the laws of physics to interfere with these quantum communication channels without being detected, since at the quantum level, light and matter are so sensitive to disturbances," Bogdanov said.

The work was first published online in July for inclusion in a print Nano Letters issue on August 8, 2018.

Using light to send information is a game of probability: Transmitting one bit of information can take multiple attempts. The more photons a light source can generate per second, the faster the rate of successful information transmission.

The Purdue University Quantum Center, including Simeon Bogdanov (left) and Sajid Choudhury (right), is investigating how to advance quantum communication for practical uses.

"A source might generate a lot of photons per second, but only a few of them may actually be used to transmit information, which strongly limits the speed of quantum communication," Bogdanov said.

For faster quantum communication, Purdue researchers modified the way in which a light pulse from a laser beam excites electrons in a man-made "defect," or local disturbance in a crystal lattice, and then how this defect emissions one photon at a time.

The researchers sped up these processes by creating a new technique that increases the secret bit rate 100-fold, to over 35 million photons per second.

"Increasing the bit rate allows us to use single photons for sending not just a sentence a second, but rather a relatively large piece of information with extreme security, like a megabyte-sized file," said Simeon Bogdanov, a Purdue postdoctoral researcher in electrical and computer engineering.

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Using light to send information is a game of probability: Transmitting one bit of information can take multiple attempts. The more photons a light source can generate per second, the faster the rate of successful information transmission.
source at room temperature. Usually sources with comparable brightness only operate at very low temperatures, which is impractical for implementing on computer chips that we would use at room temperature," said Vlad Shalaev, the Bob and Anne Burnett Distinguished Professor of Electrical and Computer Engineering.

Next, the researchers will be adapting this system for on-chip circuitry. This would mean connecting the plasmonic antenna with waveguides so that photons could be routed to different parts of the chip rather than radiating in all directions.


31. Exploring new spintronics device functionalities in graphene heterostructures

Graphene Flagship researchers have shown in a paper published in *Science Advances* how heterostructures built from graphene and topological insulators have strong, proximity induced spin-orbit coupling which can form the basis of novel information processing technologies.

Spin-orbit coupling is at the heart of spintronics. Graphene's *spin-orbit coupling* and high electron mobility make it appealing for long spin coherence length at room temperature. Graphene Flagship researchers from Chalmers University of Technology (Sweden), Catalan Institute of Nanoscience and Nanotechnology—ICN2 (Spain), Universitat Autònoma de Barcelona (Spain) and ICREA Institució Catalana de Recerca i Estudis Avançats (Spain) showed a strong tunability and suppression of the spin signal and spin lifetime in heterostructures formed by graphene and topological insulators. This can lead to new graphene spintronic applications, ranging from novel circuits to new non-volatile memories and information processing technologies.

"The advantage of using heterostructures built from two Dirac materials is that, graphene in proximity with topological insulators still supports spin transport, and concurrently acquires a strong spin-orbit coupling," said Associate Professor Saroj Prasad Dash from Chalmers University of Technology.

"We do not just want to transport spin we want to manipulate it," said Professor Stephan Roche from ICN2 and deputy leader of the Graphene Flagship's spintronics Work-Package, "the use of topological insulators is a new dimension for spintronics, they have a surface state similar to graphene and can combine to create new hybrid states and new spin features. By combining graphene in this way we can use the tunable density of states to switch on/off—to conduct or not conduct spin. This opens an active spin device playground."

The Graphene Flagship, from its very beginning, saw the potential of spintronics devices made from graphene and related materials. This paper shows how combining graphene with other materials to make heterostructures opens new possibilities and potential applications.

"This paper combines experiment and theory and this collaboration is one of the strengths of the Spintronics Work-Package within the Graphene Flagship," said Roche.

"Topological insulators belong to a class of material that generate strong spin currents, of direct relevance for spintronic applications such as spin-orbit torque memories. As reported by this article, the further combination of topological insulators with two-dimensional materials like graphene is ideal for enabling the propagation of spin information with extremely low power over long distances, as well as for exploiting complementary functionalities, key to further design and fabricate spin-logic architectures," said Kevin Garello from IMEC, Belgium who is leader of the Graphene Flagships Spintronics Work-Package.

Professor Andrea C. Ferrari, Science and Technology Officer of the Graphene Flagship, and Chair of its Management Panel added "This paper brings us closer to building useful spintronic devices. The innovation and technology roadmap of the graphene Flagship recognises the potential of graphene and related materials in this area. This work yet again places the Flagship at the forefront of this field, initiated with pioneering contributions of European researchers."


32. Nanocages in the lab and in the computer: how DNA-based dendrimers transport nanoparticles

A DNA-based dendrimer of the fifth generation in a solution with its counterions. Regular voids in the interior of this molecule can be used as transport cages for nanoparticles.

How to create nanocages, i.e., robust and stable objects
with regular voids and tunable properties? Short segments of DNA molecules are perfect candidates for the controllable design of novel complex structures. Physicists from the University of Vienna, the Technical University of Vienna, the Jülich Research Center in Germany and Cornell University in the U.S.A., investigated methodologies to synthesize DNA-based dendrimers in the lab and to predict their behavior using detailed computer simulations. Their results are published in *Nanoscale*.

Nanocages are highly interesting molecular constructs, from the point of view of both fundamental science and possible applications. The cavities of these nanometer-sized objects can be employed as carriers of smaller molecules, which is of critical importance in medicine for drug or gene delivery in living organisms. This idea brought together researchers from various interdisciplinary fields who have been investigating dendrimers as promising candidates for creating such nano-carriers. Their tree-like architecture and step-wise growth with repeating self-similar units results in dendrimers containing cavities, hollow objects with controllable design. Nevertheless, decades of research have showed that vast number of different dendrimer types experience back-folding of outer branches with growing dendrimer generations, giving rise to a higher density of constituents in the molecule's interior. The effect of back-folding is enhanced upon addition of salt in the solution, whereby flexible dendrimers undergo significant shrinking, becoming compact objects with no hollow spaces in their interior.

The team of collaborators consisted of Nataša Adžić and Christos Likos (University of Vienna), Clemens Jochum and Gerhard Kahl (TU Wien), Emmanuel Stiakakis (Jülich) as well as Thomas Derrien and Dan Luo (Cornell). The researchers found a way to create dendrimers rigid enough to prevent back-folding of outer arms even in the case of high branching generations, preserving regular voids in their interior. Moreover, their novel macromolecules are characterized by remarkable resistance to added salt: they showed that the morphology and conformational characteristics of these systems stay unaffected even upon of addition of salt even at high concentration. The nanocages they created, in the lab and studied computationally are DNA-based dendrimers, or so-called, dendrimer-like DNAs (DL-DNA). The building block they are composed of is a Y-shaped double-stranded DNA unit, a three-armed structure consisting of double-stranded DNA (ds-DNA), formed via hybridization of three single-stranded DNA chains (ss-DNA), each of which has partially complementary sequences to the other two. Each arm is made up of 13 base pairs and a single-stranded sticky end with four nucleobases which acts as a glue. While a single Y-DNA corresponds to the first dendrimer generation, the attachment of further Y-DNA elements yields DL-DNA of higher generations. The resulting dendrimer is a charged and hollow-containing macromolecular assembly with tree-like architecture. Due to the rigidity of dsDNA, the branches of DL-DNA are stiff so that the whole molecule is rigid. Since DNA is charged, the electrostatic repulsion enhances the rigidity of the molecule.

DL-DNA molecules have been assembled in the laboratory by the Jülich and Cornell partners with remarkable control and sub-nanometer precision through programmable sticky-end cohesions. Their step-wise growth is highly controllable, unidirectional and non-reversible. This property is of high importance, as it has been shown that DNA-based dendrimers have been envisioned to play a promising role in developing nanoscale-barcodes, DNA-based vaccine technologies, as well as a structural probes involving multiplexed molecular sensing processes. Sizes, shapes as well as additional conformational details invisible to the experimentalists, such as the size of voids and the degree of branches back-folding, have been analyzed by computer simulations in Vienna. To describe the complex structure of DNA units, the group used a simple monomer-resolved model with interactions carefully chosen to mimic the equilibrium properties of DNA in physiological solution. The excellent agreement obtained between experiments and simulations for the dendrimer characteristics validates the theoretical models employed and paves the way for further investigation of the nanocages' properties and their applications as functional and smart nanocarriers and as building blocks for engineering biocompatible artificial materials.


### 33. Study provides insight into how nanoparticles interact with biological systems

*Computer simulation of a lipid corona around a 5-nanometer nanoparticle showing ammonium-phosphate ion pairing.*

Personal electronic devices—smartphones, computers, TVs, tablets, screens of all kinds—are a significant and growing source of the world's electronic waste. Many of these products use nanomaterials, but little is known about how these modern materials and their tiny particles interact with the environment and living things.

Now a research team of Northwestern University chemists and colleagues from the national Center for Sustainable Nanotechnology has discovered that when certain coated nanoparticles interact with living
organisms it results in new properties that cause the nanoparticles to become sticky. Fragmented lipid coronas form on the particles, causing them to stick together and grow into long kelp-like strands. Nanoparticles with 5-nanometer diameters form long structures that are microns in size in solution. The impact on cells is not known.

"Why not make a particle that is benign from the beginning?" said Franz M. Geiger, professor of chemistry in Northwestern's Weinberg College of Arts and Sciences. He led the Northwestern portion of the research.

"This study provides insight into the molecular mechanisms by which nanoparticles interact with biological systems," Geiger said. "This may help us understand and predict why some nanomaterial/ligand coating combinations are detrimental to cellular organisms while others are not. We can use this to engineer nanoparticles that are benign by design."

Using experiments and computer simulations, the research team studied polycation-wrapped gold nanoparticles and their interactions with a variety of bilayer membrane models, including bacteria. The researchers found that a nearly circular layer of lipids forms spontaneously around the particles. These "fragmented lipid coronas" have never been seen before.

The study points to solving problems with chemistry. Scientists can use the findings to design a better ligand coating for nanoparticles that avoids the ammonium-phosphate interaction, which causes the aggregation. (Ligands are used in nanomaterials for layering.)

The results will be published Oct. 18 in the journal Chem.

Geiger is the study's corresponding author. Other authors include scientists from the Center for Sustainable Nanotechnology's other institutional partners. Based at the University of Wisconsin-Madison, the center studies engineered nanomaterials and their interaction with the environment, including biological systems—both the negative and positive aspects.

"The nanoparticles pick up parts of the lipid cellular membrane like a snowball rolling in a snowfield, and they become sticky," Geiger said. "This unintended effect happens because of the presence of the nanoparticle. It can bring lipids to places in cells where lipids are not meant to be."

The experiments were conducted in idealized laboratory settings that nevertheless are relevant to environments found during the late summer in a landfill—at 21-22 degrees Celsius and a couple feet below ground, where soil and groundwater mix and the food chain begins.

By pairing spectroscopic and imaging experiments with atomistic and coarse-grain simulations, the researchers identified that ion pairing between the lipid head groups of biological membranes and the polycations' ammonium groups in the nanoparticle wrapping leads to the formation of fragmented lipid coronas. These coronas engender new properties, including composition and stickiness, to the particles with diameters below 10 nanometers. The study's insights help predict the impact that the increasingly widespread use of engineered nanomaterials has on the nanoparticles' fate once they enter the food chain, which many of them may eventually do.

"New technologies and mass consumer products are emerging that feature nanomaterials as critical operational components," Geiger said. "We can upend the existing paradigm in nanomaterial production towards one in which companies design nanomaterials to be sustainable from the beginning, as opposed to risking expensive product recalls—or worse—down the road."


34. Nanosized ferroelectrics become a reality

Using ferroelectricity instead of magnetism in computer memory saves energy. If ferroelectric bits were nanosized, this would also save space. But conventional wisdom dictates that ferroelectric properties disappear when the bits are made smaller. Reports that hafnium oxide can be used to make a nanoscale ferroelectric have not yet convinced the field, however University of Groningen (UG) physicists have now gathered evidence that could persuade the skeptics, published in Nature Materials on 22 October.

Ferroelectric materials have a spontaneous dipole moment which can point up or down. This means that they can be used to store information, just like magnetic bits on a hard disk. The advantage of ferroelectric bits is that they can be written at a low voltage and power. Magnetic bits require large currents to create a magnetic field for switching, and thus more power. The disadvantage of ferroelectrics is that the aligned dipoles are only stable in fairly large groups, so if you make the crystals smaller, the dipole moment eventually disappears.

Skepticism

"Reducing the size of ferroelectric materials has been a research topic for more than 20 years," says UG
Functional Nanomaterials Professor Beatriz Noheda. Some eight years ago, a breakthrough was announced by the Nanoelectronic Materials Laboratory in Dresden, Germany. They claimed that hafnium oxide thin films were ferroelectric when thinner than ten nanometres and that thicker films actually lost their ferroelectric properties. Noheda says, "This went against everything we knew, so most scientists were skeptical, including me." Some of the skepticism was because the ferroelectric hafnium samples used in these studies were polycrystalline and showed multiple phases, obscuring any clear fundamental understanding of such an unconventional phenomenon.

Noheda and her group decided to investigate. They wanted to study these crystals by growing clean (single-phase) films on a substrate. Using X-ray scattering and high-resolution electron microscopy techniques, they observed that very thin films (under ten nanometres) grow in an entirely unexpected and previously unknown polar structure, which is necessary for ferroelectricity. Combining these observations with meticulous transport measurements, they confirmed that the material was indeed ferroelectric. "In the substrate that we used, the atoms were a little bit closer than those in hafnium oxide, so the hafnium crystals would be a little strained," Noheda explains.

Polar phase
To their surprise, they noticed that the crystal structure changed when the layers exceeded ten nanometres, thus reproducing the results of the Dresden lab. Noheda: "We used a totally different method, but we reached similar conclusions. This confirmed that ferroelectricity in nanosized hafnium oxide crystals is indeed real and unconventional. And that begged the question: why does this happen?"

The common denominator in both studies was size. Small crystals became ferroelectric, whereas larger crystals lost this property. This led the scientists to study the phase diagrams of hafnium oxide. At a very small size, particles have a very large surface energy, creating pressures of up to 5 gigapascals in the crystal. The phase diagrams show a different crystal arrangement at such a pressure. "This pressure, along with the substrate-imposed strain, induces a polar phase, which is in line with the observation that these crystals are ferroelectric," concludes Noheda.

Wake up cycle
One more important finding is that, in contrast to the thin films in Dresden, the new crystals do not need a ‘wake-up’ cycle to become ferroelectric. Noheda: "The previously studied thin films only became ferroelectric after going through a number of switching cycles. This increased the suspicion that ferroelectricity was some sort of artefact. We now believe that the wake-up cycles were necessary to align the dipoles in "unclean" samples grown via other techniques. In our material, the alignment is already present in the crystals."

In Noheda's opinion, the results are conclusive: hafnium oxide is ferroelectric at the nanoscale. This means that very small bits can be constructed from this material, with the added advantage that they switch at low voltage. Furthermore, the particular substrate used in this study is magnetic, and this combination of magnetic and ferroelectric bits brings an extra degree of freedom, allowing each bit to store double the information. Now that the mechanism of nanosized ferroelectricity is clear, it seems likely that other simple oxides could have similar properties. Noheda expects that, together, this will spark a lot of new research.


35. Scientists make new 'green' electronic polymer-based films with protein nanowires
An interdisciplinary team of scientists at the University of Massachusetts Amherst has produced a new class of electronic materials that may lead to a "green," more sustainable future in biomedical and environmental sensing, say research leaders microbiologist Derek Lovley and polymer scientist Todd Emrick.

They say their new work shows it is possible to combine protein nanowires with a polymer to produce a flexible electronic composite material that retains the electrical conductivity and unique sensing capabilities of protein nanowires. Results appear in the journal Small.

Protein nanowires have many advantages over the silicon nanowires and carbon nanotubes in terms of their biocompatibility, stability, and potential to be modified to sense a wide range of biomolecules and chemicals of medical or environmental interest, says Lovley. However, these sensor applications require that the protein nanowires be incorporated into a flexible matrix suitable for manufacturing wearable sensing devices or other types of electronic devices.

As Lovley explains, "We have been studying the biological function of protein nanowires for over a decade, but it is only now that we can see a path forward for their use in practical fabrication of electronic devices." Postdoctoral research Yun-Lu Sun, now at the University of Texas at Austin, discovered the proper conditions for mixing protein nanowires with a non-conductive polymer to yield the electrically conductive composite material. He demonstrated that although the wires are made of protein, they are very durable and easy to process into new materials.

"An additional advantage is that protein nanowires are a truly 'green,' sustainable material," Lovley adds. "We can mass-produce protein nanowires with microbes grown with renewable feedstocks. The manufacture of more traditional nanowire materials requires high energy inputs and some really nasty chemicals." By contrast, he says, "Protein nanowires are thinner than silicon wires, and unlike silicon are stable in water, which is very

important for biomedical applications, such as detecting metabolites in sweat."

Emrick adds, "These electronic protein nanowires bear surprising resemblance to polymer fibers and we're trying to figure out how to combine the two most effectively."

In their proof-of-concept study, the protein nanowires formed an electrically conductive network when introduced into the polymer polyvinyl alcohol. The material can be treated with harsh conditions, such as heat, or extreme pH such as high acidity, that might be expected to ruin a protein-based composite, but it continued to work well.

The conductivity of the protein nanowires embedded in the polymer changed dramatically in response to pH. "This is an important biomedical parameter diagnostic of some serious medical conditions," Lovley explains. "We can also genetically modify the structure of the protein nanowires in ways that we expect will enable detection of a wide range of other molecules of biomedical significance."

The electrically conductive protein nanowires are a natural product of the microorganism Geobacter discovered in Potomac River mud by Lovley more than 30 years ago. Geobacter uses the protein nanowires to make electrical connections with other microbes or minerals. He notes, "Material science experts like Todd Emrick and Thomas Russell on our team deserve the credit for bringing protein nanowires into the materials field. It's not just about mud anymore."

In this work supported by UMass Amherst campus funds for exploratory research, next steps for the collaborative materials-microbiology team include scaling up production of nanowire-polymer matrices, Lovley says.

He points out, "Materials scientists need a lot more nanowires than we're used to making. We're were making thimblefuls for our biological studies. They need buckets full, so we are now concentrating on producing larger amounts and on tailoring the nanowires so they'll respond to other molecules." The researchers have also applied for a patent on the idea of a conductive polymer made with protein nanowires.


六．量子物理

36. A bridge to the quantum world

Monika Aidelsburger uses a special type of optical lattice to simulate quantum many-body phenomena that are otherwise inaccessible to experimental exploration. She has now been awarded an ERC Starting Grant to pursue this work.

Over the past decade, researchers led by Professor Immanuel Bloch, who holds a Chair in Experimental Physics at LMU, have developed several techniques and strategies to probe the secrets of the quantum world. Much progress has been made, but many phenomena of interest remain unexplored, and theoretical schemes are often difficult to test. Bloch's team is primarily interested in quantum interactions that can be modelled using ultracold gases trapped in optical lattices formed by laser beams.

Dr. Monika Aidelsburger, leader of a research group in Bloch's department, has now been awarded a highly endowed Starting Grant by the European Research Council (ERC) to extend this line of work. Her aim is to use ultracold ytterbium atoms trapped in optical lattices to simulate models of quantum behavior in condensed matter on a scale that is three orders of magnitude larger than in real solids.

Indeed, Aidelsburger, who is also part of the Max Planck Institute for Quantum Optics, hopes to take this strategy further, and use it to simulate 'lattice gauge theories', which describe fundamental interactions between particles in terms of 'gauge fields'. In these models, matter fields (substance particles) are depicted as points on a fictitious lattice, and the force fields that act on them are represented by the links between these nodes. Lattice gauge theories are of fundamental significance in many branches of quantum physics. Not only do they form the basis for the Standard Model of particle physics, they can also be applied to the physics that underlies the behavior of strongly interacting electrons in solids, and can account for important phenomena in quantum electrodynamics. Therefore, Aidelsburger's experimental approach to simulating lattice gauge theories in optical lattices would provide a link between classical and quantum physics, and allow analogous simulations of phenomena observed in settings other than solid-state physics.

Aidelsburger's research has so far focused on simulating the effects of magnetic fields. "This is because magnetic fields too can be described in terms of gauge fields," she explains. Physicists hope to extend these ideas and apply them to other quantum many-body phenomena that have remained largely inaccessible.

Two long-lived states

The experimental platform is currently being designed and soon the optical tables in Aidelsburger's laboratory will be arrayed with carefully positioned lenses and mirrors, lasers and optical fibers. Controlled manipulations of ultracold atoms in optical lattices have already been successfully used to probe and simulate quantum phenomena that have been observed in condensed-matter systems. These experiments were carried out under conditions in which the atoms can 'tunnel' between lattice sites, although their collective motions are influenced by the global parameters of the lattices. Extension of the strategy to lattice gauge theories
will require site-specific control over the motions of the atoms in the lattice.

Setting up such an experiment is extremely demanding, because the symmetries inherent to gauge theories must be precisely reproduced. "A successful implementation necessitates the use of completely new approaches," says Aidelsburger. "This carries a high risk, but having a working quantum simulator of such a model would constitute a tremendous advance." Bloch's team has learned a lot about how to keep quantum gases at temperatures only a smidgen above absolute zero, generate and manipulate optical lattices and control the motions of atoms of various elements such as rubidium, sodium and lithium, to name only a few. Aidelsburger's experiments will use ytterbium (Yb) atoms, because they exhibit two long-lived quantum states, which make them particularly useful for the planned simulations. Strongly focused laser beams will be employed to site-specifically control the motions of the atoms within the lattice. In the simulation, the two atomic states will play both the roles of the matter particles and the particles that mediate the forces that act upon them.

It is technically feasible to couple the motion of the two long-lived states of Yb atoms in the lattice. "This local coupling allows us for the first time to experimentally represent the fundamental building blocks of simple lattice gauge theories in an experimental setting," says Aidelsburger. Moreover, the technique can be straightforwardly extended to larger lattice structures and higher dimensions. This would allow researchers to simulate lattice gauge theories that play an important role in both condensed-matter physics and quantum electrodynamics using tractable experimental procedures. That would be a truly ground-breaking achievement. "Our strategy opens up entirely new experimental opportunities to explore certain phenomena and develop ideas for new theories," says Aidelsburger.

The fine adjustments

The prospect of being able to work for the next few years in Immanuel Bloch's department as a tenure-track professor was one reason why she decided to return to Munich after her spell as a postdoc at the Collège de France in Paris. "Young researchers need such longer-term perspectives," she says, "especially if they wish to carry out such a complex and demanding experimental task." The design and construction of a new system can take up to three years. One begins with simple models, and asks whether their simulation produces results that agree with those obtained with theory, or are compatible with predictions derived using well-established numerical methods, such as Monte Carlo simulations. These tests serve as a calibration scale for experiments – and allow researchers to adjust conditions appropriately and gradually increase the level of complexity of the experiments. In addition, the experimental systems must be constantly checked to ensure that they provide a correct description of the phenomena they set out to describe. "This is where close collaboration with theorists in other fields is especially important," says Aidelsburger. "The risks involved are considerable, as this is largely unknown territory for us all. We have to bring very different areas of physics together. It is my fervent hope that the initial experiments with simple models will yield results that find an echo in diverse disciplines."

In the simplest models, the Yb atoms can adopt either of two defined states, the ground state and a single metastable excited state. The aim is to progressively add further states to the system, allowing more complex interactions to be implemented. This would be an important step toward the ultimate goal of using ultracold atoms to simulate the strong nuclear force – the interaction between quarks (the fundamental constituents of atomic nuclei) and gluons (the force particles that hold atomic nuclei together). The latter task will require the implementation of far more complex lattice gauge theories.

Individual cells in two-dimensional optical lattices consisting of 100 × 100 atoms can now be addressed and their occupancies controlled, allowing dynamical effects to be observed in detail. Thus, it is possible to determine whether or not a particular lattice cell is occupied under specific conditions, and the state of every atom in the lattice can be probed practically in real time. With these achievements under their belts, physicists are well on the way to realizing the idea of a quantum simulator that the famous American physicist Richard Feynman formulated in the 1980s. "We hope that our set-up will pave the way to experimentally investigate fundamental issues in quantumchromodynamics," says Aidelsburger – before adding an emphatic qualifier: "But we are still at the very beginning."


37. Quantum network to test unhackable communications

Visible through a lens at his lab, David Awschalom, a quantum scientist at Argonne and the University of Chicago, discusses a project to build a quantum "teleportation" network between Argonne and Fermi national labs.

As the number of hacks and security breaches rapidly climbs, scientists say there may be a way to make a truly
unhackable network by using the laws of quantum physics.

To explore the concept, scientists are creating a network in the Chicago area that taps the principles of quantum physics to send information. Such a link could one day form the basis for a truly secure network, which would have wide-ranging impact on communications, computing and national security. The federal government estimates that malicious cyber activity cost the U.S. economy between $57 billion and $109 billion in 2016.

The quantum network, supported by the U.S. Department of Energy (DOE), will stretch between the DOE's Argonne National Laboratory and Fermi National Acceleratory Laboratory, a connection that is expected to be among the longest in the world to send secure information using quantum physics. The experiment will "teleport" information across a 30-mile distance, as particles change their quantum states instantaneously rather than traveling between two points.

"This project launches the construction of a communications network based on the quantum states of matter, offering a fundamentally new way to create and securely send information," said David Awschalom, an Argonne scientist and the Liew Family Professor of Molecular Engineering at the University of Chicago, who is principal investigator of the project. "We will build a national testbed to develop the science for engineering quantum systems and explore the properties of quantum entanglement, a phenomenon that's fascinated scientists and the general public alike."

As the result of a growing focus on quantum research among scientists at Argonne, Fermilab and UChicago, the three institutions have formed a partnership, the Chicago Quantum Exchange, involving 70 scientists and engineers and bringing together the intellectual talents, research capabilities and engineering power of the three affiliated institutions.

"This is the first time anyone has even planned to carry out a quantum network like this: a permanent, functioning quantum teleportation network at long distances in the United States," said Fermilab Deputy Director and Chief Research Officer Joe Lykken. "We want to demonstrate the enabling quantum technology. And we want to capitalize on our expertise to pave the way for others to create their own networks. Decades ago, building something like this would have been just a dream. But we're doing it now, and soon others will be able to."

"The strange laws of quantum"

The new communications network taps the strange laws of quantum mechanics, which govern the interactions of the smallest particles.

Part of the interest in the development of quantum systems stems from a rule of quantum mechanics that states that measuring a quantum particle alters its state. Scientists believe that a quantum system could be virtually unhackable because, if someone tries to look at a transmission, it would be disturbed, the information destroyed, and the senders alerted.

The quantum systems being developed at Fermilab and Argonne will eventually tap an underground link first built in the 1980s to test data transfer. The optical fiber cables are still undisturbed and functional, scientists said.

The way the quantum network works is by "entangling" particles, another quirk of quantum mechanics that says you can link two (or more) particles so that they are in a shared state— and whatever happens to one affects the other, even if they're miles apart at the time. Thus if scientists share an entangled pair of particles between two locations, the quantum information can get across, even if the locations are far apart and they don't have a physical connection between them. While the quantum information has been "teleported," no object is being transported.

So far, systems like these have been tested in laboratories and at small scales. Even a few kilometers of distance have been a challenge, since entangled particles must not interact in any way with their environment, and scientists must overcome any loss of photons emitted by the particles and precisely coordinate the timing of their transmissions.

"Performing information teleportation across real-world distances many miles apart allows us to identify practical problems involved in operating a quantum network—what are the technological challenges, how secure is the communication, and what are the limits to transporting information in this manner," Awschalom said.

"Quantum testbeds of similar scale exist around the world. But most of them rely on entangled photons— particles of light— to teleport information. Our testbed is unique in that, for the first time, we push towards an all solid-state architecture where trapped quantum particles in solids are used as information carriers," said Tian Zhong, assistant professor of molecular engineering at University of Chicago and scientist at Argonne, who is a co-principal investigator of the project.

At Fermilab, Shang-Yi Ch'en Professor of Physics at Caltech Maria Spiropulu is currently building an onsite quantum network with partners AT&T and Jet Propulsion Laboratory. They began this effort in 2017, and one year later, Spiropulu and her team have deployed the network within Fermilab and are working on developing improved devices for long-distance entanglement distribution. Their goal is to eventually extend that network to form part of the larger Fermilab-Argonne link.

"Networking quantum devices is important for scaling quantum computation and architecting hybrid communication systems towards a quantum-enhanced internet," Spiropulu said. "It will take deliberate collaboration between the government research..."
laboratories, academia, industry and foundations to get there. The Chicago Quantum Exchange program will catalyze progress in all these areas."

On Nov. 8-9, scientists from Argonne, Fermilab and UChicago will gather with industry, academic and government leaders in the field for the Chicago Quantum Summit, a program exploring the future of quantum computing and information science.

A public event in the city of Chicago titled "Quantum Engineering: the Next Technical Arms Race," featuring a conversation between Awschalom and Hartmut Neven, director of the Google Quantum Artificial Intelligence Lab, will be held as part of the summit.


38. Shielded quantum bits

Schematic representation of the new spin qubit consisting of four electrons (red) with their spins (blue) in their semiconductor environment (grey).

A theoretical concept to realize quantum information processing has been developed by Professor Guido Burkard and his team of physicists at the University of Konstanz. The researchers have found ways to shield electric and magnetic noise for a short time. This will make it possible to use spins as memory for quantum computers, as the coherence time is extended and many thousand computer operations can be performed during this interval. The study was published in the current issue of the journal Physical Review Letters.

The technological vision of building a quantum computer does not only depend on computer and information science. New insights in theoretical physics, too, are decisive for progress in the practical implementation. Every computer or communication device contains information embedded in physical systems. "In the case of a quantum computer, we use spin qubits, for example, to realize information processing," explains Professor Guido Burkard, who carries out his research in cooperation with colleagues from Princeton University. The theoretical findings that led to the current publication were largely made by the lead author of the study, doctoral researcher Maximilian Russ from the University of Konstanz.

In the quest for the quantum computer, spin qubits and their magnetic properties are the centre of attention. To use spins as memory in quantum technology, they must be lined up, because otherwise they cannot be controlled specifically. "Usually magnets are controlled by magnetic fields – like a compass needle in the Earth's magnetic field," explains Guido Burkard. "In our case the particles are extremely small and the magnets very weak, which makes it really difficult to control them." The physicists meet this challenge with electric fields and a procedure in which several electrons, in this case four, form a quantum bit. Another problem they have to face is the electron spins, which are rather sensitive and fragile. Even in solid bodies of silicon they react to external interferences with electric or magnetic noise. The current study focuses on theoretical models and calculations of how the quantum bits can be shielded from this noise – an important contribution to basic research for a quantum computer: If this noise can be shielded for even the briefest of times, thousands of computer operations can be carried out in these fractions of a second – at least theoretically.

The next step for the physicists from Konstanz will now be to work with their experimental colleagues towards testing their theory in experiments. For the first time, four instead of three electrons will be used in these experiments, which could, e.g., be implemented by the research partners in Princeton. While the Konstanz-based physicists provide the theoretical basis, the collaboration partners in the US perform the experimental part. This research is not the only reason why Konstanz is now on the map for qubit research.


39. Tests show integrated quantum chip operations possible

From left to right Dr. Bas Hensen, professor Dzurak, Dr. Kok Wai Chan, and former PhD student Michael Fogarty, who was lead author on the paper.

Quantum computers that are capable of solving complex problems, like drug design or machine learning, will require millions of quantum bits—or qubits—connected in an integrated way and designed to correct errors that inevitably occur in fragile quantum systems.

Now, an Australian research team has experimentally realised a crucial combination of these capabilities on a silicon chip, bringing the dream of a universal quantum computer closer to reality.

They have demonstrated an integrated silicon qubit platform that combines both single-spin addressability—the ability to 'write' information on a single spin qubit without disturbing its neighbours—and
a qubit 'read-out' process that will be vital for quantum error correction.

Moreover, their new integrated design can be manufactured using well-established technology used in the existing computer industry.

The team is led by Scientia Professor Andrew Dzurak of the University of New South Wales in Sydney, a program leader at the Centre of Excellence for Quantum Computation and Communication Technology (CQC2T) and Director of the NSW node of the Australian National Fabrication Facility.

Last year, Dzurak and colleagues published a design for a novel chip architecture that could allow quantum calculations to be performed using silicon CMOS (complementary metal-oxide-semiconductor) components—the basis of all modern computer chips.

In their new study, published today in the journal Nature Communications, the team combine two fundamental quantum techniques for the first time, confirming the promise of their approach.

Dzurak’s team had also previously shown that an integrated silicon qubit platform can operate with single-spin addressability—the ability to rotate a single spin without disturbing its neighbours.

They have now shown that they can combine this with a special type of quantum readout process known as Pauli spin blockade, a key requirement for quantum error correcting codes that will be necessary to ensure accuracy in large spin-based quantum computers. This new combination of qubit readout and control techniques is a central feature of their quantum chip design.

"We've demonstrated the ability to do Pauli spin readout in our silicon qubit device but, for the first time, we've also combined it with spin resonance to control the spin," says Dzurak.

"This is an important milestone for us on the path to performing quantum error correction with spin qubits, which is going to be essential for any universal quantum computer."

"Quantum error correction is a key requirement in creating large-scale useful quantum computing because all qubits are fragile, and you need to correct for errors as they crop up," says lead author, Michael Fogarty, who performed the experiments as part of his Ph.D. research with Professor Dzurak at UNSW.

"But this creates significant overhead in the number of physical qubits you need in order to make the system work," notes Fogarty.

Dzurak says, "By using silicon CMOS technology we have the ideal platform to scale to the millions of qubits we will need, and our recent results provide us with the tools to achieve spin qubit error-correction in the near future."

"It's another confirmation that we're on the right track. And it also shows that the architecture we've developed at UNSW has, so far, shown no roadblocks to the development of a working quantum computer chip."

"And, what's more, one that can be manufactured using well-established industry processes and components."

CQC2T's unique approach using silicon

Working in silicon is important not just because the element is cheap and abundant, but because it has been at the heart of the global computer industry for almost 60 years. The properties of silicon are well understood and chips containing billions of conventional transistors are routinely manufactured in big production facilities.

Three years ago, Dzurak's team published in the journal Nature the first demonstration of quantum logic calculations in a real silicon device with the creation of a two-qubit logic gate—the central building block of a quantum computer.

"Those were the first baby steps, the first demonstrations of how to turn this radical quantum computing concept into a practical device using components that underpin all modern computing," says Professor Mark Hoffman, UNSW's Dean of Engineering.

"Our team now has a blueprint for scaling that up dramatically.

"We've been testing elements of this design in the lab, with very positive results. We just need to keep building on that—which is still a hell of a challenge, but the groundwork is there, and it's very encouraging.

"It will still take great engineering to bring quantum computing to commercial reality, but clearly the work we see from this extraordinary team at CQC2T puts Australia in the driver's seat," he added.

Other authors of the new Nature Communications paper are UNSW researchers Kok Wai Chan, Bas Hensen, Wister Huang, Tuomo Tanttu, Henry Yang, Arne Laucht, Fay Hudson and Andrea Morello, as well as Menno Veldhorst of QuTech and TU Delft, Thaddeus Ladd of HRL Laboratories and Kohei Itoh of Japan's Keio University.

Commercialising CQC2T's intellectual property

In 2017, a consortium of Australian governments, industry and universities established Australia's first quantum computing company to commercialise CQC2T's world-leading intellectual property.

Operating out of new laboratories at UNSW, Silicon Quantum Computing Pty Ltd (SQC) has the target of producing a 10-qubit demonstration device in silicon by 2022, as the forerunner to creating a silicon-based quantum computer.

The work of Dzurak and his team will be one component of SQC realising that ambition. UNSW scientists and engineers at CQC2T are developing parallel patented approaches using single atom and quantum dot qubits.

In May 2018, the then Prime Minister of Australia, Malcolm Turnbull, and the President of France, Emmanuel Macron, announced the signing of a Memorandum of Understanding (MoU) addressing a new collaboration between SQC and the world-leading French research and development organisation, Commissariat à
l'Energie Atomique et aux Energies Alternatives (CEA).

The MoU outlined plans to form a joint venture in silicon-CMOS quantum computing technology to accelerate and focus technology development, as well as to capture commercialisation opportunities—bringing together French and Australian efforts to develop a quantum computer.

The proposed Australian-French joint venture would bring together Dzurak's team, located at UNSW, with a team led by Dr. Maud Vinet from CEA, who are experts in advanced CMOS manufacturing technology, and who have also recently demonstrated a silicon qubit made using their industrial-scale prototyping facility in Grenoble.

It is estimated that industries comprising approximately 40% of Australia's current economy could be significantly impacted by quantum computing.

Possible applications include software design, machine learning, scheduling and logistical planning, financial analysis, stock market modelling, software and hardware verification, climate modelling, rapid drug design and testing, and early disease detection and prevention.


40. Computer theorists show path to verifying that quantum beats classical

Close up of an Intel computing wafer.

As multiple research groups around the world race to build a scalable quantum computer, questions remain about how the achievement of quantum supremacy will be verified.

Quantum supremacy is the term that describes a quantum computer's ability to solve a computational task that would be prohibitively difficult for any classical algorithm. It is considered a critical milestone in quantum computing, but because the very nature of quantum activity defies traditional corroboration, there have been parallel efforts to find a way to prove that quantum supremacy has been achieved.

Researchers at the University of California, Berkeley, have just weighed in by giving a leading practical proposal known as random circuit sampling (RCS) a qualified seal of approval with the weight of complexity theoretic evidence behind it. Random circuit sampling is the technique Google has put forward to prove whether or not it has achieved quantum supremacy with a 72-qubit computer chip called Bristlecone, unveiled earlier this year.

The UC Berkeley computer theorists published their proof of RCS as a verification method in a paper published Monday, Oct. 29, in the journal Nature Physics. "The need for strong evidence for quantum supremacy is under-appreciated, but it's important to pin this down," said study principal investigator Umesh Vazirani, Roger A. Strauch Professor of Electrical Engineering and Computer Science at UC Berkeley. "Besides being a milestone on the way to useful quantum computers, quantum supremacy is a new kind of physics experiment to test quantum mechanics in a new regime. The basic question that must be answered for any such experiment is how confident can we be that the observed behavior is truly quantum and could not have been replicated by classical means. That is what our results address."

The other investigators on this paper are Adam Bouland and Bill Fefferman, both postdoctoral research fellows, and Chinmay Nirkhe, a Ph.D. student, all in Vazirani's theoretical computing research group.

Investment in quantum is heating up

The paper comes amid accelerated activity in government, academia and industry in quantum informational science. Congress is considering the National Quantum Initiative Act, and last month, the U.S. Department of Energy and the National Science Foundation announced nearly $250 million in grants to support research in quantum science and technologies.

At the same time, the Lawrence Berkeley National Laboratory and UC Berkeley announced the formation of Berkeley Quantum, a partnership designed to accelerate and expand innovation in quantum information science.

The stakes are high as international competition in quantum research heats up and the need for increasingly complex computations grows. With true quantum computing, problems that are impractical for even the fastest supercomputers to date could be relatively efficient to solve. It would be a game-changer in cryptography, simulations of molecular and chemical interactions and machine learning.

Quantum computers are not confined by the traditional 0s and 1s of a traditional computer's bits. Instead, quantum bits, or qubits, can encode 0s, 1s and any quantum superposition of the two to create multiple states simultaneously.

When Google unveiled Bristlecone, it said the empirical proof of its quantum supremacy would come through random circuit sampling, a technique in which the device would use random settings to behave like a random quantum circuit. To be convincing, there would also need to be strong evidence that there is no classical algorithm running on a classical computer that could simulate a random quantum circuit, at least in a reasonable amount of time.

Detecting quantum accents

Vazirani's team referred to an analogy between the output of the random quantum circuit and a string of random syllables in English: even if the syllables don't
form coherent sentences or words, they will still possess an English "accent" and will be recognizably different from Greek or Sanskrit.

They showed that producing a random output with a "quantum accent" is indeed hard for a classical computer through a technical complexity theoretic construct called "worst-to-average-case reduction."

The next step was to verify that a quantum device was actually speaking with a quantum accent. This relies on the Goldilocks principle—a 50-qubit machine is large enough to be powerful, but small enough to be simulated by a classical supercomputer. If it's possible to verify that a 50-qubit machine speaks with a quantum accent, then that would provide strong evidence that a 100-qubit machine, which would be prohibitively hard to simulate classically, would do so, as well.

But even if a classical supercomputer were programmed to speak with a quantum accent, would it be able to recognize a native speaker? The only way to verify the output of the speaker is by a statistical test, said the Berkeley researchers. Google researchers are proposing to measure the degree of matching by a metric called "cross-entropy difference." A cross-entropy score of 1 would be an ideal match.

The alleged quantum device may be regarded as behaving like an ideal quantum circuit with random noise added. Fefferman and Bouland say the cross-entropy score will certify the authenticity of the quantum accent provided the noise always adds entropy to the output. This is not always the case—for example if the noise process preferentially erases 0s over 1s, it can actually reduce the entropy.

"If Google's random circuits are generated by a process that allows such erasures, then the cross-entropy would not be a valid measure of quantum supremacy," said Bouland. "That's partly why it will be very important for Google to pin down how its device deviates from a real random quantum circuit."

These results are an echo of work that Vazirani did in 1993 with his student Ethan Bernstein, opening the door to quantum algorithms by presenting speedups by quantum computers violating a foundational principle of computer science called the Extended Church-Turing thesis.

Peter Shor of Bell Labs took their work one step further by showing that a very important practical problem, integer factorization, could be exponentially sped up by a quantum computer.

"This sequence provides a template for the race to build working quantum computers," said Vazirani. "Quantum supremacy is an experimental violation of the Extended Church-Turing thesis. Once that is achieved, the next challenge will be to design quantum computers that can solve practically useful problems."


41. Scientists 'tame' some disruptive environmental effects on quantum computers

A team of scientists, led by Professor Winfried Hensinger at the University of Sussex, have made a major breakthrough concerning one of the biggest problems facing quantum computing: how to reduce the disruptive effects of environmental "noise" on the highly sensitive function of a large-scale quantum computer.

In the real-world, technological developments need to operate in imperfect conditions; what can be successfully tested in a highly controlled laboratory may fail when presented with realistic environmental factors, such as the fluctuations in voltage from an electronic component or stray electromagnetic fields emitted by everyday electronic equipment.

The University of Sussex's Ion Quantum Technology Group have managed to dramatically reduce the effects of such environmental "noise" affecting trapped ion quantum computers, reporting their findings in an article that has today, Thursday 1 November 2018, been published in the prestigious journal Physical Review Letters. It means the team is one step closer to building a large-scale quantum computer with the capability to solve challenging real-world problems.

Small-scale quantum computers currently in existence only contain a handful of quantum bits—components of quantum computers that store information and can exist in multiple states, also referred to as qubits. As such, current quantum computers are small enough to be operated in a highly controlled environment inside a specialized laboratory. However, such machines do not have the processing power required to solve complex problems because of the limited number of qubits.

When built, large-scale quantum computers will be able to solve certain problems that would take even the fastest super computers billions of years to calculate. In order to create a quantum computer that can solve such problems, scientists will need to increase the number of qubits, which in turn will increase the size of the quantum computer. The problem is that the more qubits that are added, the more difficult it becomes to isolate the computer from any realistic "noise" that would disrupt the computing processes.

Hensinger's team of University of Sussex physicists have made a quantum computing breakthrough that is capable of mitigating some of these problems. They collaborated with theoretical scientist Dr. Florian Mintert and colleagues from Imperial College London, who proposed a theory of how one might be able to solve this problem by manipulating the strange quantum effects in
use inside a quantum computer. The theory allows—making use of the strange properties of quantum physics—the execution of quantum computations in such a way that changes in the initial operational parameters of the machine do not lead to a substantial change in the end result of the computation. This in turn helps to insulate the quantum computer from the effects of environmental ‘noise’.

Dr. Sebastian Weidt, senior scientist in the Sussex Ion Quantum Technology Group, explains the significance: "Realising this technique may have a profound impact on the ability to develop commercial ion trap quantum computers beyond use in an academic laboratory."

The Sussex team went to work to see whether they could actually implement this theory. They used complicated radio-frequency and microwave signals capable of manipulating the quantum effects inherent in individual charged atoms (ions), to demonstrate this in practical experiments. Their implementation is based on microwave technology, such as that present in mobile phones. Following months of intensive work in the laboratory, the Sussex scientists have managed to make this new method a reality, experimentally demonstrating its capabilities to substantially reduce the effect of "noise" on a trapped ion quantum computer.

Prof Hensinger, Head of the Ion Quantum Technology Group at the University of Sussex—which last year unveiled the first blueprint for a large-scale quantum computer—says: "With this advance we have made another practical step towards constructing quantum computers that can host millions of qubits. Such machines are capable of solving certain problems that even the fastest supercomputer may take billions of years to calculate and be of great benefit to humanity; they may be able to help us create new pharmaceuticals; find new cures for diseases, such as Dementia; create powerful tools for the financial sector; be of benefit to agriculture, through more efficient fertilizer production, among many other applications. We are only starting to understand the tremendous potential of these machines."

Hensinger's group is now utilising this new technique as they put the final touches to a powerful new quantum computer prototype that is currently in their laboratory at the University of Sussex.

Hensinger says: "It's now time to translate academic achievements into the construction of practical machines. We're in a fantastic position to do this at Sussex and my team is working round the clock to make large-scale quantum computing a future reality."


42. Active noise control for a quantum drum

The central pad of a holey silicon nitride membrane (yellow, inside red silicon frame) vibrates like a “quantum drum,” thanks to the extreme acoustic isolation provided by the hole pattern invented at the Schliesser lab. Laser-based measurement of the drum’s vibrations then allows control of its motional quantum state, eliminating all noise—including the quantum perturbation by the measurement itself—analogous to noise-cancellation headphones. Earbuds in the background provide a size reference.

Researchers at the Schliesser Lab at the Niels Bohr Institute, University of Copenhagen, have demonstrated a new way to address a central problem in quantum physics: at the quantum scale, any measurement disturbs the measured object. This disturbance limits, for example, the precision with which the motion of an object can be tracked. But in a millimeter-sized membrane that vibrates like a drumhead, the researchers have managed to precisely monitor the motion with a laser—and to undo the quantum disturbance by the measurement. This allows them to control the membrane's motion at the quantum level. The result has potential applications in ultraprecise sensors of position, velocity and force, and the architecture of a future quantum computer. It is now published in the prestigious scientific magazine, Nature.

At the quantum level, making measurements disturbs the object measured: using a laser beam to determine the position or velocity of an object requires bombarding it with many photons. The photons will kick it with every impact, and the object will start moving accordingly. As the photons arrive randomly, this results in additional random motion on top of the original movements, degrading the ability to measure and control the actual motional state. If the laser intensity is turned down, in order to reduce such measurement "backaction", the signal-to-noise ratio in the detector goes down and the measurement becomes imprecise — again, "A strong measurement is needed, even though it results in quantum backaction. All we have to do is to measure and undo the quantum backaction. And that is basically what we've succeeded in doing", Professor Albert Schliesser explains.

The experiment
"Our experiments offer us a really unique opportunity: our data very clearly show quantum effects, such as quantum backaction, in the measurement of mechanical motion. So we can test in our labs if clever modifications of the measurement apparatus can improve precision—using tricks that in the last few decades could only be theorized," he continues.
A silicon nitride membrane resonator suspended from a mm-sized square silicon frame. The hole pattern in the membrane has a phononic bandgap that confines vibrations at certain frequencies to the island (‘defect’) in the center.

The experimental system is a ca. 3x3 mm-sized membrane made of the ceramic silicon nitride (Fig 1). It is under high tension and vibrates when struck—just like a drumhead. A special hole pattern invented in Schliesser's lab isolates these vibrations extremely well: once it vibrates, it undergoes a billion oscillation cycles before it loses a significant fraction of its energy to its surroundings. (For a normal drum, that number would be about one hundred.) An additional advantage of silicon nitride is that it does not absorb any of the laser light used to interrogate its motion—so the membrane does not heat up, which would again lead to some uncontrolled motion of the membrane.

Controlling the motional quantum state with active noise cancellation

Excluding external perturbations through such extreme isolation, the scientists can focus on quantum effects of the measurement. Using a very stable laser, they can indeed measure the motion, including measurement backaction, down to the quantum level. "The remarkable thing is that we can then take this measurement record, run it through some electronics, and apply a counteracting force to the membrane, to undo the random effects of quantum backaction. It basically works like a set of noise-cancelling headphones, just in the quantum regime," explains Ph.D. student Massimiliano Rossi, one of the study’s lead authors. In this manner, the scientists could deterministically prepare the motion of the membrane in a pure quantum state—an objective physicists from a range of communities have pursued for the last 20 years.

The reason lies in the versatility of such quantum control techniques when applied to motion. The LIGO interferometers are one example. They measure gravitational waves, emitted e.g. by merging black holes billions of light years away, by monitoring the motion of large mirrors on earth. To recover these extremely faint signals, they have to push the sensitivity to such an extreme that the quantum limits of motion measurements come into play. On the other hand, controlling the quantum state of mechanical systems could be of use for special components of a quantum computer. A memory element, for example, would benefit from the long lifetime of mechanical excitations. Ultimately, quantum-controlled vibrations are also interesting from a fundamental point of view: as vibration implies mass is moving, which role does gravity play? How does it influence the quantum state of motion? Today's accepted theories, let alone experiments, have yet to deliver clear answers to these question.


43. New method could lead to more powerful quantum sensors

As quantum technology continues to come into its own, investment is happening on a global scale. Soon, we could see improvements in machine learning models, financial risk assessment, efficiency of chemical catalysts and the discovery of new medications.

As numerous scientists, companies and governments rush to invest in the new era of quantum technology, a crucial piece of this wave of innovation is the quantum sensor. Improving these devices could mean more powerful computers, better detectors of disease and technological advances scientists can't even predict yet.

A scientific study from the University of Chicago's Institute for Molecular Engineering published Oct. 17 in Nature Communications could have exciting implications for the developing world of quantum sensing—and quantum technology as a whole.

"We took a recently proposed idea to make better optical classical sensors and asked whether the same idea would work in a quantum setting," said Aashish Clerk, one of the study's authors and a professor at the Institute for Molecular Engineering. "We found that this idea doesn't really work in quantum settings, but that another somewhat related approach could give you a huge advantage."

In a quantum setting, optical sensors are typically limited because light is made up of particles, and this discreteness leads to unavoidable noise. But this study revealed an unexpected method to combat that limitation.

"We think we've uncovered a new strategy for building extremely powerful quantum sensors," Clerk continued.

The path to the directional principle

Clerk and co-author Hoi-Kwan Lau, a postdoctoral scholar at UChicago, were inspired by recent high-profile studies that showed how to drastically enhance a common optical sensing technique. The "trick" involves tuning systems to an exceptional point, or a point at which two or more modes of light come together at one specific frequency.

Lau and Clerk wanted to see whether this method could succeed in settings where quantum effects were
important. The goal was to account for unavoidable "quantum" noise—fluctuations associated with the fact that light has both a wave-like and a particle-like character, Clerk explained.

The study found the exceptional point technique to be unhelpful in a quantum setting, but the research still led to promising results. "The good news is we found another way to build a powerful new type of sensor that has advantages even in quantum regimes," Clerk said. "The idea is to construct a system that is 'directional,' meaning photons can move in one direction only."

This directional principle—one based on photons being able to move in only one direction—is a brand-new development in quantum sensing.

New developments in quantum sensing

In terms of real-world applications, highly effective quantum sensors could be game-changing. Quantum systems are sensitive to the slightest environmental changes, so these detectors have the potential to be incredibly powerful.

In addition, some of the stranger aspects of quantum behavior, such as quantum entanglement, could make them even stronger. Quantum entanglement, a puzzling phenomenon even for scientists, describes how two particles can be separated by a vast distance yet actions performed on one particle immediately affect the other. This entanglement can be harnessed to make quantum sensors surprisingly resilient against certain kinds of noise.

In the future, new developments in quantum sensing could translate to significant advances in a variety of areas. The class of optical sensors described in the study can be used to detect viruses in liquids, for example. They also can act as readout devices for quantum bits in a superconducting quantum computer.

"We think our idea has the potential to generate major improvements in many of these applications," Clerk explained.

The study's implications for quantum computing are especially exciting. Not only do quantum computers have the potential to dramatically increase computing speeds, but they could also tackle problems that are completely unfeasible with traditional computing.

Lau and Clerk plan to do further research on their enhanced sensing technique. Clerk still has a lot of questions: "What sets how fast our sensor is? Are there fundamental limits on its speed? Can it be used to detect signals that aren't necessarily small?"

Their biggest hope, Clerk explained, is to inspire other researchers to build improved quantum sensors that harness this newly uncovered principle.


44. New quantum criticality discovered in superconductivity

Using solid state nuclear magnetic resonance (ssNMR) techniques, scientists at the U.S. Department of Energy's Ames Laboratory discovered a new quantum criticality in a superconducting material, leading to a greater understanding of the link between magnetism and unconventional superconductivity.

Most iron-arsenide superconductors display both magnetic and structural (or nematic) transitions, making it difficult to understand the role they play in superconducting states. But a compound of calcium, potassium, iron, and arsenic, and doped with small amounts of nickel, CaK(Fe1−xNix)4As4, first made at Ames Laboratory, has been discovered to exhibit a new magnetic state called a hedgehog spin-vortex crystal antiferromagnetic state without nematic transitions.

"Spin or nematic fluctuations can be considered to play an important role for unconventional superconductivity," said Yuji Furukawa, a senior scientist at Ames Laboratory and a professor of Physics and Astronomy at Iowa State University. "With this particular material, we were able to examine only the magnetic fluctuations, and NMR is one of the most sensitive techniques for examining them."

He continued, "using 75As NMR, we discovered that CaK(Fe1−xNix)4As4 is located at a hedgehog spin-vortex crystal antiferromagnetic quantum critical point which is avoided due to superconductivity. The discovery of the magnetic quantum criticality without nematicity in CaK(Fe1−xNix)4As4 suggests that the spin fluctuations are the primary driver of superconductivity."

Furukawa's discovery was a collaboration between Ames Laboratory's world-leading SSNMR team and the lab's condensed matter physicists, including Paul Canfield, a senior scientist at Ames Laboratory and a Distinguished Professor and the Robert Allen Wright Professor of Physics and Astronomy at Iowa State University.

"This is a new type of magnetic order," said Canfield. "You have this interesting interaction between superconductivity and magnetism from high temperatures in the normal state. This gives us some sense that this high temperature superconductivity may be coming from this near quantum critical antiferromagnetic transition."

The research is further discussed in the paper, "Hedgehog Spin-vortex Crystal Antiferromagnetic Quantum Criticality in CaK(Fe1−xNix)4As4 revealed by NMR," published in Physical Review Letters.
Pushing the extra cold frontiers of superconducting science

Ames Laboratory has developed a method to measure magnetic properties of superconducting and magnetic materials that exhibit unusual quantum behavior at very low temperatures in high magnetic fields, by placing a tunnel diode resonator, an instrument that makes precise radio-frequency measurements of magnetic properties, in a dilution refrigerator, a cryogenic device that is able to cool samples down to milli-Kelvin temperature range.

Measuring the properties of superconducting materials in magnetic fields at close to absolute zero temperatures is difficult, but necessary to understand their quantum properties. How cold? Lower than 0.05 Kelvin (-272°C).

"For many modern (quantum) materials, to properly study the fine details of their quantum mechanical behavior you need to be cool. Cooler than was formerly thought possible," said Ruslan Prozorov, a physicist at the U.S. Department of Energy's Ames Laboratory, who specializes in developing instrumentation which measures just such things.

Prozorov and his research team have developed a method to measure magnetic properties of superconducting and magnetic materials that exhibit unusual quantum behavior at very low temperatures in high magnetic fields. The method is being used to study quantum critical behavior, mechanisms of superconductivity, magnetic frustration and phase transitions in materials, many of which were first fabricated at Ames Laboratory.

They did so by placing a tunnel diode resonator, an instrument that makes precise radio-frequency measurements of magnetic properties, in a dilution refrigerator, a cryogenic device that is able to cool samples down to milli-Kelvin temperature range. While this was already achieved before, previous works did not have the ability to apply large static magnetic fields, which is crucial for studying quantum materials.

Prozorov's group worked to overcome the technical difficulties of maintaining high-resolution magnetic measurements, while at the same time achieving ultra-cold temperatures down to 0.05 K and in magnetic fields up to 14 tesla. A similar circuit has already been used in a very high magnetic field (60 T) when the team performed the experiments at Los Alamos National Lab.

"When we first installed the dilution refrigerator, the joke was that my lab had the coldest temperatures in Iowa," said Prozorov, who conducts his research where Midwestern winters are no laughing matter. "But we were not doing this just for fun, to see how cold we could go. Many unusual quantum properties of materials can only be uncovered at these extremely low temperatures."

The group studied pairing symmetry in several unconventional superconductors, mapped a very complex phase diagram in a system with field-induced quantum critical behavior, and recently uncovered very unusual properties of a spin-ice system, "none of which would be possible without this setup," said Prozorov.

Understanding the building blocks for an electronic brain

Left: A simplified representation of a small part of the brain: neurons receive, process and transmit signals through synapses. Right: a crossbar array, which is a possible architecture of how this could be realized with devices. The memristors, like synapses in the brain, can change their conductivity so that connections can be weakened and strengthened.

Computer bits are binary, with a value of zero or one. By contrast, neurons in the brain can have many internal states, depending on the input that they receive. This allows the brain to process information in a more energy-efficient manner than a computer. University of Groningen (UG) physicists are working on memristors made from niobium-doped strontium titanate, which mimic the function of neurons. Their results were published in the Journal of Applied Physics on 21 October.

UG researcher Anouk Goossens, the first author of the paper, tested memristors made from niobium-doped strontium titanate. The conductivity of the memristors is controlled by an electric field in an analog fashion: "We use the system's ability to switch resistance. By applying voltage pulses, we can control the resistance, and using a low voltage we read out the current in different states. The strength of the pulse determines the resistance in the device. We have shown a resistance ratio of at least 1000 to be realizable. We then measured what happened over time." Goossens was especially interested in the time dynamics of the resistance states.
She observed that the duration of the pulse with which the resistance was set determined how long the memory lasted. This could be between one to four hours for pulses lasting between a second and two minutes. Furthermore, she found that after 100 switching cycles, the material showed no signs of fatigue.

"There are different things you could do with this," says Goossens. "By 'teaching' the device in different ways, using different pulses, we can change its behavior." The fact that the resistance changes over time can also be useful. "These systems can forget, just like the brain. It allows me to use time as a variable parameter." In addition, the devices that Goossens made combine both memory and processing in one device, which is more efficient than traditional computer architecture in which storage (on magnetic hard discs) and processing (in the CPU) are separated.

Goossens conducted the experiments described in the paper during a research project as part of the Master in Nanoscience degree programme at the University of Groningen. Goossens' research project took place within the group of students supervised by Dr. Tamalika Banerjee of Spintronics of Functional Materials. She is now a Ph.D. student in the same group.

Before building brain-like circuits with her device, Goossens plans to conduct experiments to understand what happens within the material. "If we don't know exactly how it works, we can't solve any problems that might occur in these circuits. So we have to understand the physical properties of the material—what does it do, and why?"

Questions that Goossens wants to answer include what parameters influence the states that are achieved. "And if we manufacture 100 of these devices, do they all work the same? If they don't, and there is device-to-device variation, that doesn't have to be a problem. After all, not all elements in the brain are the same."


47. Machine learning improves accuracy of particle identification at LHC

One of major unsolved problems of modern physics is the predominance of matter over antimatter in the universe. They both formed within a second after the Big Bang, in presumably equal fractions, and physicists are trying to understand where antimatter has disappeared to. Back in 1966, Russian scientist Andrei Sakharov suggested that the imbalance between matter and antimatter appeared as a result of CP violation, i.e., an asymmetry between particles and antiparticles. Thus, only particles remained after their annihilation (mutual destruction) of resulting unbalanced contributions.

The Large Hadron Collider beauty experiment (LHCb) studies unstable particles called B-mesons. Their decays demonstrate the clearest asymmetry between matter and antimatter. The LHCb consists of several specialised detectors, specifically, calorimeters to measure the energy of neutral particles. Calorimeters also identify different types of particles. These are done by search and analysis of corresponding clusters of energy deposition. It is, however, not easy to separate signals from two types of photons—primary photons and photons from energetic π0 meson decay. HSE scientists developed a method that to classify these two with high accuracy.

The authors of the study applied artificial neural networks and gradient boosting (a machine-learning algorithm) to classify energies collected in the individual cells of the energy cluster.

"We took a five-by-five matrix with a centre at the calorimeter cell with the largest energy," says Fedor Ratnikov, one of the study's authors and a leading researcher in the HSE Laboratory of Methods for Big Data Analysis. "Instead of analysing the special characteristics constructed from raw energies in cluster cells, we pass these raw energies directly to the algorithm for analysis. The machine was able to make sense of the data better than a person."

Compared with the previous method of data pre-processing, the new machine-learning-based method has quadrupled quality metrics for the identification of particles on the calorimeter. The algorithm improved the classification quality from 0.89 to 0.97; the higher this figure is, the better the classifier works. With a 98 percent effectiveness rate of initial photon identification, the new approach has lowered the false photon identification rate from 60 percent to 30 percent.

The proposed method is unique in that it allows for elementary particles to be identified without initially studying the characteristics of the cluster being analysed. "We pass the data to machine learning in the hope that the algorithm finds correlations we might not have considered. The approach obviously worked out in this case," Fedor Ratnikov concludes.