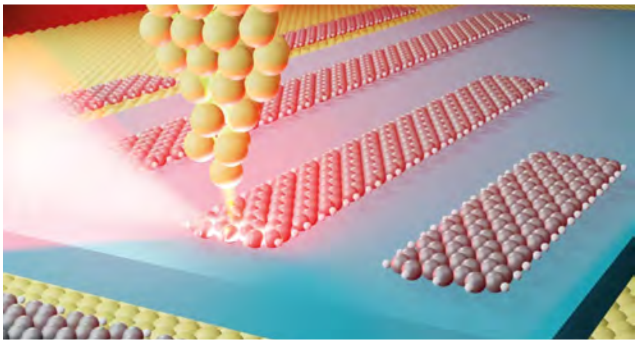

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FLUORESCENT CENTRES WITHIN GRAPHENE RIBBONS

Since their first synthesis, graphene nanoribbons (GNR) have attracted considerable interest in the nanoscience and nanotechnology communities due to unique physical properties related to their topology.

Several theoretical studies discuss in detail how the optical properties of GNRs can be advantageously controlled by atomic-scale variations in their width, length and edge shape. However, experiments on the fluorescence properties of GNRs are scarce and limited to ensemble measurements dominated by the emission of hardly controllable defects.

A team from the Institut de Physique et de Chimie des Matériaux de Strasbourg (IPCMS, CNRS / University of Strasbourg) in collaboration with the Institut des Sciences Moléculaires d'Orsay (ISMO, CNRS / University of Paris-Saclay) developed a new experimental method to study the fluorescence properties of single GNRs using a scanning tunneling microscope (STM). Their approach is to move a single ribbon with the STM tip from a metal surface - essential for ribbon synthesis - onto a thin insulating layer that protects the ribbons' optical properties. The researchers then use the STM tip to pass a very small electric current through the GNR.

In response to this current, the researchers observed light emission, which was found to be particularly intense when the tip is positioned at the ribbon termini. The researchers attributed this light emission to excitons located at the termini of the ribbon due to its particular (so-called non-trivial) topology. These termini thus behave like fluorescent centres, similarly to what is observed in many insulating and semiconducting materials. An advantage of ribbon structure is that the number and position of the fluorescent centres can be chemically engineered, providing an effective means of tuning the coupling between fluorescent centres and controlling their classical or quantum emission properties.

These structures may find their place in optoelectronic devices based on atomically flat and robust elementary units or as tunable quantum sensors of reduced dimensions.

REFERENCE

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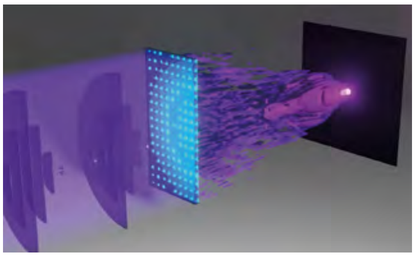
Metaoptics for attosecond extreme-ultraviolet light

Extreme-ultraviolet (EUV) radiation with its short wavelength and high-frequency electric field oscillations is a key enabling technology for achieving extreme spatial resolution in state-of-the-art semiconductor manufacturing and extreme temporal resolution in attosecond spectroscopy.

Advances in both fields come at the price of the difficult generation and handling of this light. Aside from the need for exotic laser-driven light sources, it is close to impossible to design and manufacture transmissive optical elements, lenses, or beam splitters in this wavelength range: because of their high energy, EUV photons can excite electrons in all solids and are therefore barely refracted and strongly absorbed.

A research collaboration between the Graz University of Technology in Austria and Harvard University in Boston/USA now reports in Science about a novel concept, "vacuum guiding", which facilitates metaoptical elements that can manipulate and focus EUV light. The concept exploits that holes in a silicon membrane have a higher refractive index than the surrounding material to control the transmission phase. Carefully arranging many nanoscale holes then allows emulating the function of most optical components.


Artist interpretation of an extreme-ultraviolet metalens consisting of an array of nanoscale holes. [© Second Bay Studios / Harvard SEAS]

In their work, Ossiander *et al.* manufactured the first EUV metalens by state-of-the-art electron beam lithography and reactive ion etching. The device demonstrated its refractive power by focusing a 50-nm wavelength (25-eV photon energy) attosecond pulse train close to the diffraction limit and achieving a 0.73-um beam waist.

Expanding on this concept transfers the opportunities of metaoptics for full phase, polarization, and emission control into a new spectral regime promising progress in extreme time and length scale microscopy, innovative sensing, holography, and EUV lithography.

A suite of instruments will provide the capability to observe over a spectral range from 0.6 to 28 µm wavelengths with imaging and spectroscopic configurations. The European Space Agency (ESA) contributed two of Webb's four

REFERENCE

M. Ossiander, M.L. Meretska, H.K. Hampel, S.W.D. Lim, N. Knefz, T. Jauk, F. Capasso, M. Schultze. "Extreme ultraviolet metalens by vacuum guiding" *Science* **380**, 59-63 (2023)
doi: 10.1126/science.adg6881abq6948

MEMBRANE PRIMARY MIRRORS FOR LARGE SPACE TELESCOPES

Building large space telescopes and placing them in orbit is a costly and complicated procedure. Envisioning future facilities much larger, and therefore much more sensitive than available nowadays, requires lightweight mirror structures and ways to pack those into space limited launch fairings.

This new polymer membrane approach is very different from typical mirror production and polishing procedures, and could help to solve weight and packaging issues for space telescopes.
Developed over the last years, the mirrors are grown by chemical vapor deposition on a rotating liquid inside a vacuum chamber. While this work demonstrated the feasibility of the method, with the successful fabrication of parabolic membrane mirror prototypes up to 30 cm in diameter, it lays the groundwork for larger packable mirror systems that are less expensive than usual.
For the deposition, monomeric molecules are created that deposit on the surfaces in a vacuum chamber and combine to form a polymer. Commonly used for other purposes, this is the first time, that the process has been used to create parabolic membrane mirrors with the optical qualities necessary for use in telescopes.
The process relies on a well-known basic effect: a rotating container filled with a small amount of liquid forms a perfect parabolic surface – a "mold" that is affordable and can easily be scaled up to large sizes. When the polymer is thick enough, a reflective metal layer is applied to the top and the liquid is washed away.
The thin and flexible optics can be rolled for package and launch, and deployed in orbit. As thin optics is always subject to deformations, and upon un-rolling the mirror will not be in perfect shape, an adaptive restoration method has been developed. By applying local temperature variations, the surface shape can be controlled, based on spatial variable illumination and feedback from a wavefront sensor.

REFERENCE
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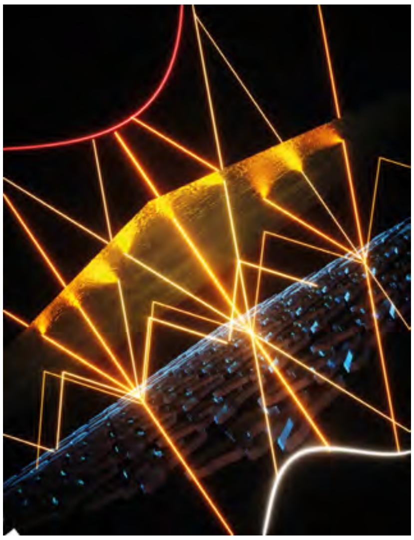
Mathematics at the speed of light

The world's ever-growing needs for efficient computing have been driving researchers from diverse research fields to explore alternatives to the current digital computing paradigm. The processing speed and energy efficiency of standard electronics have become limiting factors for novel disruptive applications entering our everyday life, such as artificial intelligence, machine learning, computer vision, and many more. In this context, analog computing has resurfaced and regained significant attention as a complementary route to traditional architectures.



A tailored silicon nanopattern coupled to a semitransparent gold mirror can solve a complex mathematic equation with light. Image credit: Ella Maru studio.

Optical analog processing refers to the use of light to perform analog computations, as opposed to traditional electronic methods which use electricity. One major benefit of using light to outsource specific computing tasks is that it can operate at much higher speeds than electronic methods, as the computation is performed at the speed of light traveling through very thin nanostructured surfaces called metasurfaces. In addition, optical analog processing can be more energy efficient than electronic methods, since it does not generate heat in the same way that electronic circuits do. This makes it well-suited for use in high-performance computing applications where speed and energy efficiency are important.

Matrix inversions in a jiffy

What kind of mathematical operations would benefit from this dramatic speed-up? One of the most frequent class of problems popping up in many fields, including engineering, science, and economics are linear inverse problems. They are called "inverse problems" because the goal is to invert the process that generated the data to obtain the solution. These typically involve matrix inversions, a rather slow mathematical operation.

Researchers at AMOLF, University of Pennsylvania, and City University of New York (CUNY) demonstrate a thin dielectric nanostructure that performs optical matrix inversion and use it to solve a special kind equation called Fredholm integral equations of the second kind. Using a special optimization technique to design the unit cell of the nanostructured array, called metagrating, they implement the desired matrix multiplication corresponding to the mathematical problem of interest. Next, a semi-transparent mirror is incorporated into the sample to continuously send back the signal to the nanostructures, each time multiplied by the metagrating scattering matrix. This series of matrix multiplications is called Neumann series and it's a useful mathematical trick for approximating the inverse of a matrix.

These results, just published on Nature Nanotechnology, demonstrate the possibility of solving complex mathematical problems and a generic matrix inversion at speeds that are far beyond those of the typical digital computing methods. Indeed, the solution converges in about 349 fs (*i.e.*, less than one thousand-millionth of a second), orders of magnitude faster than the clock speed of a conventional processor.

This new powerful alliance between nanotechnology and analog computing could pave the way for hybrid optical and electronic computing circuitry solving problems of further enhanced complexity at speed and efficiencies that were previously unthinkable.

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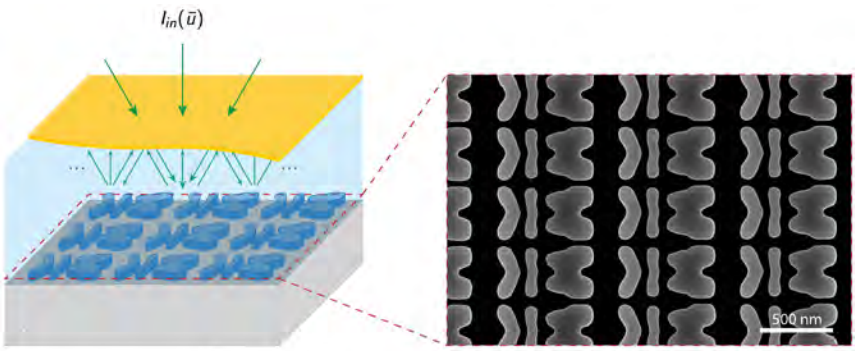
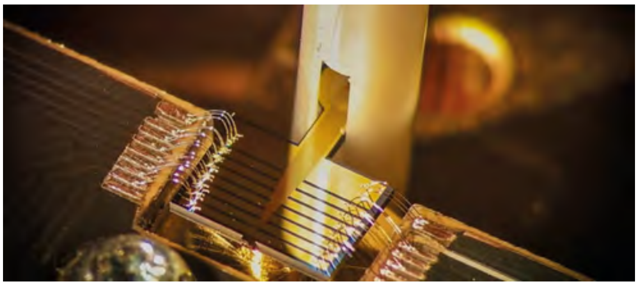


$$g(u) = I_{in}(u) + \int_a^b K(u,v)g(v)dv$$

(left) An input vector (I_{in}) is fed to the system in the form of N plane waves with different complex amplitudes incident along N diffraction channels. The signal interacts repeatedly with a metagrating bouncing back from a partially reflecting mirror, each time multiplied by the metagrating scattering matrix S and therefore building up the terms of a Neumann series of subsequent matrix multiplications required to perform matrix inversion and thus find the solution (*g*) of the integral equation. (Right) Scanning electron microscopy (SEM) image of the patterned Si metagrating.



HIGH-PERFORMANCE DETECTORS FOR PRIVATE COMMUNICATION

Today's methods for private communication are at risk to be cracked in the near future by quantum computers. The solution against this thread is given by quantum key distribution. It uses single photons (particles of light) to encode information and sends them through optical fibers to create a secret key between two parties.

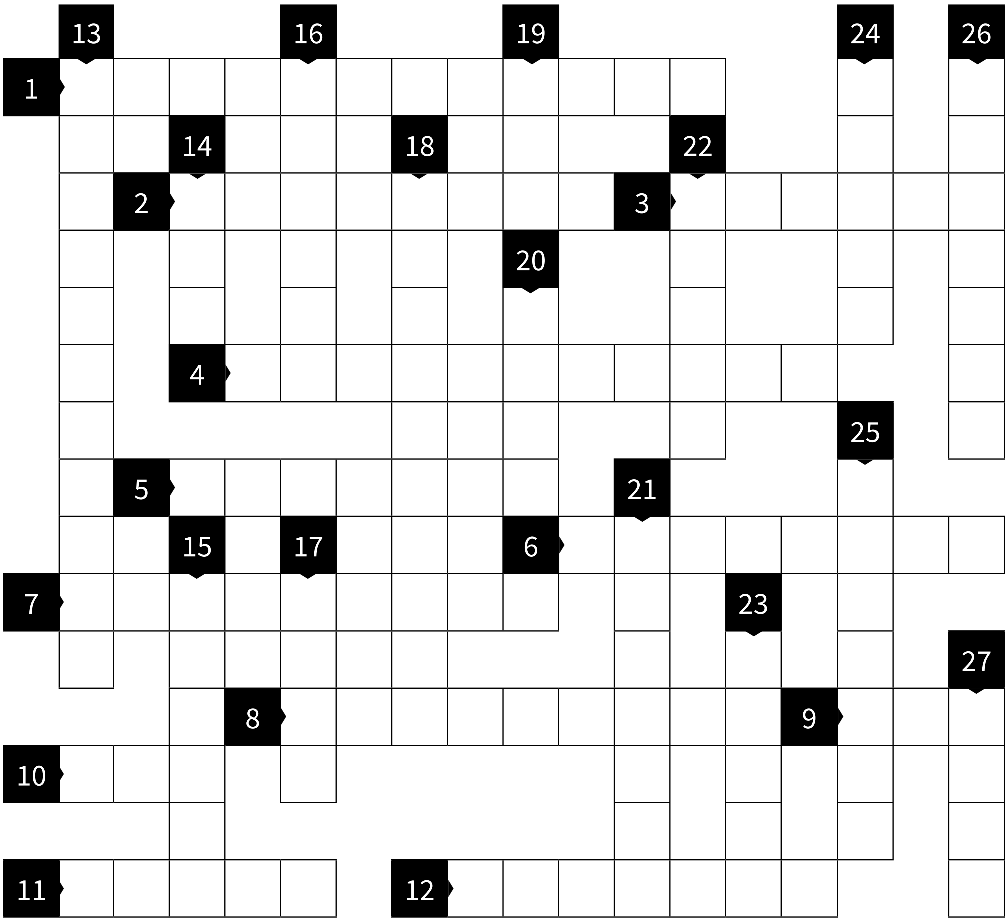
This key is perfectly secure according to the laws of physics. It can be used to encrypt your data online when you do a bank transfer, send messages to friends or just shop online.
While the first quantum key distribution protocol was invented in 1984 by Charles Bennett and Gilles Brassard, the implementation at high rates is still challenging. Nowadays, the sender can generate quantum states at a very high rate, but detecting them at a similar rate is very challenging.
A team of researchers at the University of Geneva and ID Quantique developed a single photon detector to overcome this limitation. Their method for detecting single photons is based on superconducting nanowires. A nanowire is cooled down to less than -272°C. When a photon hits it, it will heat up just slightly and become resistive. The change in resistance can be measured and therefore the photon can be registered. Then the nanowire has to cool down for a certain amount of time of the order of 10ns. During this time it is not able to detect another photon and therefore the maximum rate of detection is limited. The new design from Geneva uses not only one, but 14 intertwined nanowires in a single device. When one nanowire detected a photon, the other 13 are still capable to detect a photon. Moreover, each single nanowire is shorter than for previous designs and recovers more rapidly, hence these new detectors can register photons more than 14 times faster.
The researchers combined their new detector with their high speed QKD system and could achieve a secret key rate of 64 Mbps over 10 km of fiber optic cable. This rate is high enough to stream several 4K movies in parallel or to secure a video conference with several participants. This experiment paves the way for private communication in a future where the quantum computer exists.

REFERENCE

F. Grünenfelder, A. Boaron, G.V. Resta *et al.* Fast single-photon detectors and real-time key distillation enable high secret-key-rate quantum key distribution systems. *Nat. Photon.* (2023).
https://doi.org/10.1038/s41566-023-01168-2

CROSSWORDS
ON METASURFACES AND METAMATERIALS

By Philippe ADAM



SOLUTION ON
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1 Discovered a phase pattern for polarized light
2 Could replace glass lens in the future
3 Pionneer in the field of metamaterials
4 Laser with protected transport modes independant of local atomic arrangement
5 Engineering challenge for MS(*).
6 V-shaped MS exhibits that kind of refraction or reflection
7 Characteristic of the Harry Potter's cloak
8 Effect that allows wavelength "stretching"
9 Multiple quantum well materials for active MS in telecom applications
10 Phase Change Material
11 MS-based Bayer-type colour cell
12 Mathematical characteristics of dielectric constants of MS
13 MS coupled with polariton, enables new forms of light-matter interactions
14 Metal-Isolant-Metal resonant structure
15 Spiral wavefront generated with MS
16 Prefix for Si/Ge structure metasurfaces for wavelength-selective photodetectors
17 Subwavelength dimension to create resonant effects
18 Special functionalities onto the fiber end-facet
19 Novel plasmonic material
20 Metasurface-based special filters
21 Photonic crystals taylor this important parameter
22 Lattice characteristic dimension
23 Optical materials with extremely small losses
24 Tunable parameter for reconfigurable MS
25 Well adapted for fabricating large scale MS
26 Basic principle in wave propagation
27 PolyDiMethylSiloxane

Interview with Konrad von Volkmann, CEO of APE

APE is a company founded in 1992 in Berlin by Edlef Büttner, Jan Popien and Thomas Lindemann and providing products in the field of ultrafast lasers. APE celebrated on November 9th 2022 its 30th anniversary.

What were the motivations of the three founders for creating a new company in the field of ultrafast lasers?

In Berlin, in 1992, after German reunification the job market was challenging. In this surrounding of uncertainty and new beginnings the three founders of APE, a group of young physicists and engineers were determined to launch a company that merged their innovative ideas in optics and electronics. Due to the exceptional ultrafast community present in Berlin, it was an ideal location for their start-up. This start-up quickly evolved into a small-scale manufacturer for scientific optical devices, promoting the first commercially available autocorrelator for ultrafast lasers.

To keep up with the demand for measurement equipment for ultrafast lasers and to create and produce further devices, the company relocated to Berlin-Lichtenberg. APE rapidly became a reliable OEM partner for numerous well-known companies in the laser industry, which propelled its growth. Still, keeping close customer relations and delivering excellent service always was the basis of APE's success.

Can you describe the core of your technology? What are the main scientific fields of application of your products?

APE is focusing on the ultrafast laser market, in particular for the scientific community. Our core products are devices for the generation of tunable pulses, pulse diagnostics as well as for pulse and spectral manipulation.

APE is combining a strong expertise in physics, optics, fine mechanics, electronics and automation. These skills are used for simplifying complex structures of optics and electronics for user-friendly instruments. On the other hand APE is also known for the supply of customized optical systems for various research groups.

Can you comment on the impact of ultrashort laser pulses on science and technology?

We have been directly involved in the spread and facilitation of various applications. Our light sources have extended the range of multiphoton microscopy at many labs in different scientific areas. Through collaboration with Harvard University, APE developed a dedicated light source which made Coherent Anti-Stokes Raman Scattering (CRS) microscopy accessible to non-laser specialists. This label-free imaging technology was continuously improved and is now used in various areas such as cancer research. We also contribute to the relatively new and fascinating field of quantum technologies. For the photonics industry, our laser diagnostic devices are crucial for process monitoring and quality control of ultrafast lasers used in material processing or eye surgery.

Are you focusing your sales efforts in Europe or worldwide?
From the early beginnings of APE, our devices have been distributed globally. A nice example is that our first VIS-light source was installed in Australia. Although ultrafast technology started as a niche market, we recognized early its potential for widespread success and avoided limiting our focus to specific regions. Moreover, the ubiquity of ultrafast networks around the world has contributed to our brand awareness. Currently, we have many regional representatives to supply and support the local markets. Our strategy involves fostering close collaboration, drawing on our expertise, and engaging customers in discussions about complex issues, all to support their work.

Is Europe a great place for photonics?
Indeed, Europe is a great place for photonics and we are proud of being part of it. The reason for this rating is the fact that Europe offers a diverse selection of top-tier universities and research institutes, with ample funding opportunities. Thus it is a huge market for companies as APE focused on scientific customers. Moreover it makes Europe an ideal location for attractive collaborations, often resulting in new products. Many research groups in Europe produce exceptional works, and some have even gone on to establishing successful start-up companies.

How do you evaluate the evolution of photonics? How to increase the spread of photonic technologies and strengthen the companies and market?
As we all can see in numerous examples, photonics is becoming more and more part of our daily life. Each car, every smartphone is equipped with optical systems; diabetics can check their level of blood sugar non-invasively by light... There is many more ideas and dreams, some of them even experimentally proven yet, but the main challenge for entering mass applications consists in mastering the complexity of such schemes. Companies like APE are working hard in making complex technologies accessible to non-specialists and later-on for everybody. With this, we prepare the soil for further growth of photonics in future markets.

How do you imagine the next 20 years for your company and for photonics? Have you identified promising scientific areas for photonic technologies?
Undoubtedly the applications of ultrafast lasers and more general, photonic devices are expanding into more and more areas of research and technology. Thus we will remain committed to contributing to this progress of photonics, as we have done in the past. Let me give you two specific examples we are working on. Our efforts are targeted to bringing CRS imaging to widespread applications, among others histopathology for rapid cancer cell diagnostics. With our systems we also support the development of the 4th generation of quantum applications playing a rapidly increasing role in the coming years.
The particular requirements for APE to sharing the global advancement of photonics comprise a sustainable growth, while preserving innovative power and flexibility, and keeping balance between large series standard production for the laser industry and customized devices and systems for the research community. ●