Photoniques

N°116

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The Newton experiment revisited

EXPERIMENT
The first detection of the CMB

BACK TO BASICS
The geometric phase made simple

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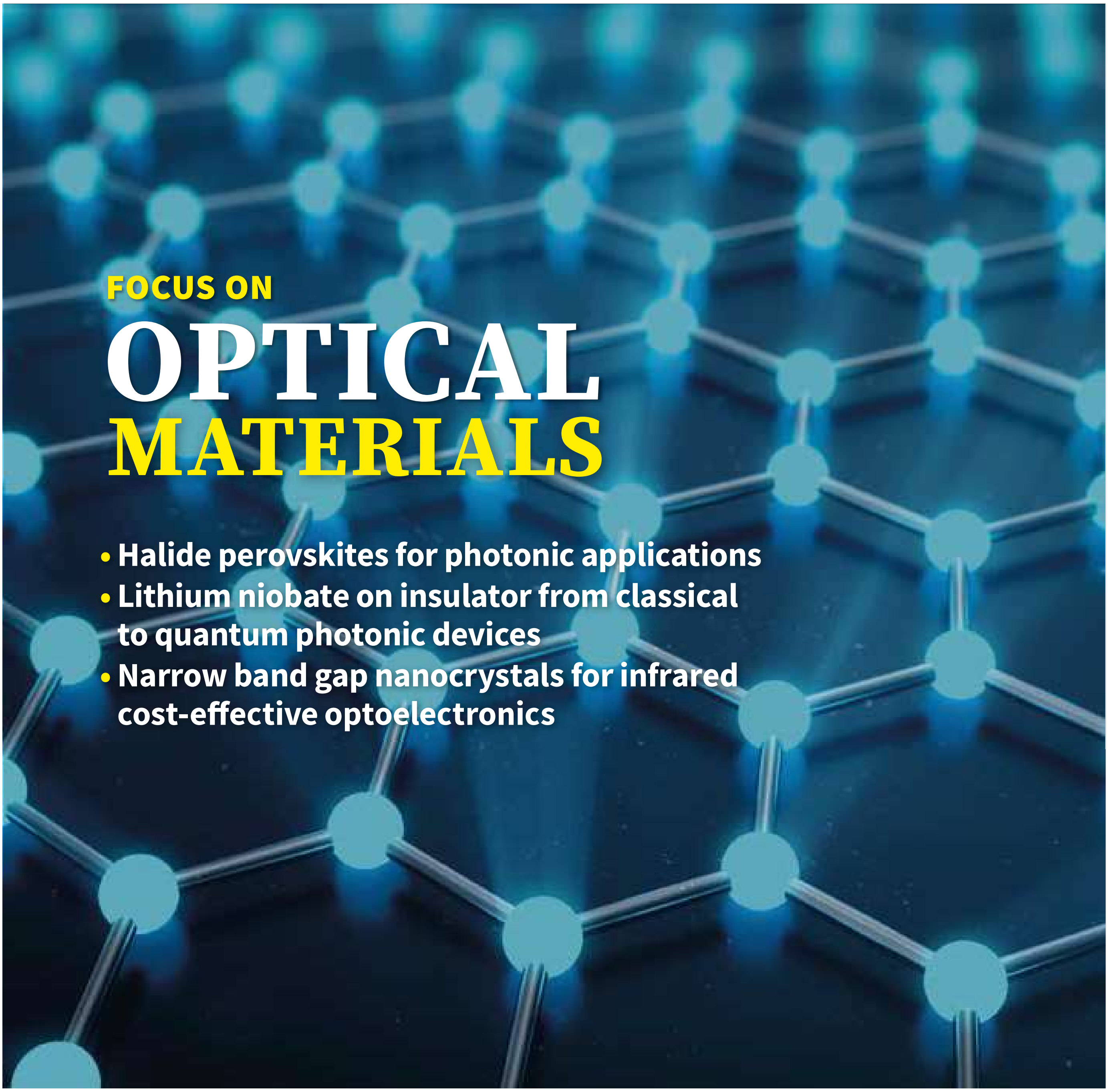

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Editorial

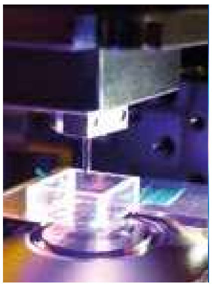
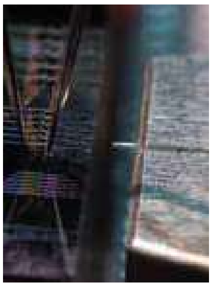
NICOLAS BONOD
Editor-in-Chief

Light, Matter and Entanglement

Optics and material science share a long history of advances and development. The 2022 International Year of Glass reminded us how the development of glass over the different centuries has allowed optics and photonics to explore novel horizons. And the story is not over: this new century has seen a soaring rise of novel materials and an acceleration in discoveries. Low dimensional materials, perovskites, phase change materials, quantum dots, to cite only a few, have opened fresh research domains and attracted a keen and growing interest from a wide scientific community. Besides these novel materials, many efforts have been made to push forward the limits on the control of optical materials at the nanoscale. Integration, tunability, linear and/or non-linear properties and efficiencies, toxicity and affordability are key elements for developing novel optical materials. The long story of entanglement between optics and materials is far from waning and the last decade has even seen a tremendous acceleration of outcomes in this exciting and multidisciplinary field of research. The second quantum revolution, green photonics, the growing needs in energy saving and efficiency along with the demand for cost effective nanostructured optical components will no doubt motivate major advances in optical materials.

Quantum entanglement has aroused the interest of the best physicists of the 20th century and is at the core of the second quantum revolution. The 2022 Nobel Prize in physics awarded to John F. Clauser, Alain Aspect and Anton Zeilinger "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science" is wonderful news for the optics and photonics community. Let me congratulate the three Nobel Laureates for this incredible recognition. It is striking to see that what started as an epistemological discussion between Bohr and Einstein eventually resulted in one of the major scientific breakthroughs of the 20th century. This shows also how fundamental questions can motivate developments in terms of instrumentation and material science and lead, a few decades later, to ground-breaking applications.

In this international issue, we present a zoom article on photonics in Lithuania. This article shows how Lithuania has been building a very solid economy based on optics and laser technologies. The laser and photonics industry has experienced fast economic growth over the last few years and envisages, as an ultimate goal, reaching an impressive 5% of the country's GDP in 2030. Other European countries have recently invested heavily in the photonics sector, both in industry and education, and we will be pleased to publish zoom articles on these countries in the upcoming issues, because photonics is worth it!

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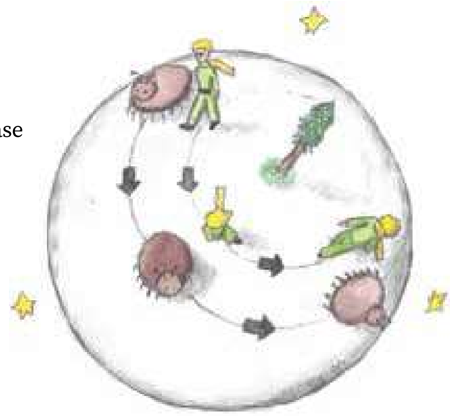

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ARIEL LEVENSON
President of the French Optical Society

"United in diversity" - "Unie dans la diversité" *
A further stage in the SFO-EOS partnership !

This Editorial had been completed when I learned with great joy that the 2022 Nobel Prize in Physics had been awarded to Alain Aspect, jointly with John F. Clauser and Anton Zeilinger. But I immediately asked myself what more I could add to the many superlatives that were already being written about these three great pioneers of quantum optics. But in the context of my role as President of the SFO, my role was clear, and this was to speak of the many activities of Alain Aspect that may perhaps be less well-known to an international readership. In particular, Alain has always been a tremendous supporter of the SFO, and participated from its creation in our COLOQ Club including serving as its President. In addition, he has tirelessly made himself available to any request from the SFO, including as a conference speaker, a panel member, as a member of a prize jury, and as a trusted advisor and mentor to SFO members at all their career stages! Thus beyond my own warmest congratulations, let me add an enormous thank you to Alain on behalf of the French optical community!

In his first interview after the award of the Nobel Prize, Alain declared "It is important that scientists maintain their international community when the world is not doing so well and nationalism is installed in many countries". This is exactly the central message of this editorial!

I am extremely proud to announce that the European Optical Society (EOS) and our Société Française d'Optique, the French branch and co-founder of the EOS, are strengthening their mutual cooperation with the ambition of further contributing to the construction and consolidation of the European coherence in optics and photonics.

Beyond the obvious importance for our academic and industrial communities of conducting exchanges and sharing good practices at the European level, current events sadly remind us of the vital need for the scientific community to contribute to society at large in order to improve international understanding, and to work towards peace.

Among other ongoing actions in this context, I am very happy to announce that the next EOS congress, EOSAM 2023, will be held in Dijon, France from 11-15 September 2023. The venue will be the Dijon Convention Center, the same place that so successfully hosted our own OPTIQUE Dijon 2021 congress with its 660 participants and its 43 industrial stands. Let's do better for 2023! The EOS and the SFO will share the organization of EOSAM 2023, under the guidance of Chairs Patricia Segonds, the new president of the EOS, Emiliano Discrovi, the new incoming president of the EOS, Guy Millot, the Chairman of OPTIQUE Dijon 2021, and Bertrand Kibler who is a well-known and very active member of SFO. The program (under construction) will be as varied as our European optical community, covering a large spectrum of hot topics in photonics.

We are counting on the strong mobilization of the European optical community - on your mobilization - to make EOSAM 2023 in Dijon a fantastic event for scientific exchange and intense academic and industrial networking…

Finally, I would like to take the opportunity of this issue's focus on Lithuanian optics to remember our dear colleague Algis Petras Piskarskas who passed away on 11 June. Algis was one of the most prominent Lithuanian physicists, pioneering the concept and the first experimental demonstration of Optical Parametric Chirped-Pulse Amplification, a technique at the heart of high power ultrafast laser technology. His passing is a great loss for European science.

Photoniquement vôtre
Ariel Levenson
Directeur de recherche CNRS
Président de la SFO

* EU motto: It signifies how Europeans have come together, in the form of the EU, to work for peace and prosperity, while at the same time being enriched by the continent's many different cultures, traditions and languages.

OPTIQUE Nice 2022, a great success


The French optical community mobilization was strong and all the echoes clearly point to the pleasure to be together as well as to the amazing quality of the technical and scientific program.

We are incredibly proud that our colleague Alain Aspect, Nobel Prize in Physics 2022, participated to the whole Congress, and were fascinated by his Plenary lecture, introduced by the Congress Chair Sébastien Tanzilli, on *Nonlocality : from concepts to applications.*

The SFO warmely thanks also all the Plenary speakers: Sophie Brasselet, Jean Dalibard, Frédérique De Fornel, Rémi Carminati, Jérôme Faist, Philippe Goldner, Sophie Kazamias, Aurélie Jullien and Philip Russell as well as Tutorials speakers: Jean-Jacques Greffet, Yannick De Wilde, Vincent Jacques, Emmanuel Beaurepaire, Clément Courde and Pernelle Bernardi.
The videos of these talks are available at www.sfoptique.fr
The next great meeting will be OPTIQUE Normandie 2024 in Rouen. See you all then.

OPTIQUE Nice 2022 in few figures

- √ 635 Attendees
- √ 48 Stands of compagnies in the ecosystem of optics and French photonics
- √ 10 Stands for educational teaching
- √ 184 Posters
- √ 247 Talk
- √ 07H40 Hours of plenary session
- √ 82H20 Hours of specific sessions in parallel
- √ 4 Prizes awarded

AGENDA

■ General Assembly of SFO,
SFO members meetings
20 October 2022 - 10 am to 12 pm
All members of the SFO are invited to vote and participate in this general assembly.

■ WAVINAIRE the third edition
Light control in complex media
december 15, 2022 at 1:30 pm

■ JNOG 2023
SFO Colloque - JNOG Club
INL, Lyon, France
July 5 - 7, 2023

■ Optomechanics & Nanophononics
Chamonix Mont Blanc Valley, France
April 17 - 28, 2023

■ LIDAR summer school SFO International Thematic School
Haute Provence, OHP, France
June 11 - 16, 2023

Waves in complex media
Chamonix Mont Blanc Valley, France
September 17 - 29, 2023

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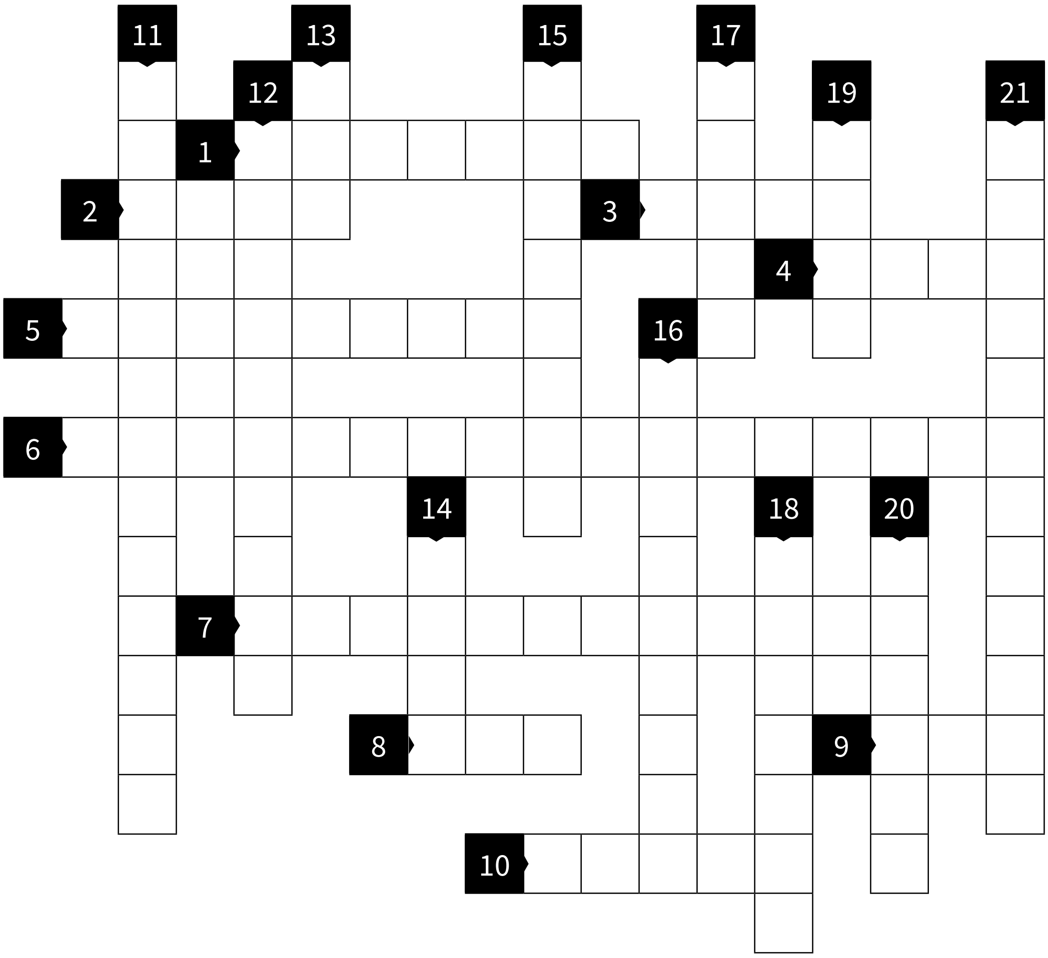
The study of the interaction between photons and phonons is a rapidly developing research field. Initially, it emerged to answer fundamental questions about thermal properties, nanomechanics, and quantum measurements. These questions constitute today the basis for new studies feeding fundamental and technological challenges.
This school aims to overview this interdisciplinary field by treating quantum concepts and effects, simulation, sensors, metrology, and ultra-sensitive detection among other fundamental effects and applications.

CROSSWORDS
ON OPTICAL MATERIALS

By Philippe ADAM



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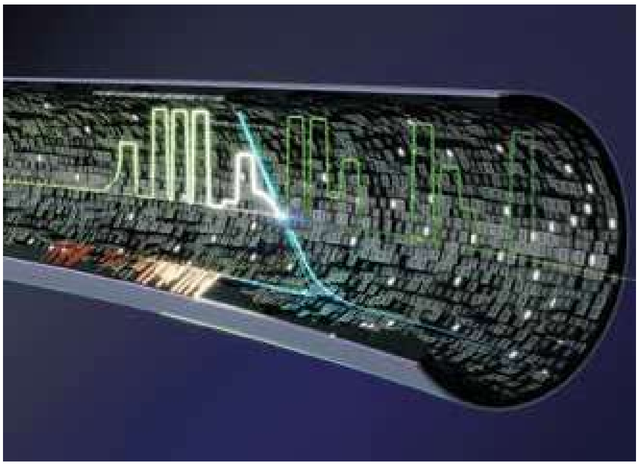
20 Laser emitting by its surface
21 Physicist, pioneer in the field of photonic crystals

TEMPORAL SHRINKING OF OPTICAL DATA PACKETS

Today's world is witnessing an exponential growth of optical data. Dealing with such a massive amount of information requires innovative approaches for stretching or compressing optical waveforms, beyond the bandwidth limitations inherent to conventional electro-optical systems. To this aim, photonic platforms exploiting ultrafast nonlinear phenomena, such as four-wave mixing interactions, have been shown to provide access to extremely large functionality bandwidths. In particular, the temporal magnification of light-waves based on the time-lens concept has been successfully implemented to outperform electronics and has enabled the observation of intricate dynamics previously inaccessible. However, the converse process — the temporal compression of arbitrary light-waves — still remains a challenging functionality that has been largely unexploited so far.

To overcome this fundamental issue, a team of researchers in France and New Zealand (at ICB CNRS laboratory in Dijon and The University of Auckland) have just reported in Nature Photonics, a novel technique enabling the temporal compression of arbitrary optical waveforms with compression factors up to 4 orders of magnitude, far ahead of any results reported so far. This technique was theoretically proposed by Russian scientist Andrey Starodumov in 1996, but never previously achieved in laboratory. In their experiments, Fatome and co-workers successfully demonstrate Starodumov's compression scheme using a counter-propagating degenerate four-photon interaction occurring in birefringent optical fibres. They report extreme temporal compression of optical waveforms by factors ranging from 4,350 to 13,000, including non-trivial on-demand time-reversal capability. This approach is scalable and offers great promise for ultrafast arbitrary optical waveform generation and related applications.



Crédit: Loïc Brunot

Temporal compression of an optical data packet through a nonlinear focusing mirror created by a counter-propagating readout pulse.

REFERENCE

N. Berti, S. Coen, M. Erkintalo, and J. Fatome, "Extreme waveform compression with a nonlinear temporal focusing mirror," Nat. Photon. In press (2022). https://doi.org/10.1038/s41566-022-01072-1

Unipolar quantum optoelectronics for high-speed free-space optics in the mid-infrared

Free-space optics (FSO) offer an attractive alternative for transmitting high-bandwidth data when fibre optics is neither practical nor feasible. This technology has emerged as a strong candidate with a large potential of applications from everyday life broadband internet to satellite links. The availability of high-quality transmitters and detectors operating in the near-infrared window makes the 1.55-micron optical wavelength a natural choice for free-space optics systems. Nevertheless, the mid-infrared region in particular between 8-12 microns can also be considered especially because of its superior transmission performances through inclement atmospheric phenomena, such as fog, clouds and dust.

In a recent work, a research team at Institut Polytechnique de Paris together with researchers from Ecole Normale Supérieure in France, made substantial progress in FSO communications using unipolar quantum optoelectronic (UQO) devices. In the experiment, the output of a quantum cascade laser was modulated by a stark effect external modulator and passed through a Herriott cell to simulate a light path with an effective length of over 30 m. Two different detectors, namely a quantum well infrared photodetector and a quantum cascade detector were tested in the receiver side. As reported in Advanced Photonics, they achieved low bit error rates even at high speeds, showcasing the potential of this technology for long-range communication links. This work marks a key step towards the realization of high-speed FSO telecommunication links that are resistant to weather conditions by adopting UQO devices. Further developments in the integration of UQO devices can help to bring high-speed Internet to challenging locations.

REFERENCE

P. Didier, H. Dely, T. Bonazzi, O. Spitz, E. Awwad, É. Rodriguez, A. Vasanelli, C. Sirtori, and F. Grillot, "High-capacity free-space optical link in the midinfrared thermal atmospheric windows using unipolar quantum devices," Adv. Photonics **4**, 056004 (2022)

A Nobel prize
for Alain Aspect, John Clauser and Anton Zeilinger

Jean DALIBARD, Sylvain GIGAN*
Laboratoire Kastler-Brossel, CNRS, ENS, Collège de France, Sorbonne Université, Paris, France
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The Nobel committee announced on October 4th that Alain Aspect, John Clauser and Anton Zeilinger were awarded the Nobel prize *"for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"* [1]. In this article, we want to put the Nobel Prize in perspective, and replace the three laureates' contribution in their historical context.

https://doi.org/10.1051/photon/202211623

The development of Quantum Physics during the 20th century is certainly one of the most extraordinary intellectual adventures of mankind. This theory has deeply modified our conception of the world, and it has had in parallel a strong impact on our life with its numerous applications: transistors, lasers, integrated circuits. One cornerstone of quantum science is the concept of photons, introduced in 1905 (see [2]) and one of the most prominent features of the quantum formalism is *entanglement* (a term coined by Schrödinger). Einstein, Podolsky and Rosen pointed out its subtle and paradoxical character in a celebrated paper. They used this notion to demonstrate the conflict between quantum mechanics and a realistic local theory of the physical world. Moreover, to the question "Can a quantum-mechanical description of physical reality be considered complete?" the answer of Einstein and co-authors was negative, and their conclusion was incompatible with the "orthodox" point of view, advocated in particular by N. Bohr. This conflict between Einstein and Bohr lasted until the end of their lives; it remained a philosophical question until the work of J.S. Bell in 1964. Bell proved that the correlations between any pair of physical quantities, when calculated within a realistic local theory, are constrained by a specific inequality, which can be violated by quantum mechanics. From this moment, the above-mentioned conflict was no longer a matter of taste, but it became a quantitative question that could be settled experimentally.

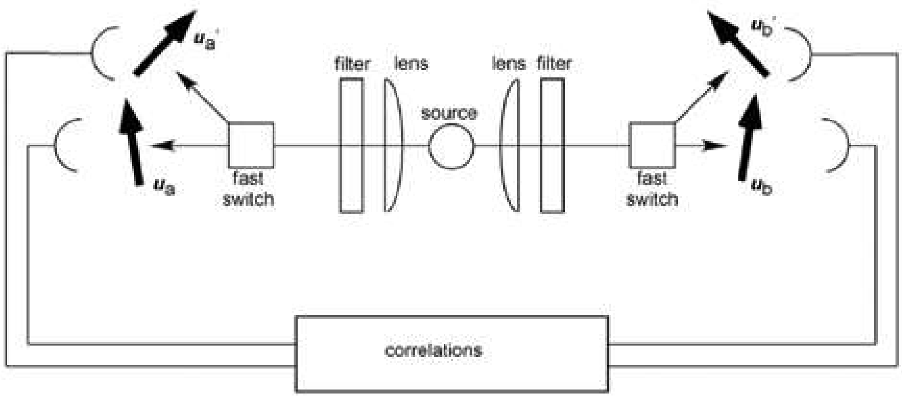

Figure 1: Concept of the Bell Inequality violation experiment designed by Aspect: a source of entangled photons (center) distributes each photon of the pair to four detectors (left and right), where fast switches enable measurements over different sets of polarizations.

This is when **John Clauser** enters into the story : first, as a graduate student at Columbia University, when he found a modified version of Bell's theorem with an inequality that can be applied to practical experiments (using pairs of entangled photons and measurement over various polarizations), then in 1972 when he performed with Stuart Freedman at the University of Berkeley the first experiment that conclusively showed a violation of Bell's inequality by more than 5 standard deviations [3]. This experiment, which was using a lamp to excite the atoms (pre-laser era!) was a tour-de-force with a data acquisition time of 200 hours. The result of Clauser was later confirmed with a similar experiment by Fry and Thompson in 1976.

In the meantime, starting in 1974, **Alain Aspect** engaged in a program in which the independence between the polarization measurements on each photon of the pair was enforced by a relativistic argument. In these experiments realized at Institut d'Optique in Orsay, the setting of each polarizer was changing rapidly in time, so that there was no possibility that an information about this setting is exchanged between the two detection channels: The choice of the measurement basis for the photons polarization was done well after the pair of entangled photons was created and the locality condition, which is an essential hypothesis of Bell's theorem, becomes a consequence of Einstein's causality that prevents any faster-than-light influence. This resulted in the publication in 1982 of two key articles [4], to which one of us (JD) was lucky to be associated, together with Philippe Grangier and with Gérard Roger -a skilful engineer. **Anton Zeilinger** realized in Innsbruck in 1997 the first quantum teleportation experiment, followed in 1998 by the third key experiment on Bell inequality violations with photons, by using ultrafast and random settings of the analyzers, thus enforcing so-called *"strict Einstein locality conditions"* [5]. As a postdoc in Vienna, where the group of Anton Zeilinger moved in the early 2000, one of us (SG) was at one of the epicenters of this revolution, and witnessed the vitality of the field, and the breadth of its application, spanning also well beyond optics, to atoms, superconductors and mechanical systems. Although very little doubts remain about local realism, the quest to experimentally close all potential loopholes continued, and remains to date an important topic, both as a fundamental subject, but also of practical importance, as pointed out by Alain Aspect in his 2015 perspective paper [6].

Beyond their crucial contributions for which the prize was awarded, one can also stress the importance and diversity of the three Laureates's other contributions to quantum science, for instance for Alain Aspect, the Bose-Einstein condensation of Helium or the Anderson localization of Atoms, to name just two salient examples. Another lasting legacy is the many outstanding PhD students and postdoctoral researchers that they formed over decades, and who continue to dynamize the field. The impact of the findings of these three physicists over our vision of the world is tremendous and it goes actually far beyond the Physics community. Philosophers and epistemologists have now incorporated all these results in their own works and concepts. The hope of Einstein for a local and realistic description of the physical world has failed, and quantum mechanics is in perfect agreement with experimental results on

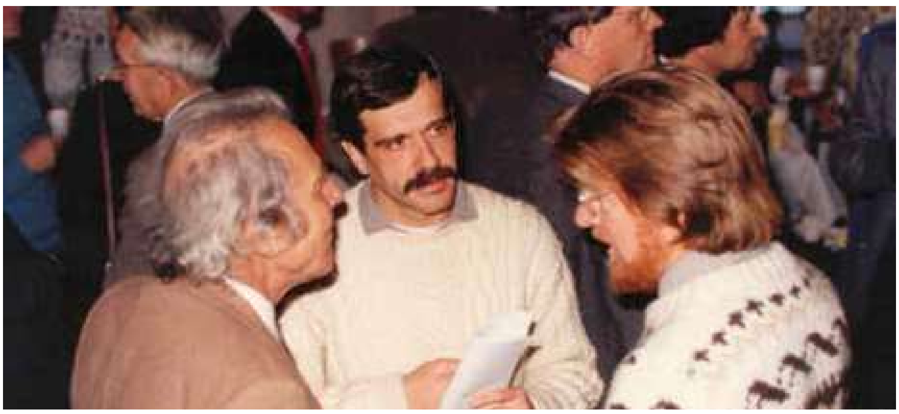

Figure 2: At a conference honoring the memory of Alfred Kastler in 1985, photo of A. Messiah, A. Aspect and J. Bell, discussing. ©Laboratoire Kastler-Brossel.

this matter. The results of Aspect, Clauser and Zeilinger are now at the core of several modern textbooks in quantum mechanics.

These seminal works crowned by the Nobel prize did not remain limited to closing a philosophical debate or to textbooks, but were rapidly followed by a stream of applications of entanglement, and to the birth of a blooming field, **quantum information processing**, that spans from teleportation, to quantum cryptography, to quantum computing. All these feats rely heavily, at their core, on the phenomenon of quantum entanglement and on non-locality. Quantum information processing is now a very active field worldwide, involving thousands of groups, and poised to revolutionize the way we communicate and compute. Quantum communications, be it on deployed fibered networks spanning across countries (and enabled by meshes of "quantum repeaters"), or along free-space link through satellites, are already a reality for unconditionally-secure cryptography. Quantum computing has recently demonstrated over different platforms the so-called "quantum advantage": its capacity to perform some specific calculations with an exponential speedup over conventional computers. While a large-scale universal quantum computer remains years away, the world is already getting prepared for the "post-quantum" era, where quantum technologies may render several of our current approaches to information processing obsolete.For example, it is reasonable to expect that quantum simulators could soon be used to solve currently intractable problems in chemistry and physics, with crucial applications such as the design of new drug molecules.

It remains a humbling lesson to witness how such a profound technological and societal change may stems from sheer curiosity-driven research : from the deep philosophical considerations of the founders of quantum mechanics, later formalized by John Bell into measurable quantities, and ultimately to the experiments imagined by Alain Aspect, John Clauser and Anton Zeilinger.

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SOME KEY ARTICLES RECENTLY PUBLISHED IN PHOTONIQUES:

C. Fabre, Photoniques **107**, 55 (2021)

B. Vest et L. Jacubowiez, Photoniques **113**, 26 (2022)

SEE ALSO:

T. Van Der Sar, T. H. Taminiau and R. Hanson, Photoniques **107**, 44 (2021)

Frustrated total internal reflection: the Newton experiment revisited

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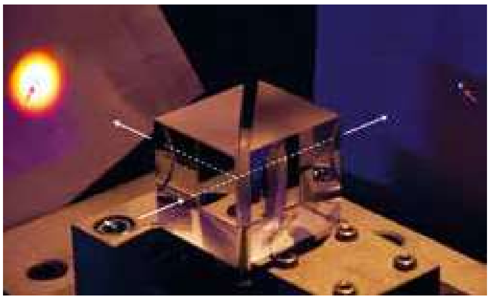

https://doi.org/10.1051/photon/202211632

Three centuries ago, Isaac Newton reported the experimental observation of the tunnelling of a light ray between two prisms separated by a small gap once one of them was shinned in total internal reflection. This article describes a modern revisit of this seminal Newton's experiment, generally known as the Frustrated Total Internal Reflection. This experiment was created in the framework of a series of lectures about near-field optics and nanophotonics for Master students. During a 4h lab work session, the students are running the experiment to evidence and quantify the evanescent wave on top of a glass prism once illuminated above the critical angle.

Any bachelor student who studies optics and electromagnetism at University knows that illuminating a prism under total internal reflection results in the generation of an evanescent wave on top of it. Near field optics, which refers to the research field on evanescent waves and their related applications, has grown amazingly since 30 years thanks to the rapid progress of nanotechnologies. Primarily restricted to the applications in subwavelength imaging by scanning probe microscopy in the late 90s and earlier in evanescent couplers for waveguide optics, evanescent waves have widely spread to the field of nanophotonics and plasmonics where they contribute to create the original properties of artificial optical materials such as metamaterials, metasurfaces or photonic crystals. Nowadays, numbers of active and passive optical systems are taking benefits of these evanescent waves such as for fingerprint recognition, tactile screens and promising cutting edge new technologies for AR/VR vision which will reach the market in a near future.

The first direct description of an optical experiment involving an evanescent wave is attributed to Isaac Newton in his seminal book *"Opticks: or, a treatise of the reflections, refractions, inflections and colours of light"* [1]. In this so-called "Frustrated" [2] Total Internal Reflection (FTIR) experiment, Newton considered two glass prisms brought together so that they do not fully touch, one of them being illuminated under total internal reflection and he wrote in Book 3: *"For the Light which falls upon the farther surface of the first Glass where the Interval between the Glasses is not above the ten hundred thousandth Part of an Inch (2.54µm), will go through that Surface, and through the Air or Vacuum between the Glasses, and enter into the second Glass"*. The theoretical background to explain this phenomenon was missing when Newton did these observations and it has been explored later on both experimentally and theoretically by Fresnel and many others. More details on attempts and advances on this subject throughout history are available in an article written by E. Hall [2] in 1902 which provides references to related works in the XVIIIth and XIXth centuries, and also in a review paper by Zhu and coworkers [3] in 1986 which makes the link to the XXth century. Because FTIR appears for very small distances •••

HALIDE PEROVSKITES FOR PHOTONIC APPLICATIONS

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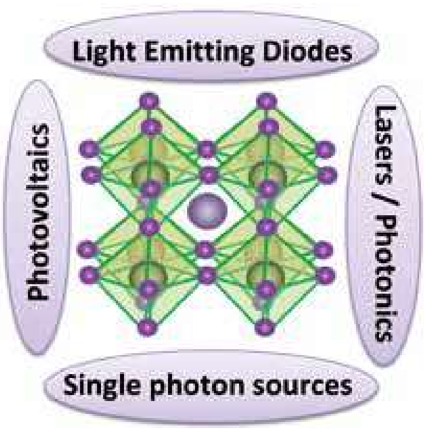

Halide perovskites are a new class of semiconductors showing an incredible set of physical properties well-suited for a large range of opto-electronic applications. These physical properties can be easily tuned and adapted to the intended application by modifying the composition and the size of the material. Additionally, these materials are solution-processed at low temperature and ambient pressure, and contain earth-abundant elements. However, some important challenges remain: the presence of lead and the stability. In this paper, we present some outlines of these materials in several fields of opto-electronics, *i.e.* photovoltaics and light-emitting devices, such as LEDs, single-photon sources, lasers, and photonics.

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ABX$_3$ perovskites constitute the oldest families of crystals described by crystallography: the calcium titanate CaTiO$_3$ was named a "perovskite" by the German mineralogist Gustav Rose around 1839 in honor of the Russian mineralogist Lev Alexeïevich Perovski. Since then, all compounds with ABX$_3$ stoichiometry are called perovskites. Since 2009, the family of the halide perovskites is at the origin of a dazzling success in the field of photovoltaics shortly followed by outstanding results in the field of optoelectronic technologies: for this family, A is an organic (inorganic) monovalent cation such as methylammonium, formamidinium, (Cesium), B is a divalent metal usually lead, and X is a halogen such as I, Br or Cl (figure 1).

A phenomenal enthusiasm of the international community has followed the first encouraging results [1] to optimize the material itself and the perovskite-based devices and to understand the physical properties of this new class of semiconductors. Very rapidly, it appeared that halide perovskites have an impressive number of advantages which explain their success story [2]: an appropriate and adjustable bandgap which