N°122

Photoniques

LIGHT AND APPLICATIONS | EOS & SFO JOINT ISSUE

40 YEARS OF SFO
The intangible heritage of French optics

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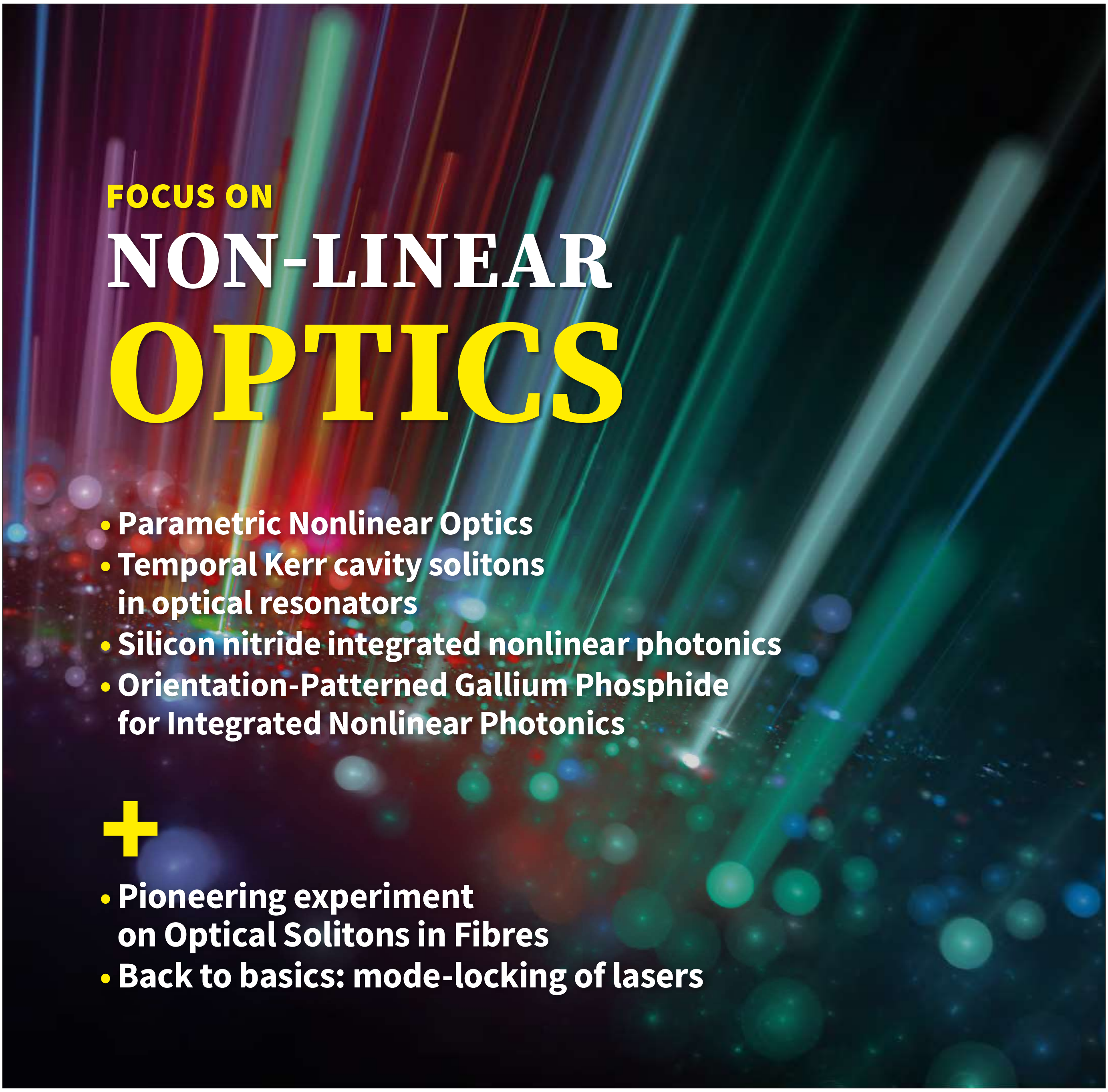

FOCUS ON

NON-LINEAR OPTICS

- Parametric Nonlinear Optics
- Temporal Kerr cavity solitons in optical resonators
- Silicon nitride integrated nonlinear photonics
- Orientation-Patterned Gallium Phosphide for Integrated Nonlinear Photonics

+

- Pioneering experiment on Optical Solitons in Fibres
- Back to basics: mode-locking of lasers

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Editorial

NICOLAS BONOD
Editor-in-Chief

Light, Everywhere, Every Time!

Light was everywhere during the announcement of the 2023 Nobel Prizes in Physics and Chemistry on October 3rd and 4th, honoring pioneering works in generating attosecond pulses and synthesizing quantum dots. To celebrate these Nobel Prizes and honor their laureates, this issue features two articles dedicated to these outstanding achievements in Physics and Chemistry. The 2023 awardees consolidate an impressive series of Nobel prizes based on light science and technologies, further highlighting how Light is a fertile topic and its interaction with matter a source of major scientific breakthroughs.

Nonlinear optics is an essential part of this exciting domain of light-matter interactions. It took only a few months after the development of lasers for the first works on nonlinear optics to emerge. It was reported as early as 1961 how a second harmonic signal in the UV spectrum can be generated by focusing a ruby laser beam onto a quartz crystal. Since these pioneering works, nonlinear optics has evolved into a cornerstone of photonics. Nonlinear optics is ubiquitous in photonic technologies, from laser chains to optical fibers and integrated circuits, to generate light sources with increasingly rich spectra and finer temporal responses. This special feature proposes no less than four articles dedicated to the latest advances in nonlinear optics, covering areas from temporal Kerr cavity solitons, Parametric Nonlinear Optics to integrated photonics on silicon nitride or patterned gallium phosphide technology.

It also only took a short time for mode-locking to be proposed after the advent of lasers, notably through the pioneering works from Bell labs published as early as 1964. Delve into this key concept in optics for generating ultrashort light pulses in the 'Back to Basics' section with the article 'Mode-locking of Lasers.' Another major outcome in nonlinear optics was the discovery of optical solitons. To celebrate the fiftieth anniversary of this discovery, this issue includes an article on the history of solitons in optical fibers, from 1973 to nowadays.

The advent of lasers propelled optics into a new era. But far from waning, the scientific and technological fields of optics and photonics continue to witness an intensified growth. At every meeting, exhibition, and conference, we can feel a strong dynamism and enthusiasm among photonics stakeholders. Let us communicate our passion and enthusiasm to students and younger generations, so that they have the opportunity to be trained in this fascinating science and to contribute in turn to advancing knowledge and broadening applicative domains in order to bring Light, Everywhere, Every Time!

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ARIEL LEVENSON
President of the French Optical Society

We are such stuff as dreams, and our history, are made!

This editorial had been completed when I learned with photonic joy that the 2023 Nobel Prize in Physics had been awarded to Pierre Agostini, Anne L'Huillier and Ferenc Krausz for the adventure of tiny temporal, attoseconds, light pulses, and in chemistry to Moungi Bawendi, Louis Brus and Alexei Ekimov for the adventure of tiny light emitters, controlled by quantum confinement. Congratulations to the Nobel Prize winners with a special thought for Anne and Pierre.

As many of you will already know, the EOSAM was held in Dijon, and this year saw a new model of collaboration with a national member society, our SFO. I would like to warmly thank EOS's Presidents, Patricia Segonds, Gilles Pauliat and Emiliano Descrovi for their trust and confidence. Beyond the impressive numbers, I especially appreciated the quality of scientific exchanges. Hats off to the General Chairs, Bertrand Kibler and Guy Millot (ICB) - the success of EOSAM 2023 owes a lot to them. The distinction of our colleague Sébastien Tanzilli (INPHYNI), as EOS Fellow was also a great moment.

In the context of our 40th anniversary we publically launch the PÉPITES project. A program dear to my heart devoted to the preservation of the memory of our rich and diverse community. You can learn more in the article in this issue co-authored with John Dudley (FEMTO-ST). PÉPITES began in a moving way during the Gala dinner in Dijon, where we brought together SFO historical personalities. It was a very touching moment and showed our commitment to continue our service to the optical and photonic community.

2024 is also going to be a rich year. We look forward to seeing you in July at our major event, OPTIQUE Normandie.

Photoniquement vôtre
Ariel Levenson,
President of SFO
Directeur de recherche CNRS

PATRICIA SEGONDS
President of the European Optical Society

A very successful EOSAM 2023 organized with SFO

On behalf of the Board of Directors of the European Optical Society, EOS, I would like to acknowledge Ariel Levenson, President of the SFO, the French Branch of EOS, for his strong support to the organization of the EOS Annual Meeting. Thanks to two exceptional general chairs, Bertrand Kibler and Guy Millot, EOSAM 2023 turned out to be a fantastic moment to exchange results and ideas and catch up with international colleagues. EOSAM is the ideal framework for researchers aiming at a comprehensive overview of the latest results in different fields of optics and photonics, as presented within many Topical Meetings (TOM). Excellent Plenaries, Focused Sessions, Tutorials and Industrial Sessions completed the high-quality dissemination offer.

Over 500 participants could attend the conference in Dijon in beautiful Burgundy. Traditional meals with local wine, cheese and croissants made lunch and coffee breaks enjoyable. The conference dinner provided a friendly atmosphere with a fantastic music group for entertainment. To follow up with some of the latest findings presented at EOSAM 2023, a topical issue has been launched in our open access Journal of the European Optical Society, JEOS:RP. Extended papers covering both fundamental and applied topics are welcome for submission. They will have to add a significant extra value to the conference proceedings, and will be subject to the standard peer review processes as for regular JEOS:RP articles. JEOS:RP publications are indexed in major databases. Acceptance times are short and authors retain copyright. EOS members benefit from significant discounts on APCs.

In 2024, EOSAM will be held in Napoli between 9 and 13 September 2024! It will be organized with the Società Italiana di Ottica e Fotonica, SIOF, the Italian branch of EOS. Visit https://www.europeanoptics.org/ to discover all the benefits EOS offers and how to strengthen your relationships with your peers ! Become a member of one of our National Optical Societies and you will be an EOS member.

Patricia SEGONDS, President of EOS
Professor at Grenoble Alpes University

Welcome to the International SFO Thematic School 2024

Thermics & Nanophotonics

April 28 / May 03 – 2024

The Houches Physics School, Chamonix Mont Blanc Valley France



The Houches School of Physics, founded in 1951 by physicist Cécile DeWitt-Morette, offers high-quality education in contemporary physics in an idyllic setting designed to foster reflection. Beyond formal classes, informal idea exchanges during meals or mountain hikes have given birth to new avenues of exploration, fruitful collaborations, and significant scientific advancements. Some young students of the School have become illustrious scientists, such as Pierre-Gilles de Gennes, Claude Cohen-Tannoudji, and Françoise Combes, passing on their knowledge to the School's students in turn.

The SFO, the French Society of Optics, continues this tradition and invites you to participate in the "Thermics & Nanophotonics" school. Joining this thematic school offers a unique opportunity to learn, share, and connect with top leaders in the field of controlling thermal emission and the reciprocal phenomenon of electromagnetic radiation absorption : Natalia DEL FATTI (ILM – FR), Jean-Jacques GREFFET (IOGS - FR), Shanhui FAN (STANFORD - USA), Pramod REDDY (UNIV. MICHIGAN - USA), Philippe BEN ABDALLAH (IOGS - FR), Giulia TAGLIABUE (EPFL - CH), Angela VASANELLI (ENS PARIS – FR), Esther ALARCON-LLADO (AMOLF – NL), Rémi CARMINATI (INST. LANGEVIN/IOGS - FR), Romain QUIDANT (ETH – CH). The development of metamaterials and complex media has resulted in remarkable advancements in heat-light conversion and transfer, driven by light-matter interactions at the subwavelength scale. The participants will explore applications in a wide range of fields, including heat management, energy harvesting and conversion, sensing, imaging, and the development of novel sources and detectors.

We expect 70 participants from over 20 countries.

Application deadline (short motivation letter + CV): December 15, 2023 www.sfoptique.fr

LightBox LE KIT PÉDAGOGIQUE DE PHOTONIQUE

The LightBox is part of the Année de la physique 2023-2024 and International Day of Light.

The LightBox, with more than 276 educational kits distributed worldwide, over 51 completed projects, and over 20 scientific advisors helps the implementation of educational projects. LightBox is a partnership between the SFO Education Commission and AtoutSciences.

OPTIQUE NORMANDIE 2024

01 - 05 july 2024 – Rouen – France
More than 600 attendees
www.sfoptique.fr

From Nano-photonics to Exoplanets, from Quantum Processing to Tissue Imaging, from Integrated Photonics to Doped Optical Fibers, and from Photonic gaps to Gender gaps, OPTIQUE Normandie 2024 will encompass all the hottest areas of Photonics.

Already confirmed plenary speakers : Alberto AMO, Marwan ABDOU AHMED, Camille BRES, Anne Marie LAGRANGE, Philippe LALANNE, Sandrine LEVEQUE-FORT, Isabelle REGNER, Pascale SENELLART, Réal VALLEE.

Exhibition

Explore the 3-day Optics and Photonics Exhibition in Rouen in France to connect, share innovations, and foster collaborations. Engage with exhibitors to discover cutting-edge designs and solutions. This event gathers researchers, engineers, and buyers, advancing technical knowledge and networking.

Participate in the industrial Workshops

Discover an engaging industrial workshop led by renowned technology experts. Tailored for engineers and researchers, this interactive event allows you to put your skills into practice. Dive into the action and get hands-on with cutting-edge technologies for an unforgettable experience!

Join our collective members and be part of this major event as an exhibitor:

ALPAO, AERODIODE, COHERENT, DIMIONE SYSTEMS, GLOPHOTONICS, EXAIL, EXFO, FC EQUIPMENTS, HAMAMATSU, IMAGINE OPTIC, FC EQUIPMENTS, LUMIBIRD, MENLO SYSTEMS, OBS FIBER, OPTON LASER INTERNATIONAL, OPTOPRIM, OXXIUS, PHASICS, SILENTSYS, THORLABS, VON ARDENNE, WAVETEL, 2BLIGHTING, ...

Interview with Basil Garabet, CEO of NKT Photonics

NKT Photonics is a company providing fiber lasers and photonic crystal fibers.

How and when was NKT Photonics founded?
NKT Photonics originates as spinouts from the Technical University of Denmark funded by NKT Holding, a company founded in 1891 in Denmark that was created to construct cables for Denmark's electrification. The company has grown to become a major company in Denmark's industrial landscape, specializing in electricity, power, and telecommunication cables. In the 1980s, NKT's venture into optical cable production set the stage for a transformative journey. Notably, the collaboration between NKT and AT&T resulted in LYCOM, later assimilated into Lucent Technology.
NKT became a large holding company acting as an incubator for small companies, notably Crystal Fibre and Koheras. These two companies were pioneers in the field of photonic crystal fibers and fiber lasers, and, in 2009, merged to establish NKT Photonics. Amid this evolution, additional acquisitions further solidified NKT's presence. My role in 2015 involved unifying these diverse elements and steering the company toward a paramount position in the photonics realm. Now, the NKT conglomerate is distilled to two key entities: NKT Cables (a publicly traded company) and NKT Photonics. NKT Photonics has recently been acquired by Hamamatsu of Japan, this acquisition awaits approval from the Danish government.

Can you describe the core of your technology?
At our core, we are trailblazers in the realm of photonic crystal fibers (PCFs). Initially, the notion was for

NKT to morph into a telecommunications entity with PCFs at its heart. Koheras, a company developing fiber lasers, came into the picture. Ultimately, NKT's merger of Koheras and Crystal Fibre solidified our focus. Our bedrock revolves around PCFs and lasers derived from them. This translates into the development and commercialization of supercontinuum lasers (the world's largest supplier), single-frequency lasers, and ultrafast lasers. Moreover, the acquisition of the Swiss firm Onefive a few years ago augmented our expertise with solid-state laser technology.

Where are your production facilities situated?
Currently, our production landscape comprises several nodes. Our ultrafast lasers grounded in solid-state technology are crafted in Zurich. For aerospace and defense applications, encompassing multi-kW lasers, production transpires in Southampton. Meanwhile, all other products, including PCF ultrafast lasers, single-frequency lasers, and supercontinuum lasers, are manufactured in Denmark.

What are the primary applications of your products?
We are operating in 4 segments: biomedical imaging and life science, quantum and nano technology, aerospace & defense, industry. Bioimaging & life science is the segment that features the fastest growth while the industrial segment is our largest market. Life science encompasses fluorescence imaging, high-resolution microscopy and ophthalmology with lasers for cataract surgery. The industrial area includes optical tools for semiconductors (e.g. metrology, lithography, quality control). Semiconductor industry operates 24|7 and requires reliable and stable products. Quantum nanotechnology is the most disruptive technology with a very dynamic scientific community involved in making the transition from fundamental science to applications. Nanotechnologies in general are very interesting for our products for characterizing nanomaterials such as 2D materials, quantum dots, plasmonic nanostructures with supercontinuum sources. Within the defense sector, we are mainly focusing on directed energy solutions. This includes multi kW fiber lasers and high-power fiber delivery for the effectors as well as target tracking lasers. Finally, we are participating in projects for space applications mainly involving systems for satellite communication.

What percentage of your budget is allocated to research and development?
Research and development constitute a substantial commitment, ●●●

NKT Photonics headquarters in Danemark

with approximately 20% of our budget channeled into these critical endeavors. Our focus remains on innovating new products aligned with our core technology, predominantly centered around photonic crystal fibers.

How do you identify the potential application areas for your products?

The scalability is a key parameter for identifying new markets. This explains why we are fully involved into quantum technology for instance, since this market is growing fast and will be a key part of the future technology in a wide range of applications. It also matches our product and technology capabilities very well, enabling us to develop unique solutions for that market. We do not aim at covering all the applications of photonics and do not want to invest into markets where other companies are well implanted. We like to be pioneers, to be the firsts. This explains why we do not do cutting, welding machines for example, since these markets are too crowded.

Do you collaborate with academic institutions and research centers?

Given the inherently innovative nature of our products, we are running several PhD programs with different universities. We have established collaborations in Denmark, UK, and Germany.

Are you focusing your sales efforts in Europe or worldwide?

Our market landscape extends worldwide with obviously emphasis in Europe and US. The acquisition by Hamamatsu will open novel doors in Asia. The largest market remains Europe that represents more than 50% of market.

You currently serve as the President of EPIC. What strategies can be implemented to enhance the photonics industry in Europe?

The difference between Europe and US/Asia is that Europe is very fractured. There are many countries that contribute to different areas in photonics and it is a problem. We believe there are not enough investments in photonics in Europe. There are a lot of talented researchers, but many leave Europe.
In EPIC, we are trying to foster the investments and to keep this great technology in Europe. We do not manage to keep leaders in a technology and we need to reverse that trend. The European government (including Denmark) invests less in high technology -including photonics- than agriculture.
EPIC is already good for networking. It is a very efficient industrial organization for bringing different companies together). If we just do that, that will be great, but we can go further by increasing investments in education and collaborations between countries. We need to allow photonics to move much faster than it did in the past. Former people involved into EPIC governance did the same thing in the past. We are just continuing the progress.

How do you envision the next two decades for your company and the global photonics market?

Regarding the company, it has been growing very fast and became a major player in the market. With the emphasis in R&D, we want to become a major company in the different markets in which we are involved. We want to push in the areas where we are in while keeping our eyes open for novel opportunities. Regarding the overall market of photonics, it will gain in maturity with the emergence of large and stable companies. At this stage, the market in photonics is still relatively immature and remains very fragmented. There are thousands of small companies. However, as an industrial customer, it is difficult to depend on small and fragile companies. We can expect more consolidations to get strong companies. ●

The scalability is a key parameter for identifying new markets. This explains why we are fully involved into quantum technology for instance, since this market is growing fast and will be a key part of the future technology in a wide range of applications. It also matches our product and technology capabilities very well, enabling us to develop unique solutions for that market.

Chemistry Nobel Prize Celebrates Colloidal Quantum Dots: Highly-Engineered, Spectrally Pure Light

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The Chemistry Nobel Prize of this year has been awarded to Alexei Ekimov, Luis Brus, and Moungi Bawendi for their significant contributions to the discovery and synthesis of colloidal quantum dots. What initially started as a strategy to explore the physics of reduced dimensionality in matter has transitioned over the past 40 years into a commercially available technology platform, the largest of which provides red and green color sources for displays. In this overview, we will delve into this transition process and the pivotal roles played by the laureates.

https://doi.org/10.1051/photon/202212218

Early in the development of quantum physics, the concept of confinement emerged when materials reached the nanometer scale. At such scales, the optical absorption and emission spectra of nanoparticles was expected to differ from that of bulk materials. However, for a long time (until the 1970s), low dimensionality remained a theoretical concept.

The first breakthrough came with the development of molecular beam epitaxy, which enabled the growth of high-quality semiconductor thin films. Under specific conditions, it is possible to achieve lattice matching between two materials with different band gaps, allowing them to be grown on top of each other. This energy offset was utilized to create structures confined in a single dimension coined *quantum wells* and, later, three-dimensionally confined systems as *quantum dots*. This innovation was a game-changer for light control. Prior to this, controlling the band gap and emission spectrum of a semiconductor was a metallurgical challenge involving the creation of alloys. Two semiconductors could be melted to form an alloy with an optical band gap generally intermediate to those of the initial components. Instead, quantum confinement allowed tuning the band gap using geometric factors while keeping the composition unchanged. This

Figure 1. Image of a glass slab grown by Ekimov containing CdSe centers. The thermal treatment conducted on the glass leads to the formation of CdSe quantum dots with various sizes due to the temperature gradient, resulting in a gradient of sizes. Quantum dots at the top are large, resulting in a narrow bandgap and in absorption of almost all visible light. Quantum dots at the bottom are small, pushing their absorption spectrum to the blue resulting in enhanced optical transparency of the glass. Picture Los Alamos National Laboratory, LA-UR-23-31622.

colleagues at LOA (Laboratoire d'Optique Appliquée) in Palaiseau, they superimposed XUV light from the new HHG source with a fraction of the fundamental laser inside a photoelectron spectrometer. In addition to electrons ionized via the absorption of single XUV photons, they also detected electrons with their energy shifted by the laser-induced continuum-continuum transitions that Pierre Agostini had discovered 15 years earlier. Since these electrons only appear when both light pulses interact simultaneously with the ionizing atoms, they encode a cross-correlation of the XUV and laser pulses on the femtosecond time scale.
The step onto the attosecond scale came with the second development, initiated in 1996 by a team of theorists from the Laboratoire de Chimie-Physique-Matière et Rayonnement (LCPMR) at Sorbonne University, led by Alfred Maquet. Based on this theoretical work, it was realized that, within this cross-correlation trace, the number of energy-shifted photo-electrons is modulated by the laser-XUV delay, with a period of half a laser cycle [7]. This changed the perspective from modulating XUV-ionized photoelectrons with a laser pulse of femtosecond duration, to modulating with the laser *field*, which varies on the attosecond time scale. These modulations result from interference between different ionization pathways involving successive XUV harmonic orders, and therefore depend on their relatives phases. This led Muller and Agostini to the development of a method called RABBIT ('Reconstruction of attosecond beating by interference of two-photon transitions') that measures via a fine scan of the XUV-laser delay the XUV spectral amplitudes and phases. A Fourier transform then yields the attosecond XUV pulse profile. Implementing this electron interferometry required great stability and a high repetition rate, which Agostini found at LOA, who had just built one of the most advanced femtosecond laser systems of the time and an associated HHG source. This collaboration demonstrated the first measurement of a train of 250-attosecond pulses [8].
The third key development was the rapid advancement of femtosecond laser technology to its ultimate limit, *i.e.* light pulses containing barely a single field oscillation cycle. **Ferenc Krausz**, then at TU Vienna and at the forefront of this work, built lasers producing intense pulses containing only 10 cycles of red light. He invited Mauro Nisoli from Politecnico di Milano, who in 1996, together with Orazio Svelto and Sandro de Silvestri, had shown how to compress such pulses further. They had spectrally broadened the laser bandwidth through nonlinear propagation in a gas-filled hollow-core fiber, before resynchronizing the newly formed spectral components, initially with a prism compressor. In Vienna, Krausz proposed to replace the prisms by so-called "chirped mirrors", which allowed a more fine-tuned compression and led to pulses of 4.5 fs, *i.e.*, less than 2 cycles [9]. With only a single oscillation cycle strong enough to drive HHG, this allowed generating the first isolated attosecond pulses in Vienna. In 2001, Ferenc Krausz's team then met the challenge to characterize them with the help of • • •

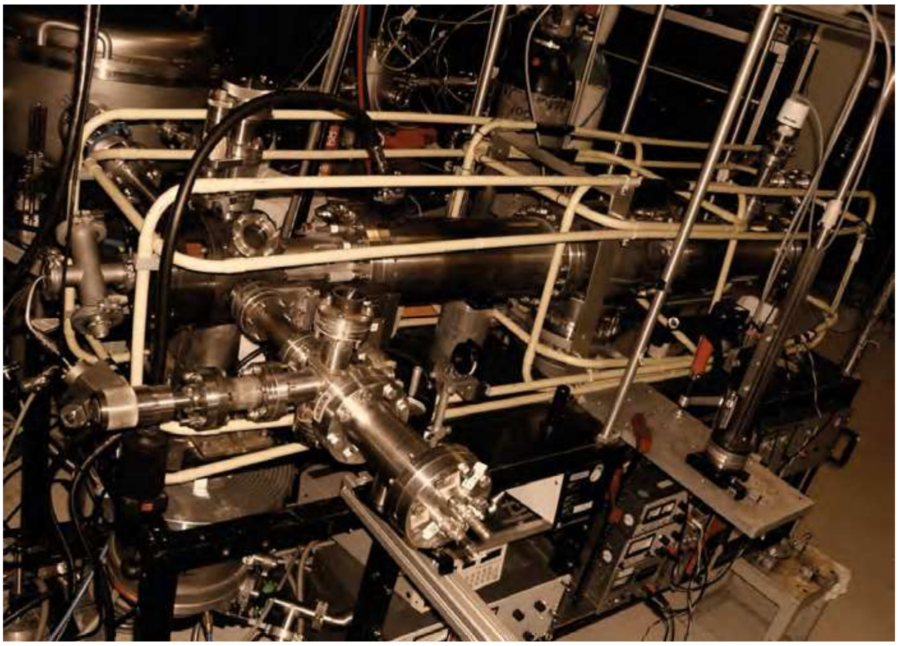

Figure 3. Picture of the magnetic bottle electron spectrometer used by the team of Pierre Agostini to detect the first attosecond pulse trains. This spectrometer is still currently operated on the ATTOLab facility of LIDYL.

Paul Corkum, by an approach related to RABBIT but using a much stronger laser field to act like a streak camera on the photoelectrons ionized by the attosecond pulse. This resulted in the first measurement of an isolated attosecond pulse of 650 as duration [10]. Such pulses became fully reproducible 2 years later when the laser field oscillation inside the pulse envelope was fully controlled by stabilization of the carrier-envelope phase [11], using the frequency-comb technique pioneered by another Nobel Prize winner, Theodor Hänsch.

This attosecond metrology had an immediate impact, as it paved the way both for the continued optimisation of attosecond sources and for their applications. Among the latter, the Nobel Committee highlighted the conceptual advance of time-resolving the photoelectric effect, a process that Einstein had theorized in 1905 through the absorption of a quantum of light (the photon) and the almost simultaneous emission of an electron. The RABBIT and the Streaking methods made it possible to measure tiny emission delays of a few tens of attoseconds. This provided valuable information about the cohesion of matter on a microscopic scale and the complex many-body quantum dynamics, whose theoretical understanding remains one of contemporary physics' major challenges.

The heirs of Anne L'Huillier, Pierre Agostini and Ferenc Krausz have extended the field opened by these pioneers to chemistry, solid-state physics, plasmas and biology. Today, on an international scale, a whole new field, attosecond science, is taking shape with exponential growth. Major investments are being made in the construction and operation of large scale facilities, such as the Hungarian pillar of the European Extreme Light Infrastructure - Attosecond Light Pulse Source (ELI-ALPS) in Szeged-Hungary. At the national scale, attosecond beamlines are already open to users at LIDYL (ATTOLab), ILM-Lyon and CELIA-Bordeaux, within the 'Ultrafast' platform of the national LUMA program, as well as at LOA. The proliferating tools of attosecond science allow observing and controlling the electronic dynamics in strongly correlated materials of interest for future electronic devices, the spin dynamics in magnetic matter, the electronic dynamics in chemistry and biology-relevant molecules, the collective dynamics of plasmas, and are of interest for photovoltaic applications or molecular screening. To fuel these new research paths, source developments are pursued, to industrialize gas phase harmonics, but also to increase their variety through the development of solid state HHG, plasma HHG, or x-ray Free Electron Laser (XFEL) facilities that are now reaching the attosecond frontier. Attosecond science, which began in a handful of laboratories in the 90s, is now emerging as a burgeoning area of research, which has not yet reached its full potential but is developing at a fascinating pace worldwide, spreading into many unexpected areas. ●

REFERENCES

[1] P. Agostini, F. Fabre, G. Mainfray, G. Petite, and N. K. Rahman, Phys. Rev. Lett. **42** (1979).

[2] M. Ferray, A. L'Huillier, X. F. Li, G. Mainfray, and C. Manus, J. Phys. B **21**, L31 (1988).

[3] K. J. Schafer, B. Yang, L. F. Dimauro, and K. C. Kulander, Phys. Rev. Lett. **70**, 1599 (1993).

[4] P. B. Corkum, Phys. Rev. Lett. **71**, 1994 (1993).

[5] M. Lewenstein, Ph. Balcou, M.Yu. Ivanov, A. L'Huillier, and P. B. Corkum, Phys. Rev. A **49**, 2117 (1994).

[6] P. Antoine, A. L'Huillier, and M. Lewenstein, Phys. Rev. Lett. **77**, 1234 (1996).

[7] V. Véniard, R. Taïeb, and A. Maquet, Phys. Rev. A **54**, 721 (1996).

[8] P. M. Paul, E. S. Toma, P. Breger, G. Mullot, F. Augé, Ph. Balcou, H. G. Muller, and P. Agostini, Science **292**, 1689 (2001).

[9] M. Nisoli, S. De Silvestri, O. Svelto, R. Szipöcs, K. Ferencz, Ch. Spielmann, S. Sartania, and F. Krausz, Opt. Lett. **22**, 522, 1997.

[10] M. Hentschel, R. Kienberger, Ch. Spielmann, G. A. Reider, N. Milosevic, T. Brabec, P. Corkum, U. Heinzmannß, M. Drescher, and F. Krausz, Nature **414**, 509 (2001).

[11] A. Baltuška *et al.*, Nature **421**, 611 (2003).

Safeguarding the intangible heritage of French optics

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The fortieth anniversary of the SFO is an ideal occasion to launch PÉPITES [1], a national program to safeguard the scientific memory of French optics. By understanding the intergenerational links that have created today's vibrant photonics sector, we can ensure that its future will be as radiant as in the past.

https://doi.org/10.1051/photon/202311925

The importance of intangible heritage

In 2003, UNESCO adopted the Convention for the Safeguarding of Cultural Intangible Heritage [2], filling an important gap in their broader 1972 World Heritage Convention. It is now generally accepted that all heritage is "a compendium of tangible and intangible" and indeed, as stated in a recent article in a journal published by the International Council of Museums, preserving intangible heritage is important to strengthen inclusiveness, representation and community involvement in a sustainable way [3].

Of course, it takes time to recognize what constitutes "heritage," and this is as true in science and technology as it is in fields such as culture and architecture. On the human level, however, we know that the emergence of scientific or technological discovery is a complex process resulting from the sharing of ideas, chance encounters, not to mention friendships and controversies. In other words, scientific heritage is transmitted not only by written and spoken words, but also through conversations and arguments, as well as through general prevailing ideas and attitudes [4]. In practice, this means that simply preserving physical instrumentation or documents does not capture the many factors that actually combine to generate discovery. And especially when the human stories are lost, this hinders the development of a complete picture of the scientific process.

1 Catalogue	2 Collect	3 Safeguard	4 Disseminate
Choice of the subject that makes heritage	**Interview** of actors	**Transcription**	**Help build community**
Criteria - Scientific, tech evolution - Institutional - Celebration	**Source crossing**	**Formatting**	**Through historians of science**
Identifying actors and viewpoints	**Contextualization** of testimonials	**Permanent preservation**	**Museums, public**
→ Problematization → Good practices → Collab. historians	→ Informed agreement canvas → Interview protocol → Help with the implementation (shooting, sound)	→ Centralized permanent storage, compatible with local storage → Accessibility → Archives legal status	→ SFO Website → Flyers → Workshops → Exhibitions → Video editing,

Figure 1. Summary of the main four phases of the program. In the boxes in violet some of the possible contributions of the national program to the local initiatives are highlighted.

Safeguarding scientific heritage

There are of course many examples where the material heritage of science is successfully safeguarded, most notably by museums, universities, research institutes, and associations. Yet within optics, such conservation is far from widespread, and it is often only by chance that important instrumentation or documents is saved from destruction. In France, the SFO clearly has a key role to play in raising awareness of the importance of our shared history, and to encourage national and local initiatives.

But what about our intangible scientific heritage? If efforts to safeguard instruments and other material still leave a lot to be desired, efforts to save the intangible heritage of French optics are almost non-existent. And even when they do exist, even though commendable and important, efforts are often isolated and unstructured, and without a long-term plan for preservation.

The AIP example

Internationally, there are some examples of successful initiatives focused on the intangible heritage of science. One, which in fact serves as inspiration for this project, is that of AIP (American Institute of Physics). Their Oral History Interviews programme was initially launched in 1960, but it has continued to the present day, and now has 1,500 transcriptions of interviews with major physicists, all available online [5].The wealth of information in these interviews is colossal!

BOX 1: OPTICS HERITAGE IN FRANCHE-COMTÉ

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The PEPITES project at the University of Franche-Comté (UFC) kicked off during 2023, celebrating both the 60th anniversary of a dedicated optics laboratory (now part of the Institut FEMTO-ST UMR 6174), and the 600th anniversary of the university itself. In collaboration between the university's science, art and culture outreach service, the initiative aimed to preserve the rich heritage of optics in the region by interviewing and recording the memories of retired members of the laboratory. We found that a very effective method was to work with science communication graduate students, and to speak in very general terms in an informal setting. This proved very effective in uncovering insights and experiences, many of which had been forgotten and which were remembered only during the interviews. This project has not only celebrated important milestones but also bridging the gap between generations, shedding light on the progression and impact of optical research and education in the region.

The PEPITES project on intangible heritage at UFC has been accompanied by a parallel project on preserving physical heritage which now includes a museum of around 200 historical instruments (see photo), some dating to 1845. Inviting retired staff members to visit this collection allows us to complete our understanding of when the collection was established and when some of the equipment was last used in teaching or research.

The AIP project was the brainchild of the celebrated historian and philosopher Thomas Kuhn, and is widely considered to be the origin of the "science in action" perspective. It was initially focussed on recording memories of the early days of quantum physics, which even in the 1960s was a race against time given the age of the scientists involved. But after its initial success, the program has evolved considerably over time and has expanded to many other areas of physics.

The AIP interviews follow a structured protocol, and are designed and conducted in collaboration between physicists and historians of science. They explore a wide range of topics: the scientific contributions of the interviewees, their family environment, the origins of their scientific careers, and stories of collaboration between interviewees and their contemporaries [6]. One particularly rich example is Kuhn's 1962 interviews of Léon Brillouin. These include discussions about the French educational system of the time, Brillouin's family, the pro and anti-quantum sentiments of the time, working methods, as well as insights into the general process of scientific discovery. However, of the 1500 interviews in the AIP archives, only 9 are of French scientists: Léon Brillouin, Pierre Aigrain, Gérard De Vaucouleurs, Jules Guéron, Hélène Langevin-Joliot, Xavier Le Pichon, Francis Perrin, Bernard Sadoulet and Jean Ullmo. This is understandable given the particular focus of the AIP project, but at the same time it underlines the fact that if French scientific heritage is to be preserved more widely, the effort must come from within France.

Existing initiatives in France

Without claiming to be exhaustive, it is useful to mention a few similar programs that have been developed nationally in France. The Sciences: Histoire Orale (SHO) program in the

Figure 2. Some of the interwees, from left to right. First row: Jean Bulabois, 1st SFO President; Françoise Chavel, 1st SFO General Secretary, Hervé Lefevre SFO President (2005-2007) and SFO Honorary member. Second row : Claude Fabre SFO President (2009-2011); Riad Haidar Editor Chef of Photonics (2014-2019); Pascale Nouchi, SFO President (2017-2019)

field of materials science (chemistry, physics, biology, instrumentation etc) has conducted around 30 interviews with researchers from academia and industry [7]. SHO, coordinated by the historian and philosopher of science Bernadette Bensaude-Vincent, is supported by the ESPCI and the Ile-de-France Region through the C'Nano IdF network. Interviews include: Jacques Friedel, Mildred Dresselhaus, Pierre-Gilles de Gennes, Jacques Livage, Hervé Arribart, Jean-Pierre Boilot. There are also platforms dedicated to medical themes, including HISTRECMED, which has 115 interviews on aspects of 20th century medical research and public health [8].

These interviews are carried out by the science historian Jean-François Picard, who also runs the HISTCNRS programme [9]. which itself has compiled 85 interviews related to the history of the CNRS. And ●●●

of course, the historical archives of bodies such as the Collège de France and the Académie des sciences may well contain similar interview material, and it is encouraging to see other research organizations developing programs centred on their own histories. For example, the MANIP initiative of the Institut d'Optique Graduate school has placed a series of thematic interviews online [10], and the Optics Department of the Institut FEMTO-ST has begun recording interviews with former staff members (see Box 1). And of course since 2020, Photoniques has played its part by regularly publishing interviews and testimonials [11].

BOX 2: THE PÉPITES SCIENTIFIC COMMITTEE

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Science heritage conference at FEMTO-ST 2023. Photo © Vincent Boudon.

- **David Aubin, Science historian, Institut de Mathématiques de Jussieu-Paris rive Gauche, Sorbonne Université/CNRS/Université Paris Cité**
- **Charlotte Bigg, Science historian, Centre Alexandre-Koyré, CNRS/EHESS**
- **Nicolas Bonod, Physicist, Institut Fresnel, CNRS/Aix Marseille Université/ Centrale Marseille**
- **John Dudley, Physicist, FEMTO-ST, Université Franche Comté/CNRS**
- **Marie-Madeleine Greffet, Physicist, Professor secondary level**
- **Ariel Levenson, Physicist, Centre de Nanoscience et de Nanotechnologies, CNRS/Université Paris-Saclay**
- **Eric Picholle, Physicist, Institut de Physique de Nice, CNRS/Université Côte d'Azur**
- **Catherine Schwob, Physicist, Institut de Nanosciences de Paris, Sorbonne Université/CNRS**

Advisor: Florence Descamps, Historian and economist

We warmly thank Alain Aspect, Nobel Prize Physics 2022, for his support and encouragement of this initiative.

PÉPITES – safeguarding the heritage of French optics

Although these existing efforts are important, there is clearly much more to be done. This is why SFO is launching the PÉPITES program that aims to both safeguard and disseminate the memory of the French optics community. Coordinated by a multidisciplinary committee (see Box 2), PÉPITES will focus on the entire ecosystem: academics, research scientists, engineering and technical staff, administrative staff and institutional leadership. The committee will ensure best practice, consistency in the information gathered, and will provide advice on procedures and tools in order to simplify local initiatives. The project will encompass both academia and industry, involve a series of annual and longer-term (five year) milestones, and key results will be summarised and prepared in a format suitable for the public. This will highlight both the rich heritage of French optics, as well as the many ways that the research in optics and photonics has benefitted society.

Methodology

Supporting the local dimension is central to the project's ambition and methodology. After all, it will be members of the local community who know best the particular episodes and individuals who have contributed to the development of optics in particular towns and regions. It is also important to stress that the process does not only involve physicists – safeguarding intangible heritage requires participation from the humanities (e.g. the French *Maison des Sciences de l'Homme et de la Société* structures), local museums, and libraries, and the wider community. PÉPITES is designed around an existing methodology developed by oral history expert Florence Descamps [12]. Schematically represented in Fig. 1, there are four key stages: Catalogue, Collect, Safeguard, and Disseminate, each associated with a number of more detailed elements as shown. Fig. 1 also presents the main typology of the contributions of PÉPITES to the local initiatives (bottom box in each column). Of course, how much can be achieved in practice will depend on available resources, but this structure provides a working template that can be readily adapted to particular local constraints.

Conclusion

Oral history is a key component of intangible heritage, providing a unique and personal window into the past that allows us to understand how scientific ideas develop and advance. It is essential that this is safeguarded for the generations to come. As Auguste Comte wrote - We do not fully understand a science until we know its history [13]. Oral memory through recent history, helps to anchor scientific discovery and progress in this very same hisorical flow.

PÉPITES aims to safeguard the scientific memory of the French optics community, but to be effective it needs your involvement and commitment. We will be delighted to hear from anyone interested in implementing an oral history project within their own institutions, and to provide them with advice, information and practical assistance. Equally, we are certain that our plans will resonate within the broader international optics and photonics community, and we welcome collaboration with sister learned societies in Europe and worldwide.

Acknowledgements

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REFERENCES

[1] PrÉservation du Patrimoine Immatériel TEchnologique et Scientifique de l'optique française. Pépites is French for nuggets or treasures.

[2] https://ich.unesco.org/fr/convention

[3] M. L. Stefano, *Renewing museum meanings and action with intangible cultural heritage*, International Journal of Intangible Heritage **17**, 237 (2022). https://icom.museum/fr/news/renouveler-les-significations-et-laction-des-musees-avec-le-patrimoine-culturel-immateriel/

[4] F. Lempereur, *La transmission et la diffusion du patrimoine scientifique immatériel : état des lieux et perspectives*, Cultures et Musées **24**, 127 (2014) https://doi.org/10.4000/culturemusees.681

[5] https://www.aip.org/history-programs/niels-bohr-library/oral-histories

[6] A. te Heesen, *Thomas Kuhn, Earwitness : Interviewing and Making of a New History of Science*, Isis **111**, 86 (2020); A. te Heesen, *Spoken Words, Written Memories : Early Oral History and Elite Interviews*, History of Humanities **6**, 163 (2021).

[7] www.sho.espci.fr/?lang=fr

[8] www.histrecmed.fr/temoignages-et-biographies/temoignages

[9] www.histcnrs.fr/temoignages.html

[10] https://bit.ly/2QStult

[11] www.sfoptique.org/medias/files/photoniques115-2022.pdf

[12] F. Descamps, *Archiver la mémoire, de l'histoire orale au patrimoine immatériel*. Editions EHESS, 2019

[13] A. Comte, *Cours de philosophie positive*, Paris, Hermann, 1975