

# Photoniques

N°107

LIGHT AND APPLICATIONS ■ EOS & SFO JOINT ISSUE

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Partner news & highlights

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Patricia Era Bath

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Microscope objectives

## PRODUCTS

In optics and photonics

## FOCUS

# QUANTUM TECHNOLOGIES

- Generation of quantum states of light in nonlinear AlGaAs chips: engineering and applications
- Towards real-time quantum imaging with single photon avalanche diode cameras
- Semiconductor single-photon sources: progresses and applications
- Diamond-based quantum technologies
- Quantum sensing with nitrogen-vacancy colour centers in diamond



Quantum Correlations and Entanglement

Photoniques is published  
by the French Physical Society.  
*La Société Française de Physique  
est une association loi 1901  
reconnue d'utilité publique par  
décret du 15 janvier 1881  
et déclarée en préfecture de Paris.*

<https://www.sfpnet.fr/>

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Tel.: +33(0)1 44 08 67 10  
CPPAP : 0124 W 93286  
ISSN: 1629-4475, e-ISSN : 2269-8418

[www.photoniques.com](http://www.photoniques.com)



The contents of Photoniques  
are elaborated under  
the scientific supervision  
of the French Optical Society.  
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Photoniques is hosted and distributed by  
EDP Sciences,  
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91944 Les Ulis Cedex A, France  
Tel.: +33 (0)1 69 18 75 75  
RCS: EVRY B 308 392 687

#### Subscriptions

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#### Printer

Imprimerie de Champagne  
Rue de l'Etoile de Langres  
ZI Les Franchises  
52200 Langres  
Dépôt légal : May 2021  
Route STAMP (95)



## Editorial



NICOLAS BONOD

Editor-in-Chief

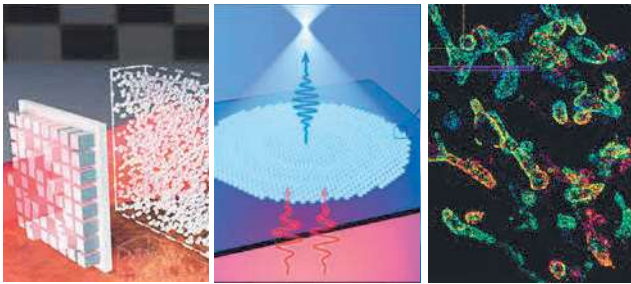
## Welcome to the Quantum World

The year 2021 marks the 100<sup>th</sup> anniversary of the 1921 Nobel Prize in Physics awarded to Albert Einstein “for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect”. Einstein introduced the concept of “light quantum” in a seminal paper he submitted on March 17, 1905, at the age of 26, in which he wrote “Each incident energy quantum of frequency  $\nu_1$  is absorbed and generates by itself a light quantum of frequency  $\nu_2$ ”. Einstein himself did not anticipate how much this term “quantum” would revolutionize physics and change our perception of physical reality. This paper opened a prolific period for theoretical physicists who established the theoretical frameworks of quantum physics in only a few decades. They quickly established revolutionary concepts such as uncertainty and entanglement, which greatly changed our comprehension of physics. Quantum mechanics allowed a deep understanding of the optical and electronic properties of semiconductors. It is remarkable to see how such fundamental and theoretical results have rapidly and profoundly influenced technologies with the surge in the use of transistors and lasers that opened the information age.

But a second quantum revolution is underway. While the pioneers of quantum physics focused their efforts on understanding existing states of matter, researchers are now developing new, man-made quantum systems. Objectives are now to shape complex coherent quantum systems and achieve coherent and entangled quantum states that have never been observed before. This new degree of control over quantum states opens novel routes to reinventing fields such as information processing, computing, communications and sensing. This current scientific challenge goes beyond the improvement of existing classical components and offers a new paradigm in technological applications.

You will discover in this special issue some of the latest advances in one of the most exciting and promising scientific fields of the 21<sup>st</sup> century: quantum sensing, quantum imaging, diamond-based quantum technologies, single photons sources and engineered quantum states. The back-to-basics article is devoted to quantum correlations and entanglement. Also, do not forget to test your lexical skills in quantum physics with our crossword puzzle! Welcome to the quantum world!





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## SFO/EOS forewords

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**PHILIPPE ADAM**

President of the French Optical Society

**T**he important events of 2021 are rapidly approaching. In order to make them as profitable as possible, the implementation of a communication strategy towards the Optics-Photonics community is essential in order to affirm the positioning of the SFO on its choice of commitment for a face-to-face meeting. The mobilization is strong around the OPTIQUE 2021 congress in Dijon in July. We warmly thank those who have already submitted a contribution. The echoes from our community clearly indicate the willingness and impatience of future participants to come together to renew technical and scientific links in a version if not "fully liberated", at least in the as user-friendly format as possible. Even if the situation has not yet stabilized and is evolving day by day, the measures (e.g. gauge limitation), that we have adopted and inherent to the locations chosen, completely reassure us about the relevance of our choice of a face-to-face format.

However, the current period requires us to be vigilant and plan for fallbacks... just in case. For example, the SFO organized remote conferences on Freeform Optical Systems: this event was a great success with more than 150 participants and a flawless digital management.

In conclusion on this event chapter, essential for the life of our Society, I do believe that the OPTIQUE 2021 Congress will take place in Dijon from Monday 05 July to Friday 09 July.

At Dijon, the SFO scientific prizes will be awarded. For the Arnulf Françon prize, the selection is under process; for the Fabry - de Gramont prize, the winners are already known. For the Léon Brillouin Grand Prix, the jury selected a winner in a selection with a complete parity.

At the same time, we will participate with enthusiasm in the constitution of French nominations to obtain the much sought-after "EOS fellow" distinction and this for the greater influence of our community: our links with EOS are still active and friendly.

Finally, I am delighted the current issue of Photonics is devoted to quantum technologies. Few fields have seen such rapid and efficient development from fundamental research in the 90s to current industrial activities in the fields of sources, sensors, quantum computing, communications. A revolution is underway; being able to follow these advances in real time is a great opportunity. Photonics review is actively participating in it.



**GILLES PAULIAT**

President of the European Optical Society

**R**esearch and scientific careers are characterized by uncertainty and doubt. Overcoming these difficulties to move forward together on the subjects that are important to us and the society is an immense satisfaction and one of the pleasures of our professions. Nevertheless, this long-lasting pandemic adds to this insecurity and affects many of us and our relatives. Not to mention the acute health problems, morale and enthusiasm deteriorate.

We learned how to partly compensate for the absence of physical meetings by an extensive use of videoconferencing. These valuable tools are without any doubt good for the planet and for keeping close contacts and collaborations despite the distances. Nevertheless, we are all eager to revive with in-person meetings. These meetings are invaluable for networking, for reconnecting with old colleagues in the corridors, for meeting new ones to build new projects... These meetings are also an opportunity for our younger colleagues to build their career and find new laboratories for their post-docs.

Learned societies are actively preparing these next eagerly awaited in-person meetings. Just to mention a few, the next meetings in July of the French Optical Society, SFO, in Dijon, "Optique Dijon", or in September for the German Optical Society, DGAO, General Assembly in September in Bremen. It is worth reminding that internal agreements signed within EOS allow members of EOS branches to participate to meetings organized by other branches at members rates. For example, DGAO members can benefit for low registration rates at SFO meeting and vice-versa. Similarly, all EOS members, and thus of EOS branches or affiliated societies, benefit for reduced rate in many international meetings of the EOS partner societies throughout the world. Please see the EOS website for more information.

Of course, do not miss the EOS general meeting EOSAM2021. It will be held in Rome, on Sept 13-17, in close collaboration with the Italian Optical Society, SIOF. You will have the opportunity to meet with colleagues from all over Europe and beyond. The meeting covers all topics in photonics, including the bubbling "Non-linear optics and Quantum Optics". The multiple facets of Quantum optics are covered by this issue of Photonics. Enjoy your reading! Keep safe, looking forward to seeing you in-person this year for an ever-renewed European cooperation!

## OPTIQUE DIJON 2021: VENEZ À DIJON

The French Optical Society affirms its choice of face-to-face format: OPTIQUE Dijon 2021 will take place in Dijon from the 5<sup>th</sup> to the 9<sup>th</sup> of July 2021.



**T**he mobilization is strong around the OPTIQUE 2021 congress in Dijon. We warmly thank those of you who have already submitted.

The echoes from our community clearly indicate the willingness and impatience of future participants to come together to renew technical and scientific links. Even if the situation is not yet completely stabilized, the large spaces of Congrexpo would allow OPTIQUE Dijon to run normally with a 50% gauge. So you are cordially invited to attend and participate in the 8<sup>th</sup> Congress of the French Optical Society SFO.

OPTIQUE Dijon 2021 will cover a wide range of topics from the fundamental to the applied research, industrial developments and pedagogical innovations. An exhibition area for photonics industry, including start-ups, will be set up at the heart of the congress. This congress provides fertile ground for beneficial exchanges between the actors of optics and photonics.

Professor Gérard Mourou, Nobel Prize in Physics 2018, will deliver the keynote opening plenary speech in this congress. OPTIQUE Dijon 2021 also includes

plenary sessions led by guest speakers renowned internationally for their expertise, several thematic conferences and poster sessions.

### OPTIQUE Dijon 2021 Prizes, to promote optics and photonics research

To recognize excellence, the SFO awards three Scientific Prizes during this congress. The Léon Brillouin Prize rewards researchers for all their research in optics in France. The Fabry-de Gramont Prize rewards a young researcher (under 40), for the quality, originality and potential impact of his (her) research. The Arnulf-Françon Prize aims to promote outstanding teaching book in higher education or popular science. OPTIQUE Dijon 2021 welcomes for the first time the awarding of the Jean Jerphagnon Prize, which promotes technological innovation and the dissemination of optics and photonics in all fields of application.

### Women in Physics committee, to promote parity in Optics

In symbiosis with the commission "Women and Physics, achieve parity in optics" the congress pays a special attention to the number of women working in optics, at all responsibility levels and tends to parity on invited conferences.

### PhD students are welcome in OPTIQUE Dijon 2021

Our goal is to allow all PhD students to participate once in the congress during their thesis. 200 students are expected in this congress.

### Dijon hosts the 8<sup>th</sup> SFO congress

The local organizing committee orchestrated by Guy Millot is very happy to host the SFO Congress. They do their utmost to welcome hundreds of participants in the best conditions. The congress facilities at Palais des congrès de Dijon are well located and easy to reach. During our networking program, you will get to know this exciting city in all its aspects.

We invite you to submit and present your research and to make friendships in friendly atmosphere.

Welcome to OPTIQUE Dijon 2021!

### OPTIQUE DIJON 2021 IN FEW FIGURES

- 8<sup>th</sup> edition of the SFO congress
- 600 expected attendees
- 45 stands of companies in the ecosystem of optics and French photonics
- 7 hours of plenary sessions
- 70 hours of specific sessions in parallel
- 5h30 dedicated to the industrial sector.
- 10 Thematic sessions

### THEMATIC SESSIONS

- Crystals for Optics
  - Optics and Photonics diagnostic
  - Optical Fibers and Networks
  - Frontiers of Optics
  - Lasers and Quantum Optics
  - Nanophotonics
  - Guided Optics
  - Adaptive Optics
  - Organic Photonics
  - Atomic, Molecular, and Optical Physics (\*)
- (\*) SFP thematic session, PAMO



### The French Optical Society invites you to attend

the 11<sup>th</sup> International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'21)

17<sup>th</sup> International Symposium on the Science and Technology of Lighting (LS:17)

**For the first time, the two conferences will be held jointly Toulouse, November 8<sup>th</sup> to 10<sup>th</sup>, 2021**

<https://eedal-ls21.sciencesconf.org/>

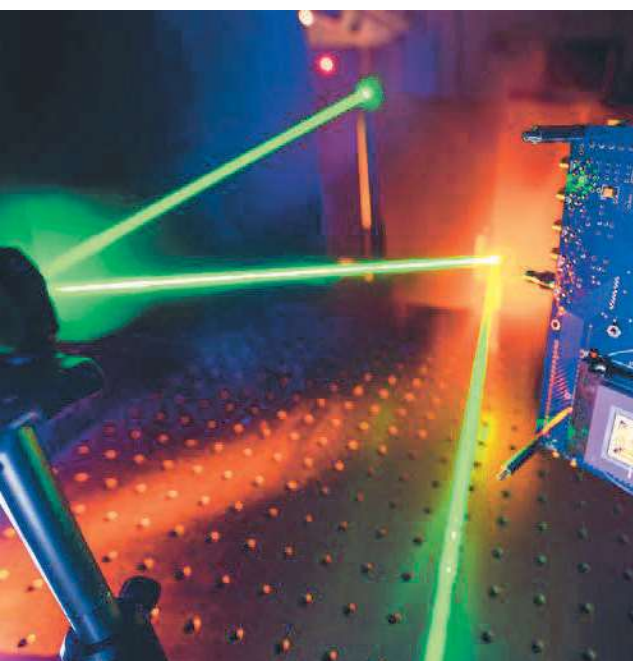


# TOWARDS REAL-TIME QUANTUM IMAGING WITH SINGLE PHOTON AVALANCHE DIODE CAMERAS

**Hugo DEFLENNE, Daniele FACCIO**

School of Physics and Astronomy, University of Glasgow, G12 8SU Glasgow, United Kingdom

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By harnessing the properties of photonic quantum states and their interaction with the environment, quantum imaging promises to go beyond the limits of classical imaging. However, the inherent weakness of detected signals and the fragility of quantum states make their properties difficult to measure in practice. In recent years, the emergence of single-photon sensitive cameras enabled the field to take a step closer to practical applications. In this respect, single-photon avalanche diode (SPAD) cameras are one of the most promising technologies as they can detect single photons across many pixels with unparalleled speed, temporal resolution, and very low noise.

<https://doi.org/10.1051/photon/202110736>

Quantum imaging harnesses quantum properties of light to break the fundamental limitations of imaging. In a typical quantum imaging system, a non-classical state of light illuminates an object from which an image is formed onto a set of photodetectors. The specific measurement performed by the detectors (e.g. single or coincidence detections) combined with the state properties (e.g. single-photon, entangled photon pairs or squeezed states) enables to improve the image

quality. Proof-of-principle demonstrations range from super-resolution to contrast-enhanced and sub-shot-noise imaging, leading to the development of unique imaging modalities such as imaging with undetected photons, quantum illumination and non-local imaging [1]. However, despite recent significant advancements in this field, the practical potential of quantum imaging can be questioned. The doubts about applicability arise from a combination of limiting factors including the inherently weak intensity of quantum sources, the fragility of quantum states and the

difficulty to measure their properties. While source brightness is likely to keep improving constantly because it is an essential aspect also for other fields such as quantum communications, the efficiency of imagers for quantum light has stalled for several years and impedes the advances in quantum imaging. To highlight how critical this is, it is worth noting that most quantum imaging experiments performed to date used raster-scanning single-pixel techniques to capture images, which is obviously a very photon-inefficient, time-consuming, and non-scalable process.



# HARNESS THE POWER OF QUANTUM COMPUTING



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Founded in 2019, PASQAL develops and markets scalable Quantum Processing Units (QPUs) that have the potential to address complex computing issues, from fundamental science to real-world grand challenges.

The company is a spin-out from Institut d'Optique Graduate School in Palaiseau (France), one of the leading quantum research centres in the world.

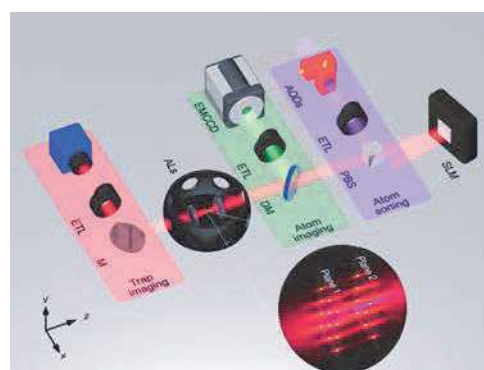
PASQAL is the only European company offering Quantum Processing Units with a number of qubits, level of performance and maturity allowing practical use for both industrial and academic applications as of today.

## A sketch of the QPU

model and process various use cases and calculations.

100 qubit QPUs are available as of 2021 and 1000 qubit QPUs will be available by 2023.

Our processors are designed as accelerators which integrate easily into High Performance Computing (HPC) Centres, and are operated at room temperature. They come with a full software stack, allowing control from any standard computer.



## Thousands of qubits shaped by light

## The core of the QPU



We are building multi-purpose quantum processors in the 100 – 1000 qubit range

## TECHNOLOGY

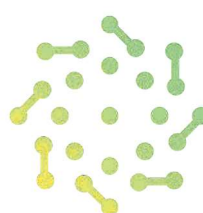
Our QPUs are built around a core of neutral atoms which can be precisely addressed, controlled and arranged in 1D, 2D and 3D geometries, thus providing outstanding flexibility to

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  - » On the Cloud, with QPUs operated at PASQAL (Software as a Service & Platform as a Service)



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