Photoniques

N°119

LIGHT AND APPLICATIONS | EOS & SFO JOINT ISSUE

40 YEARS OF SFO
The Nobels and light

ZOOM
Photonics in Finland

EXPERIMENT
First exoplanet detection

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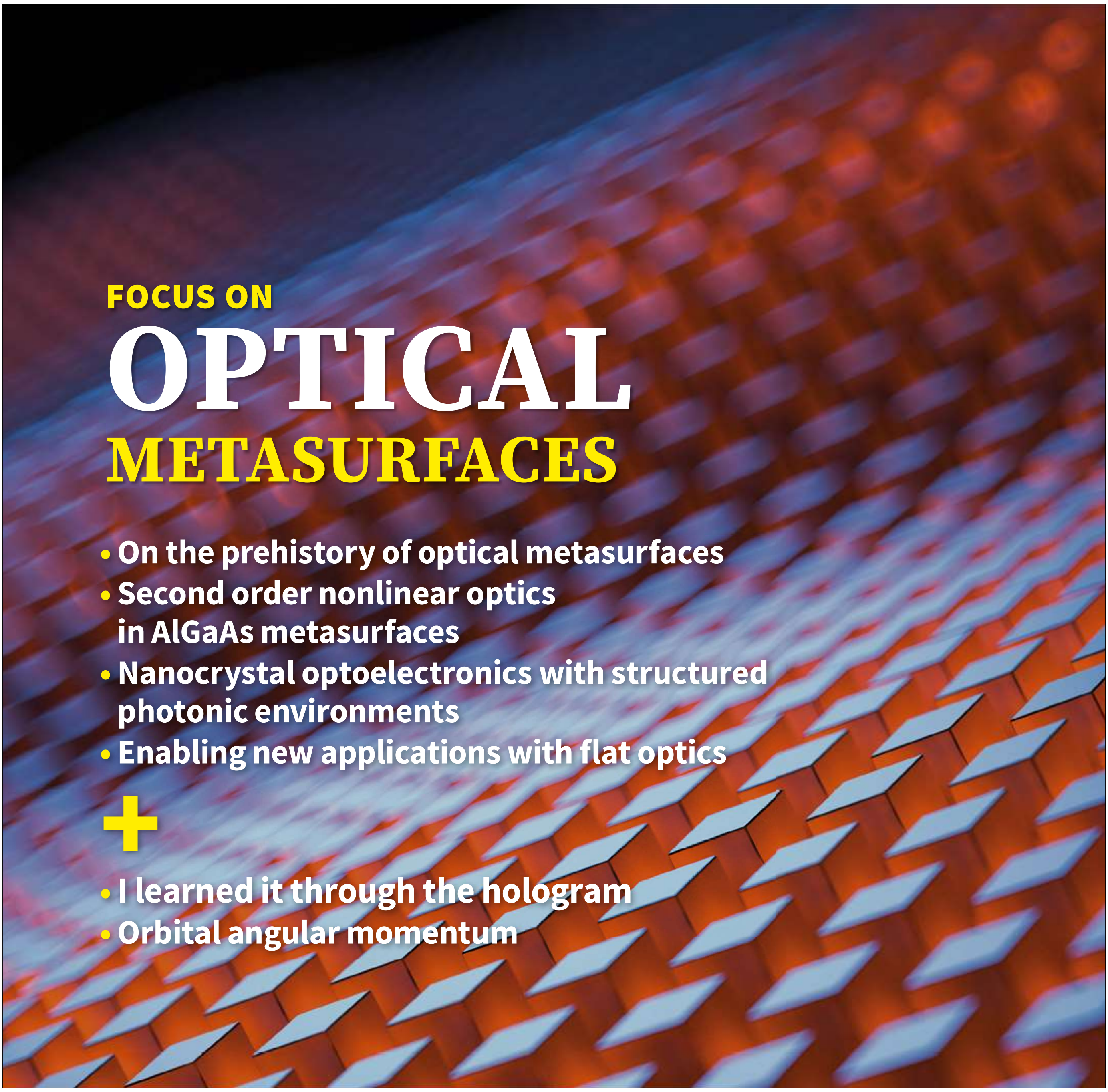

FOCUS ON

OPTICAL METASURFACES

- On the prehistory of optical metasurfaces
- Second order nonlinear optics in AlGaAs metasurfaces
- Nanocrystal optoelectronics with structured photonic environments
- Enabling new applications with flat optics

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- I learned it through the hologram
- Orbital angular momentum

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2 avenue Augustin Fresnel
91127 Palaiseau Cedex, France
Florence HADDOUCHE
General Secretary of the SFO
florence.haddouche@institutoptique.fr

Publishing Director
Jean-Paul Duraud, General Secretary of the French Physical Society

Editorial Staff
Editor-in-Chief
Nicolas Bonod
nicolas.bonod@edpsciences.org
Journal Manager
Florence Anglézio
florence.anglezio@edpsciences.org
Editorial secretariat and layout
Agence la Chamade
https://agencelachamade.com/

Advertising
Annie Keller
Cell phone: +33 (0)6 74 89 11 47
Phone/Fax: +33 (0)1 69 28 33 69
annie.keller@edpsciences.org

International Advertising
Bernadette Dufour
Cell phone + 33 7 87 57 07 59
bernadette.dufour@edpsciences.org

Photoniques is hosted and distributed by
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P.A. de Courtaboeuf,
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Editorial

NICOLAS BONOD
Editor-in-Chief

Meta-optics

Opticians have long sought to control light by structuring matter. One early experiments was carried out in 1785 by David Rittenhouse, inspired by Francis Hopkinson's correspondence, who observed the phenomenon of dispersion by studying the transmission of light through periodically aligned hairs. *"I was surprised to find that the red rays are more bent out of their first, direction, and the blue rays less; as if the hairs acted with more force on the red than the blue rays, contrary to what happens by refraction,"* wrote D. Rittenhouse, a visionary who anticipated that *"By pursuing these experiments, it is probable that new and interesting discoveries may be made, respecting the properties of this wonderful substance, light, which animates all nature in the eyes of man".*

If sub-wavelength modulation no longer leads to diffraction, it still alters the properties of light; and this ability to manipulate the properties of light by structuring the surfaces of materials at a sub-wavelength scale opens up a vast field of investigation.

While the prefix *meta* in optics was inspired by earlier works on metamaterials, for which it expressed the desire to develop exotic properties in wave physics, the sudden rise of metasurfaces over the last decade certainly comes from the desire to take advantage of design approaches and nanotechnologies for both optical instrumentation and cutting-edge research. Optical metasurfaces have opened new paths to explore some of the most fundamental concepts of photonics but they also showed their ability to replicate conventional optical functions such as wave plates, lenses, frequency conversion and spectral filters with very thin devices. The capacity of metasurfaces to address both fundamental and applied challenges by nanostructuring material surfaces has laid solid foundations for this new disciplinary field. The industrial sector is also quickly investing in this domain. The latter raises a large interest from very large industries while several startups have been created in recent years to manufacture and commercialize meta-optics, and partnerships between complementary actors in this industry have been established to boost research and innovation.

This issue focuses on Finland, a country that has made significant investments in photonics. Like other countries in Europe and worldwide, Finland launched flagship initiatives in 2019 to invest in interdisciplinary themes. These initiatives aim to tackle major societal challenges such as health, energy, and sustainable development, while fostering collaborations between academic and industrial actors to achieve international prominence. Finland recognized early on the potential of photonics to meet these criteria, leading to the funding of the Photonics Research and Innovation flagship, one of the six initiatives launched in 2019 for a duration of eight years. We are delighted to highlight countries that have chosen to prioritize photonics and showcase how investing in photonics creates an ecosystem that drives advancements in research, education, and industry to meet the challenges of tomorrow.

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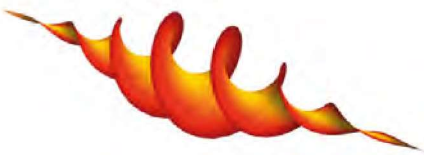

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SFO/EOS forewords

ARIEL LEVENSON
President of the French Optical Society

Let's celebrate together !

As this year 2023 recognizes 40 years since the creation of the French Optical Society (SFO), we have been delighted to learn of many other anniversaries also being celebrated!
1963 for example saw the foundation of the Laboratory of General Physics and Optics in Besançon in France (now part of the Institute FEMTO-ST), building on roots established in 1933 by Jean-Jacques Trillat (a disciple of De Broglie). In fact, the first SFO President in 1983 was Jean Bulabois from this laboratory (see Photoniques 37 and 118), and this issue includes an article by another member John Dudley who retraces the laser epic through stories of the Nobel Prizes. Another French institute celebrating a milestone this year is the Laboratoire de Physique des Lasers, Atomes et Molécules (PHLAM) in Lille which has its 25th birthday on June 16, 2023! PHLAM emerged through a nonlinear pathway under the guidance of the late Pierre Glorieux who pioneered important studies of chaos in lasers.
And of course the SFO's 40th anniversary coincides with 30 years of the European Optical Society! SFO has always been fully committed to the EOS alongside our sister societies, and our firm conviction is that being "United in diversity" makes us smarter and stronger. It is therefore a great pleasure to share this Edito page with EOS President Patricia Segonds who follows the endlessly engaged Gilles Pauliat.
What better celebration of these coinciding French and European anniversaries than the co-organisation of EOSAM 2023 in Dijon from 11-15 September. All are welcome to celebrate together the excellence of European photonics, and the human foundations on which it rests in both academia and industry through colleagues in research, development, and teaching. EOSAM will also allow us to benefit from the hospitality of our fantastic General Chairs Bertrand Kibler and Guy Millot (Institut Carnot de Bourgogne) and will showcase a remarkable programme of talks! Don't delay in making your plans to attend and see you there!

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

PATRICIA SEGONDS
President of the European Optical Society

Let's meet at EOSAM !

As the new President of the European Optical Society (EOS), gathering 4000 members, it is a real pleasure to share this editorial with the President of the SFO, one of our 17 national optical societies (NOS). Together, we are organizing the next EOS Annual Meeting, EOSAM. It will be held from 11 to 15 September 2023, in the beautiful city of Dijon. Bertrand Kibler and Guy Millot (General Chairs), Emiliano Descrovi and myself (Program Chairs), Ariel Levenson (SFO President), Elina Koistinen (EOS Executive Director) and Florence Haddouche (SFO Executive Director), are working very closely to ensure that we meet the participants' expectations with the highest quality and novel research results in different fields of optics.
Thus, exceptional plenary lectures will be given by Ursula Keller, Valentina Emiliani, Laura Na Liu, Thomas Ebbesen, Fabio Sciarrino and Jean-Pierre Wolf. Do not miss the tutorials teached by Sara Ducci, Sandrine Fort-Lévêque, Sébastien Bidault, John M. Dudley, Rüdiger Paschotta, Philippe Grelu, Oliver Fähnle, Julien Charton, and Roozbeh Shokri, to address the topics of EOSAM. These are silicon photonics and integrated optics (TOM1), adaptive and freeform optics (TOM2), biophotonics (TOM3), nanophotonics (TOM4), optical materials (TOM5), nonlinear and quantum optics (TOM6), optical frequency combs (TOM7), ultrafast optics (TOM8) and applications of optics and photonics (TOM9).
Focused sessions will cover specialty optical fibers, structured light, chiroptical phenomena, and machine-learning for optics and photonic computing for AI. Photonics21 has joined us to run the EU projects session and students are organizing the Early-Stage Researcher session. Students, new EOS Fellows, the EOS and the International Commission for Optics (ICO) prizes will be awarded.
Last but not least, the industrial mastering of optical technologies and systems (IMOTS), the optics podium organized with EPIC, and an exhibition aim to foster our relationship with industry. The Annual General Assembly will report on the work of our Executive Committee, Board of Directors and NOS Presidents. We hope to see you all in Dijon !

Patricia SEGONDS
Professor at Grenoble Alpes University
President of EOS

AGENDA

■ **LIDAR summer school**
SFO International Thematic Summer School at the observation of Haute Provence, OHP, France
June 11- 16 2023

■ **JNOG Lyon 2023**
Registration for the conference is open now
INL, Lyon, France
Follow us on https://www.sfoptique.org/
5 au 7 July 2023

■ **Waves in complex media**
SFO International Thematic School Houches Physics School, Chamonix Mont Blanc Valley, France
September 17- 29 2023

■ **EOSAM 2023 in Dijon by SFO and EOS**
Congrexpo, Dijon, France
September 2023 11- 15 2023

EVENTS SPONSORED BY SFO

■ **SFP Congress**
3/07/2023 - 7/07/2023, Paris

■ **QUEST 2023**
27/06/2023 - 30/06/2023 Paris

■ **ICL 2023**
27/08/2023 - 01/09/2023 Paris

■ **MNO 2023 conferences**
19/09/2023 - 21/09/2023 Université de Technologie de Troyes (UTT)

Follow all optic events by SFO on https://www.sfoptique.org/

Early Stage Researcher Session @ EOSAM 2023, boosted by the SFO Young Researchers Club

We are fully committed to co-organizing EOSAM 2023 and participating in almost all the committees for the Topical Optical Meeting and Special Sessions. We are confident that EOSAM 2023 will be a great success!
The SFO Young Researchers Club, which was recently created, is at the forefront of co-organizing the Early Stage Researcher Session with the EOS Finland Student Club. This session will provide a stress-free opportunity for young people from the European optical community to exchange ideas and network, discussing topics such as small scientific advances, challenges faced, and practices in other countries. The session will be led by the Chairs, Pierre Balage, co-president of the SFO Young Researchers Club, and Roman Calpe, of the EOS Finland Student Club.

LIGHT WITH SFO LIGHTBOX

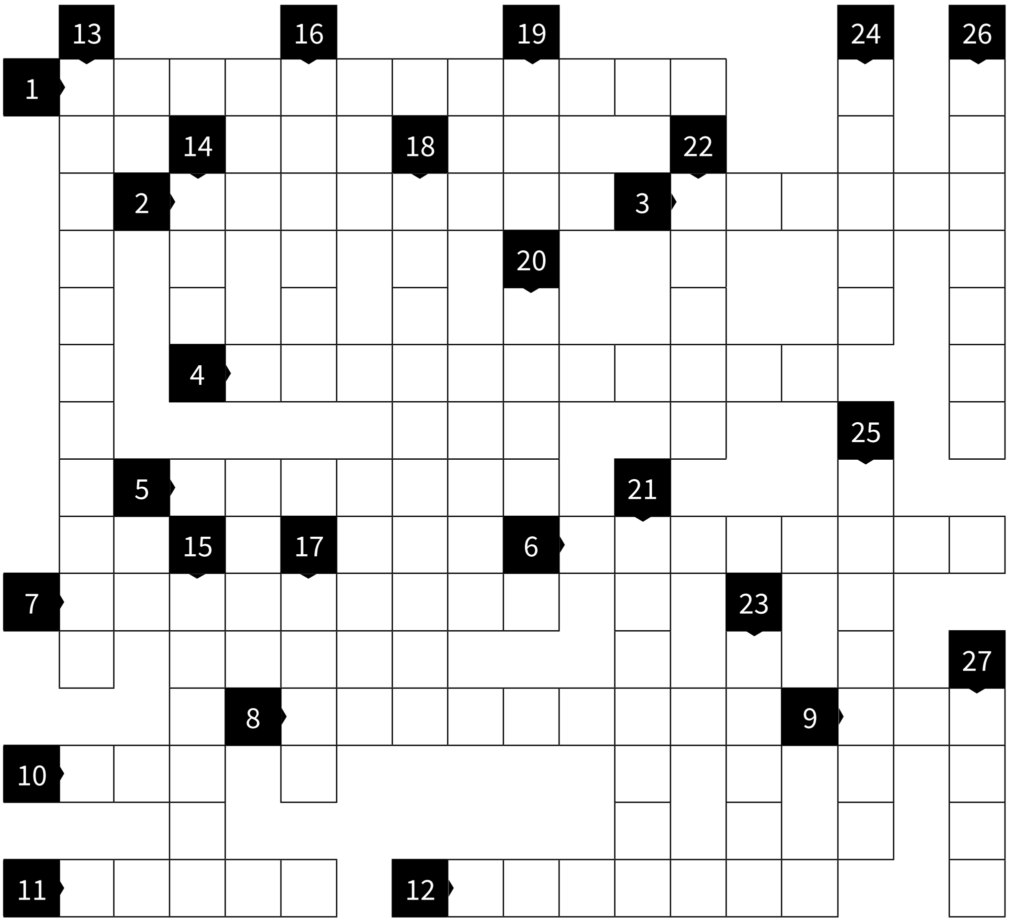
On this International Day of Light (IDL - May 16th, 2023), the SFO, French Optical Society promotes the scientific culture of optics and photonics by encouraging education, scientific outreach, and networking of scientific leaders throughout the country.

MORE INFORMATIONS:
https://www.lightday.org/ - https://www.sfoptique.org/

CROSSWORDS

ON METASURFACES AND METAMATERIALS

By Philippe ADAM



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PHOTONIQUES.COM

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

Interview with Konrad von Volkmann, CEO of APE

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

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

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

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

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

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

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

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

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

Are you focusing your sales efforts in Europe or worldwide?

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

Is Europe a great place for photonics?

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

How do you evaluate the evolution of photonics? How to increase the spread of photonic technologies and strengthen the companies and market?

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

How do you imagine the next 20 years for your company and for photonics? Have you identified promising scientific areas for photonic technologies?

Undoubtedly the applications of ultrafast lasers and more general, photonic devices are expanding into more and more areas of research and technology. Thus we will remain committed to contributing to this progress of photonics, as we have done in the past. Let me give you two specific examples we are working on. Our efforts are targeted to bringing CRS imaging to widespread applications, among others histopathology for rapid cancer cell diagnostics. With our systems we also support the development of the 4th generation of quantum applications playing a rapidly increasing role in the coming years.

The particular requirements for APE to sharing the global advancement of photonics comprise a sustainable growth, while preserving innovative power and flexibility, and keeping balance between large series standard production for the laser industry and customized devices and systems for the research community.

The Nobels and light

John DUDLEY[1,*]
[1] Université de Franche-Comté, Besançon, France
***john.dudley@univ-fcomte.fr**

Milestones such as the 40th anniversary of the French Optical Society are an ideal time to reflect on historical achievements, and there is no shortage of major highlights to celebrate in photonics. What is not always appreciated, however, is just how many different areas of light-related science have been recognized by perhaps the most prestigious scientific celebration of all - the award of the Nobel Prize !

https://doi.org/10.1051/photon/202311921

The second week in October every year is eagerly awaited by scientists around the world. For a very select few, they may be hoping for a phone call from a representative of the Royal Swedish Academy of Sciences, but for most of us, we are just waiting impatiently to learn which specific areas of science have been recognized by the tremendous honour of the Nobel Prize. However, the decision of who receives the call is the result of a process that actually begins 12 months before.

According to the Nobel Prize website, the details depend on the particular subject of the prize but for physics at least, the procedure begins when thousands of invitations are sent out to scientists around the world to submit nominations.

Figure 1. It is not unusual to find several Nobel laureates in the same discipline coming from the same laboratory, and this is usually indicative of a scientific environment that encourages basic science and support for fundamental and long-term research. Examples include Bell Labs and Berkeley in the United States, and another example is the celebrated École Normale Supérieure (ENS) in Paris where Kastler, Cohen-Tannoudji, and Haroche all performed their prize-winning work. This remarkable photo taken around 1966 shows Kastler (centre) with Cohen-Tannoudji (left) and Haroche (right.) © Archives LKB - Photothèque ENS, 1966.

1964	Townes, Basov, Prokhorov Laser-Maser Principle	Physics
1966	Kastler Precision studies of optical resonances	Physics
1967	Granit, Hartline, Wald Physiological and chemical visual processes in the eye	Physiology or Medicine
1967	Eigen, Norrish, Porter Flashlamp Pump-Probe Studies of Chemical Reactions (µs)	Chemistry
1971	Gabor Holography	Physics
1981	Bloembergen & Schawlow Laser Spectroscopy	Physics
1981	Hubel & Wiesel Information Processing in the Visual System	Physiology or Medicine
1989	Ramsey, Dehmelt, Paul Atomic Clocks, the Ion Trap	Physics
1997	Chu, Cohen-Tannoudji, Phillips Laser Cooling and Trapping	Physics
1999	Zewail Femtochemistry	Chemistry
2000	Alferov & Kroemer Optoelectronics, Semiconductor Heterostructures	Physics
2001	Cornell, Ketterle, Wieman Bose Einstein Condensation	Physics
2005	Glauber, Hall, Haensch Quantum Optics, Spectroscopy, Optical Frequency Comb	Physics
2008	Shimomura, Chalfie, Tsien Green Fluorescent Protein GFP	Chemistry
2009	Kao, Boyle and Smith Optical Fiber Communications ; Imaging and the CCD	Physics
2012	Haroche & Wineland Individual Quantum Systems	Physics
2014	Akasaki, Amano, Nakamura The Blue LED and Energy-Saving White Light Sources	Physics
2014	Betzig, Hell, Moerner Super-resolution microscopy	Chemistry
2018	Ashkin, Mourou, Strickland Optical Tweezers & Biophotonics Chirped Pulse Amplification	Physics
2022	Aspect, Clauser, Zeilinger Entangled photons and quantum information	Physics

Table 1. A selection of Nobel Prizes related to the physics of light dating from the invention of the laser in 1960. The descriptions are highly abridged from the formal citation, and this is only a partial list; many other Nobel Prizes have been related to light science in some way or another especially in areas of astronomy and crystallography. © Archives LKB - Photothèque ENS, 1966.

Typically around 250–350 individuals are nominated before the deadline of 31 January, and then the difficult task begins of assessing their work. As might be expected, this takes several months, and the assessment is followed by the preparation of a formal report by the Nobel Committee, which is submitted together with recommendations to the Academy. The final decision on who the laureates will be is then made in October.

The first Nobel Prizes were awarded in 1901, and according to the Testament of Alfred Nobel, the prizes were intended to be awarded for work performed during the year preceding the award. However, it was soon realized that such a strict criterion did not reflect the realistic timescale on which the impact of scientific research can actually be determined. As a result, this restriction was relaxed and the rules now allow for the recognition of research performed many years ago in cases where its significance has been appreciated only recently.

Importantly, the rules also state clearly that the prize is not a lifetime achievement or career award. Rather it is for a particular body of work or result ("invention or discovery" in physics for example) that has had impact on science, or shown the usefulness of science to society. Indeed, societal significance is a key part of the Nobel Prize, and Nobel's testament explicitly states his intention to recognize work that has led to "the greatest benefit to humankind."

Understanding these rules gives us insight into how Nobel prizes recognize both fundamental long-term conceptual advances, as well as work that has had more direct or short-term societal relevance. This dual aspect of the Nobel Prize becomes especially clear when we consider the many awards related to optics and photonics. And indeed, one particular example dates right back to the very first Nobel prizes. Specifically, although not widely appreciated, the early studies of black body radiation (that led to the development of quantum mechanics) were stimulated by a very practical and economic question: Berlin was deciding between gas and electric lighting for its urban environment, and making the best choice required standardization of the spectral efficiency of the different light sources. This practical question led to precision measurements, and although Wein was able to successfully develop a model relating source temperature to peak emission wavelength, understanding the detailed form of the full emission curve was only possible after Max Planck introduced the quantum hypothesis in 1900.

The 1921 Nobel Prize was awarded to Einstein, and one can imagine how difficult it must have been for the committee to decide which amongst his many discoveries would be the focus of the award. In the end, the official citation recognizes "services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect." Now given Einstein's immense contributions to special and general relativity, this can seem a little unusual to us now, but the wording was very carefully chosen to circumvent controversy that still surrounded relativity at the time. The presentation speech by Arrhenius mentioned relativity briefly, but focused more on Einstein's studies of Brownian motion, specific heat, photoluminescence, the photoelectric effect, as well as applications in fields such as photochemistry. In photonics, it is Einstein's prediction of stimulated emission from 1917 that is widely cited as being at the foundation of the development of the laser. Indeed, Einstein's insights here were tremendous: as well as developing the now familiar rate equation theory of emission and absorption, he realized that stimulated emission would be associated with directionality. It is this particular characteristic that allows for amplification, and whilst Einstein did not actually foresee any form of practical laser, his work is justifiably seen as central to everything that followed.

The following decades saw extensive international work extending both theory and experiment in atomic physics and light-matter interactions. This was an exciting period, and it paved the path to the first demonstration of the maser in 1953 by Charles Townes and his PhD student Jim Gordon. Townes and Arthur Schawlow wrote a theoretical proposal for the optical maser in 1958, yet it was Ted Maiman at Hughes Research Laboratories who first saw laser oscillation. Maiman had deliberately avoided complex pumping approaches that seemed to require cryogenics, and by building on his intuition that flashlamp pumping would yield a dynamic population inversion sufficient to reach threshold, he observed pulsed laser oscillation at 694.3 nm on May 16th, 1960. This date is now recognized by UNESCO as the International Day of Light. There are many excellent surveys of the diverse international contributions in quantum electronics leading to the laser.

The maser and laser were recognized in 1964 with the award of the Nobel Prize to Charles Townes, Nicolay •••

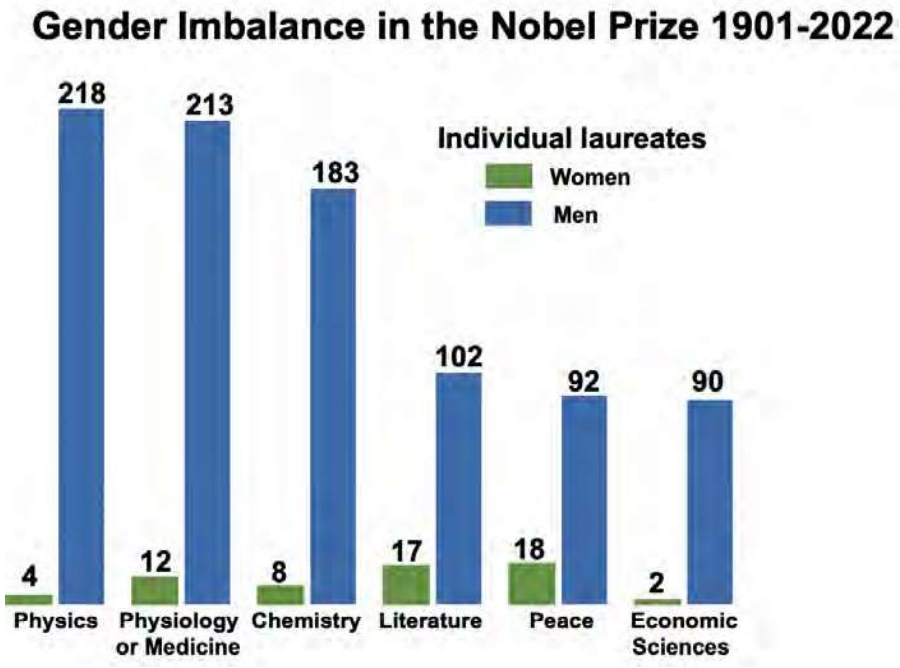

Figure 2. Plotting the public data from the Nobel prize website clearly shows the gender imbalance amongst Nobel laureates across all categories of the award. Although one reason for this imbalance is the fact that women have historically been underrepresented in some of the fields that the Nobel Prizes are awarded in (such as physics and chemistry) it is almost certain that systemic biases also play a role. For example, women are often excluded from academic and scientific networks, which can limit their opportunities for nomination and recognition. Data from nobelprize.org . Figure design adapted from 2020 infographic by Felix Richter (www.statista.com/chart/2805/nobel-prize-winners-by-gender/) CCBY 3.0

Basov, and Aleksandr Prokhorov. Two years later in 1966, Albert Kastler received the Nobel Prize for his work on optical pumping, and Bloembergen and Schawlow shared the 1981 Nobel Prize for laser applications in spectroscopy. Absent from the list of Nobel laureates are Gordon and Maiman, but we can understand this when we learn that they simply were not frequently nominated. From the Nobel archives (which are now openly accessible up until 1971) we find that Maiman was actually nominated only twice (1964 and 1969) and Gordon only once (1963). In contrast, Charles Townes received 30 nominations in the year in which he won, and had in fact been nominated a total of 75 times since 1958 (where Kastler was amongst the first of his nominators!). Clearly winning a Nobel Prize requires a strong and persistent network of supporters!

The development of the laser opened up the field of photonics with its many multidisciplinary applications, and led to the many advances in both fundamental and applied physics that members of the international optical physics community have been privileged to witness at first hand. Lasers and their impact have been recognized in many Nobel Prizes since 1960, and Table 1 highlights a selection since the invention of the laser.

However, this figure is necessarily incomplete, and we know that lasers and other photonics-related instrumentation have been central to prizes such as gravitational wave astronomy, the imaging of black holes, and no doubt many other Nobel prizes in Chemistry or Medicine or Physiology. It is highly recommended to explore the Nobel Prize website to learn more, not only about the themes that have been recognized, but also about the inspiring stories of the laureates themselves.

Considering the history of the laser is an opportunity to think about the tremendous economic and societal benefits that can arise from basic curiosity-driven scientific research. As Charles Townes himself remarked, the laser is "a textbook example of broadly applicable technology growing unexpectedly out of basic research." Anniversaries provide the chance to look to the past in order to improve the future, and as science seems to be directed more and more to short-term goal-driven objectives, the lesson of the laser is something we all need to remember.

REFERENCES

[1] Nobel Prizes in all fields and the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel have been awarded to a total of 954 individuals and 27 organisations since 1901. Laureates, nomination archives, and transcripts of the Presentation Speeches, can be seen at www.nobelprize.org

[2] H. Kubbinga, *Europhysics News* **49/4** 27-33 (2018)

[3] C. H. Townes, *How the Laser Happened: Adventures of a Scientist*, Oxford University Press (1999)

[4] T. H. Maiman, *The Laser Inventor: Memoirs of Theodore H. Maiman*, Springer (2018)

[5] M. Bertolotti, *Optica Acta: International Journal of Optics* **32**, 961-980 (1985)

[6] J. M. Dudley, *Advanced Photonics* **2**, 050501 (2020)

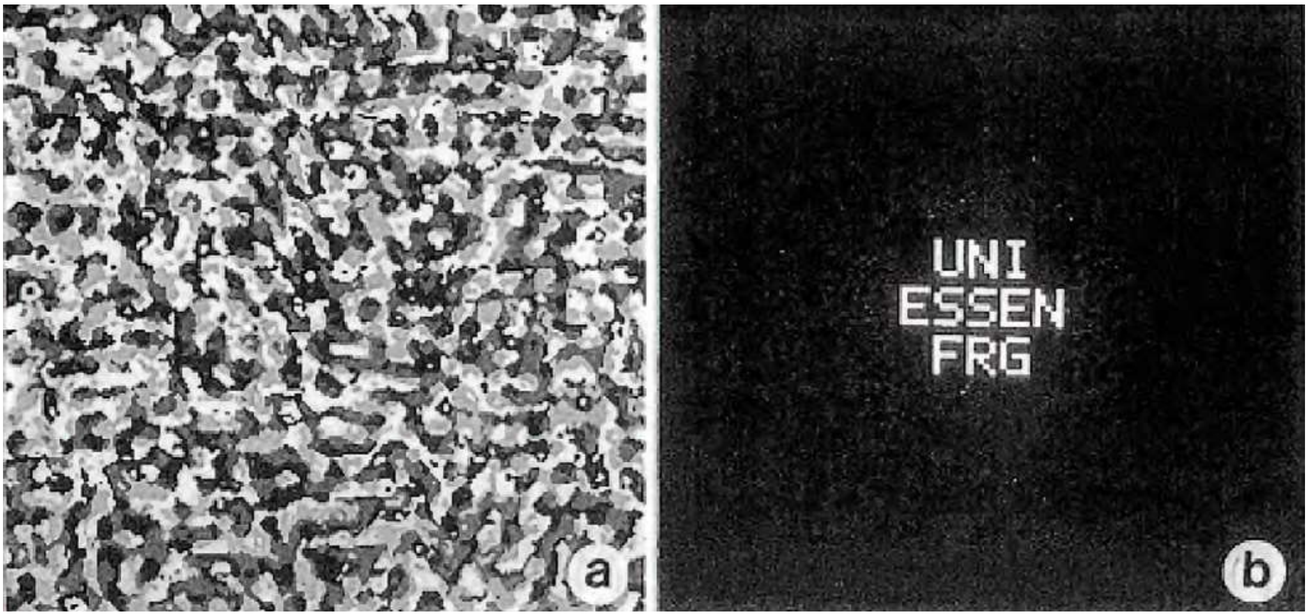

Figure 2. Example of unintuitive optimization of CGHs in the 1980's. a) Iteratively optimized 4-phase-level pattern. b) Calculated intensity of the diffracted light in a Fourier plane. Reprinted with permission from [3] © The Optical Society

deflection of light in order 1 of a grating to encode an arbitrary phase (Figure 1).

Many metasurfaces nowadays are designed with a computer and therefore qualify as "computer generated holograms". Similarly, Lohmann CGHs with a thin chromium coating qualify as "metasurfaces". In fact, as opposed to current metasurfaces, they used large cell sizes due to obvious limitations in lithography resolution at the time. Another difference is that they faithfully implemented the desired wavefront with an independent control of phase and modulus amplitude. But just like look-up type metasurfaces, they were based on one-to-one relation between the diffractive pattern and the desired local complex amplitude, and they suffered rather low diffraction efficiencies (a few percents) that are comparable to those reported in [1] with 'V' patterns of a similar thickness.

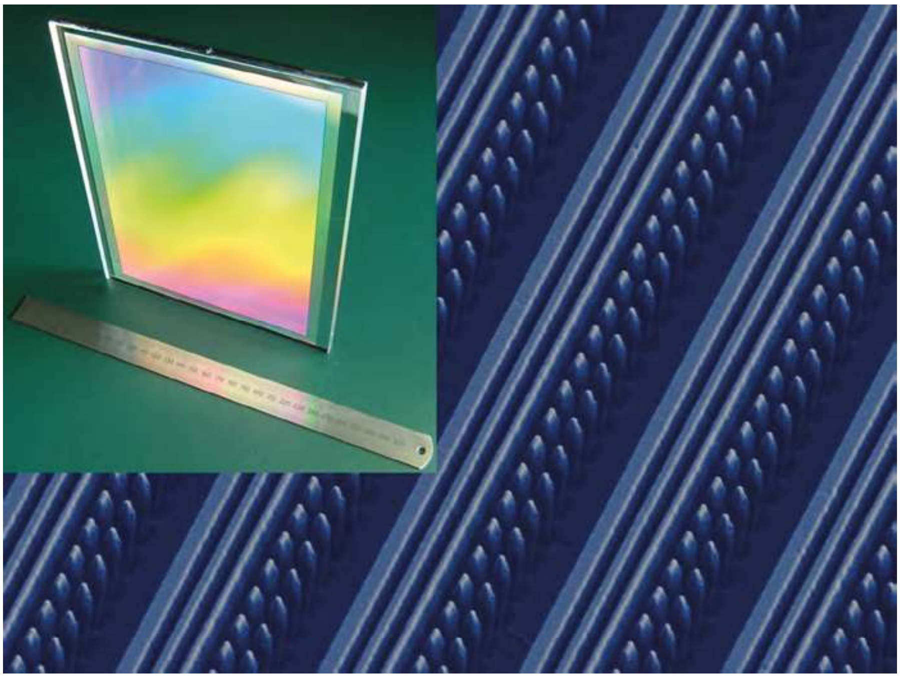

Figure 3. Scanning electron micrography of 20.5×15.5 cm^2 grating used in a spectrophotometer sent to space in 2013. The initial design was composed of pillars only for polarization insensitivity issue. Optimization has led to a combination owing to the difficulty of manufacturing high-aspect ratio pillars with large surface coverages. Courtesy Uwe Zeitner.
See [6] or http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=44093.

UNINTUITIVE DESIGN THROUGH ITERATIVE ENCODING OPTIMIZATION

Around the last quarter of the last century, efforts to improve the efficiency of such CGHs were therefore developed. To that end, the phase coding by an inclined carrier was abandoned, and therefore holographic concepts as well. In parallel, the wavefront sampling grew smaller as technology improved. Thus, it became possible to waste less energy into parasitic diffraction orders (in Fig. 1f, only a few are shown). To do this, one option is to fabricate continuous microstructures whose thickness is modulated between 0 and $\lambda/(n{-}1)$ associated to a phase delay between 0 and 2π.

This continuous approach is relevant for transmittances requiring only phase modulation, *e.g.*, lenses. When the desired transmittance further requires a modulation of the modulus of the transmitted wave, maintaining high efficiency becomes problematic and there is no general solution. However, when only the illumination matters in the observation plane as it is the case for display holograms, an elegant solution, very popular in the 80s, consists in exploiting the degrees of freedom left by the phase of the diffracted wave, and finding a transmittance $\exp i\varphi(x, y)$ of a pure phase component which produces the target intensity distribution $I_s(x', y')$ in a prescribed angular window W, while wasting as little light as possible outside that window for the benefit of diffraction efficiency.

This synthesis of phase profiles by inverse diffraction is a complex optimization problem that can be solved by iterative methods. The latter may be based on the minimization of a cost function, $E_\varphi = \iint_W \left(\eta I_s(x', y') - G_\varphi(x', y')\right)^2 dx'dy'$, where η determines the diffraction efficiency and G_φ is the intensity observed in the signal window for a given phase function $\varphi(x, y)$ at the exit of the metasurface. Generally, the cost function minimization is performed for discrete phase values. For a diffraction efficiency close to unity, the signal window differs from the target intensity distribution and the cost function takes on a large value. By lowering the targeted efficiency, *e.g.*, to 80%, very acceptable fidelity may often be achieved using 4 or 8 phase levels diffractive components (Figure 2).

The algorithms used to minimize the cost function rely on iterative direct and inverse fast-Fourier transforms in the case of a small angle window of interest, where Fourier optics is the appropriate framework. They are reminiscent of the adjoint gradient methods developed in the 1950s for logistic optimization, and further used since the 1980s for machine learning, and nowadays also for inverse design in various photonics problems. As shown in Figure 2, the resulting patterns are rather unintuitive. The technology was passed to industries around the turn of the millennium and is used nowadays for manufacturing various diffractive optical elements ("array generators" to illuminate a prescribed set of points, diffusers with specified scattering diagrams ...).

As the lithographic technology moved to smaller and smaller resolutions, electromagnetic models progressively took over from Fourier optics for modelling, implying heavier calculations but leading to wide angular windows W. In that case, the sampling period becomes smaller than the wavelength and the modulation is devoted to shaping the only existing nonevanescent order, the (0,0) order, as will be discussed in the last section.

NANOSTRUCTURED METASURFACES

Nothing was subwavelength in the visible domain before the 90's and design relied on scalar optics. In the 90's, photonic research was starting to enjoy the benefits of nanotechnologies and rapidly, metasurfaces

In parallel, the first metasurfaces composed of minutely arranged arrays of nanostructures, *e.g.*, holes, pillars, or combination of both in the most advanced design accounting for dispersion, were implemented for beam shaping or beam steering.

much similar to those encountered nowadays were implemented. In a first phase, designs inspired by effective medium theory were used for fabricating other functions than wavefront shaping including moth-eye antireflection coatings or optical analogues of the wire-grid polarizers used at radiofrequencies by Hertz in the late nineteenth century or broadband wave plates [4]. It was also during this period that the first resonant filters, now known as nonlocal metasurfaces, were successfully fabricated by etching gratings in waveguides [5].

In parallel, the first metasurfaces composed of minutely arranged arrays of nanostructures, *e.g.*, holes, pillars, or combination of both in the most advanced design accounting for dispersion, were implemented for beam shaping or beam steering. It was then realized that efficiencies much larger than those achieved with classical sawtooth surface-relief profiles could be achieved for gratings with large deviation angles or lenses with high numerical apertures, by abandoning effective medium considerations and by controlling the phase instead through high-index single-mode nano waveguides operating nearly independently [4].

As a conclusion and summarizing the progress made in the 1990s in the field, Figure 3 shows a remarkable "metagrating" [6] designed and manufactured at Jena and sent in space on 19. Dec. 2013 in the Gaia-satellite of the ESA. The grating has been optimized for operation at 850 nm. The design was able to overcome the challenges of fabricating dense pillar arrays over large surfaces and relies on a combination of tiny pillars and large ridges. Its behavior is nearly insensitive to the polarization. Over the 205×155 mm^2 area surface, the efficiency measured for unpolarized light varies between 80% and 84% and the wavefront accuracy in the first order is 8.4 nm rms. Such gratings are indeed much more costly than sawtooth profile gratings that can be fabricated at low price over large area by embossing plastic films for instance, but they are more efficient and are able to meet the stringent requirements of space applications. ●

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REFERENCES

[1] N. Yu, P. Genevet, M. A. Kats, F. Aieta, J.-P. Tetienne, F. Capasso, and Z. Gaburro, *Science* **334**, 333–337 (2011).

[2] B. R. Brown and A. W. Lohmann, *Appl. Opt.* **6**, 1739 (1966).

[3] F. Wyrowski, *J. Opt. Soc. Am. A* **7**, 961-969 (1990).

[4] H. Benisty, J.J. Greffet, and P. Lalanne, *"Introduction to nanophotonics"*, Oxford University Press, Oxford, (2022), ISBN 978-0-19-878613-9, Sections 18.4 and 18.5.

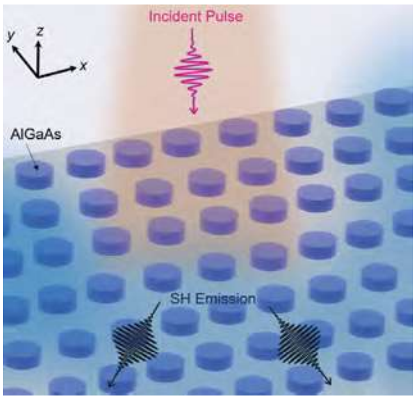
[5] S. Peng and G. M. Morris, *Opt. Lett.* **21**, 549-551 (1996).

[6] U. D. Zeitner, M. Oliva, F. Fuchs, D. Michaelis, T. Benkenstein, T. Harzendorf and E.-B Kley, *Appl. Phys. A* **109**, 789-796 (2012).

SECOND ORDER NONLINEAR OPTICS IN AlGaAs METASURFACES

Davide ROCCO[1,*], Luca CARLETTI[1], Andrea LOCATELLI[1], Andrea TOGNAZZI[2], Paolo FRANCESCHINI[1], Marco GANDOLFI[1], Alfonso C. CINO[2], Giuseppe LEO[3], Costantino DE ANGELIS[1]

[1] Department of Information Engineering, University of Brescia, Brescia, Italy
[2] Department of Engineering, University of Palermo, Palermo, Italy
[3] Matériaux et Phénomènes Quantiques, Université Paris Cité, Paris, France
*** davide.rocco@unibs.it**



Recently, nonlinear optics at the nanoscale level has emerged as a promising branch of nanophotonics. In this work, we focus our attention on Aluminum Gallium Arsenide (AlGaAs) nanoantennas and metasurfaces for efficient and controlled second harmonic photon emission. After a brief introduction concerning the main studies in this field, we present the latest results achieved in AlGaAs platforms both in the lossless and absorption regimes.

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In the last years, nano-antennas made of dielectric materials have attracted much attention for the nonlinear generation of light, mainly because of their lower loss with respect to the metallic counterparts. The nonlinear phenomena in Gallium Arsenide (GaAs) and AlGaAs nano-platforms constitute innovative solutions for pioneering researches on phenomena such as Second Harmonic Generation (SHG) in GaAs nanowires, hybrid GaAs plasmonic nano-holes, GaAs micro-ring resonators on insulator and newly, dielectric nano-antennas and metasurfaces. The AlGaAs success mainly stems from the dependence of its band-gap energy on the alloy composition. Notably, AlxGa1−xAs presents a direct gap that increases with the Al molar fraction x and permits two-photon-absorption-free operation close to the third communication window (~ 1.5 µm) for x ≥ 0.18 [1]. Another aspect to underline is that, AlGaAs possess a large non-resonant quadratic susceptibility, $\chi(2)$ (of the order of 200 pm/V for $Al_{0.18}Ga_{0.82}As$ in the near infrared) [2]. All the aforementioned properties highlight the potential of AlGaAs for achieving efficient second order harmonic generation.

In this work, we present the newest achievements related to SHG in AlGaAs platforms. The manuscript is organized as follow: firstly, we briefly describe the state of the art of these devices and their practical implications by highlighting the main breakthrough studies. Finally, we discuss the opportunity offered by AlGaAs metasurfaces to enlarge the operating working wavelength by exploiting higher order multipoles at the fundamental wavelength that guarantee a sizable SHG efficiency even in the dielectric absorption spectral region.

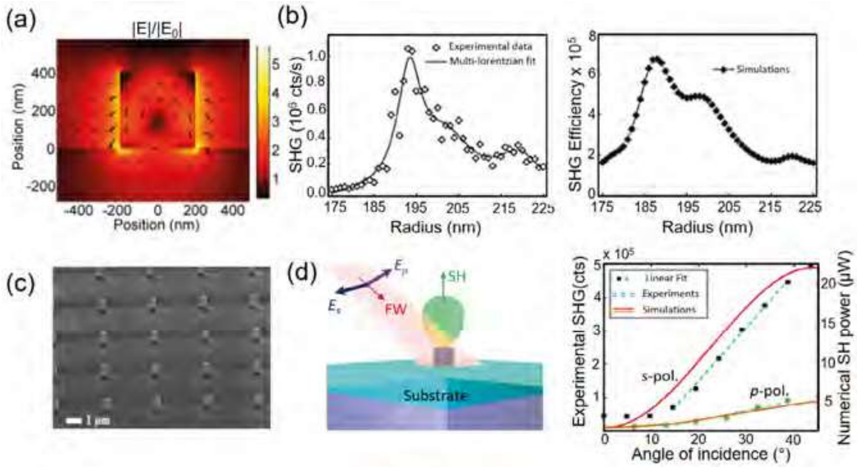
For the sake of completeness, we underline that, when facing nonlinear generated signals, the SHG efficiency is not the only interesting parameter for optical applications. For instance, a few recent studies have demonstrated that the SH phase control and engineering is fundamental for achieving nonlinear metasurfaces acting as a metalens or with considerable nonlinear beam steering performance [2], therefore increasing the potential applications of AlGaAs meta-devices.

EXPECTED CONTENTS

One of the first theoretical demonstration of the great promise of AlGaAs for nonlinear nanophotonics considered a platform made by isolated cylindrical nanodisk in a homogenous air environment which leads to an individual SHG efficiency of the order of 10^{-3}. The incident excitation, assumed to be a linearly polarized plane wave with intensity, I_0, of $1GW/cm^2$, was in the near-infrared region (1550 nm) in order to excite a magnetic dipolar resonance of the dielectric pillar (radius of 225 nm and height equal to 400 nm). Since AlGaAs belongs to the *3m* symmetry group and it presents a cubic crystalline structure, the nonlinear currents at the SH frequency can be expressed as: $J_i^{SH} = i\omega_{SH}\varepsilon_0\chi(2)E_j^{\omega}E_k^{\omega}$ with $i \neq j \neq k$ where ε_0 is the dielectric permittivity of vacuum, ω_{SH} is the SH angular frequency, and $E_{j(k)}$ is the *j(k)* Cartesian component of the electric field at the pump frequency ω. The SH signal radiated by the dielectric nanocylinder was computed by using such currents as the sources in the numerical calculations at the SH. This breakthrough numerical demonstration was shortly after followed by a laboratory experiment [1]. In this scenario, for manufacturing reasons, the cylindrical pillar was grown over a low refractive index substrate that provokes a reduction of the measured SH efficiency down to 10^{-5}. Let us point out that this value is orders of magnitude higher with respect to the record one reached in plasmonic nanoantennas. In this framework, hybrid metallo-dielectric structures have been deeply investigated [3]. Nevertheless, a lot of efforts [4-6] have also been spent to improve the SHG performance of fully dielectric devices both in terms of nonlinear efficiency and emission directivity as reported in Fig. 1.

More recently, dielectric nanoresonators have been proved to sustain modes with extremely high quality-factor, *Q*, by demonstrating that an individual AlGaAs nanocylinder can attain high *Q* supercavity modes which originate from the interference of two similar leaky modes. This mechanism, which is inspired by • • •

Figure 1. (a) The electric field distribution around the MD resonance and the (b) experimental and simulated SHG efficiency as a function of the pillar radius. (c) SEM image of an AlGaAs cylindrical sample. Adapted with permission from [1] © The Optical Society. (d) The SH directivity toward the normal direction can be increased by tilting the input wavefront.



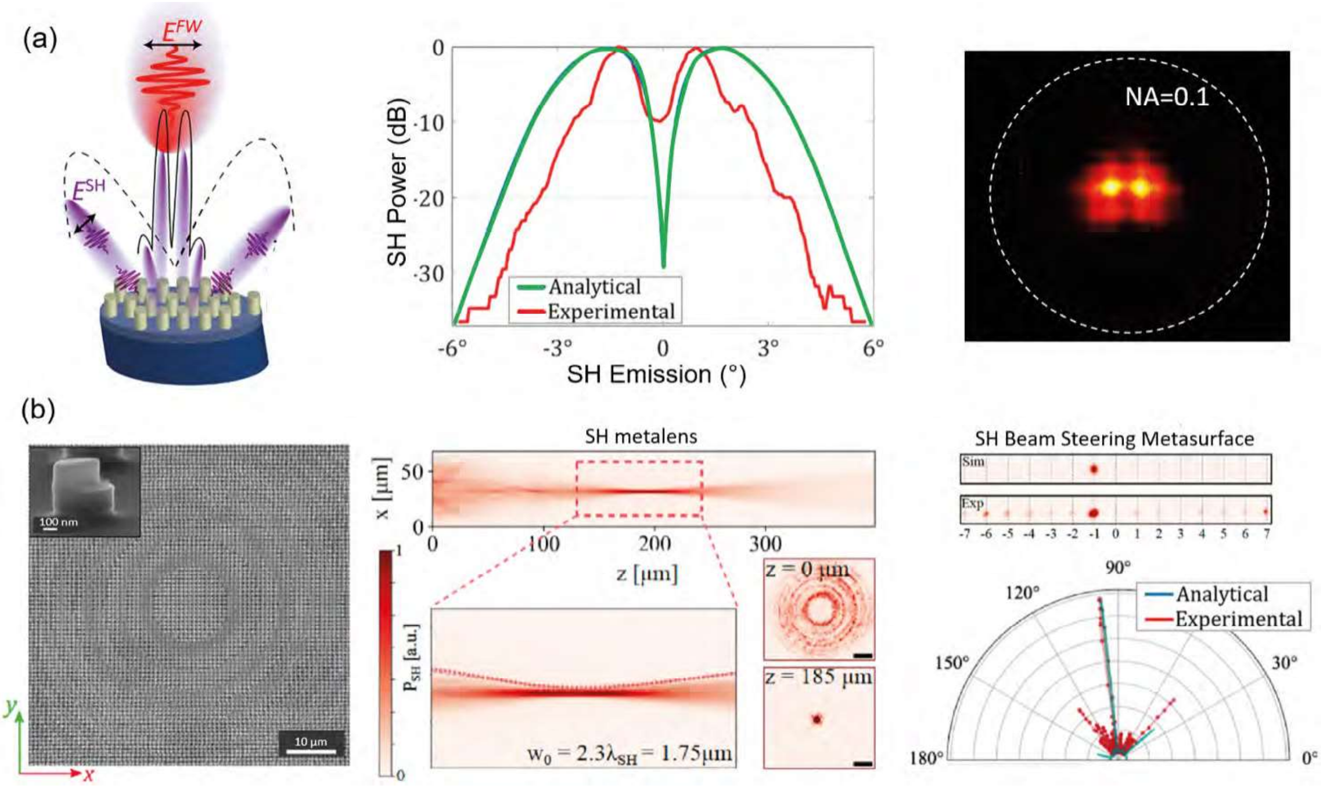


Figure 2. (a) Analysis of the SHG in an AlGaAs metasurface close to the normal direction. (b) SH metalens and beam steering for AlGaAs metasurface with nano-chair meta-atoms. Adapted with permission from [2] © The Optical Society.

the physical concept known as Bound-state In the Continuum (BIC), is today generally referred to as quasi-BIC [5]. Importantly, it has been proved a huge SHG enhancement when the resonator (an AlGaAs nanodisk) parameters are tuned to the quasi-BIC regime. The obtained SH efficiency surpasses by 2 orders of magnitude the largest one achieved when a magnetic dipolar resonance is excited at the fundamental wavelength. All these concepts, related to the isolated nanoresonator, have been subsequently implemented in nonlinear metasurfaces (*i.e.* structures obtained by properly engineering the spatial repetition of the individual pillar) design [2], as summarized in Fig. 2.

In any case, most of the aforementioned solutions are related to the circumstance where either the pump and emission wavelengths are in the lossless region of the nonlinear material that constitutes the metasurface under consideration. Instead, in the following, we exploit the extreme versatility offered by AlGaAs platforms which allows to efficiently operate even beyond the material transparency window. In more details, we reveal that, for an optimized structure, the SH efficiency emitted in the visible part of the electromagnetic spectrum

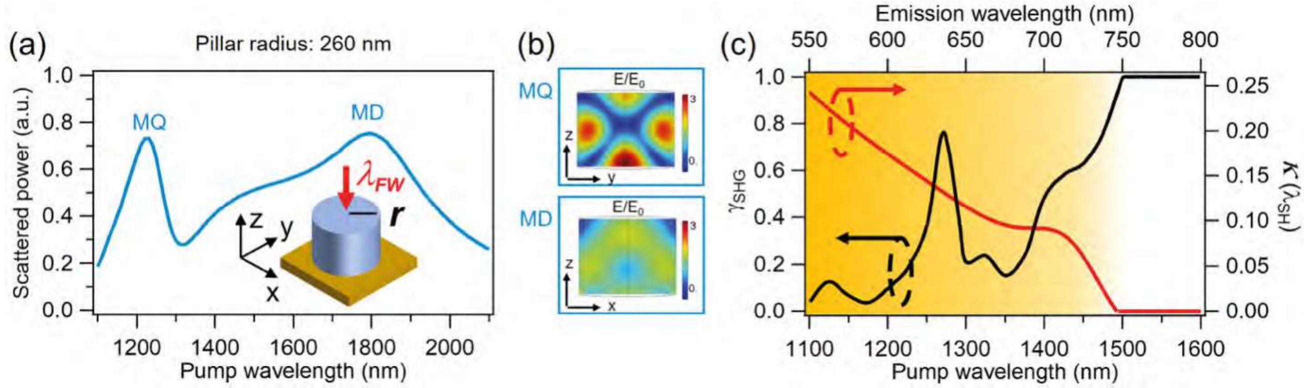


Figure 3. (a) Scattered power as a function of the incident pump wavelength for the pillar with radius 260 nm, height 400 nm. (b) Normalized field distributions at the MQ and MD resonances (c) The γSHG parameter as a function of the incident wavelength evaluated for the nanodisk with radius of 260 nm (left axis, blue curve) in comparison with the imaginary part of the complex AlGaAs refractive index (right axis, brown curve) as a function of the emission wavelength. Adapted with permission from [7].