



NEWSLETTER

COMMISSION INTERNATIONALE D'OPTIQUE • INTERNATIONAL COMMISSION FOR OPTICS

Getting used to quantum optics ...

... and measuring one photon at both output ports of a beam splitter.

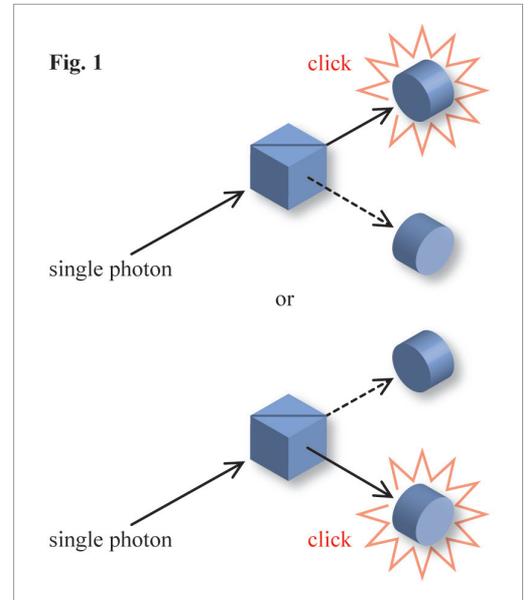


INTERNATIONAL
YEAR OF LIGHT
2015

When asked whether a photon can be split, one familiar with parametric down conversion (PDC) is tempted to answer yes, of course. In PDC, a photon is absorbed and two new ones are created, their energies adding up to the energy of the initial photon. In a way one might say that the PDC interaction is a perfect beam splitter, the two output beams being perfectly correlated. This nonlinear optical process is one of the workhorses in quantum optics and deserves many pages of appraisal¹ – but it is not the subject of this article. In this article I address the question of whether or not a single photon is split on a normal beam splitter, which is a linear optical element² – split in the sense that it will simultaneously affect the signal measured by two detectors in the two output ports of the beam splitter.

Let us begin by asking the fundamental question: What is a photon? Interestingly, this question (one to which there have been multiple, and sometimes conflicting, responses) takes us to Maxwell's equations, which celebrated their 150th anniversary in the International Year of Light, 2015. Maxwell wrote down his famous equations well before Fitzgerald first published what was later called the Lorentz transformation and well before quantum theory was formulated. Yet in a way, Maxwell anticipated the later developments: The equations in vacuum are invariant under Lorentz transformation, and their solutions are functions describing the modes in which the quantized field excitations live. And on top of this, it seems as if Maxwell's equations are also closely related to the properties of the quantum vacuum (see appendix).

Light as described by Maxwell's equations has four degrees of freedom (DOF), the helicity and the three components of the momentum vector. These can be translated into the polarization,

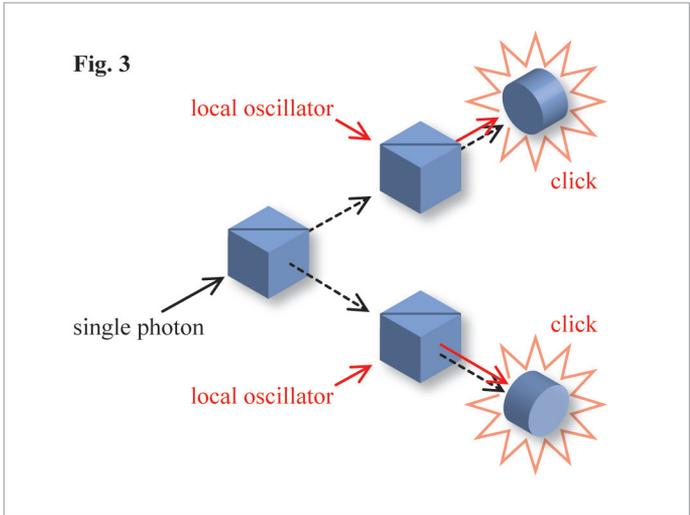
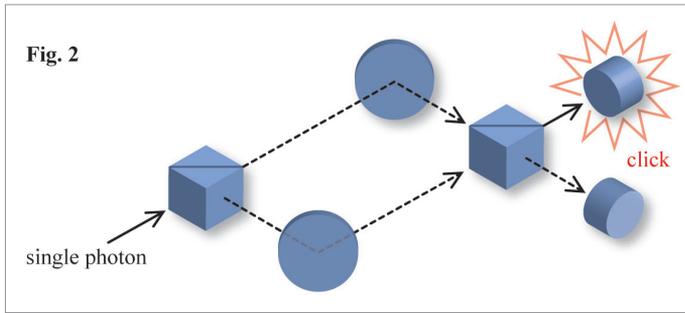


the transverse mode profile (two DOFs) and frequency. The four degrees of freedom provide the space where quantum excitations “live”. Since the quantum description of field modes is analogous and mathematically identical to that of a quantum harmonic oscillator, it is not surprising that the energy spectrum of the light field is comprised of equidistant energy levels, describing the energy in the mode. If the mode is in the n th energy eigenstate, one says that there are n photons in the mode. In that sense a single photon refers to the first excitation of this mode. For many practical purposes a mode can be thought of as an object with finite spatial extent and which may be moving with time. The first excited state of this moving mode is called a single photon wave packet, or simply a single photon.

In most systems of interest, multitudes of photons exist simultaneously. We thus ask the question, can we produce a single photon, i.e., is it possible to put a single quantum of energy into a particular mode of a system? The answer is yes, and interestingly, one standard method is by parametric down conversion. We do not know when we will detect a photon produced by PDC, but we do know that it is accompanied by a twin. Thus, upon detecting one photon of the pair we can be sure that the other one is

¹ Theory: W H Louisell, A Yariv, A E Siegman, *Physical Review* 124, 1646 (1961); and D N Klyshko, *Soviet Phys. JETP Letters* 6, 23 (1967)
Experiment: (3 in one year): S E Harris, M K Oshman, R L Byer, *Physical Review Letters* 18, 732 (1967); D Magde and H Mahr, *Physical Review Letters* 18, 905 (1967); and S A Akhmanov, V V Fadeev, R V Khozhlov, O N Chunaev, *JETP Letters* 6, 85 (1967)

² A Luis, L L Sánchez-Soto, *Quantum and Semiclassical Optics* 7, 153 (1995)



³ H J Kimble, M Dagenais, L Mandel, *Phys. Rev. Lett.* 39, 691 (1977)
⁴ J D Cresser, J Häger, G Leuchs, M Rateike, H Walther, *Topics in Current Physics* 27 (edited by R Bonifacio), 21 (1982)
⁵ P Grangier, G Roger, A Aspect, *Europhys. Lett.* 1, 173 (1986)
⁶ $|\Psi_{in}\rangle = |1\rangle_a |0\rangle_b$ and $|\Psi_{out}\rangle = \frac{1}{\sqrt{2}}(|1\rangle_c |0\rangle_d + e^{i\phi} |0\rangle_c |1\rangle_d)$, a and b denoting the two input and c and d being the two output ports of the beam splitter. This is also referred to as a photon entangled with the vacuum. Representing the system by this Fock state basis makes it obvious that a measurement of the energy, such as by a click detector, will result in measuring the photon at either of the two ports but not in both
⁷ 'Symmetric' refers to the output port at which two paths interfere positively – one path along which the photon was first reflected and then transmitted and the other path vice versa
⁸ S M Tan, D F Walls and M J Collett, *Physical Review Letters* 66, 252 (1991)

there: we have a conditionally prepared single photon wave packet, conditioned on the detection of the twin.

Such a single photon wave packet we now let impinge on a beam splitter. Conventional wisdom tells us that while the beam splitter may well split a macroscopic beam of light, it does not split a single photon: a single photon is undividable (at least under linear interaction); it is either transmitted or reflected but not both. This statement we want to challenge.

First, we remind ourselves of the reason for this statement. In the standard arrangement a single photon is sent to a beam splitter at the outputs of which two click detectors are placed. These are detectors capable of detecting single photons. A short electrical pulse “click” indicates the absorption of a photon by the detector, as suggested in fig. 1. In such a scenario only one detector clicks in response to a single input photon^{3,4,5}. Hence the statement that a photon is undividable and will be either reflected or transmitted. One can even formulate a model ascribing a stochastic property to the beam splitter responsible for sending the photon out of either of the two output ports. This is alright; the model describes the experiment satisfactorily. Yet, deep inside one may sense a little grumbling: is the beam splitter not a unitary element and would that not exclude any stochastic operation? And yes, there is this other view: the beam splitter “divides” the photon and sends it out both ports. In quantum physics this is described by the superposition of two quantum states, one photon in the first output port and none in the second super imposed with no photon in the first and one photon in the second output port⁶. In this model the detectors introduce the stochastic element. Whether or not they click is stochastic, with the boundary condition that the detection process “projects” the quantum state to a localized single photon state at the detector, the detection process requiring the full energy of the photon. The other detector will then never click in coincidence. If the experiment is repeated many times one finds that each detector has a 50% probability to click. This projection is the conceptually

difficult part of quantum physics: in the quantum theoretical description an object is viewed as a wave described by a wave function, a concept well familiar from everyday life with interference, dispersion etc.; but in a quantum measurement much of the information content is lost, the object ‘appearing’ at one particular location (projection) although the wave function describing the object before detection was delocalized. The most common way to come to terms with this concept of ‘projection’ is to perform as many experiments as possible and to educate oneself to develop the proper understanding and intuition. So let us do the next experiment.

We now test whether the stochastic model of the beam splitter properly describes the more complex situation encountered when the two output beams of the first beam splitter are recombined on a second beam splitter. Obviously the system is an interferometer and the stochastic model does not work. For identical 50% beam splitters it would predict the photon to exit stochastically on either output port of the second beam splitter, independent of any change in the difference of the optical path lengths of the two interferometer arms. The contrary is what one observes. If the arm lengths are exactly equal the photon will exit from the symmetric⁷ interferometer output, as illustrated in fig. 2. If the path length difference is changed, the count rates at the two output ports are complementary varying in a sinusoidal manner such as to add up to the constant entrance count rate. But this, one may argue, is not the decisive measurement, because we do not measure through which arm of the interferometer the photon travels. Two decades ago this question was open for a while.

Then, back in 1991, Tan, Walls and Collett⁸ proposed repeating the single beam splitter experiment, this time not with click detectors measuring the energy in the beam but rather with detectors measuring electromagnetic fields, so called field quadratures, using

A homodyne detector is comprised of a local oscillator, a beam splitter and a direct photo detector. Measurement by a homodyne detector projects the excitation of the mode onto a precise value of an electric field component (called field quadrature). The phase of the local oscillator determines which field quadrature is measured. Heisenberg's uncertainty principle requires that the eigenstates of the field quadratures have infinite energy. Therefore, in practice, one will always measure the field quadrature with a residual uncertainty. Measuring both output ports of the beam splitter inside the homodyne detection device and taking the difference of the two direct detector readings is called balanced homodyne detection. With field quadrature detectors one and the same "photon" can induce measurement results in two different detectors, unlike in the case of click detectors.

⁹ Both types of measurement 'click' and 'homodyne' are destructive, demolishing the excitation in the mode they measure. Quantum non-demolition experiments exist but will not be discussed here

¹⁰ Electric field variance $E^2 = \hbar\nu/\epsilon_0 V$, with \hbar = Planck's constant, ν = optical frequency, ϵ_0 = dielectric constant and V = volume of mode

¹¹ C Gabriel, C Wittmann, D Sych, R Dong, W Mauerer, U L Andersen, C Marquardt, G Leuchs, *Nature Photonics* 4, 711 (2010)

¹² C Riek, D V Seletskiy, A S Moskalenko, J F Schmidt, P Krauspe, S Eckart, S Eggert, G Burkart and A Leitenstorfer, *Science* 350, 420 (2015)

¹³ G Björk, P Jonsson and L L Sánchez-Soto, *Physical Review A* 64, 042106 (2001)

¹⁴ B Hessmo, P Usachev, H Heydari and G Björk, *Physical Review Letters* 92, 180401 (2004)

¹⁵ S J van Enk, *Physical Review A* 72, 064306 (2005)

¹⁶ A I Lvovsky, H Hansen, T Aichele, O Benson, J Mlynek and S Schiller, *Physical Review Letters* 87, 050402 (2001)

¹⁷ M G Raymer, M Beck and D F McAlister, *Phys. Rev. Lett.* 72, 1137 (1994); A I Lvovsky and M G Raymer, *Reviews of Modern Physics* 1, 299 (2009)

¹⁸ S A Babichev, J Appel and A I Lvovsky, *Physical Review Letters* 92, 193601 (2004)

¹⁹ M D'Angelo, A Zavatta, V Parigi and M Bellini, *Physical Review A* 74, 052114 (2006)

²⁰ M Fuwa, S Takeda, M Zwier, H M Wiseman and A Furusawa, *Nature Communications* 6, 6665 (2015)

²¹ G K Gulati, B Srivathsan, B Chng, A Cerè, D Matsukevich and C Kurtsiefer, *Physical Review A* 90, 033819 (2014)

²² R Maiwald, A Golla, M Fischer, M Bader, S Heugel, B Chalopin, M Sondermann and G Leuchs, *Physical Review A* 86, 043431 (2012)

²³ I Elishakoff, *Applied Mechanics Reviews* 58, 117 (2005)

homodyne detectors. With homodyne detection there is no projection onto an energy eigenstate of the field. Of course, ultimately the photo-detector measures energy, but this energy is provided by the superposition of the single photon and the local oscillator⁹. Ideally, a homodyne detector rather projects onto a field quadrature eigenstate of the signal field. Thus, without any excitation in the signal mode, homodyne detection can be used to measure the zero point electric field uncertainty of the light¹⁰, one application being a high-speed quantum random number generator¹¹. For a related measurement of the field variance of the ground state see Riek *et al*¹².

Implementing the proposal by Tan *et al*⁵ did not seem easy. So 10 years later, Björk, Jonsson and Sánchez-Soto¹³ proposed a variation that combined a local oscillator with click detectors instead of the less sensitive direct photo detectors and that seemed more accessible experimentally. Then in 2003, Hessmo, Usachev, Heydari and Björk¹⁴ actually conducted the latter experiment. A simplified illustration of the experimental system is shown in fig. 3. The experiment showed that a single photon at the input of the beam splitter caused correlated clicks at the two detectors. Depending on the relative phase of the two local oscillators the clicks were correlated, anti-correlated or uncorrelated. With the input photon blocked, there was no correlation for any relative local oscillator phase settings. This was the decisive experiment, which resolved the dispute on whether or not the superposition state displayed in footnote 3 qualifies as quantum entanglement¹⁵. The experiment is also conceptually quite important because it means that a single photon can have a simultaneous influence at two distant

locations. The experiment proposed by Björk, Jonsson and Sánchez-Soto⁹ and performed by Hessmo *et al*¹¹ is a seminal experiment that has not yet received the recognition it deserves.

In hindsight, another seminal paper by Lvovsky, Hansen, Aichele, Benson, Mlynek and Schiller¹⁶ also involved the splitting of a single photon. In their experiment a single photon interfered with a local oscillator on a beam splitter and two direct detectors measured the signal at the two output ports comprising a homodyne detector. The difference of the signals measured with the two direct detectors (see box) was recorded and used as the input data for tomographic reconstruction of the single photon Wigner function¹⁷, requiring the experiment to be repeated many times. The correlation between the signals at the output ports was, however, not recorded separately. Two such set-ups would have been required for the experiment proposed by Tan *et al*⁵.

Closely related to the experiment by Hessmo *et al*.¹⁰ and submitted and published only a few weeks later is the work by Babichev, Appel and Lvovsky¹⁸, who used homodyne detection following more closely the proposal by Tan *et al*.⁵ By now several groups have exploited the simultaneous detection of a single photon with two detectors^{19,20}. One may not only detect a single photon simultaneously at two different locations – with the help of local oscillators – but one can also measure a single photon at the same location at different times. Gulati, Srivathsan, Chng, Cerè, Matsukevich and Kurtsiefer²¹ have performed such an experiment recently looking at the fluorescence of a single Rubidium atom using a local oscillator. The data shown are accumulated over many measurements, but in principle a single measurement on a single photon should show the exponential shape of the wave packet with a signal to noise ratio of two provided the whole solid emission angle is recorded. Collecting the fluorescence with a deep parabolic mirror should make this demonstration feasible²².

As a conclusion one might say that nature challenges us if we want to cast it into models and theoretical frames. At times one recognizes that a concept that was helpful throughout most of our lives as physicists has to be modified. In the middle of this process of modification there may be heated discussions and disputes, and for a while one may be reminded of a phrase one can read in a paper by Elishakoff:²³ "The world is divided into people who think they are right". But the good thing about science is that in the end the dispute converges because scientists have learnt the survival strategy: if new experimental results challenge the old view – such as a single photon being either reflected or transmitted at a beam splitter – then one has to accept this, be flexible and develop a more appropriate point of view.

Acknowledgement

It is my great pleasure to acknowledge helpful and enlightening discussions with Elisabeth Giacobino, Luis Lorenzo Sánchez-Soto, Maria Vladimirovna Chekhova, Markus Sondermann, Christoph Marquardt, William T Rhodes and Angela M Guzman.

Appendix

One may speculate about a possible (and maybe obvious) connection between classical optics, i.e., Maxwell's equations, and the modern quantum vacuum, which is not void but filled with virtual elementary particles. A light field polarizes this vacuum and any linear response of the vacuum must be part of Maxwell's equations. In this sense Maxwell's displacement would be merely the sum of the polarization

of the vacuum and real matter and the linear response of the vacuum is already accounted for in his equations: $\vec{D} = \epsilon_0 \vec{E} + \vec{P} = \vec{P}_{vac} + \vec{P}_{mat}$. See G Leuchs, A S Villar, L L Sánchez-Soto, *Appl. Phys. B* 100, 9 (2010) and G Leuchs, L L Sánchez-Soto, *Eur. Phys. J. D* 67, 57 (2013).



Gerd Leuchs, professor of physics, Institute for Optics, Information and Photonics, Univ. Erlangen. Director of the Max Planck Institute for the Science of Light in Erlangen. His research spans the whole range from classical to quantum optics.

Aydogan Ozcan awarded the 2015 ICO Prize



Aydogan Ozcan, Chancellor's Professor and HHMI Professor in the Electrical Engineering Department of the University of California at Los Angeles (UCLA).

The ICO Prize Committee awarded the ICO Prize 2015 to Aydogan Ozcan, Chancellor's Professor and HHMI Professor in the Electrical Engineering Department of the University of California at Los Angeles (UCLA). The award citation reads: "for his seminal contributions to bio-photonics technologies impacting computational microscopy and digital holography for telemedicine and global health applications".

Dr Ozcan is one of the most innovative researchers in the bio-photonics field. Together with his group he pioneered the area of lensless high-throughput cytometry and computational on-chip microscopy platforms (see figures 1-3). Various means of counting, imaging or characterizing cells have been available for many years now. However, most of the existing systems are either quite complex and expensive or have low throughput. As a transformative solution, Ozcan developed a high-throughput computational on-chip microscopy system that can analyze more than 100,000 cells in a few seconds over a sample field of view of $>10\text{-}20\text{cm}^2$. Using this platform, which is based on partially coherent digital in-line holography, Ozcan demonstrated landmark results for computational on-chip imaging, including the imaging of single viruses or nanoparticles across a very large field of view. The technique consists of forming liquid nano-lenses around each nano-particle seated on a hydrophilic surface. These self-assembled nano-lenses are stable for more than an hour at room temperature without significant evaporative loss, and are composed of a bio-compatible buffer that prevents nano-particle aggregation while also acting as a spatial 'phase mask' that relatively enhances the scattered light from the embedded nano-particle/nano-

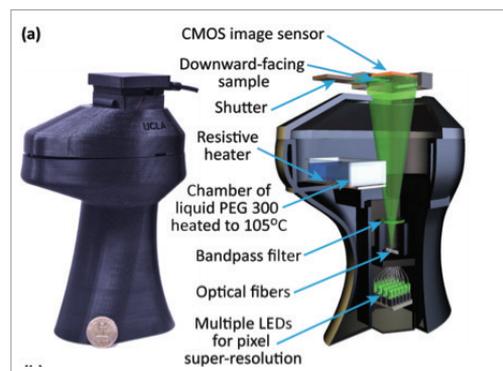


Figure 1. Nanoparticle imaging and sizing platform based on lensfree holographic imaging on a chip. Physical hardware photograph and diagram are shown. Imaging and vapor-condensed nanolens self-assembly are performed in a single hand-held device.

lens assembly. These results constitute the first time that single nano-particles and viruses have been imaged using lens-free on-chip imaging techniques. Such an advancement in performance is achieved through a unique implementation of pixel-super-resolution in partially coherent lens-free holography as well as self-assembly of liquid nano-lenses that enhance the holograms of individual nano-objects. The same computational framework was also pushed by Ozcan's lab into a field-portable and cost-effective nano-particle imaging and quantification interface, with various applications in environmental monitoring and biomedicine.

Another unique landmark result that Ozcan pioneered is a wide-field lens-free on-chip imaging technique that can track the three-dimensional (3D) trajectories of $>1,500$ individual human sperms within an observation volume of $\sim 8\text{-}17\text{mm}^3$ with sub-micron accuracy. This high-

throughput imaging platform demonstrated more than an order of magnitude larger imaging volume compared with other microscopy tools, permitting the tracking of 3D swimming patterns of human or animal sperms over several hours.

Some of these computational imaging and microscopy techniques of Ozcan (see figures 1-3) are miniaturized and integrated onto regular smart phones and thus show significant promise for telemedicine and point-of-care diagnostic applications, especially relevant to global health problems in resource-limited setting.

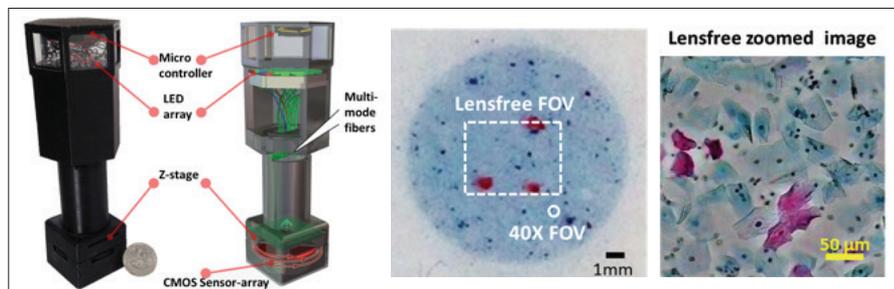


Figure 2. (Left) A prototype of a handheld lensfree super-resolution microscope (weighing <200 grams – shown next to a US quarter) that can achieve sub-micron resolution over a wide field of view (FOV) of >20 mm². This lensfree microscope is based on digital in-line holography and pixel super-resolution and its assembly is extremely cost-effective. (Right) High-resolution and wide-field imaging of a Pap smear using lensfree microscopy.

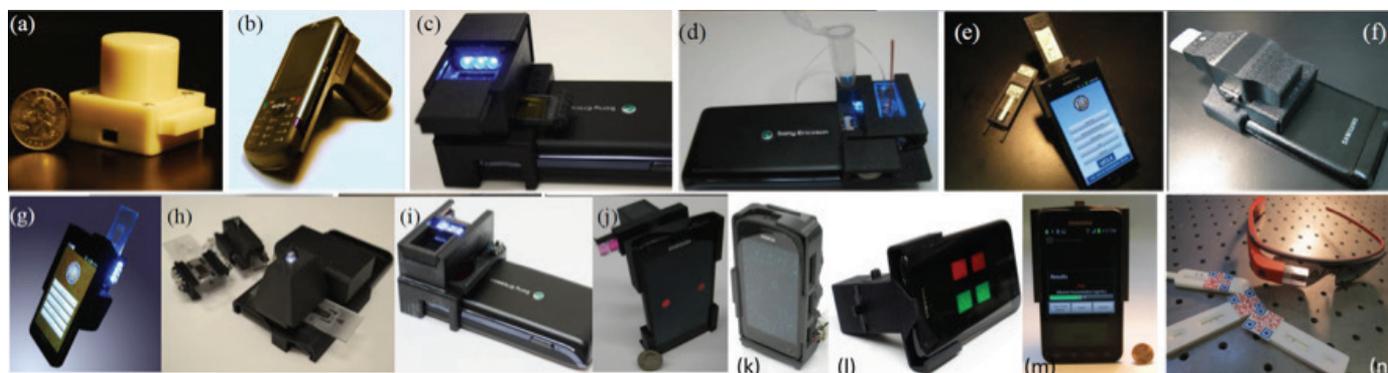


Figure 3. Computational Microscopy, Sensing and Diagnostic Tools – Created in Ozcan's Lab. (a) A lensfree holographic microscope that weighs ~45 grams. (b) A cellphone that is modified based on the same lensless holographic microscopy technology. (c) A wide-field fluorescent microscope that is installed on a cellphone using a compact and cost-effective optical interface. (d) An imaging fluorescent flow-cytometer installed on a cellphone. (e-f) A cellphone attachment for automated reading and quantification of immunochromatographic rapid diagnostic tests (RDTs). (g-h) A compact and cost-effective blood analysis platform installed on a cellphone for the measurement of the density of red and white blood cells as well as hemoglobin concentration in blood samples. (i) An optical attachment for *E. coli* detection on a cellphone using quantum dot based sandwich assay in glass capillary tubes, with a detection sensitivity of ~5-10 CFU/mL. (j) A personalized allergen testing platform running on a cellphone that images and automatically analyzes colorimetric assays toward sensitive (~1 ppm) and specific detection of allergens in food samples. (k) Cellphone based fluorescent microscope that is capable of imaging single nanoparticles. (l) Detection and spatial mapping of mercury contamination in water samples using a smart-phone (sensitivity: ~3-4 ppb). (m) Smartphone-based urinary albumin tester. (n) Immunochromatographic diagnostic test analysis using Google Glass. <http://goo.gl/uYeikn>

2015 IUPAP Young Scientist Prize in Optics



Dr Frank Koppens, professor at ICFO, Barcelona, Spain, who initiated the field of graphene plasmonics.

Dr Frank Koppens from ICFO – The Institute of Photonic Sciences in Castelldefels (Barcelona), Spain – was awarded the 2015 IUPAP Young Scientist Prize in Optics for “his remarkable, outstanding, groundbreaking, pioneering and numerous contributions to Nano-Optoelectronics”.

Dr Koppens conducted his PhD research in Delft under the supervision of Leo Kouwenhoven and Lieven Vandersypen, one of the top scientists working on quantum information processing with spins. In recognition of this achievement, he was awarded the prestigious Huygens prize for his ground-breaking work on quantum technologies”. After his PhD, Dr Koppens obtained a postdoctoral position at Harvard with a prestigious IQC fellowship.

Koppens is a world leading researcher on

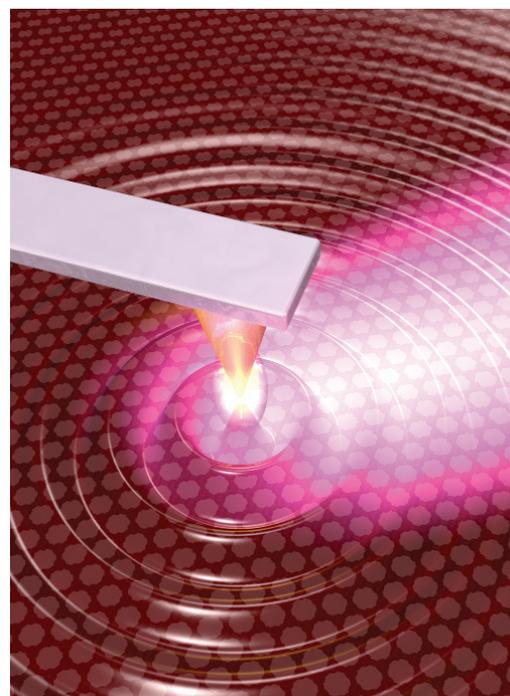
graphene nano-optoelectronics and nano-optics. His diverse research activities have led to high-impact publications and to new research directions followed by many other researchers. One example is the first realization of an integrated quantum plasmonic circuit with on-chip detection [*Nature Physics* 5, 475 (2009)]. This hybrid quantum nano-optoelectronic system, interfacing single photons, plasmons and electrical plasmon detectors, has enabled electrical detection of surface plasmons emitted by a single quantum dot.

Koppens’ contributions to the graphene opto-electronics field have laid the foundation for two novel subfields: graphene-based hybrid systems and graphene nano-photonics (surface plasmonics). Koppens’ group demonstrated the first highly-sensitive graphene-based

photodetection for infrared frequencies [*Nature Nanotechnology* 7, 363 (2012)], using a hybrid device based on graphene and semiconductor nanoparticles, which exhibits a detection sensitivity 10 million times higher than former existing graphene photodetectors. This landmark advance has opened pathways for novel infrared detectors, flexible detectors for wearables etc.

Graphene, a material with many fascinating properties, exhibits extraordinary optical behaviour. One specific outstanding feature is the so-called surface plasmons, wave-like excitations that were predicted to exist in the sea of conduction electrons of graphene. The wavelength of graphene plasmons is 100 to 150 times smaller than the wavelength of light, enabling very strong light confinement as well as slow light, relevant for a plethora of applications such as sensors and opto-electronics.

Graphene surface plasmons are tunable by voltages and can be converted into electrical signals, providing a unique platform for merging nano-photonics and nano-electronics. Dr Koppens was one of the pioneers in this field of graphene plasmonics. He recognized the potential of graphene surface plasmons and published pioneering work (e.g. *Nano Lett.* 11, 3370 (2011)) establishing new directions for graphene optics and opto-electronics. Shortly after, his long sought after goal was achieved: the first observation of propagating graphene surface plasmons and active electrical control of graphene-based plasmonic cavities [*Nature* 487, 77 (2012)]. The experiments revealed that graphene is an excellent host for guiding, confining and electrical manipulation of light at nanoscale dimensions. Recently, the group led by Koppens has realized significant progress in the field of graphene plasmonics by exploiting graphene-boron nitride heterostructures [*Nature Materials* 14, 425 (2015)] and showing high-quality factors for highly-confined plasmons and antenna-based plasmon launching [*Science* 344,

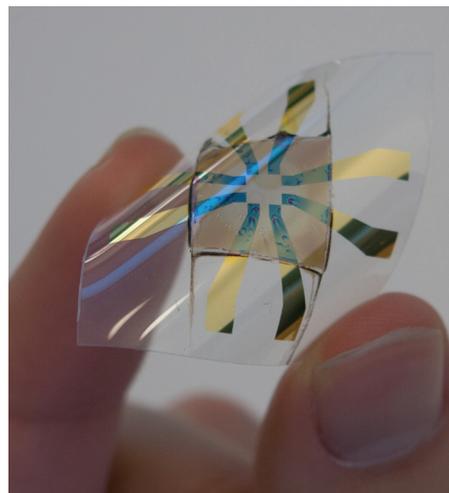


Light propagating along the surface of graphene (plasmons), visualised by a scanning near-field microscope.

1369 (2014)].

They have also performed pioneering work investigating graphene as a promising material for light harvesting and photodetection. This includes the first observation of highly efficient carrier interactions after photo-excitation in monolayer graphene and the quantification of the conversion efficiency of light into the electronic degree of freedom [*Nature Physics* 9, 248 (2013)]. The field of carrier-carrier and light-carrier interactions in graphene is very rich, as it involves many-body interactions and ultra-fast timescales. The strong carrier-carrier interactions were recently observed and monitored with record-high time resolution [*Nature Nanotechnology* 190, 437 (2015)].

Left: Graphene enabled flexible wristband. Right: A flexible photodetector.



Correlation Optics 2015 held in Ukraine

The 12th International Conference of a series initiated in 1993 was held in Ukraine.

Despite political circumstances in Ukraine associated with Russia's occupation of Crimea and a part of Donbass, the Twelfth International Conference on Correlation Optics was held on 14–18 September at Chernivtsi National University (Ukraine). Participants from Canada, China, Denmark, Finland, France, Germany, India, Israel, Japan, Mexico, Poland, Romania, Scotland, South Korea, Spain, Sweden, Ukraine, UK, and USA, contributed about 120 research reports. The number of participants was smaller than on previous occasions, lacking the usual contributions of researchers from Russia and Crimea.

The main topics of the conference are singular optics; information content of statistical optical fields, including optical chaos, polarization optics, and coherence; optical correlation devices based on diffractive optical elements, including optical and digital holography, fractal optics, and optical sensors; optical correlation diagnostics, interferometry and microscopy of rough surfaces and random media; and new applications of correlation optics in biology and medicine.

Among invited speakers were Prof. M Berry (UK), Prof. Y Miyamoto (Japan), Prof. G Swartzlander (USA), Prof. K Bliokh (Japan), Prof. S Hanson (Denmark), Prof. Tim Lee (Canada);



On the first day of the conference, from left to right: chair of the conference Prof. Oleg V Angelsky, Sir Michael V Berry (University of Bristol, UK) and Dr Valeriy Yashchuk (Lawrence Berkeley National Laboratory, USA).

and the invitees of the OSA/SPIE Student Chapters: Prof. M Berry from the University of Bristol (UK), Prof. M Dennis from the University of Bristol (UK), and Prof. A Bekshaev from Odessa University (Ukraine).

ICO contributions helped support the participation of students from the Optical Engineering Department of the National Technical University of Ukraine "Kyiv Polytechnic Institute". The proceedings of the Conference has been published in Proc. SPIE V. 9809.

Optics in Indonesia: ISPhOA to be held in 2016

The 1st International Seminar on Photonics, Optics, and its Applications in Bali.

The first International Seminar on Photonics, Optics, and its Applications (ISPhOA 2014) was held 14–15 October, 2014, at the Sanur Paradise Hotel, Sanur, Bali. It was the first international scientific event to be organized by the Department of Engineering Physics – FTI, the Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. As a debut, the organizing of this scientific event was regarded as a big success, and the organizer decided then to make it a biannual scientific event that will be held in even-numbered years. As it was started in year 2014, the second ISPhOA will be held in 2016.

The seminar gathered contributions from 11 invited speakers from ASEAN countries (Indonesia, Malaysia, Singapore, and Thailand), Europe (Germany, UK), Australia, and USA. In addition to the invited papers, 42 contributed papers were accepted for presentation – 55% of them were contributed nationally from universities and research centers related to optics and photonics; the remaining 45% were contributed from overseas, i.e., from China, Malaysia, Korea, India, Australia, New Zea-



Participants in ISPhOA 2014.



Prof. Jutamulia (right) and the 3rd Vice Rector of ITS (left).



Cultural act during the Gala Dinner of ISPhOA 2014.

chapters have been established at the Institut Teknologi Sepuluh Nopember (ITS) Surabaya. Their activities have already been stimulating wider interest among ITS's students and students at schools in Surabaya as well as in the neighboring cities and provinces. Members of the chapters are very active and enthusiastic in promoting optics and photonics.

Researchers were also successful in establishing the Optical Society (OSA) Indonesia Section. Aulia Nasution, its first appointed President, is leading the formulation of programs for this local section. He acknowledges ICO endorsement and support for ISPhOA, thanks to which, the conference was organized successfully. In particular he acknowledges the kind advice and guidance from the ICO Associate Secretary, Gert von Bally, which he considers to be beneficial for him and other officers to organize and run the local section well.

land, and Germany.

The proceedings of ISPhOA 2014 have been published by the SPIE as Volume 9444 of the Proceedings of SPIE, and OSA and SPIE student

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 W T Rhodes, Florida Atlantic University; K Baldwin, Australian National University, Australia; J Dudley, Université de Franche-Comté, France



Forthcoming events with ICO participation

Below is a list of 2016/17 events with ICO participation. For further information, visit the new ICO webpage at <http://e-ico.org/node/103>.

15-26 February 2016 Wintercollege on Optics

Trieste, Italy
 Contact: Joe Niemela
 tel: +39-040-2240555
 niemela@ictp.it
 smr2811@ictp.it

28 February - 2 March 2016 ODF'16

Weingarten, Germany
 Contact: Michael Pfeffer
 tel: +49 751 501 9834
 pfeffer@hs-weingarten.de www.odf16.de/

17-21 May 2016 International Conference on Applied Optics and Photonics 2016

Hanover, Germany
 Contact: Eduard Reithmeier
 tel: +49 511 762-3334
 Eduard.Reithmeier@imr.uni-hannover.de
 dgao2016@hot-uni.hannover.de
www.imr.uni-hannover.de/

20 June - 1 July 2016 ICO/ICTP Workshop on Lasers, Laser safety and Applications

Sede Manizales, Colombia
 Contact: Freddy Monroy
 tel: +571 316500 ext 13074
 famonroyr@unal.edu.co
www.e-ico.org/calas/2016

24-25 August 2016 2nd International Seminar on Photonics, Optics and its Applications (ISPhOA 2016)

Legian-Kuta, Indonesia
 Contact: Aulia Nasution
 tel: +62 821 4226 1063
 isphoa2016@ep.its.ac.id
www.isphoa2016.org

3-8 September 2017 24th Congress of the International Commission for Optics (ICO-24)

Yokohama, Japan
 Contact: Yasuhiko Arakawa
 tel: +81-3-5452-6245
 arakawa@iis.u-tokyo.ac.jp
www.scj.go.jp/ja/event/ico2017

Responsibility for the correctness of the information on this page rests with ICO, the International Commission for Optics; <http://www.e-ico.org/>. *President*: Prof. Yasuhiko Arakawa, Director, Collaborative Institute for Nano & Quantum Information Electronics, University of Tokyo, Japan, arakawa@iis.u-tokyo.ac.jp. *Associate Secretary*: Prof. Gert von Bally, Centrum für Biomedizinische Optik und Photonik, Universitätsklinikum Münster, Robert-Koch-Straße 45, 48149 Münster, Germany; bally@uni-muenster.de