



NEWSLETTER

COMMISSION INTERNATIONALE D'OPTIQUE • INTERNATIONAL COMMISSION FOR OPTICS

Early experiences with lasers in the USA

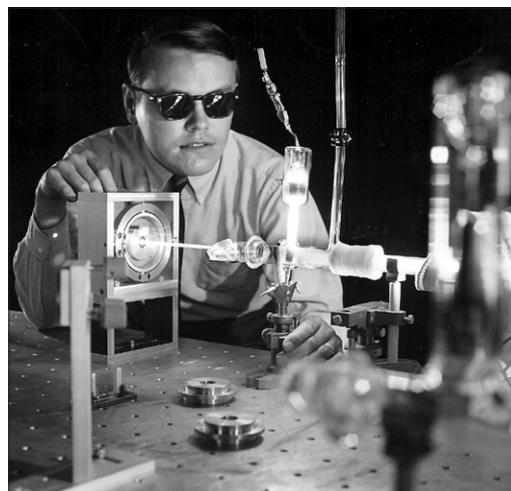
William Silfvast, laser pioneer and co-inventor of many of the first heated metal-vapour lasers, recalls his experiences as a doctoral student shortly after the announcement of the first operational laser.

My intrigue with lasers began when I was working on a research project as an undergraduate with Prof. Franklin Harris at the University of Utah in late 1960. We were measuring the diffraction of light in the shadow of an infinite half-plane using various metallic straight edges. I remember Harris showing me an article in a trade magazine that announced the discovery of some new device called a laser, and I remember the article suggesting that the laser might possibly solve many of the world's problems.

I had no idea what a laser was at the time, but not too long after that we purchased a ruby laser rod and flashlamp, hooked them up in the laboratory to a large capacitor, and fired the lamp. After several attempts we saw a large spot of red light appear on a nearby wall and realized that we had made a laser! But after the initial excitement of producing that red beam, we also realized that the ruby laser was not suitable for our project because we needed a continuous light source.

Later, Harris decided to leave the university to take a position at the Aerospace Corporation in southern California, leaving me wondering who I might have as adviser for my PhD thesis. Fortunately for me, Prof. Grant Fowles had become interested in lasers and had a couple of graduate students working for him on laser-related projects. While I was finishing up my PhD coursework in late 1963 and taking the doctoral programme preliminary examinations, Fowles and his student Russ Jensen obtained laser output from ionized iodine vapour. At that time only a few gas lasers had been produced and those were based on noble gases, so the iodine laser was quite significant. I became intrigued by their research programme and approached Fowles about joining his group. He agreed to let me be his next student, and I began hanging around their laboratory.

Fowles' work with lasers was prompted by his interest in hyperfine structure spectroscopic studies of the nuclei of various atoms. After success with iodine, he began looking around for other atoms to investigate and came up with the idea of looking at the odd isotopes of bismuth. If lasing could be achieved using bismuth, he presumed, the line-narrowing of the laser could lead to a more precise measurement



Silfvast with an early He-Cd laser at Bell Labs in 1969.

of the isotope shift between the different isotopes of bismuth. The only problem was how to make a laser in atomic bismuth. It would somehow require heating bismuth in a laser tube to a temperature of around 1000 °C, a task which, at the time, seemed insurmountable.

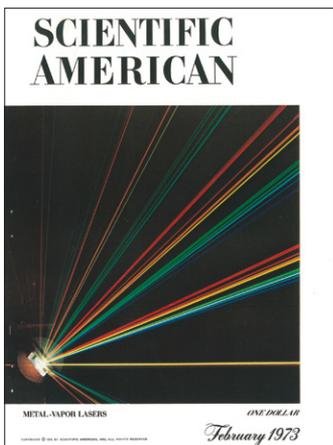
We decided we would try sprinkling some bismuth metal shavings into a quartz laser tube, adding a buffer gas, heating it up to 1000 °C, and putting various high-reflecting mirrors at the ends of the tube to see if we could produce a laser beam. At that time we were not aware of which types of transitions might lead to population inversions other than that, from results previously obtained using noble gases, they seemed to originate from highly excited states. So we planned to have the capability of investigating a wide range of experimental parameters.

Thus I began to think about how to set up the apparatus to make a bismuth laser. As an undergraduate, I had worked one summer in the ceramic engineering department, so I went there looking for some means of heating the discharge tube to 1000 °C. I spotted an old zone-refining furnace that was about 80 cm long with a segmented lid arrangement that would allow easy opening and provide access to the inside of a long 5 cm diameter tubular furnace that was capable of temperatures of over 1200 °C. It was ideal. Because the furnace was no longer in use, I was able to borrow it. I built a glass

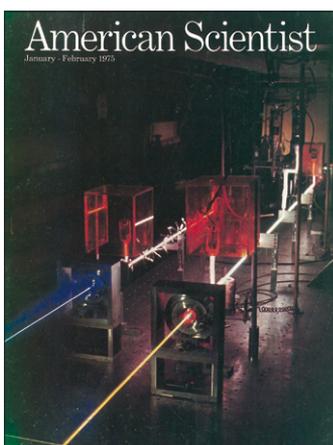




Silfvast and colleague Obert Wood attempting to pump a lead vapour laser with a Febatron at Sandia Labs in Albuquerque, NM in 1974.



The helium-selenium laser on the cover of *Scientific American* in 1972.



An *American Scientist* cover showing Silfvast's laboratory with a He-Cd laser and a He-Se laser.

manifold system with various buffer gases available, essentially copying Jensen's set-up for the iodine laser, with the addition of the furnace surrounding the discharge tube. Fortunately, we had access to a great glass blower – an employee of the chemistry department. We used neon sign electrodes, old neon sign transformers for the high voltage and inexpensive microscope cover slips for the Brewster angle windows. We didn't have the money to buy fancy optically flat windows like other people were using, but the cover slips worked very well. Observing them with a sodium vapour lamp, we selected the flattest ones, and placed them on the thickened glass ends of the laser tube (cut at Brewster's angle), holding them there with vacuum grease.

I spent approximately three months playing around with bismuth at various gas pressures and discharge currents, including both pulsed and CW excitation, and using high-reflecting mirrors of various wavelengths in the visible spectral region, and saw no laser action. Needless to say, I was getting quite discouraged. Then one day I decided to go over to the chemistry department stockroom and inquire about other metals they had in granular form. Using vapour pressure charts, I selected zinc as another metal to try in our system. I sprinkled zinc shavings in the tube, heated it up, with helium added as a buffer gas, and applied the discharge current, using a spark gap as a triggering mechanism. I happened to have blue-green mirrors at the ends of the tube and immediately saw this beautiful bright turquoise-blue beam develop between the mirrors in the external regions in the laser cavity. I couldn't believe my eyes. And this was something no-one else had ever seen before!

After shutting the system down, I rushed out of the laboratory to find Fowles, who I finally discovered was in a meeting in the administration building. I ran there and interrupted his meeting, which he immediately left to come to the lab. I turned the system back on and we were both amazed at what we saw. We measured the wavelength to be 492.5 nm and decided that if zinc worked, then maybe cadmium would also. The similar transition in cadmium soon lased in the green at 533.7 nm. At that point we were flying high. We also obtained lasing action with sulphur and phosphorous, and Fowles presented all of these results at the IEEE Electron Device Conference in Urbana, Illinois, in June, where we found we had scooped two separate Bell Labs groups. What an amazing feeling that gave us! I did not obtain laser action on the well known cadmium 441.6 nm blue transition until somewhat later, because it required different excitation conditions.

But perhaps the most exciting achievement was our operation of the first lead vapour laser. I was trying to make a laser operate in the blue part of the spectrum in ionized lead, having high-reflecting blue mirrors surrounding the



The first compact He-Cd laser, built in 1971.

laser cavity. There was no blue beam developing between the mirrors when the system was pulsed, but then I noticed a bright red spot on the wall in line with the optical axis of the laser cavity. I didn't see how my device could possibly be a laser because the mirrors had very little reflectivity in the red part of the spectrum. But I soon realized that it was indeed a laser because it responded to changes in the mirror's orientation. It was in fact a very high-gain laser that we later measured to operate at 722.9 nm in the neutral spectrum of lead. It was a totally new type of laser, lasing from the first excited state of neutral lead to a lower-lying level that was part of the ground-state configuration and therefore was inherently pulsed and self-terminating. I did my PhD thesis on this laser, which was the forerunner of the copper vapour laser that TRG later developed. (Our furnace wasn't capable of reaching the necessary 1600 °C for the copper laser.)

While on an NSF-sponsored NATO post-doctoral fellowship at the University of Oxford, John Deech and I later measured the gain of the lead laser to be over 6 dB/cm. This was the highest measured gain for a laser at that time. While doing the postdoc, I was offered a position at Bell Laboratories in Holmdel, New Jersey, where I subsequently spent 22 years doing laser research. Interestingly, while still at the University of Utah, I had interviewed at Bell Labs and they didn't even respond to me, but when I was at Oxford, they suddenly became interested in hiring me.

William Silfvast, Napa Valley, California

William Silfvast, Emeritus Professor of Optics with the College of Optics and Photonics at the University of Central Florida, is co-inventor with Grant Fowles of heated metal-vapour lasers. As a doctoral student he produced laser action for the first time in the vapour of nine different elements. He went on to pursue a 22-year career at Bell Laboratories, where he is best known for developing the blue-light He-Cd laser, as well as various recombination lasers, photo-ionization-pumped lasers, lasers in laser-produced plasmas, and some of the first experiments demonstrating EUV lithography. During his time at Bell Labs he spent a year at Stanford University on a Guggenheim fellowship. He is the author of Laser Fundamentals, published by Cambridge University Press.

Chirped pulse amplification turns 25

Chirped pulse amplification (CPA) techniques for producing ultrashort, high peak power laser pulses were developed 25 years ago, halfway back in time to the invention of the laser. Donna Strickland, currently an ICO vice-president and a worldwide recognized pioneer in the area of ultrashort laser pulse generation, shares her remembrances about the development of the first CPA system.



Donna Strickland.

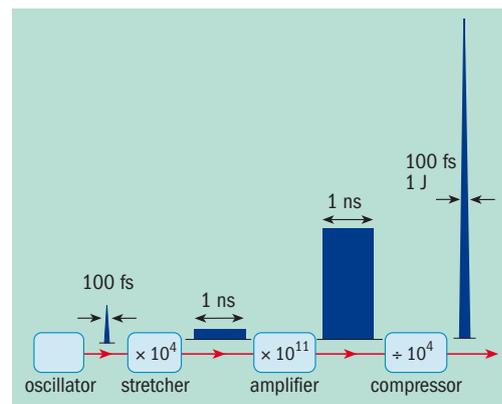
During my first week of graduate school at the University of Rochester's Institute of Optics, I met a fellow Canadian, Bedros Afeyan, who offered to show me around the Laboratory for Laser Energetics (LLE), where he was working as a graduate student. One of the laboratories that I toured was Dr Gérard Mourou's femtosecond dye laser lab. There was a red dye laser pumped by a green laser and the whole lab reminded me of a Christmas tree. Out of all the labs I had seen, that one looked like it would be the most fun to work in.

I wasted no time in asking Mourou if he would let me start working in his lab for a few hours a week during that first year. He agreed, but alas there was no more room for me in the dye lab. He already had three top students working in there: Jim Kafka, Todd Sizer and Irl Duling. Mourou had other top students as well: Janis Valdmánis was working for him on electro-optic sampling and Wayne Knox, who is currently the director of the Institute of Optics, was working for him on developing a picosecond streak camera. Steve Williamson was the one staff member of the group and he was working on picosecond electron diffraction. All of the projects in Mourou's group were at the forefront of ultrafast technology. My very first project with the group was to machine a metal cover for a pulsed YAG laser that was to be used by a group of electrical engineers. We all have to start somewhere.

My PhD thesis was supposed to be about harmonic generation. This was before the French group started a whole new field of study – high-order harmonic generation, with the observation of 33 harmonics generated in argon gas. We were aiming for just the 15th harmonic.

Before I could work on nonlinear optics, I needed a high-intensity laser. At the time, in Mourou's group we had 100 fs dye lasers and 30 ps Nd:YAG lasers. The dye lasers could give you shorter pulses, but the YAG could give you more energy. My project was to compress the 30 ps, 5 mJ pulses from the YAG laser using CS₂ as the nonlinear medium. I managed to compress the pulses down to 5 ps.

The main problem with this compression scheme was that it was not spatially uniform. This was back in 1983–1984. At the Ultrafast Phenomena Conference in 1984, pulse compression of 100 ps pulses from an Nd:YAG oscillator down to 2 ps was reported. Optical fibre was used for the nonlinear medium. The fibre had a couple of advantages over the liquid CS₂ cell. The main one was that the fibre was singlemode, so the entire beam underwent the same nonlinear process of self-phase modulation to increase the spectral bandwidth of the



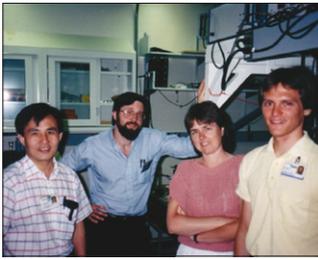
The basic steps of CPA, the technique currently used to reach laser powers up to the petawatt range, which was introduced by Strickland and Mourou in 1985.

pulses. Fibres turned out to have an added advantage in that group velocity dispersion stretches the pulse duration so that the frequencies vary almost linearly in time throughout the pulse. This allows for good compression using a pair of parallel gratings.

After attending this conference, Mourou told me that my project was changing because the correct way to get short amplified pulses was to first stretch low energy pulses in a fibre, as had been reported, but then put in an amplifier before the grating compressor. This way you can amplify a short pulse without the peak power getting too high in the amplifier. I never did study high-harmonic generation but I was lucky enough to get to do one of the world's best PhD projects and develop chirped pulse amplification (CPA).

It took me about a year to build the first CPA system. The Nd:YAG oscillator that I used was the one used to pump the dye laser. Because there was still no room for me in that lab we had to string a fibre through the ceiling over the length of LLE down to the lab where I would build the CPA system. Mourou managed to get Corning Incorporated (then Corning Glass Works) to donate 2.5 km of fibre for the project. However, when I rewound the fibre to get to both ends I ended up breaking it almost in the middle and had 1.4 km for the project. Luckily that was enough to stretch the pulses.

Once I had the pulse spectrum and duration broadened, I built a 10 Hz Nd:glass regenerative amplifier. Glass has a broader gain bandwidth than YAG so it could amplify the broadened spectrum. I was greatly helped by Marcel Bouvier, our electronics engineer at the time. He developed the Pockel cell driver, which he later sold through the company Medox. To this day, I still use the same type of driver, having purchased them from Medox. After I ampli-



From left to right: See Leang Chin, David Meyerhofer, Donna Strickland and Steve Augst.

fied and compressed the pulses I wanted to see how short they were but did not have any pulsewidth measurement device. Williamson had just got a new streak camera with 2 ps resolution for his experiment and he very kindly brought it to my lab and helped me measure the pulses. The pulses were streak camera-limited at 2 ps and we had a CPA system. That was 25 years ago, the summer of 1985.

We wrote the paper and sent it off to *Optics Communications*, which had a very fast time to publication. We sent the manuscript in July and it was published in October, but the main figure, which was a basic diagram showing the different parts of the CPA system – oscillator, fibre stretcher, regenerative amplifier and grating compressor – turned into a figure of a sandbed furnace, oxisorb and rotometers. I was greatly disappointed that my first publication was ruined. Mourou got the journal to reprint the entire paper again, with the correct figure. This version was published in December 1985.

The first CPA laser only generated 1 mJ pulses, which was not enough for nonlinear experiments. Mourou hired Patrick Maine to help build an amplification system to bring the laser power to a terawatt. This laser would become known as the T3 laser at LLE (Table-Top Terawatt).

By 1987 we had amplified the pulses to the joule level and were using a shorter pulse Nd:YLF oscillator (still located in a different lab) so that we could compress the pulses

down to a single picosecond. Technically we did not have a terawatt laser because we didn't have gratings large enough to handle the entire joule energy, but we could deliver 300 mJ, 1 ps pulses to an experiment. See Leang Chin of Laval University in Canada came to Rochester for a sabbatical to work with Mourou and Joe Eberly and study multiphoton ionization with the unprecedentedly short pulse intensity of the T3 laser. A new assistant professor at LLE, David Meyerhofer, was put in charge of T3 experiments and, along with a new physics graduate student, Steven Augst, we all worked on the very first experiments with the T3 laser: multiphoton ionization of rare gas atoms.

A business magazine contacted Mourou and told him that CPA had been chosen as one of the top 10 inventions of that year and they sent a photographer to take pictures of the laser. Afterward they called back and asked if we could make it more colourful. In the end, CPA didn't get listed as one of the top inventions because it didn't photograph well. The magazine knew that most people, like me, are able to see the excitement of red and green lasers. You couldn't see the excitement of CPA, but you could feel it in the lab. You have to be lucky to be in the right place at the right time and I was lucky to be at the University of Rochester, working with Gérard Mourou back in 1985.

Donna Strickland, University of Waterloo, Canada

Optics conference in Tangier is a resounding success



The 7th Moroccan Meeting on Optics and Photonics, was held on 21–23 April in Tangier.

The beautiful city of Tangier was home to OPTICS 2010. The conference was hosted by the National School of Applied Sciences of Tangier (ENSAT) and chaired by Prof. Otman Filali, SPIE member. The meeting was organized with the support of the Optical Society of Morocco (SMOP), which celebrated its 10th anniversary this year.

The participation of high-calibre scientists, postdocs and students provided strong evidence of success for this meeting. The scientific programme encouraged the fruitful exchange of ideas in areas including advanced photonic materials, optical sensing, photonic crystal fibres, metamaterials, quantum optics,

nonlinear optics, and recent advances in holography.

Prof. María L Calvo (ICO president 2008–2011) was an invited speaker. Meeting participants had discussions with her about how to conduct and promote research activities in optics and photonics in Morocco.

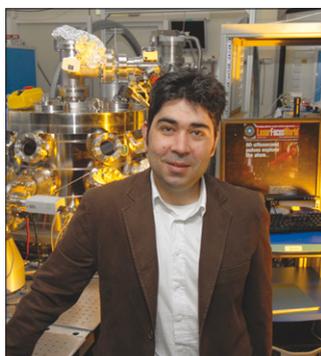
Three prizes were awarded to the best posters, presented by young scientists. Members of the award committee were M L Calvo, A Bouzid (president of SMOP) and M Smlali (past president of SMOP). First prize went to Hicham Ezzaher for “A new architecture for the block DCT-2 in the JPEG image compression norm”. Second prize went to Rachid El Gouri for “A low-cost design and implementation of maximum power tracker for photovoltaic power conversion”. Third prize went to Samira Kassimi for “Modelling the specific absorption rate (SAR) in the case of exposing the human head to GSM frequencies”.

The 8th Moroccan Meeting on Optics and Photonics will be held in 2012 in Marrakech.

Otman Filali, National School of Applied Sciences of Tangier

Young scientist prize awarded to Goulielmakis

The IUPAP Young Scientist Prize in Optics was created in 2009. The first winner is Dr Eleftherios Goulielmakis from the Max Planck Institute for Quantum Optics in Garching, Germany.



Dr Goulielmakis in his lab.

Dr Eleftherios Goulielmakis, a 35-year-old research scientist at the Max Planck Institute of Quantum Optics in Garching, Germany, is the first recipient of the IUPAP Young Scientist Prize in Optics, administered by ICO. The prize is awarded to individuals who have made noteworthy contributions to applied optics and photonics within the first eight years of research experience after earning their PhD. Goulielmakis was awarded the prize in recognition of his “outstanding contributions in attosecond physics, particularly for the generation of attosecond pulses and their application for the direct measurement of light waves”.

ICO successfully applied to IUPAP in 2009 for the creation of the prize. The award committee is made up of ICO board members Min Gu, Yasuhiko Arakawa, Duncan Moore and Carmen Cisneros, who serves as the IUPAP representative to ICO. The committee is chaired by ICO past-president Ari Friberg.

Goulielmakis’s research interests includes ultrafast transient phenomena in atoms, molecules and condensed matter that evolve at enormous rates, on a timescale of tens to thousands of attoseconds ($1 \text{ as} = 10^{-18} \text{ sec}$). To investigate these processes he has developed techniques that allow the precise control of ultrashort light pulses.

One of his main achievements is the generation and measurement of pulses in the extreme ultraviolet part of the spectrum that last only 80 as (Goulielmakis *et al.* 2008 *Science* 320 1614). These pulses, which comprise the shortest “flashes of light” generated to date, are produced when intense, precisely controlled fields of light interact with atoms to emit X rays. Such pulses open the door to the study of ultrafast transient phenomena in atoms, molecules and condensed matter with unprecedented temporal resolution that

approaches the atomic unit of time ($\sim 24 \text{ as}$).

Goulielmakis pioneered the use of attosecond pulses in the sampling of the waveform of light with sub-optical-cycle resolution. This enabled him and his colleagues to perform in 2004 the first direct measurement of lightwaves with a technique dubbed the “oscilloscope of light waves”. This provided the groundwork for creating and controlling waveforms of light with sub-optical-cycle accuracy. Such waveforms can be used to steer the ultrafast motion of electrons at unprecedented speeds and may someday enable the realization of lightwave electronics – electronics driven by the electric field of light at petahertz frequencies, several orders of magnitude beyond the state of the art of modern electronics (Goulielmakis *et al.* 2007 *Science* 317 769).

Goulielmakis studied physics at the University of Crete, in Greece. He received his PhD from Ludwig-Maximilians-Universität München, Germany, in 2005. At present he is a scientist in the Max Planck Institute’s Division of Attosecond Physics, as well as an adjunct professor of physics at Pohang University of Science and Technology in South Korea. In 2007 he received the Foteinos Prize of the Academy of Athens.

His current research includes the creation and control of sub-optical-cycle waveforms of light for triggering ultrafast dynamics on the nanoscale as well as the combination of attosecond technologies with classical spectroscopic techniques with the aim of investigating unexplored electronic processes in atoms and molecules.

Goulielmakis has been invited to receive the award and deliver a paper on his research at ICO-22, the ICO general meeting to be held in Puebla, México, in August 2011.

To the optics community worldwide...

The process of ICO Bureau elections has started.



Ari T Friberg.

The ICO Bureau will be reconstituted through elections at the General Meeting that takes place at the 22nd ICO Triennial Congress on 15–19 August 2011 in Puebla, Mexico. As ICO past-president, I am *ex officio* chair of the ICO Nominating Committee. Together with the other members of the committee – Anna Consortini, Rene Dändliker, John Love and Chris Dainty – I will be overseeing the nomination and election process. The electorate that does the actual voting consists of participating ICO members.

Nominations for all positions, with the exception of past president and the vice-presidents appointed by international organization

members, are requested by 28 February 2011. Candidates are thus expected for president, secretary, associate secretary, treasurer and the eight elected vice-presidents, of which two must be from industry, according to statute.

Candidate nominations can be made by the territorial committees and an endorsement of all candidates by their respective territorial committee is needed. The regulations covering the election process and the rules of the eligibility for nomination are available on the ICO website. Calls for ICO Bureau nominations, together with a description of the election procedures, are also sent directly to the territorial committees.

It is important that the ICO Bureau officers represent all parts of the world and all areas of optics and photonics. Therefore we hope to receive numerous nominations of varied high-quality candidates. After 15 April 2011 I will send all ICO members an update about the status of the nominations, so that they may identify those candidates they wish to endorse

for any particular position.

I must emphasize that nominations for all positions are accepted until 24 hours before the election. If you have any questions or concerns, I would appreciate hearing from you. Send your nominations by e-mail (ari.friberg@tkk.fi).

Ari T Friberg, ICO past president, chair of the ICO Nominating Committee

Contacts

International Commission for Optics (www.ico-optics.org).

Bureau members (2008-2011)

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Past-president A T Friberg
Treasurer J A Harrington
Secretary A M Guzmán, Physics Department, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431, USA; e-mail angela.guzman@fau.edu.

Associate secretary G von Bally

Vice-presidents, elected
Y Arakawa, Z Bingkun, Z Ben Lakhdar, H Lefèvre, F Mendoza, D T Moore, M Oron, T Szoplik
Vice-presidents, appointed
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IUPAP Council representative
C Cisneros

Editor in chief A M Guzmán
Editorial committee K Baldwin, Australian National University, Australia; J Dudley, Université de Franche-Comté, France; M Kujawinska, Warsaw University of Technology, Poland

Forthcoming events with ICO participation

Below is a list of events with ICO participation that are coming up soon. For further information, see www.ico-optics.org/events.html.

17-21 October

Transparent Conductive Materials (TCM2010)

Crete, Greece

Contact: George Kiriakidis, tel +302 810391271, fax +302 810391306, kiriakid@iesl.forth.gr
www.tcm2010.org

26-29 October

Annual Meeting of the European Optical Society (EOS AM 2010)

Paris, France

Contact: Silke Kramprich, tel +49 5112788117, kramprich@myeos.org
www.myeos.org/eosam2010

26-29 October

ICO/EOS Topical Meeting on Optics & Energy (TOM 7)

Paris, France

Contact: Maria Calvo, tel +34 913944684, mlcalvo@fis.ucm.es
www.myeos.org/events/eosam2010-TOM7

11-15 December

Photonics 2010: International Conference on Fibre Optics and Photonics

India

Contact: Sunil Khijwania, tel +91 3612582716, fax +91 3612582749, skhijwania09@gmail.com
www.iitg.ernet.in/photonics2010

29 November – 2 December

2nd Mediterranean Photonics Conference

Eilat, Israel

Contact: Jacob Scheuer, tel +972 36407559, kobys@eng.tau.ac.il
www.engineers.org.il/Index.asp?CategoryID=2451

31 January – 11 February 2011

ICTP Winter College on Optics in Imaging Science

Trieste, Italy

Contact: ICTP secretariat, tel +39 04022409932, fax +39 04022407932, smr2132@ictp.it
http://cdsagenda5.ictp.trieste.it/full_display.php?ida=a10126

3-7 May 2011

International Conference on Applications of Optics and Photonics

Braga, Portugal

Contact: Manuel Filipe Pereira da Cunha Martins Costa, tel +351 253 604070/604320, fax +351 253604061, mfcosta@fisica.uminho.pt
www.spidof.pt/AOP

18-20 May 2011

Information Photonics (IP 2011)

Ottawa, Canada

Contact: Pavel Cheben, tel +1 6139931624, fax +1 6139907656, pavel.cheben@nrc.ca
www.uop.ca/communications/ip2011

7-17 June 2011

Panamerican Advanced Studies Institute on Frontiers in Imaging Science

Bogotá, Colombia

Contact: Catalina Ramírez Gómez, tel +57 13165154, cdramirezgo@unal.edu.co
<http://pasi.fau.edu>

8-10 July 2011

Education and Training in Optics and Photonics (ETOP)

Carthage, Tunisia

Chair: Zohra Ben Lakhdar
Contact: Mourad Zghal, tel +216 71856240, fax +216 71856829
mourad.zghal@supcom.rnu.tn

15-19 August 2011

ICO-22, International Commission for Optics Congress

Puebla, Mexico

Contact: Fernando Mendoza Santoyo, tel +52 477 44142, fax +52 477 4414208, fmendoza@cio.mx
www.cio.mx/ICO2011/1.htm

Responsibility for the accuracy of this information rests with ICO. President: M L Calvo, Universidad Complutense de Madrid, Departamento de Óptica, Facultad de Ciencias Físicas, Ciudad Universitaria s/n, E 28040 Madrid, Spain; mlcalvo@fis.ucm.es. Associate secretary: Gert von Bally, Centrum für Biomedizinische Optik und Photonik, Universitätsklinikum Münster, Robert-Koch-Straße 45, 48149 Münster, Germany; Ce.BOP@uni-muenster.de.



IOP