



ICFOnians

Community News from the Institut de Ciències Fotòniques



EDITOR'S CORNER

Together we are ICFO



BROOK HARDWICK
Coordinating Editor



On the 18th of June, ICFO inaugurated the new CELLEX-NEST building. The special colloquia with Dr. Vest as well as the inauguration ceremony are highlighted in this issue of ICFOians with pictures to commemorate what was a special day for ICFO as an institution.

What cannot be captured in pictures or in news flashes is the feeling of community that the events of the 18th made palpable to me and I believe all of us. ICFOians packed into the auditorium, standing room only. Dr. Mir and his wife in the front row enjoying the dedication of a project made possible by their Cellex Foundation. Jose Antonio Muñiz from *Digivision* hidden in the back row watching as we aired for the first time the video "Putting light to Work" that he and his team produced. Carlos Dengra outside the auditorium making sure that the NEST building was in top form for its inauguration. Lluís Torner, smiling from ear to ear at the accomplishments of an institution that was a "Big Plan" just 10 years ago. Dr. Charles Vest at the podium reminding us that what we do to support science and technology is important not just for the world of academia, but for society as a whole.

It hit me that just as it takes a village to raise a child, the ambitious goals that ICFO is striving to achieve would not be possible without this complex support network. ICFOians are scientists, mechanics, economists, designers, receptionists, project managers, talent recruiters, and more. ICFO would not be possible without the support of the Government of Catalunya and the UPC. Important projects which bring research "made at ICFO" to the local community would not be possible without the support of CatalunyaCaixa Foundation and la Caixa Foundation. The NEST project including the building and the research teams it supports would not exist without the generous support of the Cellex Foundation. The ERC, ICREA, industrial collaborators and many other important supporters... together we are a varied group of stake-holders and together we make the wheels of this ICFO bus go around.

Together we are ICFO and in this context, we can congratulate all ICFOians in this community on the accomplishments highlighted in this issue. We have shared our research in several important publications. We have joined forces with new companies to ensure that our research can have an impact on industry. We are launching new training programs for young minds. We are connecting with kindred spirits around the world to ensure that the effects of scientific discovery can make a difference to society.

I hope that you enjoy reading about all this and more in this issue of ICFOians.

COVER



During the summer months, ICFO is buzzing with activity. It is the ideal season for Summer Fellows and students to visit ICFO, carry out research in the institute's facilities, learn about the research being conducted in our center, and to interact with ICFOians.

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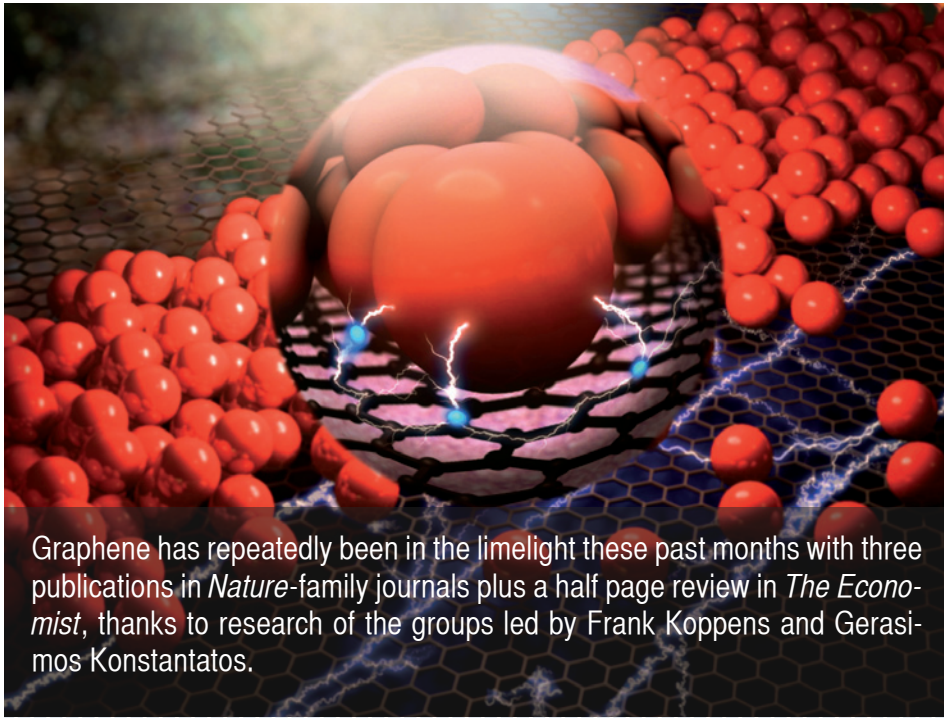
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ICFO NEWS



Graphene has repeatedly been in the limelight these past months with three publications in *Nature*-family journals plus a half page review in *The Economist*, thanks to research of the groups led by Frank Koppens and Gerasimos Konstantatos.

ICFO IN *THE ECONOMIST*

The May 12th issue of *The Economist* features the new hybrid graphene-quantum dot phototransistors technology, developed at ICFO by the groups led by Frank Koppens and Gerasimos Konstantatos. The piece enthusiastically reported on the potential of these flexible, affordable, and ultra-sensitive photodetectors which could shape a new generation of consumer electronics.

STORM WORKSHOP AT ICFO

ICFO hosted the I European STORM Workshop on June 29-30, co-sponsored by Nikon Instruments, Europe. STORM (Stochastic Optical Reconstruction Microscopy) is a novel imaging technique that allows scientists to peer into biological samples with unprecedented resolution. The theoretical talks were delivered by Graham Dempsey from Harvard University and Norman Brede from University of Heidelberg, together with researchers of ICFO's Advanced Fluorescence Imaging and Biophysics group led by Melike Lakadamyali. Nineteen researchers (mostly biologists) from across Europe were trained in this enabling technology which will help to open new doors for ground breaking discoveries in biology.

LASER WORKSHOP IN THE PYRENEES

ICFO continues its annual participation in Fundació CatalunyaCaixa's summer Youth and Science program, introducing high school students to "*Lasers- Fascinating Science and Technology!*" As a very special feature, Nobel Laureate Prof. Roy Glauber delivered a talk on his experience as a scientist. ICFO participants included PhD Students Tobias Grass, Pelayo García de Arquer, Luis Martínez, Piotr Migdal, Jordi Tura, and Alejandro Zamora; Dr. Chaitanya Suddapali, Dr Alessio Celi and Prof. Maciej Lewenstein, coordinated by Dr. Alejandra Valencia and Míriam Martí.

LASERLAB AT ICFO

As part of the LASERLAB-EUROPE III program, in June 2012 ICFO began granting access to two of its facilities: The Attoscience and Ultrafast Optics (ICFO-Atto) facility, for strong field and extreme nonlinear optics experiments; and the Super-resolution Light Nanoscopy & Microscopy (SLN) facility, with a large range of microscopes operating a step beyond commercial systems. ICFO joins the efforts of the Laserlab consortium in building a network of centers which work together to strengthen Europe's leading role in opening novel applications of laser research while reaching out to new scientific communities.

ERC STARTING GRANT AWARDED TO PROF. FRANK KOPPENS

Frank Koppens, leader at ICFO of the Nano-Optoelectronics group, has been awarded a European Research Council (ERC) Starting Grant for his project "Carbon Light". Koppens efforts aim to capture and manipulate light at the nano-scale by exploiting the unique optical and electronic properties of graphene. The project also plans to study quantum electrodynamics at the level of single electrons and photons trapped into nano-structured graphene. Congratulations, Frank, and good luck!

ICFO NEWCOMERS



Marcel·li Grimau Puigbert
Undergraduate Student



Stewe Bekk
International Project Manager



Eduard Benasques Borau
Postgraduate Student



Uros Ralevic
Visiting Scientist



Stephen Corcuff
Undergraduate Student



Joseph Culver
Visiting Professor



Juan Carlos Diaz Gallo
Biosecurity Coordinator



Armela Dino
Program Mgr Outreach



Marisol Reyes-Reyes
Visiting Scientist



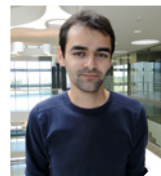
Céline Fresson
Undergraduate Student



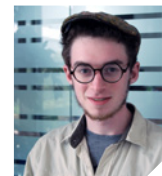
Sebastian Heunisch
Postgraduate Student



Sosuke Higuchi
Postgraduate Student



Raphaël Jorand
Visiting PhD-student



Samuel Markson
Undergraduate Student



Miriam Martí Pallarès
Outreach



Javier Martínez García
Postgraduate Student



Pedro Martínez Cordero
Research Engineer



Jesús Planagumà Valls
Visiting Scientist



Kanupriya Sinha
Visiting PhD-student



Simon Tassy
Postgraduate Student



Thomas Vanderbruggen
Postdoctoral Researcher



Hari Varma
Postdoctoral Researcher



Mireia Vilamala Díez
Internships&Fellowships



Dominik Vogt
Undergraduate Student



Pau Mestre
PhD-student



Andreas Brenneis
Visiting PhD-student

Many of us joined ICFO or took a new position at the Institute between April and June this year.



LATEST ADVANCES



SOLUTION-PROCESSED OPTOELECTRONICS

The July issue of *Nature Photonics* featured a novel architectural platform for inorganic solution-processed optoelectronics presented by researchers in the group led by Prof. Gerasimos Konstantatos. The device, a bulk nano-heterojunction platform easily implemented by mixing different semiconductor nanocrystals in solution, may be implemented to improve the performance of solar cells and other optoelectronic nano-composite materials. The paper *Solution-processed inorganic bulk nano-heterojunctions and their application to solar cells* was written by Dr. Arup K. Rath, Dr. Maria Bernechea, PhD students Pelayo García de Arquer and Luis Martínez and research engineer Johann Osmond, all led by Konstantatos, leader at ICFO of the Solution-processed nanoelectronics group.

TRAPPING AND MANIPULATION OF LIGHT IN GRAPHENE

A collaborative effort between IQFR-CSIC (Madrid), nanoGUNE (San Sebastian) and ICFO was able to experimentally demonstrate the use of graphene plasmons for the trapping and manipulation of light. The breakthrough was published in the July issue of *Nature* and could have important applications in optical information processing and sensing. The paper *Optical nano-imaging of gate-tunable graphene plasmons* has been published by a team of researchers including PhD student Michela Badioli (ICFO), Postdoctoral researcher Dr. Marko Spasenovic (ICFO), Research Engineer Dr. Johann Osmond (ICFO), Prof. Javier García de Abajo (IQFR-CSIC), Prof. Rainer Hillebrand (nanoGUNE), and Prof. Frank Koppens (ICFO).

THE DIMENSION OF A QUANTUM SYSTEM

The first device-independent quantum estimation for characterizing the dimension of unknown quantum systems was presented in *Nature Physics* by the groups led by Juan P. Torres and Antonio Acín. Dr. Martin Hendrych and co-workers demonstrated that it is possible to assess the dimension and even certify the quantum nature of an unknown system from experimental data alone. To date, these facts are normally assumed rather than certified when studying a quantum system. The possibility of being able to actually demonstrate this opens new roads in quantum information science, where dimension represents a powerful resource.

REPULSIVE POLARONS

Dr. Pietro Massignan was part of a research team led by Prof. Rudolf Grimm of IQOQI and University of Innsbruck (Austria) reporting in *Nature* the experimental detection of repulsive polarons in ultracold Fermi gases. The study represents an experimental set-up for the detailed analysis of many-body states relying on repulsive interactions. Since ultracold Fermi gases are an ideal system to simulate physical phenomena in condensed matter, this set-up can be used to study the simplest model for ferromagnetism, a goal which has not been achieved since its theoretical proposal by Edmund Stoner in 1938.

GRAPHENE-BASED PHOTODETECTORS

The groups led by Gerasimos Konstantatos and Frank Koppens announce in *Nature Nanotechnology* the development of a novel hybrid graphene-quantum dot photodetector with the potential to revolutionize the development of consumer electronics. This graphene-nanocrystal combination device is a billion of times more sensitive than existing graphene photodetectors to date. The development of a low-cost, ultra-sensitive photodetector has been a pressing challenge for physicists and engineers, and might find applications in flexible screens, biomedical imaging and night vision, as well as remote sensing and metrology.

BUSINESS NEWS by Silvia Carrasco

Two New companies join ICFO's Corporate Liaison Program

ICFO welcomes 2 new partners from the Health sector to its CLP: the multinational company B. Braun and the start-up Medlumics.

B. Braun is one of the world's leading healthcare suppliers. By exchanging knowledge with its customers, B. Braun helps to improve treatments and working procedures in hospitals and medical practices and to increase the safety of patients, doctors and nursing staff. B. Braun is currently engaged in several collaborative projects with the groups led by Dr. Pablo Loza-Álvarez, Dr. Turgut Durduran and Dr. Romain Quidant at ICFO.

Rapid progress in biophotonics is opening up rich opportunities for novel diagnostic and therapeutic techniques. Medlumics is a medical device start-up created in 2009 with the goal of improving human living standards by means of technology. MedLumics' founding team has broad expertise in integrated optics and medical imaging. This unique combination is driving a new generation of advanced optical coherence tomography (OCT) technology devices delivering real-time optical biopsy information. In November 2011, the company closed a 3.5M€ A-round led jointly by Ysios Capital Partners and "la Caixa", through Caixa Capital Risc. The funds will be used to complete the development of the company's breakthrough imaging diagnostic platform and the recruitment of its executive and technical teams. Welcome on Board!

B | BRAUN
SHARING EXPERTISE



The 2012 Corporate Liaison Day will be held at ICFO on **Friday 28 September** 2012. The focus theme this year will be 'Advances in graphene photonics for industry' and CLP partners, interested companies, and other potential collaborators are all welcome to attend. For more info contact: clp@icfo.eu

ICFO HUD Technology receives the Duran Farrell Award for Technological Research

The Duran Farell Award for Technological Research was convened for the first time in 2000 by the Social Council of the Technical University of Catalonia (UPC) as a tribute to the entrepreneur from the gas sector, Pere Duran Farell. The award, granted every two years, aims to encourage research of excellence through the recognition of the quality of a research work carried out during the last three years in the field of technology.

The prize this year has been awarded to Prof. Valerio Pruneri, ICREA Professor leading the Optoelectronics group at ICFO, and two members of his team, Daniel Infante, Research Engineer, and Davide Janner, Research Fellow. The team has developed a prototype of an advanced Head-Up Display (HUD) based on nanotechnology. The system is compact and innovative, and can be integrated into any type of vehicle. ICFO's patented technology also leads to high quality images under all lighting conditions and eliminates the so called ghosting effects. The HUD has a strong market potential in different industrial sectors, including automotive, aerospace, and defense. ICFO collaborates with key partners in this project including AD Telecom, Ficosa and SEAT (automotive sector) and Zero2Infinity (aerospace sector). "The HUD developed is a clear example of innovative use of nano-structured photonic materials to solve real life problems as well as of team effort with the industrial partners and the KTT Team at ICFO" says Valerio Pruneri. The prize was awarded in a ceremony held at the UPC campus on June 12th.



INFRASTRUCTURE



ICFO celebrates the inauguration of the CELLEX NEST Building

4,000 m² of new space, including formal and informal meeting areas, laboratories, and highly functional work areas were inaugurated in an event which highlighted the important role of science and learning institutions in society.

In 2008, ICFO and Cellex Foundation Barcelona embarked on an important friendship based on the common belief that research is an important building block on which a country can grow and advance. Initially providing funding for medical applications based on Photonics, the relationship grew in 2010 with the announcement that the private foundation funded and chaired by Dr. Pere Mir i Puig would bequeath to ICFO the largest act of scientific patronage in Spain to date, funding an ambitious research and building program called NEST. At this juncture, Cellex Foundation became a full-member of ICFO's Board of Governors.

The NEST program, as the name implies, aims to cultivate a research environment that focuses on the development of young talent. The NEST Fellows, exceptional young tenure-track group leaders, build new research groups at ICFO in order to explore and expand the use of photonics in areas of science and technology, such as biology, medicine, information technologies, renewable energy sources, nanotechnology and environment. When completely manned, the project will employ approximately fifty researchers, including group leaders, post-doctoral researchers, PhD students and technicians. The ultimate goal is to help Catalonia develop a strong scientific learning infrastructure developing talented scientists, producing cutting edge scientific results, and generating wealth for society.

The construction of the NEST building which has taken place on land donated by the Government of Catalonia, began in November of 2010 and was completed in

a bit more than one year. On June 18th, ICFO celebrated the inauguration of the NEST building which comprises 4000 square meters of space in which to carry out frontier research. As home to the NEST Project, the new facility contains unique formal and informal meeting areas, laboratories, and highly functional work areas.

The inaugural event opened with the showing of the new corporate video, "Putting Light to Work", a collaborative effort by all ICFOnians to showcase the importance of basic and applied research conducted at the Institute. Following this introduction, Dr. Charles Vest, President Emeritus of MIT and President of the US National Academy of Engineering, gave a momentous address. In keeping with the mission of the NEST program, Dr. Vest's talk offered important reflections on the central role of science and learning institutions in society. His address was followed by closing words from Prof. Andreu Mas-Colell, Minister of Economy and Knowledge of the Government of Catalonia and President of ICFO.

Distinguished members of the Cellex Foundation Barcelona, including Dr. Pere Mir and his wife Ms. Núria Pamies, Mr Jordi Segarra, Mr Agustí Jausas and Mr. Josep Esteve, were present at the formal inauguration. The Rector of the Universitat Politècnica de Catalunya-Barcelona Tech (UPC), Antoni Giró Roca, as well as the Mayor of Castellet del, Manuel Reyes López, gave brief dedication addresses, which were followed by a celebratory reception.



ICFO's Home

PHASE I ICFO: Inaugurated in 2005.
PHASE II ICFO: Inaugurated in 2008.
CELLEX-NEST: Inaugurated in 2012.
Architect: Mr. Xavier Farré

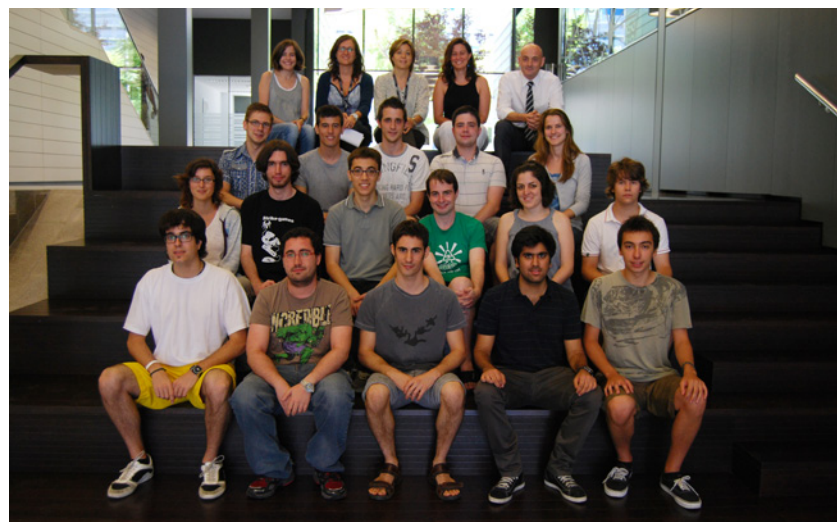


YOUNG TALENT

ICFO's Young Minds Program offers research opportunities in Photonics

ICFO expands its portfolio of training program, opening its doors to talented students and young researchers.

In the summer months, ICFO opens its doors to young, talented minds who are motivated to learn about Science with a focus on Photonics. In addition to annually participating in the *E²C³ - Centre Recerca* program and hosting the *ICFO - CX Summer Fellowship program*, this year the portfolio of training programs has grown to include the *ICFO - Outreach Summer Fellows 2012* and the *ICONS Summer Workshop*.

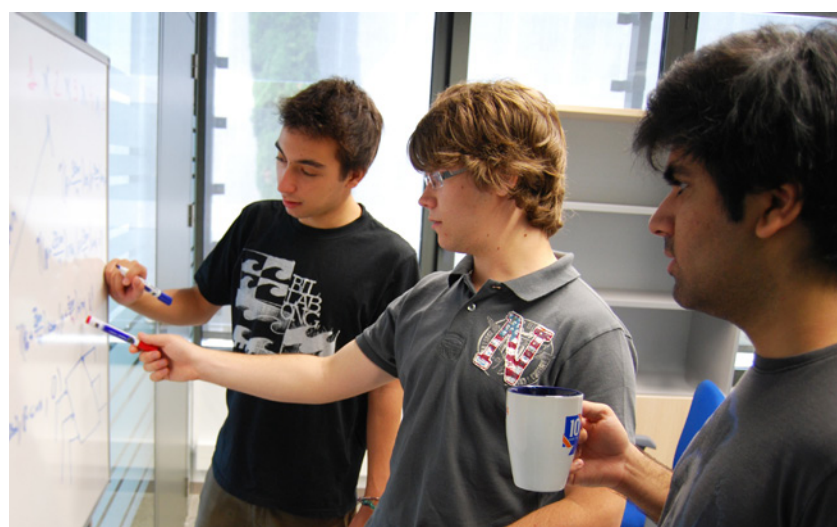


ICFO – CX SUMMER FELLOWS 2012

Every summer, the ICFO – CX Summer Fellows Program, in the framework of the Ignacio Cirac - CatalunyaCaixa Program Chair, offers a limited number of research fellowships to carry out a challenging research project on a variety of topics in Photonic Sciences at ICFO.

In this year's edition, ICFO welcomes 14 Summer Fellows, who will be hosted and coached by 12 different research groups, collaborating in projects as varied as "Photoacoustic microscopy of tissues" and "Improving efficiency of organic solar cells".

Please welcome Barbara Buades, Pau Buch, Frederic Català, Carlos Florensa, Albert Gallemí, Andrea Inglés, Ignasi Jorba, Antonio Jesús Leal, Adrián López, Eloi Marín, Jordi Morales, Hernán Pino, Rocío Saenz, and Rubén Seoane.



ICFO - OUTREACH SUMMER FELLOWS 2012

ICFO launches the first edition of the ICFO - Outreach Summer Fellowship Program. This initiative aims to use robotics as a tool for bringing science and technology to society. University students, coached by ICFOians, will work to create very special robots that will incorporate the use of light in their mechanisms. The result will be "Photonic Robots" which will help to demonstrate some of the possibilities of applying photonics to electronics and automata.

Within the scope of their fellowships, these same Outreach Summer Fellows will work to tutor visiting high school students throughout the year.

Please welcome Mrityunjaya Nebhwani, Albert Pumarola, and Pol Via.

E2C3 @ ICFO

ICFO hosts high school students for a 4 to 5 week stay within the *E²C³-Centre Recerca* program, supported by Fundació Catalunya Caixa. This summer we welcome 6 students who will be working in the following projects: "Image Compression" within the Theoretical quantum-nano photonics group, "Laser Light" within the Quantum optics theory group, and "Quantum non - locality" within the Quantum information Theory Group.

Please welcome Marta Miret, David Moran, Júlia Amorós, Marc Ballbé, Cèlia Franch and Júlia Alsina.

ICONS WORKSHOP

ICONS (ICfo Organization and Network of Students) offers a week packed with photonics related activities for high school students from Catalonia. The week's activities will offer students with an interest in science the opportunity to enjoy activities related to frontier research, optics, photonics and the science of light and life, as well as leisure activities. The workshop has the support of the International Society of Optics and Photonics (SPIE).



In parallel to the research experience that students have within their assigned groups, ICFO hosts the Summer Lecture Series. These Lectures are planned to provide a general overview of the remarkable potential of photonics in areas as diverse as health, quantum information and energy. The lectures are delivered by international experts in their fields, including distinguished guest speakers and ICFO Group Leaders. Taking place throughout the summer months, these lectures provide detailed insights into the range and depth of research activities taking place at ICFO.

Throughout the year, ICFO continues its efforts to develop young talent with other targeted programs, like the Internships Program, which is directed towards outstanding students from top Universities around the world in the final year of their studies. Opportunities to participate in the internship program, carrying out a collaboration with a research group at ICFO will be published in the ICFO Job Openings & Fellowships website.

BEYOND ICFO By Iain Cormark

As a child I loved taking things apart to learn exactly how they worked. My curiosity grew through the years into a special fascination with light and how it interacts with the world around us. This led me to carry out a PhD in Laser Physics at the University of St Andrews where I investigated various techniques for fully characterising ultrashort laser pulses.

Whilst at St Andrews I met two ICFOnians, Pablo Loza Alvarez, then a fellow PhD student and David Artigas, a visiting scientist from Barcelona. David returned to Barcelona and Pablo soon followed to become one of the first members of ICFO. I stayed in St. Andrews as a postdoctoral researcher for another wet and windy Scottish winter before my thoughts also turned to the sunnier climate of Barcelona. In June 2003 I joined the ICFO adventure in the newly formed ultrafast imaging group led by Pablo. In those early days, the enthusiasm and energy within ICFO was infectious. I especially enjoyed the team efforts of overcoming the challenges that affected this new research institute. Who could forget the constant power cuts in the temporary research labs which at times resembled a building site and at other times a sauna.

During my first year at ICFO I was awarded a Human Frontier Science Programme Long Term Fellowship which funded two more years at ICFO as well as an extra year's research back in the UK. This enabled me to continue to develop multi-photon

imaging techniques within Pablo's group and to be part of new collaborations between various biological research groups within Barcelona. In my last year at ICFO, we moved into our new home in Castelldefels, where the Institute has since gone from strength to strength.

Back in St. Andrews in 2006, I used the biological experience I gained at ICFO to carry out Raman spectroscopy within Professor Kishan Dholokia's optical trapping group. And then in 2007 I made the big step into industry, moving to Glasgow to work for the laser manufacturer, Coherent Scotand. Today I am the lead development engineer on the Chameleon range of lasers, the main application of which is multiphoton imaging. The R&D I carry out at Coherent is far more targetted towards a final product than the research I did at ICFO, but I find the process of developing a breadboard laser system into a robust and reliable commercial product tremendously rewarding.

Time really does fly. I am now married with a daughter, and twins due in October. The time I spent at ICFO was unforgettable both professionally and personally, and provided me with a unique opportunity to observe the formation of a world leading research institute, now celebrating its 10th birthday. For those who remember me, I wish to say a big hello and look forward to seeing you when I return to Spain to visit!

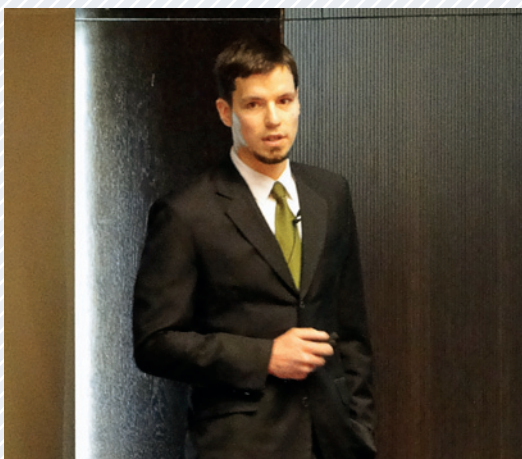


**Iain Cormark is the lead development engineer on the Chameleon range of lasers at Coherent Scotland in Glasgow*

GO & FLY

Congratulations!

These ICFOnians have successfully defended their PhD Theses. Honoring ICFO's tradition, ICFOnians gather together to celebrate your accomplishments and encourage you to Go & Fly! Remember that wherever you go, you will always be part of the ICFO community.



Dr. Florian Wolfgramm graduated on June 29 with a thesis on Atomic Quantum Metrology. His thesis '*Atomic Quantum Metrology with Narrowband Entangled and Squeezed States of Light*' was supervised Prof. Morgan Mitchell, leader at ICFO of the Quantum information with cold atoms and non-classical light group.



On May 10, Dr. Giorgio Volpe graduated with a thesis on Optical Nanoantennas. His thesis '*Nanoscale Spatial Control of Light in Optical Antennas*' was supervised by ICREA Prof. Romain Quidant, leader at ICFO of the Plasmon nano-optics group.



HIGH PROFILE



Charles Vest:

“Of all the extraordinary experiences in my career, I have valued most the opportunity to serve and represent the remarkable people and activities of MIT as its president.”



Dr. Charles Vest has had a distinguished and varied career, currently serving as President of the U.S. National Academy of Engineering. The NAE and its members provide independent advice to the US government on matters involving engineering and technology.

Could you give us a “bird’s eye view” of your background and career path?

I graduated from West Virginia University as a mechanical engineer in 1963 and earned my PhD at the University of Michigan in 1967. I initially did research in heat transfer and fluid mechanics but then moved into applied optics. Together with my graduate students, I contributed to the development of optical holographic interferometry as a quantitative measurement technique and I wrote a book on this topic in 1979. Later, I became dean of engineering and provost at the University of Michigan and in 1990 was appointed president of the Massachusetts Institute of Technology (MIT) and served in that role for 14 years. Along the way I served on several federal committees and commissions and was a director of DuPont and IBM. Currently I am the president of the U.S. National Academy of Engineering.

What is the most interesting thing you learned from teaching?

The best way to really learn something deeply is to prepare to teach bright students. It also is amazing how many important new perspectives students can bring to a subject they are learning about for the first time. The first lesson I learned as a teacher is always

to say clearly, “I don’t know” when you don’t really know the answer to a student’s question.

As an advocate for Science and Technology, what, in your opinion, are the biggest challenges facing scientific learning institutions (be it MIT or ICFO) today?

In much of the U.S. and Europe, our biggest challenge is attracting larger numbers of talented young men and women into science and engineering. We also seem to share a declining appreciation on the part of many policy makers of how critically important strong investment in research and advanced education is to the future strength of our economies and quality of life. I am optimistic that first-rate institutions like MIT and ICFO will remain strong, but the enterprise needs to be larger.

Any special challenges you see that are specific to Europe?

I think Europe faces a challenge in the wide variation of gender equity in science and education across various countries. It also should continue efforts to build outstanding collective activities and organizations like CERN, and work to maintain tight linkages between education and research.

You also serve on boards of several non-profit organizations and foundations devoted to education, science and technology. What role are not-for-profit entities playing in critical processes of R&D+I today?

The role of private foundations in supporting advanced research, especially in the life sciences, is growing. However, the ability of non-profit organizations to significantly advance education appears to be limited because of the scale of the challenge. Nonetheless, at least in the U.S., private support has helped to establish new schools and new approaches from which the larger public system can learn.

In your opinion, what should be the role of industry in scientific advancement today?

Industry today is global, fast-paced, and quite complex. It is in constant need of innovation, but does not contribute much basic research to the “commons” to be shared by all. In large measure this is because of narrow financial margins and intense competition. This adds pressure on universities and independent research institutes. There should be more large-scale partnerships among industry, academia and government to advance our R&D base.

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EASY

1	6	7			3			9
	2	4	5			3	1	
3				9		6		
				3	5	9	2	
			2		8			
	7	1	4	6				
		5		8				2
	4	2			7	1	9	
6			3			5	8	7

MEDIUM

4					2		8	5
			8					1
6			1				9	
			2	9	3		6	
	2						7	
	3		5	7	8			
	9				7			3
3					4			
2	6		3					4

DIFFICULT

		7	5					
8		5						
	2			8			5	3
9					6	2	3	
		4		3		9		
	6	2	7					8
6	8			4			7	
						1		2
						1	4	

VERY DIFFICULT

	3						8	
4				8				7
9			5		6			1
		6	2		4	3		
				9				
		2	7		8	9		
6			1		5			4
1				2				3
	5						2	

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