NEWSLETTER Y2

"COMPACT ULTRAFAST LASER SOURCES BASED ON NOVEL QUANTUM DOT STRUCTURES"
INTEGRATED PROJECT

Funded by the European Commission
under SEVENTH FRAMEWORK PROGRAMME: Photonic Components and Subsystems

FAST-DOT is a 7th Framework European Integrated Project targeting at development of new generation of quantum dot based lasers for use in Biophotonics applications. Being compact and efficient these lasers will improve the performance of procedures such as precision cutting and imaging.

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Project overview

FAST-DOT is a €13.7M project (EU contribution €10.1M), aimed at developing a new generation of lasers for biomedical applications. Led by the University of Dundee, Scotland, 18 of Europe's leading photonics research groups and companies from 12 countries are working together to realise miniature lasers designed specifically for bio-photonics use. The vision of the FAST-DOT project is to revolutionise the use of lasers in the biomedical field, providing both practitioners and researchers with pocket-sized ultra-high performance lasers at a substantially lower cost, making their widespread use affordable.

The new lasers will be designed for use in microscopy and nano-surgery, where high-precision cutting, imaging and treatment therapies will be made possible. The project will use novel nano materials called quantum dots, and exploit their unique light generating properties to produce devices with tuneable wavelengths and ultra-fast light pulses while cutting the cost of lasers and making them more portable. Quantum-dots are sometimes called artificial atoms because of their nanoscale dimensions and unique properties.

The very short, high energy pulses delivered by these lasers means they can be used in new ways like cutting cells and tissues without the undesirable heat generation associated with normal lasers. Furthermore, the wavelengths available from the new lasers will potentially open new areas of bio-photonic applications.

Partners

1.	(CO) University of Dundee (UNIVDUN)	UK
2.	Innolume GmbH (SME) (INNOLUME)	Germany
3.	University of Sheffield (USFD)	UK
4.	Tampere University of Technology (TUT)	Finland
5.	Swiss Federal Institute of Technology Zurich (ETH)	Switzerland
6.	Royal Institute of Technology Stockholm Sweden (KTH)	Sweden
7.	Institute of Photonic Sciences (ICFO)	Spain
8.	The Foundation for Research and Technology – Hellas (FORTH)	Greece
9.	Alcatel Thales III-V Lab (ALCATELTHALES)	France
10.	Vilnius University (VUFC)	Lithuania
11.	M Squared Lasers Limited (SME) (M2)	UK
12.	Philips (PFLA)	Germany
13.	Technical University of Darmstadt (TUD)	Germany
14.	TOPTICA Photonics AG (SME) (TOPTICA)	Germany
15.	Time Bandwidth Products (SME) (TBWP)	Switzerland
16.	Politecnico di Torino (POLITO)	Italy
17.	University of Athens (NKUA)	Greece
18.	Molecular Machines and Industries GmbH (SME) (MMI)	Germany

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Summary of second year's highlights

The activities during the second year of the project were, according to the initial schedule, devoted mainly to the realization and characterization of devices and subsystems. In this respect, significant progress has been made in the following areas:

- ***Tapered lasers with QD active media have been grown and processed. An innovative architecture for these devices has resulted in picosecond pulse generation with average power in excess of 200mW directly from a monolithic device.***

- ***Novel operating regimes for the mode-locked QD lasers have been identified (dual-waveband emission from ground state and excited state, ground state splitting, ground state - excited state switching).***

- ***Efficient frequency conversion (760 mW at 610 nm) has been demonstrated using an optically pumped VECSEL with a 2-mm-long lithium tantalate crystal.***

- ***The first electrically pumped VECSEL structures have been grown and processed, demonstrating output power > 100 mW using a 10% output coupler.***

- ***Growth of OP VECSEL structure with QDs demonstrating > 2 W output power at 1180 nm.***

- ***The first optically pumped VECSEL/SESAM mode-locking prototype has been demonstrated.***

- ***Multiphoton images taken with a prototype semiconductor disk-laser mode-locked by a quantum dot SESAM, which has been provided by project partners.***

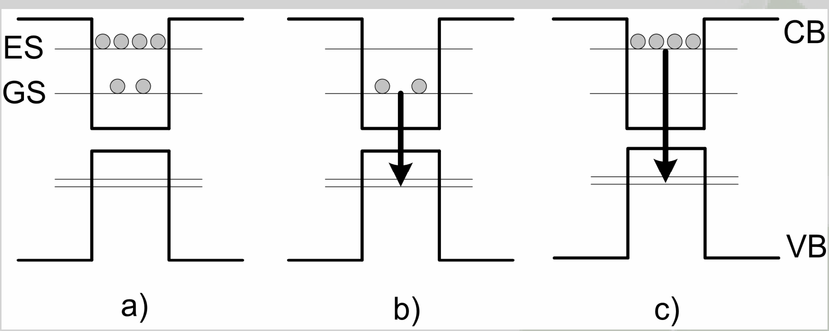
- ***Controlled supercontinuum generation and ultrashort pulses has been demonstrated from a mode-locked fiber laser.***

In conclusion, the project is proceeding according to the original schedule and, in its second year, has already produced a number of novel and interesting results which have been published in ***16 journal publications*** and ***27 international conference publications***.

Mode-locked QD edge-emitting lasers and amplifiers

FAST-DOT researchers unveil novel dual-wavelength ultrashort-pulse generation regime

The first demonstration of a dual-ultrashort pulse generation in a semiconductor quantum-dot (QD) laser at widely separated wavelengths has been unveiled [1], as a result of a FAST-DOT research collaboration between the University of Dundee (UK), the University of Athens (Greece) and Innolume GmbH (Germany). The groups' pioneering work has shown that the pulses can be generated from both the ground (GS) and the excited-state (ES) energy levels of the QDs, which are quite well separated energetically – resulting in two trains of pulses being generated simultaneously with two very distinct wavelengths. The recent results have demonstrated a very compact GaAs-based quantum-dot laser diode (2 mm long) that was designed and operated in a particular way which enabled the generation of picosecond pulses from both ground (λ = 1263 nm) and excited state transitions (λ = 1180 nm), with each coexisting pulse train exhibiting an output power in the range of 20-30 mW. This represents the widest spectral separation (83 nm) ever to be observed in a dual-wavelength mode-locked non-vibronic laser. Moreover, the results have been reproduced by numerical simulations which provide a better insight on the dual-wavelength mode-locked operation. The exploitation of this novel regime could enable a wide range of applications extending from nonlinear frequency conversion through to time-domain spectroscopy, optical interconnects, wavelength-division multiplexing and ultrafast optical processing.

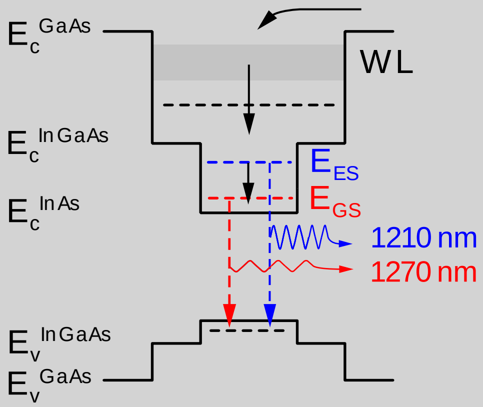


Schematic of the energy levels in a QD material (a), radiative transitions via GS - ground state (b) and ES - excited state (c). Legend: CB – conduction band; VB – valence band .

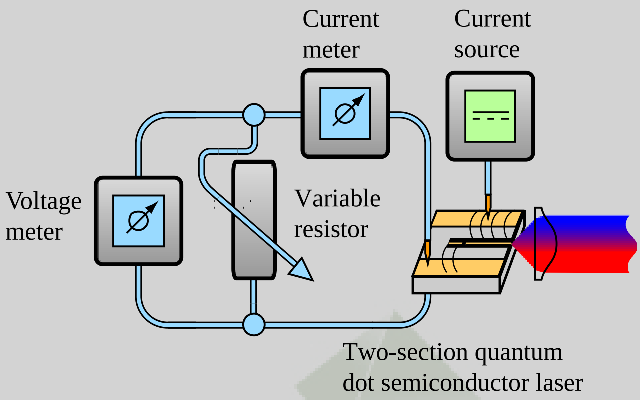
[1] M. A. Cataluna, et al., Optics Express 18, 12832-12838 (2010).

Switching in a Dot

QD lasers have already manifoldly proven their particular interesting emission dynamics within the FAST-DOT project [2,3]. Due to the existence of ground state and excited state a quite sophisticated interaction scenario includes the potential of lasing and mode-locking on two-states, GS and ES. Novel regimes of mode-locking in QD lasers, involving these two transitions, were recently reported by UNIVDUN [4,5]. Mode-locked two-state lasing, i.e. a coexistence of GS and ES emission, was experimentally investigated in detail by UNIVDUN and other teams [1]. With increasing gain current a transition from GS to ES emission was found and a coexistence regime at intermediate currents with lasing of both transitions. These emission dynamics have been complemented by the very recent observation of the so-called reverse-state dynamics in a particular designed two-section QD structure by TUD, where lasing first started on the ES and then, with increasing current, a transition from ES to ES+GS emission took place. TUD has now experimentally explored the so-called resistor Self-Electro Optical Device Effect (resistor SEED) configuration involving a two-section QD laser. The SEED effect based on quantum well (QW) structures has been pioneered by D. A. B. Miller and intensively studied with respect to applications in bistability, switching and modulation. In a recently published paper [6], the team at the University of Darmstadt shunted the absorber section of a particularly designed, strongly inhomogeneously broadened QD two-section laser by a simple ohmic resistor. By simply tuning this external resistance value TUD demonstrated wavelength-switching of the mode-locked pulses from the ES to the GS and vice versa. For a 1 kΩ resistance, mode locking occurred on the GS at 1270 nm. The ES state was not lasing. With decreasing resistance, at around 500 Ω, simultaneous lasing of GS and ES occurred with equal intensity of both states, until finally, at a resistance of 1 Ω, only mode-locked ES emission at a wavelength of 1207 nm appeared. This fascinating novel concept allows tailored emission wavelengths and picosecond-short mode-locked pulses quasi "on demand" interesting for a lot of applications.



Scheme of the energy structure of a QD depicting the two-state emission.



Experimental set-up to realize wavelength-switching of a two-section QD laser by a resistor SEED configuration.

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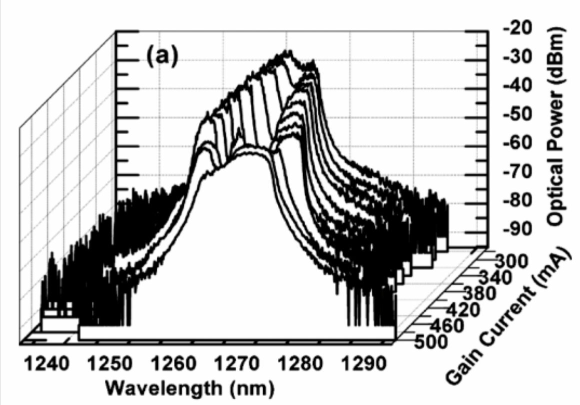
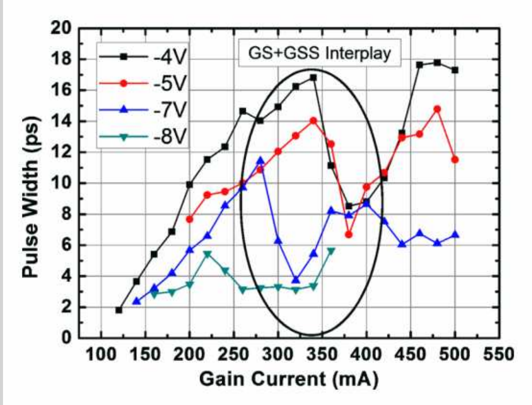
[2] M. Butkus et al., Optics Letters, 34 (11), 1672 (2009)
[3] S. Zolotovskaya et al. Photonics Technology Letters, 21 (16), 1124-1126 (2009)
[4] M. A. Cataluna et al., CLEO/Europe-EQEC 2009, CB4.6 (2009)
[5] Fast Dot Newsletter Year 1
[6] S. Breuer et al., Electronics Letters 46(2), 161 (2010)

Generation of short-pulses based on dual GS emission

The simultaneous mode locking from the GS and ES and the pulse narrowing effect from the GS due to continuous wave (CW) emission from the ES, have been investigated by FAST-DOT partners and other research groups. Recently, FAST-DOT partners NKUA (Greece) and Innolume GmbH (Germany) investigated the additional emission bands which appear under specific conditions from the splitting of the GS in two discrete wavebands. In particular, they demonstrated experimental results which relate the existence of dual waveband emission from the GS in a multisection QD mode-locked laser, with the narrowing of the generated pulses when increasing the injection current [7]. This behaviour is in contrast with the typical monotonic increase of the pulsewidth with increasing injection current, and it is attributed to the suppression of the competition effects between phase locked-modes due to in the dual GS emission. From the practical point of view, the major contribution of this novel operating regime is the generation of pulses with simultaneous increased peak and average power with respect to the usual device operation, which is a desired feature for biomedical applications.



Experimental optical spectra which demonstrate the splitting of the ground state into two individual wave-bands versus the electrical pumping, for a multi-section passively ML QD laser.



Experimental measurements of the pulse-width versus the electrical pumping for a multi-section passively ML QD laser under dual-GS emission.

[7] C. Mesaritakis et al., Applied Physics Letters, 96 (21), 211110 (2010)

Broadly Tunable Quantum Dot Laser Diode Module for Biomedical Applications

Lasers based on semiconductor active material structures represent a versatile and practical group of coherent light sources. Flexibility in the choice of semiconductor material compounds allows vast emission wavelength coverage. The active medium band-structure engineering enables optimisation of the laser parameters to a particular application by the use of a variety of artificial structures. Fast progress in the field of self-organised quantum dots has enabled the extension of the available range of coherent light sources within the diagnostic spectral range - also known as the therapeutic window ranging from 600 *nm* to 1300 *nm* - where most tissues exhibit weak absorption permitting significant penetration depth of the laser radiation.

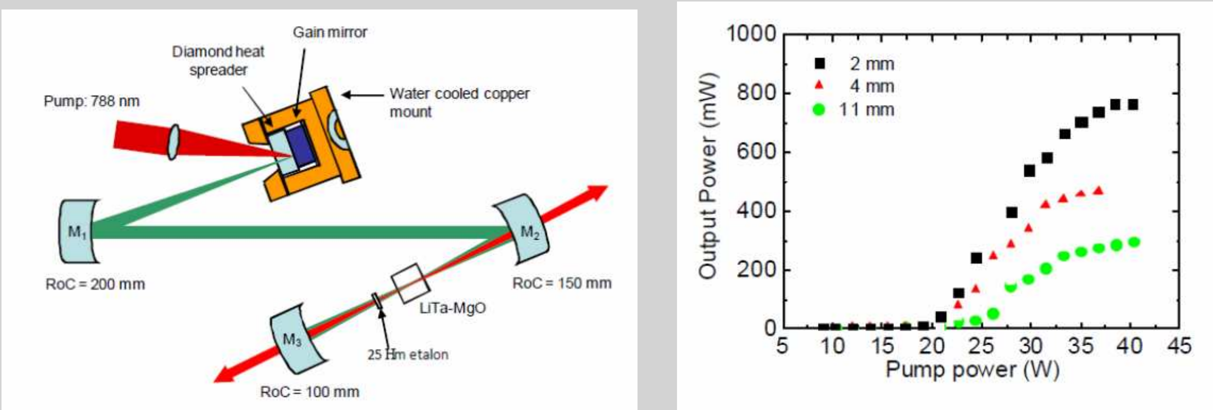
High-power broadband *InAs/GaAs Quantum Dot* laser diodes, developed in *Innolume GmbH*, facilitate further development of coherent light systems for new biomedical applications which were previously inaccessible due to the absence of a suitable source in the operational range from 1100 nm to 1320 nm.

Recently *TOPTIKA Photonics AG* has presented a prototype of widely tunable diode laser ***DL pro*** with an *Innolume* quantum dot diode laser at the heart of the system. The combined attributes of 150-nm tunability range around the central wavelength of 1220 nm and 270-mW of output power obtained from the grating stabilised laser diode are believed to not to be achievable with any other conventional semiconductor laser system.

Optically pumped VECSELs

Efficient frequency conversion

Compact coherent laser sources emitting red light are required for several applications such as photodynamic therapy, laser projection displays, and biophotonics. An optically pumped semiconductor disk laser (OP-SDL or OP-VECSEL) can produce high power with nearly diffraction-limited beam and by using proper semiconductor compounds they can be designed to emit from 650 nm to midinfrared (midIR). However some wavelengths are hard to achieve; particularly, direct generation of visible light at nm from SDL is problematic due to the shortage of efficient semiconductor gain materials and the limited availability of short-wavelength high power pump sources. Alternatively, visible wavelengths can be generated from an infrared SDL by second-harmonic generation (SHG). FAST-DOT team of TUT (Finland) in collaboration with the team from UNIDUN (UK) have demonstrated an OP-SDL frequency doubled with periodically poled lithium tantalate crystal [8]. The semiconductor disk laser exploited GaInNAs-based active region with GaAs–AlAs distributed Bragg mirror to produce emission at 1.2 µm. Crystals with various lengths were tested for intracavity frequency conversion and the achieved frequency doubled output power was 760 mW at 610 nm (red wavelength) with a 2-mm-long crystal.

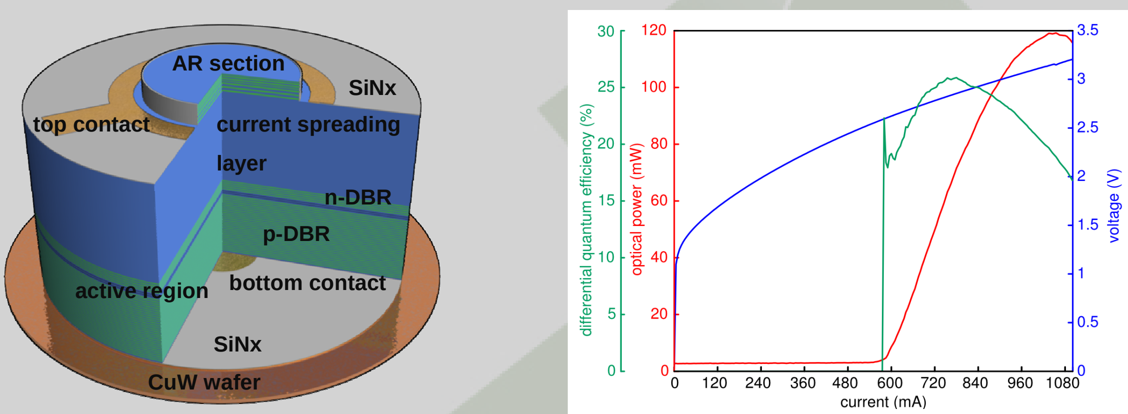


Left: Experimental setup for the frequency doubling with the OP-SDL. Right: Output power at red wavelength with different lengths of nonlinear crystal

[8] J. Rautiainen et al., Photonics Technology Letters, 22 (7), 453-155 (2010)

Electrically pumped VECSELs

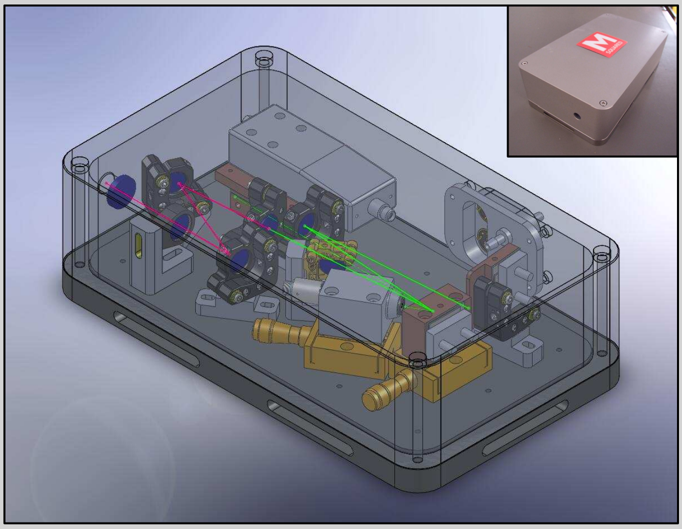
One of the key activities of the project is the development of electrically pumped vertical-external-cavity surface-emitting lasers (EL-VECSELs) for the generation of short pulses at multi-GHz repetition rates. Partner ETHZ achievements in the second year include the design and development of EP-VECSEL devices generating >100 mW CW power. Homogeneous current injection is achieved even for large devices, showing very good agreement with the numerical simulations.



Left: The design of the EP-VECSEL developed by ETHZ. Right: Output power and differential quantum efficiency vs pump power.

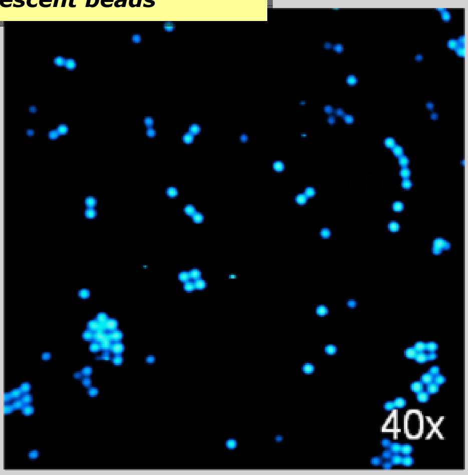
Mode-locked solid state and fiber lasers

Optically pumped VECSEL/SESAM mode-locking prototype

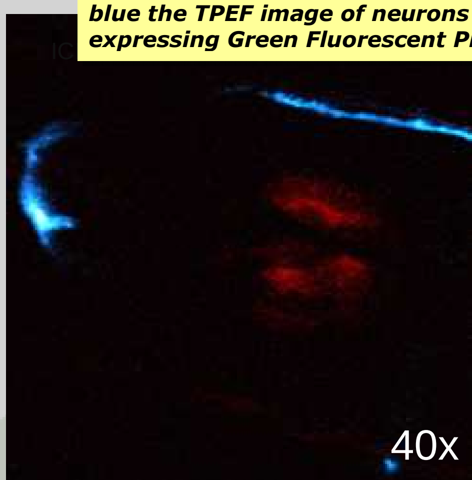


Compact packaging of Watt-level average power mode-locked lasers is an important issue affecting stability of the laser and eventually the usability in nonlinear imaging systems. Efficient solutions for heat-load management, are crucial for reliable hands-off laser operation. FAST-DOT partner M-Squared Ltd has developed a unified compact packaging technology platform for high-repetition rate watt-level mode-locked solid state lasers and optically-pumped VECSELs. The new prototype laser is mode-locked by employing QD-SESAM designed and fabricated by FAST-DOT partners. The laser, envisioned for nonlinear imaging applications, generates pulses shorter than 1.5 ps at a repetition rate of 500 MHz and average powers exceeding 300 mW. The laser center wavelength is 965 nm, which is ideally suited for two-photon excitation of the widely used GFP marker, given that its absorption maximum is located at 470 nm. Some biomedical imaging samples taken at ICFO with the M-Squared prototype are shown below:

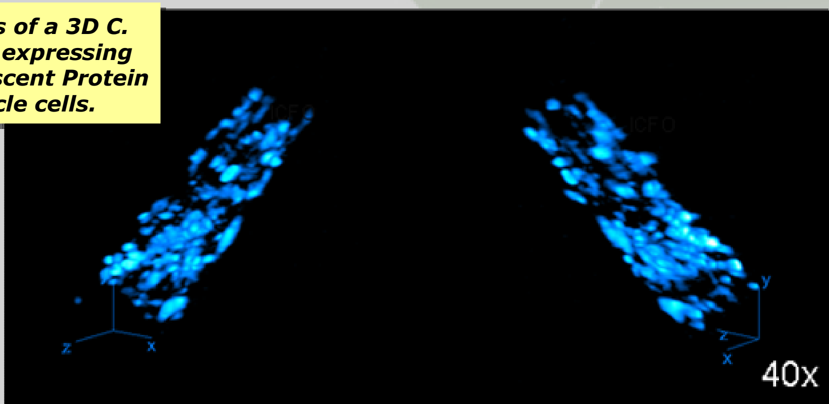
TPEF images of green fluorescent beads



C. elegans nematode head. In red is the Second-Harmonic Generation (SHG) image of pharyngeal muscles and in blue the TPEF image of neurons expressing Green Fluorescent Protein.



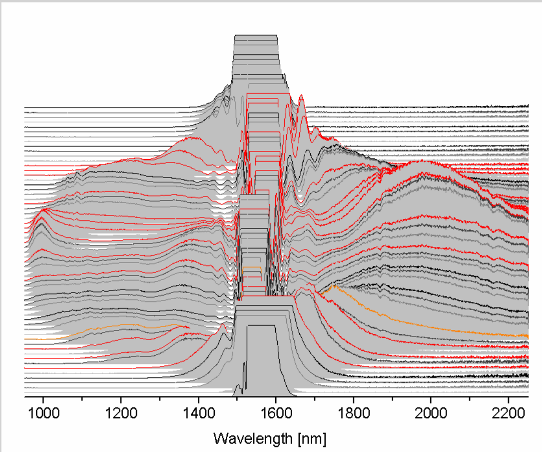
Rotated views of a 3D C. elegans head expressing Green Fluorescent Protein (GFP) in muscle cells.

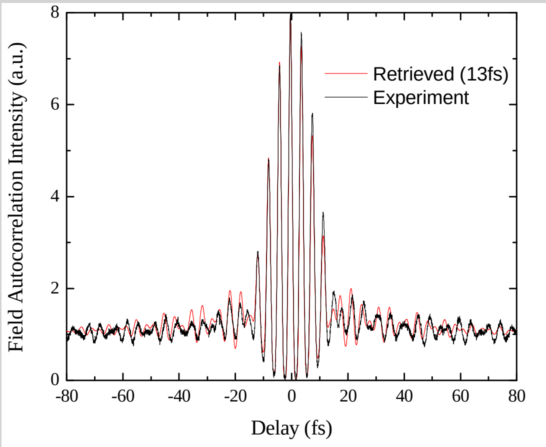


Nonlinear images taken at ICFO with the M-Squared prototype.

Controlled supercontinuum generation and ultrashort pulses from mode-locked fiber laser

Careful modeling allowed TOPTICA to devise a way to generate tunable supercontinuum from highly nonlinear fiber by adjusting chirp rate of the pulses from their mode-locked fiber laser. This feature is interesting for nonlinear imaging and OCT applications. Experimental demonstration of this technique is shown in the figure below. Moreover large spectral broadening by self-phase modulation in highly nonlinear fiber allowed subsequent compression of the mode-locked fiber laser pulses down to 13 fs.





Left: Controlling supercontinuum spectrum by adjusting pulse chirp. Right: 13 fs pulses generated by spectral broadening and compression of mode-locked fiber laser output

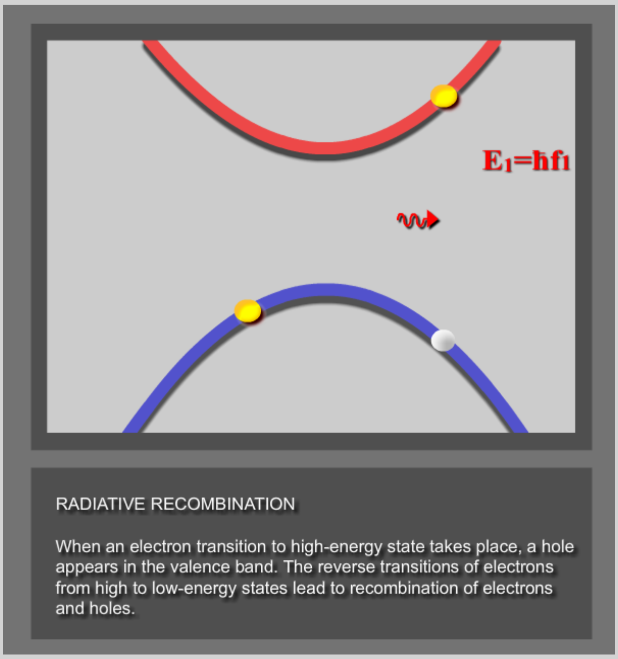
Exploitation and dissemination activities

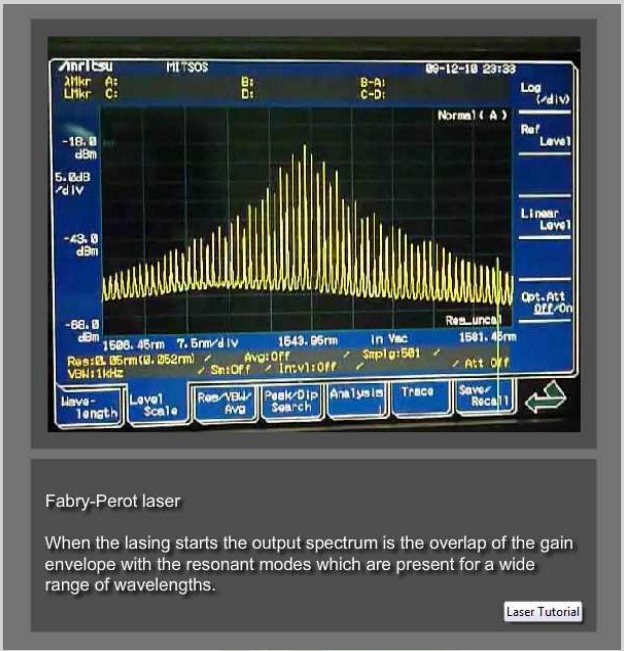
Organization of the FAST-DOT summer school on ultra-fast non-linear optics

FAST-DOT initiated the organization of an international summer school in collaboration with Heriot-Watt University (SUSSP 66) and will be held on 11-21 of August 2010 in Edinburgh, Scotland. The ten-day summer school topic is the "ultrafast non-linear optics" and it aims to bring together PhD students and young postdoctoral researchers from a diverse range of fields relevant to the study of ultrafast nonlinear optics, enable the exchange of new ideas across these fields. The core program consists of lectures by internationally renowned experts, supplemented by workshops, poster presentations and informal discussion sessions.

An animated tutorial for semiconductor lasers

The team from NKUA (Greece) has developed a user-friendly flash-based tutorial for semiconductor lasers and FAST-DOT related devices. The first part which is available in the FAST-DOT site, visualizes the main physical mechanisms involved in semiconductor lasers. The second part which is under development, will focus on the devices to be developed in the project and thus providing to the students and early researchers the possibility to become familiar with advanced physical principles and state of the art photonics applications.





Screenshots of the animated tutorial for semiconductor laser hosted at the FAST-DOT site.

FAST-DOT Academic wins prestigious fellowship

Dr Maria Ana Cataluna, a leading researcher with the FAST-DOT project, has been awarded a prestigious Research Fellowship from the Royal Academy of Engineering/EPSRC. The Fellowship, which will allow Dr Cataluna to develop her work on compact and ultra-versatile lasers based on quantum-dot materials, is one of only ten awarded each year. It provides funding for five years to encourage outstanding researchers in developing successful academic careers in engineering. Dr Cataluna is involved in the research and management of FAST-DOT, leading Work Package 2 and developing miniature lasers for use in ultra-compact microscopes to image live cells and tissues.

University of Dundee signs up as Juno supporter

IOP Institute of Physics
Juno Supporter

The Division of Electronic Engineering and Physics at the University of Dundee has pledged its commitment to increasing the representation of women in physics by signing up as a supporter of Project Juno. Launched by the Institute of Physics in 2007 the project recognises and rewards physics departments that can demonstrate they have taken action to address the under-representation of women in university physics and to encourage better practice for both women and men.

Project Juno offers three levels of awards beginning with supporter and moving on to practitioner and then champion. The Division of Electronic Engineering and Physics at Dundee has achieved supporter status by accepting and implementing the five principles of the Project Juno Code of Practice. These are:

- a robust organisational framework to deliver equality of opportunity and reward;
- appointment, promotion and selection processes and procedures that encourage men and women to apply for academic posts at all levels;
- departmental structures and systems which support and encourage the career progression of all staff and enable men and women to progress and continue in their careers;
- Departmental organisation, structure, management arrangements and culture that are open, inclusive and transparent and encourage the participation of all staff.
- flexible approaches and provisions that encompass the working day, the working year and a working life in SET and enable individuals, at all career and life stages, to maximise their contribution to SET, their department and institution.

For more information on Project Juno see:
http://www.iop.org/activity/diversity/initiatives/juno/page_38467.html

Women in science and engineering workshop held

A range of issues affecting women in science and engineering from leadership to glass ceilings and work-life balance were highlighted at a workshop organised by the FAST-DOT Project's Gender Awareness Group and the University of Dundee's College of Art, Science and Engineering. Held at the University of Dundee the workshop featured talks by Professor Ursula Keller, Head of Research at ETH Zurich, Professor Inke Nathke, Professor of Epithelial Biology and Cancer Research UK Senior Fellow in the College of Life Sciences at the University of Dundee and Ms Gameelah Ghafoor, Global Project manager at NCR in Dundee and also Vice President of WIN (Women in NCR). Those attending the free event also had the opportunity to quiz the speakers and raise their own topics of interest. Their talks can be found on the FAST-DOT website, under the section "Women in FAST-DOT":
http://fast-dot.eu/index.php?option=com_content&task=view&id=143&Itemid=111

Lasers under Café Science spotlight

EVENING TELEGRAPH PICTURE SPECIAL Monday, January 18, 2010 – 23

It's Sensational

DUNDEE'S award-winning science encounter facility, Sensation is often seen as something for children to enjoy, but as the Tele photographer discovered, there's something for all ages. "Reclaim" evenings give adults a chance to make the most of Sensation with a series of fascinating lectures and practical demonstrations. They also include Cafe Science Extra — an informal talk from a local scientist followed by a Q&A session over coffee.

The informal atmosphere of the Cafe Science Extra Q&A session.

Maria Ana Cataluna of Dundee University's Physics and Electrical Engineering Department gave a talk and held a Q&A session at Sensation on Laser Technology in Medical Science.

The Sensation Team welcoming guests to the

FAST-DOT researcher Dr. Maria Ana Cataluna gave members of the public a fascinating insight into her work on lasers at a talk at the Dundee Science Centre earlier this year. Her talk entitled "Lasers: Illuminating new frontiers in Medicine", formed part of the popular Café Science programme of outreach events. Dr Cataluna explained in lay terms the recent development of a new generation of miniature ultrafast lasers and discussed how these sophisticated lasers are pushing the boundaries in biomedical imaging and minimally-invasive treatments. "Participating in the Café Science was an

exciting opportunity which I really enjoyed," she said. "The audience was extremely engaged in the discussion and their questions were very interesting! "Inevitably you take a fresher look at your research and how it fits in the "big picture", particularly when you explain complex phenomena in lay terms. The beauty of coming face-to-face with the general public is that not only it raises awareness of your research and its impact, but you also feel rewarded and accountable for what you do as a researcher – and I found that a very inspiring experience!".
More than 50 members of the general public attended the event, which was followed by a lively questions and answers session. The event was featured in the local newspaper and the talk can be found at http://www.youtube.com/watch?v=ZPuGmtYs7jw

FAST-DOT researcher awarded PhD

Svetlana Zolotovskaya, a researcher on FAST-DOT's Work Package 6, has been awarded her PhD by the University of Dundee for a thesis entitled "Novel Semiconductor-based laser Systems and their Applications." Dr Zolotovskaya received her BSc degree in Optical Engineering & Laser Technology from Belarus National Technical University (BNTU), Minsk, Belarus. She began her postgraduate studies at Dundee in 2006 after obtaining an Overseas Research Students Awards Scheme (ORSAS) scholarship funded through the Scottish HEI's Funding Council. A member of the Photonics and Nanoscience Research Group within the Division of Electrical Engineering and Physics at the University of Dundee Dr Zolotovskaya's areas of research include the study of ultra-short optical pulse generation from solid state and quantum dot lasers, spectral narrowing and multi-wavelength operation of semiconductor laser diodes. Her work includes second order harmonic generation and applications of compact light sources in the fields of biophotonics and medicine.