NEWSLETTER Y3b

"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.

CONTENTS

www.fast-dot.eu

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 the third year's highlights (second-half)

The activities during the second-half of the third year of the project were, devoted to the implementation of advanced laser systems using the already realized chips and their application to bio-imaging systems. In parallel, optimized devices have been designed. In this respect, significant progress has been made in the following areas:

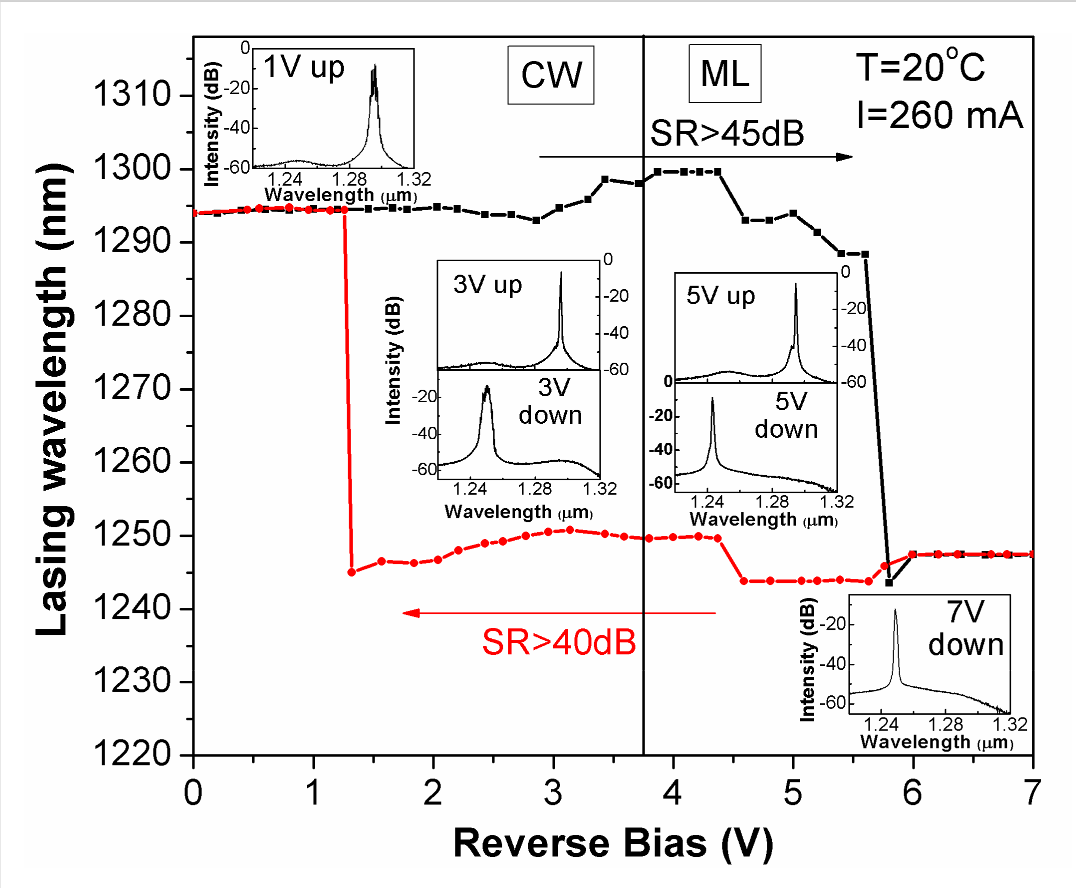
- ***High-power wavelength bistability in mode-locked quantum-dot mode-locked lasers.***
- ***Broad repetition-rate tunability in quantum-dot external-cavity passively mode locked lasers.***
- ***Femtosecond operation of a high power vertical extended cavity surface emitting laser (VECSEL).***
- ***Nonlinear microscopy using a portable ultrafast Semiconductor Disk Laser (SDL) or VECSELs.***
- ***Two-Photon Excited Fluorescence (TPEF) and Second Harmonic Generation (SHG)***

In conclusion, the project is proceeding according to the original schedule and, in its third year, has produced a number of novel and interesting results which have been published in ***6 journal publications*** and ***11 international conference publications***.

Mode-locked QD edge-emitting lasers and amplifiers

High-power wavelength bistability in mode-locked quantum-dot mode-locked lasers

The University of Dundee has recently demonstrated robust and high-power wavelength bistability between 1245nm and 1295nm, controllable via the reverse bias applied to the saturable absorber [1]. This corresponds to the largest spectral separation to be demonstrated from a wavelength bistable laser. Depending on the range of reverse bias applied, continuous wave (CW) or mode-locked regimes are obtained, with average powers up to 25mW and 17mW, respectively. This output power performance represents an improvement of more than one order of magnitude when compared with the current state-of-the-art. A suppression ratio higher than 40dB is demonstrated. This new approach could potentially have a high impact in all-optical processing and optical communications.

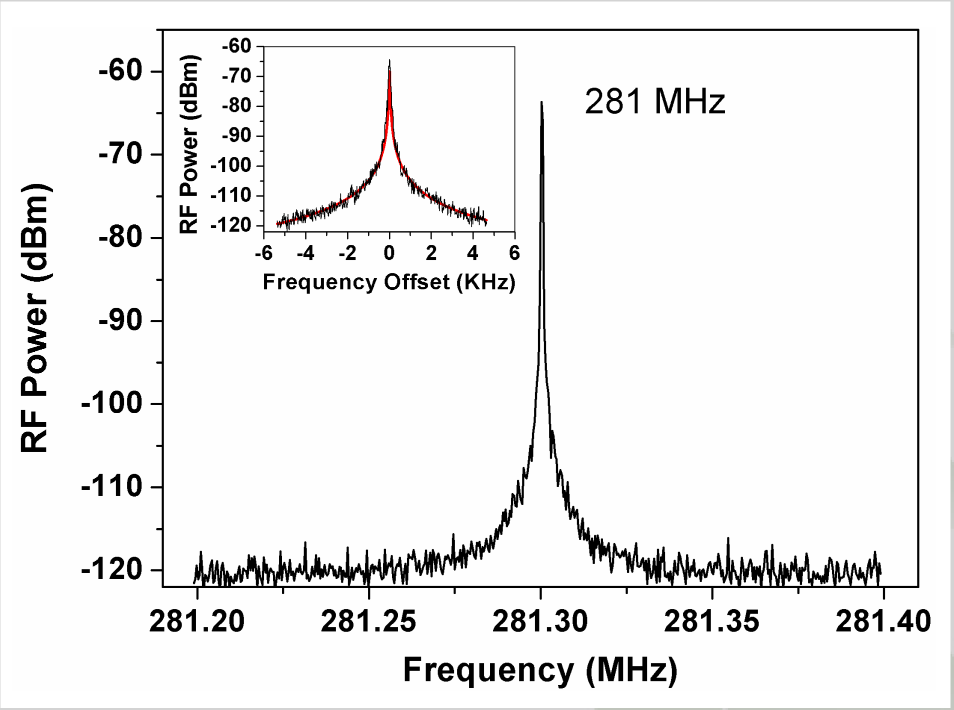


Dynamics of the emission wavelength with various values of ascending and descending reverse bias. A transition between continuous wave (CW) and mode-locked (ML) regimes occurs at 3.75V. Insets: optical spectra at several operating points, depicting the suppression ratio (SR) between the modes.

[1] M. A. Cataluna, et al., "High-Power Versatile Picosecond Pulse Generation from Mode-Locked Quantum-Dot Laser Diodes", IEEE Journal of Selected Topics in Quantum Electronics, to appear on the September /October 2011 issue.

Broad repetition-rate tunability in a quantum-dot external-cavity passively mode locked laser

The University of Dundee, in collaboration with Innolume, has demonstrated an external cavity passively mode-locked quantum-dot laser with a repetition rate which could be continuously tuned from 1 GHz to a record-low value of 191 MHz, which could prove useful for non-linear imaging techniques, especially in the bio-medical field [1]. A nearly constant pulse peak power at the different pulse repetition rates is revealed in the continuous repetition rate tuning range. Moreover, an RF linewidth of a record value of ~30 Hz is demonstrated, which indicates the low noise operation and high stability of the quantum-dot external-cavity passively mode-locked laser. These recent advances confirm the potential of quantum-dot lasers as versatile, compact and low-cost sources of ultrashort pulses.



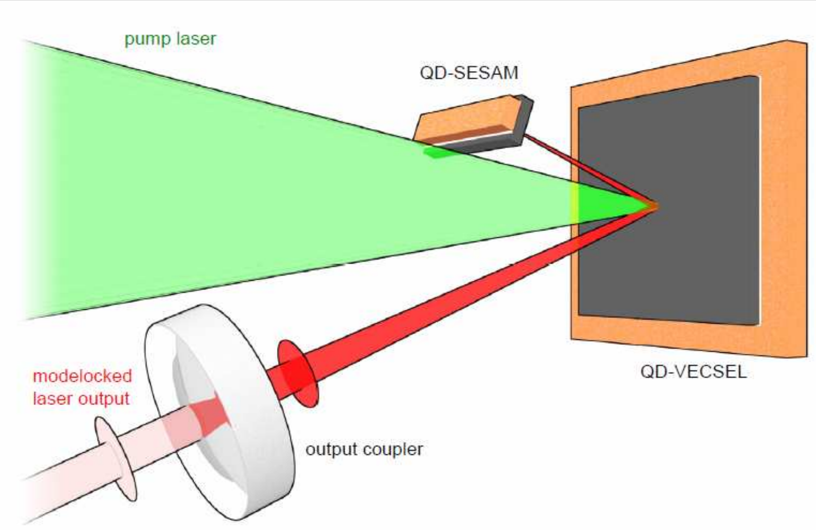
Measured RF spectrum of the external-cavity mode-locked laser, at a 281 MHz pulse repetition rate. Inset: RF spectrum with a 10 KHz span, with a -3dB linewidth of ~30 Hz (obtained after Lorentzian fit). The resolution and video bandwidth for this acquisition were 30 Hz and 3 Hz, respectively.

[2] Y. Ding, et al, "Broad repetition-rate tunable quantum-dot external-cavity passively mode-locked laser with extremely narrow RF linewidth", accepted to Applied Physics Letters (2011).

Optically pumped VECSELs

Femtosecond operation of a high power VECSEL

In the journal Optics Express, we report on the first femtosecond vertical external cavity surface emitting laser (VECSEL) exceeding 1 W of average output power. The VECSEL is optically pumped, based on self-assembled InAs quantum dot (QD) gain layers, cooled efficiently using a thin disk geometry and passively modelocked with a fast quantum dot semiconductor saturable absorber mirror (SESAM). We developed a novel gain structure with a flat group delay dispersion (GDD) of ± 10 fs^2 over a range of 30 nm around the designed operation wavelength of 960 nm. This



amount of GDD is several orders of magnitude lower compared to standard designs. Furthermore, we used an optimized positioning scheme of 63 QD gain layers to broaden and flatten the spectral gain. For stable and self-starting pulse formation, we have employed a QD-SESAM with a fast absorption recovery time of around 500 fs. We have achieved 1 W of average output power with 784-fs pulse duration at a repetition rate of 5.4 GHz. The QD-SESAM and the QD-VECSEL are operated with similar cavity mode areas, which is beneficial for higher repetition rates and the integration of both elements into a modelocked integrated external-cavity surface emitting laser (MIXSEL).

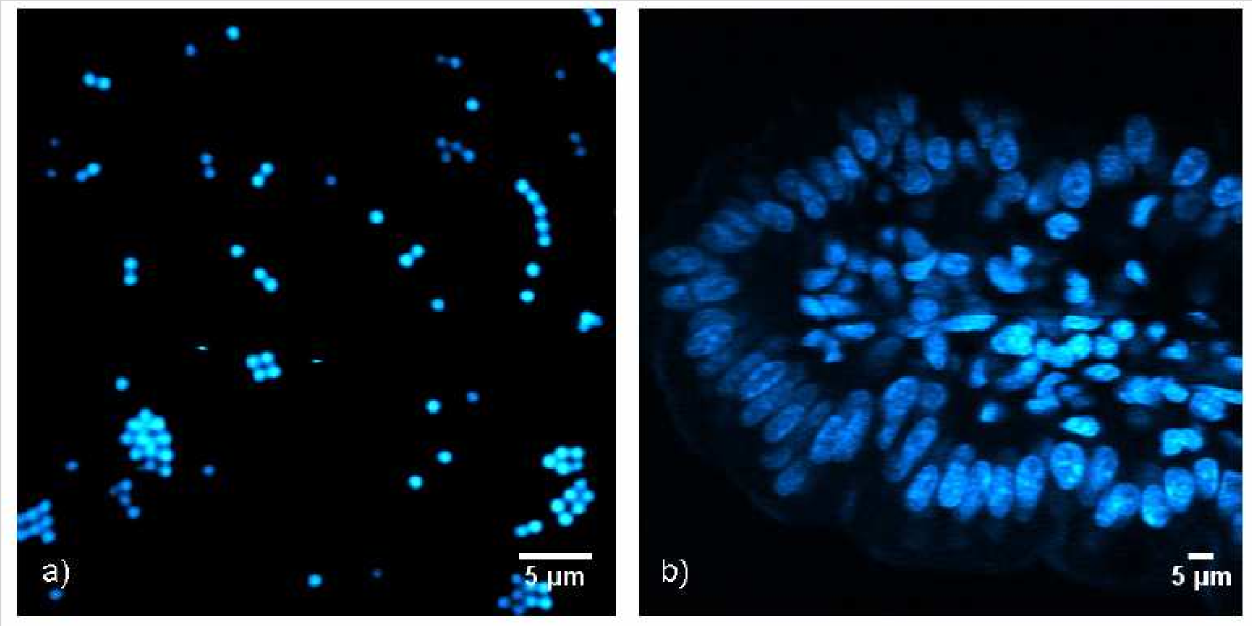
[3] J. Martin Hoffmann et al., "Femtosecond high-power quantum dot vertical external cavity surface emitting laser", Optics Express, vol. 19 (9), pp. 8108-8116 (2011), http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-19-9-8108

Biomedical imaging

Imaging with Semiconductor Disk Laser - I

In the journal Biomedical Optics Express, we present a portable ultrafast Semiconductor Disk Laser (SDL) (or vertical extended cavity surface emitting laser—VECSELs), to be used for nonlinear microscopy. The SDL is modelocked using a quantum-dot semiconductor saturable absorber mirror (SESAM), delivering an average output power of 287 mW, with 1.5 ps pulses at 500 MHz and a central wavelength of 965 nm. Specifically, despite the fact of having long pulses and high repetition rates, we demonstrate the potential of this laser for Two-Photon Excited Fluorescence (TPEF) imaging of in vivo Caenorhabditis elegans (C. elegans) expressing Green Fluorescent Protein (GFP) in a set of neuronal processes and cell bodies. Efficient TPEF imaging is achieved due to the fact that this wavelength matches the peak of the two-photon action cross section of this widely used fluorescent marker. The SDL extended versatility is shown by presenting Second Harmonic Generation images of pharynx, uterus, body wall muscles and its potential to be used to excite other different commercial dyes. Importantly this non-expensive, turn-key, compact laser system could be used as a platform to develop portable nonlinear bio-imaging devices.

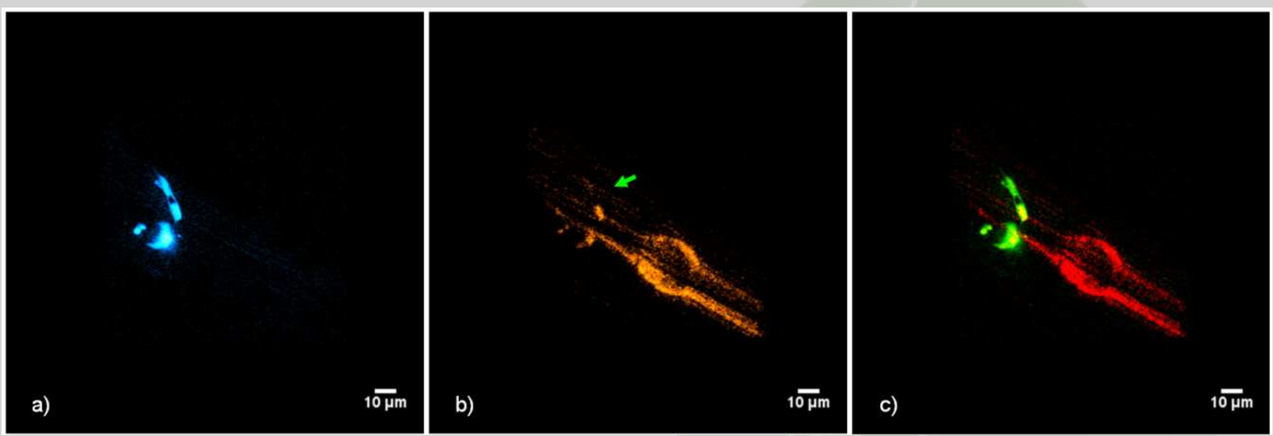
[4] Rodrigo Aviles-Espinosa et al., "Compact ultrafast semiconductor disk laser: targeting GFP based nonlinear applications in living organisms", Biomedical Optics Express, 2 (4), pp. 739-747 (2011), http://www.opticsinfobase.org/boe/abstract.cfm?uri=boe-2-4-739



Two-Photon Excited Fluorescence images from a) green fluorescent beads and b) mouse intestine section.

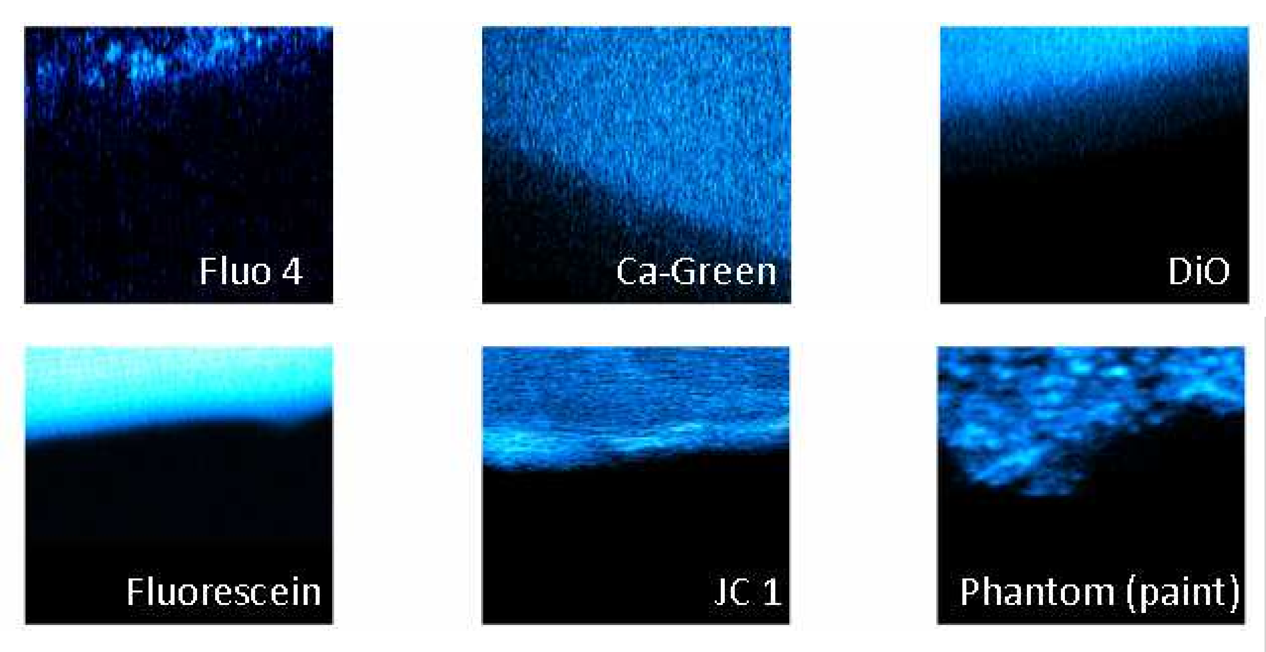
Imaging with Semiconductor Disk Laser - II

The second and third Quantum Dot-based laser prototypes where tested at ICFO to extend the versatility of the system for obtaining multiphoton images from different samples containing different biological dyes. The second and third iterations of the Quantum Dot based semiconductor disk laser systems developed by MSquared were tested at ICFO (with the participation of



3D projections of a) TPEF signal from neurons forming the nerve ring expressing GFP (blue) and b) SHG signal from the pharyngeal region (orange) of the C. elegans nematode. c) Merged TPEF (Green) and SHG (red) images of both structures.

Msquared personnel). The new lasers could deliver up to 1 W average output power. The obtained results have enabled to demonstrate to extend the versatility of this device for efficient excitation not only of green fluorescent protein (GFP) but also of different biological dyes. These results (including the first demonstration of Two-Photon Excited Fluorescence (TPEF) and Second Harmonic Generation (SHG) of in-vivo C. elegans nematodes) have been published in several conference papers and journals [4-7].



TPEF images from different biological dyes in solution that can also be efficiently excited using Msquared quantum dot based systems.

[5] Rodrigo Aviles-Espinosa et al, "Compact ultrafast semiconductor disk laser for nonlinear imaging in living organisms", in Proc. Photonics West, San Francisco C.A (USA), Paper 7903-99 (2011).
[6] Rodrigo Aviles-Espinosa et al, "Efficient nonlinear excitation of encoded fluorescent proteins in living samples using a semiconductor disk laser," in Proc. Focus on Microscopy, Konstanz Germany, Paper 39 (2011).
[7] Rodrigo A. Aviles-Espinosa et al, "Portable semiconductor disk laser for in vivo tissue monitoring: a platform for the development of clinical applications," in Proc. European conferences on biomedical optics, Munich Germany, Paper 8092-19 (2011).

Exploitation and dissemination activities

Successful implementation of new conference at Photonics West

The scientific and industrial importance of the research performed in the FASTDOT project was highlighted by the successful implementation of a new conference at Photonics West, January 21-26, 2011 in San Francisco, USA. The conference LA116, which was initiated and organized by FASTDOT member Ursula Keller, focused on current work in the rapidly developing field of optically and electrically pumped vertical external cavity surface emitting lasers (VECSELs). These lasers, which are also referred to as optically pumped semiconductor lasers (OPSLs) or semiconductor disk lasers (SDLs) have gained a strong interest for power scaling. In a VECSEL, the light is emitted perpendicular to the epitaxial layers, unlike edge-emitting lasers, where the beam propagates in the epitaxial layers. In contrast to a VCSEL (i.e. a vertical cavity surface emitting laser) the external cavity of the VECSEL offers additional mode control for excellent transverse beam quality even at highest power levels and enables the integration of elements for nonlinear intracavity frequency conversion, wavelength tuning elements or passive mode-locking. An extensive selection of tutorial and invited papers provided a comprehensive overview of the latest progress in this new field. In addition, many submitted papers treated various state-of-the-art technologies, such as:

- power scaling of VECSEL, OPS, SDL and MIXSEL
- heat management
- spectral coverage; material systems, quantum dots, epilayer design
- intracavity nonlinear frequency conversion
- epilayer growth challenges
- numerical modeling of gain, dynamical behavior, thermal behaviour
- optical in-barrier and in-well pumping
- electrical pumping
- mode-locked operation
- single frequency operation
- integrated extended cavities and wafer processing
- specific applications.

As the conference was a large success with high attendance, it will be again organized in the next year. Approximately 40% of the committee members are FASTDOT partners, illustrating the high impact of our research.
Link to next year's conference: http://spie.org/LA116

2nd FAST-DOT summer school organized

The second FAST-DOT Summer-school with title "Photonics meets Biology" is planned for 15 - 18 September, 2011 in Hersonissos on the Crete island, Greece. The school is organized by FAST-DOT partners IESL/FORTH (Greece) and the University of Dundee (UK). More information and details can be found in the web site: http://fastdot.iesl.forth.gr/

FAST-DOT paper highlighted in Nature Photonics

Nature Photonics has highlighted a FAST-DOT paper published by the Technical University of Darmstadt, in collaboration with the Politecnico di Torino, III-V Lab and University of Sheffield. The paper was published in Applied Physics Letters [8], and it presents experimental and simulation results on a regime of reverse-emission-state-transition mode-locking, as well as a transition to stable simultaneous two-state mode locking on excited state and ground state. The highlight in Nature Photonics can be found in page 733:
http://www.nature.com/nphoton/journal/v4/n11/full/nphoton.2010.245.html

[8] Stefan Breuer, Mattia Rossetti, Wolfgang Elsasser, Lukas Drzewietzki, Paolo Bardella, Ivo Montrosset, Michel Krakowski, and Mark Hopkinson, "Reverse-emission-state-transition mode locking of a two-section InAs/InGaAs quantum dot laser", Applied Physics Letters 97, 071118 (2010).