NEWSLETTER

"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 the 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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Introduction - First year's highlights

Quantum Dot Technology is moving fast from the research labs to the production lines. A broad range of application sectors profit from the advantages of the new technology, covering areas from electronics, optics and extending to cellular imaging and therapeutic detection capabilities for life sciences and biomedicine. According to a recent technical market research report [1,2] (BCC Research of Wellesly Mass. Sept. 2008) the global market value for QD technology is $28,6 million (mainly colloidal particles) and is expected to rise to $721,1 million in 2013 covering apart from colloidal dots applications, sectors in optics ($212 million in 2013), electronics ($61 million in 2013, mainly for QD flash memory applications), and optoelectronics ($245,7 million in 2013).

In view of the above data, FAST-DOT is strategically placed very well, being temporally in phase with the expanding market wave but also targeting at QD based devices of the optoelectronics sector. The objective of the project is to provide compact, high performance and low cost lasers for biophotonics applications such as laser microsurgery and imaging.

The activities during the first year of the project were, according to the initial schedule, devoted mainly to the detailed setting of the target specifications for the planned devices and subsystems and the development of the underlying technology needed for their realization. In this respect, significant progress has been made in the following areas:

- ***Detailed theoretical/numerical models have been developed for the simulation of the mode-locked quantum dot lasers.***
- ***Quantum dot semiconductor material with different compositions and properties has been grown and evaluated.***
- ***Novel operating regimes for the mode-locked QD lasers have been identified.***
- ***The electrically pumped vertical external cavity surface emitting lasers have been realized and evaluated.***
- ***Highly efficient optically pumped QD VECSEL with more than 4.3W average output power has been demonstrated.***
- ***Highly efficient optically pumped vertical-emitting semiconductor laser with more than 20W average output power in the fundamental transverse mode has been demonstrated.***
- ***The first mode locked QD vertical external cavity surface emitting laser has been demonstrated generating 10 ps optical pulses at 2.54 GHz rep. rate (1053 nm) with average power of 22 mW.***
- ***Non linear images of starch granules have been obtained using lasers provided by project partners.***

In conclusion, the project is proceeding according to the original schedule and, in its first year, has already produced a number of novel and interesting results.

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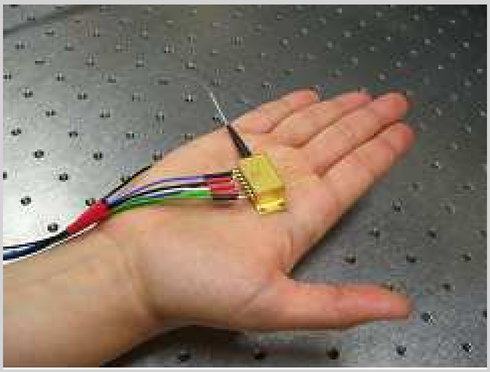
[1] "Quantum Dots: Technical Status and Market Prospects", Report Number: NAN027B
[2] "Quantum Dots point to a $721.1 million market" Photonics Spectra, Nov. 2008, pp 28.

Mode-locked QD edge-emitting lasers and amplifiers

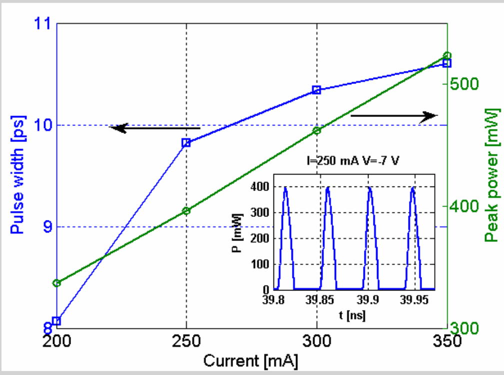


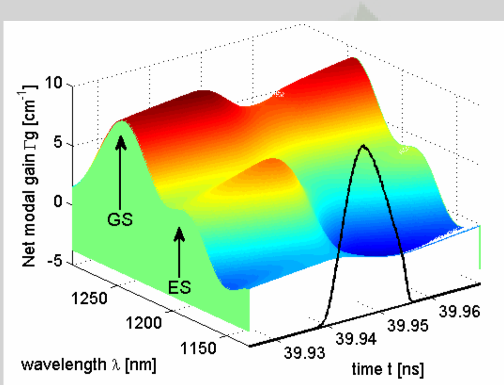
The project aim is to develop high-power, tunable, ultrafast edge-emitting quantum dot lasers, based on novel compact monolithic and external cavity configurations and subsequent frequency conversion to generate visible light, for key biophotonic and medical applications.

Our goal: ultrafast and ultra-compact electrically-pumped QD lasers

Modelling passive mode locking

During the first year of FAST-DOT, the team at Politecnico di Torino has successfully modelled passive mode-locking in quantum-dot lasers via a time-domain travelling-wave model including an accurate description of QD gain and absorption dynamics and related refractive index changes using multi-population rate equations [3].



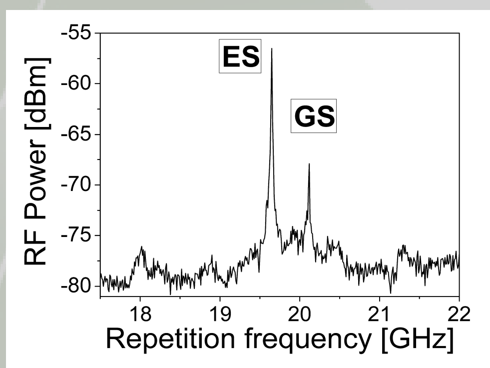


Calculations of passive mode-locking in a two section QD laser with a total length of 2mm, a 300 µm-long SA section and 5 QD layers.

[3] M. Rossetti, P. Bardella, M. Gioannini, and I. Montrosset, "Time Domain Travelling Wave Model for Simulation of Passive Mode Locking in Quantum Dot Lasers", CLEO/Europe-EQEC 2009, paper CF.P.21 (918)

Experimental demonstration of novel regimes of mode-locking in QD lasers

Recently, the team at the University of Dundee demonstrated a dual-wavelength passive mode-locking regime where picosecond pulses were generated from both excited-state (λ=1180nm) and ground-state (λ=1263nm), in a two-section GaAs-based QD laser[4]. This is the widest spectral separation (83nm) ever observed in a dual-wavelength mode-locked non-vibronic laser. The exploitation of this novel mode-locked regime could enable a range of applications extending from dual-wavelength nonlinear imaging modalities to frequency mixing, time-domain spectroscopy and ultrafast optical processing.



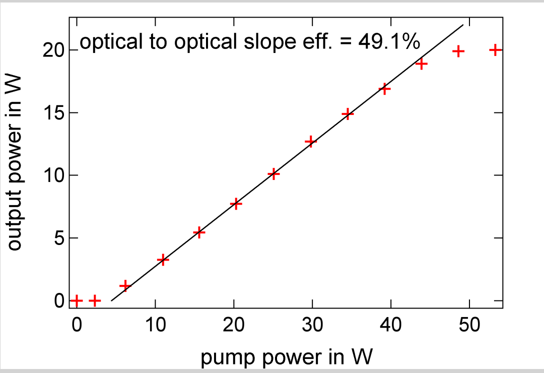
[4] M. A. Cataluna, D. I. Nikitchev, I. Krestnikov, D. A. Livshits, A. R. Kovsh, and E. U. Rafailov, "Dual-wavelength mode-locked GaAs-based quantum-dot laser", CLEO/Europe-EQEC 2009, paper CB4.6 (892).

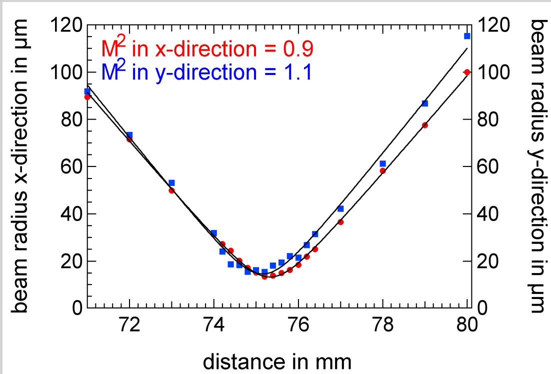
Optically pumped VECSELs

One of the key activities of the project is the development of optically pumped vertical-external-cavity surface-emitting lasers (OP-VECSELs) for multi-photon imaging, RGB generation and sub-picosecond pulses for continuum generation. Major achievements in the first year include:

Highly efficient optically pumped vertical-emitting semiconductor laser with more than 20 W average output power in a fundamental transverse mode [5]

Partner ETHZ has demonstrated an optically pumped vertical-external-cavity surface-emitting laser (OP-VECSEL) generating more than 20 W of continuous wave output power in a fundamental transverse mode M^2<1.1 at 960 nm. The laser is highly efficient with a slope efficiency of 49%, a pump threshold of 4.4 W, and an overall optical-to-optical efficiency of 43%.

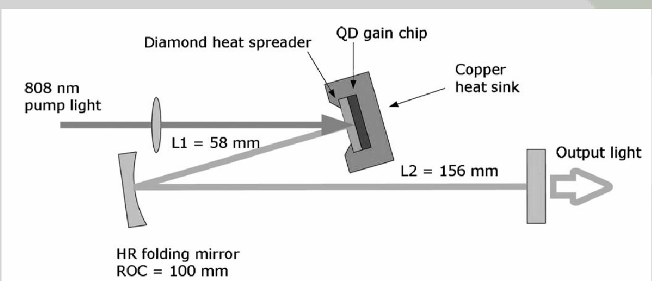


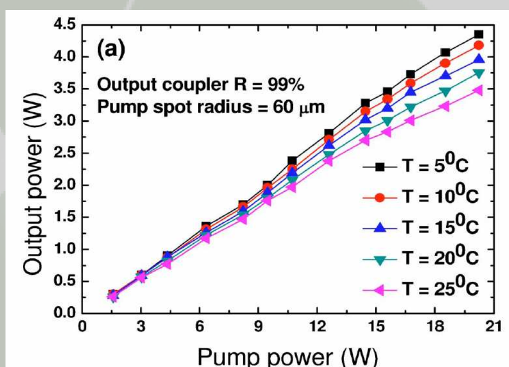


Output power vs pump power and right: M2 measurements (M2<1.1 in both directions).

High-power quantum-dot-based semiconductor disk laser [6]

The teams from Univ. Dundee, ORC Univ. Tampere, Innolume and ETHZ have demonstrated multi-watt cw output power from an optically-pumped quantum-dot VECSEL. Continuous-wave output power of 4.35 W with 22% slope efficiency was demonstrated at a center wavelength of 1032 nm. This represents an increase in power of 15 times and an increase in slope efficiency of 10 times from the previously published results using Stranski–Krastanow grown quantum dots. An intracavity diamond heat spreader was used for thermal management. The maximum output power was limited by the available pump power, and no sign of thermal rollover was observed.

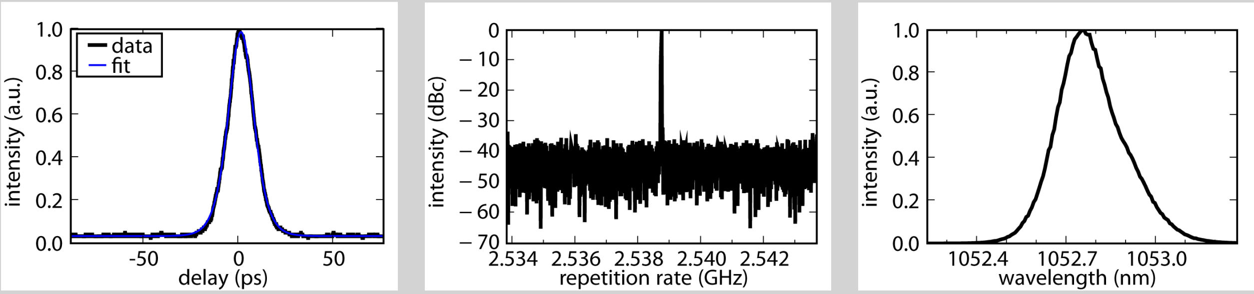




Schematic of the V-cavity laser configuration and right output power versus pump power characteristics of diamond heat spreader optically pumped VECSEL.

Modelocked Quantum Dot Vertical External Cavity Surface Emitting Laser [7]

The teams from ETHZ and Innolume have demonstrated the first modelocked all-QD VECSEL. Pulses of 10 ps length, at 2.54 GHz repetition rate, 1053 nm wavelength with an average output power of 22 mW have been obtained. The performance is limited by the poor thermal properties of the VECSEL structure. Substrate removal will enable power levels of several watts [6], as demonstrated previously for QW-VECSELs [5]. Optimizing QD-SESAM recovery dynamics and cavity dispersion should allow the generation of femtosecond pulses in the near future.

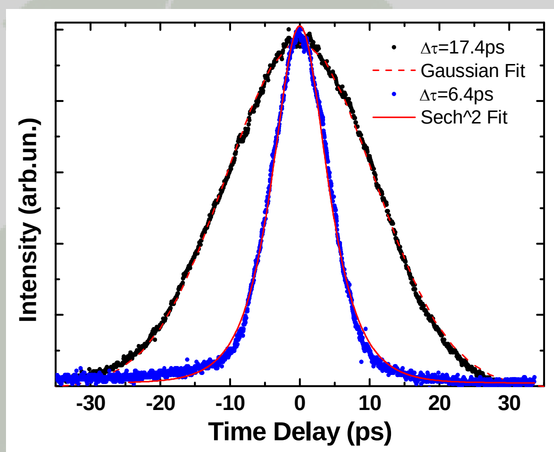


The autocorrelation trace and its fit (left), the RF-spectrum (center) and the optical spectrum (right).

[5] B. Rudin et al., Optics Letters, Vol. 33, Issue 22, pp. 2719-2721, 2008.
[6] M. Butkus et al., Optics Letters, Vol. 34, Issue 11, pp. 1672-1673, 2009.
[7] M. Hoffmann et al., Applied Physics B, Vol. 93, Issue 4, pp. 733-736, 2008

QD SESAMs

The teams from Univ. Dundee and Innolume have demonstrated the pulse duration control from stable mode-locked Cr:forsterite laser using a voltage controlled p-n junction QD SESAM. Output shortening from 17.4 to 6.4 ps near-transform limited pulses was obtained by applying reverse bias [8].

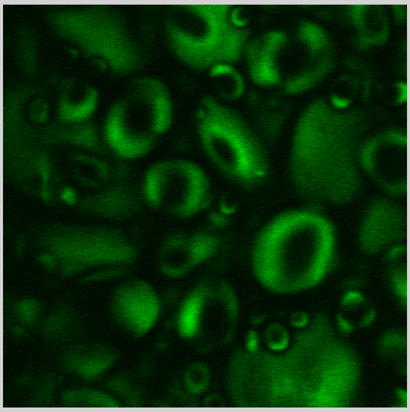


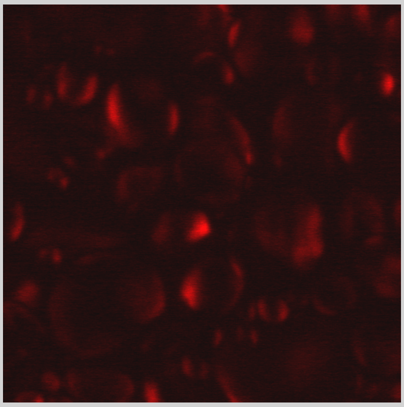
Intensity autocorrelation trace of the pulses obtained with unbiased (black dots) and biased (blue dots) p-n QD SESAM.

[8] Zolotovskaya et al. Phot. Tech. Lett. accepted for publication (2009).

Non-linear images acquired by ICFO team using TOPTICA laser.

The results of a first attempt to produce non-linear images of starch granules using a 1550 nm TOPTICA laser with an output power of 428 mW are presented below.





THG image of starch granules (left), and SHG image of starch granules (right).

Outreach activities

Public Engagement Award for UNIVDUN team

A team of FAST-DOTers at the University of Dundee was awarded the D'Arcy Thompson Prize for Excellence in Public Engagement. The awarded group is formed by Maria Ana Cataluna (FAST-DOT WP leader and researcher), Daniil Nikitichev (FAST-DOT PhD student) and Ksenia Fedorova (EPSRC-funded PhD student). The prize is awarded by the College of Art, Science and Engineering at the University of Dundee and recognises the work of outstanding science communicators towards improving understanding of the research of the College and University to a wider audience. The awardees will receive a certificate of recognition and prize money of £500 that can be used towards their future science communication activity.

The dynamic trio has been actively engaged in several public outreach events, in the framework of the "Revealing Research" and the "Women in Science, Technology and Engineering" programmes organized by the University of Dundee in the past few months. Together they have prepared several experiments that were used to demonstrate exciting phenomena related with optics and lasers to members of the public, at several Science Centres all over Scotland. Their enthusiasm also granted local press coverage (figure on the right).

The dynamic trio will use the prize money for developing and running workshops for pupils at the primary and S1/S2 levels, with the main goal of stimulating the interest of younger generations in the excitement of the scientific discovery, whilst encouraging a better understanding of the impact of optics and lasers in everyday life.

Matthew Begg learns about lasers with Daniil Nikitichev of Dundee University.

Science secrets unveiled

SOME OF the murky secrets of science were shared with a family audience in Dundee at the weekend thanks to a bevy of boffins from Dundee University and the Sensation science centre.

The Sharing Science event offered visitors of all ages the chance to get hands-on with demonstrations of leading research taking place in Scotland.

The Dundee contingent were joined by researchers from Edinburgh University and the Scottish Association for Marine Science in Oban.

A steady stream of visitors ensured Saturday's demonstrations, which also included a chance for visitors to take away a sample of their own DNA, went well.

Dr Jon Urch, who organised the event on behalf of Dundee University and Sensation, expressed his delight with the turnout.

He said, "We're looking at ways in which to bring some of the work taking place in Scotland to the general public, to allow them to engage with science.

"All of the researchers were asked to come up with a hands-on demonstration of something within their field of expertise and we've got some fantastic examples."

The event was co-ordinated by Dundee University's Revealing Research unit with Scottish Government funding.

Daniil featured in the local news!