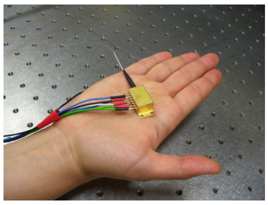
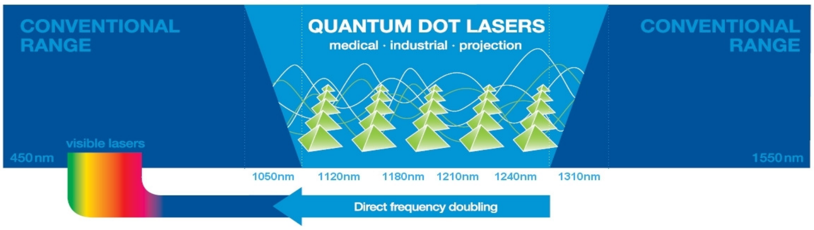
1. Publishable Summary



The laser systems that are traditionally used for biomedical applications are very expensive, bulky and complicated to 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 matchbox-sized, ultra-high performance lasers at a substantially lower cost, making their widespread use more affordable.

FAST-DOT is a €13.7M project (EU contribution €10.1M) coordinated by the University of Dundee, with a project consortium consisting of 18 of Europe's leading photonics research groups and companies from 12 different countries. The aim of the project is to take advantage of the unique properties of nano-materials based on quantum dots (QDs) to develop a new class of miniature lasers designed specifically for biomedical and imaging applications such as multi-photon imaging and cell surgery. FAST-DOT has already delivered significant advances and world record performances in defining the unique properties of semiconductor nano-materials based on quantum dots to realise a new class of semiconductor lasers components.

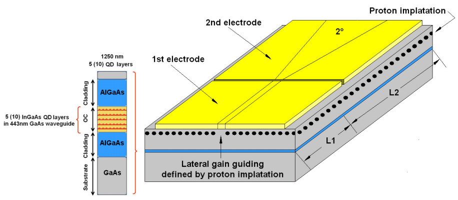
Quantum dots are special semiconductor materials which, when produced under highly controlled conditions can be custom designed and are sometimes called artificial atoms because of their nano-scale dimensions and unique properties. The high level of control that is possible over the size of the crystal produced means that it is possible to precisely design QD-based lasers with particular characteristics to produce specific wavelengths (or colours) that are difficult to reach using conventional laser technologies, ultrafast / ultra short pulses and generation of difficult to reach wavelengths.



With ultra short pulses, very high levels of energy can be delivered to a very small area, making this kind of laser very useful for applications such as cell surgery as there is not the undesirable heat generation association with normal lasers.

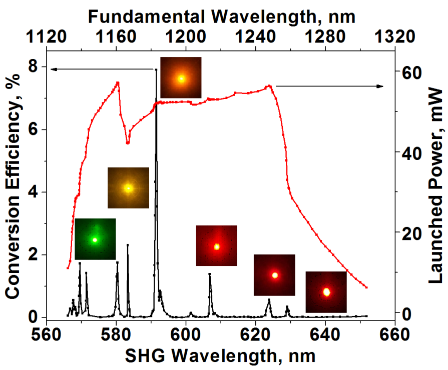
Laser power is often thought of as a constraint of semiconductor laser devices and FAST-DOT has been successful in overcoming this challenge. The consortium has achieved a new world record in peak power of pulses generated by a monolithic diode laser (17.7 W with 1.26 ps pulse duration), by using a tapered laser.

This result was achieved using advanced simulation modelling techniques to optimise the design of tapered mode-locked lasers and in QD fully gain guided two sections tapered laser. The schematic structure is shown here.



The state-of-the-art in semiconductor laser power has also been advanced by the demonstration of record-high peak power achieved from an external-cavity quantum dot laser at the 1.3 μm wavelength band. Without pulse compression or optical amplification, picosecond pulses with 1.5 W peak power were generated.

Large tuneability, or the range of wavelengths available from semiconductor lasers has been a long standing aspiration of laser users and FAST-DOT has made substantial progress here, with a tuning range of 130 nm being achieved from a mode-locked (pulsed output) external cavity quantum dot laser (EC-QDL). Tuneable light has also been achieved in continuous wave, with tuning from green to red (567.7 to 629.1 nm).



This was achieved by using a method called second harmonic generation (or frequency doubling), where effectively an infrared wavelength is converted using a crystal (in this case periodically poled KTP) into visible wavelengths.

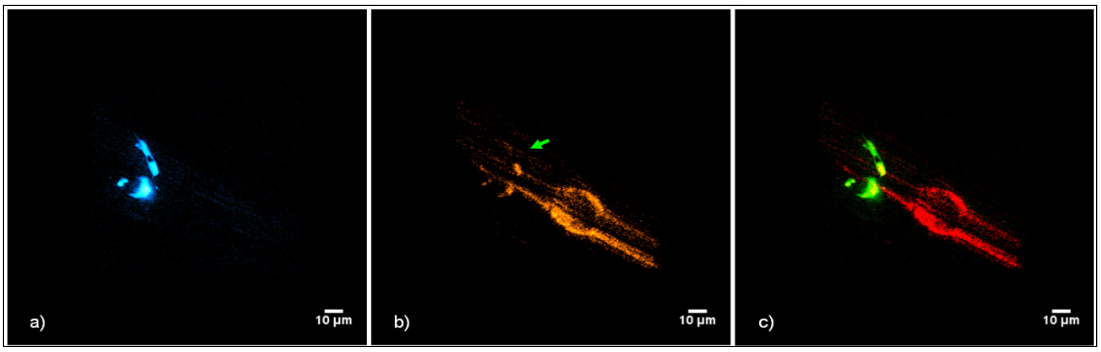
Theoretically it would be expected to achieve excellent wavelength tuning capabilities with quantum dot vertical-cavity surface-emitting lasers (QD-VECSELs) with very large bandwidth and this has been demonstrated and confirmed at 3 wavelengths in the infrared part fo the spectrum (1040, 1180, and 1260 nm) within the FAST-DOT project. Also, wavelengths that are difficult to achieve using conventional lasers have been accessed: 590 nm (orange), 515 nm (green) and 624 nm (red).

A semiconductor saturable absorber mirror (SESAM) is a mirror structure with an incorporated saturable absorber, all made out of semiconductor materials. Such devices are mostly used for the generation of ultrashort pulses by passive mode locking of various types of lasers, but they are also useful for purposes of nonlinear filtering outside laser resonators, e.g. for cleaning up pulse shapes, and in optical signal processing.

The unique properties of quantum dots have been shown to be especially relevant in developing SESAMs where the energy per unit area (saturation fluence) and very fast recovery times presents particular advantages over normal SESAM designs. The FAST-DOT consortium have successfully mode-locked a VECSEL to to produce up to 3 W of average output power with 5 ps pulse width.

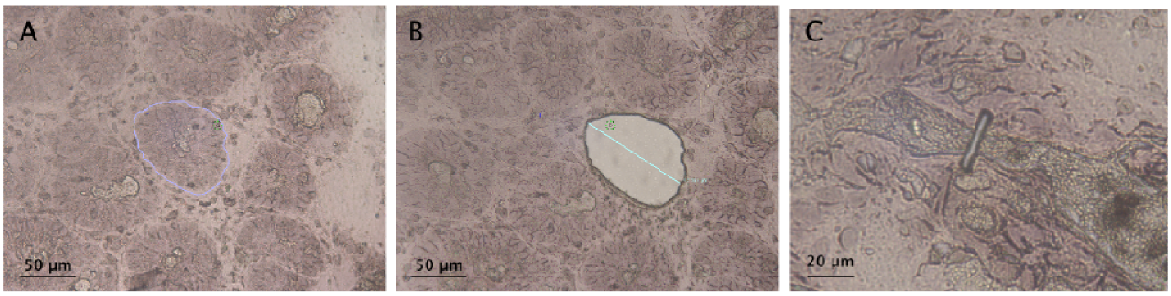
The FAST-DOT consortium has taken these new high performance quantum dot based materials and components and implemented them in a range of prototypes for validation and demonstration in bio-photonic applications where the novel properties offer advances in terms of cost and performance to a number of biological imaging and intervention techniques.

A prototype cost-effective ultrafast laser has been assembled by the consortium, delivering up to 1 W average power at a pulse duration of <1.5 ps operating at 975 nm and 500 MHz repetition rate. The dimensions of the system are only 220 x 80 x 65 mm, virtually an order of magnitude smaller than conventional systems with similar capability, making this a very attractive alternative. These images demonstrate the suitability of this laser for Two-Photon Excited Fluorescence which is an imaging technique that allows imaging of living tissue up to a very high depth (up to 1 mm). This technique has been demonstrated by imaging in vivo C. elegans (a roundworm of about 1 mm in length that is used extensively as a model organism) expressing green flourescent protein (GFP) in neuronal cell bodies and axons.



In addition to nonlinear imaging, cell surgery results have been also been obtained and published using this laser design.

A series of dissection experiments were performed with an ultrafast laser prototype developed by FAST-DOT on a preparation of mouse colon tissue, aiming to demonstrate the utility of ultrashort, pulsed lasers for biological tissue microdissection. The images below show: A – a piece of tissue marked; B – marked area of tissue was cut and removed; C – a thin cut is made through the tissue. These experiments are a precursor to cell surgery experiments: Once the optical setups and procedures are optimised and the results are acceptable, the procedure will be applied to live cell surgery. It is very important that these laser interventions do not irreversibly damage cells and cell viability has been demonstrated.



The FAST-DOT project has contributed significantly to advances in QD technology with 18 papers being published in high quality scientific journals and 32 papers presented at international conferences in the 3rd year alone.

For more information on the FAST-DOT project see www.fast-dot.eu .