# "FAST and CURIOUS"
# A brief introduction to ultrafast lasers and their applications

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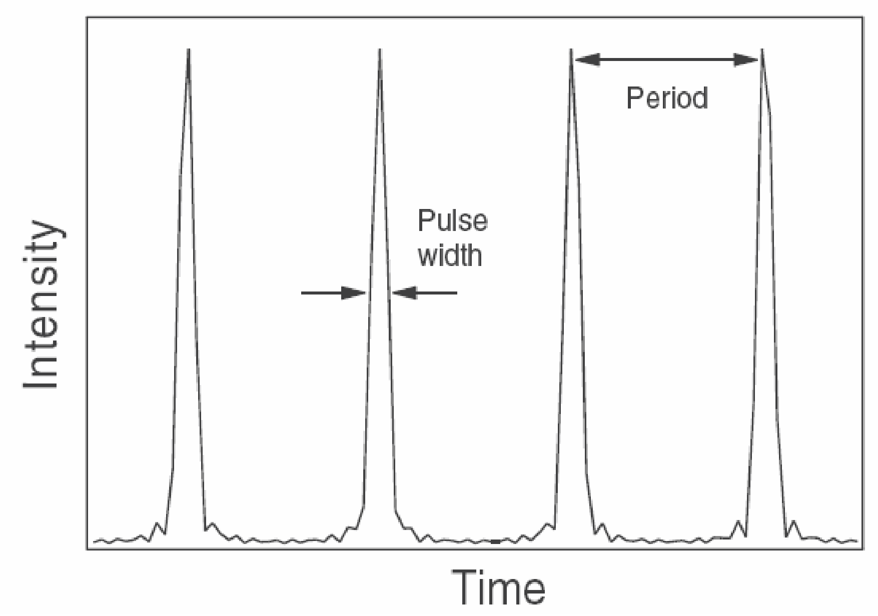
The FASTDOT project has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement no 224338

# How fast is ultrafast?

Instead of emitting light in a continuous manner (like most lasers do), ultrafast lasers emit a regular train of ultrashort pulses, i.e., extremely short bursts of light with durations between…

…a few femtoseconds ($10^{-15}$s) to a few picoseconds ($10^{-12}$s)



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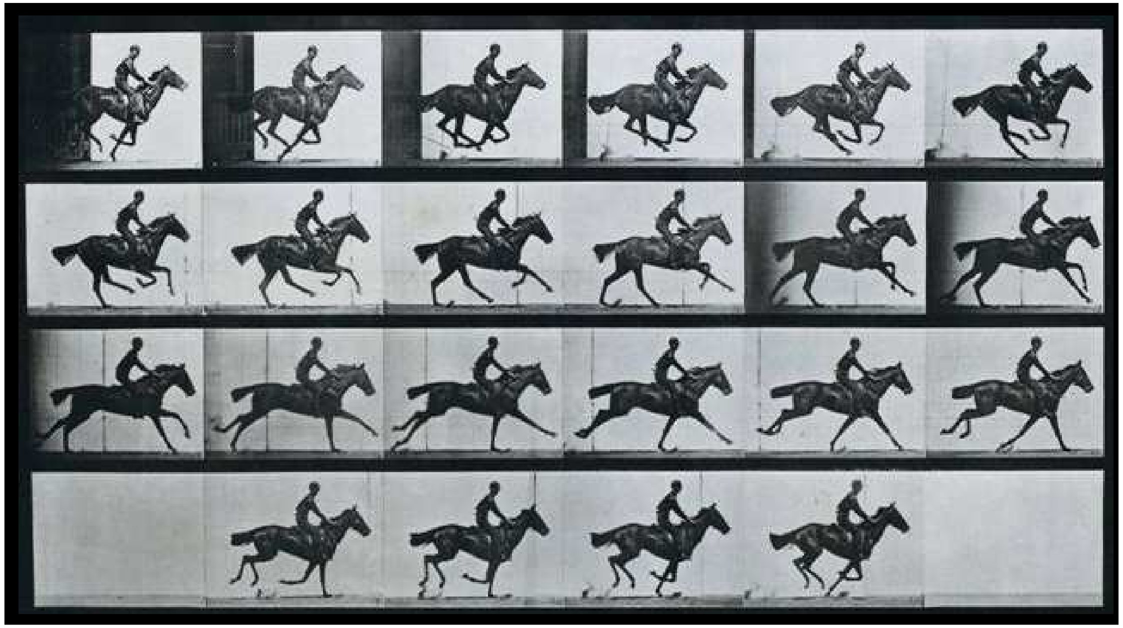
# How fast is ultrafast?

*Ultrafast lasers emit a regular train of ultrashort pulses, i.e., with durations between a few femtoseconds ($10^{-15}$s) to a few picoseconds ($10^{-12}$s)*

**Now compare this with snapshots that last a few milliseconds ($10^{-3}$s)…**



**[Eadweard Muybridge, Galloping Horse, 1887]**

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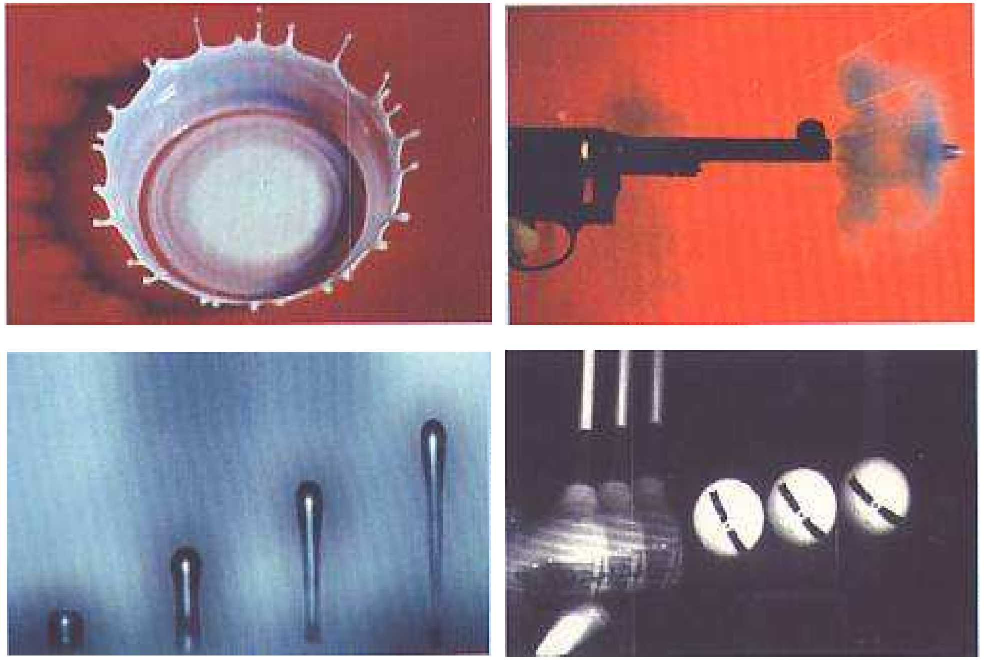
# How fast is ultrafast?

*Ultrafast lasers emit a regular train of ultrashort pulses, i.e.,*
*with durations between a few femtoseconds ($10^{-15}$s) to a few picoseconds ($10^{-12}$s)*

**Or compare with snapshots that last a few microseconds ($10^{-6}$s)…**



***Using 1 microsecond flashes***
***from a xenon flashbulb!***

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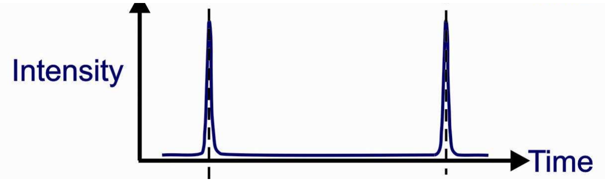
# How fast is ultrafast?

With snapshots that last between…

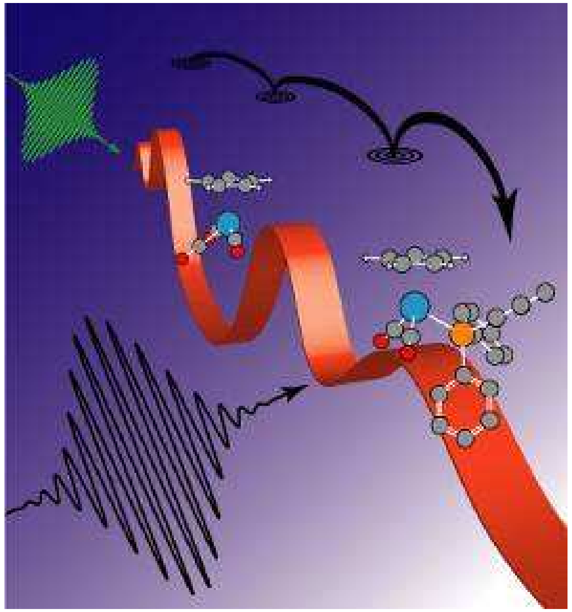
…a few femtoseconds ($10^{-15}$s) to a few picoseconds ($10^{-12}$s),

one can "photograph" chemical reactions as they happen!



Prof. Zewail

Nobel Prize in Chemistry, 1999



Femtochemistry

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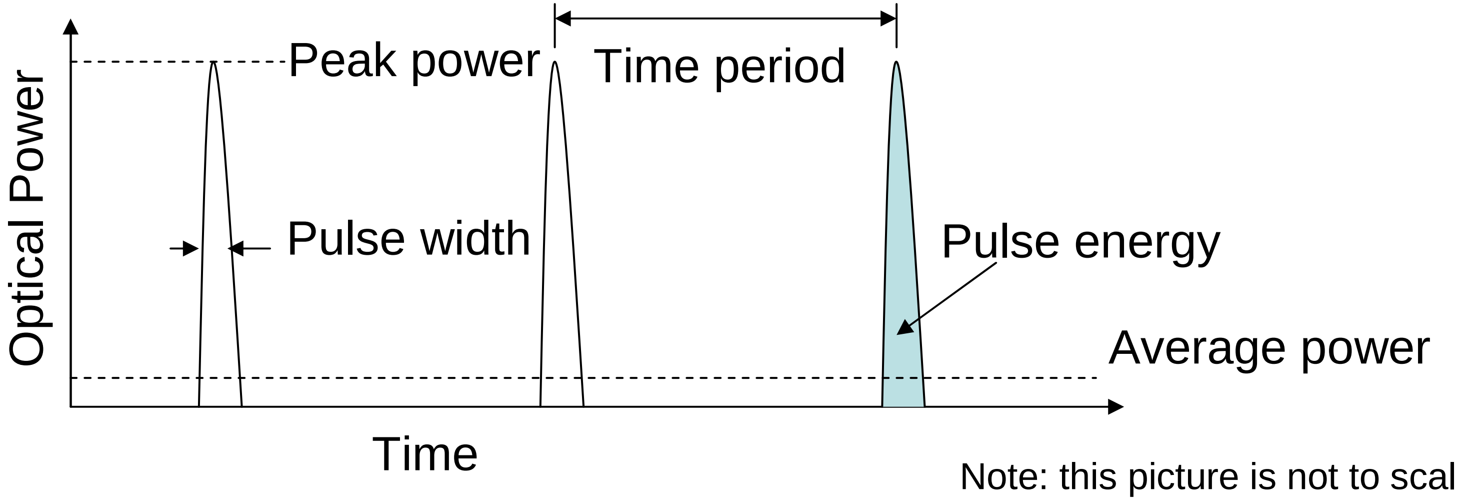
# Anatomy of a laser pulse



Note: this picture is not to scale.

- Ultrashort pulses are usually generated with a certain periodicity. What’s interesting is that the interval of time between each pulse can be thousands of times longer than the duration of the pulse. This means that the laser is actually “switched off” most of the time. So, **in average,** the optical power can be quite **low**.

- However, as all the optical energy of light is highly concentrated in time, the instantaneous or **peak power** can be incredibly **high**. And for a given energy, the shorter the pulse, the greater the peak power.

$$Peak\ power = \frac{Energy}{Pulse\ duration}$$

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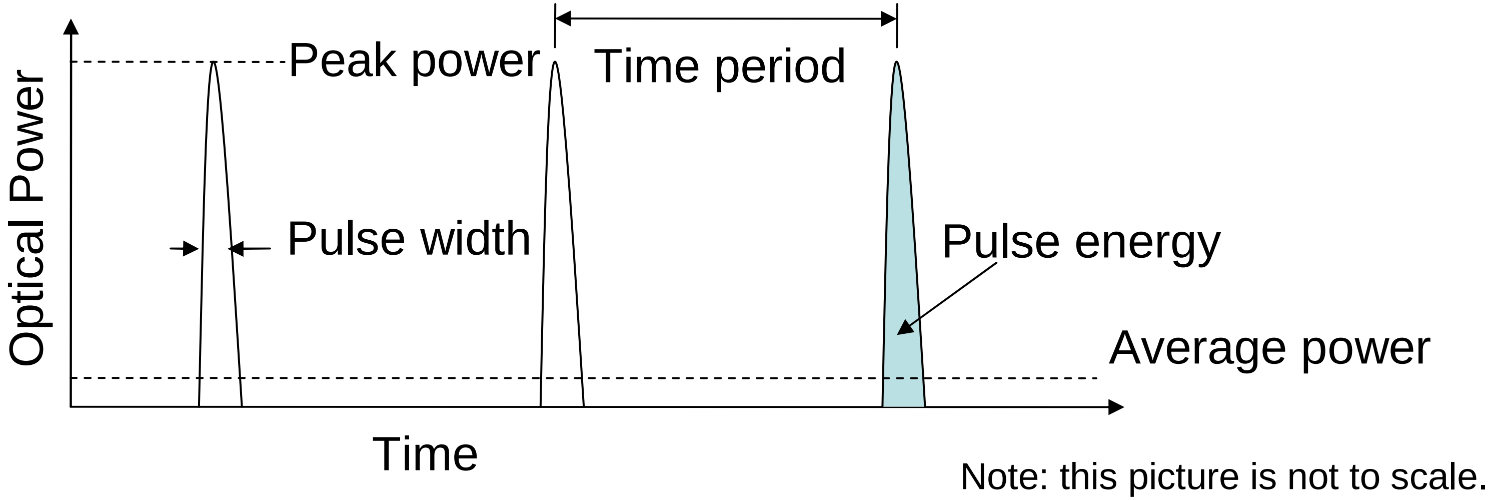
# Anatomy of a laser pulse



Note: this picture is not to scale.

**A key feature of ultrafast lasers:**

low average power AND very high peak power

- If you shine an ultrafast laser onto a material, the optical pulse duration is so short that the laser can cut something out before the energy from the pulse heats up and possibly damages the surrounding area.
- This means ultrafast lasers can be used in new ways like cutting biological tissues with extreme precision – down to individual cells and intracellular organelles – without collateral damage. More recently, lower-power ultrafast lasers started to be explored in non-invasive imaging techniques which can probe into live cells and tissues, without disrupting their biological activity.

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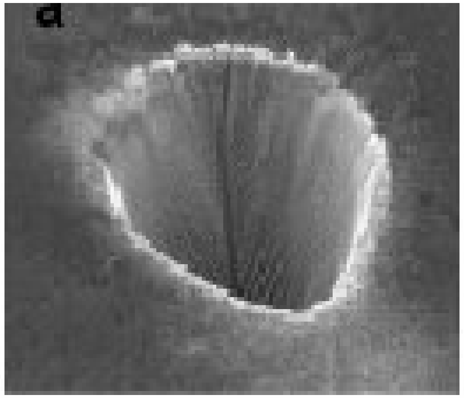
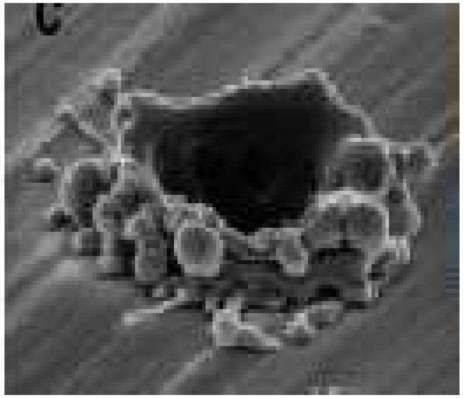
# Ultrashort pulse micromachining



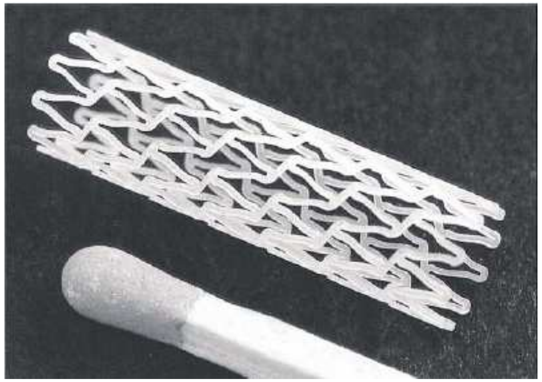
**Ti: sapphire, 120fs**



**Nd:YAG, 100ns**

(Sandia National Labs)

→ Extremely short pulses allow for minimal thermal damage to surroundings



A medical stent micromachined from a biodegradable polymer using a femtosecond laser (LZH/Cortronik).

☑ Can be used in an variety of materials including dielectrics, semiconductors, metals, plastics…

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# Applications in dentistry

- Alternative to mechanical drills and CW lasers
- Reduced thermal stress
- Reduced micro cracks in enamel

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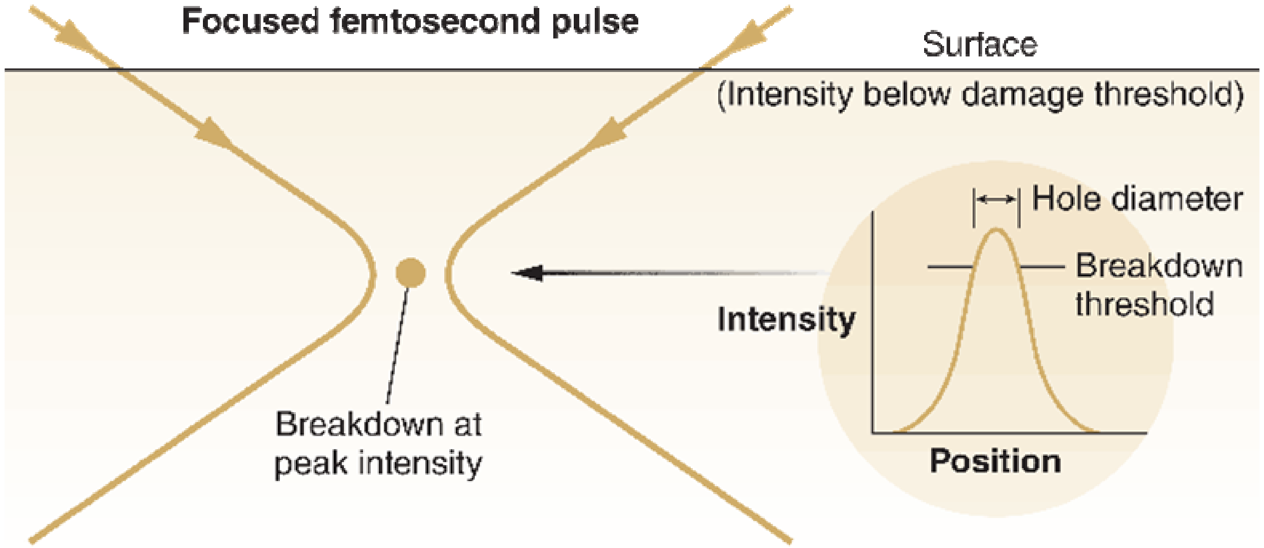
# 3-D structuring in transparent materials

The beam of an ultrafast laser can also be focused down inside a transparent material, in such a way that while avoiding damage to the surface, one can produce a high optical power density zone within the bulk material. Only at this point the material is affected. This means that these lasers can be used to create 3-D structures inside a transparent material, by changing the position and the focusing conditions of the beam!



The next slides will show some applications that use this functionality.

SEVENTH FRAMEWORK PROGRAMME

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The Royal Academy of Engineering

UNIVERSITY OF DUNDEE

# Eye surgery - Ultrafast LASIK

Did you hear about LASIK?

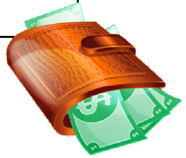
Well, in the new **Ultrafast** or **Femto**Lasik procedure, the cornea does not need to be cut with a mechanical blade; the flap necessary for refractive correction is produced with great precision in a fast and painless operation with a femtosecond laser.

- Check this link for an animated illustration of how LASIK works: http://www.lasik-center.com/lasik/femto-lasik.html

- There are also real LASIK surgery movies in Youtube or Google Videos (but not for the faint-hearted!!)

With FemtoLasik, patient recovery is much faster and less painful. The success rate is also higher.

However, the procedure is more expensive and not so widely available, because the LASIK system can cost around 0.5million euros, mostly due to the **high cost of the femtosecond laser**.



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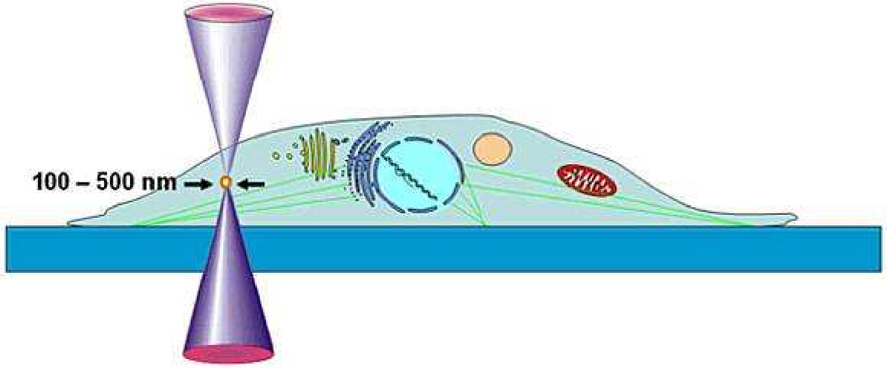
# Nanosurgery in living cells

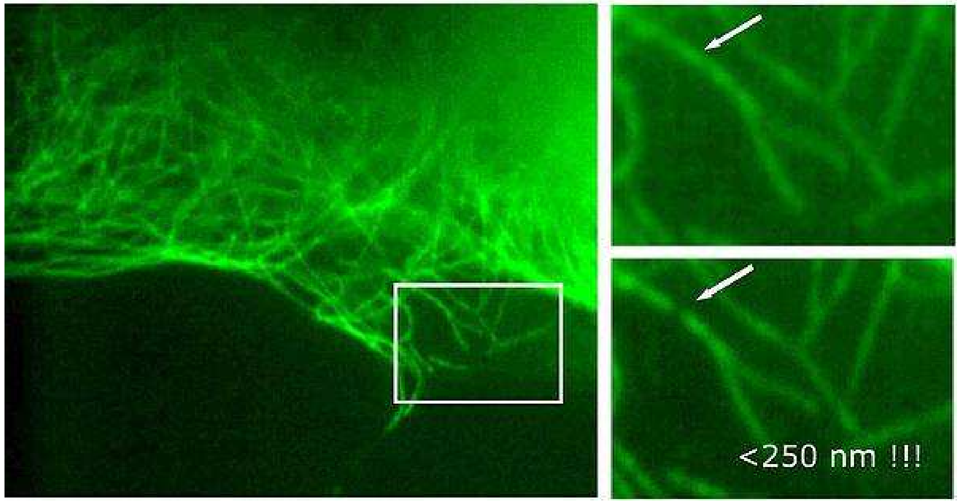
Nano surgery in a living cell –
without punching a hole on the membrane!

Biologists can use this feature to cut, modify or knock off targeted intracellular components. They can then evaluate what impact this has on the cell, which generates many insights about how cells work.

(“Break something and see what goes wrong!”)



(Lazer Zentrum Hannover)



Laser manipulation on an endothelial cell,
cutting of a single microtubule is shown on the right

(Lazer Zentrum Hannover)

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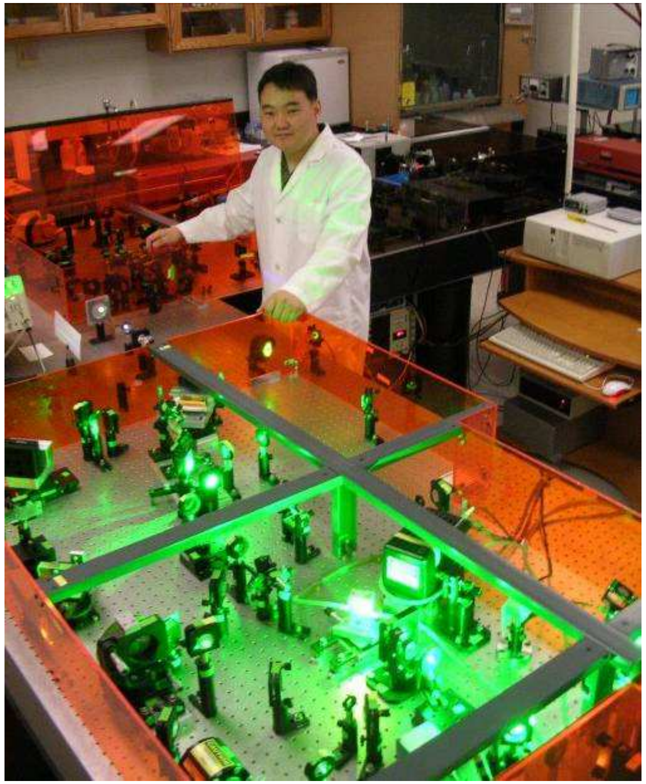
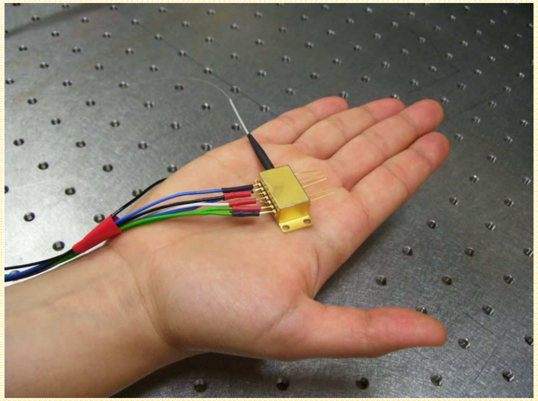
# Disadvantages of current ultrafast lasers

- High complexity and footprint
- High cost of ownership (€100k - €500k)
- High cost of maintenance
- As a consequence, there is not a widespread use of ultrafast lasers outside research labs.



How a typical bulky ultrafast laser looks

In the FAST-DOT project, we are developing compact, efficient and low-cost ultrafast lasers.



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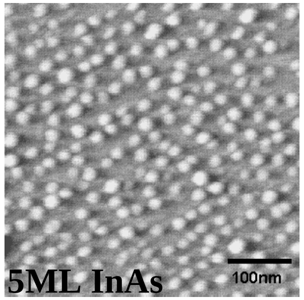
# Targets of FAST-DOT

- Enable widespread bio-photonic applications
  - Macro-, Micro- and Nanosurgery
  - Multiphoton microscopy
  - Optical Coherent Tomography
- By development of
  - Compact Ultrashort pulsed lasers
  - High efficiency and low cost lasers
- Based on unique properties of novel nanostructures - Quantum Dots



Quantum dots are tiny clusters of semiconductor material, with unique light-generating properties. These novel nanomaterials are particularly promising for the generation of ultrashort pulses.

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# Impact of this research

- Leading position of Europe in this area.
- Impact on Life Sciences and Medical research: enabling technology to generate new knowledge in these areas.
- Impact on widespread use of already existing medical applications.
- Societal impact:
  - Better healthcare;
  - Non-invasive diagnostics/therapies become available;
  - Quality of life of patients.
- Economic impact:
  - Transfer of knowledge to industry;
  - Business opportunities in a blooming market.

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# **FAST-DOT:** Compact Ultra**FAST** Laser Sources based on Novel Quantum-**DOT** Structures

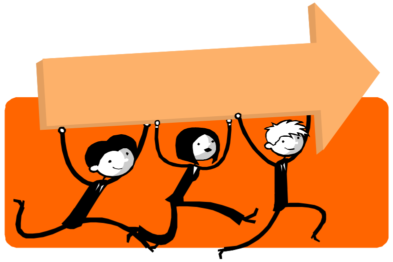
**Integrated Project, FP7 European Programme, ICT**
**Coordinator:** Dr Edik Rafailov, University of Dundee
**Duration:** June 2008 – 2012
**Project Cost:** 13.7 Million Euros **Project Funding:** 10.1 Million Euros

## Academic Partners

- University of Dundee
- University of Sheffield
- ETH Zurich
- Tampere University of Technology
- KTH - Royal Institute of Technology, Stockholm
- ICFO - Institut de Ciències Fotòniques, FUND. PRIV.
- FORTH - The Foundation for Research and Technology Hellas
- Vilnius University
- Politecnico di Torino
- University of Athens
- Technical University of Darmstadt

## Industrial Partners

- Philips
- Alcatel Thales III-V Lab
- Innolume GmbH (SME)
- M Squared Lasers Limited (SME)
- TOPTICA Photonics AG (SME)
- Time-Bandwidth Products AG (SME)
- Molecular Machines and Industries GmbH (SME)



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# The FAST-DOT team

If you have any questions, don't hesitate to contact us: fastdot@dundee.ac.uk

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