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# R&D ULTRAFAST LASERS LTD.

# Femtosecond pulse lasers, technologies and control


**Róbert Szipőcs, PhD**

*R&D Ultrafast Lasers Kft.*

*E-mail: r.szipocs@szipocs.com*

www.szipocs.com


June 2, 2015

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# R&D ULTRAFAST LASERS LTD.

## Introduction
## R&D Ultrafast Lasers Research and Development Ltd.

**BOOTH NUMBER: 8109**

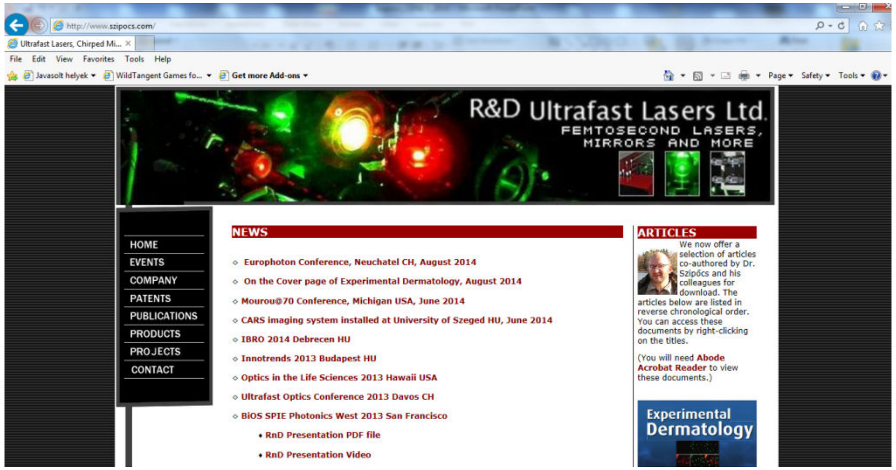
R&D ULTRAFAST LASERS LTD.

BiOS SPIE Photonics West

Company Description

Featured Product: Dual wavelength fs laser system for 3D CARS imaging including tunable Ti.sapphire and Yb fiber laser

Manufacturer of single or double wavelength ultrafast laser systems including ultrashort (ps or fs) pulse, ultrabroadband or broadly tunable Ti:sapphire lasers, Yb-doped fiber lasers, amplifiers and optical parametric oscillators. Their typical applications include time resolved or CARS spectroscopy or nonlinear (2P, SHG or SRS/CARS) microscopy. Manufacturer of ultrafast laser optical coatings including different dispersive mirrors such as chirped mirrors. Complete laser laboratory construction.




| | |
|---|---|
| Founded: | in 1997 |
| Location: | 1121 Budapest, Konkoly Thege út 29-33. 6. ép. I. em. (KFKI Campus) |
| Infrastructure: | 3 laser-optical laboratories, 1 electronic and 1 mechanical workshops, offices |
| Web-site: | www.szipocs.com |

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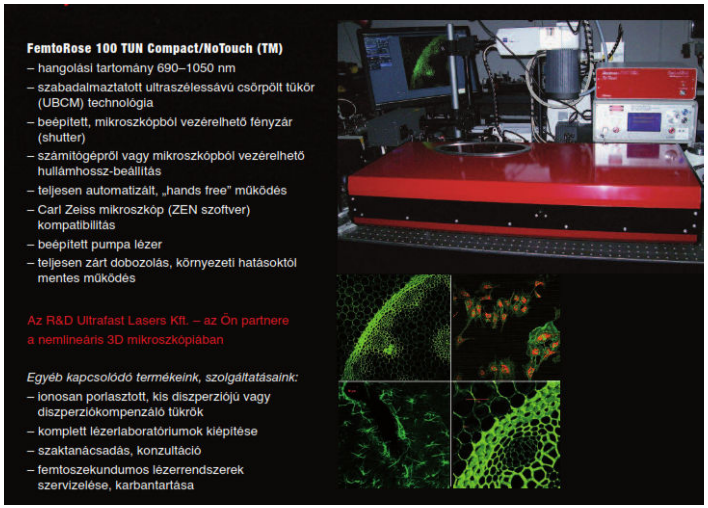
Main activities in BIOPHOTONICS:

1. Lasers and Optics
2. Applications in Biology and Medicine

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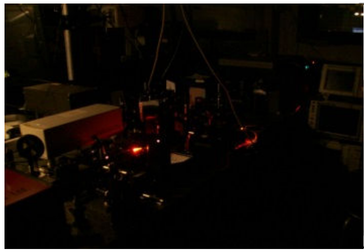
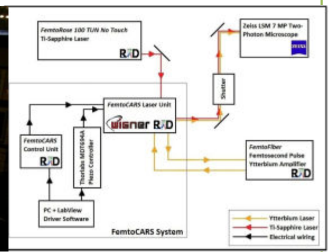
# R&D ULTRAFAST LASERS LTD.

1. Lasers and optics

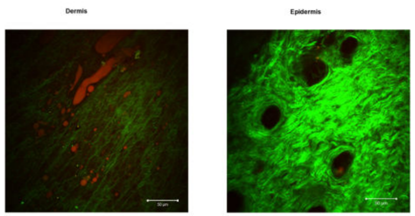
- ps and fs pulse lasers and amplifiers
- dispersive mirrors
- scanning nonlinear microscopy

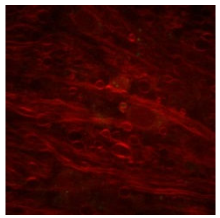




2. Biomedical diagnostics and applications in pharmacology

- dermatology
- neurology
- pharmacology



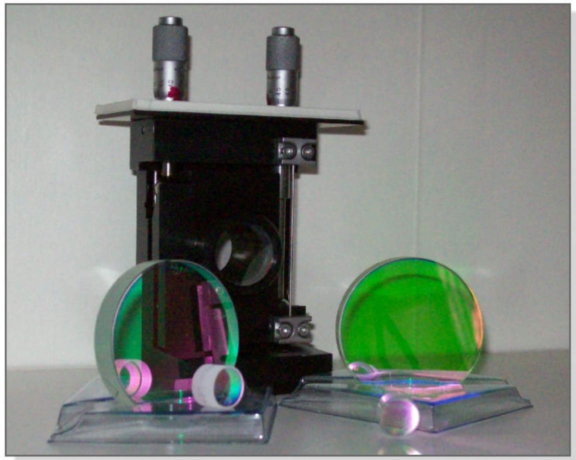




HUNGARIAN BRAIN RESEARCH PROGRAM
NEMZETI AGYKUTATÁSI PROGRAM

OPTICS

# Femtosecond Dispersive and Broadband Optics by IBS technology

- Chirped mirrors (CM)
- Low dispersion ripple, highly dispersive negative dispersion mirrors (MCGTI)
- Ultrabroadband chirped mirrors (UBCM)



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# R&D ULTRAFAST LASERS LTD.

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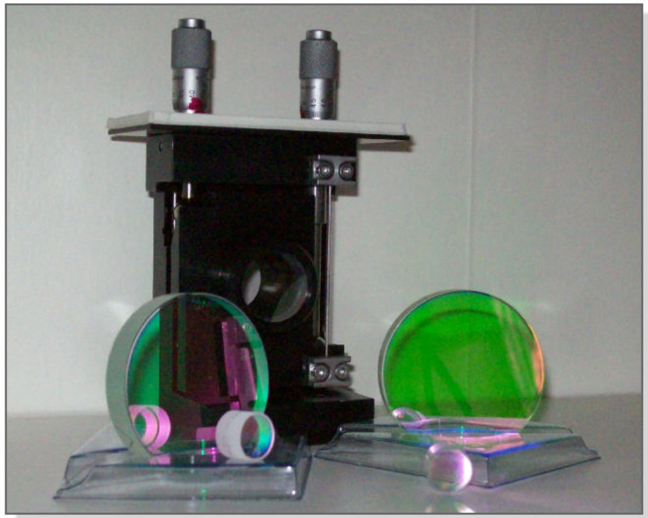
**Pioneering Ultrafast LaserTechnology by R&D**

**INVENTING CHIRPED MIRRORS**

Femtosecond Dispersive
and Broadband Optics by IBS technology

## Patents

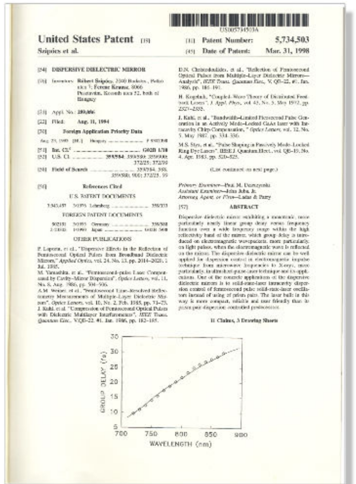



SZABADALMI OKIRAT


The United States of America

The Commissioner of Patents and Trademarks

United States Patent


United States Patent

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# PAST: INVENTING CHIRPED MIRRORS IN 1993 (Wigner RCP / TU Wien)
# THE SOLUTION FOR ULTRAFAST SOLID STATE LASERS

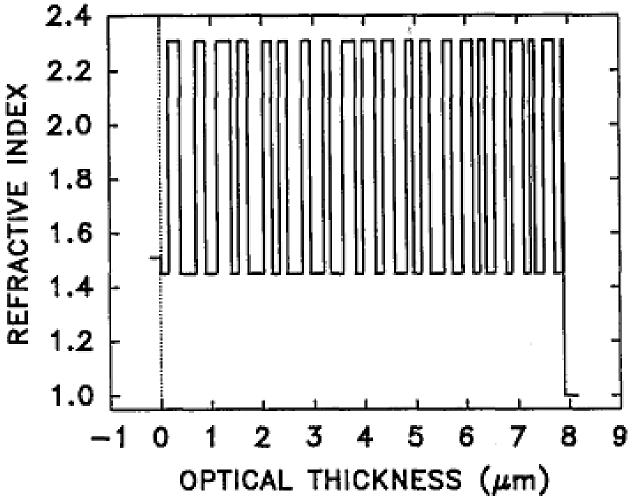



Fig. 1. Theoretical refractive-index profile of a high-reflectivity $TiO_2$–$SiO_2$ multilayer coating designed specifically for broadband GDD control in femtosecond lasers.

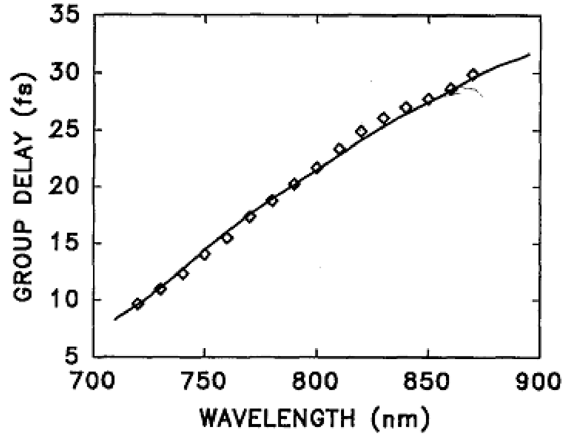



Fig. 3. Computed group delay as a function of wavelength (solid curve) together with experimental data (squares) for the multilayer design of Fig. 1. Note that the absolute delay could not be measured; therefore a wavelength-independent constant delay was added to the measured relative data.

R. Szipőcs, K. Ferencz, Ch. Spielmann, F. Krausz, *Opt. Lett*. 19, pp. 201-203 (1994)

R. Szipőcs, F. Krausz: Dispersive dielectric mirror; U. S. Pat. No.: 5,734,503 (1993)

# DISPERSIVE MIRRORS, CHARACTERIZATION: WHITE LIGHT INTERFEROMETRY

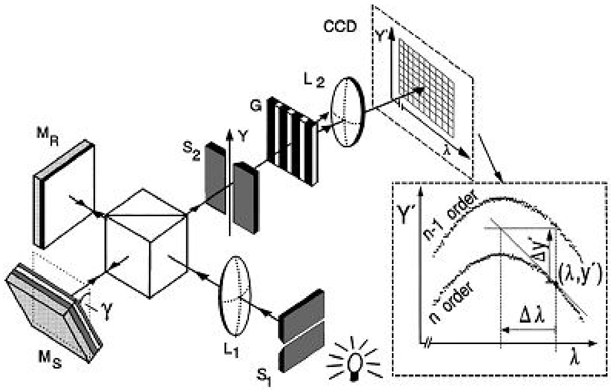
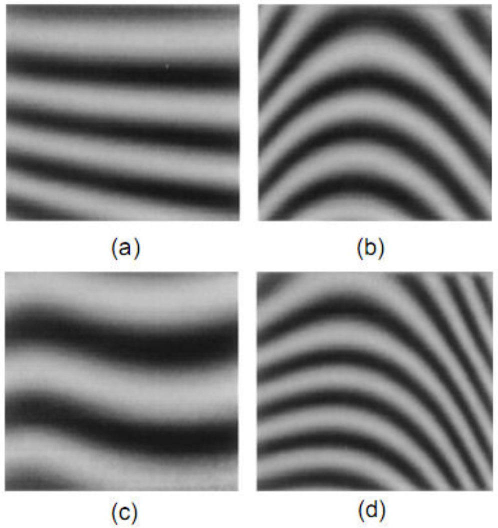



Fig. 1. Spectrally resolved white-light interferometer for group-delay measurement of dielectric mirrors. $L_1$, $L_2$, achromatic lenses; $S_1$, $S_2$, slits; $M_S$, sample mirror; $M_R$, reference mirror; G, transmission grating.



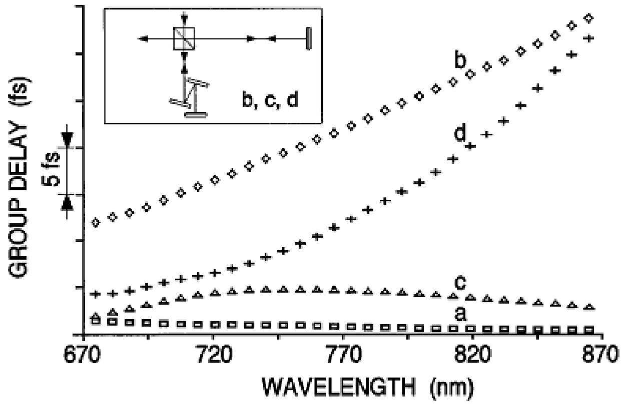




Fig. 4. Measured group-delay functions obtained by computer processing of the images shown in Fig. 3 (every fifth point is plotted). The curves correspond to a single reflection. Inset: four-reflection arrangement used for measuring curves b–d.

**(a) Low dispersion sample (linear phase shift)**

**(b) Chirped mirror sample (quatratic phase shift)**

**(c) Gires-Tournois Intereferometer mirror (cubic phase shift)**

**(d) (c)+(d)**

A.P. Kovács, K. Osvay, Zs. Bor, R. Szipőcs, Opt. Lett. 20, 788-790 (1995)

# Ultrabroadband chirped mirrors for ultrafast lasers

528 OPTICS LETTERS / Vol. 22, No. 8 / April 15, 1997

## Ultrabroadband chirped mirrors for femtosecond lasers

E. J. Mayer, J. Möbius, A. Euteneuer, and W. W. Rühle

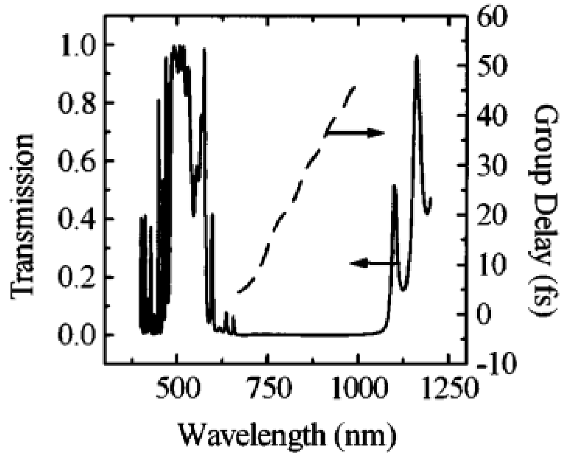
*Department of Physics, Philipps University, Renthof 5, D-35032 Marburg, Germany*

R. Szipőcs

*R&D Lézer-Optika Bt., P.O. Box 622, H-1539 Budapest, Hungary*

Received November 25, 1996

We report on the performance of widely tunable femtosecond and continuous-wave Ti:sapphire lasers that use a newly developed ultrabroadband mirror set. The mirrors exhibit high reflectivity ($R > 99\%$) and smooth variation of group delay versus frequency over a wavelength range from 660 to 1060 nm. Mode-locked operation with pulse durations of 85 fs was achieved from 693 to 978 nm with only one set of ultrabroadband mirrors. 




- The first widely tunable femtosecond pulse Ti:sapphire laser
- High reflectivity (*R . 99%) and* smooth variation of group delay over a wavelength range from 660 to 1060 nm
- Mode-locked operation from 693 to 978 nm using one set of mirrors

E.J. Mayer, J. Möbius, A. Euteneuer, W. Rühle, R. Szipőcs: Opt. Lett. 22, 528-530 (1997)

ULTRAFAST LASERS

**High-quality seed pulses from mirror-dispersion-controlled Ti:sapphire system allow chirped pulse amplification without a pulse stretcher.**

## Chirped dielectric mirrors improve Ti:sapphire lasers

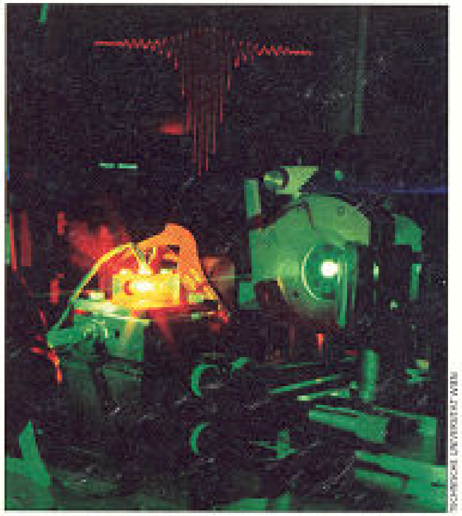
*Ch. Spielmann, M. Lenzner, F. Krausz, R. Szipöcs, and K. Ferencz*

Titanium-doped sapphire (Ti:sapphire) is probably the most successful laser medium used in ultrafast lasers because of its broad gain bandwidth (approximately 200 nm FWHM) and excellent mechanical and thermal properties. The discovery of self- or Kerr-lens mode-locking has also opened the way to an efficient exploitation of its enormous optical bandwidth for ultrashort pulse generation.[1,2]

Commercial self-modelocked Ti:sapphire lasers, offering average output powers up to 2 W and pulse durations as low as 30 fs, are now commonplace in ultrafast laboratories. The Ti:sapphire medium is also well suited for extracavity amplification, yielding high-power femtosecond pulses. Several manufacturers offer Ti:sapphire oscillator-amplifier systems that can produce pulses in the 100-fs range with terawatt peak powers and repetition rates of 10 Hz or less. Whereas these femtosecond commercial systems represent dramatic progress in terms of reliability, lifetime, and peak power, the pulse duration they offer is not significantly shorter than that available from the previous-generation, dye-laser-based systems. Nevertheless, the broad bandwidth of Ti:sapphire and the ultrafast response of the Kerr effect potentially allow the generation of substantially shorter pulses.

The motivation for further decreasing pulse durations comes from a number of fields. Researchers often need to achieve high powers without producing excessive pulse energies that cause damage to solid targets. In reversible optical experiments, metals, semiconductors, and insulators can be exposed to femtosecond pulses with intensities orders-of-magnitude higher than practicable with picosecond pulses. In moderate-intensity spectroscopy, pulse duration determines the achievable time resolution of pump-probe experiments.

Sub-100-fs time resolution, available since the early 1980s, is usually sufficient to "freeze" the rotational and vibrational dynamics of complex atomic systems such as molecules, clusters, and condensed matter, and even the motion of sufficiently heavy atoms in chemical processes. Microscopic dynamics, however, often take place on a time scale of roughly 10 fs or less. For instance, the study of coherent light-matter interaction, which provides information about the coupling of atoms, ions, and molecules to their surroundings, calls for sub-10-fs



Multipass Ti:sapphire amplifier is seeded with high-quality 8-fs pulses generated by a Ti:sapphire oscillator incorporating chirped dielectric mirrors for dispersion compensation.

CH. SPIELMANN and M. LENZNER are postdoctoral researchers and F. KRAUSZ is assistant professor at the Abteilung Quantenelektronik and Lasertechnik, Technische Universität (Vienna, Austria). R. SZIPÖCS is a postdoctoral researcher and K. FERENCZ is the head of the Optical Coating Laboratory at the Research Institute for Solid State Physics (Budapest, Hungary).



# PUSHING THE LIMITS

## of Femtosecond Technology: Chirped Dielectric Mirrors

By Robert Szipöcs, Andreas Stingl, Christian Spielmann, and Ferenc Krausz

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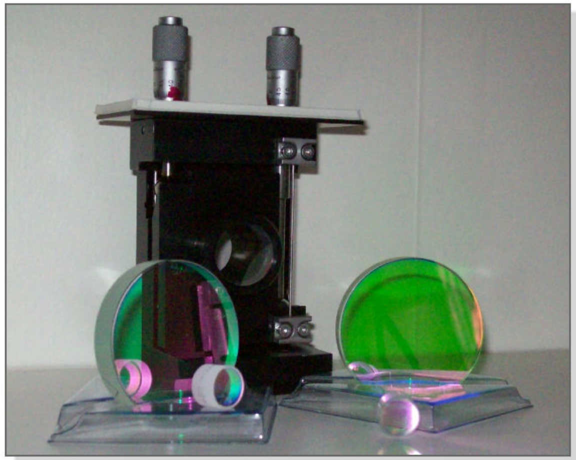

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Femtosecond Dispersive
and Broadband Optics by IBS technology

## Products

- Low-loss, **Multicavity Gires-Tournois type dispersive dielectric mirrors** developed for Mirror-Dispersion-Controlled mode-locked Ti:S, Cr:LiSAF, Cr:LiSGaF, Yb:KGW, Yb:glass, etc. lasers.
- **Ultra-broadband mirror** set for broadly tunable femtosecond pulse Ti:sapphire lasers (Xwave or Xband optics)
- **Chirped mirrors for linear group delay vs. frequency control** in optical parametric amplifiers (OPA-s) or in white light continuum experiments in the visible and NIR.

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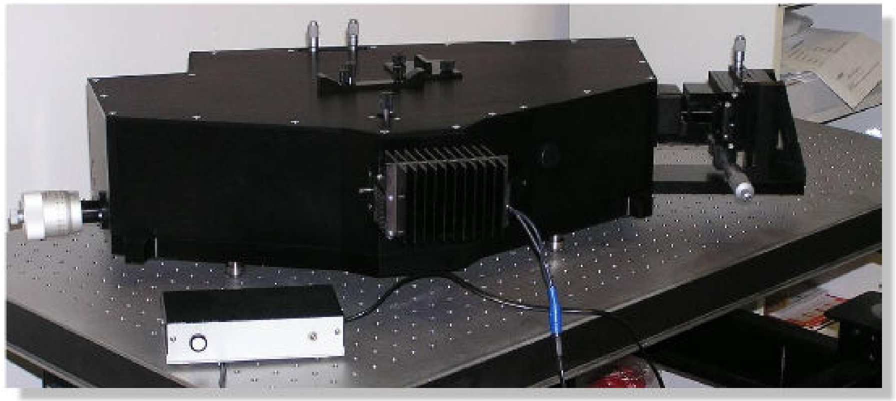
Femtosecond Dispersive
and Broadband Optics by IBS technology

## Services

- **Custom design** of femtosecond laser mirrors for dispersion compensation (Ti:S, Cr3+, Yb3+, etc.)
  IR OPO, Vis-OPO, OPA, etc.
- **Dispersion measurement** on laser mirrors and other optical components.



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# LASERS

## Company Description

Featured Product: Dual wavelength fs laser system for 3D CARS imaging including tunable Ti.sapphire and Yb fiber laser

Manufacturer of single or double wavelength ultrafast laser systems including ultrashort (ps or fs) pulse, ultrabroadband or broadly tunable Ti:sapphire lasers, Yb-doped fiber lasers, amplifiers and optical parametric oscillators. Their typical applications include time resolved or CARS spectroscopy or nonlinear (2P, SHG or SRS/CARS) microscopy. Manufacturer of ultrafast laser optical coatings including different dispersive mirrors such as chirped mirrors. Complete laser laboratory construction.

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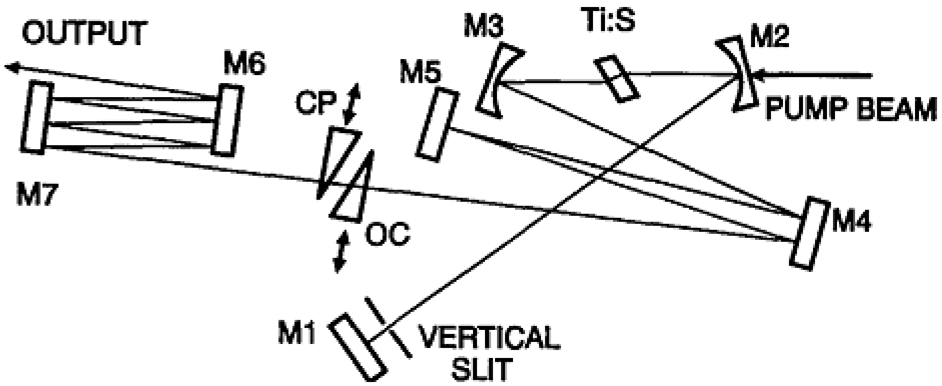
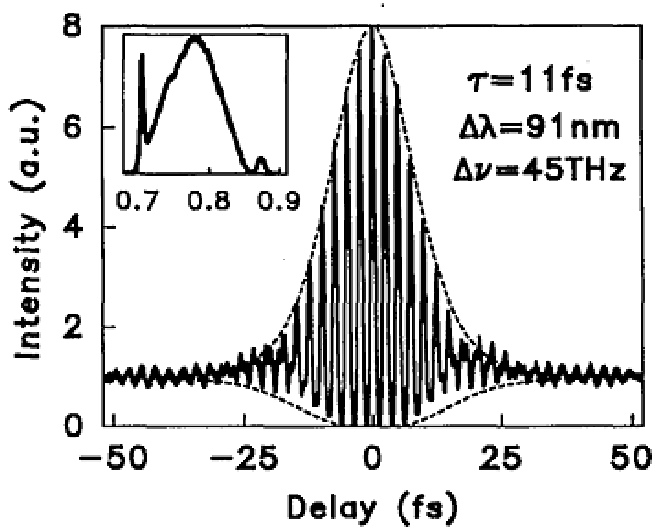
# MIRROR DISPERSION CONTROLLED Ti:SAPPHIRE LASER




LINEAR CAVITY

☺ Highly stable femtosecond pulses with duration of ~ 11fs

A.Stingl, Ch. Spielmann, F. Krausz, R. Szipőcs, *Opt. Lett.* 19, pp. 204-206 (1994)

R. Szipőcs, F. Krausz: U. S. Pat. No.: 5,734,503 (1993)

# Compression of laser pulses down to 4.6 fs

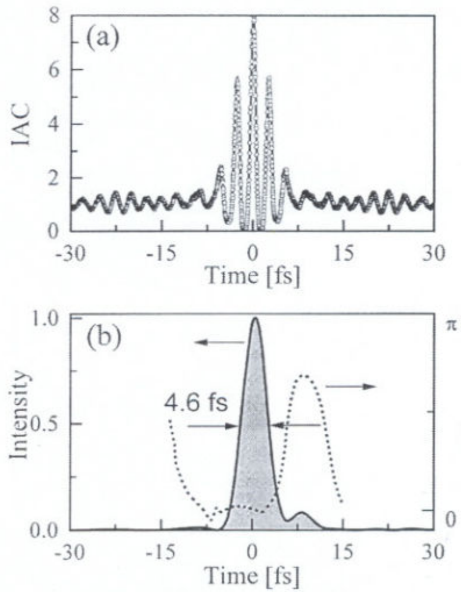


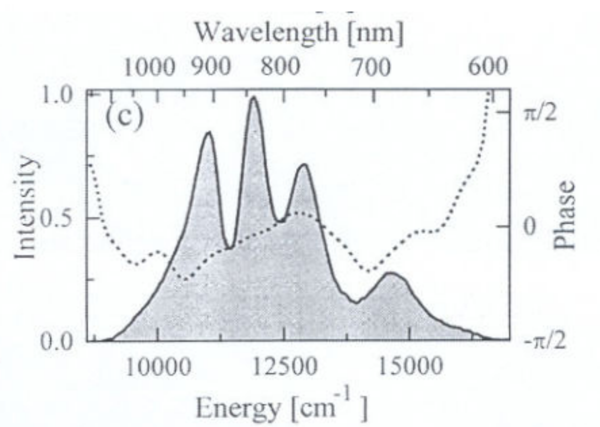
## ULTRAFAST TECHNOLOGY

### A Compact All-Solid-State Sub-5-fsec Laser

Andrius Baltuška and Maxim S. Pshenichnikov, Ultrafast Laser and Spectroscopy Laboratory, Dept. of Chemistry, Univ. of Groningen, Groningen, The Netherlands; Róbert Szipöcs, Research Institute for Solid State Physics, Budapest, Hungary; and Douwe A. Wiersma, Ultrafast Laser and Spectroscopy Laboratory, Dept. of Chemistry, Univ. of Groningen, Groningen, The Netherlands.

Recent developments in solid-state lasers,[1] chirp-mirror technology,[2] and methods of pulse characterization[3] made it possible to design an all-solid-state laser that delivers sub-5-fsec pulses at a 1-MHz repetition rate.[4] Such extremely short light pulses at a high




**Baltuška Figure 1.** (a) Interferometric autocorrelation (circles are experimental points, and the solid line is the fit). (b) Retrieved intensity profile (filled contour) and phase (dashed line). (c) Measured spectrum of compressed pulse (filled contour) and retrieved spectral phase (dashed line).

SCIENTIFIC BACKGROUND

# Compression of high-energy laser pulses below 5 fs

---

522 OPTICS LETTERS / Vol. 22, No. 8 / April 15, 1997

## Compression of high-energy laser pulses below 5 fs

**M. Nisoli, S. De Silvestri, and O. Svelto**

*Centro di Elettronica Quantistica e Strumentazione Elettronica—Consiglio Nazionale delle Ricerche, Dipartimento di Fisica, Politecnico, Piazza L. da Vinci 32, 20133 Milano, Italy*

**R. Szipöcs and K. Ferencz**

*Szilárdtestfizikai Kutatóintézet, Pf. 49, H-1525 Budapest, Hungary*

**Ch. Spielmann, S. Sartania, and F. Krausz**

*Abteilung Quantenelektronik und Lasertechnik, Technische Universität Wien, Gusshausstrasse 27, A-1040 Wien, Austria*

Received October 25, 1996

High-energy 20-fs pulses generated by a Ti:sapphire laser system were spectrally broadened to more than 250 nm by self-phase modulation in a hollow fiber filled with noble gases and subsequently compressed in a broadband high-throughput dispersive system. Pulses as short as 4.5 fs with energy up to 20-$\mu$J were obtained with krypton, while pulses as short as 5 fs with energy up to 70 $\mu$J were obtained with argon. These pulses are, to our knowledge, the shortest generated to date at multigigawatt peak powers. 

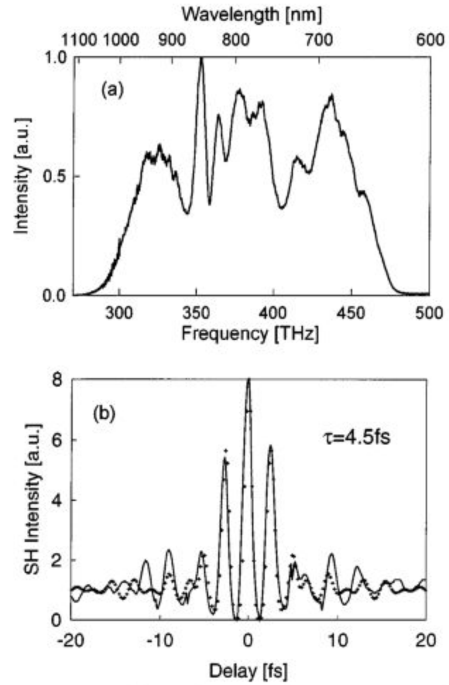
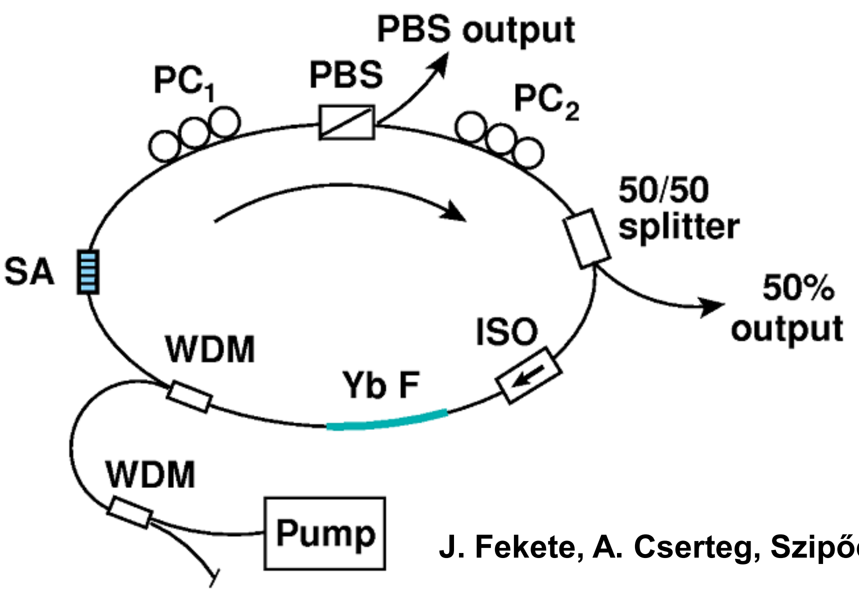



Fig. 2. (a) Spectral broadening in krypton at $p = 2.1$ bars and $P_0 = 2$ GW. A low-intensity pedestal (~1% of the peak) extends below 600 nm. (b) Measured (solid curve) and calculated (crosses) autocorrelation trace; an evaluation of the pulse duration (FWHM) is also given.

# FIBER LASERS
## All-Fiber, All-Normal-Dispersion Ytterbium Ring Oscillator

- Determined by interplay between **gain**, **self-phase modulation**, **dispersion** and **filtering** effects
- Pulse shaping is based on **nonlinear polarization rotation** in the fiber together with **spectral and temporal filtering** by a polarizing element




PC: polarization controller
PBS: polarizing beam splitter
ISO: isolator
Yb F: Ytterbium doped fiber
WDM: wavelength division multiplexer
SA: saturable absorber

**J. Fekete, A. Cserteg, Szipőcs; All-fiber, all-normal dispersion ytterbium ring oscillator, Laser Physics Letters 6, 49-53, 2009**

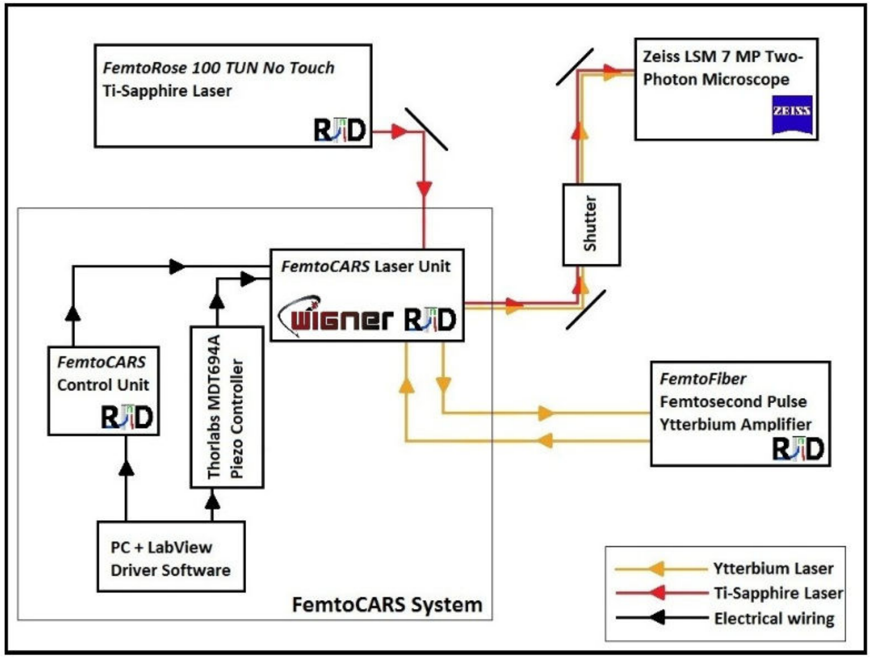
 

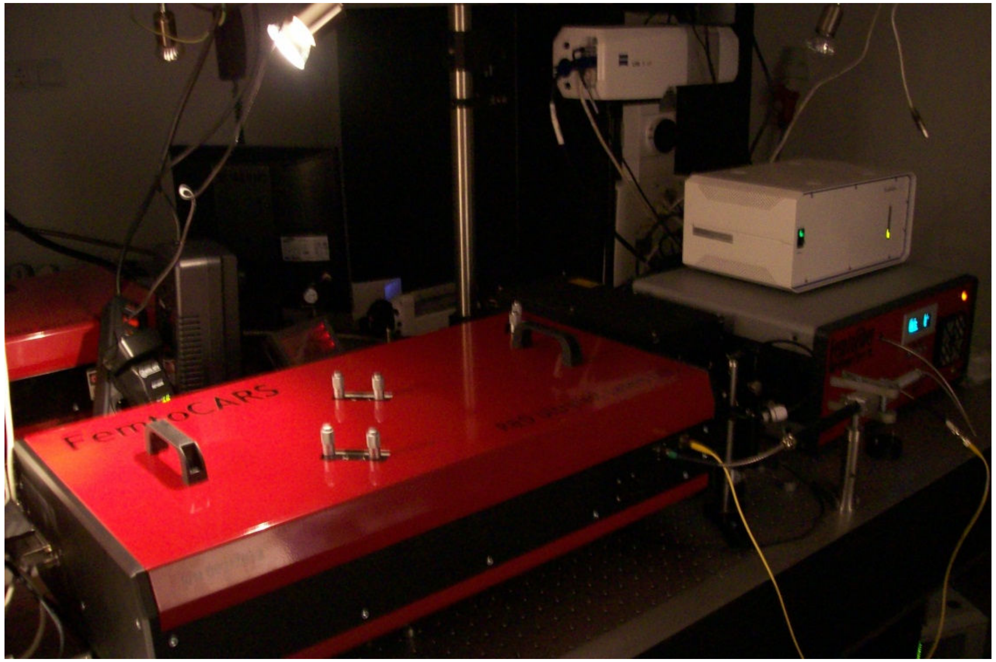
# CONTROL

## FemtoCARS

the

Label-free, 3D Microscopic Imaging System for Real-time in vivo Diagnostics

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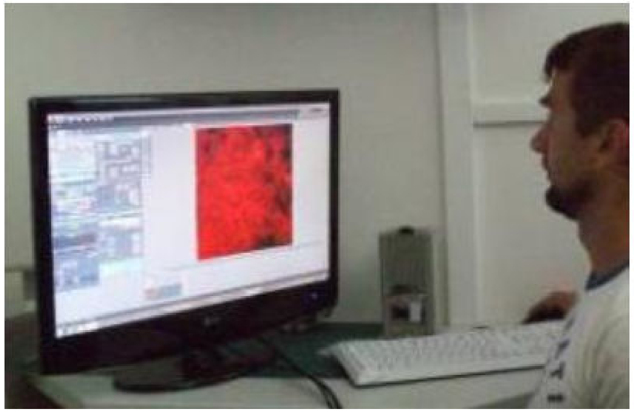
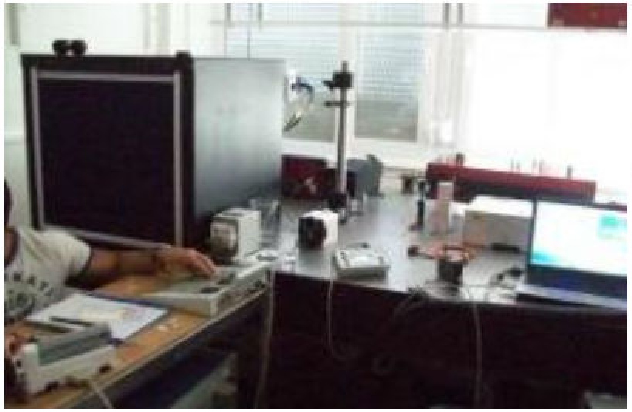
## CARS SYSTEM INSTALLED AT UNIVERSITY OF SZEGED

Related articles

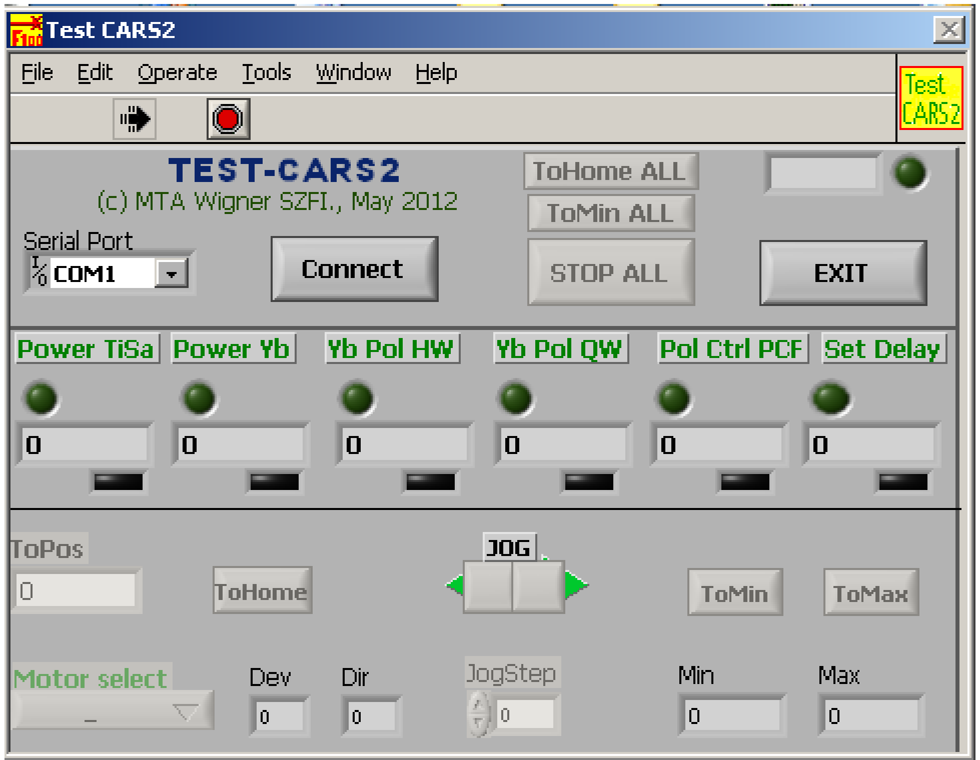
**CARS imaging system installed at the University of Szeged, Department of Neurology (Prof. Gábor Tamás lab), June 2014**

**Photo Gallery**





# CONTROL

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LabView programs for control
Data colletion by DAQmX cards (NI)

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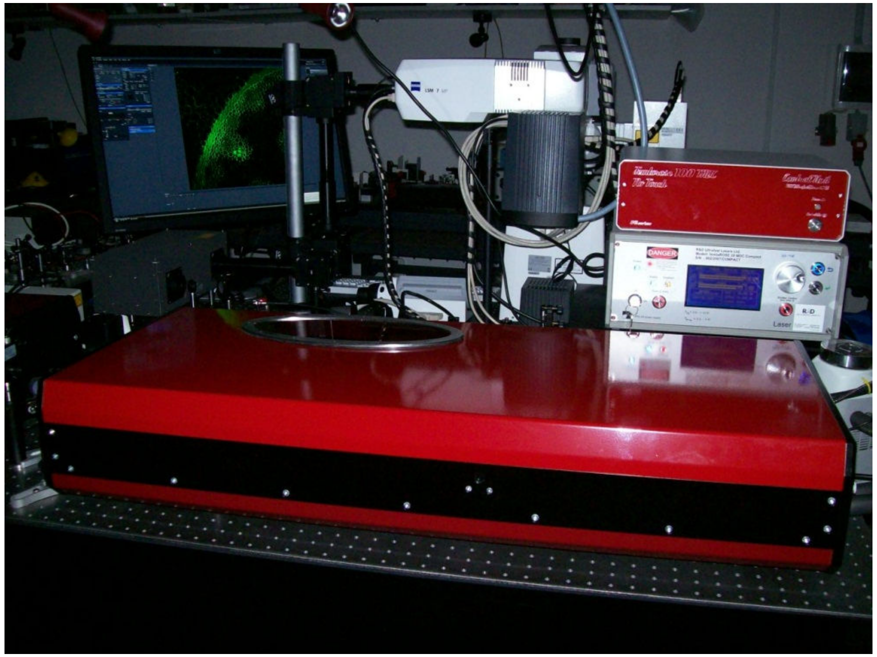
# R&D ULTRAFAST LASERS LTD.

## FemtoRose 100 TUN/NoTouch

The First

Broadly Tunable, femtosecond pulse Ti:sapphire laser



Pioneering Ultrafast LaserTechnology by R&D

INTRODUCING THE FIRST ULTRABROADBAND CHIRPED MIRRORS
FOR BROADLY TUNABLE FEMTOSECOND LASERS

528 OPTICS LETTERS / Vol. 22, No. 8 / April 15, 1997

### Ultrabroadband chirped mirrors for femtosecond lasers

**E. J. Mayer, J. Möbius, A. Euteneuer, and W. W. Rühle**

*Department of Physics, Philipps University, Renthof 5, D-35032 Marburg, Germany*

**R. Szipőcs**

*R&D Lézer-Optika Bt., P.O. Box 622, H-1539 Budapest, Hungary*

Received November 25, 1996

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**BOOTH NUMBER:**

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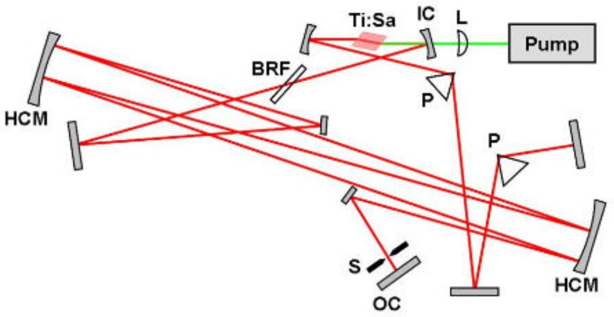
## FemtoRose 300 TUN/NoTouch

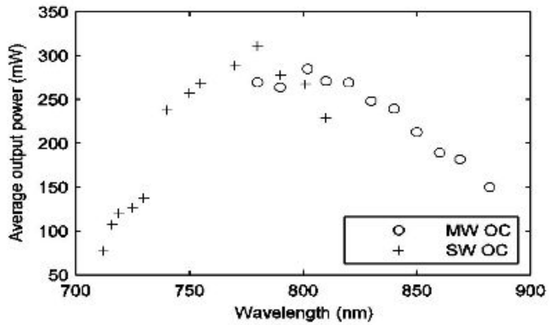
The Concept

### Schematic of the oscillator




**L:** pump focusing lens, **IC:** input coupler mirror, **Ti:Sa:** titanium-sapphire crystal, **BRF:** birefringent filter for tuning, **P:** prisms, **HCM:** Herriott-cell mirrors, **OC:** output coupler, **S:** slit for hard-aperture KLM

### Typical measured output power vs. wavelength (at 2.6 W pump)




**Two different output couplers were used for short wavelengths (SW OC, crosses) and for** longer wavelengths (MW OC, circles).

**Reference**

Antal P, Szigligeti A, Kolonics A, Szipőcs R; Tunable, Low Repetition Rate, Femtosecond Pulse Ti:Sapphire Laser for In Vivo Imaging by Nonlinear Microscopy; In: Optics int he Life Sciences Congress (OSA, 4-6 April 2011, Monterey, CA) Paper JTuA12, 2011

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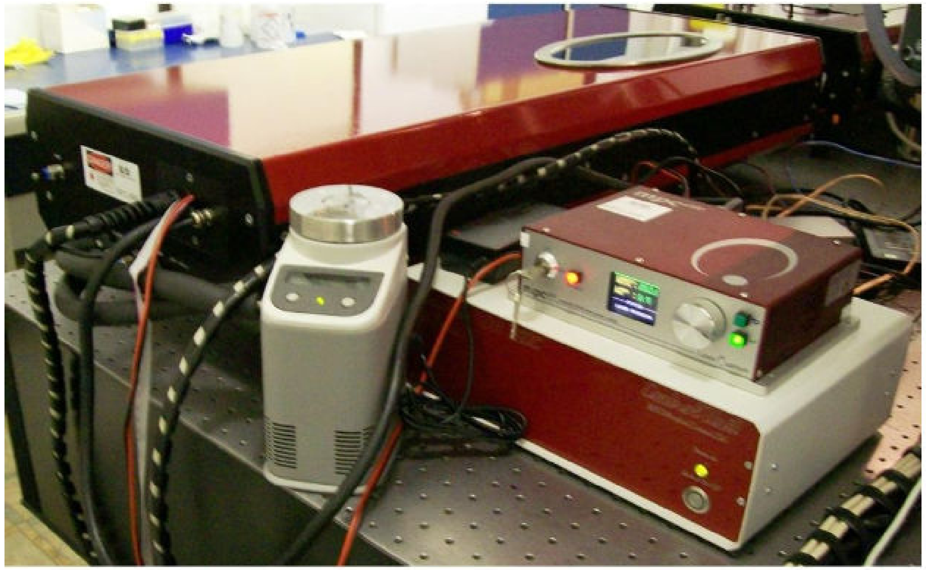
**BOOTH NUMBER:**

# R&D ULTRAFAST LASERS LTD.

## FemtoRose 300 TUN/NoTouch

The Cost Efficient
Long-Cavity, Broadly Tunable, femtosecond pulse Ti:sapphire laser



### Key features

- Low pump laser cost (~ 2.6 W pumping)
- Low, 22 MHz repetition rate
- Higher fluorescence signal
- Lower thermal damage in sample
- No extra-cavity chirp control is required
- Wavelength control by a Zeiss 2P microscope

### Applications

- Multiphoton microscopy
- Ultrafast spectroscopy

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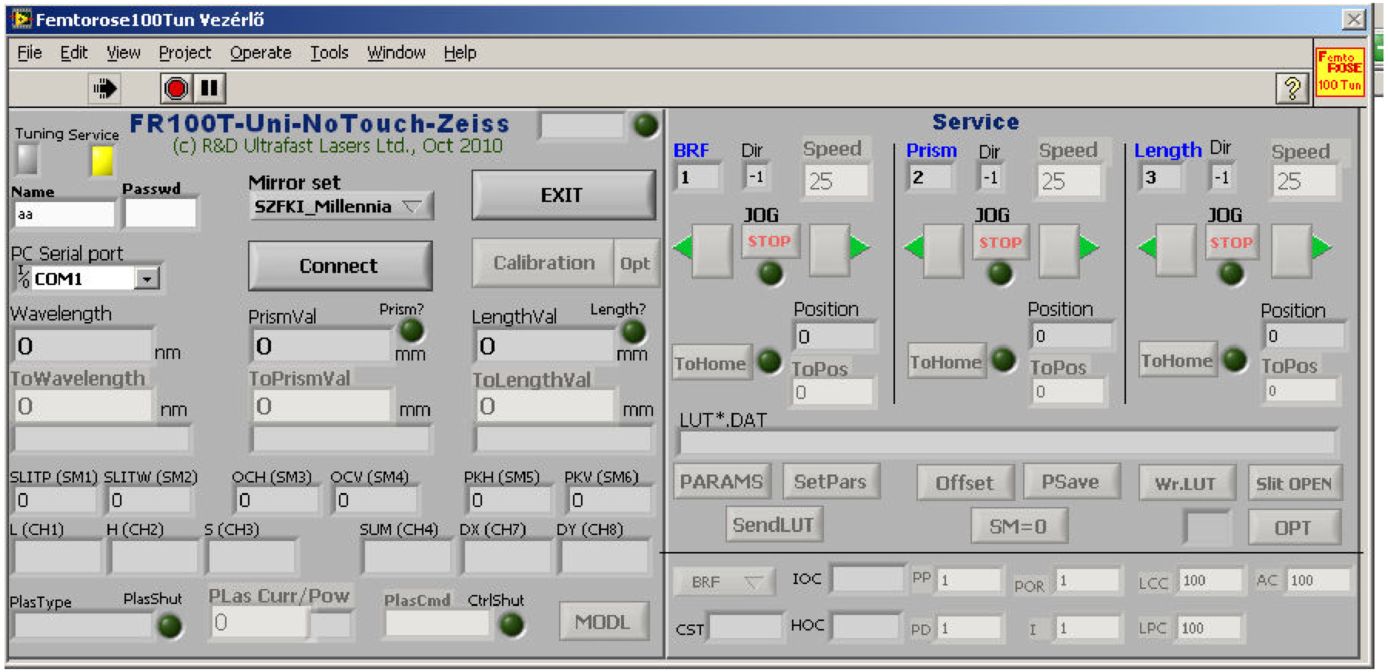
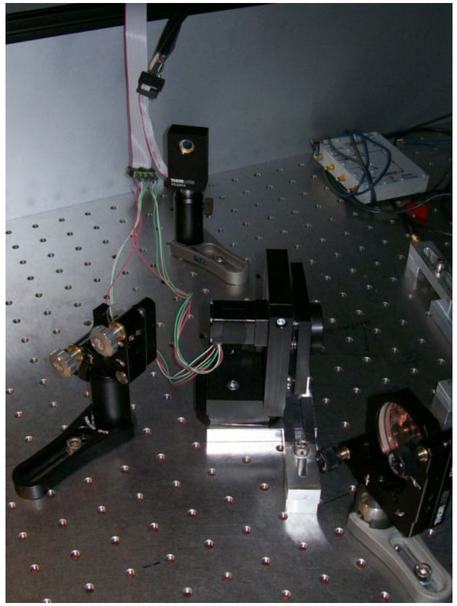
# LASER CONTROL

STEP and DC micromotor drivers, SW
Photodiodes, quadrant detectors for beam position sensing
PIC and ARM microcontrollers



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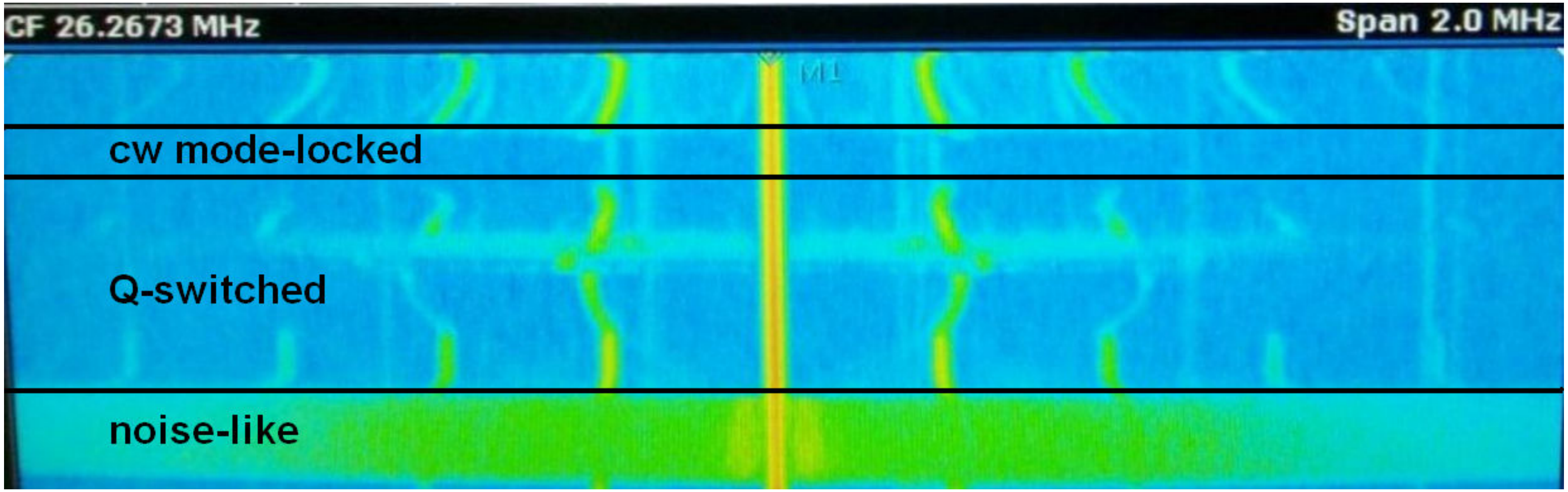
# Monitoring mode-locking performance of Yb-fiber laser




Measured radio-frequency power spectrum at around the central frequency of the all-fiber, all-normal-dispersion Yb-fiber ring laser for different polarization settings in front of the PBS

RF spectrum is measured by a radio-frequency spectrum analyser (FSV3, product of Rohde&Schwarz)

- NOT PRACTICAL FOR A TURN-KEY SYSTEM!

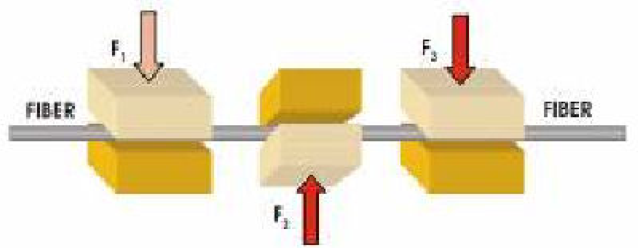
 

# Polarization control by electronics

## POLARIZATION MANAGEMENT MODULES

### Dynamic Polarization Controller with Miniature Piezo Driver Card


This module integrates a General Photonics all-fiber dynamic polarization controller with an MPD-001 miniature piezo driver card, so that the SOP of the signal can be directly controlled either by a 0-5V analog control signal or a 12-bit TTL digital control signal. Because there is an on-board HV DC/DC converter, no external high voltage power supply is required. The card can be configured to accept either a ±12 volt power supply or an optional external 160-volt power supply (PWR-002 recommended). As a polarization controller, the PCD-M02 can convert any input polarization state to any desired output polarization state. As a scrambler, it can randomize the output polarization state. This module offers the low insertion loss, low back reflection, and low activation loss needed for test and measurement applications, combined with the compact size needed for system integration or handheld devices.

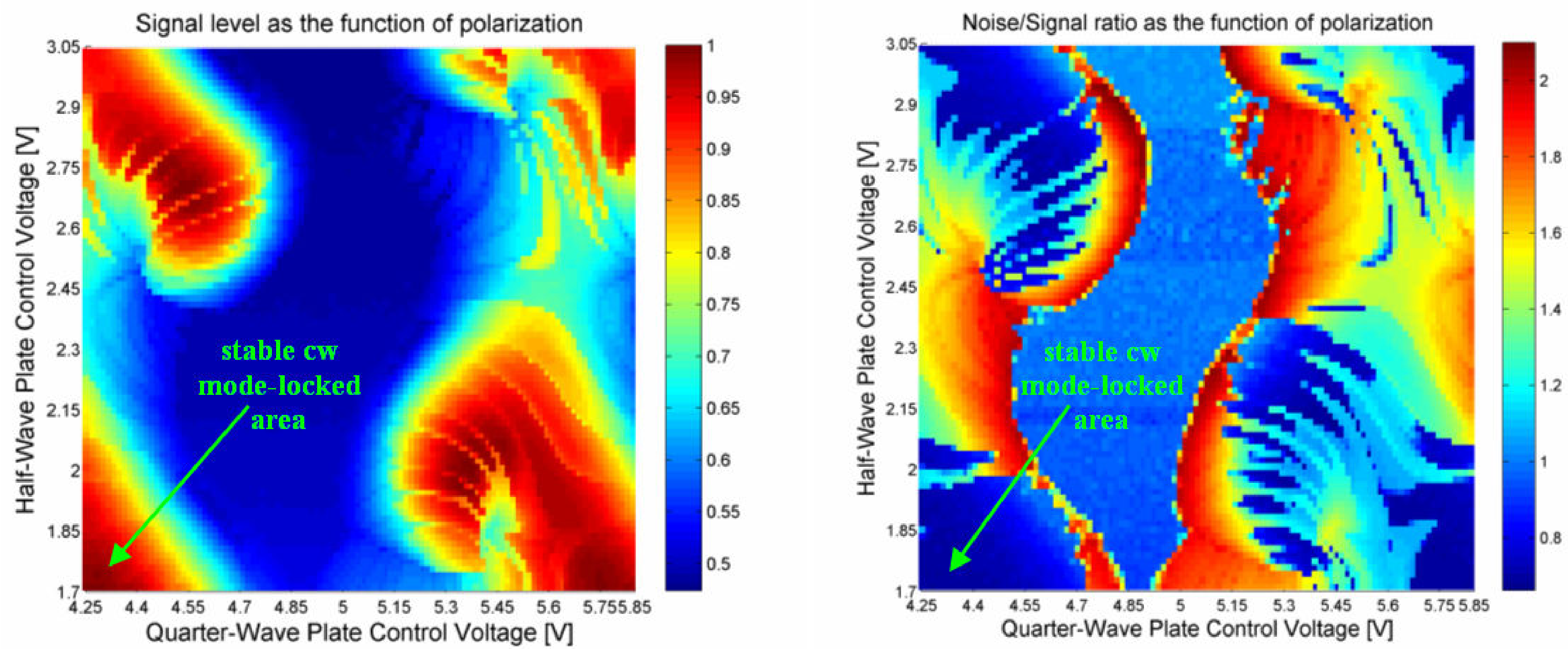



PolaRITE III - Mini dynamic polarization controller, product of General Photonics

http://www.generalphotonics.com

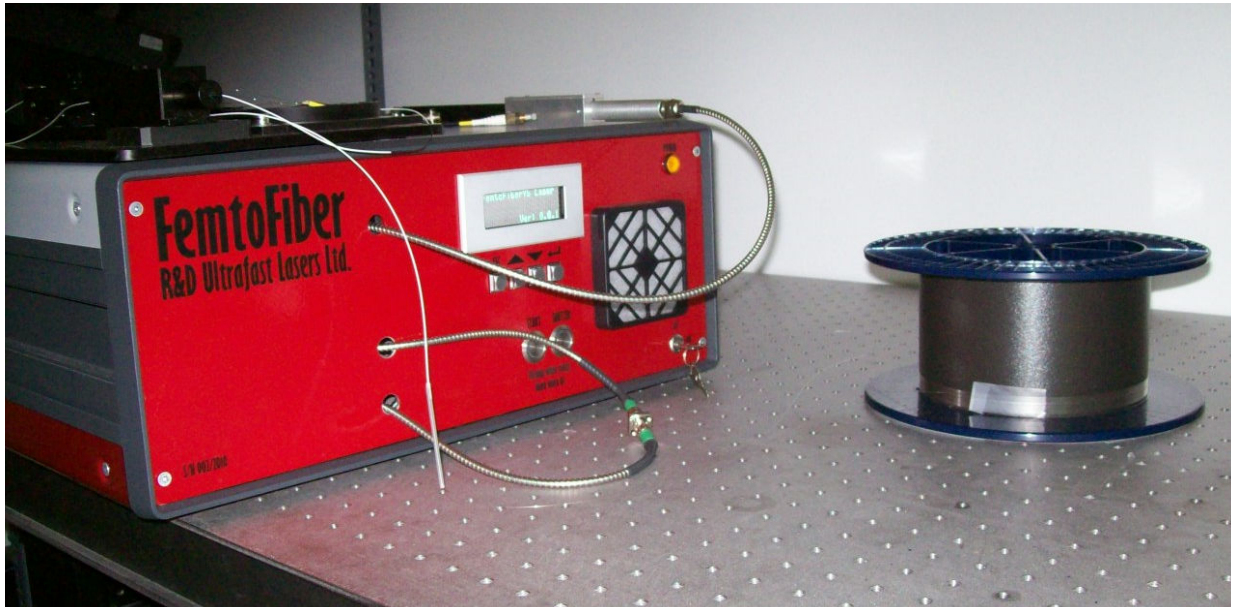
 

# Recording of „stability maps" using SLH circuits




Measured signal power (left) and normalized noise power (right) as the function of control voltage on the polarization controllers.

# Microcontrollers for turn key laser systems

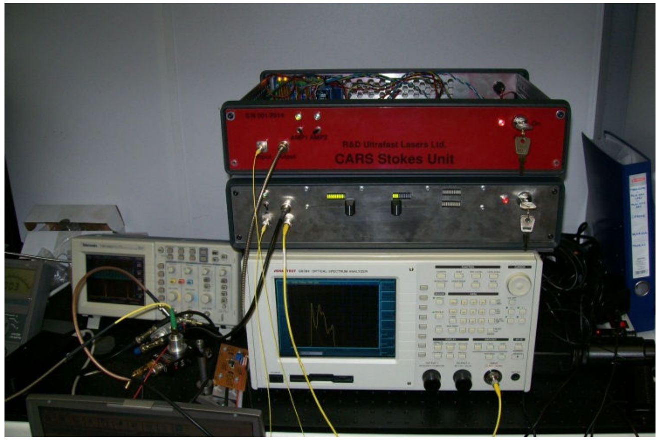



- **Polarization is controlled by a built in PolaRITE III polarization controller**
- **Control voltages of the PolCont are set by a computer through an RS232 interface**
- **ARM microcontroller unit**

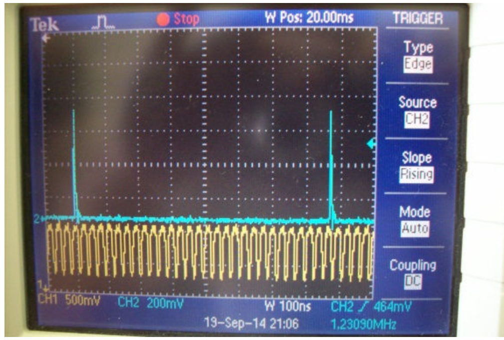
 

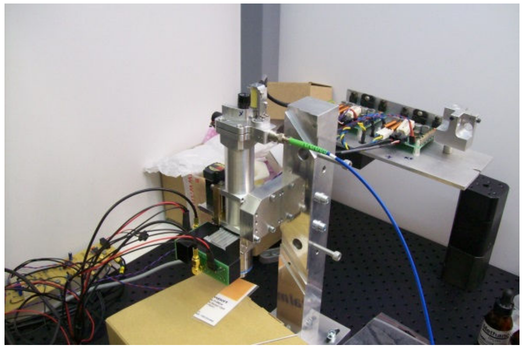
# APPLICATIONS OF FIBER LASERS

## Collaboration with industry – nonlinear microscopy




*FiberScope, a kézben tartott nemlineáris mikroszkóp*



**Lasers source: 2-36 MHz pulsed Yb-fiber laser**

**Imaging optics: small size scanning 2P microscope**

**Optimized for application: low cost**

# Applications in Pharmacology

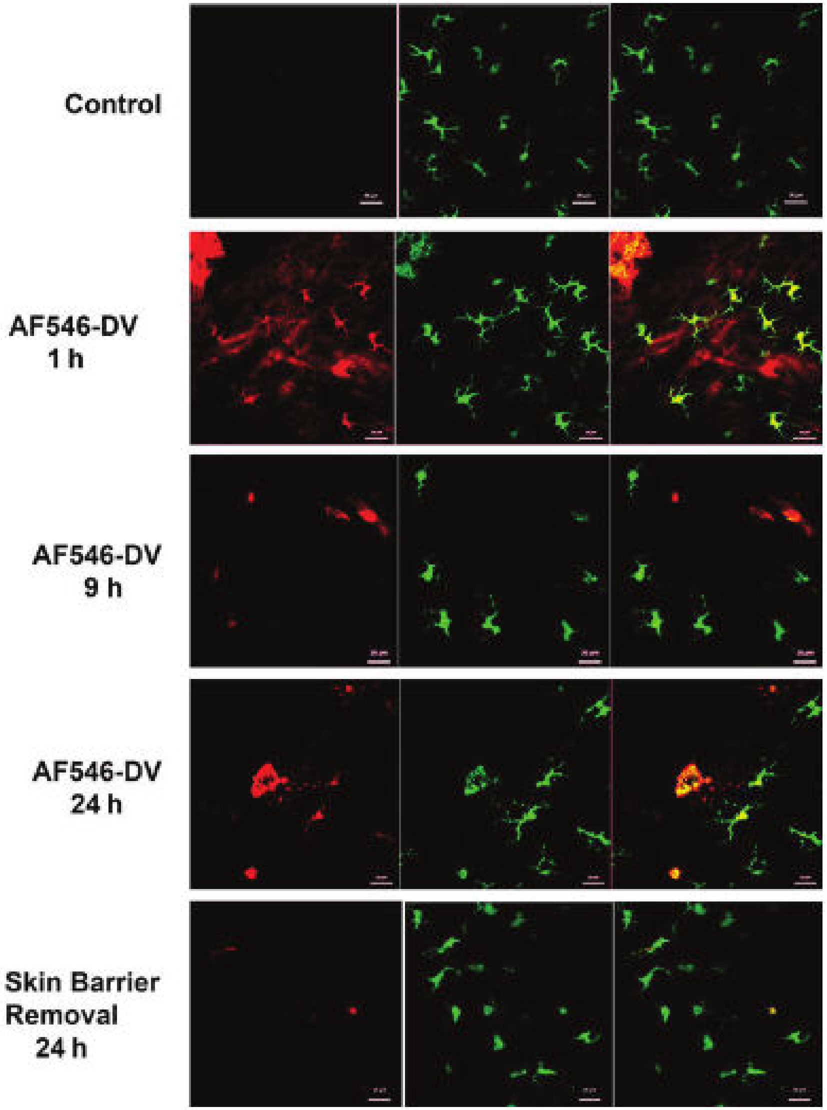
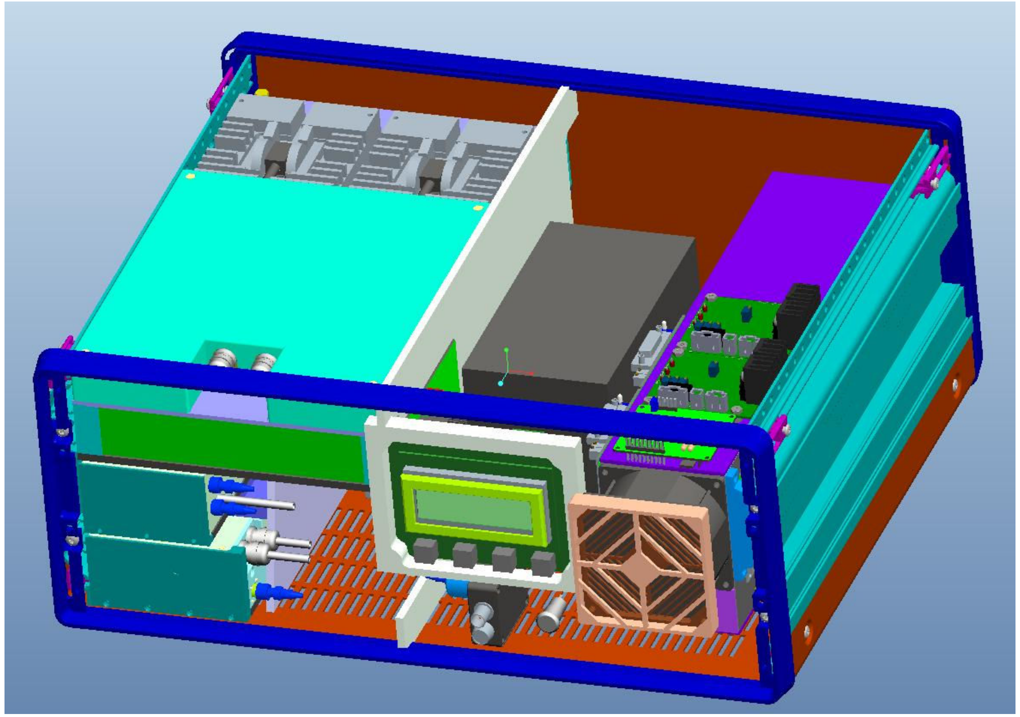




**Figure 2.** Kinetics of AF546-DV uptake by Langerhans cells (LCs) in eGFP-Langerin knock-in mouse ear *in vivo*. Nearly all LCs had incorporated AF546-DV after 1 h of topical treatment: strong colocalization was detected in both channels [NDD 2 – green/eGFP (middle column) versus NDD 1 – red/AF546-DV (left column)] as presented on the merged pictures (right column). Images of red light emission also revealed that the nanoparticles were distributed homogenously in all parts of the LCs. After 9 h, the intensity of red light emission by AF546-DV decreased significantly and disappeared from the dendrites and concentrated around the nucleus. Intriguingly, after 24 h, the nuclear location as well as a weak signal of AF546 in the dendrites could still be observed. The removal of the stratum corneum resulted in the activation of the vast majority of the LCs characterized by a rounded potato-like shape. The scale bar represents 20 μm.

# MECHANICS

## Fibers lasers



ProEngineer models for CNC manufacturing

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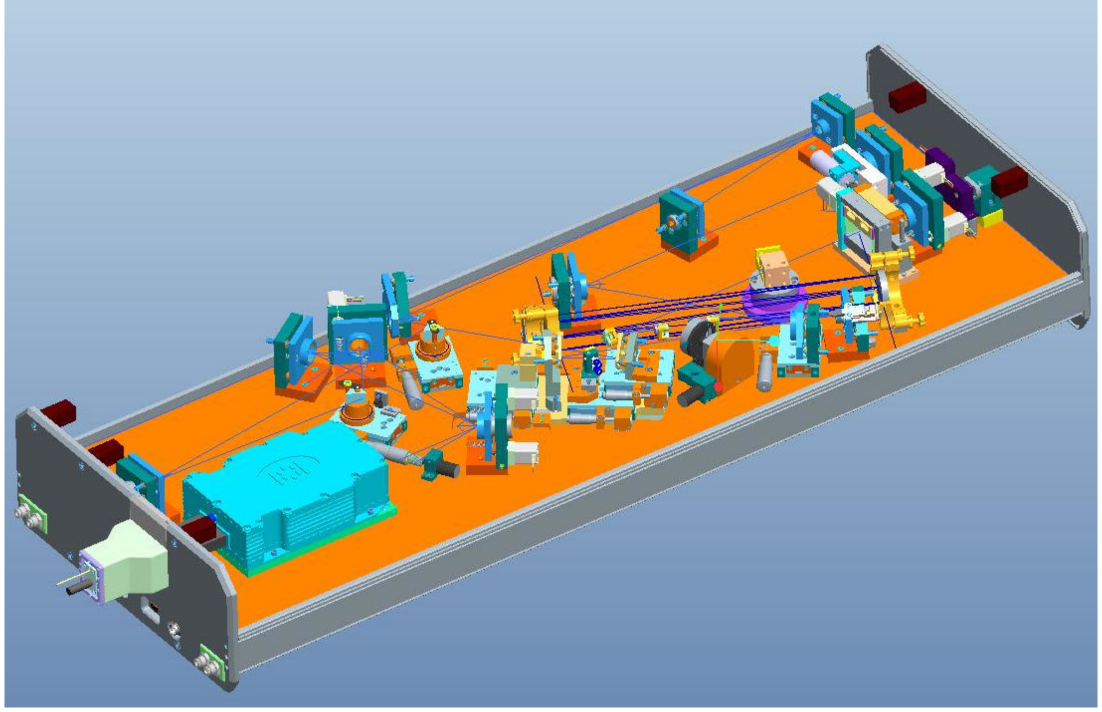
# MECHANICS

## Solid state lasers



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