HEPTech Academia
Industry Matching Event on High Energy Lasers
12-13 November 2014, Hamburg, GERMANY

Wigner RCP and the ELI Project

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WIGNER Research Centre for Physics
Budapest, HUNGARY

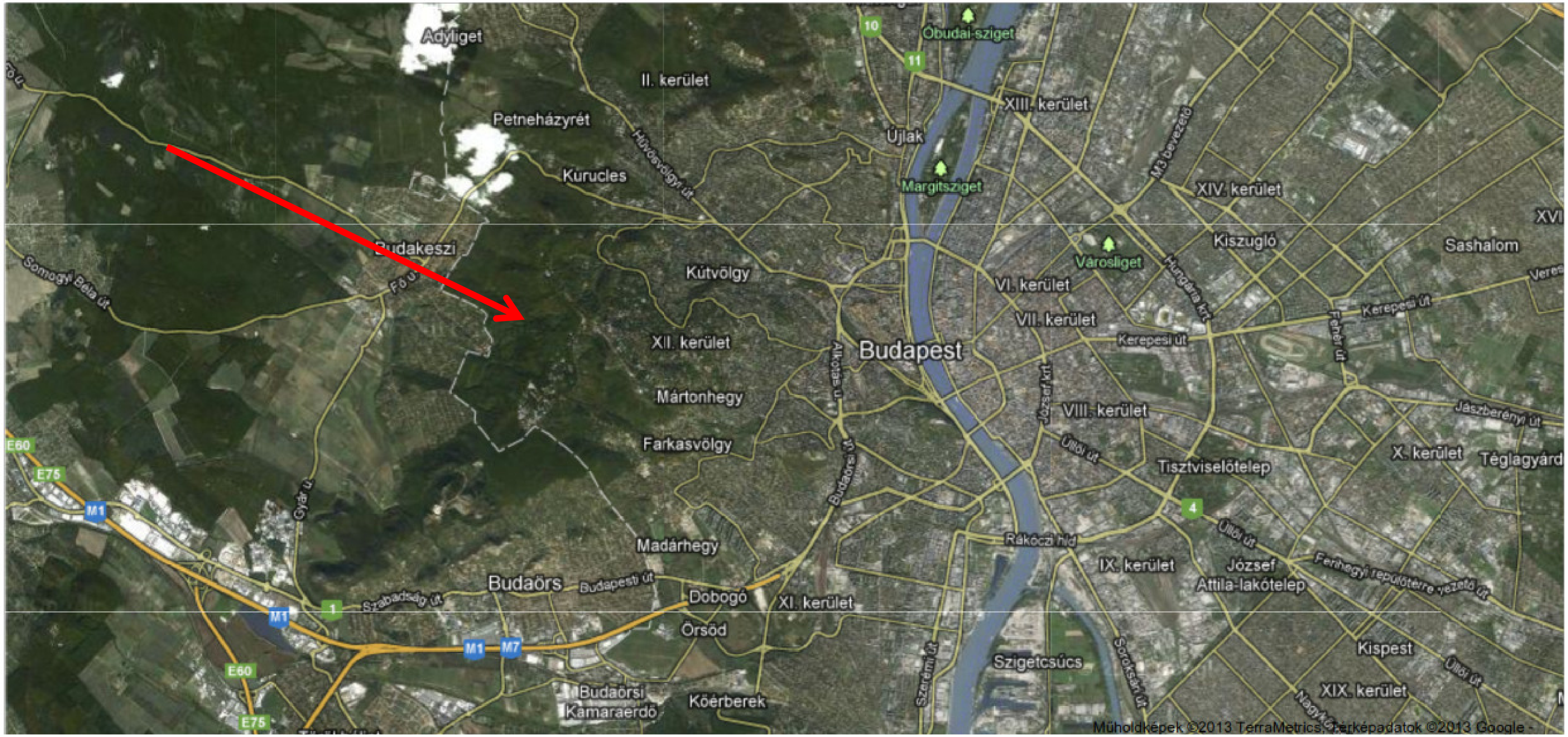
OUTLINE

- Introducing Wigner RCP
- Past
  - Proposal for attosecond light pulse generation using HHG in rare gases
  - Inventing chirped mirrors, MDC Ti:sapphire oscillators (with TU Wien)
  - Compression of high energy laser pulses below 5 fs (with TU Wien and Milano)
- Present
  - Helios lab (A. Czitrovszky)
  - Strong-field ultrafast electron phenomena on the nanoscale (P. Dombi)
  - Dispersive mirrors, optical fibers and fiber lasers (R. Szipőcs)
  - Spin off companies related to Wigner RCP
- Future?

Introducing Wigner RCP

HUNGARIAN ACADEMY OF SCIENCES

WIGNER RESEARCH CENTRE FOR PHYSICS



Introducing Wigner RCP

- ❑ Institute for Particle and Nuclear Physics
- ❑ Institute for Solid State Physics and Optics

PAST: Proposal for attosecond light pulse generation using HHG in rare gases

Physics Letters A 168 (1992) 447–450
North-Holland

PHYSICS LETTERS A

Proposal for attosecond light pulse generation using laser induced multiple-harmonic conversion processes in rare gases

Gy. Farkas and Cs. Tóth
Research Institute for Solid State Physics, Central Research Institute for Physics, P.O. Box 49, H-1525 Budapest, Hungary

Received 11 June 1992; accepted for publication 13 July 1992
Communicated by V.M. Agranovich

A new principle of attosecond light pulse generation is suggested. The method is based on a Fourier synthesis of laser induced multiple harmonics, which all are oscillating with the same fixed phase as predicted and observed recently in rare gases. According to our calculation using published experimental data, the production of a regular sequence of ~30–70 as duration light pulses is expected to be realizable.

Gy. Farkas and Cs. Tóth, Physics Letters A 168, 447-450 (1992)

PAST: Proposal for attosecond light pulse generation using HHG in rare gases

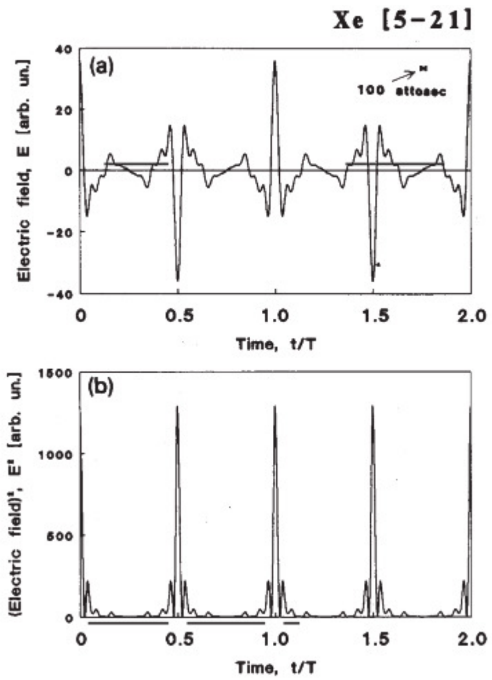


Fig. 1. The electric field strength $E(t)$ (a) and the square of the electric field strength $E^2(t)$ (b) of the light beam, in which high harmonic modes are coherently summarized from the 5th up to the 21st harmonic component. The results are plotted for two full oscillation periods ($2T$) of the basic harmonic component ω_0 of the Nd laser beam (T=3.53 fs).

Table 1
Resulting pulse durations and pulse height increase ratios after the Fourier synthesis of high harmonic components of the plateau region for various noble gases. The first (n_p) and the last (n_c) component of the plateau region are given

Gas	n_p	n_c	τ from $E(t)$ (as)	τ from $E^2(t)$ (as)	Increase ratio $(\sum E_n^2)/E_n^2$
xenon	5	21	97	72	81
krypton	5	25	76	56	169
argon	7	29	74	52	180
neon	13	53	38	28	441

Gy. Farkas and Cs. Tóth, Physics Letters A 168, 447-450 (1992)

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

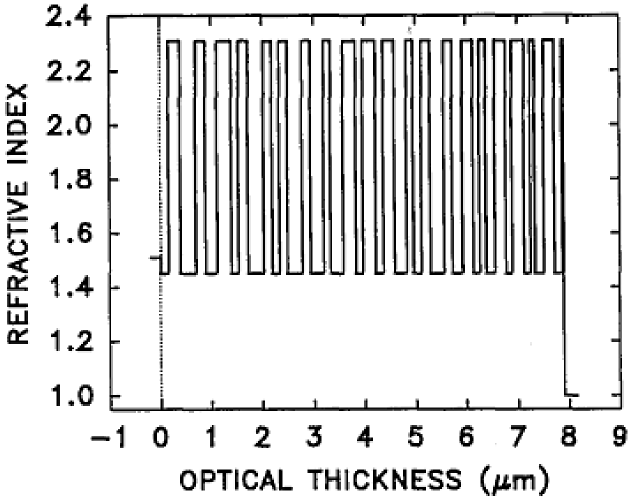


Fig. 1. Theoretical refractive-index profile of a high-reflectivity TiO_2–SiO_2 multilayer coating designed specifically for broadband GDD control in femtosecond lasers.

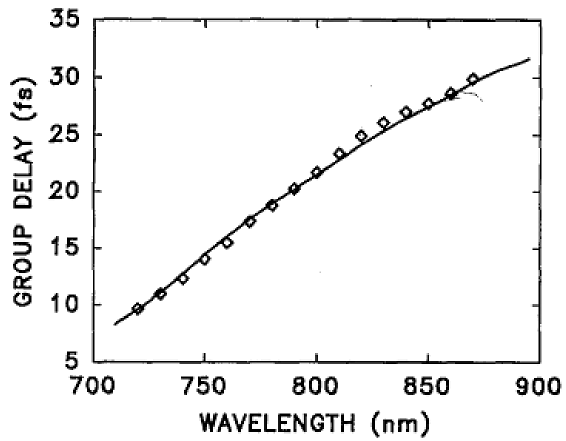
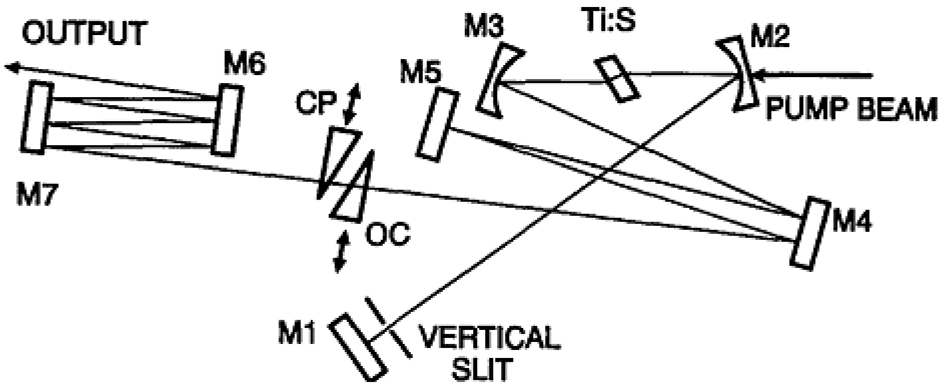


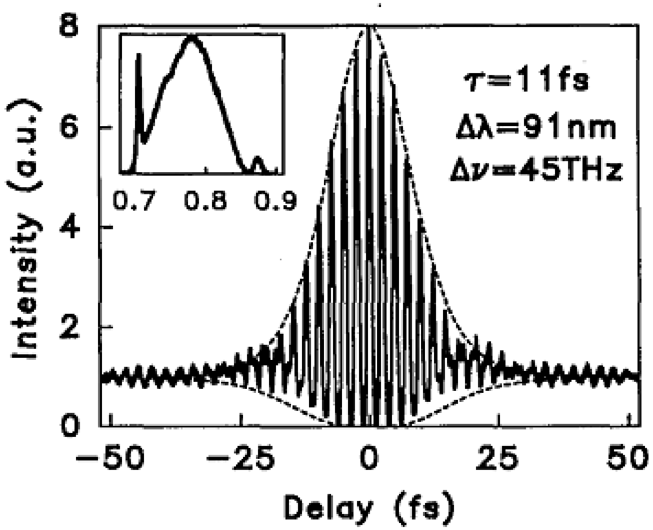
Fig. 3. Computed group delay as a function of wavelength (solid curve) together with experimental data (squares) for the multilayer design of Fig. 1. Note that the absolute delay could not be measured; therefore a wavelength-independent constant delay was added to the measured relative data.

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)

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)

DISPERSIVE MIRRORS, CHARACTERIZATION: WHITE LIGHT INTERFEROMETRY

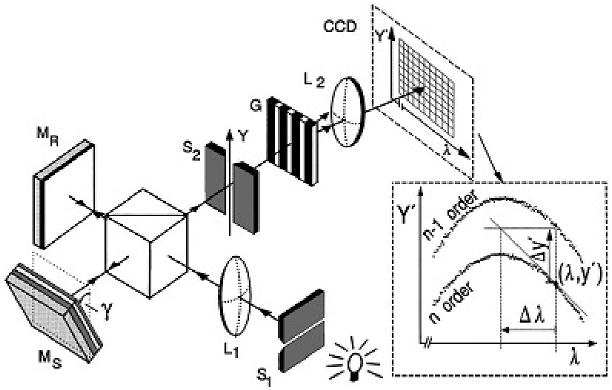
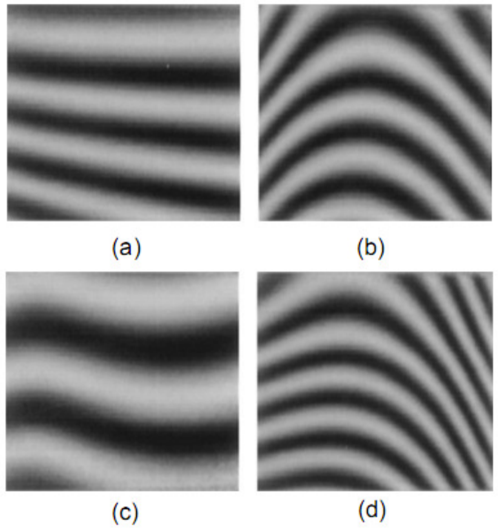


Fig. 1. Spectrally resolved white-light interferometer for group-delay measurement of dielectric mirrors. L_1, L_2, achromatic lenses; S_1, S_2, slits; M_S, sample mirror; M_R, reference mirror; G, transmission grating.



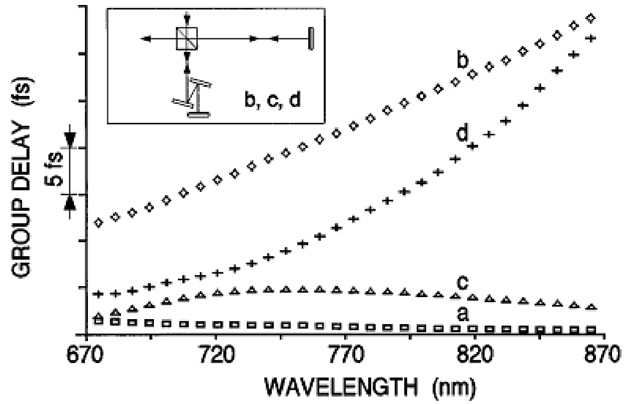


Fig. 4. Measured group-delay functions obtained by computer processing of the images shown in Fig. 3 (every fifth point is plotted). The curves correspond to a single reflection. Inset: four-reflection arrangement used for measuring curves b–d.

(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)

MIRROR DISPERSION CONTROLLED Ti:SAPPHIRE LASER

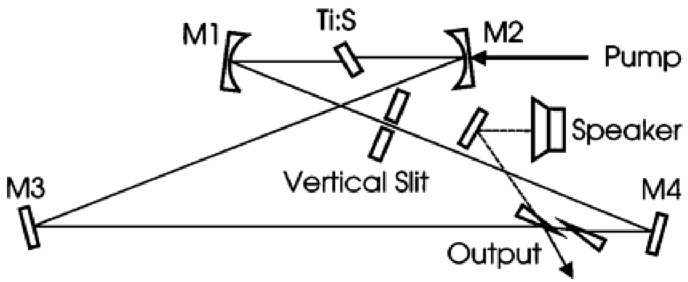


Fig. 1. Schematic of the MDC Ti:sapphire (Ti:S) ring laser. The pump beam is focused with a 40-mm lens onto the Ti:S crystal. M1, M3, M4, chirped mirrors; M2, chirped dichroic mirror. The radius of curvature of M1 and M2 is 50 mm.

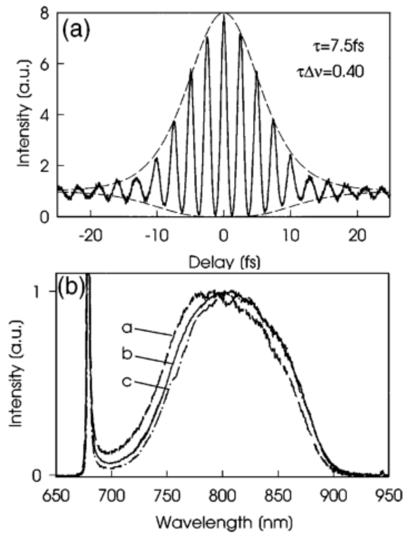


Fig. 2. (a) Single-scan FRAC trace of the output of the MDC Ti:sapphire laser. (b) Spectrum of the mode-locked laser measured through a pinhole positioned at (curve b) the center of the beam and (curves a and c) the half-intensity-maximum points in the horizontal plane. In the vertical plane no spatial chirp was observed.

RING CAVITY

☺ **Highly stable femtosecond pulses with duration of ~7.5 fs**

Lin Xu, Christian Spielmann, Ferenc Krausz and Róbert Szipőcs, *Opt. Lett.* 21, pp. 1259-1261 (1996)

Route to phase control of ultrashort light pulses (TU Wien)

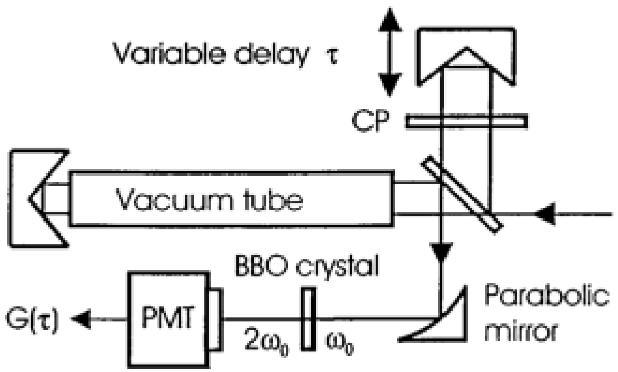


Fig. 1. Schematic diagram of the correlator used to the measure $\Delta\psi$. To balance dispersion in the correlator arms precisely, we evacuate a delay section equal to the resonator round-trip length in the long arm, a compensation plate (CP) is used to introduce the same amount of fused silica into the short arm as the tube windows introduce into the long arm, and pulse splitting and recombination are implemented by identical broadband dielectric coatings on opposite sides of the beam splitter. PMT, photomultiplier tube; BBO, β-barium borate.

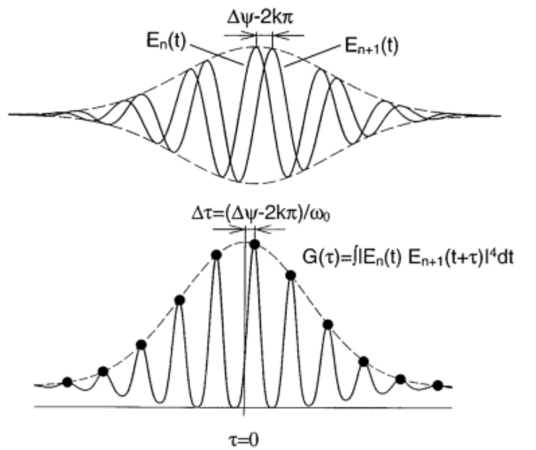


Fig 2. Principle of the measurement of $\Delta\psi$. $E_n(t)$ and $E_{n+1}(t)$ describe successive pulses from the laser. $\Delta\psi - 2k\pi$ can be determined from the position of the fringe peaks on the envelope of $G(\tau)$.

We thank R. Szipöcs and K. Ferencz (Research Institute for Solid State Physics, Budapest, Hungary) for providing the special dispersive mirrors used in the Ti:sapphire laser. This research was supported by Fonds zur Förderung der wissenschaftlichen Forschung grants P-09710 and P-10409, and by Österreichische Nationalbank grants 5335 and 5124.

Lin Xu, Christian Spielmann, Ferenc Krausz and Robert Szipőcs, *Opt. Lett.* 21, pp. 1259-1261 (1996)

L. Xu, Ch. Spielmann, A. Poppe, T. Brabec, F. Krausz and T. W. Hansch, *Opt. Lett.* 21, 2008-2011 (1996)

Ultrabroadband chirped mirrors for ultrafast lasers

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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

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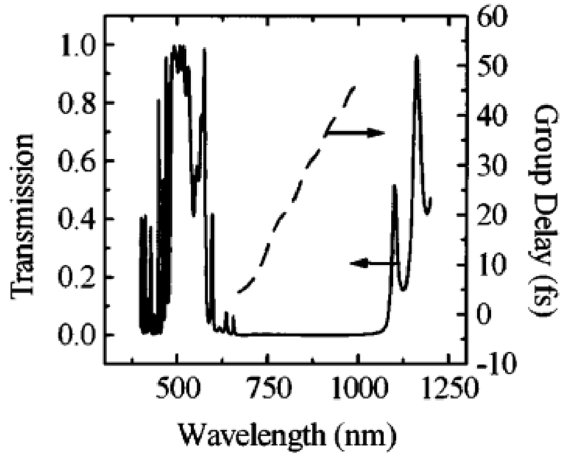
R&D Lézer-Optika Bt., P.O. Box 622, H-1539 Budapest, Hungary

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)

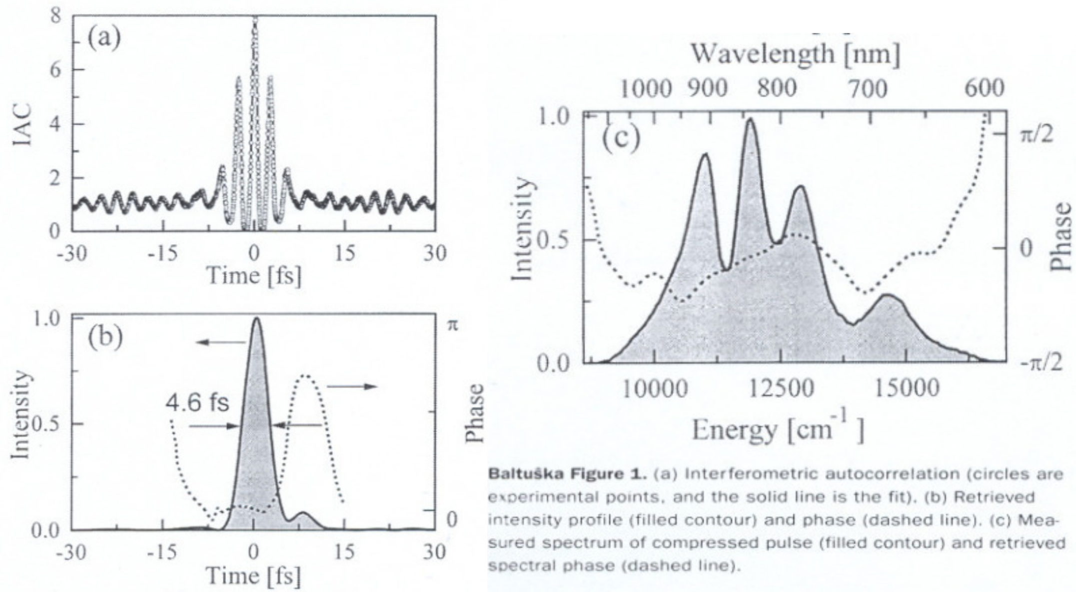
Compression of laser pulses down to 4.6 fs

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).

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

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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-μJ were obtained with krypton, while pulses as short as 5 fs with energy up to 70 μJ were obtained with argon. These pulses are, to our knowledge, the shortest generated to date at multigigawatt peak powers. © 1997 Optical Society of America

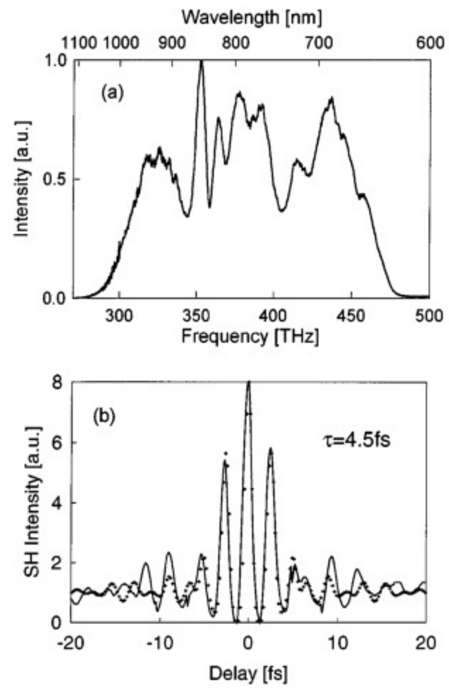


Fig. 2. (a) Spectral broadening in krypton at $p = 2.1$ bars and $P_0 = 2$ GW. A low-intensity pedestal (~1% of the peak) extends below 600 nm. (b) Measured (solid curve) and calculated (crosses) autocorrelation trace; an evaluation of the pulse duration (FWHM) is also given.

Wigner RCP and ELI-ALPS

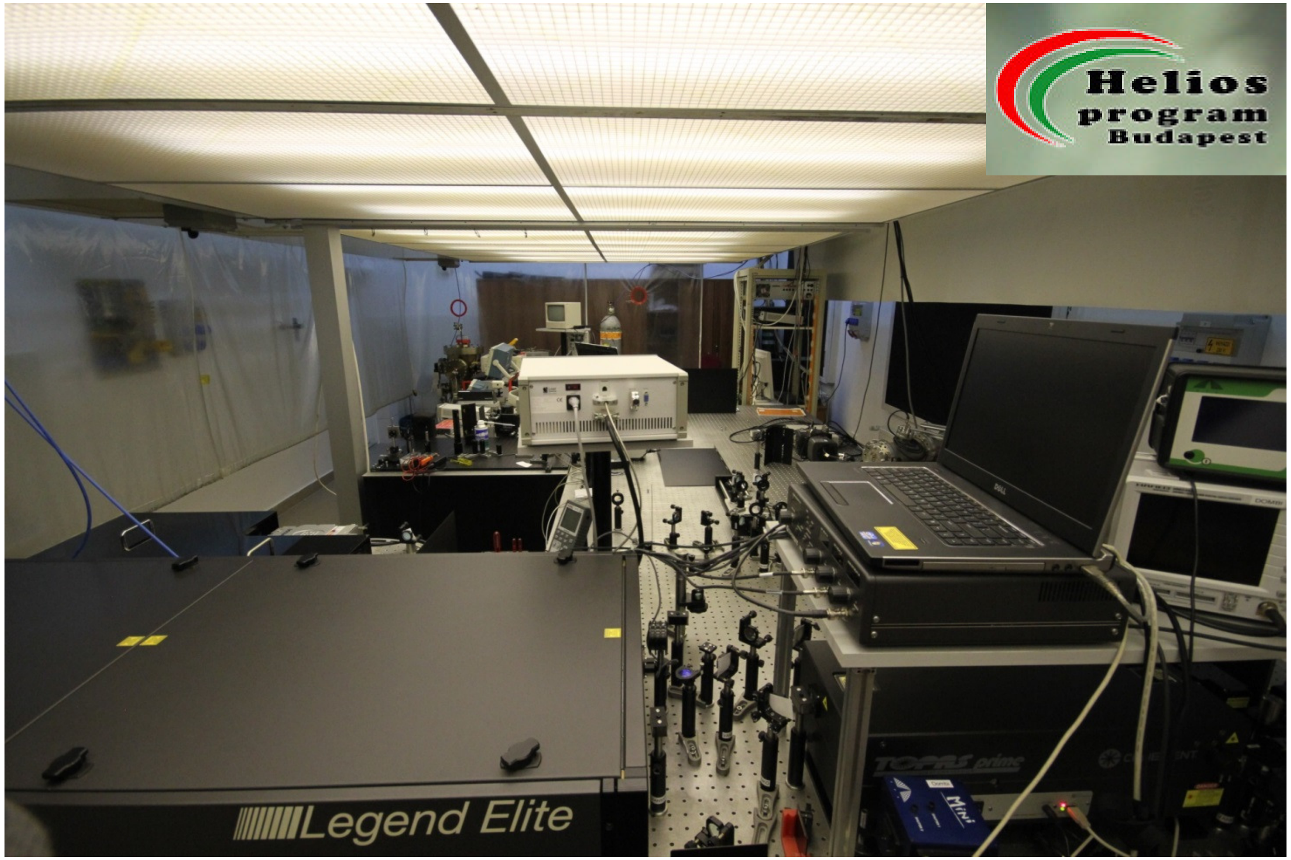
The HELIOS program in Budapest (A. Czitrovszky):

Attosecond pulse generaton, optical thin films, metrology

Wigner RCP and ELI-ALPS

The HELIOS program in Budapest (A. Czitrovszky):

Attosecond pulse generaton, optical thin films, metrology



Integrated ultrafast laboratory (HELIOS lab)

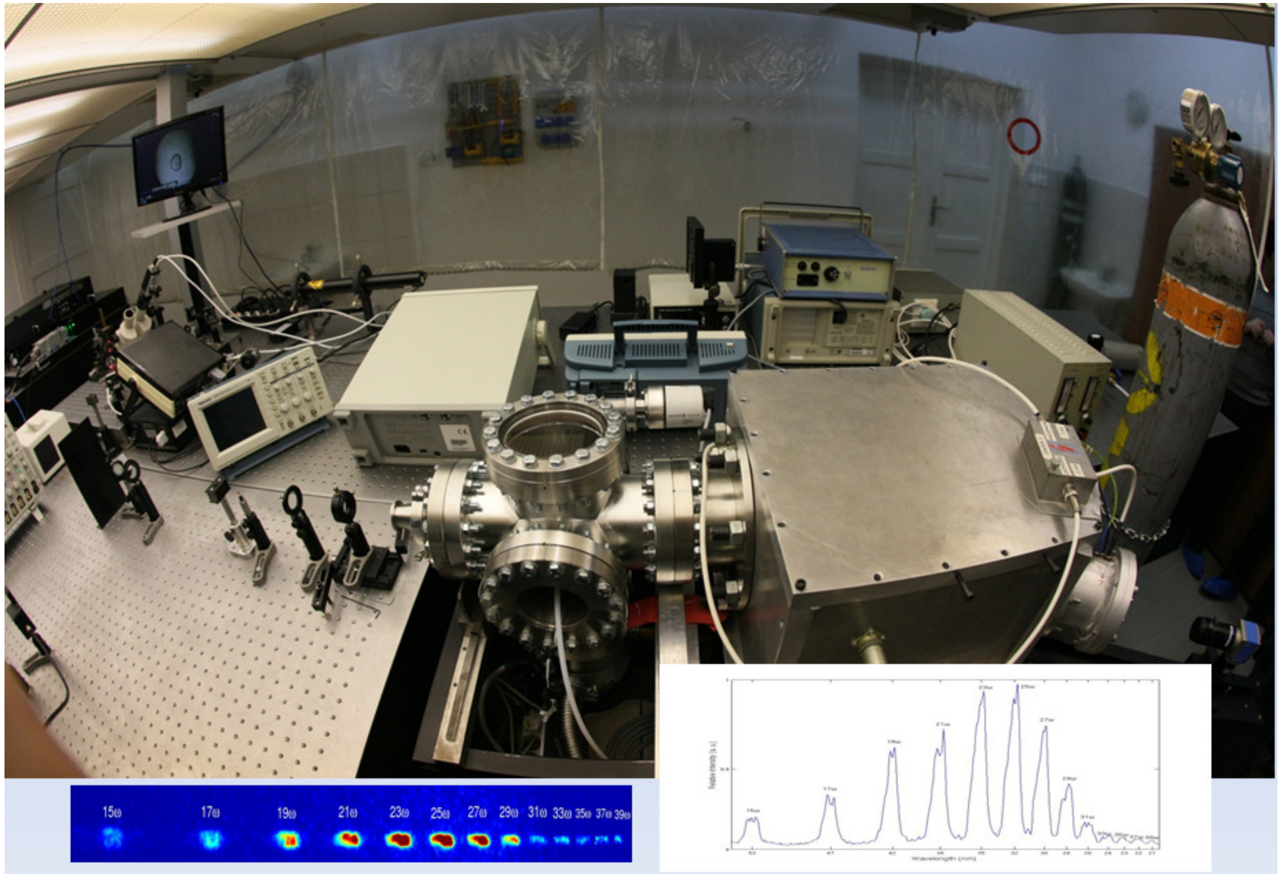
INFRASTRUCTURE

- 1 kHz / 4 mJ / 30 fs Ti:S amplifier
- commercial optical parametric amplifier covering 300-15000 nm with fs pulses
- XUV spectrometer
- time-of-flight electron spectrometer

APPLICATIONS

- Ultrafast plasmonics
- Pump-probe experiments on functional molecules (e.g. light harvesting)
- Femtosecond metrology (damage threshold and monitoring etc.)
- High harmonic generation on clusters

Integrated ultrafast laboratory (HELIOS lab)

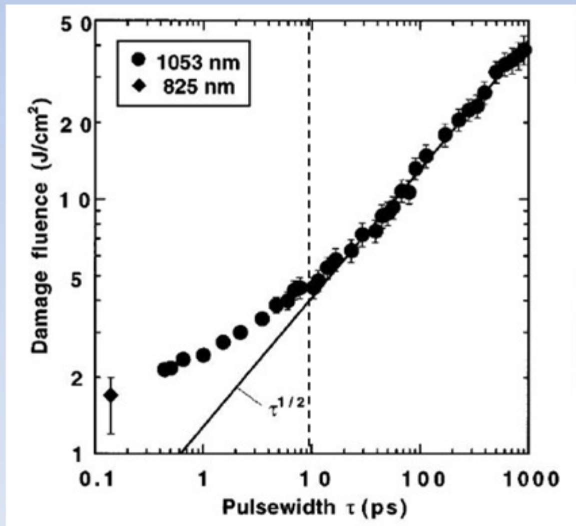


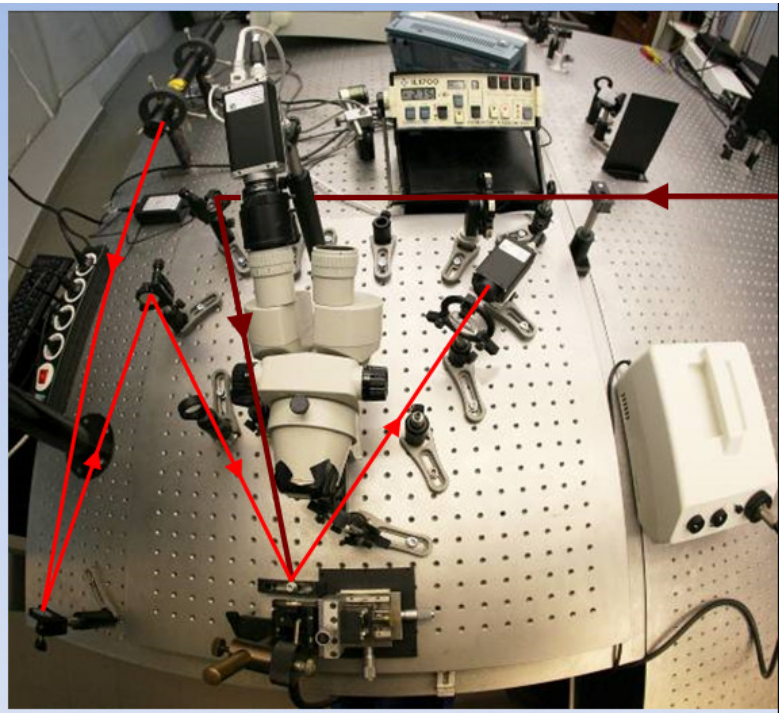
Vacuum chamber for HHG

Integrated ultrafast laboratory (HELIOS lab)

Main parameters:

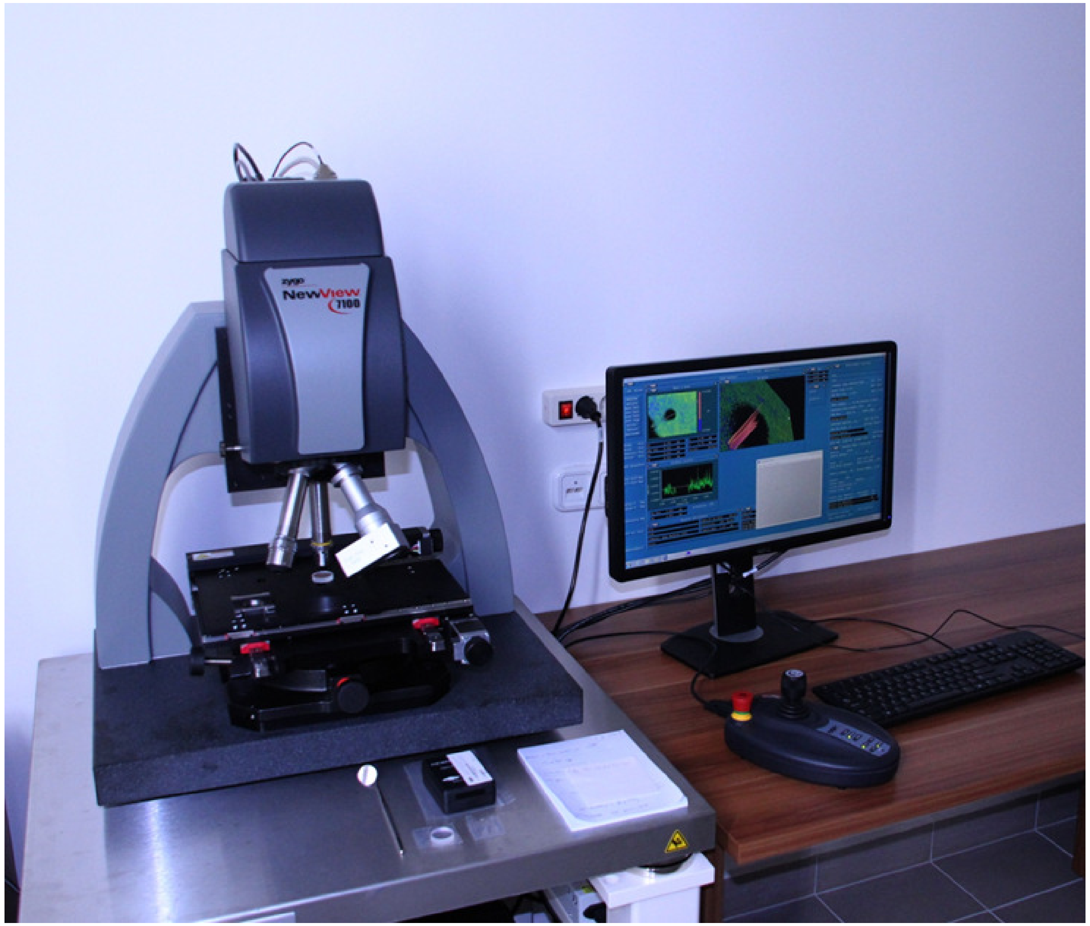
Pulse energy	0.5 mJ
Spot size	10 µm (FWHM)
Pulse duration	35 fs (FWHM)
Rep. Rate	1 kHz
Intensity	125 J/cm^2





Damage threshold measurements

Integrated ultrafast laboratory (HELIOS lab)



ZYGO 7100 interferometer

Strong-field physics @ WIGNER

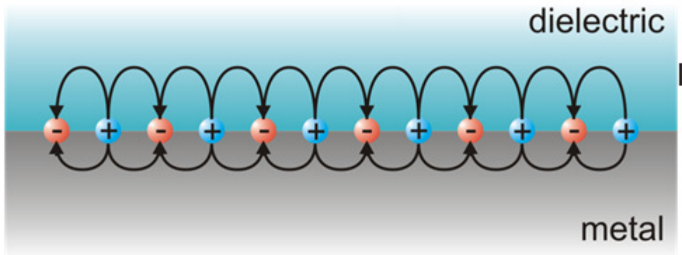
PAST:
Strong-field and attosecond physics traditions
Group of Győző FARKAS (from 1970s on)

First proposal on atto pulse generation (1992)

PRESENT:
Strong-field ultrafast electron phenomena on the nanoscale
Group of **Péter DOMBI**

Strong-field ultrafast electron phenomena on the nanoscale

Experiments with: 1. propagating surface plasmons on thin metal films:

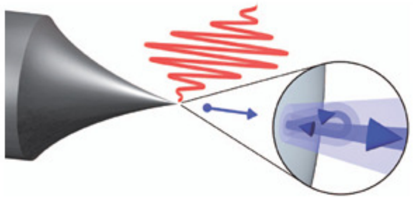


Irvine, Dombi et al., Phys. Rev. Lett (2006)

Dombi et al. Opt. Express 18, 24206 (2010).

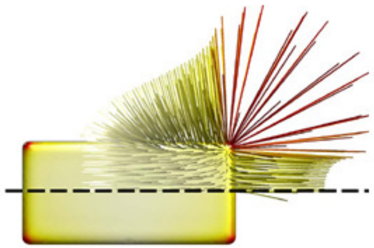
2. metal (typically non-plasmonic) nanotips

Krüger et al., Nature 475, 78 (2011),
Herink et al., Nature 483, 190 (2012),
Park et al., PRL 109, 244803 (2012).

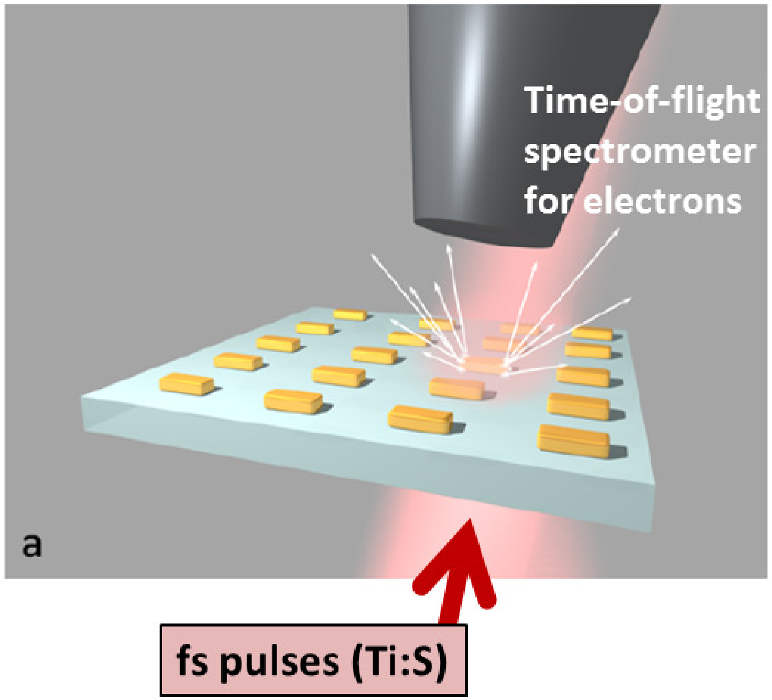


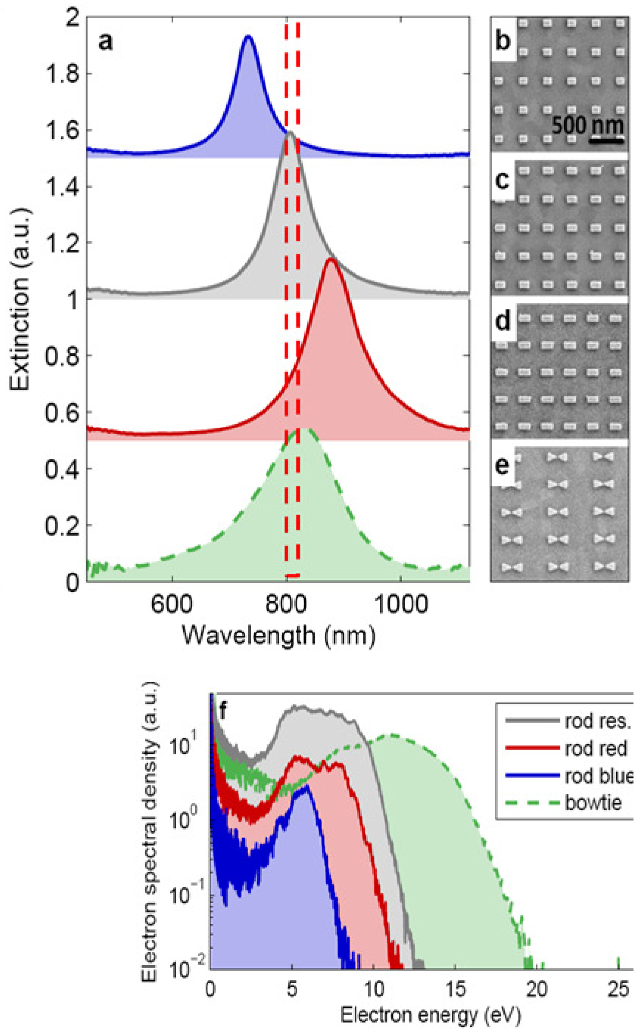
3. plasmonic nanoparticles in strong fields

Dombi et al., Nano Lett. 13, 674 (2013),
Sci. Rep., accepted for publicatio n (2014).



Controlling electrons with plasmon resonance





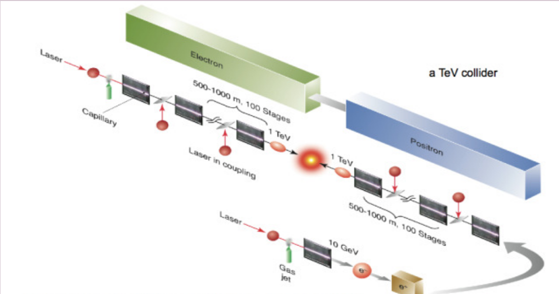
Electron spectra controlled with plasmonic resonance

Dombi et al., Nano Lett. 13, 674 (2013).

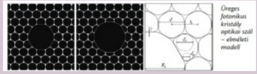
Wigner RCP and the ELI Project – PRESENT
Competences at Szipőcs Group

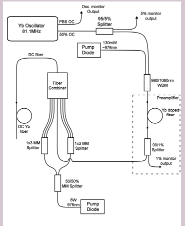
Szipőcs Group

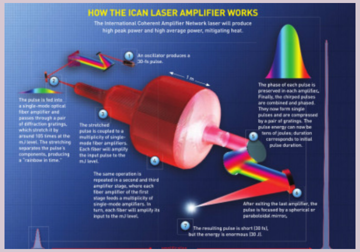
Particle acceleration by fiber lasers (ICAN Project)



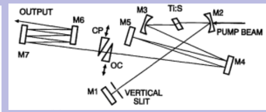
Leemans and Esarey (Phys. Today, 09)

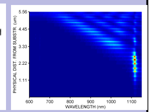


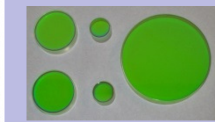


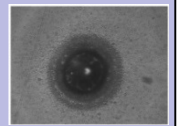


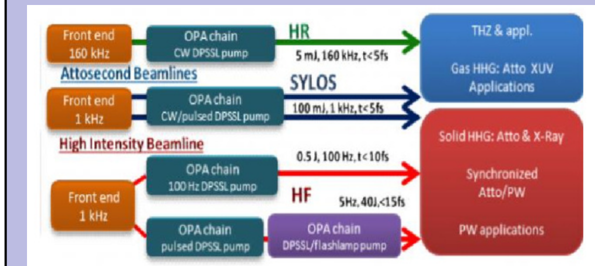
Femtosecond pulse solid state lasers and optics (ELI/Helios Project)











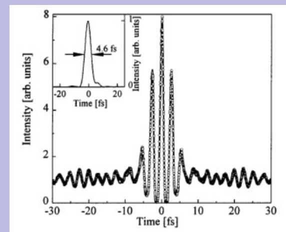
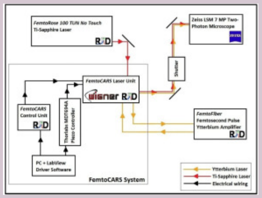
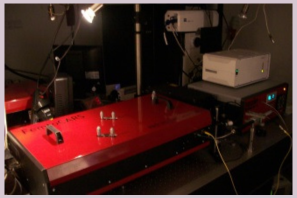
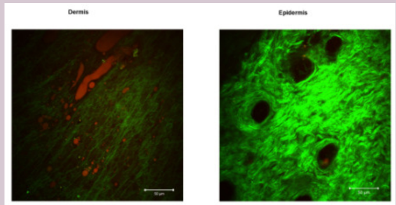


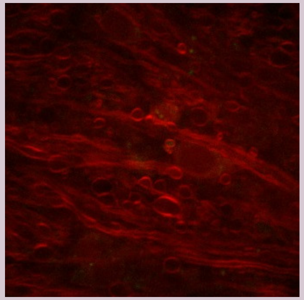
Fig. 14. Interferometric autocorrelation of a 4.6-fs pulse. *Open circles* experimental points, *solid line* calculated IAC of deduced pulse shape shown in the inset

LifeScience@Wigner (e.g. National Brain Research Program (NAP))





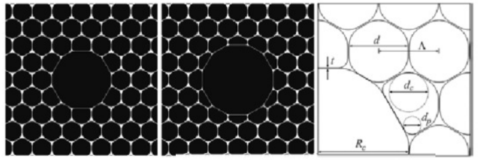




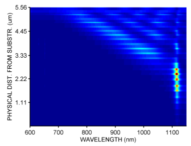
Scientific background, present competences @ Szipőcs Group

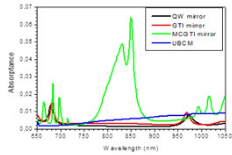
Research Topics:

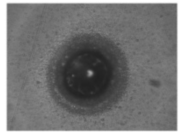
- ***Theory of photonic crystal fibers. Design, manufacturing and quality test of photonic crystal fibers. Applications in optical fiber lasers, amplifiers and 3D microscopic imaging systems.***
- ***Damege threshold of dispersive dielectric mirrors in the > 50 ps and in the sub-ps time domain***
- ***Development of femtosecond pulse solid state and fiber lasers for in vivo 3D nonlinear microscopy***
- ***Double wavelength pulsed laser systems for CARS microscopy***
- ***Applications of nonlinear microscopy in dermatology, neurology and pharmacology***

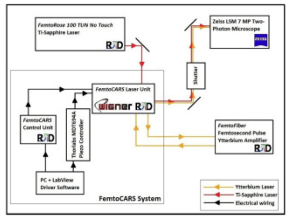


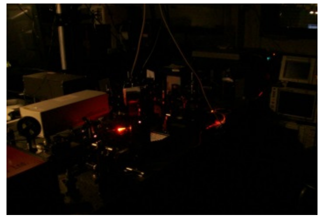
Üreges fotonikus kristály optikai szál – elméleti modell



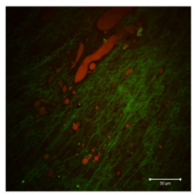




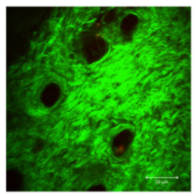


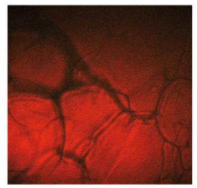


Dermis



Epidermis





Zsírszövetről CARS módszerrel az MTA SZFKI-ban készített mikroszkópiás kép

Recent publications

1. Várallyay Z, Saitoh K, Fekete J, Kakihara K, Koshiba M, Szipőcs R: *Reversed dispersion slope photonic bandgap fibers for broadband dispersion control in femtosecond fiber lasers*, *OPTICS EXPRESS* 16, 15603-15616 (2008)

2. Fekete J, Várallyay Z, Szipőcs R: *Design of high bandwidth one- and two-dimensional photonic bandgap dielectric structures at grazing incidence of light*. APPLIED OPTICS 47, 5330-5336 (2008)

3. Fekete J, Cserteg A, Szipőcs R: *All-fiber, all-normal dispersion ytterbium ring oscillator*, *LASER PHYSICS LETTERS* 6, 49-53 (2009)

4. Várallyay Z, Saitoh K, Szabó Á, Szipőcs R: *Photonic bandgap fibers with resonant structures for tailoring the dispersion*, *OPTICS EXPRESS* 17, 11869-11883,(2009)

5. Antal P, Szipőcs R: *Tunable, low-repetition-rate, cost-efficient femtosecond Ti:sapphire laser for nonlinear microscopy*, *APPL. PHYS. B107*, 17–22 (2012)

6. Antal P, Szipőcs R: *Relation between group delay, energy storage and loss in dispersive dielectric mirrors*, *CHINESE OPTICS LETTERS* 10, 053101/1-4 (2012)

7. P. Bognár, D. Haluszka, N. Wikonkál, A. Kolonics, R. Szipőcs, S. Kárpáti, *Reduced Inflammatory Threshold Indicates Skin Barrier Defect in Transglutaminase 3 Knockout Mice, J. INVESTIGATIVE DERMATOLGY* 134, *105-111* (2014)

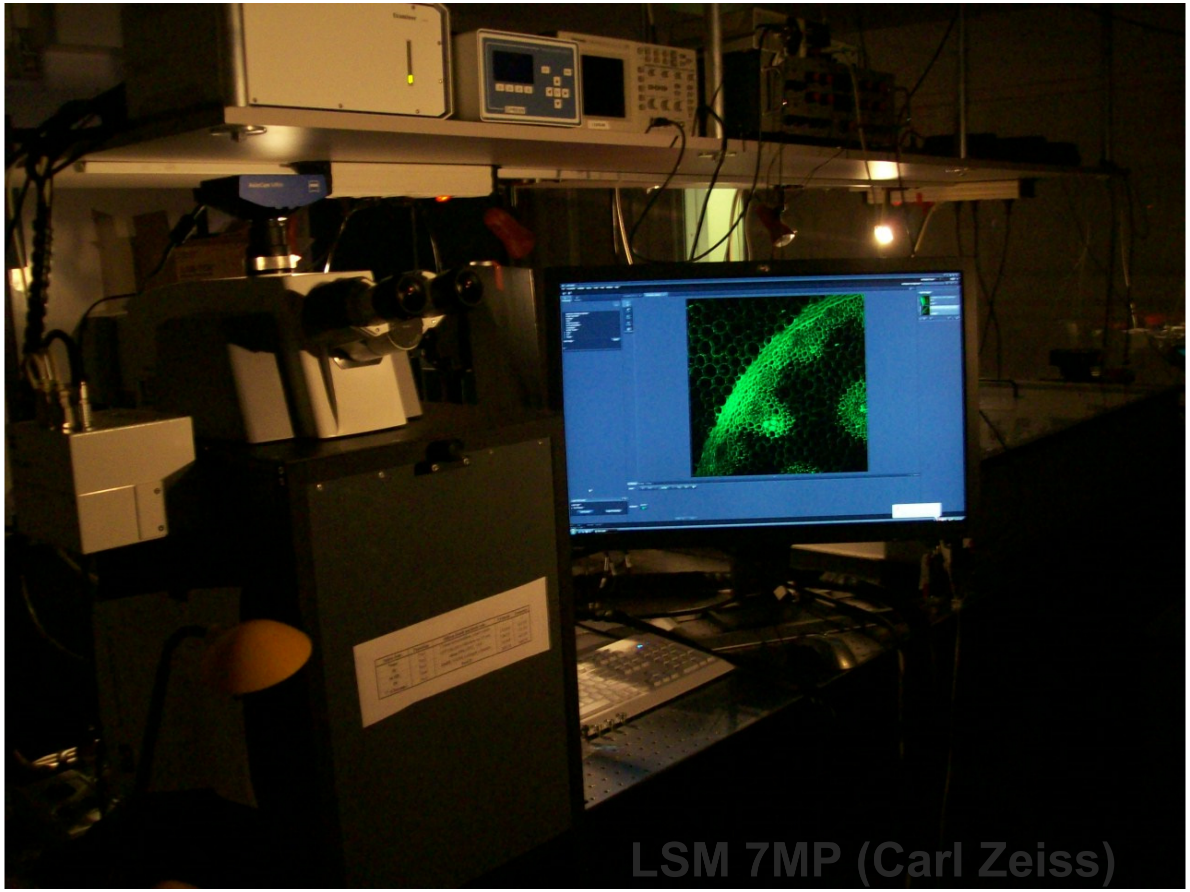
8. Grósz T, Kovács AP, Kiss M, Szipocs R, Measurement of higher order chromatic dispersion in a photonic bandgap fiber: Comparative study of spectral interferometric methods, *APPLIED OPTICS* 53, *1929-1937* (2014)

9. Kolonics A, Csiszovszki Zs, Tőke ER, Lőrincz O, Haluszka D, Szipőcs R, *In vivo study of targeted nanomedicine delivery into Langerhans cells by multiphoton laser scanning microscopy, EXPERIMENTAL DERMATOLOGY* 23, *596-605* (2014)

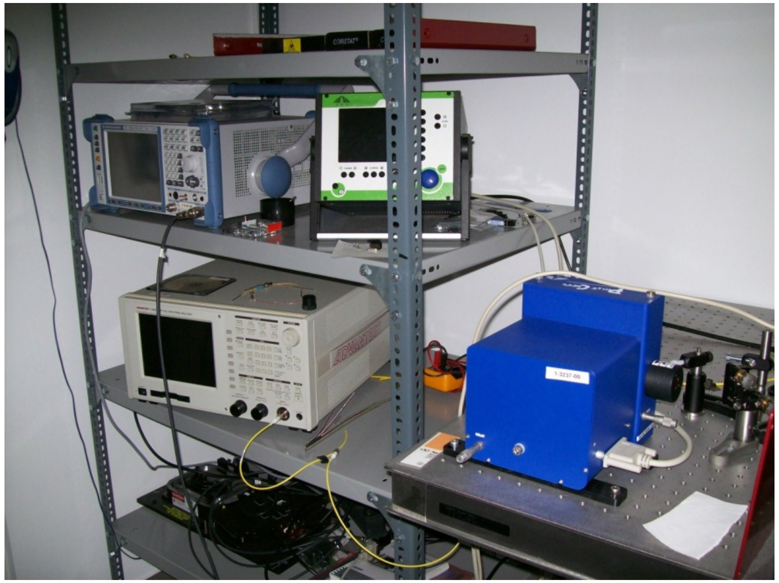
10. Toke ER, Lorincz O, Csiszovszki Z, Somogyi E, Felföldi G, Molnár L, Szipőcs R, Kolonics A, Malissen B, Lori F, Trocio J, Bakare N, Horkay F, Romani N, Tripp CH, Stoitzner P, Lisziewicz J, *Exploitation of Langerhans cells for in vivo DNA vaccine delivery into the lymph nodes*, *GENE THERAPY* 21, *566-574.*(2014)

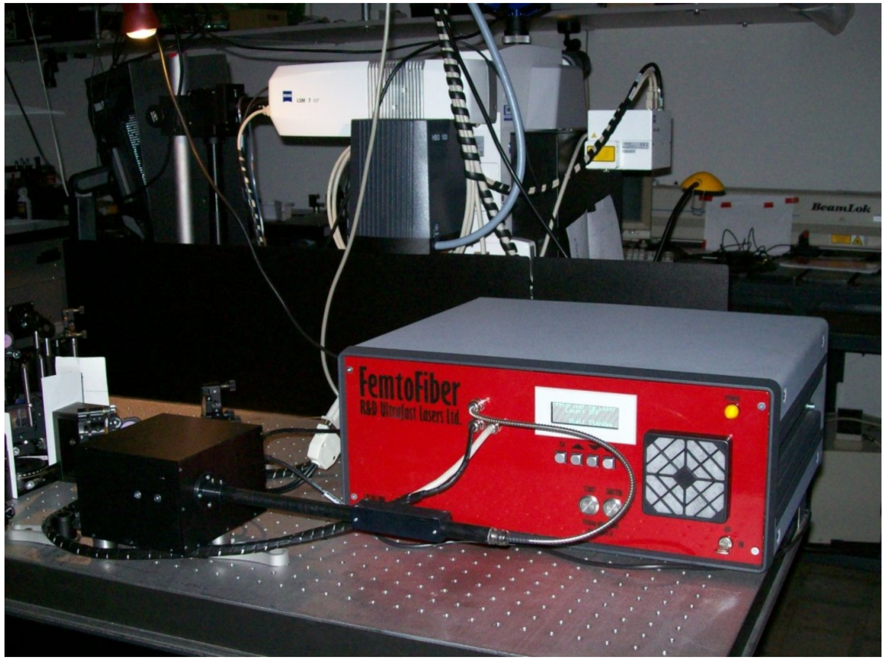
11. Várallyay Z, Szipőcs R, *Stored Energy, Transmission Group Delay and Mode Field Distortion in Optical Fibers, IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS* 20, 0904206/1-6 (2014)

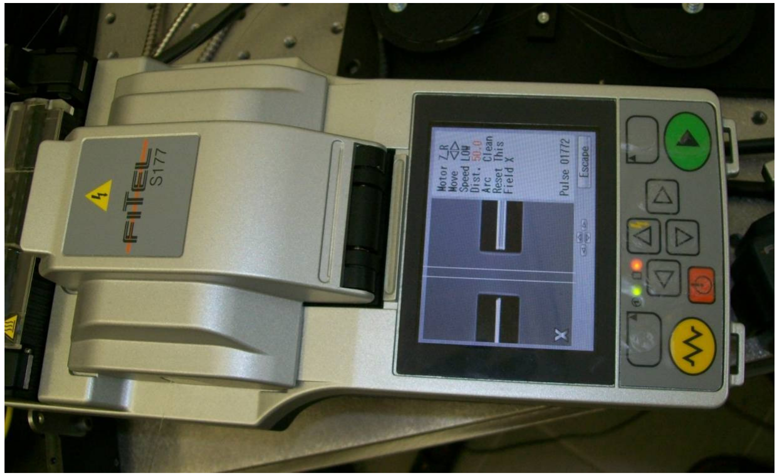
Infrastructure – nonlinear microscopy

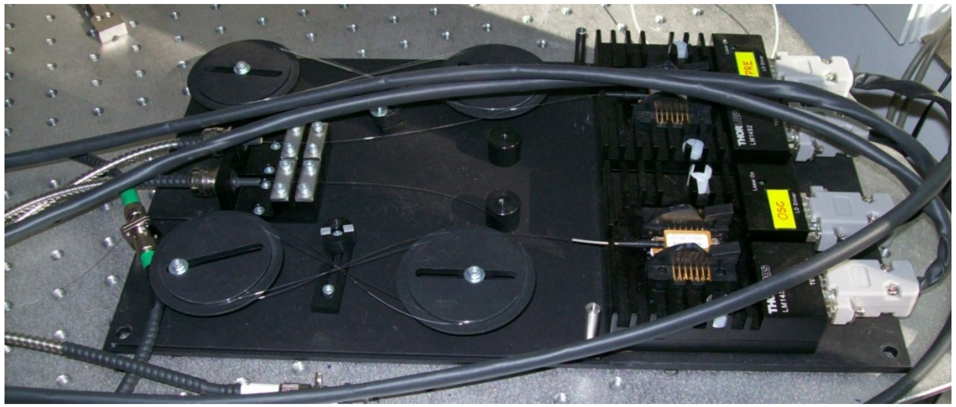


Infrastructure – laboratory for optical fibers

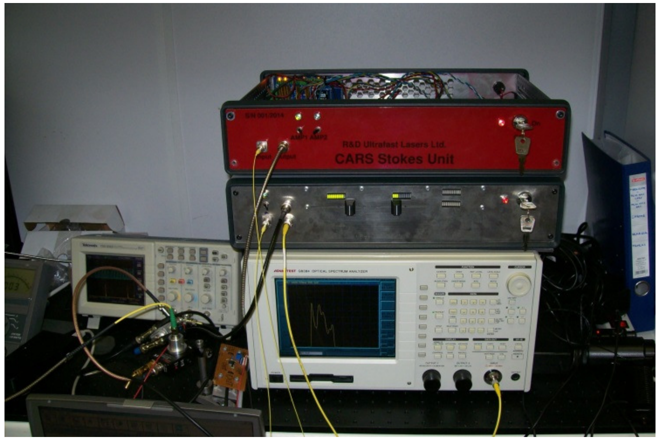




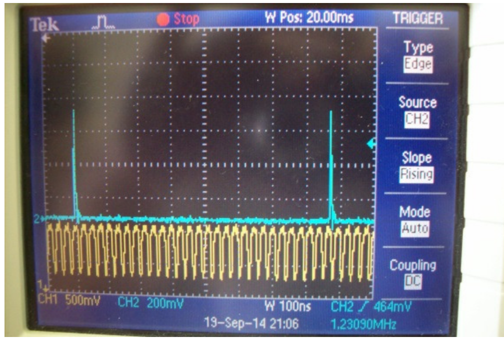


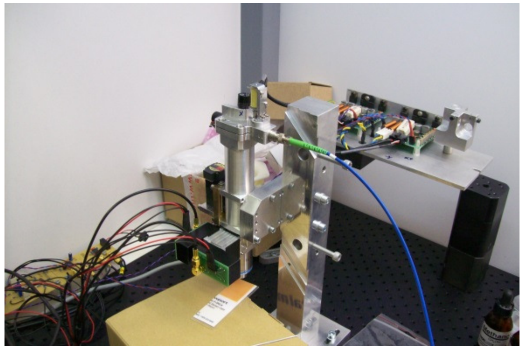


Collaboration with industry – nonlinear microscopy



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

DOI: 10.1111/exd.12464
www.wileyonlinelibrary.com/journal/EXD

Letter to the Editor

In vivo study of targeted nanomedicine delivery into Langerhans cells by multiphoton laser scanning microscopy

Attila Kolonics[1,2], Zsolt Csiszovszki[3,5], Enikő R. Tőke[3,5], Orsolya Lőrincz[3,5], Dóra Haluszka[1,4] and Róbert Szipőcs[1,2]

[1]Institute for Solid State Physics and Optics of Wigner RCP, Budapest, Hungary; [2]R&D Ultrafast Lasers Ltd, Budapest, Hungary; [3]Genetic Immunity Kft, Budapest, Hungary; [4]Department of Dermatology, Venereology and Dermatooncology, Semmelweis University Hungary, Budapest, Hungary

Correspondence: Róbert Szipőcs, Institute for Solid State Physics and Optics of Wigner RCP, PO Box 49, H-1525 Budapest, Hungary, Tel./Fax: +36 1 3922582, e-mail: szipocs.robert@wigner.mta.hu

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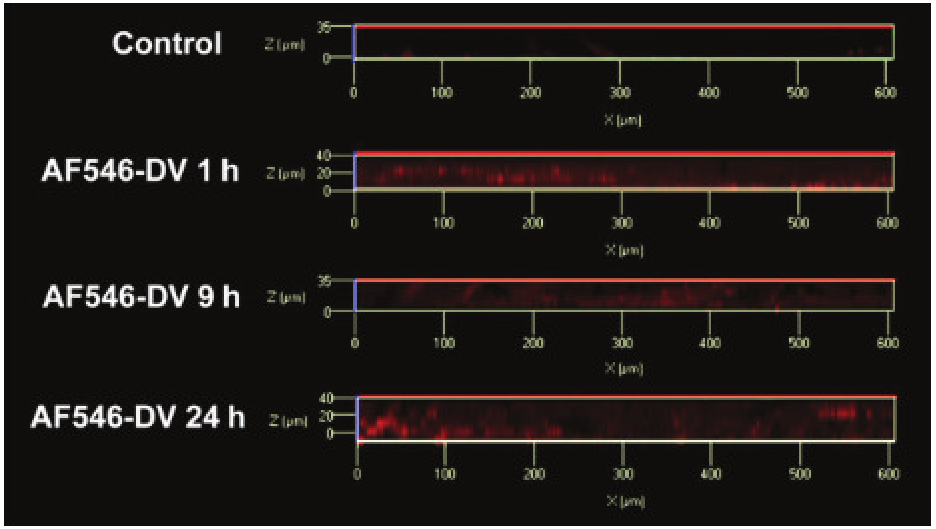
Abstract: Epidermal Langerhans cells (LCs) function as professional antigen-presenting cells of the skin. We investigated the LC-targeting properties of a special mannose–moiety-coated pathogen-like synthetic nanomedicine DermaVir (DV), which is capable to express antigens to induce immune responses and kill HIV-infected cells. Our aim was to use multiphoton laser microscopy (MLM) *in vivo* in order to visualize the uptake of Alexa-labelled DV (AF546-DV) by LCs. Knock-in mice expressing enhanced green fluorescent protein (eGFP) under the control of the langerin gene (CD207) were used to visualize LCs. After 1 h, AF546-DV penetrated the epidermis and entered the eGFP-LCs. The AF546-DV signal was equally distributed inside the LCs. After 9 h, we observed AF546-DV signal accumulation that occurred mainly at the cell body. We demonstrated in live animals that LCs picked up and accumulated the nanoparticles in the cell body.

Key words: eGFP-Langerin knock-in mice – *in vivo* – Langerhans cells – multiphoton laser microscopy – nanomedicine formulation

Accepted for publication 3 June 2014

Figure 1. Penetration kinetics of AF546-DV through the stratum corneum in enhanced green fluorescent protein (eGFP)-Langerin knock-in mouse ear *in vivo*. *xz*-Multitracking sections were composed from a stack of *xy*-optical sections with 5 μm distances between the sections. The sections were recorded from the stratum corneum (Z = 0 μm) to the epidermis (Z = 35–40 μm). These representations reveal the penetration profiles of AF546-DV into eGFP-Langerin knock-in mouse skin reaching an average of 20 μm penetration depth underneath the honeycomb-shaped corneocyte layer after 1 h of topical treatment. AF546-DV diffused in the whole depth of the skin after 9 or 24 h despite of the fact that a part of the AF546-DV formula dried on the stratum corneum. Control: intact skin without AF546-DV.



Applications in Pharmacology

Szipőcs Group

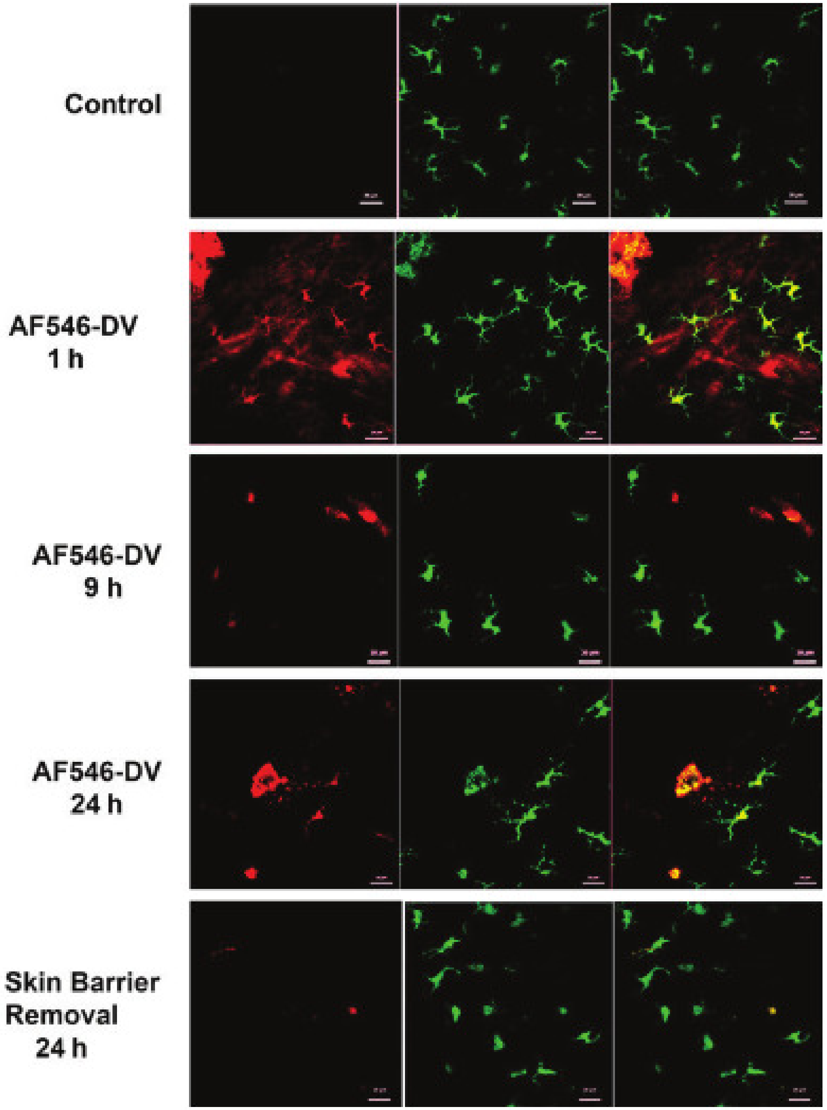


Figure 2. Kinetics of AF546-DV uptake by Langerhans cells (LCs) in eGFP-Langerin knock-in mouse ear *in vivo*. Nearly all LCs had incorporated AF546-DV after 1 h of topical treatment: strong colocalization was detected in both channels [NDD 2 – green/eGFP (middle column) versus NDD 1 – red/AF546-DV (left 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.

GROUP DELAY AND ABSORPTION LOSS IN A MULTISTACK DIELECTRIC MIRROR

substrate/ 0.6(H 2L H)^9 0.5(H 2L H)^9 0.42(H 2L H)^9 / air

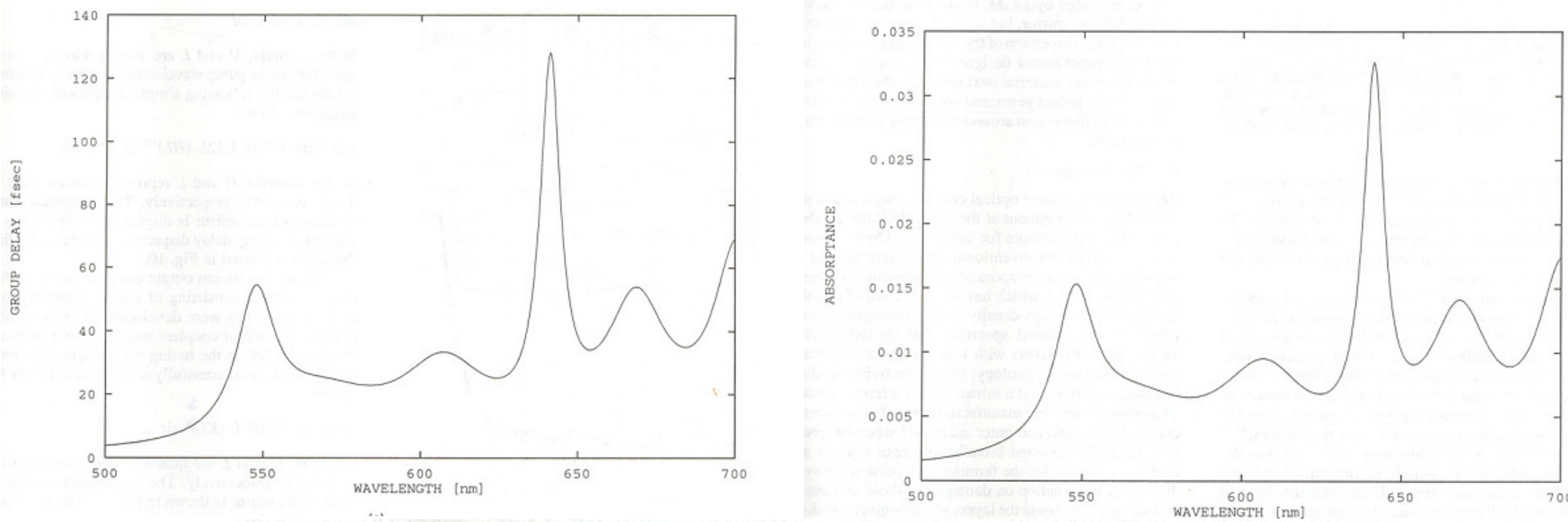


Fig. 5 Comparison of (a) group delay and (b) absorptance versus wavelength functions of the same mirror design as in Fig. 3, but with $\lambda_0 = 533$ nm. Material dispersion of the TiO_2 layers is considered using the Sellmeier dispersion formula: $n(\lambda)^2 = c_0 + c_2/\lambda^2$ ($c_0 = 4.9$, $c_2 = 280{,}000$ nm^2). The other refractive indices are $n_S = 1.51$ (BK7), $n_A = 1.0$ (air), and $n_L = 1.45$ (SiO_2). For the absorptance computation extinction constants $k_H = 0.0001$ and $k_L = 0.0001$ are used.

- **GROUP DELAY IN REFLECTION IS PROPORTIONAL TO ABSORPTION LOSS**
- **BUT WHY?**

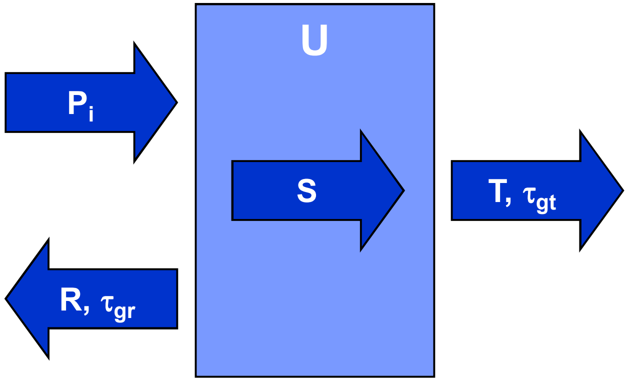
K. Ferencz, R. Szipöcs: *Opt. Eng. 32, pp. 2525-2538* (1993)

THEORY

- For low loss layer structure, we get:

$$T \cdot \tau_{gt} + R \cdot \tau_{gr} = \tau_d = \frac{U}{P_i}$$

where τ_d is the so called dwell time.



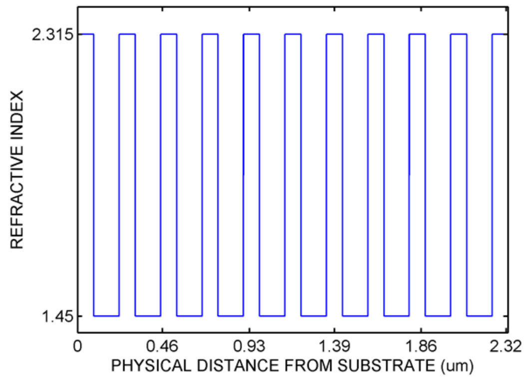
For highly reflective (R~1) dispersive dielectic mirror coatings, we can write:

$$\tau_{gr} \approx \frac{U}{P_i}$$

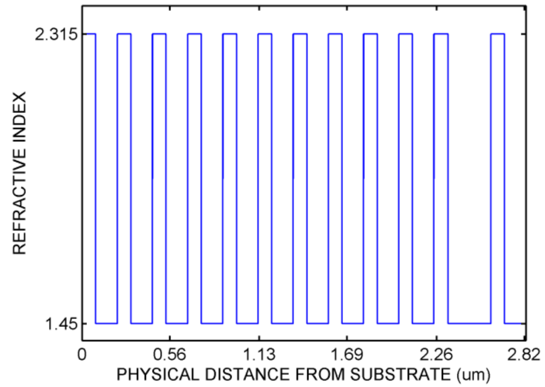
GROUP DELAY ON REFLECTION IN PROPORTIONAL TO THE ENERGY STORED IN DISPERSIVE DIELECTRIC MIRRORS!

Antal P, Szipőcs R: Relation between group delay, energy storage and loss in dispersive dielectric mirrors
CHINESE OPTICS LETTERS 10, 053101/1-4 (2012)

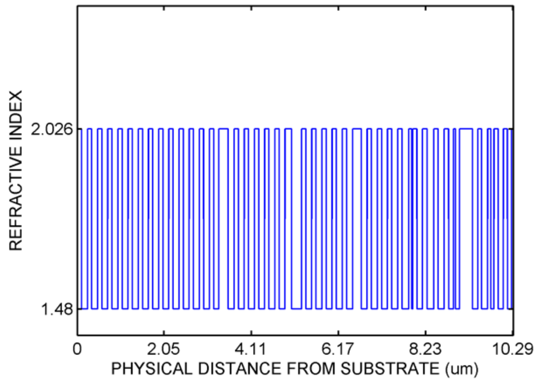
1D NUMERICAL EXAMPLES: THE REFRACTIVE INDEX PROFILES



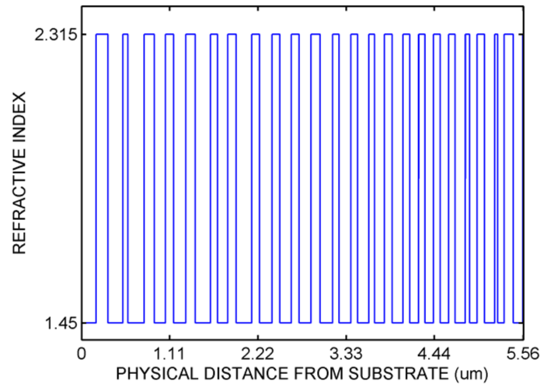
QW STACK



GTI MIRROR



HIGH-DISPERSIVE MCGTI MIRROR

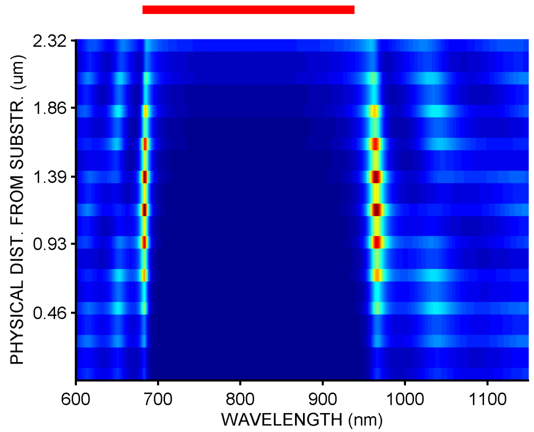


UBCM MIRROR

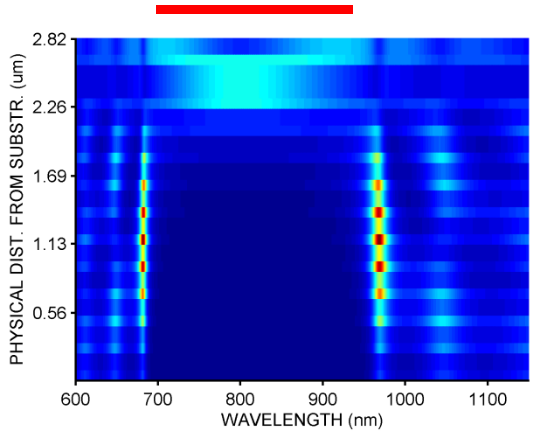
V. Pervak, C. Teisset, A. Sugita, S. Naumov, F. Krausz, A. Apolonski, “High-dispersive mirrors for femtosecond lasers,” Opt. Exp. 16, 10220-10232 (2008).
E.J. Mayer, J. Möbius, A. Euteneuer, W. Rühle, R. Szipőcs, “Ultrabroadband chirped mirrors for femtosecond lasers,” Opt. Lett. 22, 528-530 (1997).

Relation between group delay, energy storage and absorbed/scattered power in highly reflective dispersive dielectric mirror coatings

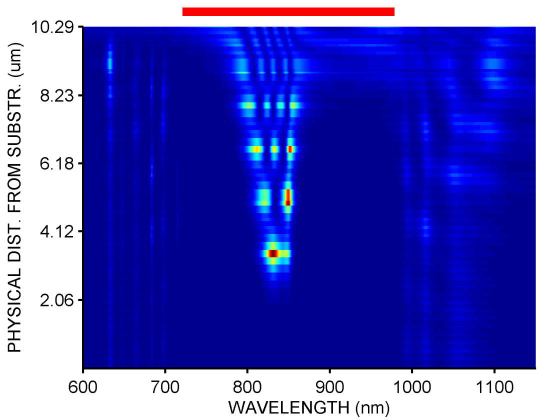
1D NUMERICAL EXAMPLES: THE COMPUTED ENERGY DENSITY FUNCTIONS



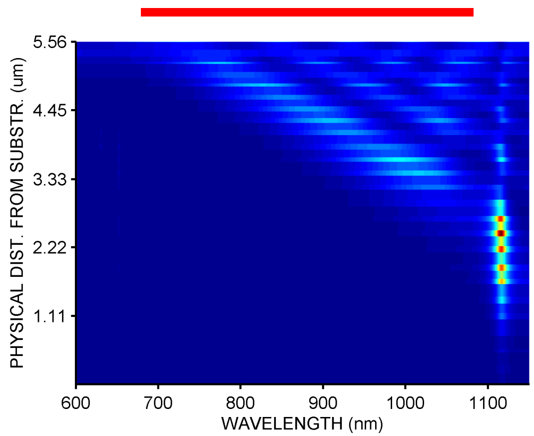
QW STACK



GTI MIRROR



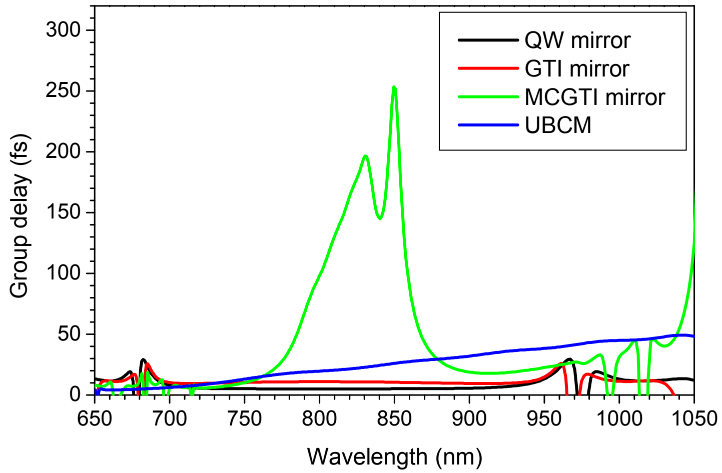
HIGH-DISPERSIVE MCGTI MIRROR

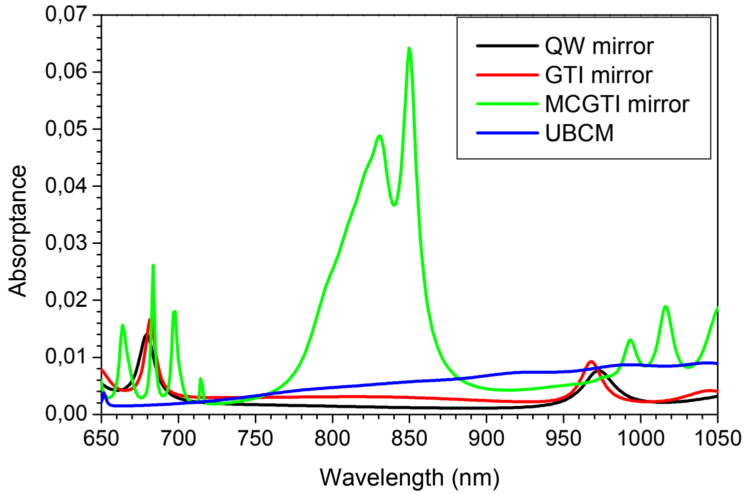


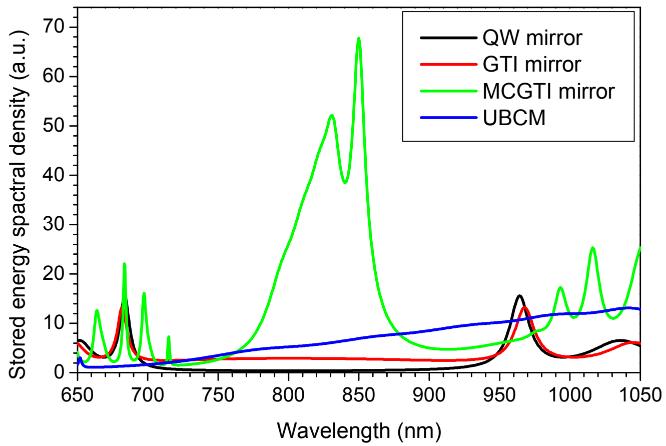
UBCM MIRROR

Relation between group delay, energy storage and absorbed/scattered power in highly reflective dispersive dielectric mirror coatings

1D NUMERICAL RESULTS:
THE COMPUTED GROUP DELAY, ENERGY STORED AND ABSORBED POWER







For computing absorptance, a wavelength independent k = 0.0001 extinction constant was used for both H and L layers.

TWO ORDERS OF MAGNITUDE HIGHER ABSORPTION FOR THE HIGH-DISPERSIVE MCGTI MIRROR STRUCTURE! ☹

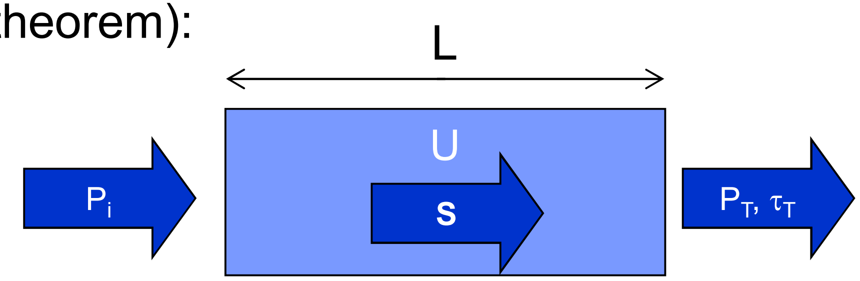
Loss can be reduced by state of the art deposition technologies. ☺

Antal P, Szipőcs R: CHINESE OPTICS LETTERS 10, 053101/1-4 (2012)

THEORY (2D) – OPTICAL FIBERS

- Contiunity of energy flow (Poyting's theorem):

$$-\oint_s S\hat{n}\ \mathrm{da} = \frac{\mathrm{dU}}{\mathrm{dt}}$$



- Stored energy (U) is volume integral of energy density *u(x,y,z)* in the fiber:

$$\mathrm{U} = \iiint u\, dV = \iiint \left(\frac{1}{2}\varepsilon E^2 + \frac{1}{2}\mu H^2\right) dV$$
$$= \frac{L}{2}\iint \left(\varepsilon_o n^2 E^2 + \mu_o H^2\right) dA$$

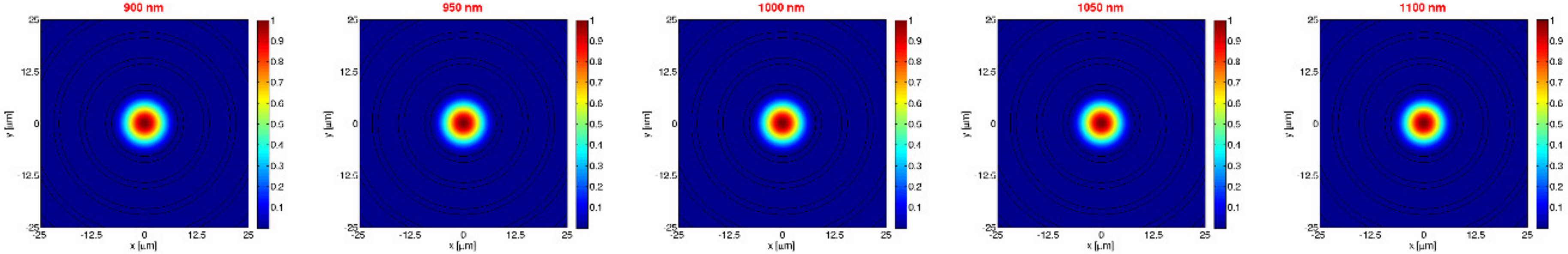
- The group delay (τ) for transmission is computed as

$$\tau = \frac{\mathrm{d}\phi}{\mathrm{d}\omega} = \frac{d}{\mathrm{d}\omega}\left(\frac{\omega \mathrm{L}}{c} n_{\mathrm{eff}}(\omega)\right)$$

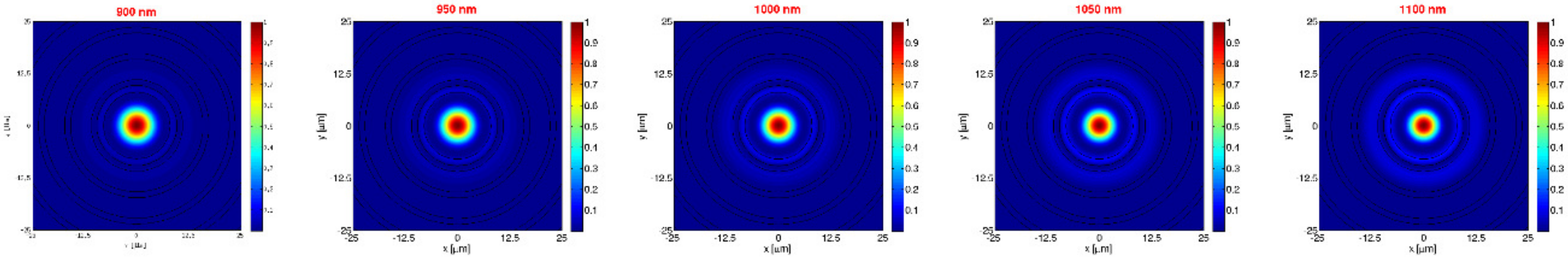
Z. Várallyay, R. Szipőcs *„Stored Energy, Transmission Group Delay and Mode Field Distortion in Optical Fibers,"*
IEEE J.STQE Vol. 20, No. 5, SEPTEMBER/OCTOBER (2014)

NUMERICAL RESULTS – OPTICAL FIBERS

Mode profiles in a regular Bragg structure:

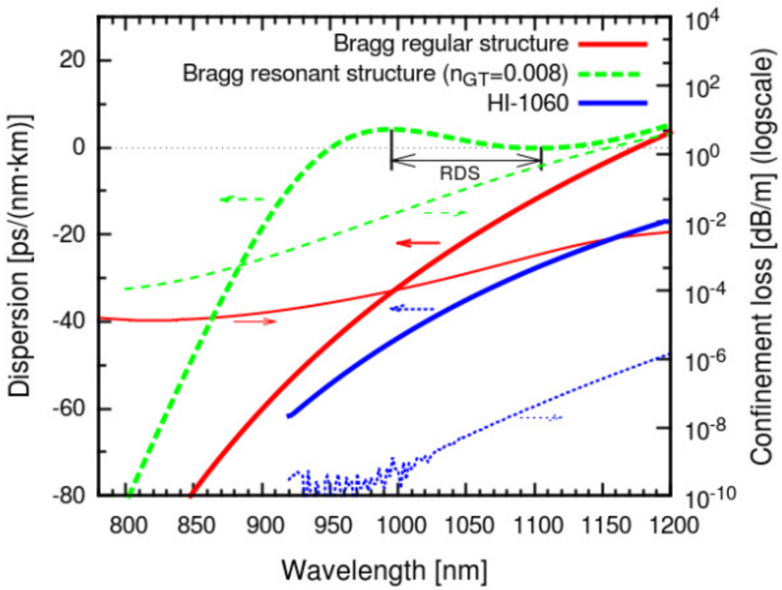


Mode profiles in a Bragg structure having a resonant circular layer around the core with δn_{GT}= 0.008:

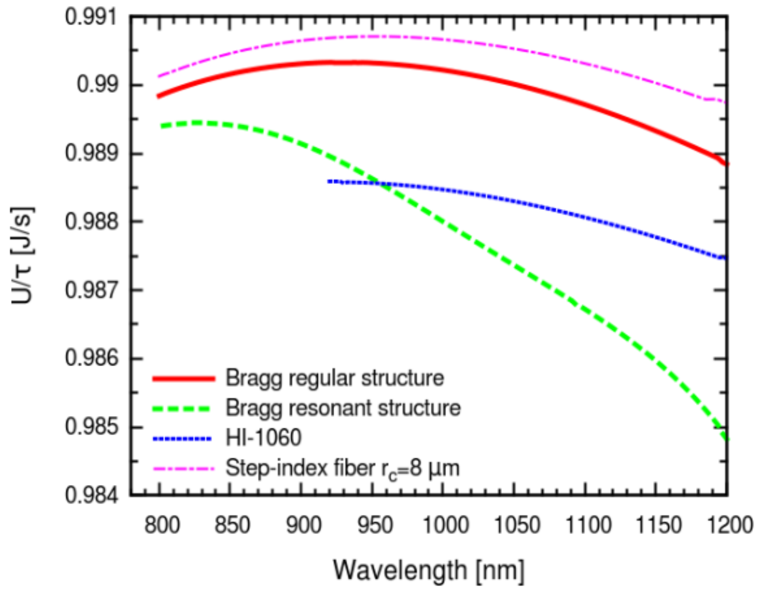


Z. Várallyay, R. Szipőcs *„Stored Energy, Transmission Group Delay and Mode Field Distortion in Optical Fibers,”*
IEEE J.STQE Vol. 20, No. 5, SEPTEMBER/OCTOBER (2014)

NUMERICAL RESULTS – OPTICAL FIBERS



(a)



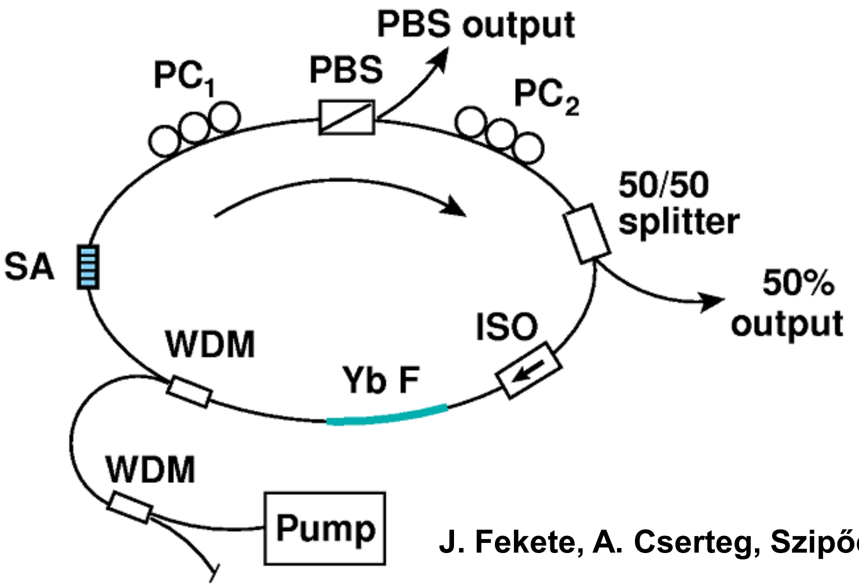
(b)

(a) Computed **dispersion vs. wavelength functions (thick lines), corresponding confinement losses (thin lines) and (b) computed stored energy-group delay ratio (U/τ) vs. wavelength functions** of solid core PBG fibers of two differen designs and of two different index-guiding fibers. One of the index guiding fibers is similar to HI-1060 of Corning, while the second one has an 8 μm core radius. Each fiber has a unit length of 1 m and the incident power is 1W.

Z. Várallyay, R. Szipőcs *„Stored Energy, Transmission Group Delay and Mode Field Distortion in Optical Fibers,”*
IEEE J.STQE Vol. 20, No. 5, SEPTEMBER/OCTOBER (2014)

All-Fiber, All-Normal-Dispersion Ytterbium Ring Oscillator
Pulse dynamics

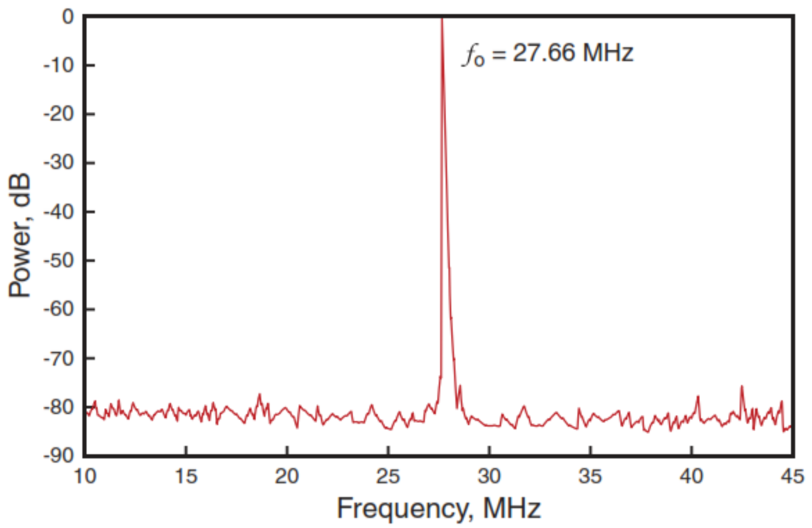
- Determined by interplay between **gain**, **self-phase modulation**, **dispersion** and **filtering** effects
- Pulse shaping is based on **nonlinear polarization rotation** in the fiber together with **spectral and temporal filtering** by a polarizing element



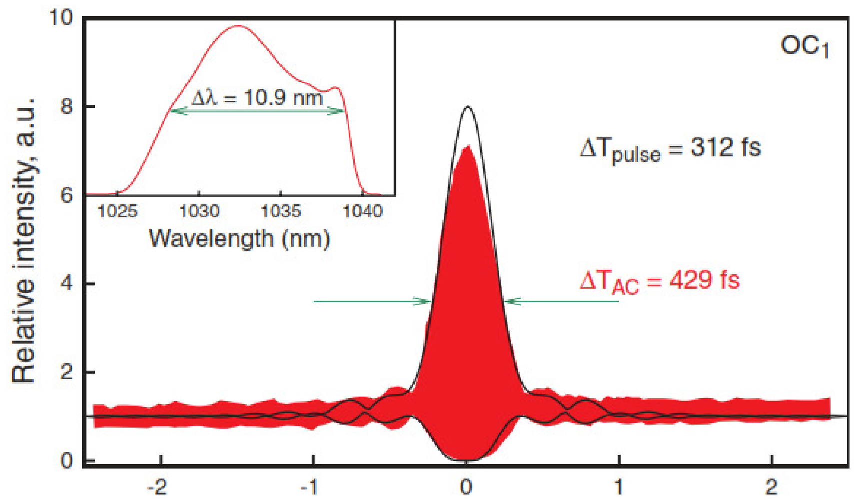
PC: polarization controller
PBS: polarizing beam splitter
ISO: isolator
Yb F: Ytterbium doped fiber
WDM: wavelength division multiplexer
SA: saturable absorber

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

Mode-locking performance



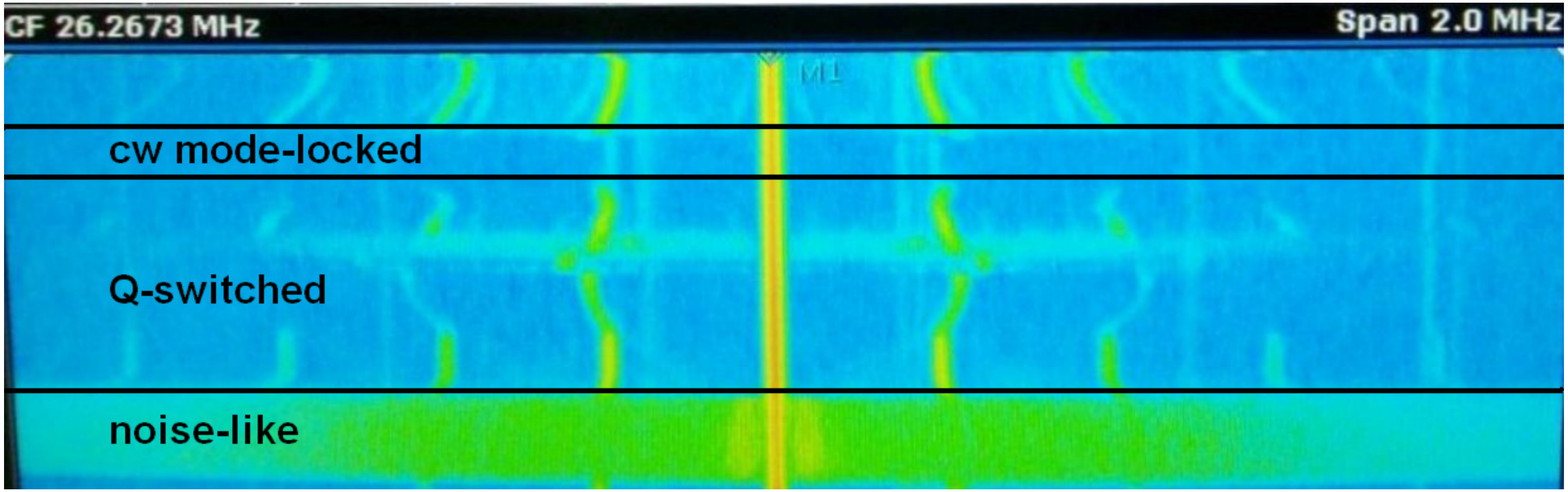
Measured RF spectrum



Measured optical spectrum and AC trace

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

Monitoring mode-locking performance



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

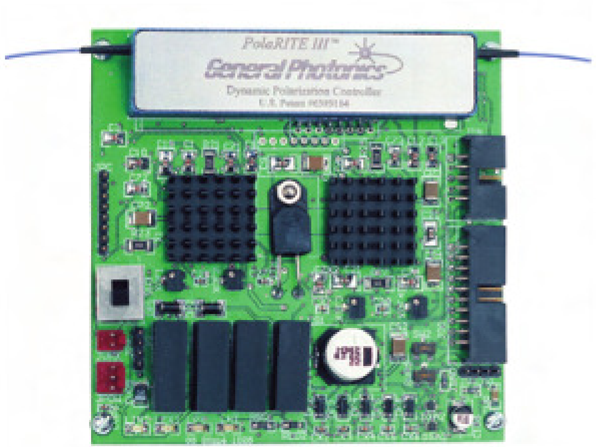
RF spectrum is measured by a radio-frequency spectrum analyser (FSV3, product of Rohde&Schwarz)

- **NOT PRACTICAL FOR A TURN-KEY SYSTEM!**

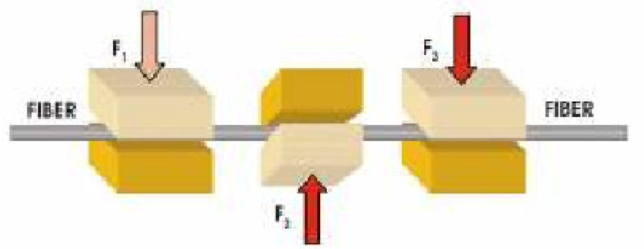
Polarization control by electronics

POLARIZATION MANAGEMENT MODULES

Dynamic Polarization Controller with Miniature Piezo Driver Card



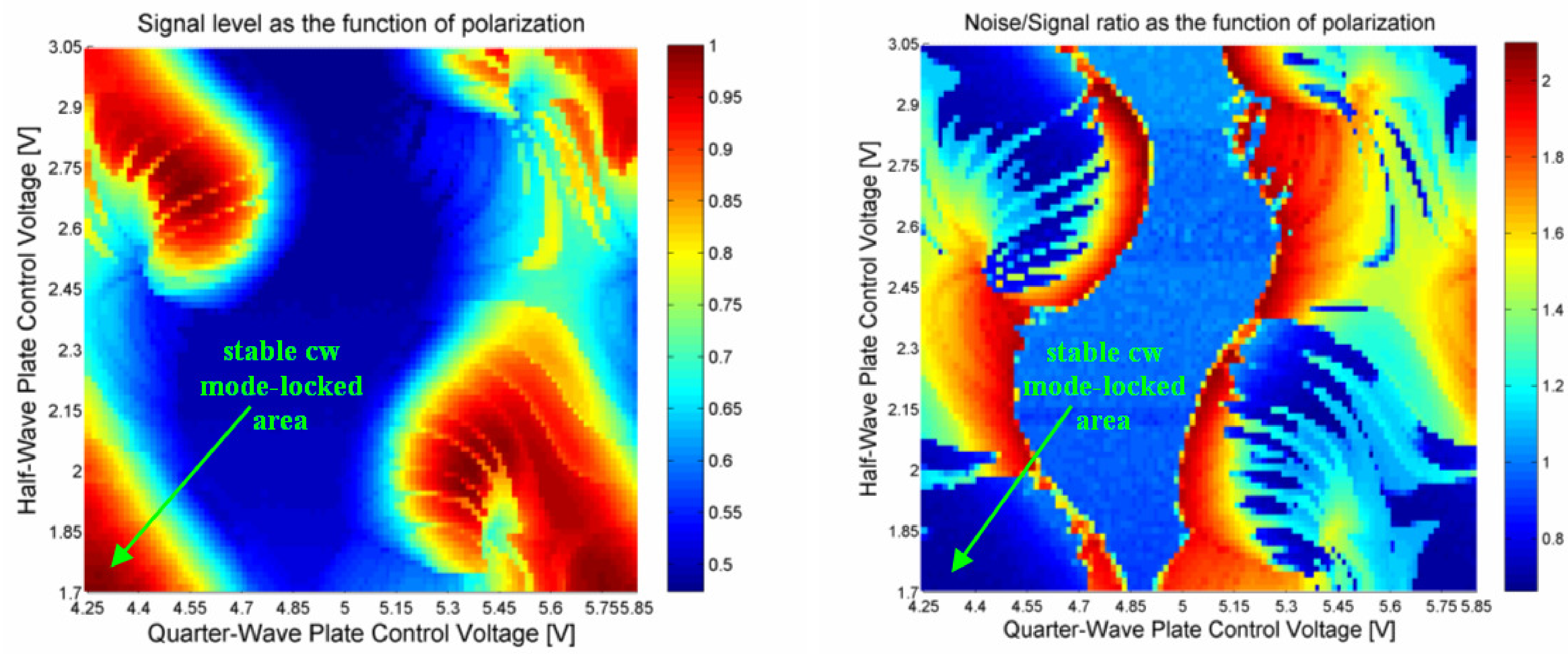
This module integrates a General Photonics all-fiber dynamic polarization controller with an MPD-001 miniature piezo driver card, so that the SOP of the signal can be directly controlled either by a 0-5V analog control signal or a 12-bit TTL digital control signal. Because there is an on-board HV DC/DC 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

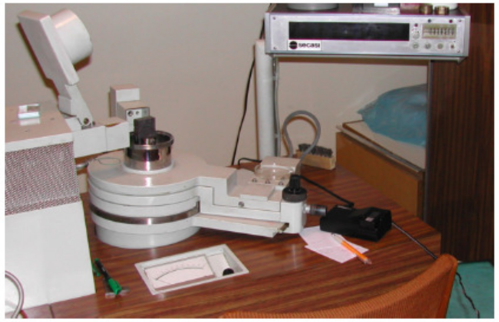
Recording of „stability maps" using SLH circuits

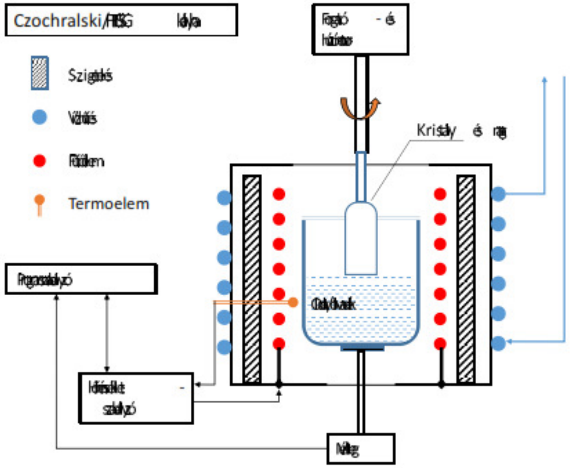


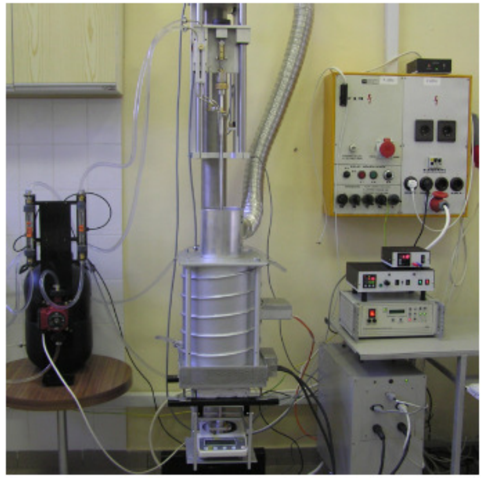
Measured signal power (left) and normalized noise power (right) as the function of control voltage on the polarization controllers.

Crystal grow

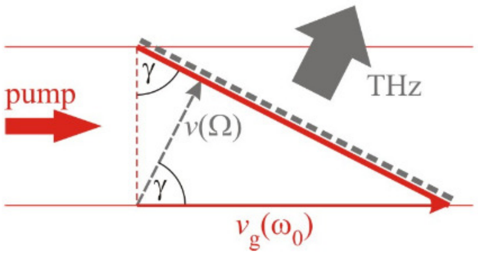
INFRASTRUCTURE



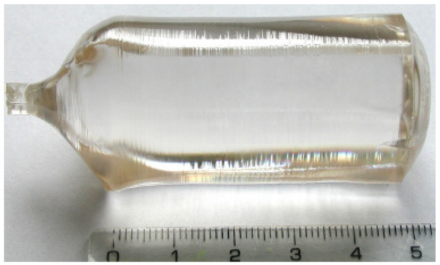




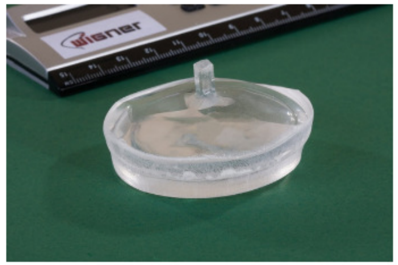
APPLICATIONS



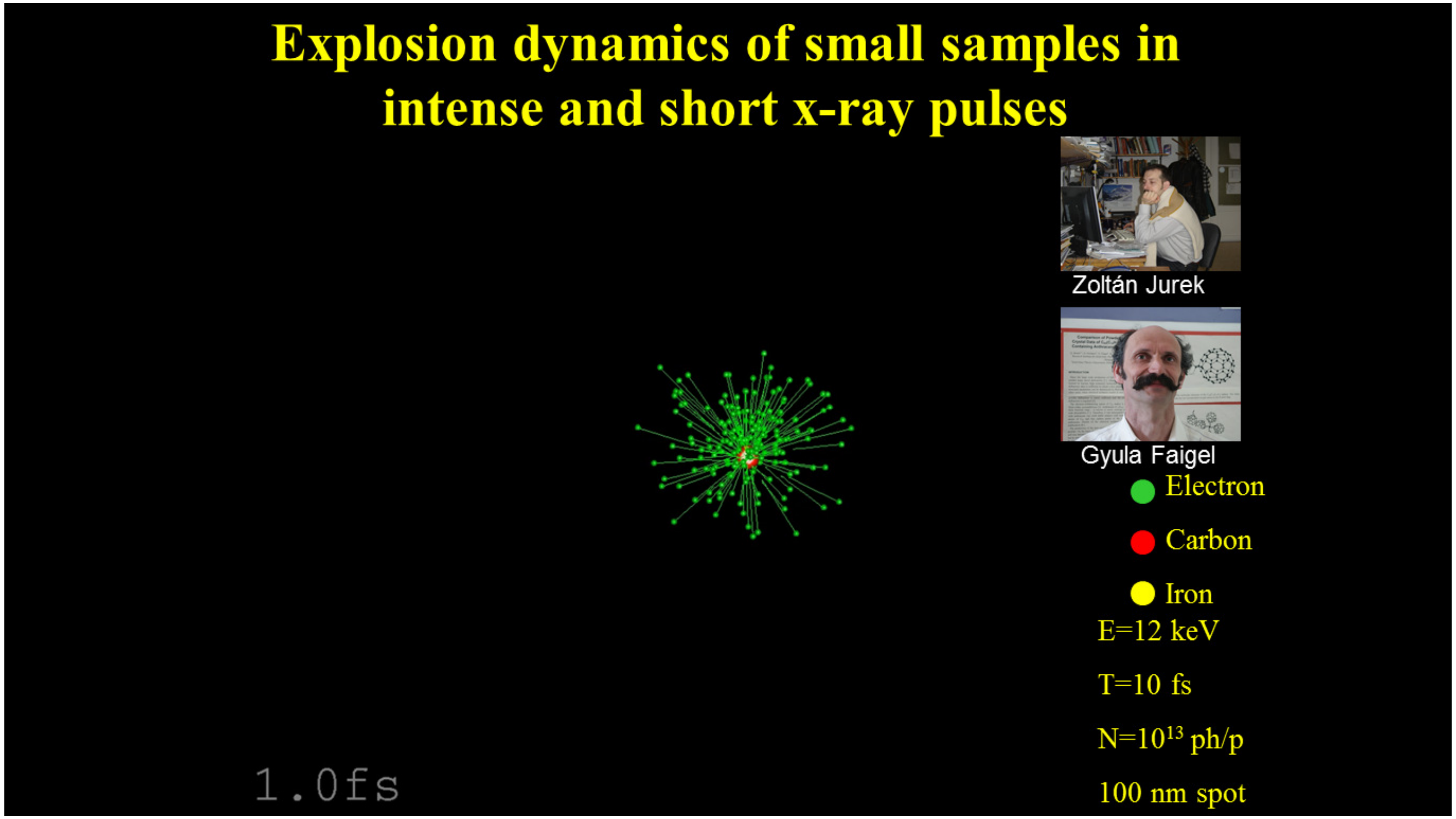
Sztöchiometrikus $LiNbO_3$



β-BaB_2O_4



Explosion dynamics of small samples in intense and short x-ray pulses



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Founded as Stingl OAG in 1994
by Andreas Stingl, Christian Spielmann and Ferenc Krausz

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Founded in 1991 by Kárpát Ferencz and Róbert Szipőcs

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Founded as R&D Lézer-Optika Bt.
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- low disp. hig reflectors (HR)
- low disp. dichroic coatings (input coupler, IC)
- low disp. partial reflectors (output coupler, OC)
- low disp. protected silver mirrors
- low disp. protected thin BBO plates for autocorrelators (from 0.012 mm)
- thin fused silica wedges for dispersion management
- substrate diameters: from 3 mm to 101.6 mm at present
- substrate surface ROC: from +/-25 mm to +/-36000 mm at present

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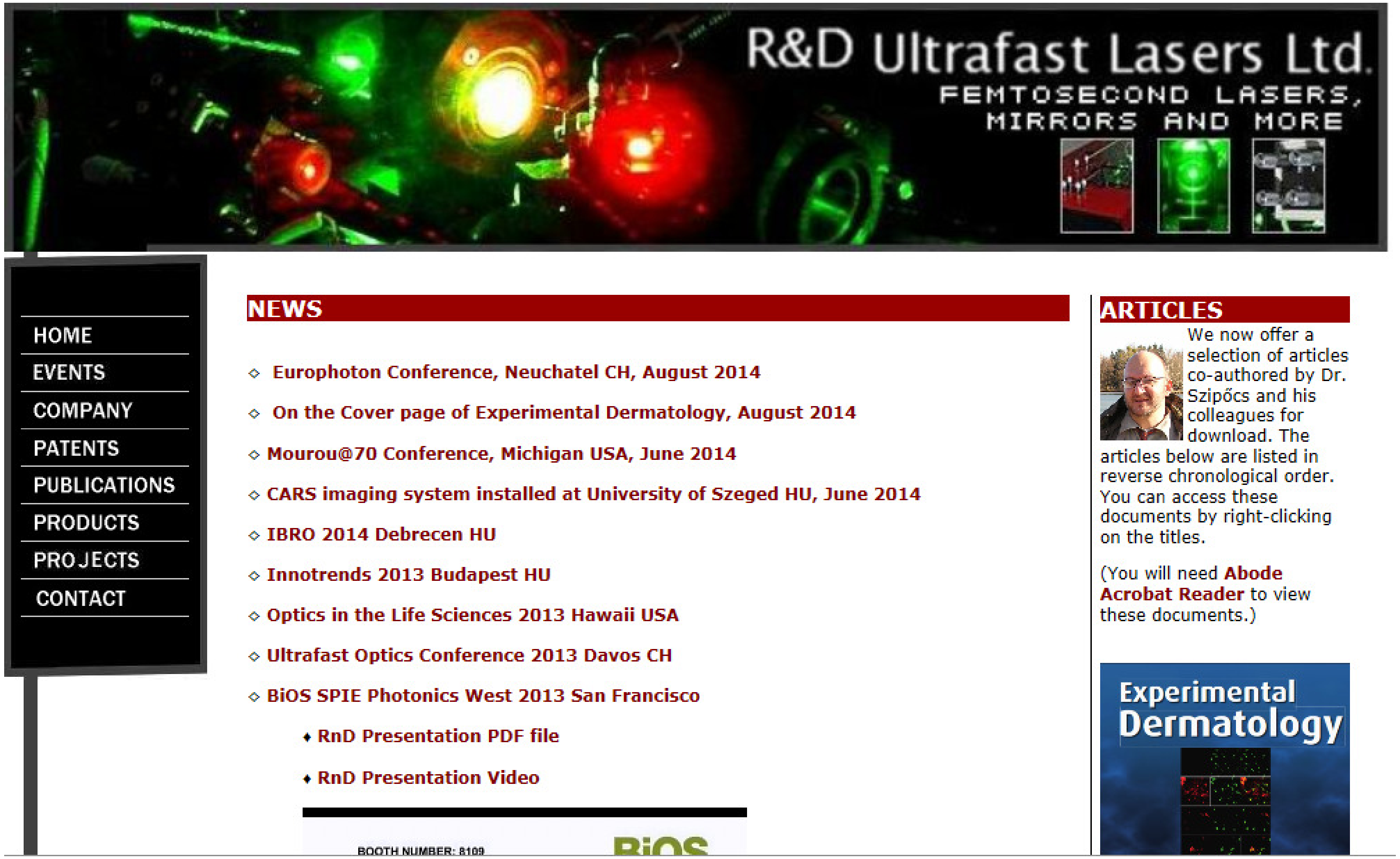

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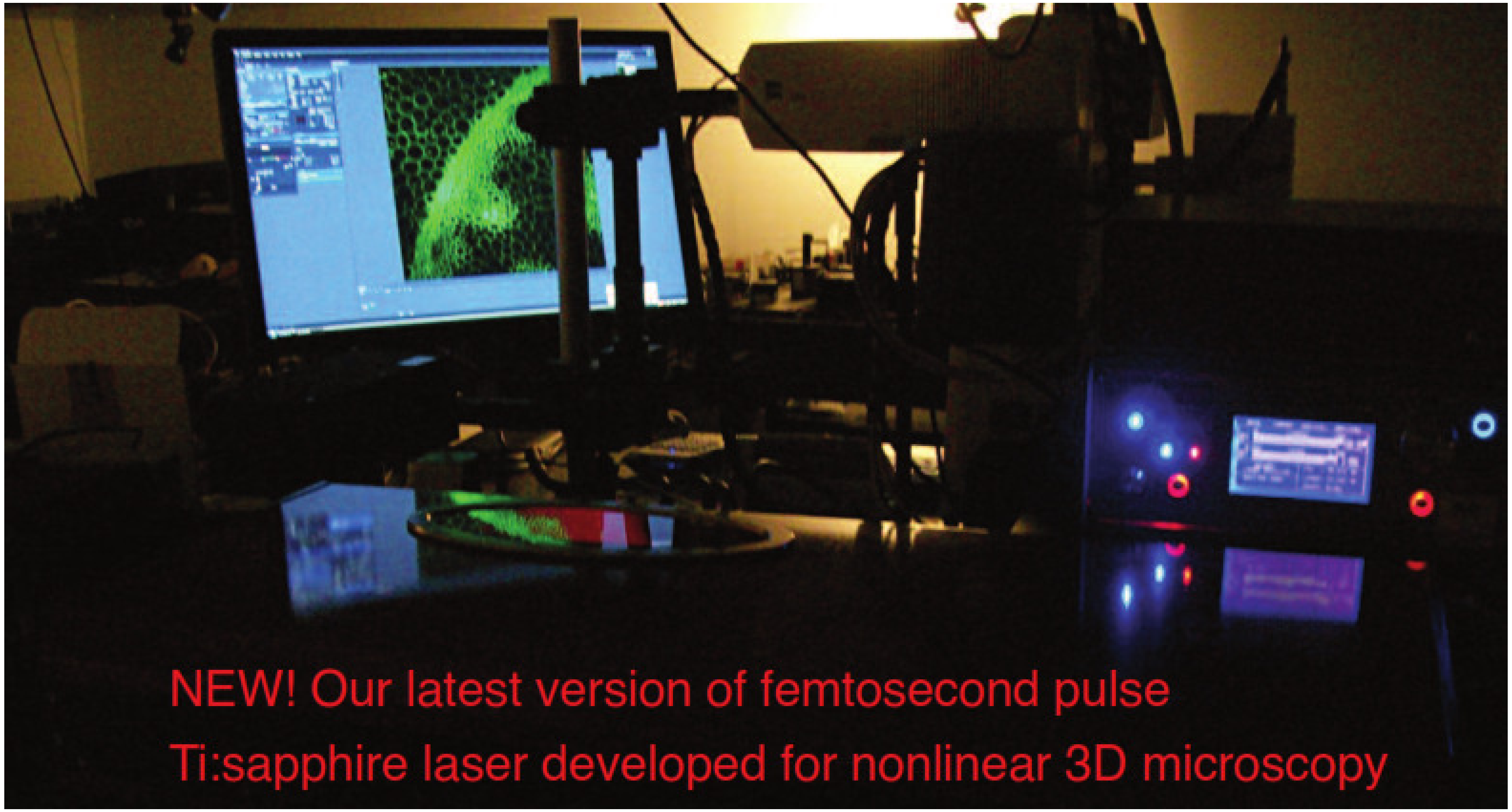

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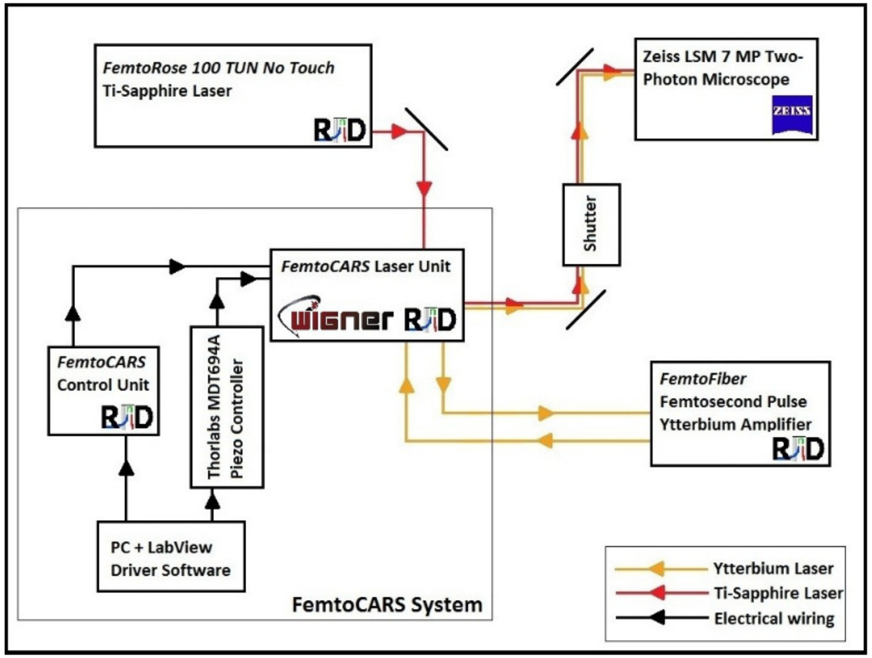
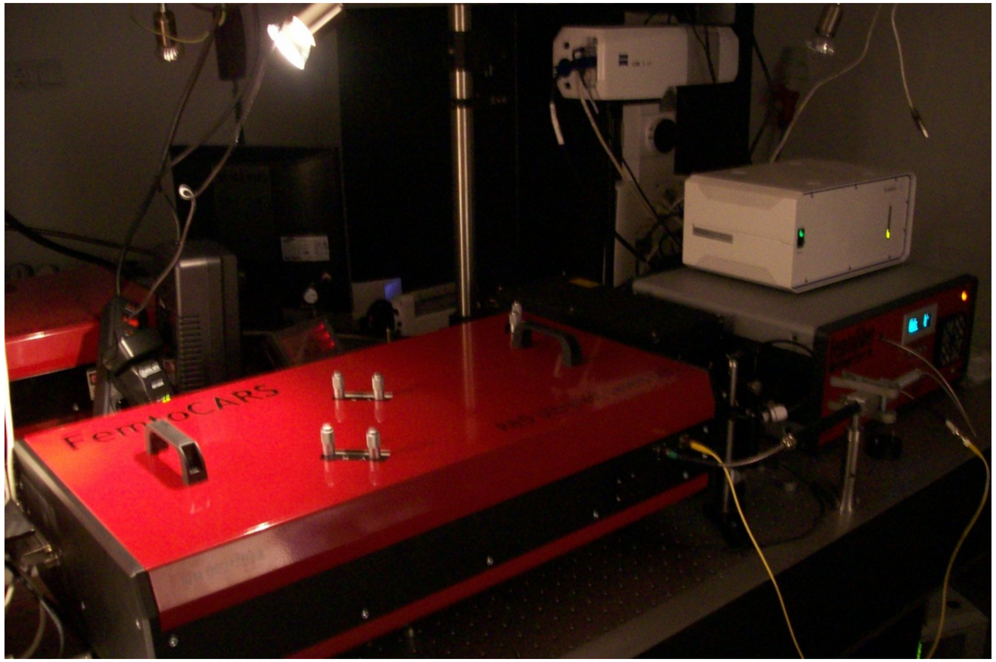
FemtoCARS

the

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





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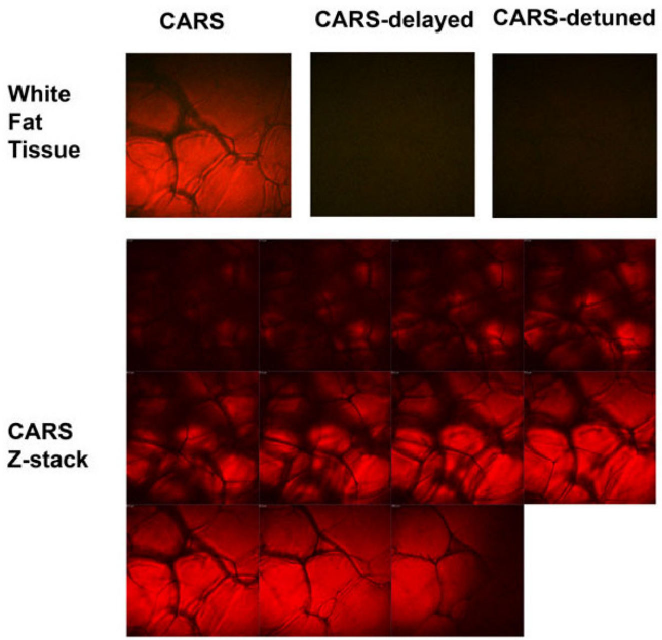

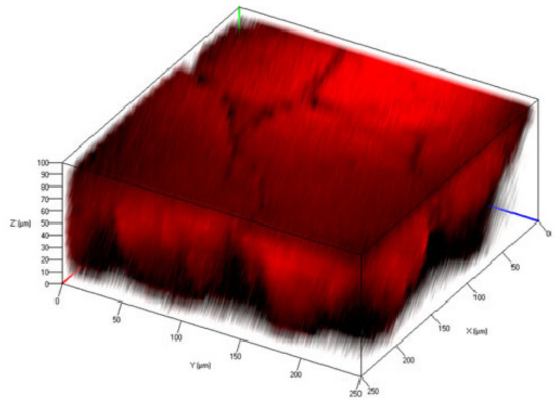

Fig. 3 CARS-images of murine white adipose tissue.

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FUTURE?

THANK YOU!