HUN-REN Wigner Fizikai Kutatóközpont

R&D ULTRAFAST LASERS LTD.

Starting spin off companies in at the Hungarian Academy of Sciences in the 90-es: hand in hands

Róbert Szipőcs, PhD

HUN-REN Wigner RCP / R&D Ultrafast Lasers Kft.

E-mail: szipocs.robert@wigner.hu / r.szipocs@szipocs.com

www.wigner.hu / www.szipocs.com

HEPTECH Board Meeting
Tihany, 30 May, 2024

OUTLINE

1. Background

- Invention of chirped mirrors, patening at MTA SZFKI (inventors: Robert Szipocs, Ferenc Krausz)
- Nobel Prize in Physics in 2023 – chirped mirrors for attosecond pulse generation

2. Founding spin off companies

- Founding spin off companies at MTA SZFKI and TU Wien, Austria (R&D Lézer-Optika Bt., Stingl OAG)
- Application of chirped mirror technology for science (e.g. at MPI Stuttgart, TU Wien, Uni. Groningen)
- Application of chirped mirror technology for industry (e.g. Spectra-Physics, Coherent, FemtoLasers)
- Founding R&D Ultrafast Lasers Ltd (broadly tunable Ti:sapphire lasers and OPO-s for life science)

3. R&D Ultrafast Lasers as an industrian partner of Wigner RCP

- Development of a 20 MHz repetition rate Ti-sapphire laser at MTA SZFI finaced by R&D Ltd.
- FemtoBio project (National Technology Program 2006-2009) with Furukawa Electric (fiber lasers)
- FiberScope project (National Technology Program 2010-2014) with Genetic Imminity (nonlinear microscopy)
- Quantum microscopy (EUREKA Project on Quantum Optics, 2023-2026) with Ulm University (FLIM microscopy)

4. Hand in hands: how technology supports science, how science develops industy

The effect of dispersion in ultrafast laser systems and our solution for the problem

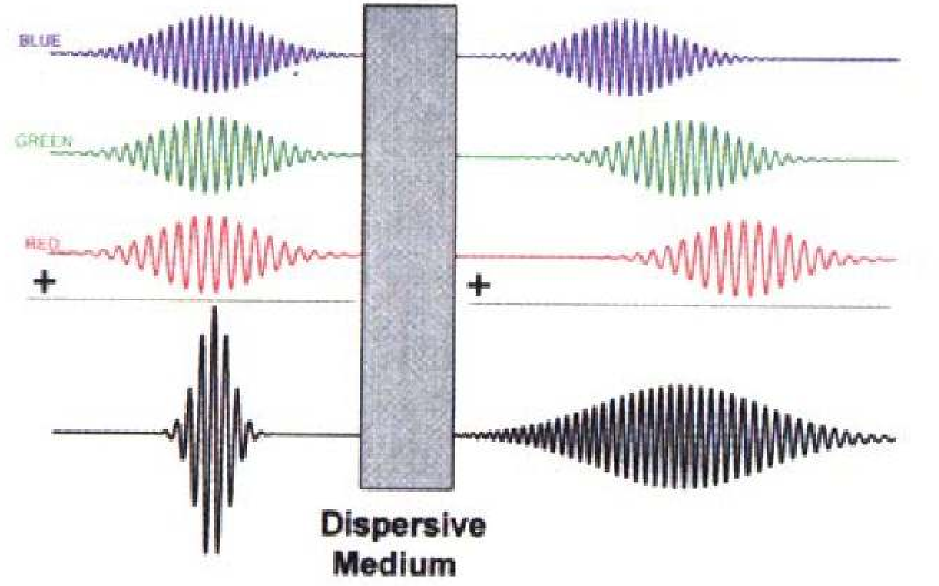
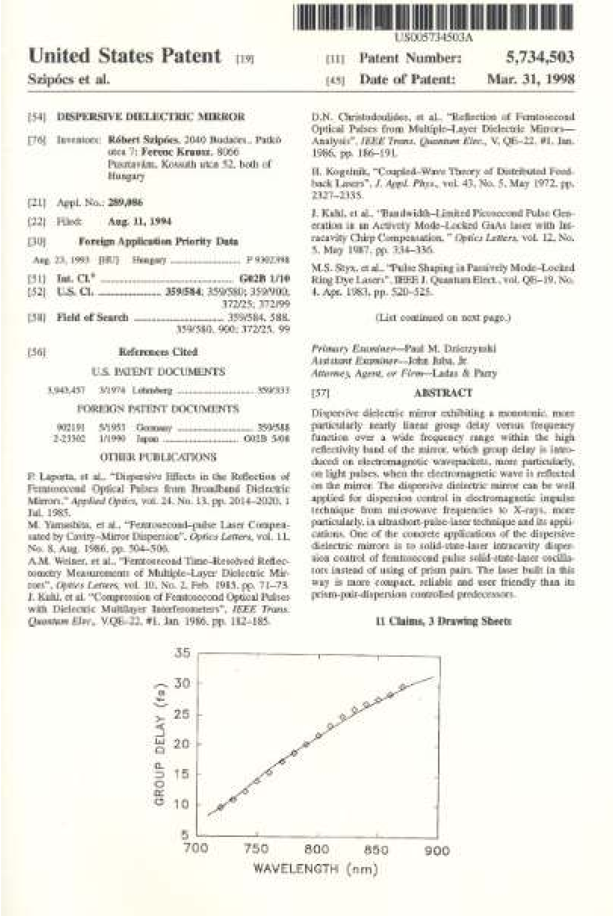


Figure 1. Optical pulse propagation through a dispersive medium: a frequency-dependent group delay leads to a pulse broadening and to a carrier frequency sweep.



US005734503A

United States Patent [19]
Szipőcs et al.

[11] **Patent Number:** **5,734,503**
[45] **Date of Patent:** **Mar. 31, 1998**

[54] **DISPERSIVE DIELECTRIC MIRROR**

[76] Inventors: **Róbert Szipőcs**, 2040 Budaörs, Patkó utca 7; **Ferenc Krausz**, 8066 Pusztavám, Kossuth utca 52, both of Hungary

[21] Appl. No.: **289,086**

[22] Filed: **Aug. 11, 1994**

[30] **Foreign Application Priority Data**

Aug. 23, 1993 [HU] Hungary .... P 9302398

[51] **Int. Cl.⁶** **G02B 1/10**
[52] **U.S. Cl.** **359/584**; 359/580; 359/900; 372/25; 372/99
[58] **Field of Search** 359/584, 588, 359/580, 900; 372/25, 99

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,943,457 3/1974 Lohmberg 359/333

FOREIGN PATENT DOCUMENTS

902191 5/1951 Germany 359/588
2-23302 1/1990 Japan G02B 5/08

OTHER PUBLICATIONS

P. Laporta, et al., "Dispersive Effects in the Reflection of Femtosecond Optical Pulses from Broadband Dielectric Mirrors," *Applied Optics*, vol. 24, No. 13, pp. 2014–2020, 1 Jul. 1985.
M. Yamashita, et al., "Femtosecond-pulse Laser Compensated by Cavity-Mirror Dispersion", *Optics Letters*, vol. 11, No. 8, Aug. 1986, pp. 504–506.
A.M. Weiner, et al., "Femtosecond Time-Resolved Reflectometry Measurements of Multiple-Layer Dielectric Mirrors", *Optics Letters*, vol. 10, No. 2, Feb. 1985, pp. 71–73.
J. Kuhl, et al. "Compression of Femtosecond Optical Pulses with Dielectric Multilayer Interferometers", *IEEE Trans. Quantum Elec.*, V.QE-22, #1, Jan. 1986, pp. 182–185.
D.N. Christodoulides, et al., "Reflection of Femtosecond Optical Pulses from Multiple-Layer Dielectric Mirrors—Analysis", *IEEE Trans. Quantum Elec.*, V, QE-22, #1, Jan. 1986, pp. 186–191.
H. Kogelnik, "Coupled-Wave Theory of Distributed Feedback Lasers", *J. Appl. Phys.*, vol. 43, No. 5, May 1972, pp. 2327–2335.
J. Kuhl, et al., "Bandwidth-Limited Picosecond Pulse Generation in an Actively Mode-Locked GaAs laser with Intracavity Chirp Compensation," *Optics Letters*, vol. 12, No. 5, May 1987, pp. 334–336.
M.S. Stix, et al., "Pulse Shaping in Passively Mode-Locked Ring Dye Lasers", IEEE J. Quantum Elect., vol. QE-19, No. 4, Apr. 1983, pp. 520–525.

(List continued on next page.)

Primary Examiner—Paul M. Dzierzynski
Assistant Examiner—John Juba, Jr.
Attorney, Agent, or Firm—Ladas & Parry

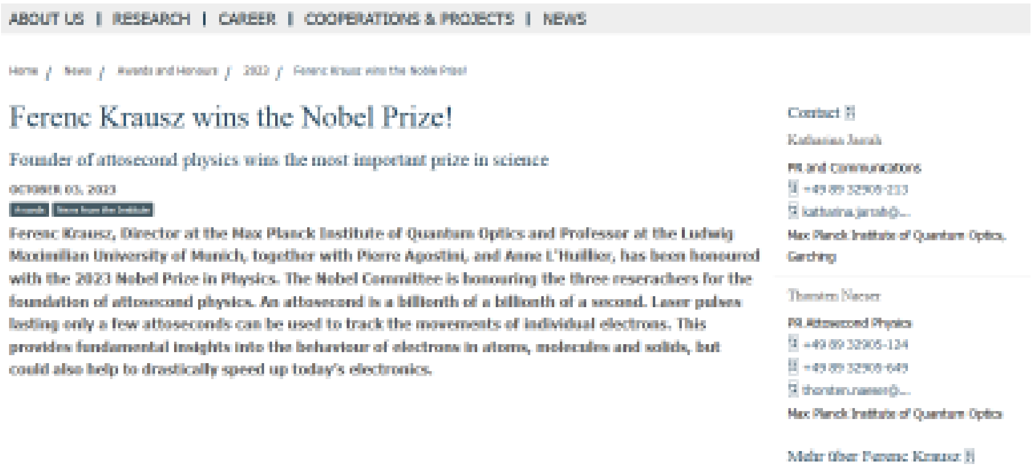
[57] **ABSTRACT**

Dispersive dielectric mirror exhibiting a monotonic, more particularly nearly linear group delay versus frequency function over a wide frequency range within the high reflectivity band of the mirror, which group delay is introduced on electromagnetic wavepackets, more particularly, on light pulses, when the electromagnetic wave is reflected on the mirror. The dispersive dielectric mirror can be well applied for dispersion control in electromagnetic impulse technique from microwave frequencies to X-rays, more particularly, in ultrashort-pulse-laser technique and its applications. One of the concrete applications of the dispersive dielectric mirrors is to solid-state-laser intracavity dispersion control of femtosecond pulse solid-state-laser oscillators instead of using of prism pairs. The laser built in this way is more compact, reliable and user friendly than its prism-pair-dispersion controlled predecessors.

11 Claims, 3 Drawing Sheets

R. Szipőcs, A.Stingl, Ch. Spielmann, and Ferenc Krausz,
"Pushing the Limits of Femtosecond Technology: Chirped Dielectric Mirrors," Optics & Photonics News **6**(6), 16- (1995)
R. Szipőcs, F. Krausz U. S. Pat. No.: 5,734,503

The use of ultrabroadband chirped mirrors for attosecond pulse generation



Ferenc Krausz wins the Nobel Prize!

Founder of attosecond physics wins the most important prize in science

OCTOBER 03, 2023

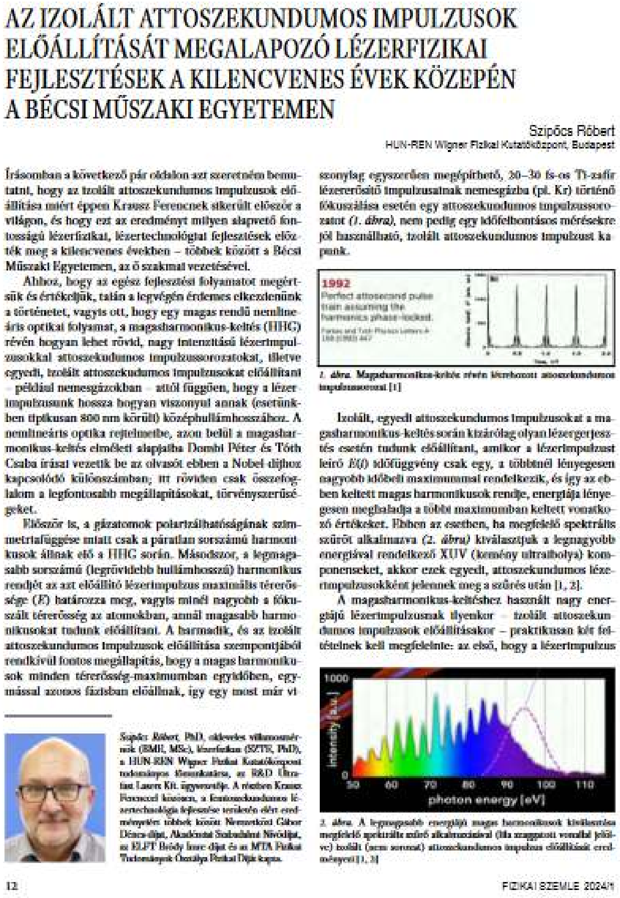
Ferenc Krausz, Director at the Max Planck Institute of Quantum Optics and Professor at the Ludwig Maximilian University of Munich, together with Pierre Agostini, and Anne L'Huillier, has been honoured with the 2023 Nobel Prize in Physics. The Nobel Committee is honouring the three reserachers for the foundation of attosecond physics. An attosecond is a billionth of a billionth of a second. Laser pulses lasting only a few attoseconds can be used to track the movements of individual electrons. This provides fundamental insights into the behaviour of electrons in atoms, molecules and solids, but could also help to drastically speed up today's electronics.

Contact

Katharina Jarrah
PR and Communications
+49 89 32905-213
katharina.jarrah@...
Max Planck Institute of Quantum Optics, Garching

Thorsten Naeser
PR Attosecond Physics
+49 89 32905-124
+49 89 32905-649
thorsten.naeser@...
Max Planck Institute of Quantum Optics

Mehr über Ferenc Krausz



AZ IZOLÁLT ATTOSZEKUNDUMOS IMPULZUSOK ELŐÁLLÍTÁSÁT MEGALAPOZÓ LÉZERFIZIKAI FEJLESZTÉSEK A KILENCVENES ÉVEK KÖZEPÉN A BÉCSI MŰSZAKI EGYETEMEN

Szipőcs Róbert
HUN-REN Wigner Fizikai Kutatóközpont, Budapest

Írásomban a következő pár oldalon azt szeretném bemutatni, hogy az izolált attoszekundumos impulzusok előállítása miért éppen Krausz Ferencnek sikerült először a világon, és hogy ezt az eredményt milyen alapvető fontosságú lézerfizikai, lézertechnológiai fejlesztések előzték meg a kilencvenes években – többek között a Bécsi Műszaki Egyetemen, az ő szakmai vezetésével.

Ahhoz, hogy az egész fejlesztési folyamatot megértsük és értékeljük, talán a legvégén érdemes elkezdenünk a történetet, vagyis ott, hogy egy magas rendű nemlineáris optikai folyamat, a magasharmonikus-keltés (HHG) révén hogyan lehet rövid, nagy intenzitású lézerimpulzusokkal attoszekundumos impulzussorozatokat, illetve egyedi, izolált attoszekundumos impulzusokat előállítani – például nemesgázokban – attól függően, hogy a lézerimpulzusunk hossza hogyan viszonyul annak (esetünkben tipikusan 800 nm körüli) középhullámhosszához. A nemlineáris optika rejtelmeibe, azon belül a magasharmonikus-keltés elméleti alapjaiba Dombi Péter és Tóth Csaba írásai vezetik be az olvasót ebben a Nobel-díjhoz kapcsolódó különszámban; itt röviden csak összefoglalom a legfontosabb megállapításokat, törvényszerűségeket.

Először is, a gázatomok polarizálhatóságának szimmetriafüggése miatt csak a páratlan sorszámú harmonikusok állnak elő a HHG során. Másodszor, a legmagasabb sorszámú (legrövidebb hullámhosszú) harmonikus rendjét az azt előállító lézerimpulzus maximális térerőssége (E) határozza meg, vagyis minél nagyobb a fókuszált térerősség az atomokban, annál magasabb harmonikusokat tudunk előállítani. A harmadik, és az izolált attoszekundumos impulzusok előállítása szempontjából rendkívül fontos megállapítás, hogy a magas harmonikusok minden térerősség-maximumban egyidőben, egymással azonos fázisban előállnak, így egy most már viszonylag egyszerűen megépíthető, 20–30 fs-os Ti-zafír lézererősítő impulzusainak nemesgázba (pl. Kr) történő fókuszálása esetén egy attoszekundumos impulzussorozatot (*1. ábra*), nem pedig egy időfelbontásos mérésekre jól használható, izolált attoszekundumos impulzust kapunk.

1. ábra. Magasharmonikus-keltés révén létrehozott attoszekundumos impulzussorozat [1]

Izolált, egyedi attoszekundumos impulzusokat a magasharmonikus-keltés során kizárólag olyan lézergerjesztés esetén tudunk előállítani, amikor a lézerimpulzust leíró $E(t)$ időfüggvény csak egy, a többinél lényegesen nagyobb időbeli maximummal rendelkezik, és így az ebben keltett magas harmonikusok rendje, energiája lényegesen meghaladja a többi maximumban keltett vonatkozó értékeket. Ebben az esetben, ha megfelelő spektrális szűrőt alkalmazva (*2. ábra*) kiválasztjuk a legnagyobb energiával rendelkező XUV (kemény ultraibolya) komponenseket, akkor ezek egyedi, attoszekundumos lézerimpulzusokként jelennek meg a szűrés után [1, 2].

A magasharmonikus-keltéshez használt nagy energiájú lézerimpulzusnak ilyenkor – izolált attoszekundumos impulzusok előállításakor – praktikusan két feltételnek kell megfelelnie: az első, hogy a lézerimpulzus

Szipőcs Róbert, PhD, okleveles villamosmérnök (BME, MSc), lézerfizikus (SZTE, PhD), a HUN-REN Wigner Fizikai Kutatóközpont tudományos főmunkatársa, az R&D Ultrafast Lasers Kft. ügyvezetője. A részben Krausz Ferenccel közösen, a femtoszekundumos lézertechnológia fejlesztése területén elért eredményeiért többek között Nemzetközi Gábor Dénes-díjat, Akadémiai Szabadalmi Nívódíjat, az ELFT Bródy Imre díjat és az MTA Fizikai Tudományok Osztálya Fizikai Díját kapta.

2. ábra. A legnagyobb energiájú magas harmonikusok kiválasztása megfelelő spektrális szűrő alkalmazásával (lila szaggatott vonallal jelölve) izolált (nem sorozat) attoszekundumos impulzus előállítását eredményezi [1, 3]

12 FIZIKAI SZEMLE 2024/1

In 2001, Ferenc Krausz generated light pulses in the attosecond range (1 attosecond = 10-18 seconds) for the first time. Their use for observing electron movements in atoms was honoured by Nature and Science as one of the 10 most important scientific achievements of 2002.

The basis for this was laid by Ferenc Krausz and his compatriot Robert Szipöcs with the development of mirrors with which extremely intense laser pulses can be generated from a few oscillations of a light wave. In 2002, Ferenc Krausz and Theodor Hänsch, who is also director at the Max Planck Institute of Quantum Optics and professor at the LMU, succeeded in controlling not only the intensity of light pulses but also the phase, i.e. the exact course of a light wave, using the Ted Hänsch's frequency comb technique, which also won a Nobel Prize - in 2005.

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

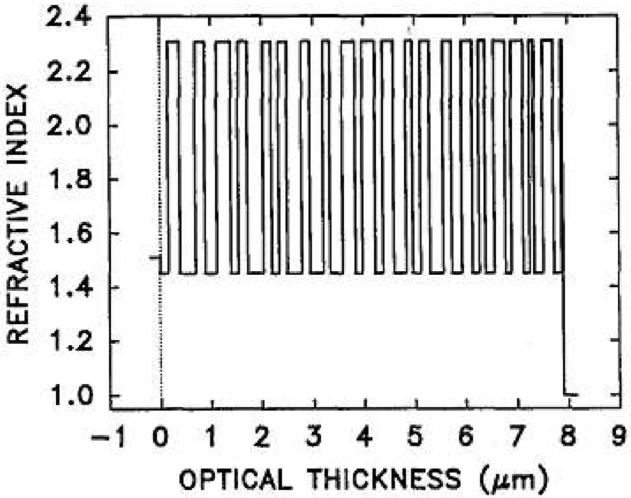


Fig. 1. Theoretical refractive-index profile of a high-reflectivity TiO_2-SiO_2 multilayer coating designed specifically for broadband GDD control in femtosecond lasers.

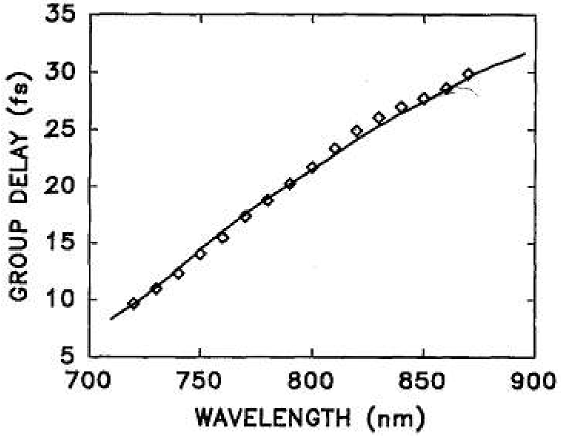


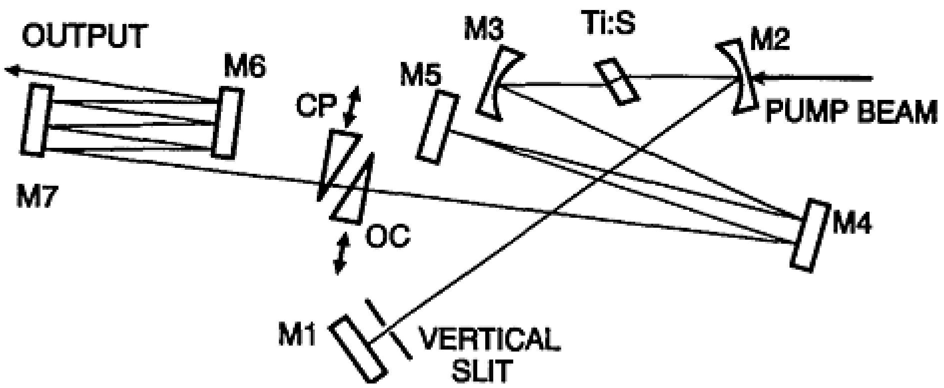
Fig. 3. Computed group delay as a function of wavelength (solid curve) together with experimental data (squares) for the multilayer design of Fig. 1. Note that the absolute delay could not be measured; therefore a wavelength-independent constant delay was added to the measured relative data.

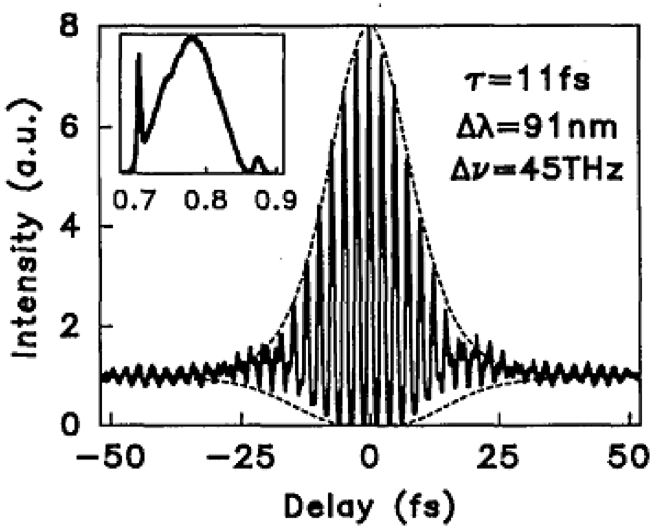
R. Szipőcs, K. Ferencz, Ch. Spielmann, F. Krausz, *Opt. Lett*. 19, pp. 201-203 (1994)

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

MIRROR DISPERSION CONTROLLED Ti:SAPPHIRE LASER

Founding Stingl OAG in Vienna by Ferenc Krausz





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)

Development of a Ti:sapphire oscillator + CPA system at TU Wien using chirped mirrors for generating sub-mJ, ~18 fs pulses for pulse compression in a hollow fibre filled with noble gases (Ar/Kr)

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. Szipőcs, and K. Ferencz

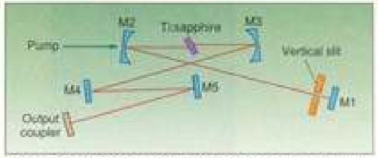


FIGURE 1. Femtosecond Ti:sapphire laser uses chirped dispersive mirrors (M1–M5) for intracavity dispersion compensation.

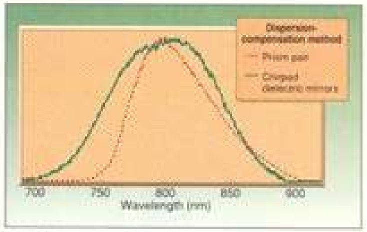


FIGURE 3. Comparison of spectra from prism-controlled and chirped-mirror Ti:sapphire oscillators reveals enhanced performance of chirped-mirror system, which yields a more symmetric pulse.

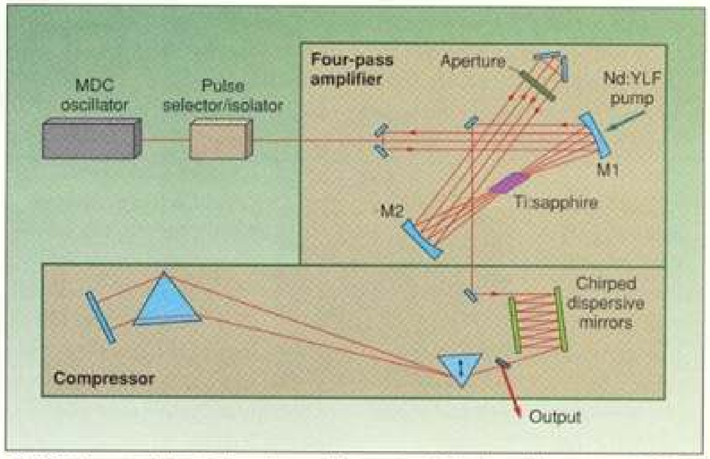
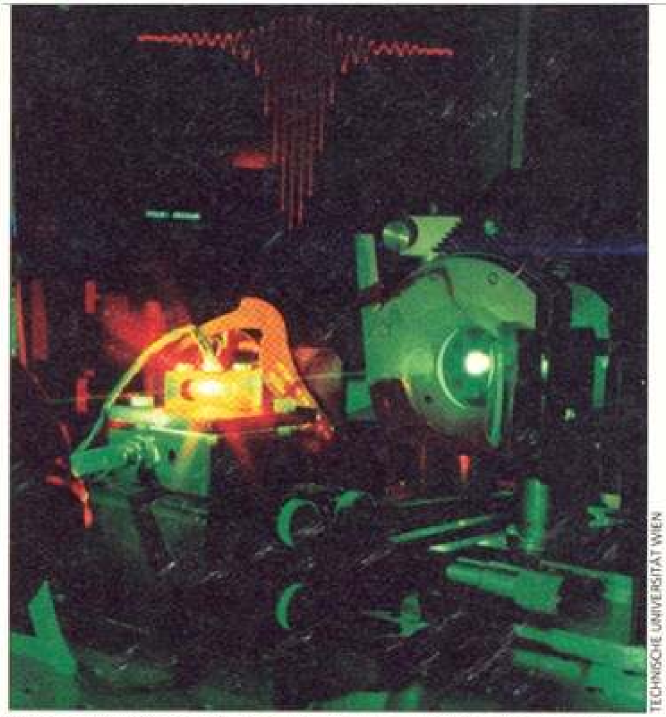


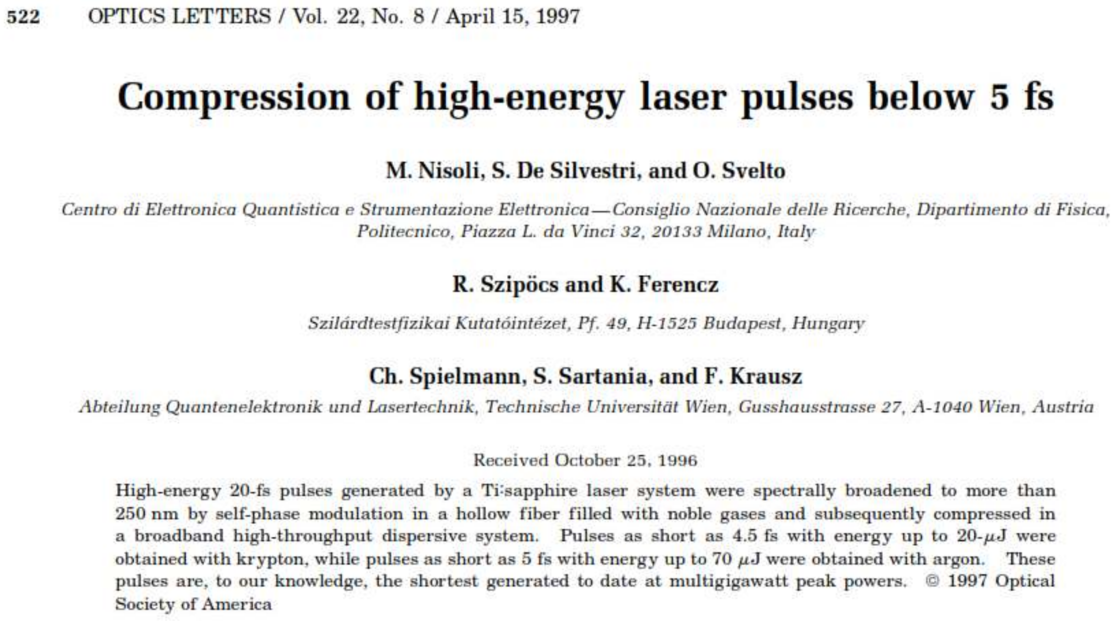
FIGURE 4. Four-pass kilohertz Ti:sapphire amplifier produces 18-fs pulses with an energy of 100 μJ (after compression) when pumped with 6-mJ pulses from a frequency-doubled Nd:YLF laser.



TECHNISCHE UNIVERSITÄT WIEN

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, M. Lenzner, F. Krausz, R. Szipőcs, K. Ferencz,
„Chirped dielectric mirrors improve Ti:sapphire lasers," Laser Focus World, 1995 December, pp. 55-60 (1995).



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-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

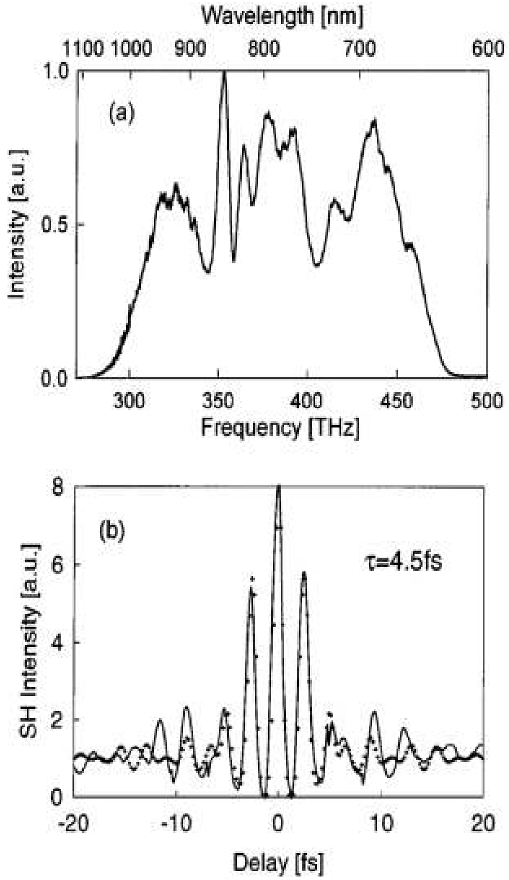
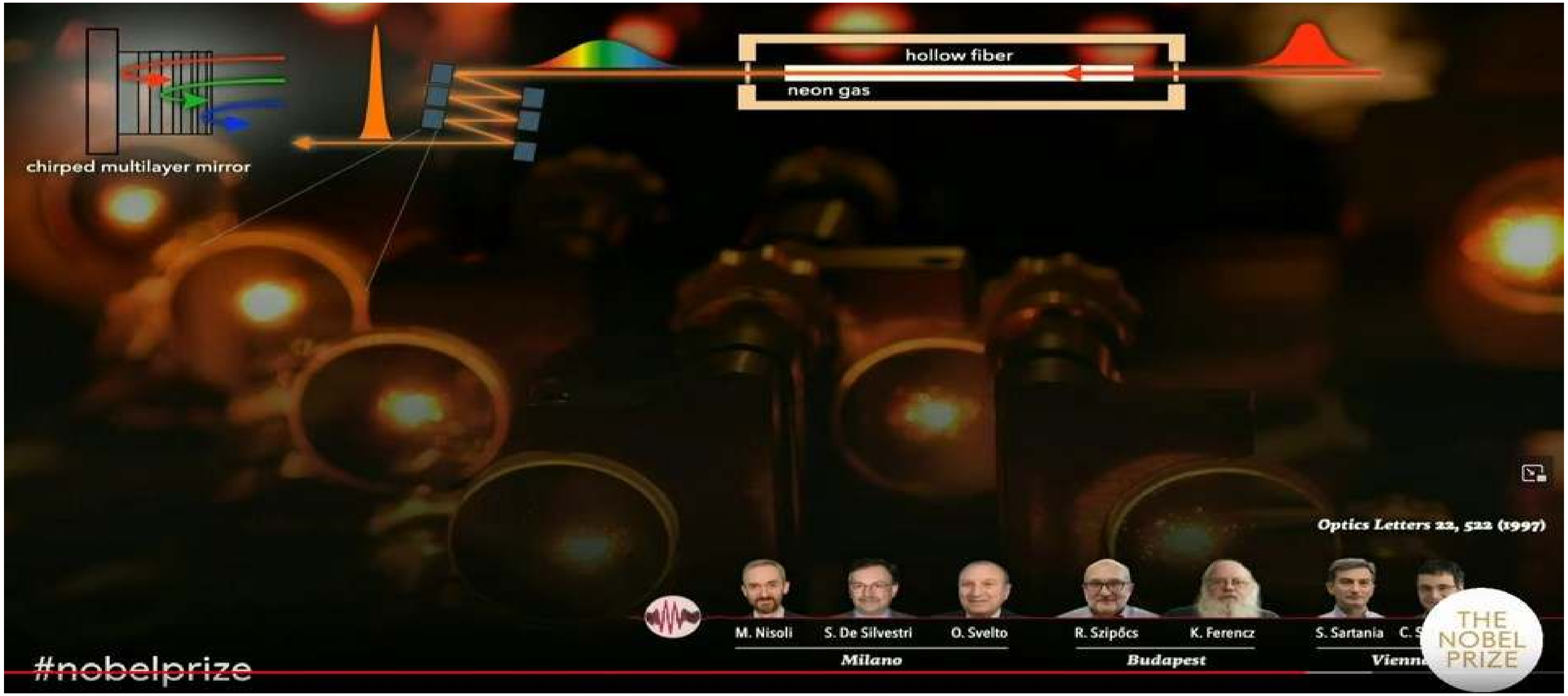


Fig. 2. (a) Spectral broadening in krypton at $p = 2.1$ bars and $P_0 = 2$ GW. A low-intensity pedestal (~1% of the peak) extends below 600 nm. (b) Measured (solid curve) and calculated (crosses) autocorrelation trace; an evaluation of the pulse duration (FWHM) is also given.

- Spectral broadening in hollow core fibre filled with noble gas (Ar/Kr)
  (M. Nisoli, S. De Silvestri, O. Svelto, Appl. Phys. Lett. 68, 2793 (1996))
- Dispersion compensation by ultrabroadband chirped mirror
  (E.J. Mayer, J. Möbius, A. Euteneuer, W.W. Rühle, R. Szipőcs: Opt. Lett. 22, 528 (1997))
- Compressed pulse duration ~5 fs at ~800 nm
- ~1.5 oscillation of elecromagnetic field > allows generation of **isolated attosecond pulses** by high harmonic generation (HHG)

Generating isolated attosecond pulses by HHG of a sub-mJ, 5 fs pulse



Generetion of **~5 fs, sub-mJ laser pulses** using **spectral broadening** of ~18 fs amplified laser pulses in a noble gas filled hollow core fiber and **chirped mirrors for dispersion compensation**

2023 Nobel Prize lectures in physics, Pierre Agostini, Ferenc Krausz and Anne L'Huillier, https://www.youtube.com/watch?v=xVXjFBW-2kI

M. Nisoli, S. De Silvestri, O. Svelto, R. Szipőcs, K. Ferencz, Ch. Spielmann, S. Sartania, and F. Krausz, "Compression of high-energy laser pulses below 5 fs," Opt. Lett. 22, 522-524 (1997)

HUN-REN Wigner Fizikai Kutatóközpont

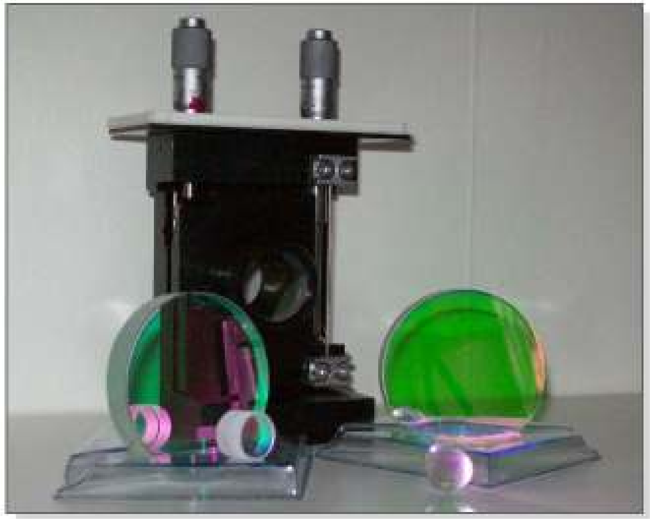
OPTICS

Pioneering Ultrafast LaserTechnology by R&D

INVENTING CHIRPED MIRRORS

Femtosecond Dispersive
and Broadband Optics by IBS technology

Patents

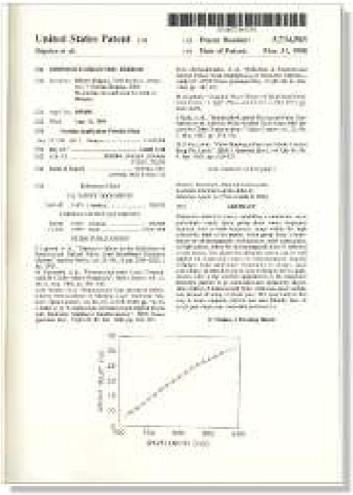


SZABADALMI OKIRAT

The United States of America

The Commissioner of Patents and Trademarks

United States Patent



United States Patent

Founding R&D Lézer-Optika Bt. in 1995 for commercalization of chirped mirror technology

Related patent submitted in August 1993 by Róbert Szipőcs and Ferenc Krausz at MTA SZFKI

Femtosecond Dispersive and Broadband Optics by IBS technology

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

DISPERSIVE MIRRORS, CHARACTERIZATION: WHITE LIGHT INTERFEROMETRY AND CCD

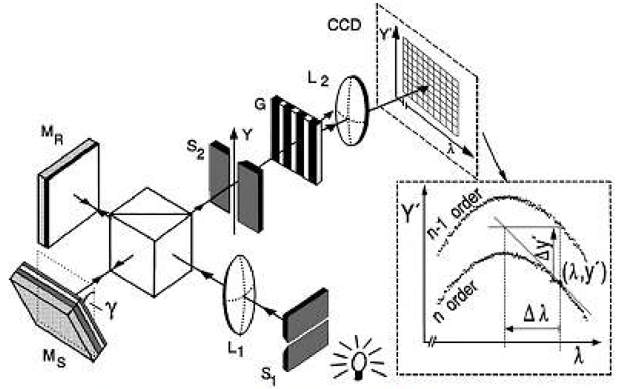
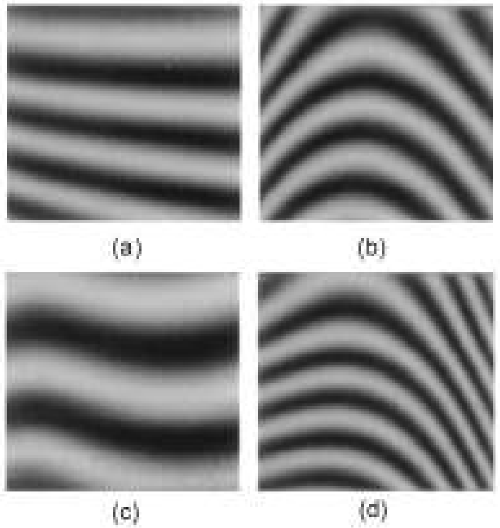


Fig. 1. Spectrally resolved white-light interferometer for group-delay measurement of dielectric mirrors. L$_1$, L$_2$, achromatic lenses; S$_1$, S$_2$, slits; M$_S$, sample mirror; M$_R$, reference mirror; G, transmission grating.



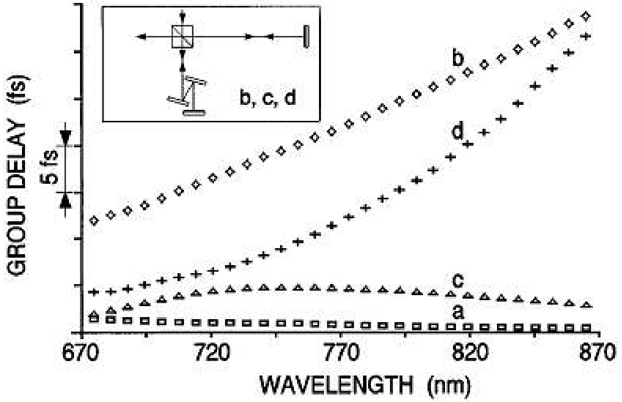


Fig. 4. Measured group-delay functions obtained by computer processing of the images shown in Fig. 3 (every fifth point is plotted). The curves correspond to a single reflection. Inset: four-reflection arrangement used for measuring curves b–d.

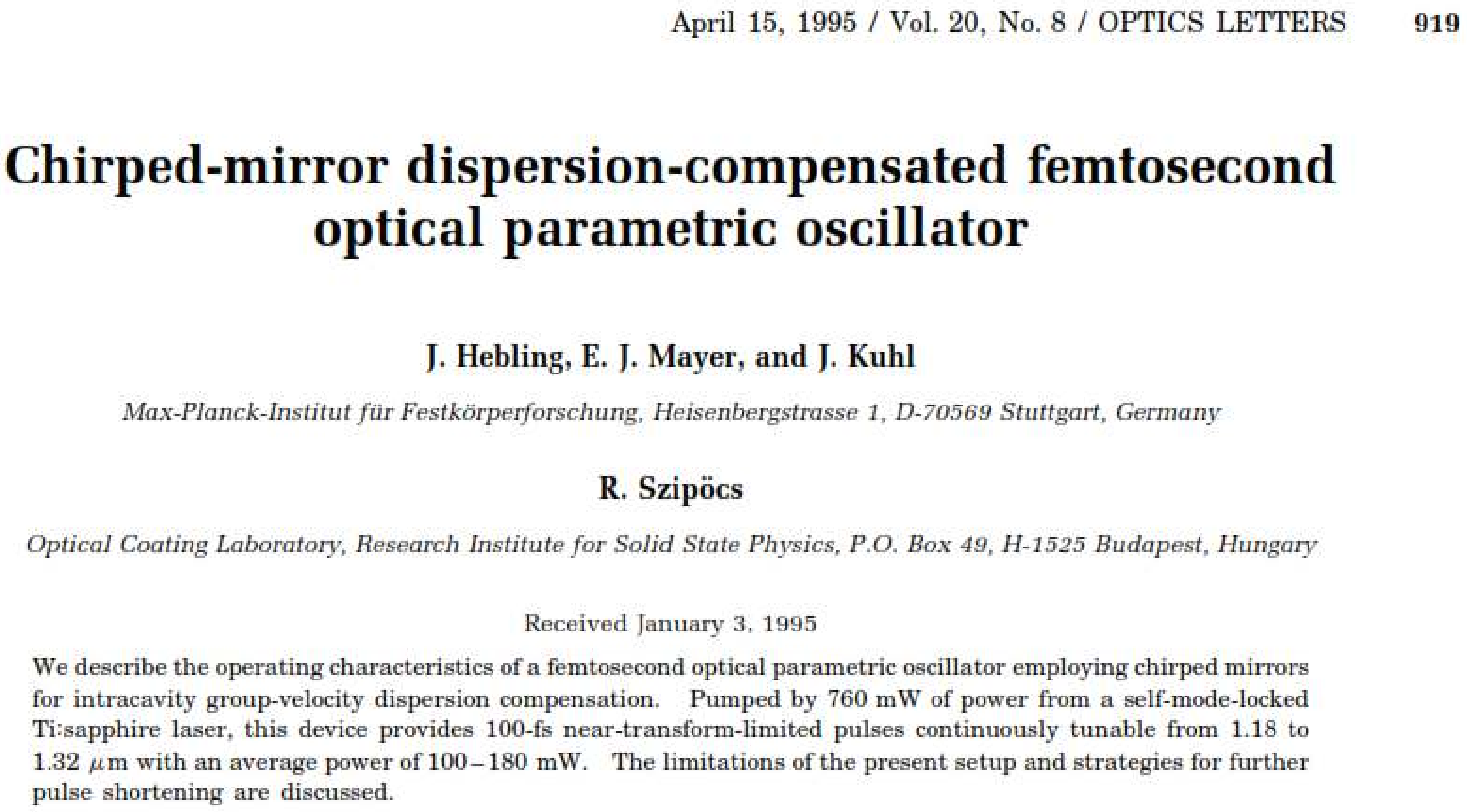
- **(a) Low dispersion sample (linear phase shift)**
- **(b) Chirped mirror sample (quatratic phase shift)**
- **(c) Gires-Tournois Intereferometer mirror (cubic phase shift)**
- **(d) (c)+(d)**

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

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.

Chirped mirrors for fs optical parametric oscillators



April 15, 1995 / Vol. 20, No. 8 / OPTICS LETTERS 919

Chirped-mirror dispersion-compensated femtosecond optical parametric oscillator

J. Hebling, E. J. Mayer, and J. Kuhl

Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

R. Szipöcs

Optical Coating Laboratory, Research Institute for Solid State Physics, P.O. Box 49, H-1525 Budapest, Hungary

Received January 3, 1995

We describe the operating characteristics of a femtosecond optical parametric oscillator employing chirped mirrors for intracavity group-velocity dispersion compensation. Pumped by 760 mW of power from a self-mode-locked Ti:sapphire laser, this device provides 100-fs near-transform-limited pulses continuously tunable from 1.18 to 1.32 μm with an average power of 100–180 mW. The limitations of the present setup and strategies for further pulse shortening are discussed.

Ultrabroadband chirped mirrors for ultrafast lasers

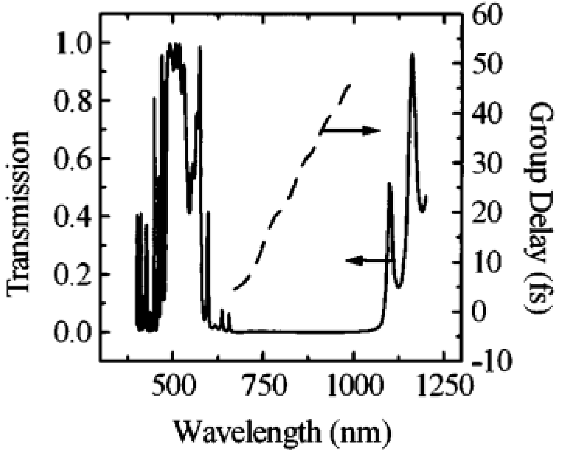
528 OPTICS LETTERS / Vol. 22, No. 8 / April 15, 1997

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

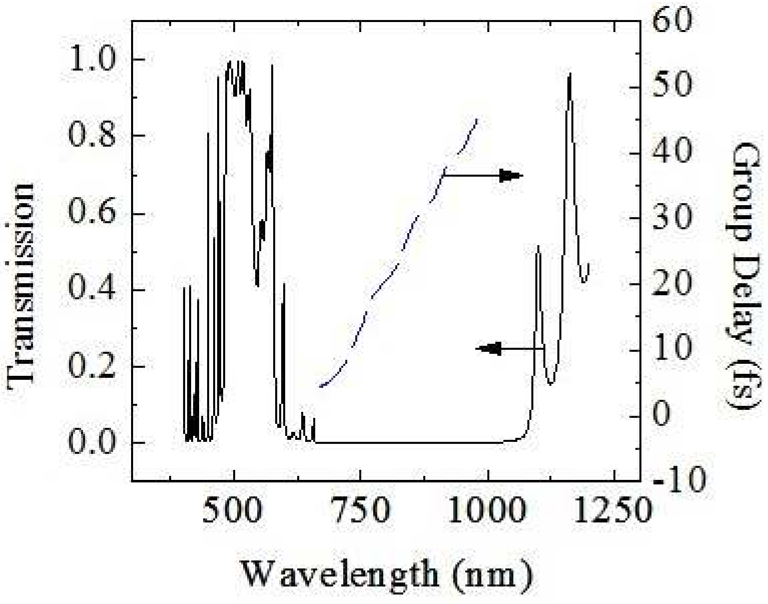
We report on the performance of widely tunable femtosecond and continuous-wave Ti:sapphire lasers that use a newly developed ultrabroadband mirror set. The mirrors exhibit high reflectivity ($R > 99\%$) and smooth variation of group delay versus frequency over a wavelength range from 660 to 1060 nm. 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)

Ultrabroadband chirped mirrors for ultrafast lasers



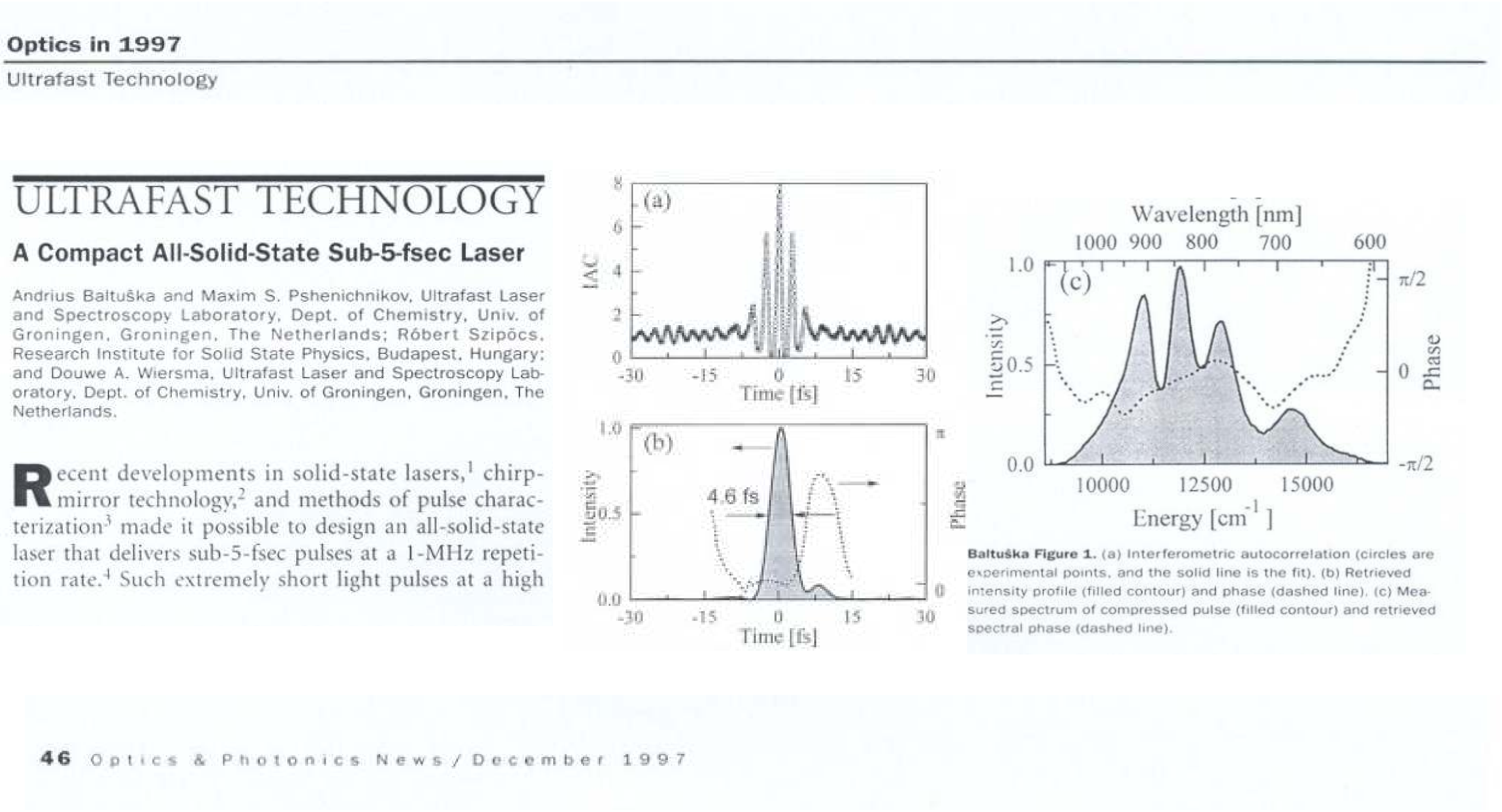
Increased reflectivity band and smooth dispersion over the 680-1060 nm wavelength range.

„Broadband Optics with λ-track Extend the Reach of Multiphoton Microscopy"

Spectra-Physics
The Solid State Laser Company™

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



Optics in 1997

Ultrafast Technology

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).

46 Optics & Photonics News / December 1997

Founding
R&D Ultrafast Lasers Research and Development Ltd. in 1997

BOOTH NUMBER: 8109

R&D ULTRAFAST LASERS LTD.

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.

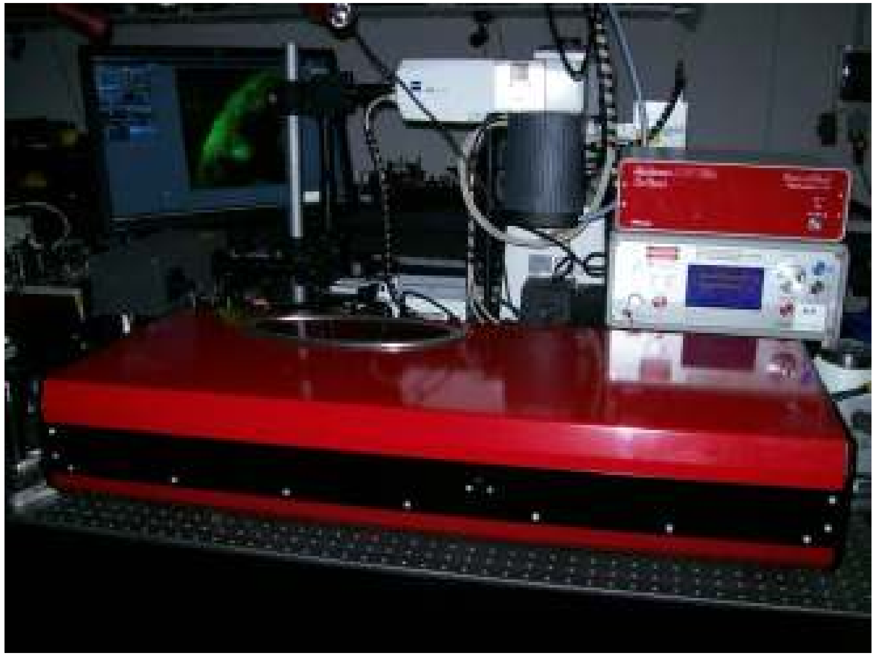
Founded:	in 1997
Location:	1121 Budapest, Konkoly Thege út 29-33. 6. ép. I. em. (KFKI Campus)
Infrastructure:	3 laser-optical laboratories, 1 electronic and 1 mechanical workshops, offices
Staff:	Engineering (2), Software (1), Optics/Lasers (1), Administration (0.5 + 0.5)
Web-site:	www.szipocs.com

1. **Scientific background**
    - 1.1 Optics (ultrafast – ps, fs)
    - 1.2 Lasers (ultrafast – ps, fs)
        - 1.2.1 Solid state
            - **Ti:saphire (680 – 1040 nm)**
            - **OPO-s (signal: 1020- 1240 nm, idler: 2 – 2.5 μm**)
        - 1.2.2 Fiber
            - **Yb-fiber (1020-1060 nm)**
            - Er-fiber (1520-1600 nm), SHG: 760 – 800 nm)
    - 1.3 Microscopy
        - 2PEF, SHG, **CARS for Life Science**
        - **FLIM (confocal, 2P) for Life Science and Quantum Optics**
2. **Technical background**
    - 2.1 Optics (thin films, optical design – Zemax)
    - 2.2 Mechanics (ProE, SolidWorks)
    - 2.3 Electronics (Eagle)
    - 2.4 Software (C# (ARM, PIC), Vivado (FPGA), Delphi, LabView)

FemtoRose 100 TUN/NoTouch

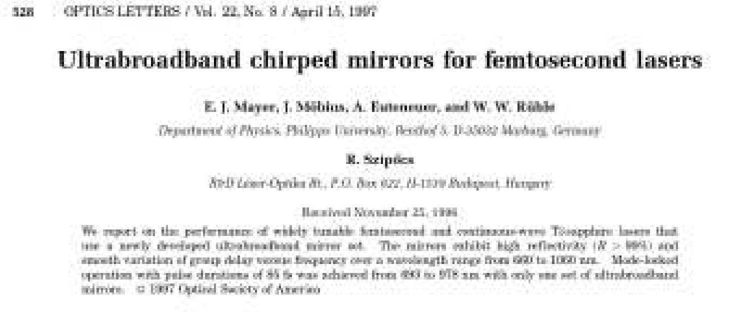
The First

Broadly Tunable, femtosecond pulse Ti:sapphire laser in 1998



Pioneering Ultrafast LaserTechnology by R&D

INTRODUCING THE FIRST ULTRABROADBAND CHIRPED MIRRORS
FOR BROADLY TUNABLE FEMTOSECOND LASERS



328 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

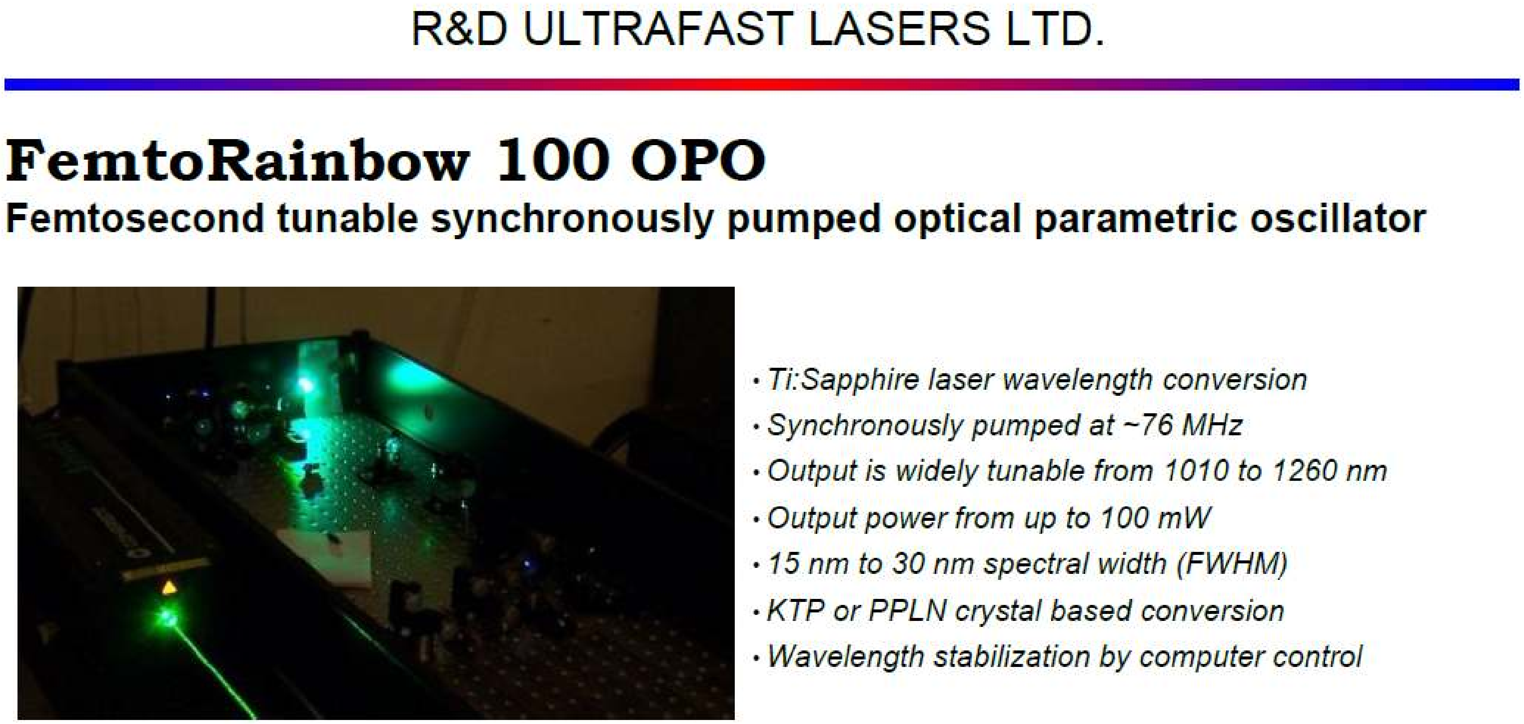
R. Szipőcs

R&D Laser-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 690 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. © 1997 Optical Society of America

PPLN OPO FOR 1 to 1.4 MICRON (signal) AND 2.0-2.5 MICRON (idler)



R&D ULTRAFAST LASERS LTD.

FemtoRainbow 100 OPO

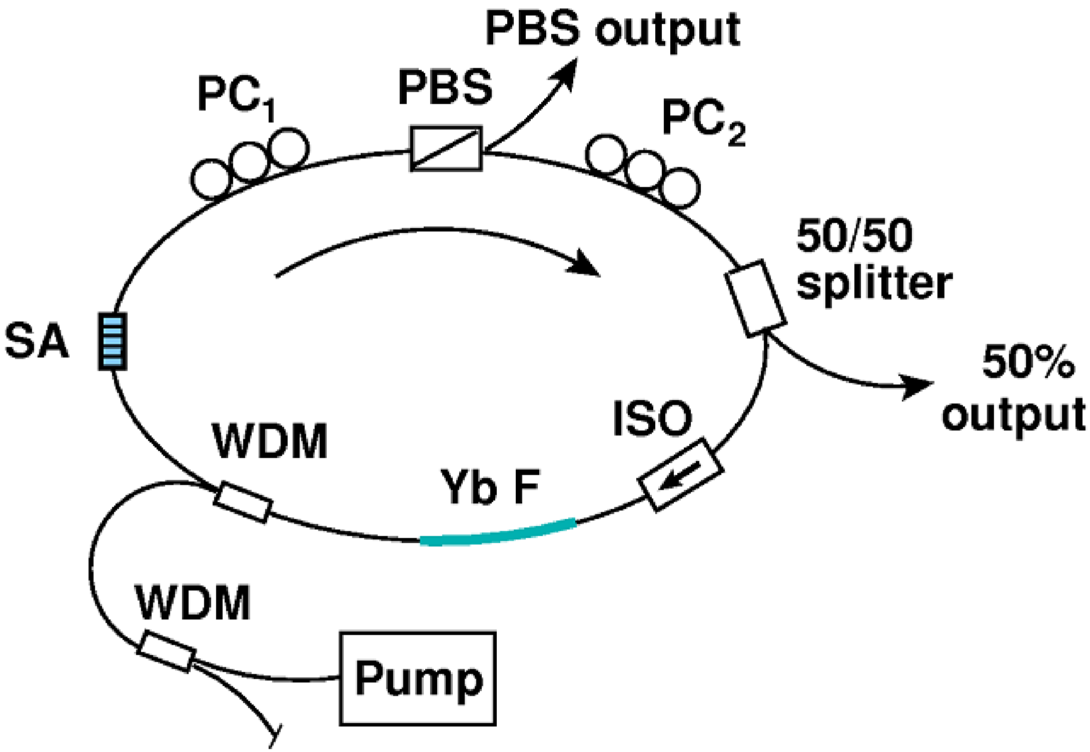
Femtosecond tunable synchronously pumped optical parametric oscillator

- *Ti:Sapphire laser wavelength conversion*
- *Synchronously pumped at ~76 MHz*
- *Output is widely tunable from 1010 to 1260 nm*
- *Output power from up to 100 mW*
- *15 nm to 30 nm spectral width (FWHM)*
- *KTP or PPLN crystal based conversion*
- *Wavelength stabilization by computer control*

Develoment of Yb-fiber laser technology in the FemtoBio NTP project (2006-2009)
MTA SZFKI – R&D Ultrafast Lasers Ltd – Furukawa Electric

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

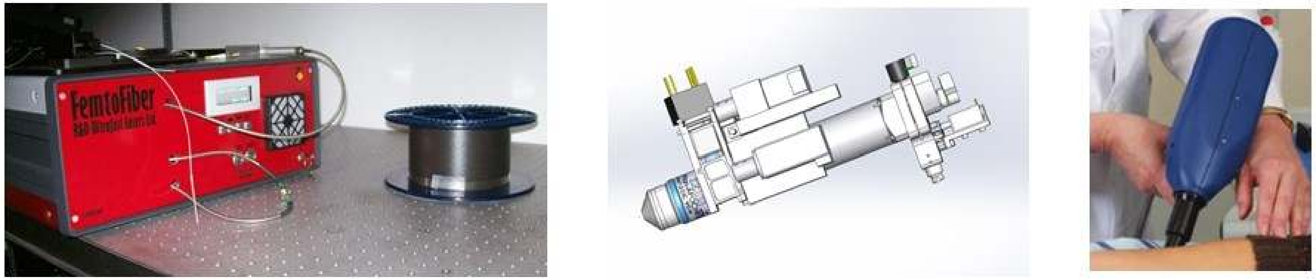
Develoment of Yb-fiber laser technology in the FemtoBio NTP project (2006-2009)
MTA SZFKI – R&D Ultrafast Lasers Ltd – Furukawa Electric



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

Our *FiberScope* project for Biomedical imaging applications (2010-2014)

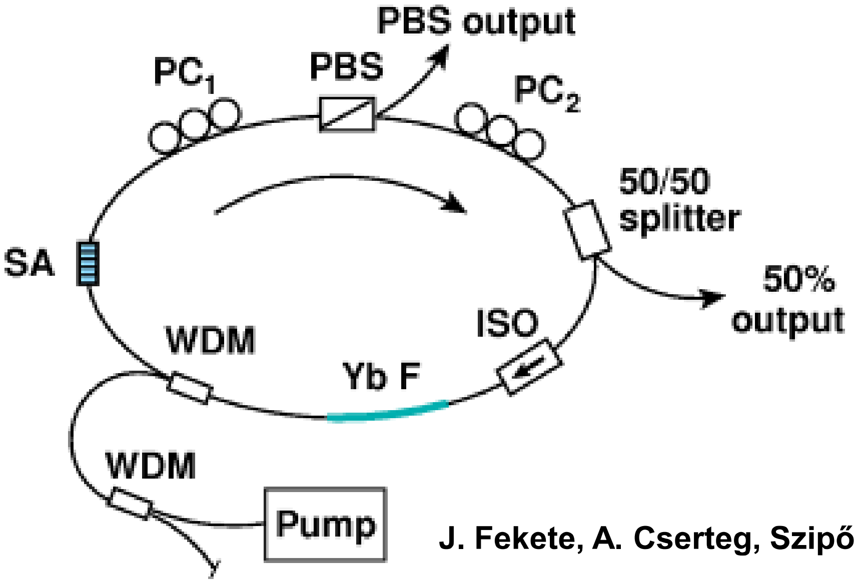
- *Reduce the cost of the pulsed laser applied (Yb-fiber instead of Ti:sapphire)*
- *Deliver the ligth for measurements through optical fiber* ***(fiber delivery)***
- *Small size scanning microscope head (handheld device)*
- *In vivo 3D measurements: laser safety issues*
- ***Applications in dermatology and nanomedicine***



FemtoFiber + scanning head for confocal/2PF imaging = FiberScope

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

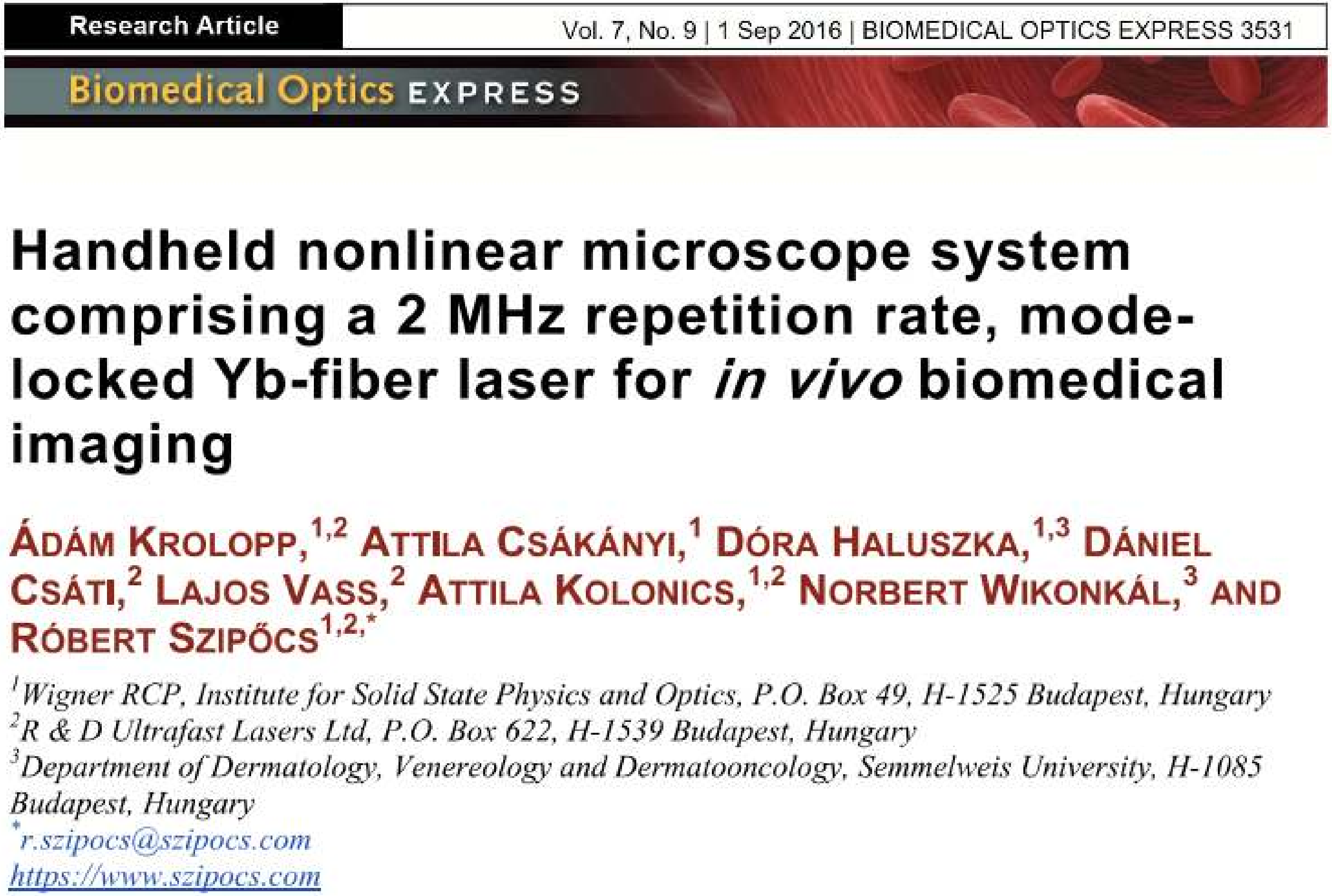
Yb F: Ytterbium doped fiber

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

FiberScope system description, for details, see:



Research Article Vol. 7, No. 9 | 1 Sep 2016 | BIOMEDICAL OPTICS EXPRESS 3531

Biomedical Optics EXPRESS

Handheld nonlinear microscope system comprising a 2 MHz repetition rate, mode-locked Yb-fiber laser for *in vivo* biomedical imaging

ÁDÁM KROLOPP,[1,2] ATTILA CSÁKÁNYI,[1] DÓRA HALUSZKA,[1,3] DÁNIEL CSÁTI,[2] LAJOS VASS,[2] ATTILA KOLONICS,[1,2] NORBERT WIKONKÁL,[3] AND RÓBERT SZIPŐCS[1,2,*]

[1] *Wigner RCP, Institute for Solid State Physics and Optics, P.O. Box 49, H-1525 Budapest, Hungary*
[2] *R & D Ultrafast Lasers Ltd, P.O. Box 622, H-1539 Budapest, Hungary*
[3] *Department of Dermatology, Venereology and Dermatooncology, Semmelweis University, H-1085 Budapest, Hungary*
[*] *r.szipocs@szipocs.com*
https://www.szipocs.com

FiberScope bloch scheme

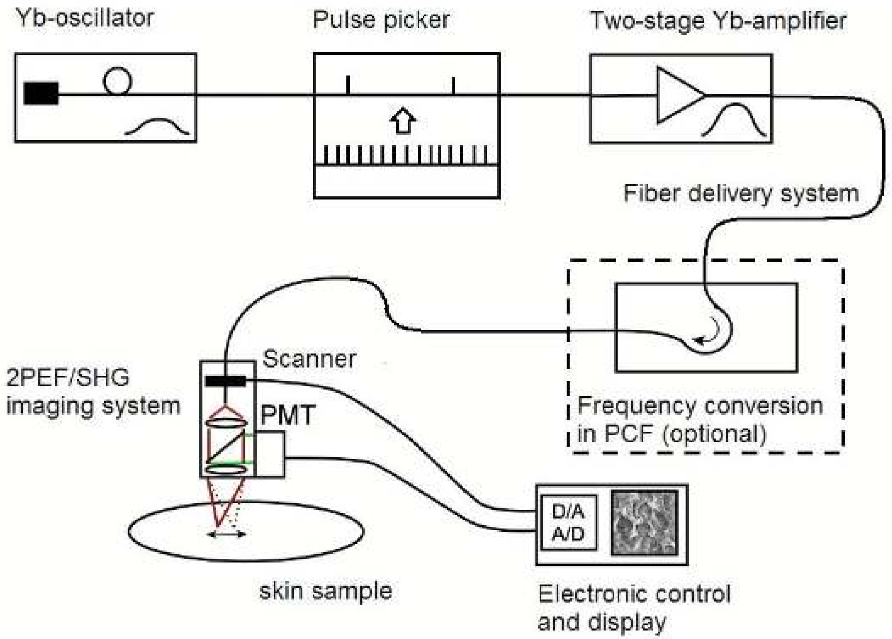


Fig. 1. Bloch scheme of the handheld 2PEF/SHG microscope imaging system comprising a 2 MHz mode-locked Yb-fiber laser.

Á. Krolopp, A. Csákányi, D. Haluszka, D. Csáti, L. Vass, A. Kolonics, N. Wikonkál, and R. Szipőcs, “Handheld nonlinear microscope system comprising a 2 MHz repetition rate, mode-locked Yb-fiber laser for in vivo biomedical imaging,” Biomed. Opt. Express 7(9), 3531–3542 (2016).

FiberScope nonlinear microscope

Photo of the 2MHz Yb-fiber laser system used as a pulsed laser light source of our *FiberScope* device

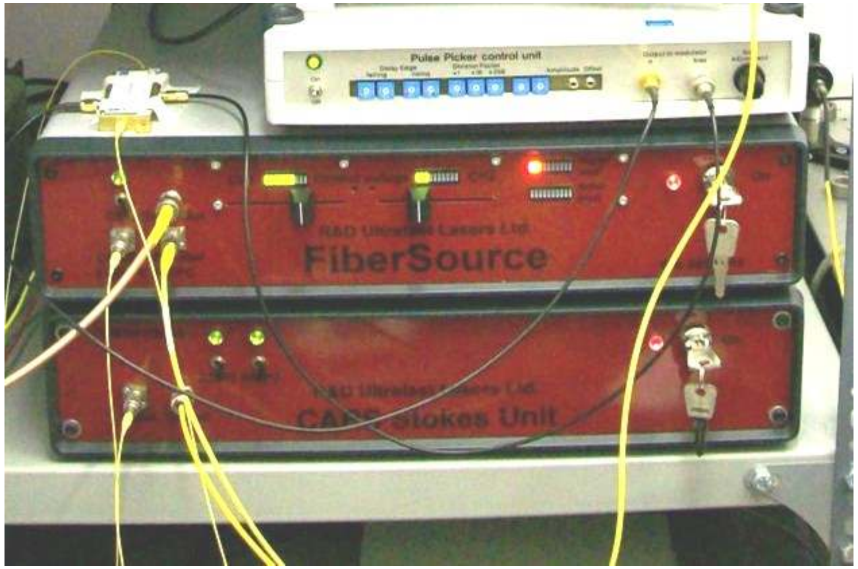
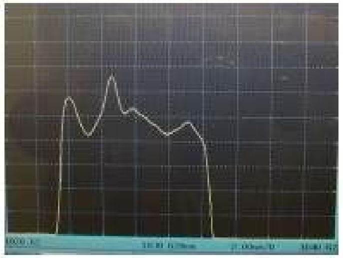


Photo of the scanning microscope head of the *FiberScope* device with plastic covering

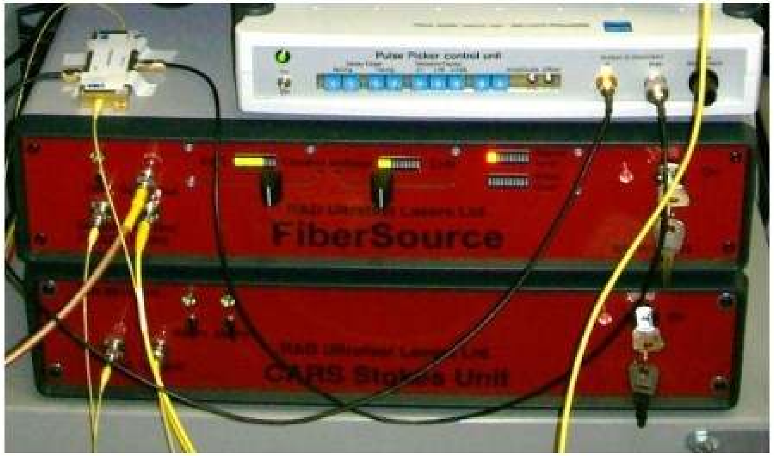
The low cost, flexible, ~2 MHz pulsed laser source

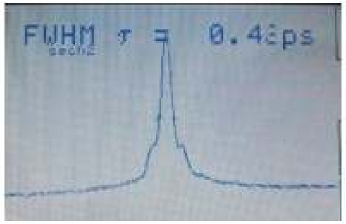
Laser components and performance

- All-fiber, AND type, mode-locked Yb-fiber oscillator (*R&D*)
- Pulse picker (*JenOptik*, Jena, Germany)
- Two-stage Yb-amplifier (*R&D Ultrafast Lasers Ltd.*)



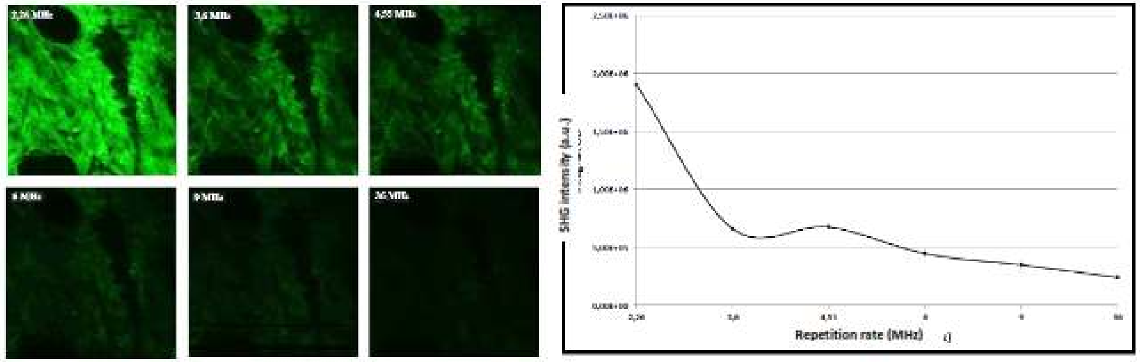
Pave: ~ 200 mW
τ < 0.5 ps
λ0 ~ 1030 nm
Δλ: 8-12 nm
ν: ~ 1.89 MHz



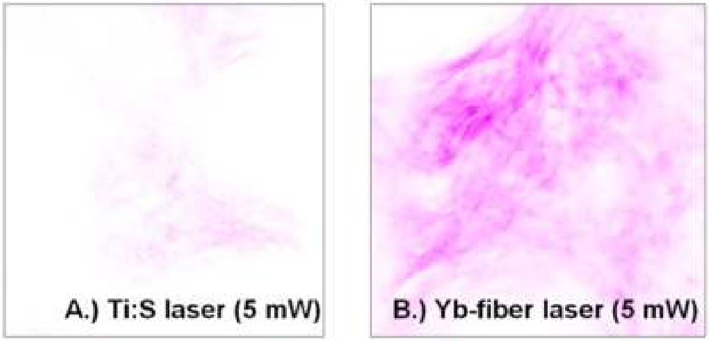


Á. Krolopp, A. Csákányi, D. Haluszka, D. Csáti, L. Vass, A. Kolonics, N. Wikonkál, and R. Szipőcs, “Handheld nonlinear microscope system comprising a 2 MHz repetition rate, mode-locked Yb-fiber laser for in vivo biomedical imaging,” Biomed. Opt. Express 7(9), 3531–3542 (2016).

Low repetition rate [7] and IR excitation [4] advantage



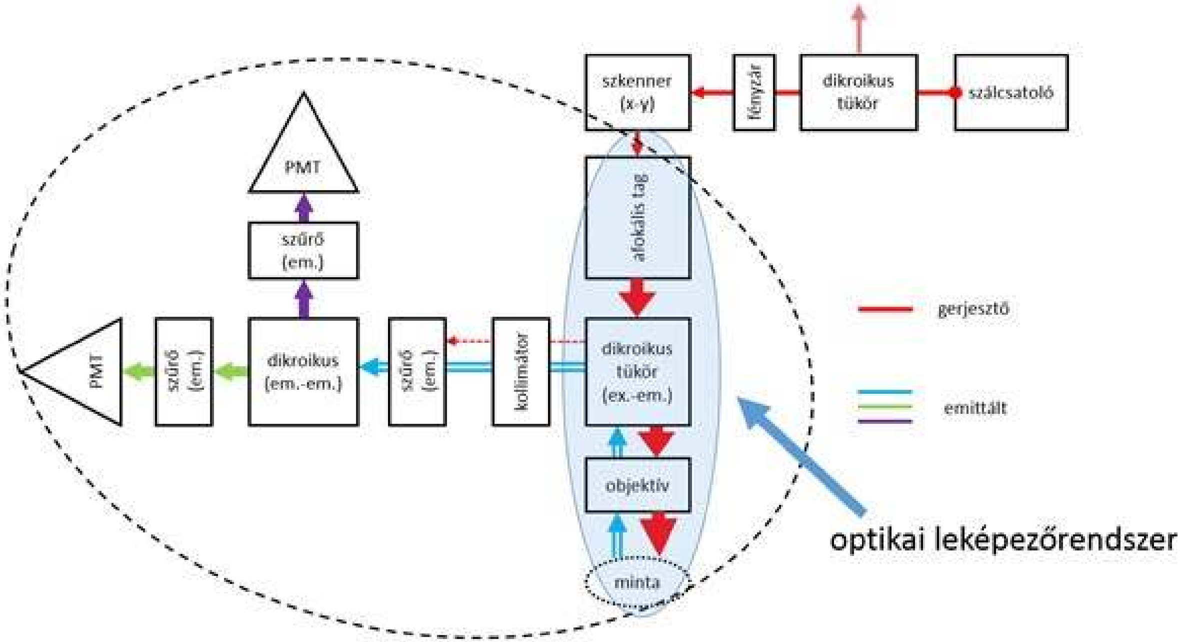
SHG signal intensity as the function of repetition rate of the Yb-fiber laser. Average power: 5 mW (measured after the microscope objective). Pixel dwell time: 5 µs. Operation wavelength: 1030 nm. Fixed transmission grating distance of ~ 80 mm. Ex-vivo murine skin sample.



Comparison of SHG imaging performance of different mode-locked lasers having the same average power of 5 mW (on the sample) for nonlinear microscopy. Ex-vivo murine skin sample, imaging depth: z = 30 µm, same microscope settings. Collagen distribution measured by A) an industry standard, 80 MHz Ti:sapphire laser operating at 800 nm, and by B) our 2MHz Yb-fiber oscillator and amplifier system operating at 1030 nm.

Á. Krolopp, A. Csákányi, D. Haluszka, D. Csáti, L. Vass, A. Kolonics, N. Wikonkál, and R. Szipőcs, "Handheld nonlinear microscope system comprising a 2 MHz repetition rate, mode-locked Yb-fiber laser for in vivo biomedical imaging," Biomed. Opt. Express 7(9), 3531–3542 (2016).

Optical design of the scanning microscope head of the *FiberScope*



szkenner (x-y)

fényzár

dikroikus tükör

szálcsatoló

PMT

szűrő (em.)

afokális tag

PMT

szűrő (em.)

dikroikus (em.-em.)

szűrő (em.)

kollimátor

dikroikus tükör (ex.-em.)

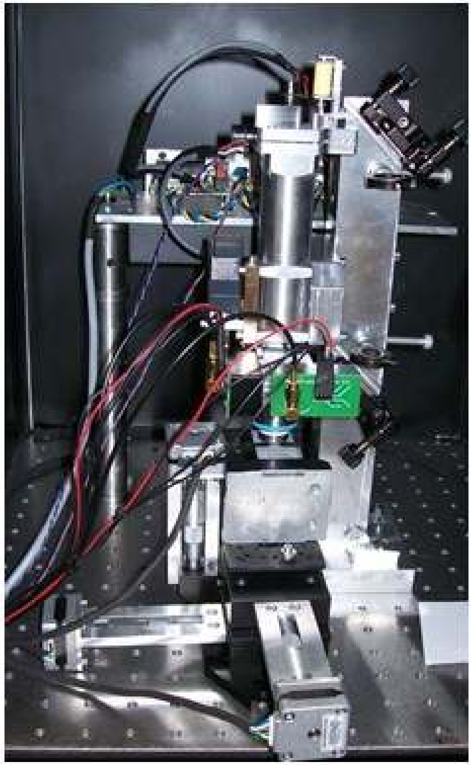
objektív

minta

gerjesztő

emittált

optikai leképezőrendszer



A. Csákányi, R. Szipőcs R: Design of optical imaging system of a scanning nonlinear microscope „*Fiberscope*”

Kvantumelektronika 2014, Budapest, 28.11.2014, Paper P64.

Investigation of skin tumor basalioma (BCC)

- **Collagen, as marker**
- Ex vivo samples, immediately after surgery

Skin Research and Technology

Diagnosis of BCC by multiphoton laser tomography

Stefania Seidenari[1], Federica Arginelli[1], Sara Bassoli[1], Jennifer Cautela[1], Anna Maria Cesinaro[2], Mario Guanti[1], Davide Guardoli[1], Cristina Magnoni[1], Marco Manfredini[1], Giovanni Ponti[1] and Karsten König[3,4]

[1]Department of Dermatology, University of Modena and Reggio Emilia, Modena, Italy
[2]Department of Pathology, University of Modena and Reggio Emilia, Modena, Italy
[3]Department of Biophotonics and Lasertechnology, Saarland University, Saarbrücken, Germany and [4]JenLab GmbH, Schillerstrasse 1, 07745, Jena, Germany

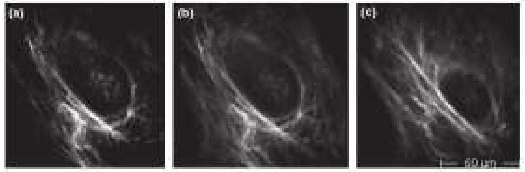
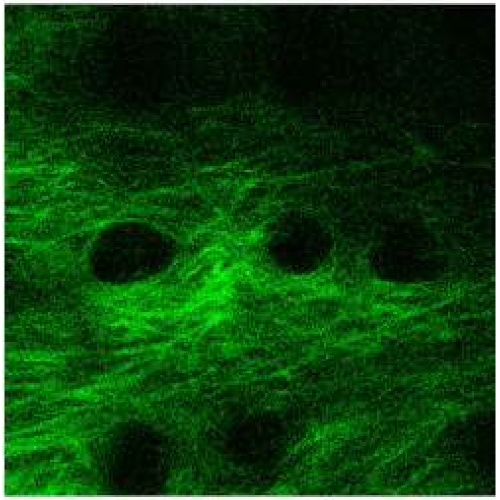
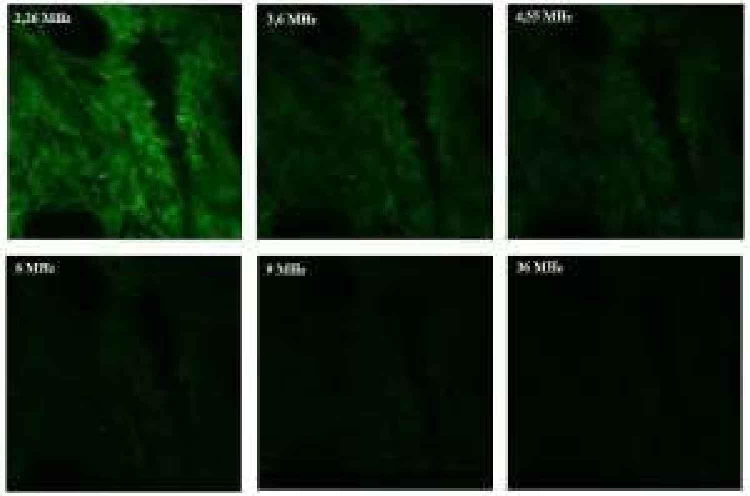
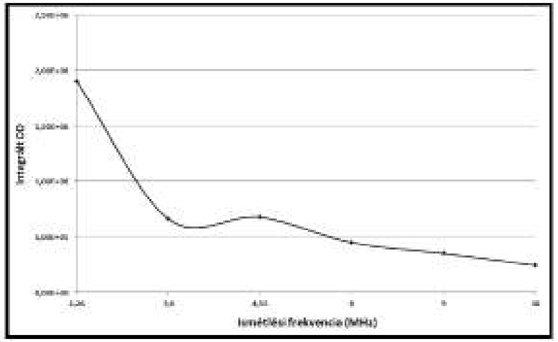


Fig. 4. Basal cell carcinoma. (a) 100 μm depth, excitation wavelength 800 nm. Shifting the wavelength to 800 nm, basaloid cells become less visible; employing an excitation wavelength of 820 nm basaloid cells disappear and it is possible to observe empty spaces surrounded by collagen fibres (phantom island); (b) 100 μm depth; (c) 120 μm depth.

Using *FiberScope* for collagen detection





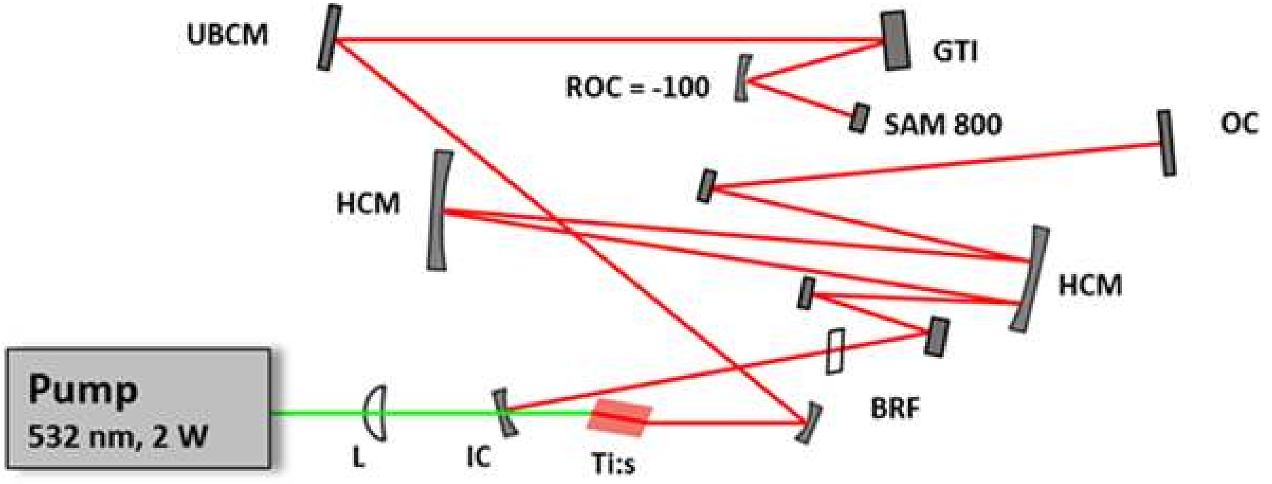


SHG intensity of collagen as the funtcion of repetition rate of our Yb-fiber laser
(average power: ~5 mW, pixel dwell time: 5 μs)

Femtosecond Lasers for Nonlinear Microscopy Research Group
(Principal investigator: Robert Szipőcs, Ph.D.)

20 MHz, tunable, sub-ps Ti:sapphire laser

Setup upgraded for DVRF CARS and fiber delivery



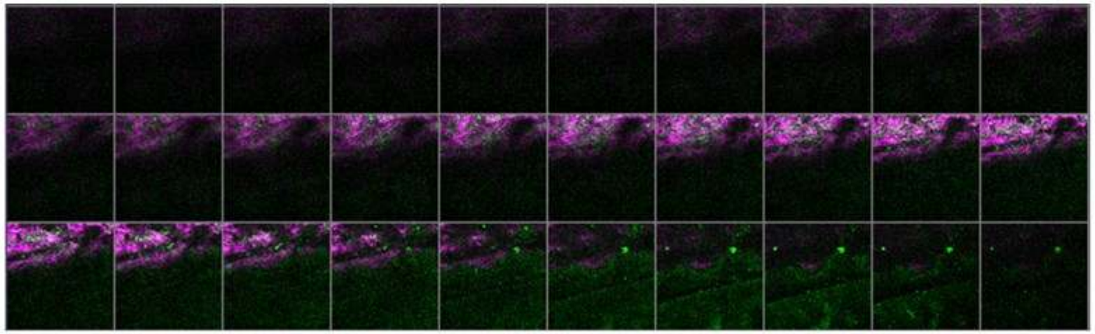
- **Prism pair is replaced by GTI mirrors**
- **SESAM for mode-locking instead of hard aperture Kerr-lens mode-locking**
- **Ultrabroadband chirped mirrors**

- **Pump power at 532 nm: ~ 2.1 W**
- **Repetition rate: ~ 20 MHz**
- Pulse duration: 0.6 – 1.0 ps (adjustable)
- **Spectral bandwidth: < 2 nm**

P. Antal, R. Szipőcs, "Tunable, low-repetition-rate, cost-efficient fs Ti:S laser for nonlinear microscopy,"
Appl. Phys. B**107**, 17-22 (2012)

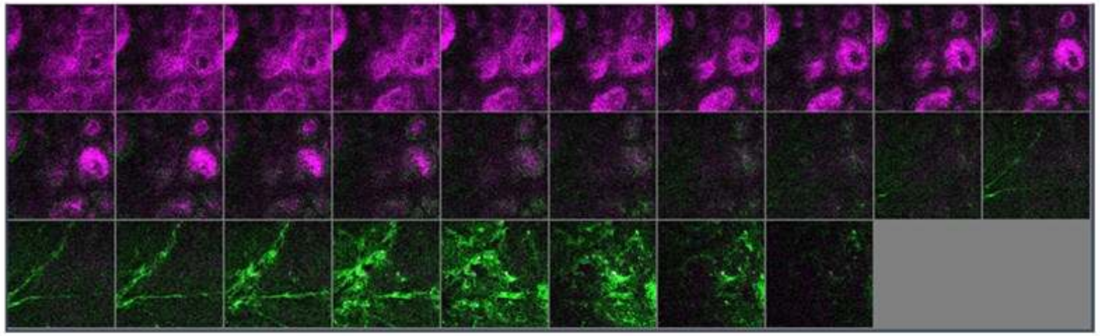
Femtosecond Lasers for Nonlinear Microscopy Research Group
(Principal investigator: Robert Szipőcs, Ph.D.)

Z-stack imaging of basal cell carcinoma (BCC) biopsy



In case of BCC, we could **detect the border of the tumor** highlighted by a **strong contrast of AF (cells with basal cell morphology)** and **SHG (collagen fibers around tumor nest).**

Z-stack imaging of hemangioma biopsy



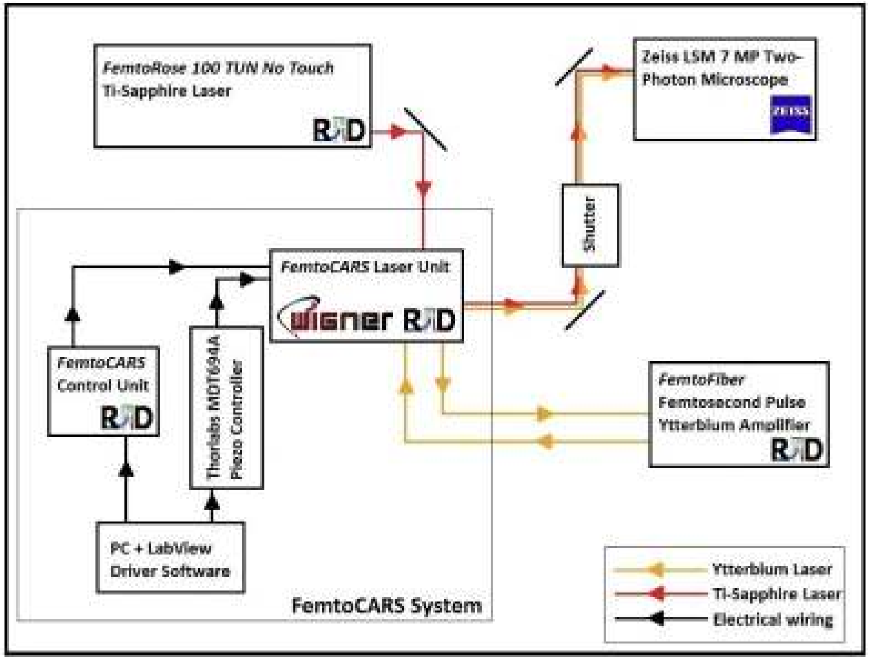
Hemangioma and **angiokeratoma** are vascular proliferations. **Hemangiomas** can be either congenital or acquired, spontaneously evolving with age. These **do not require further treatment. Angiokeratomas (AK) can not be distinguished from hemangiomas macroscopically,** and even though these have dermatoscopic features, **dermatoscopic differentiation is often challenging**. The distinguishing between hemangiomas and AK is important as **AK may indicate the presence of other severe diseases**. It is the most characteristic sign of **Fabry-disease** leading to **severe heart, lung and kidney damage**. **Early diagnosis** could be promote by the **recognition of AKs**. AKs can be a sign of other storage diseases.

Yb-FIBER AMPLIFIER FOR CARS IMAGING

FemtoCARS

the

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



FemtoRose 100 TUN No Touch
Ti-Sapphire Laser

Zeiss LSM 7 MP Two-Photon Microscope

Shutter

FemtoCARS Laser Unit

FemtoCARS
Control Unit

Thorlabs MDT694A
Piezo Controller

FemtoFiber
Femtosecond Pulse
Ytterbium Amplifier

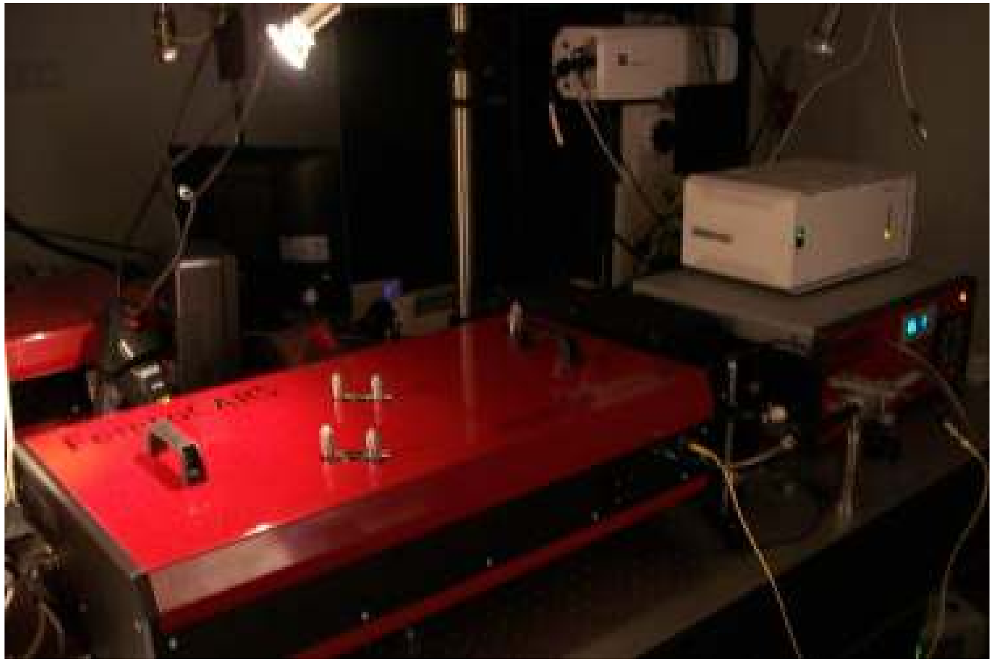
PC + LabView
Driver Software

FemtoCARS System

Ytterbium Laser

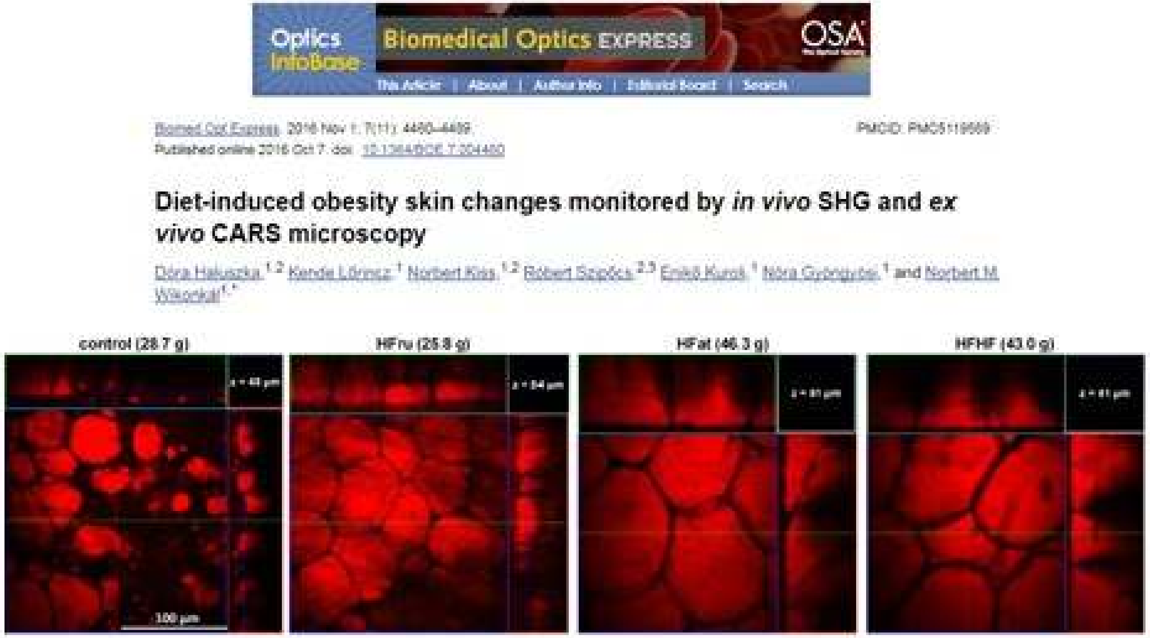
Ti-Sapphire Laser

Electrical wiring



Dual vibration resonance frequency CARS microscopy imaging of basal cell carcinoma to achieve stain free histopathology

Previously, we utilized CARS microscopy to visualize lipids in the adipocytes of murine skin



Biomed Opt Express. 2016 Nov 1; 7(11): 4460–4469.
Published online 2016 Oct 7. doi: 10.1364/BOE.7.004460
PMCID: PMC5119569

Diet-induced obesity skin changes monitored by *in vivo* SHG and *ex vivo* CARS microscopy

Dóra Haluszka,[1,2] Kende Lőrincz,[1] Norbert Kiss,[1,2] Róbert Szipőcs,[2,3] Enikő Kuroli,[1] Nóra Gyöngyösi,[1] and Norbert M. Wikonkál[1,*]

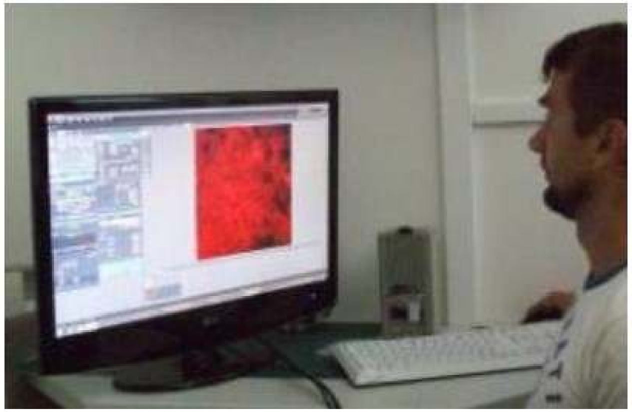
BUILDING LABORATORIES

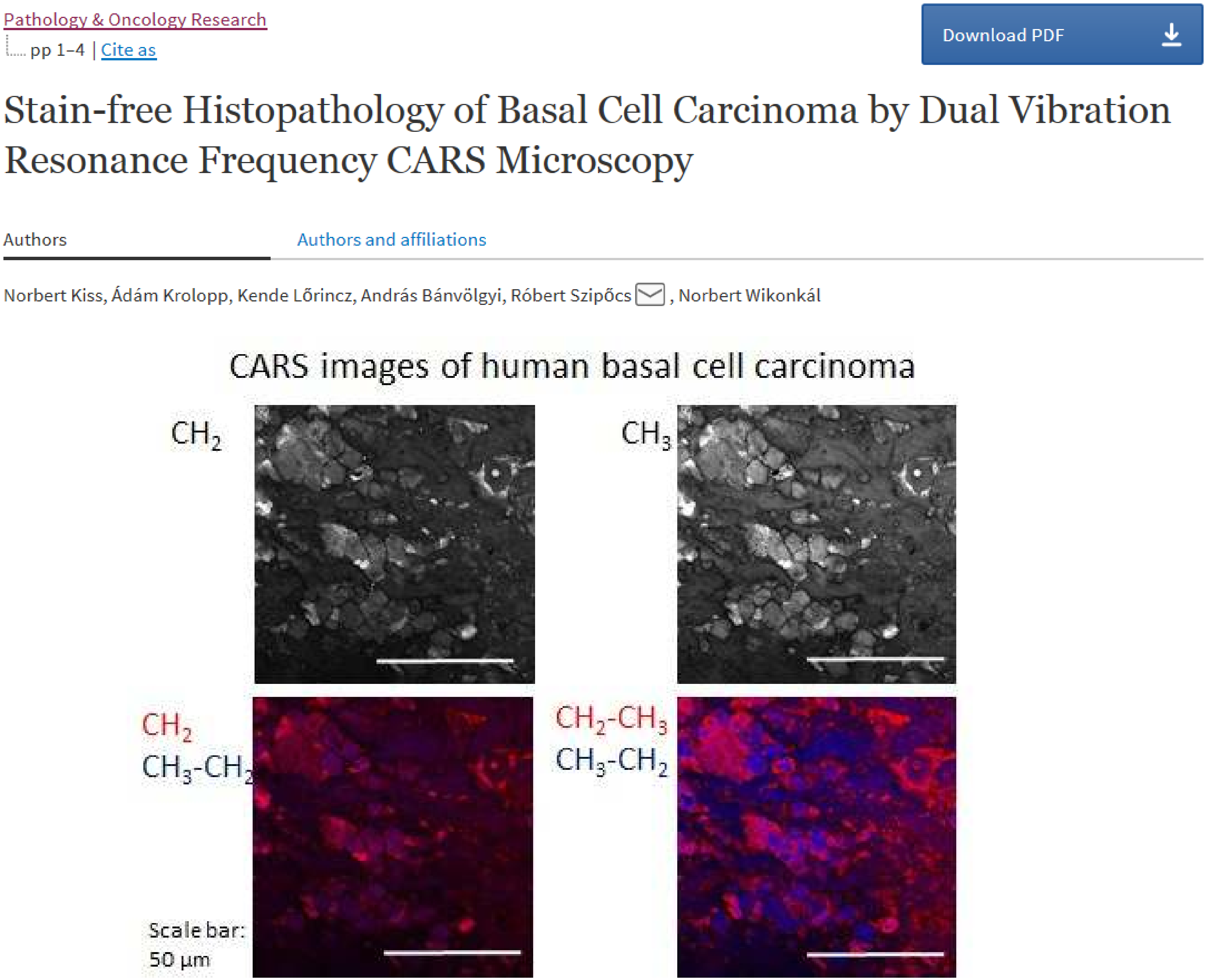
CARS SYSTEM INSTALLED AT UNIVERSITY OF SZEGED

Related articles

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

Photo Gallery





Pathology & Oncology Research

pp 1–4 | Cite as

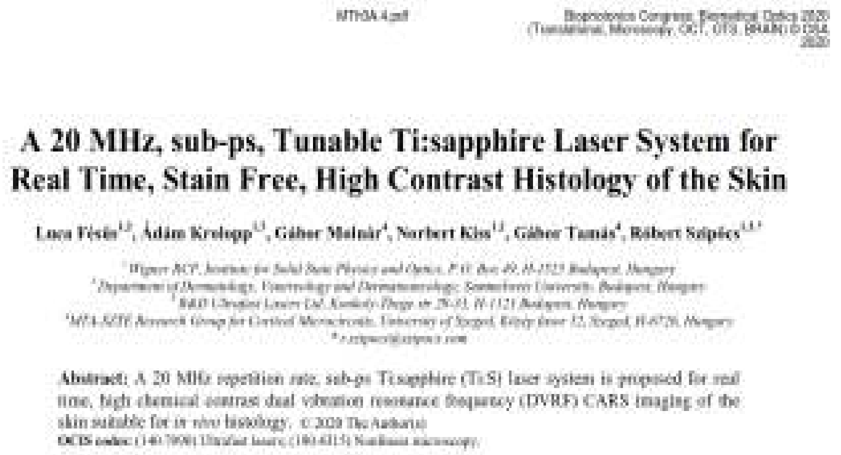
Stain-free Histopathology of Basal Cell Carcinoma by Dual Vibration Resonance Frequency CARS Microscopy

Norbert Kiss, Ádám Krolopp, Kende Lőrincz, András Bánvölgyi, Róbert Szipőcs, Norbert Wikonkál

CARS images of human basal cell carcinoma

Kiss, N. et al. Pathol. Oncol. Res. (2017). https://doi.org/10.1007/s12253-017-0356-6

Real time DVRF-CARS (double channel, lipid/protein detection) using a 20 MHz, sub-ps Ti:sapphire laser



MTH3A.4.pdf

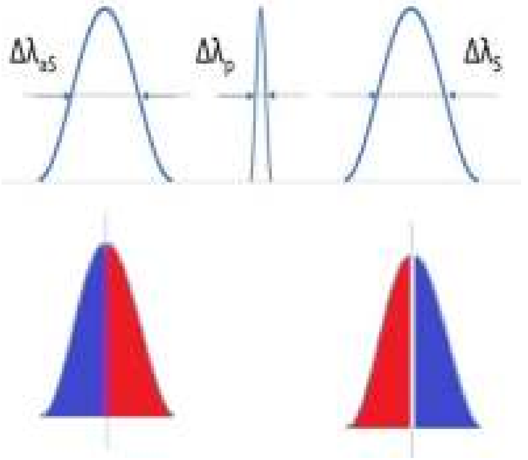
Biophotonics Congress: Biomedical Optics 2020 (Translational, Microscopy, OCT, OTS, BRAIN) © OSA 2020

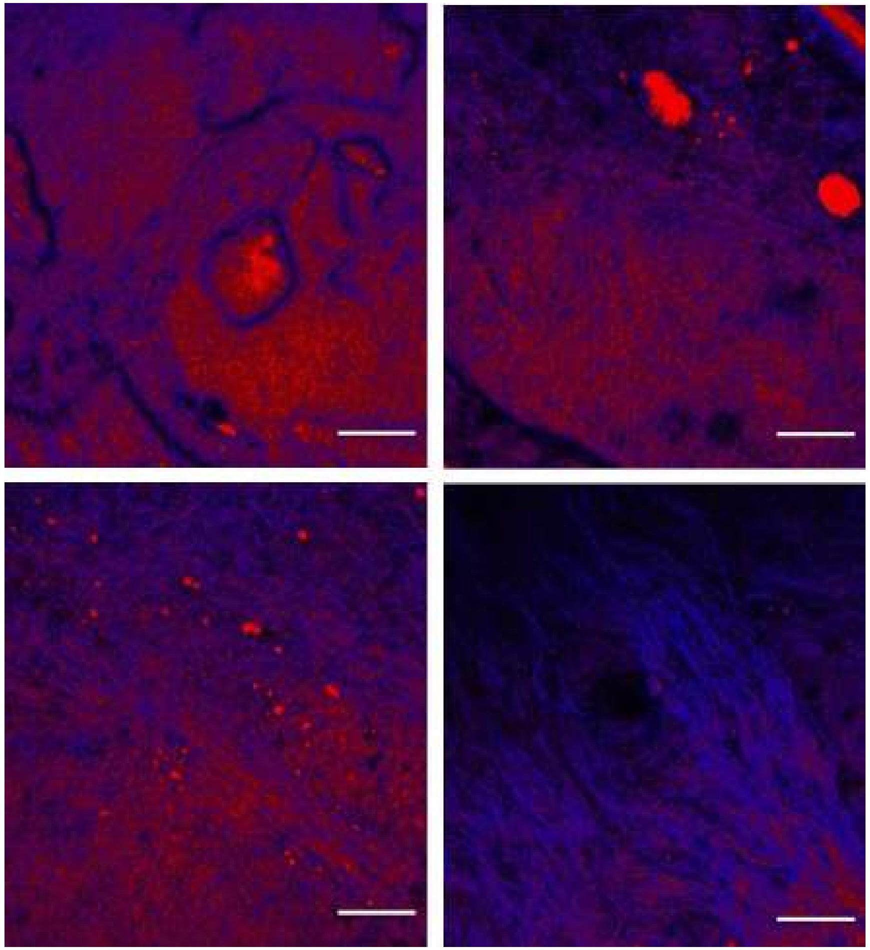
A 20 MHz, sub-ps, Tunable Ti:sapphire Laser System for Real Time, Stain Free, High Contrast Histology of the Skin

Luca Fésin[1,2], Ádám Krolopp[1,3], Gábor Molnár[4], Norbert Kiss[1,2], Gábor Tamás[4], Róbert Szipöcs[1,3,*]

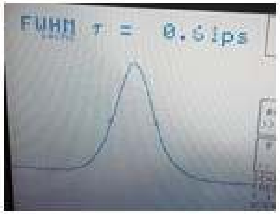
Abstract: A 20 MHz repetition rate, sub-ps Ti:sapphire (Ti:S) laser system is proposed for real time, high chemical contrast dual vibration resonance frequency (DVRF) CARS imaging of the skin suitable for *in vivo* histology. © 2020 The Author(s)

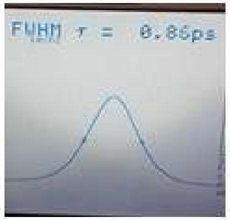
OCIS codes: (140.7090) Ultrafast lasers; (180.4315) Nonlinear microscopy.

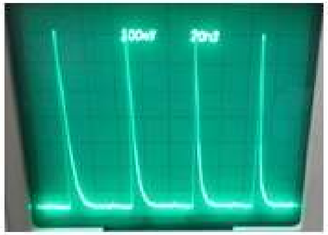




20 MHz, sub-ps, Tunable Ti:sapphire Laser for DVRF CARS imaging

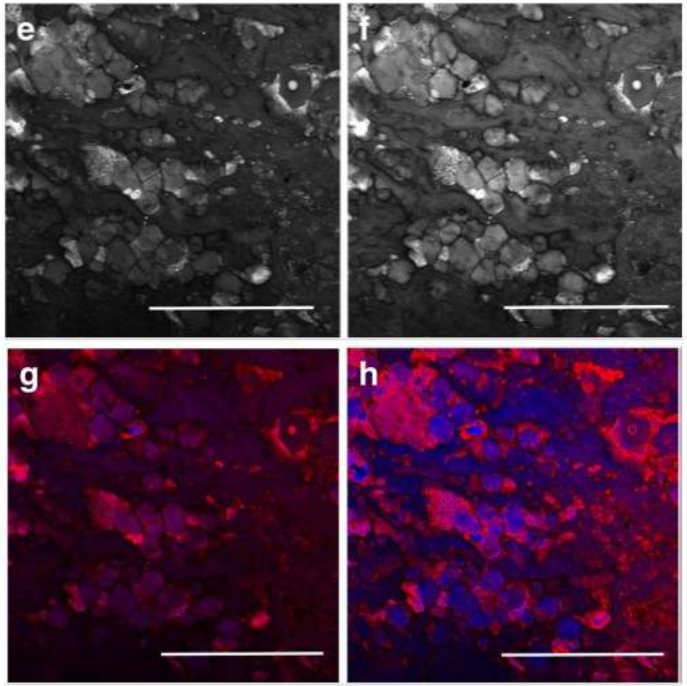






For real time, *in vivo* CARS imaging: **Ppump** (794 nm) = **10 mW**, **Pstokes** (1030 nm) = **5 mW** (**measured on sample**), PixelDwellTime: **6 µs**

Nonlinear optical microscopy for imaging basal cell cancer



Lipid and protein channels (red and blue color encoding)

Single channel detection

Measurement takes at least 3-5 minutes (changing pumpe wavelength, set zero delay for pump and Stokes pulses), processing takes also 5-10 minutes

CARS on *ex vivo* basal cell cancer sample

Kiss N, Krolopp Á, Lőrincz K, Bánvölgyi A, Szipőcs R, Wikonkál N: Stain-free Histopathology of Basal Cell Carcinoma by Dual Vibration Resonance Frequency CARS Microscopy, Pathol Oncol Res. 24(4):927-930. doi: 10.1007/s12253-017-0356-6 (2018)

Science

RESEARCH ARTICLES

Cite as: C. Cserép *et al.*, *Science*
10.1126/science.aax6752 (2019).

Microglia monitor and protect neuronal function via specialized somatic purinergic junctions

Csaba Cserép[1*], Balázs Pósfai[1,2*], Nikolett Lénárt[1], Rebeka Fekete[1,2], Zsófia I. László[2,3], Zsolt Lele[3], Barbara Orsolits[1], Gábor Molnár[4], Steffanie Heindl[5], Anett D. Schwarcz[1], Katinka Ujvári[1], Zsuzsanna Környei[1], Krisztina Tóth[1,2], Eszter Szabadits[1], Beáta Sperlágh[6], Mária Baranyi[6], László Csiba[7], Tibor Hortobágyi[8,9,10], Zsófia Maglóczky[11], Bernadett Martinecz[1], Gábor Szabó[12], Ferenc Erdélyi[12], Róbert Szipőcs[13], Michael M. Tamkun[14], Benno Gesierich[5], Marco Duering[5,15], István Katona[3], Arthur Liesz[5,15], Gábor Tamás[4], Ádám Dénes[1†]

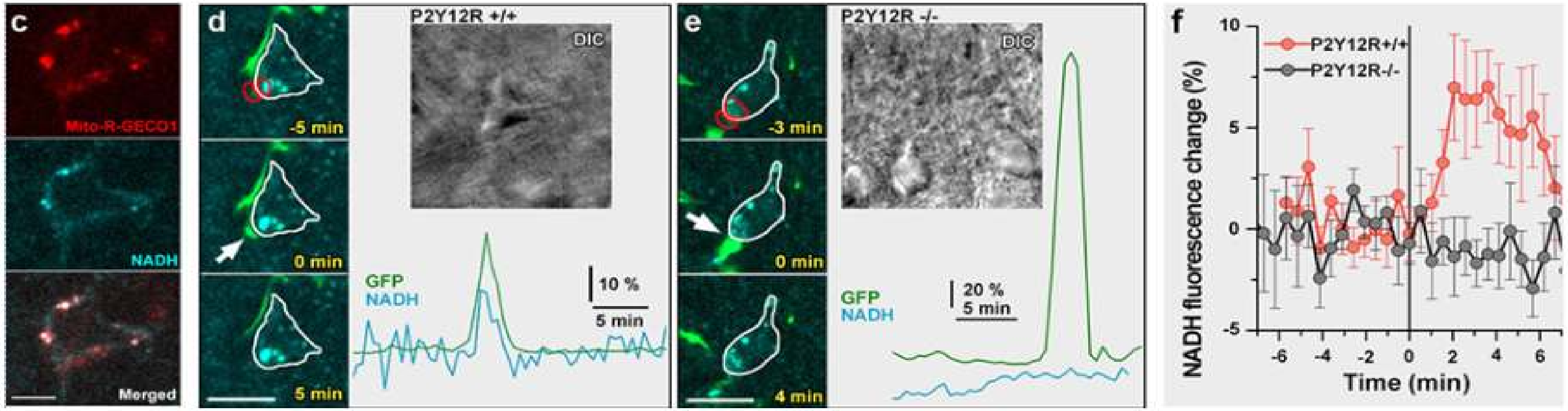
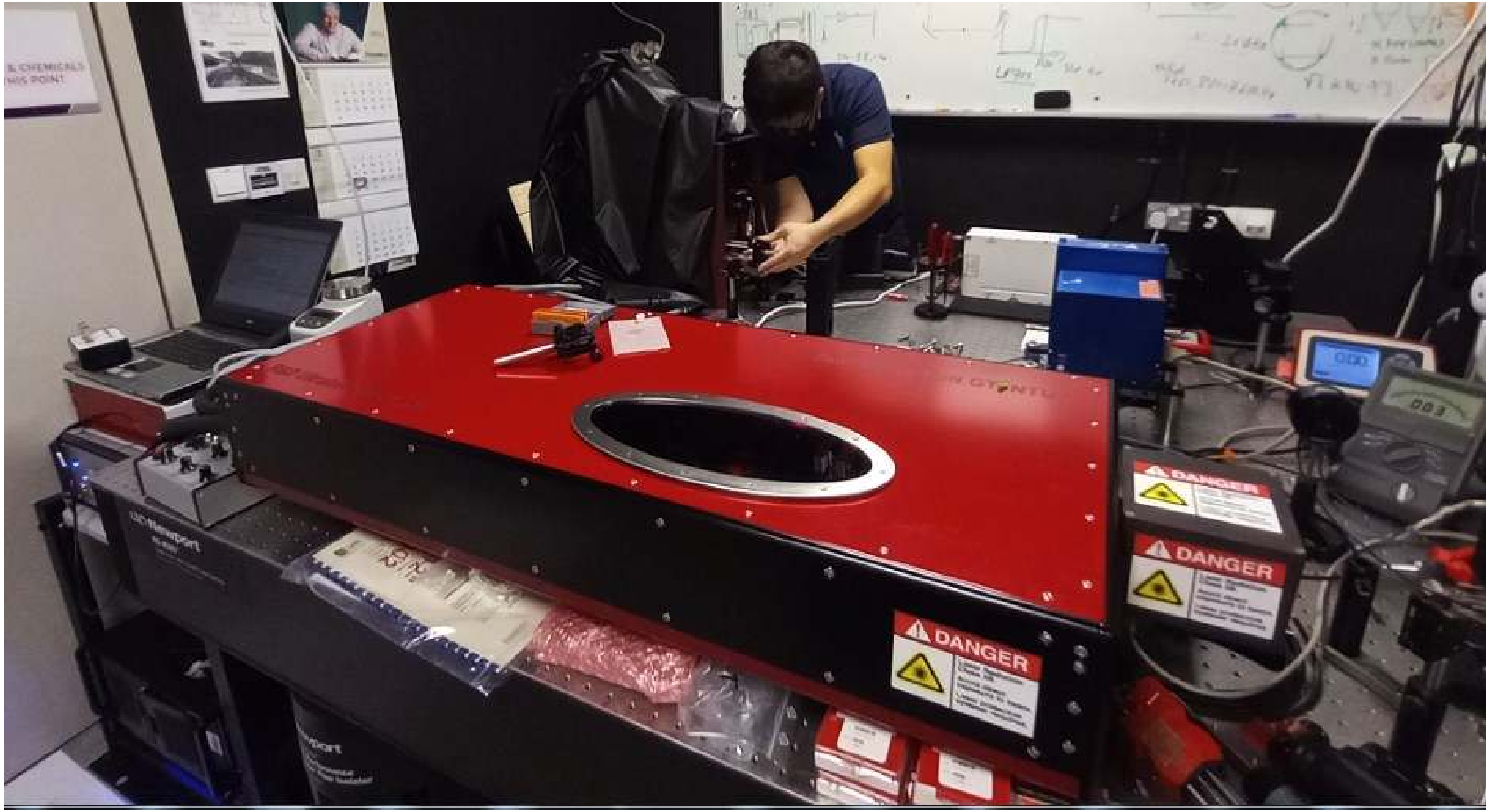
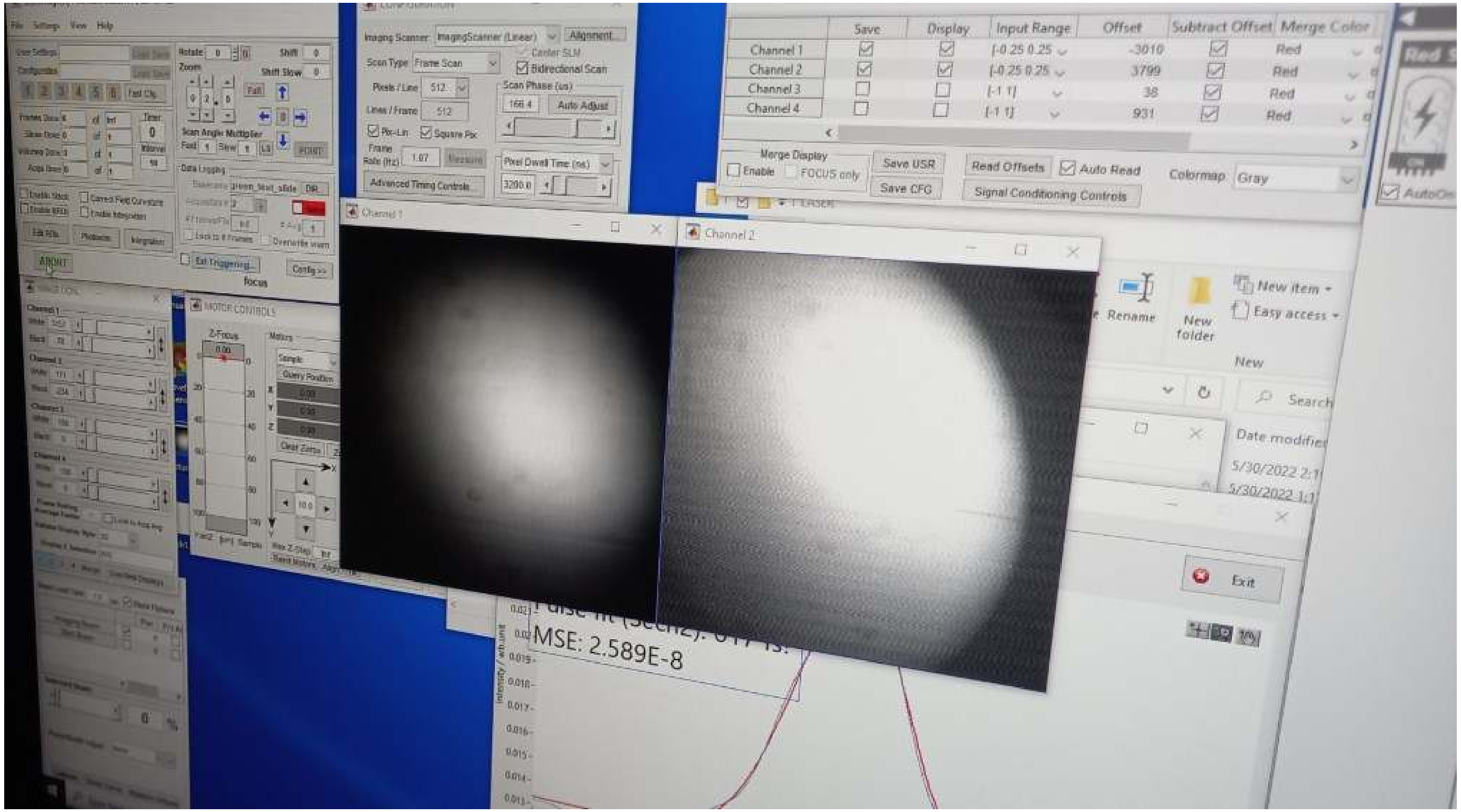


Figure 4. *Physiological microglia-neuron communication at the somatic junction site is P2Y12R-dependent and is linked with neuronal mitochondrial activity. a) b) are not shown here. c) Mito-R-Geco1 expression co- nicotinamide adenine dinucleotide (NADH) intrinsic fluorescence. d-e) Representative samples from time-lapse imaging of microglia show processes extend and contact neuronal soma in CX3CR1+/GFP/P2Y12R+/+ (d) and CX3CR1+/GFP/P2Y12R-/- (e) mice. White arrow indicates the contact site of microglia. DIC images of the imaged neurons and the fluorescence signal of GFP (green) and NADH (dark cyan) of red outlined areas are shown. f) Average of NADH intrinsic fluorescence of all neurons in P2Y12R+/+ (red, n=10) and P2Y12R-/- mice (black, n=11).*

Testing for fiber delivery and 2-photon imaging developed for Alzheimer's disease research for at NTU, Singapore



Testing for fiber delivery and 2-photon imaging at NTU NOBIC lab, Singapore



Imaging Scanner: ImagingScanner (Linear)
Scan Type: Frame Scan
☑ Bidirectional Scan
Pixels / Line: 512
Lines / Frame: 512
☑ Pix=Lin
☑ Square Pix
Scan Phase (us): 166.4
Frame Rate (Hz): 1.07
Pixel Dwell Time (ns): 3200.0

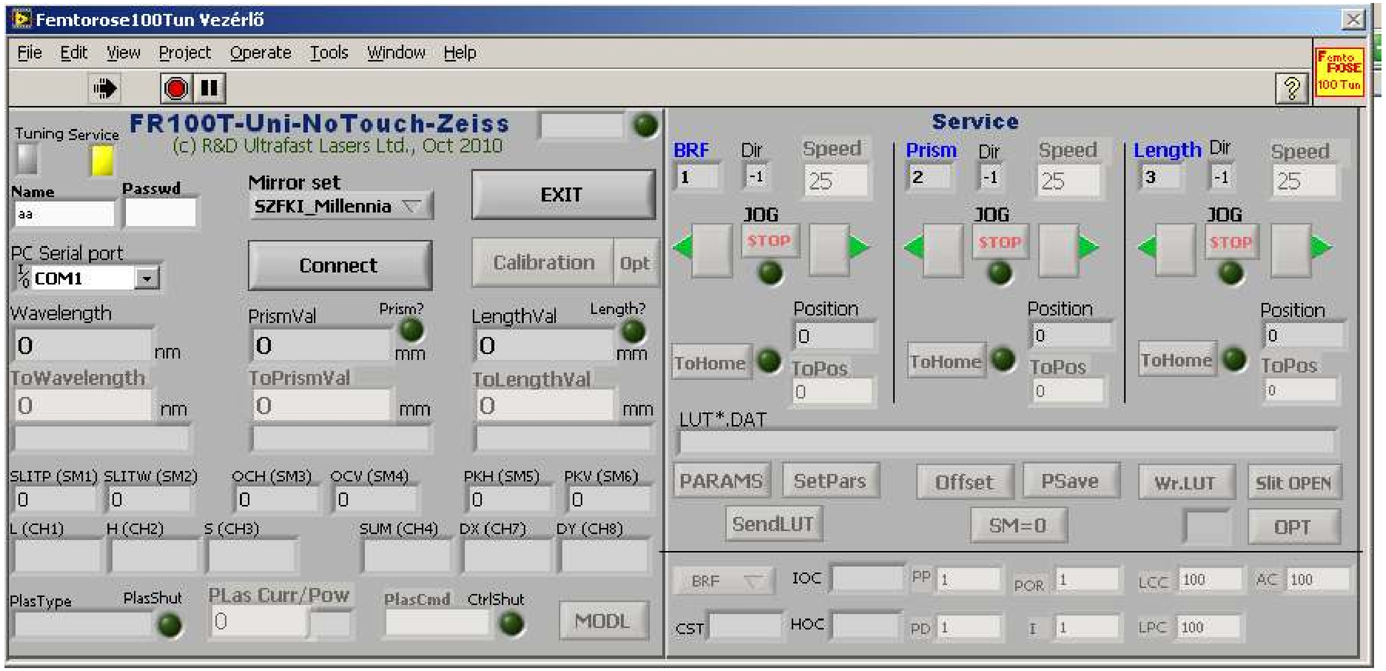
	Save	Display	Input Range	Offset	Subtract Offset	Merge Color
Channel 1	☑	☑	[-0.25 0.25	-3010	☑	Red
Channel 2	☑	☑	[-0.25 0.25	3799	☑	Red
Channel 3	☐	☐	[-1 1]	38	☑	Red
Channel 4	☐	☐	[-1 1]	931	☑	Red

Merge Display: ☐ Enable ☐ FOCUS only
☑ Auto Read
Colormap: Gray

MSE: 2.589E-8

LASER CONTROL (HW + SW)

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



FR100T-Uni-NoTouch-Zeiss
(c) R&D Ultrafast Lasers Ltd., Oct 2010

Name: aa
Passwd:
Mirror set: SZFKI_Millennia
PC Serial port: COM1
Wavelength: 0 nm
ToWavelength: 0 nm
PrismVal: 0 mm
Prism?
ToPrismVal: 0 mm
LengthVal: 0 mm
Length?
ToLengthVal: 0 mm

SLITP (SM1)	SLITW (SM2)	OCH (SM3)	OCV (SM4)	PKH (SM5)	PKV (SM6)
0	0	0	0	0	0

L (CH1) H (CH2) S (CH3) SUM (CH4) DX (CH7) DY (CH8)

PlasType
PlasShut
PLas Curr/Pow: 0
PlasCmd
CtrlShut

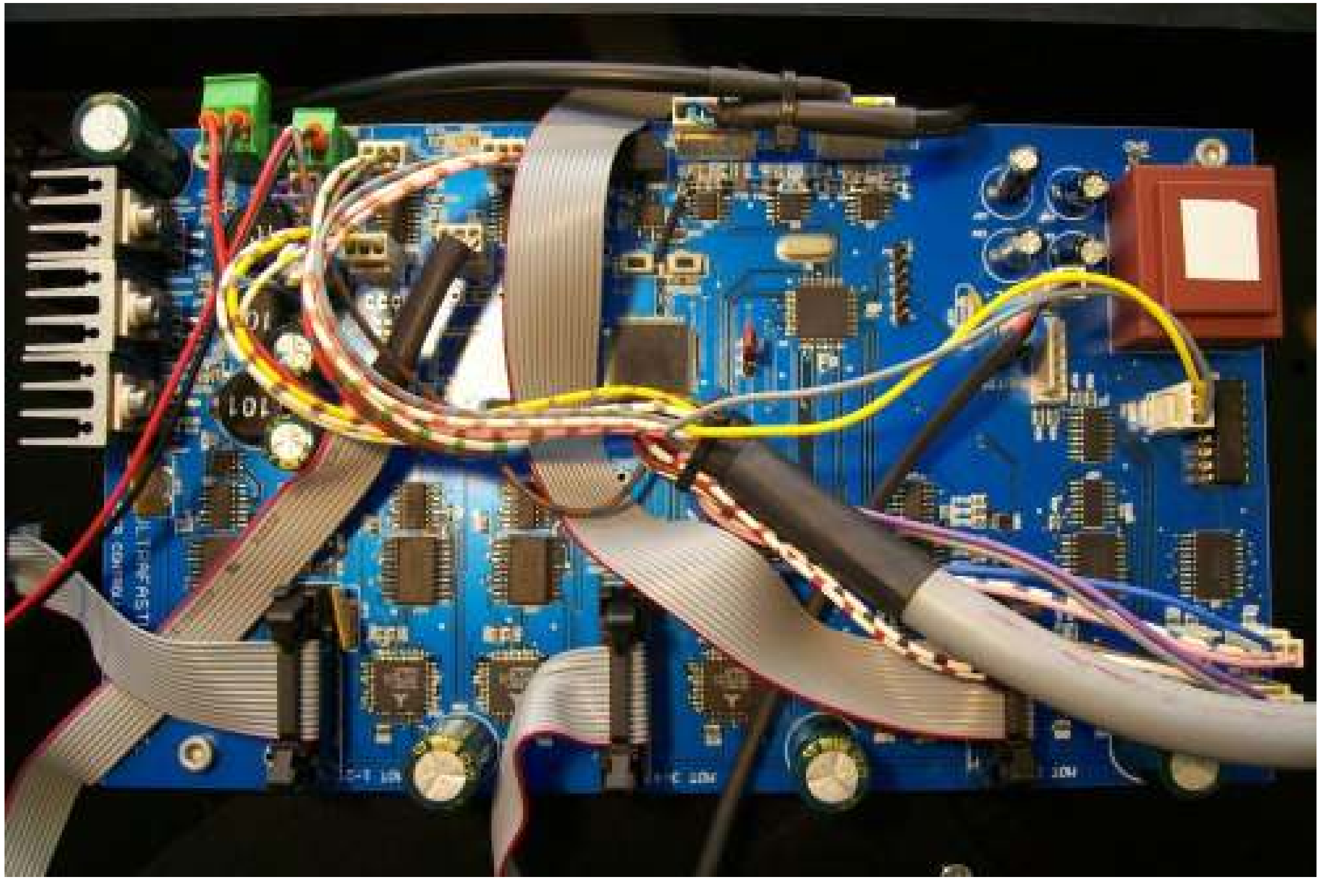
	BRF	Prism	Length
	1	2	3
Dir	-1	-1	-1
Speed	25	25	25
Position	0	0	0
ToPos	0	0	0

LUT*.DAT

BRF
IOC
CST
HOC
PP: 1
PD: 1
POR: 1
I: 1
LCC: 100
LPC: 100
AC: 100

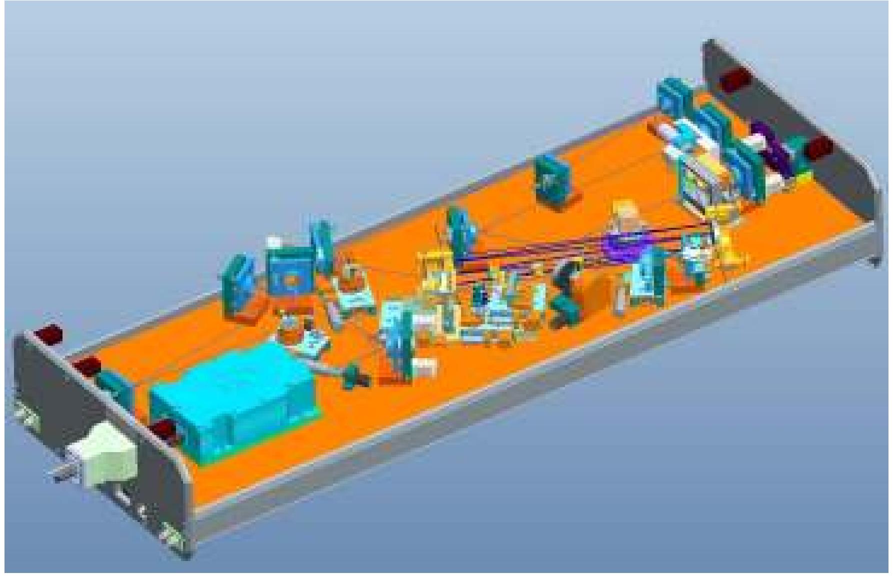
ELECTRONICS

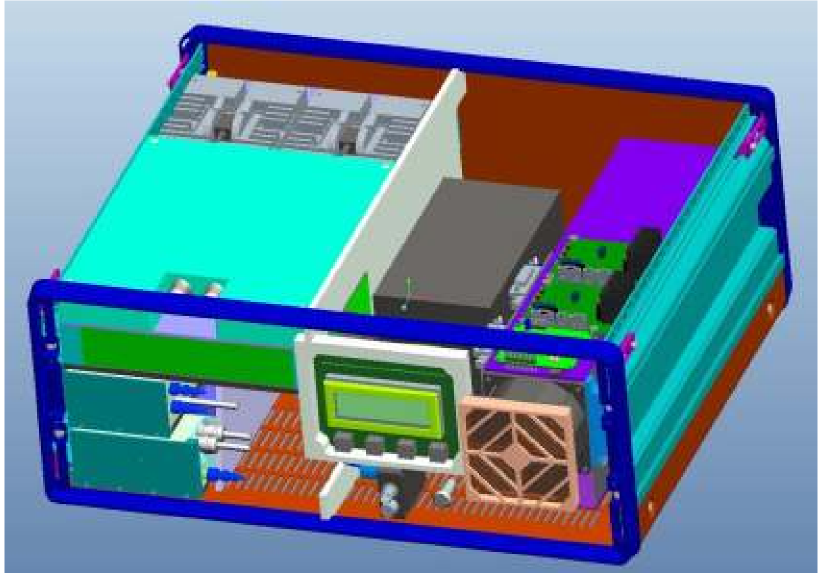
PCB-s with ARM and PIC microcontrollers



MECHANICS

Mechanics for solid state and fiber lasers





ProEngineer models for CNC manufacturing

Femtosecond Lasers for Nonlinear Microscopy Research Group

(Principal investigator: Robert Szipőcs, Ph.D.)

● **Research and development of ultrafast (ps, or fs) pulse solid state or optical fiber lasers for applications in *in vivo* 3D nonlinear microscopy**

Our aim is to develop laser systems that improve the quality of imaging (e.g. imaging depth, resolution), support easier handling (held-held imaging systems, fiber integration) or minimize the risk of thermal or photochemical damage of the living tissue.

● **Main R&D results:**

- **Development of a long cavity, sub-ps pulse, tunable Ti-sapphire laser operating at ~22 MHz repetition rate utilizing a piezo controlled GTI for intracavity dispersion control**
- **Development of an all-fiber Yb-fiber oscillator and amplifier laser operating at ~2 MHz repetition rate and delivering ~0.5 ps pulses**
- **Development of a two-wavelength sub-ps pulse laser system for CARS imaging applications.**

The research group involved in **development and applications of different label free imaging techniques (2PEF, SHG, CARS, FLIM)** in the fields of **dermatology, neurology and metabolic research** with its partners at **Semmelweis University** (SE), **Szeged University** (SZTE) and **University of Sports Science** (TF), respectively.

Femtosecond Lasers for Nonlinear Microscopy Research Group

(Principal investigator: Robert Szipőcs, Ph.D.)

Publications of the group

[1] Cserép C, Pósfai B, Lénárt N, Fekete R, László ZI, Lele Z, Orsolits B, Molnár G, Heindl S, Schwarcz AD, Ujvári K, Környei Z, Tóth K, Szabadits E, Sperlágh B, Baranyi M, Csiba L, Hortobágyi T, Maglóczky Z, Martinecz B, Szabó G, Erdélyi F, **Szipőcs R**, Tamkun MM, Gesierich B, Duering M, Katona I, Liesz A, Tamás G, Dénes Á. *Microglia monitor and protect neuronal function through specialized somatic purinergic junctions*. **Science**. 367(6477):528-537. (2020).

[2] **L. Fésűs, Á. Krolopp**, G. Molnár, N. Kiss, G. Tamás, and **R. Szipőcs**, "*A 20 MHz, sub ps, Tunable Ti:sapphire Laser System for Real Time, Stain Free, High Contrast Histology of the Skin,*" in **Biophotonics Congress: Biomedical Optics 2020**, OSA Technical Digest (Optica Publishing Group, 2020), paper MTh3A.4. (2020).

[3] **Á. Krolopp, L. Fésűs, G. Szipőcs, N. Wikonkál, and R. Szipőcs**, "*Fiber coupled, 20 MHz Repetition Rate, sub ps Ti:sapphire Laser for in vivo Nonlinear Microscopy of the Skin,*" in **Biophotonics Congress 2021**, OSA Technical Digest (Optical Society of America, 2021), paper DF2A.5. (2021).

[4] **L. Fésűs, N. Wikonkál, and R. Szipőcs**, "*Numerical Analysis on ex vivo Second Harmonic Generation Images of Collagen Structure of Unstained Basal Cell Carcinoma Sections*," in **European Conferences on Biomedical Optics 2021** (ECBO), OSA Technical Digest (Optical Society of America, 2021), paper EW4A.9. (2021).

[5] **L. Fésűs**, D. Plázár, **A. Kolonics**, L. Martin, **N. Wikonkál**, M. Medvecz, and **R. Szipőcs**, "*Low concentration Phloxine B staining for high chemical contrast, nonlinear microscope mosaic imaging of skin alterations in pseudoxanthoma elasticum*," **Biomed. Opt. Express** 13, 252-261 (2022).

[6] **A. Kolonics**, T. Kawamura, **R. Szipőcs**, Zs. Radák, „*Accelerated epigenetic changes may contribute to the development of metabolic syndrome revealed by NADH FLIM*", 13th MiPschool, Obergurgl, Austria,(2023).

[7] **G. Szipőcs, Á. Krolopp**, S. P. Chong, P. Török, and **R. Szipőcs**, "**Low Reflection Loss Dispersion Compensation Scheme for Broadly Tunable sub-ps Solid State Lasers**," in **CLEO 2023**, Technical Digest Series (Optica Publishing Group, 2023), paper JTh2A.121. (2023).

[8] **Á. Krolopp, L. Fésűs, G. Szipőcs, N. Wikonkál, R. Szipőcs R**. A 20 MHz Repetition Rate, Sub-Picosecond Ti-Sapphire Laser for Fiber Delivery in Nonlinear Microscopy of the Skin. Life (Basel)., **14**(2) 231 (2024).