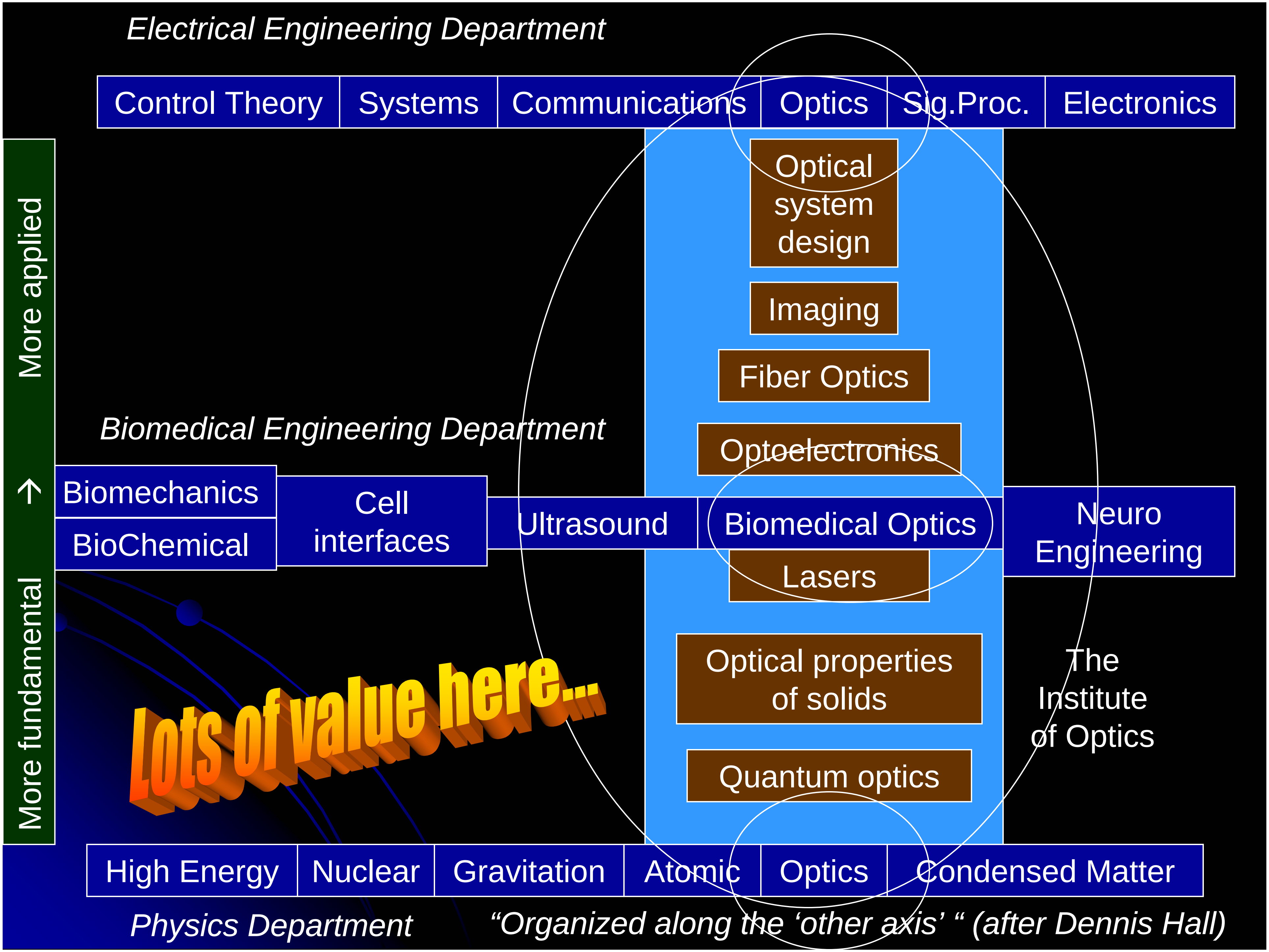
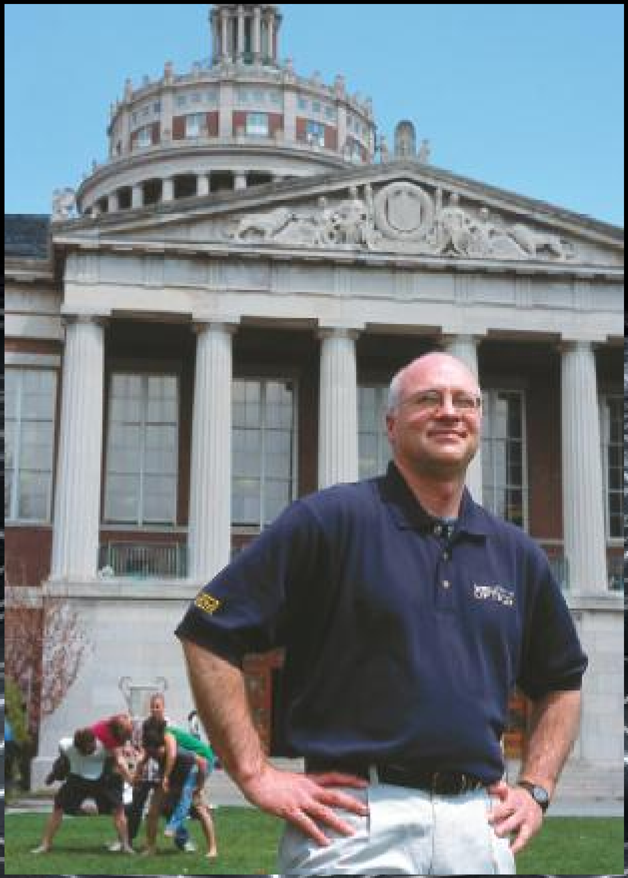

Electrical Engineering Department
Control Theory
Systems
Communications
Optics
Sig.Proc.
Electronics
More applied
More fundamental
Optical system design
Imaging
Fiber Optics
Biomedical Engineering Department
Optoelectronics
Biomechanics
BioChemical
Cell interfaces
Ultrasound
Biomedical Optics
Neuro Engineering
Lasers
Optical properties of solids
The Institute of Optics
Lots of value here...
Quantum optics
High Energy
Nuclear
Gravitation
Atomic
Optics
Condensed Matter
Physics Department
“Organized along the ‘other axis’ “ (after Dennis Hall)

Ultrafast Science and Technology in the W.H. Knox Research Group



Ultrafast laser technology:

Scalable in rep rate, wavelength, pulsewidth, compact, high efficiency, low noise, CEP locking...etc...

Photonic crystal fiber technology:

Dispersion micromanagement, high nonlinearity fibers, continuum generation, solitons, single-cycle pulse regime

Ultrafast Manufacturing:

Subwavelength structuring of polymers, novel devices, etc...

Biomedical Optics:

fs cell transfection, retinal imaging via femtosecond technology using adaptive optics

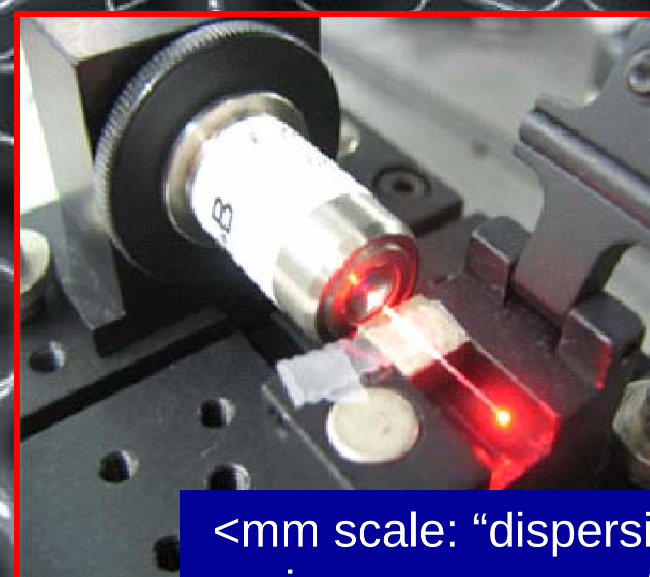
Funding: NYSTAR, B&L, CEIS, NIH, etc.

Dispersion Micro-management in Ultrashort Tapered Optical Fibers: A New Knob to Tweak

Wayne H. Knox
Director and Professor of Optics
The Institute of Optics
University of Rochester
Rochester, NY 14627

km scale dispersion management

Meter scale dispersion management



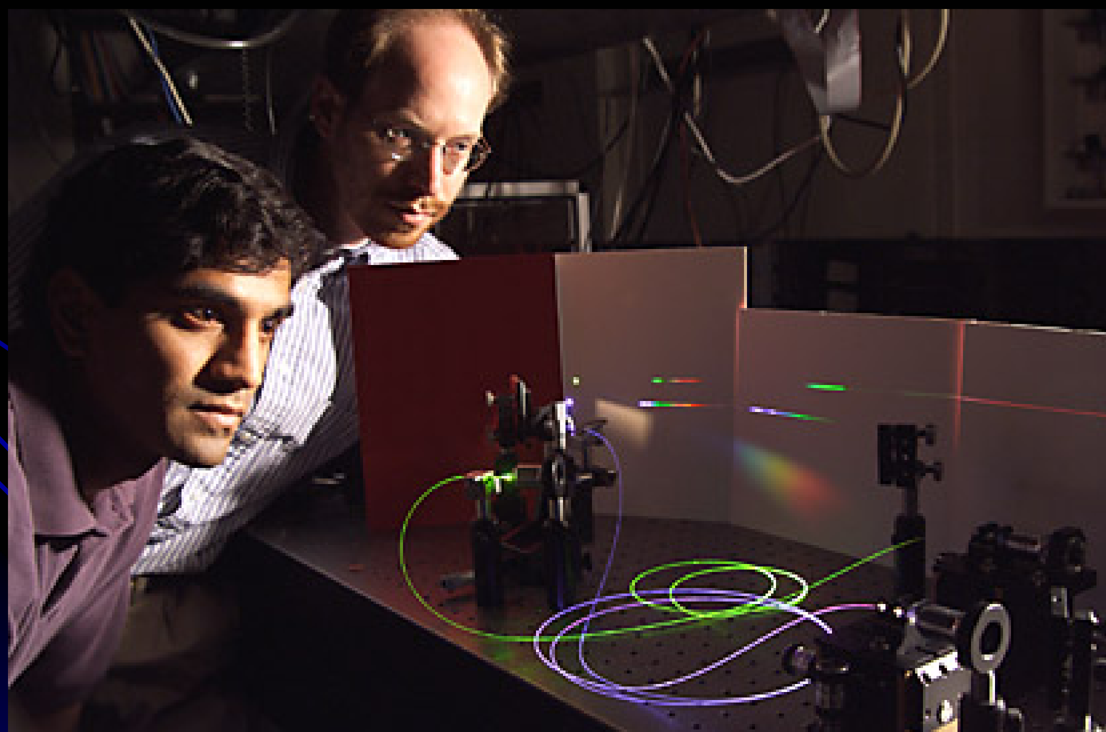
<mm scale: “dispersion micro-management”

January 1, 2000 / Vol. 25, No. 1 / OPTICS LETTERS 25

Visible continuum generation in air–silica microstructure optical fibers with anomalous dispersion at 800 nm

Jinendra K. Ranka, Robert S. Windeler, and Andrew J. Stentz

Bell Laboratories, Lucent Technologies, 700 Mountain Avenue, Murray Hill, New Jersey 070974



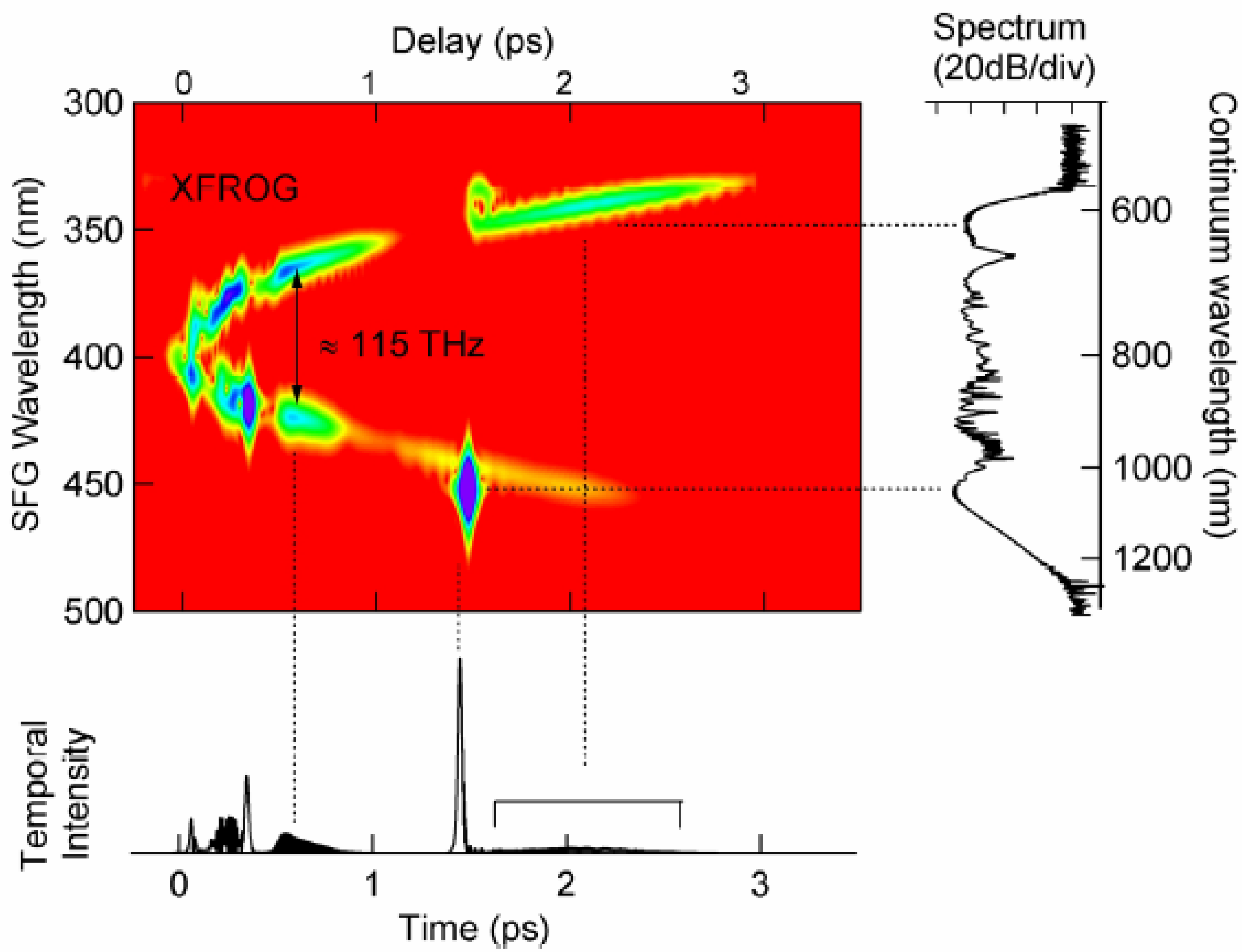


Fig. 3. (917 KB) Calculated XFROG trace with its structure correlated with the intensity and spectrum showing evolution with propagation distance. Note the nonlinear wavelength axis used in the plot of the fundamental SC spectrum.

Dudley et. al OPEX 21 October 2002 / Vol. 10, No. 21 / OPTICS EXPRESS 1215

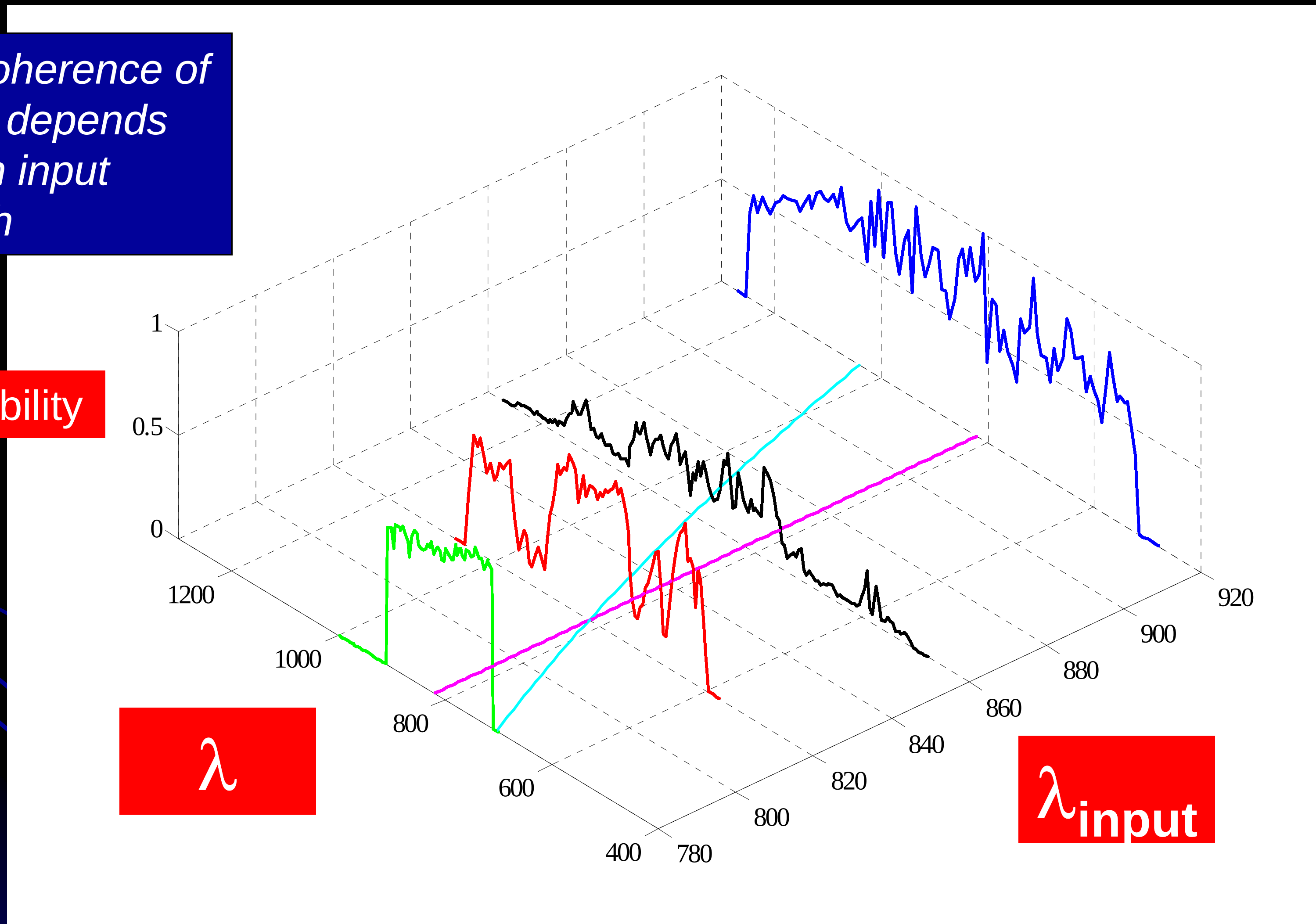
Why should we care about noise in continuum sources ?

- A limitation in Optical Coherence Tomography, where source can give < 1 micron coherence length… (Fujimoto et al.)
- A limitation in precision frequency metrology… (Cundiff et al.)
- A limitation in telecommunications for WDM sources…(WHK or CX, et al.)

As much as 20 dB excess noise has been reported

Generation of a broadband continuum with high spectral coherence in tapered single-mode optical fibers, Optics Express, Vol. 12 Issue 2 Page 347 (January 2004), Fei Lu, Wayne H. Knox

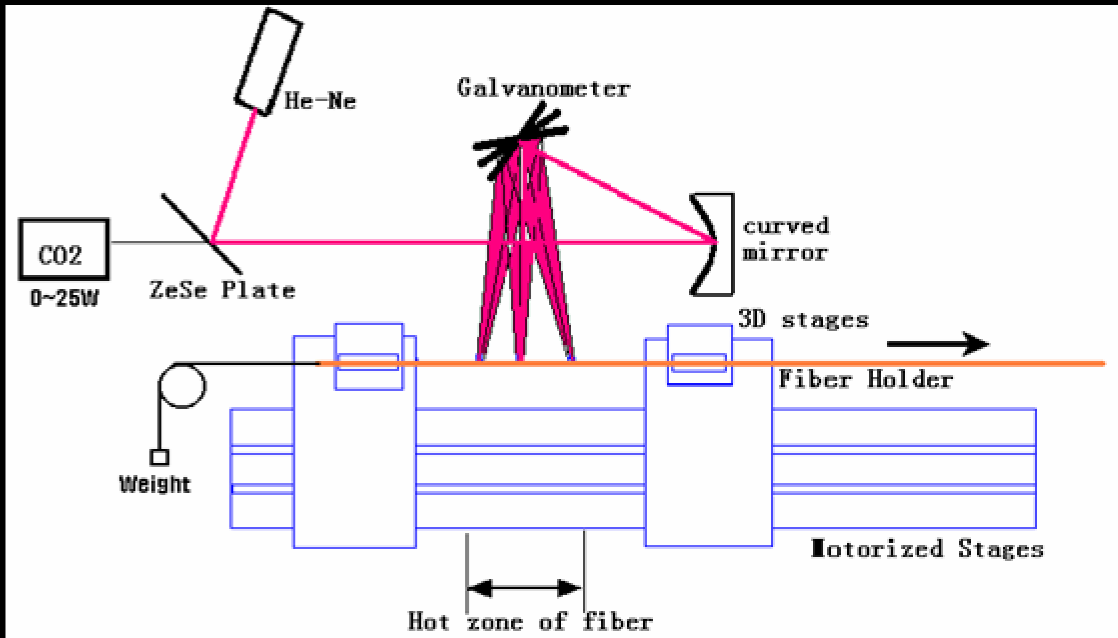
Spectral coherence of continuum depends strongly on input wavelength



Optimizing dispersion profile along axis may be the key to generating low noise continuum !

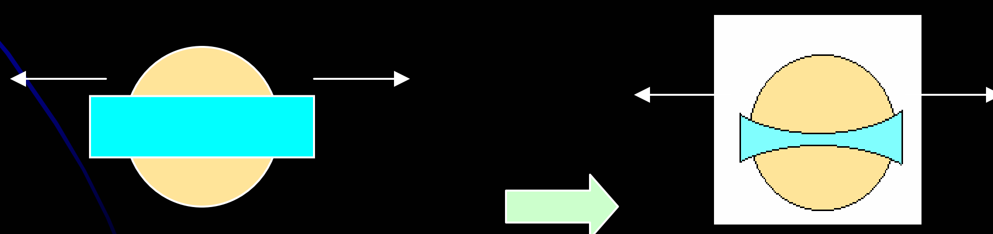
Setup for CO_2 Laser Tapering with self-regulation

1. Galvo scan/computer
2. Self-regulation
3. 1D stepper control



- Up to 30 cm long…
- Down to 2 microns
- Loss as low as 1.6 dB

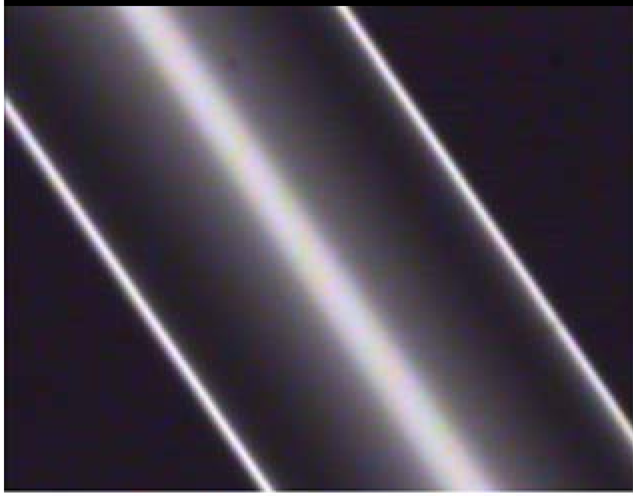
Self Regulation Tapering:



Heat Absorption>> Dissipation

Heat Absorption = Dissipation

Why Micro-Manage Dispersion ?



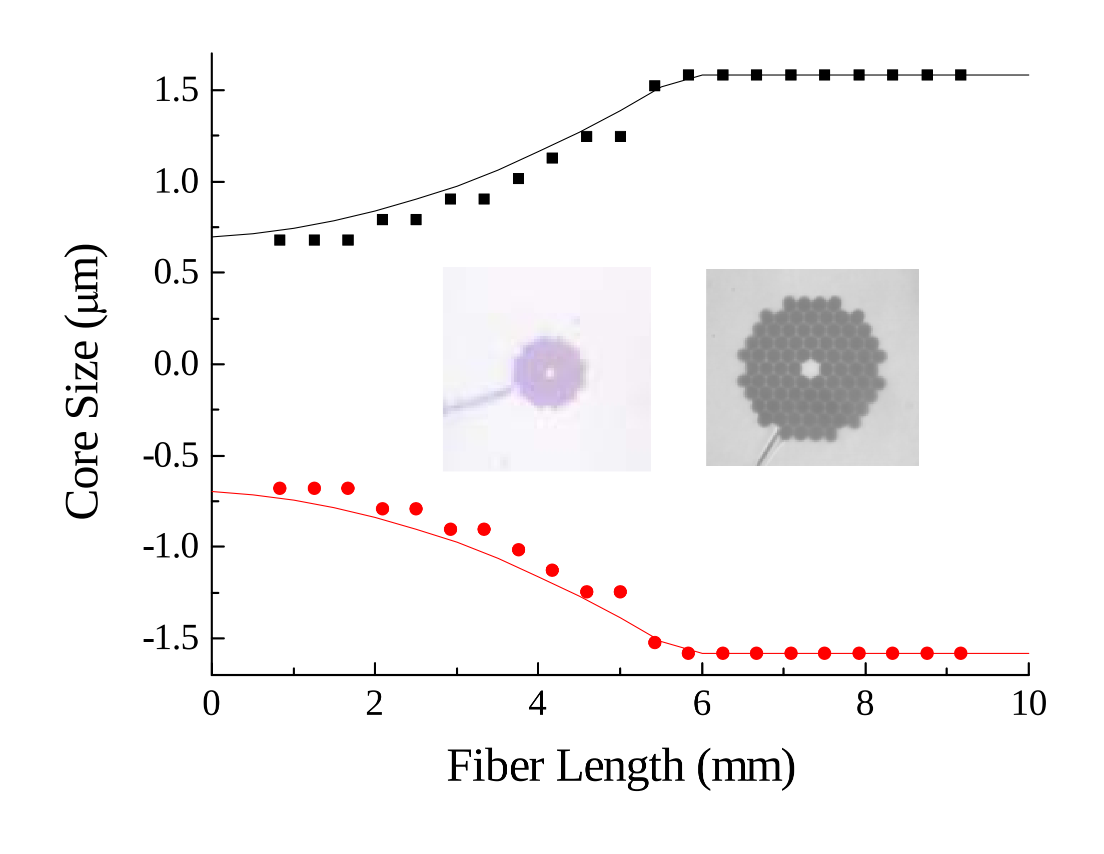
D =125um SMF28 Fiber

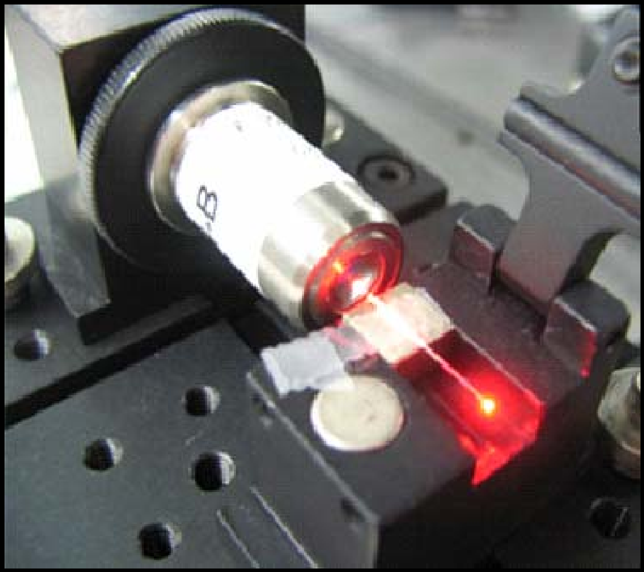
Taper Transitional Region

D = 3um Tapered Fiber

- *Because we can !*
- *Because at high intensities, the nonlinear phase in only 1 mm propagation length with a 2.5 micron core size is $\pi/4$!!*
- *Should be very important with very short pulses like <10 fs …*

We fabricated a parabolically tapered holey fiber 1 cm long from : Blaze NL 3.3 -880

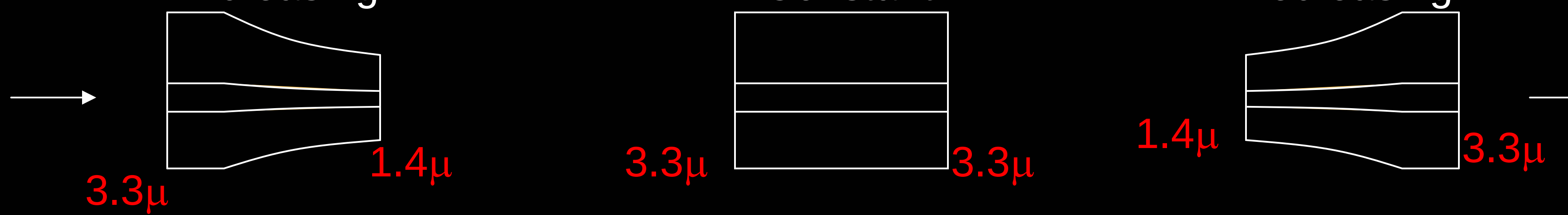


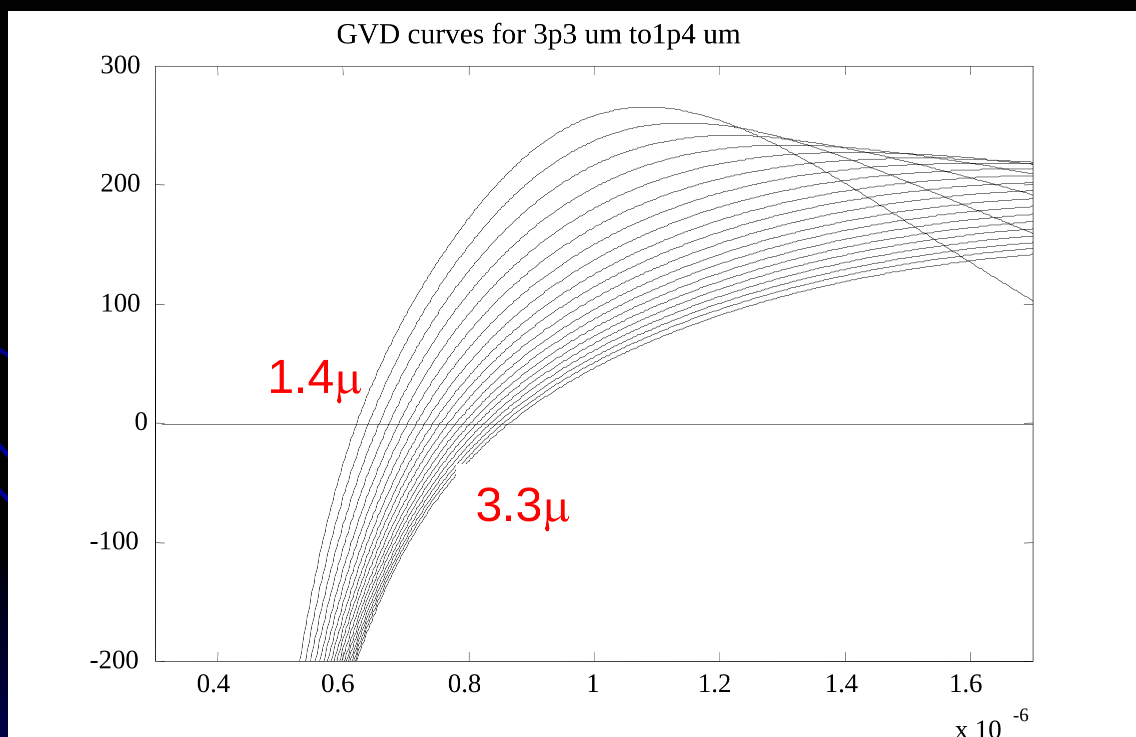


<mm scale: “dispersion micro-management”

Three configurations

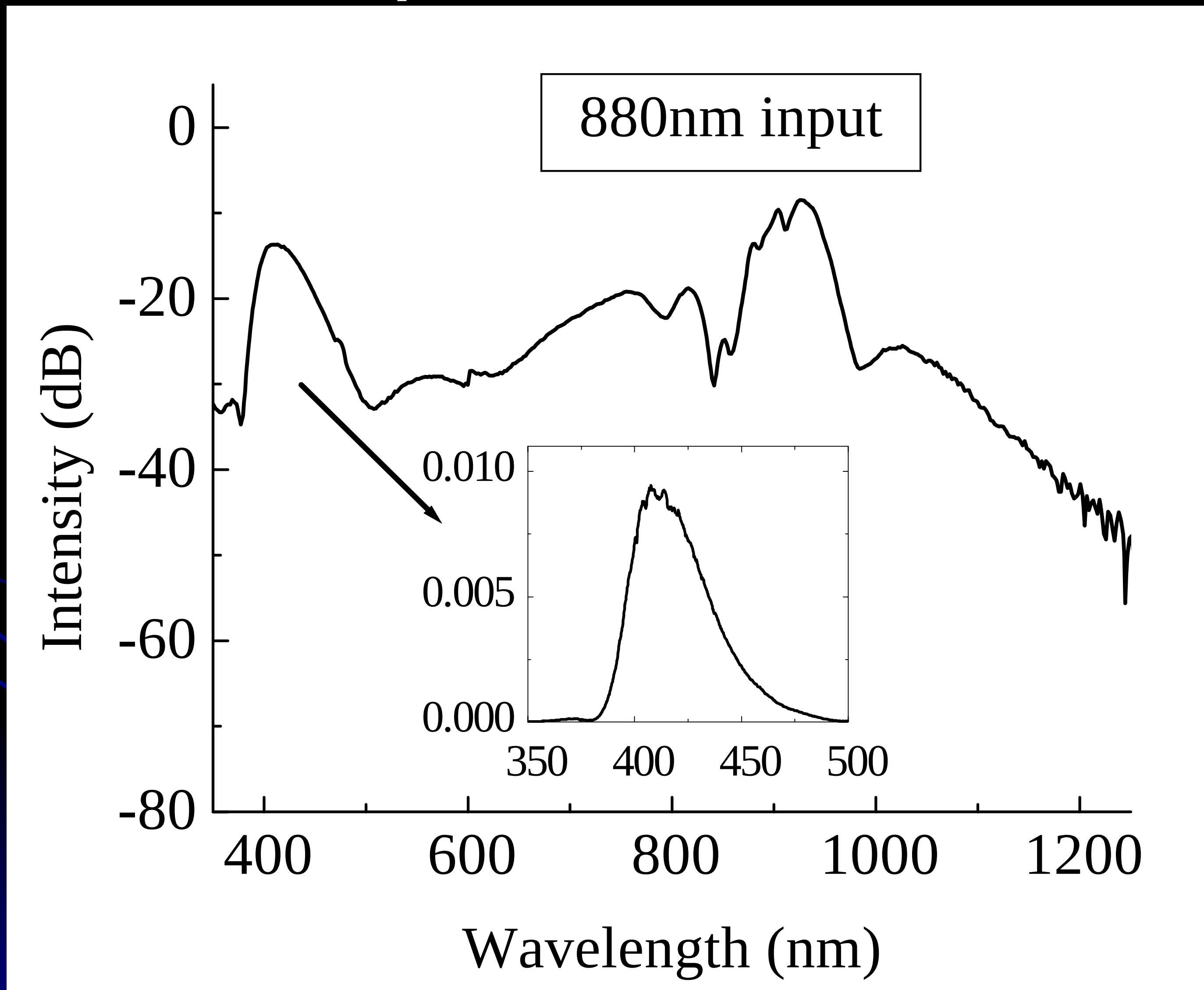
"Forward" Dispersion Increasing | Dispersion Constant | "Backward" Dispersion Decreasing

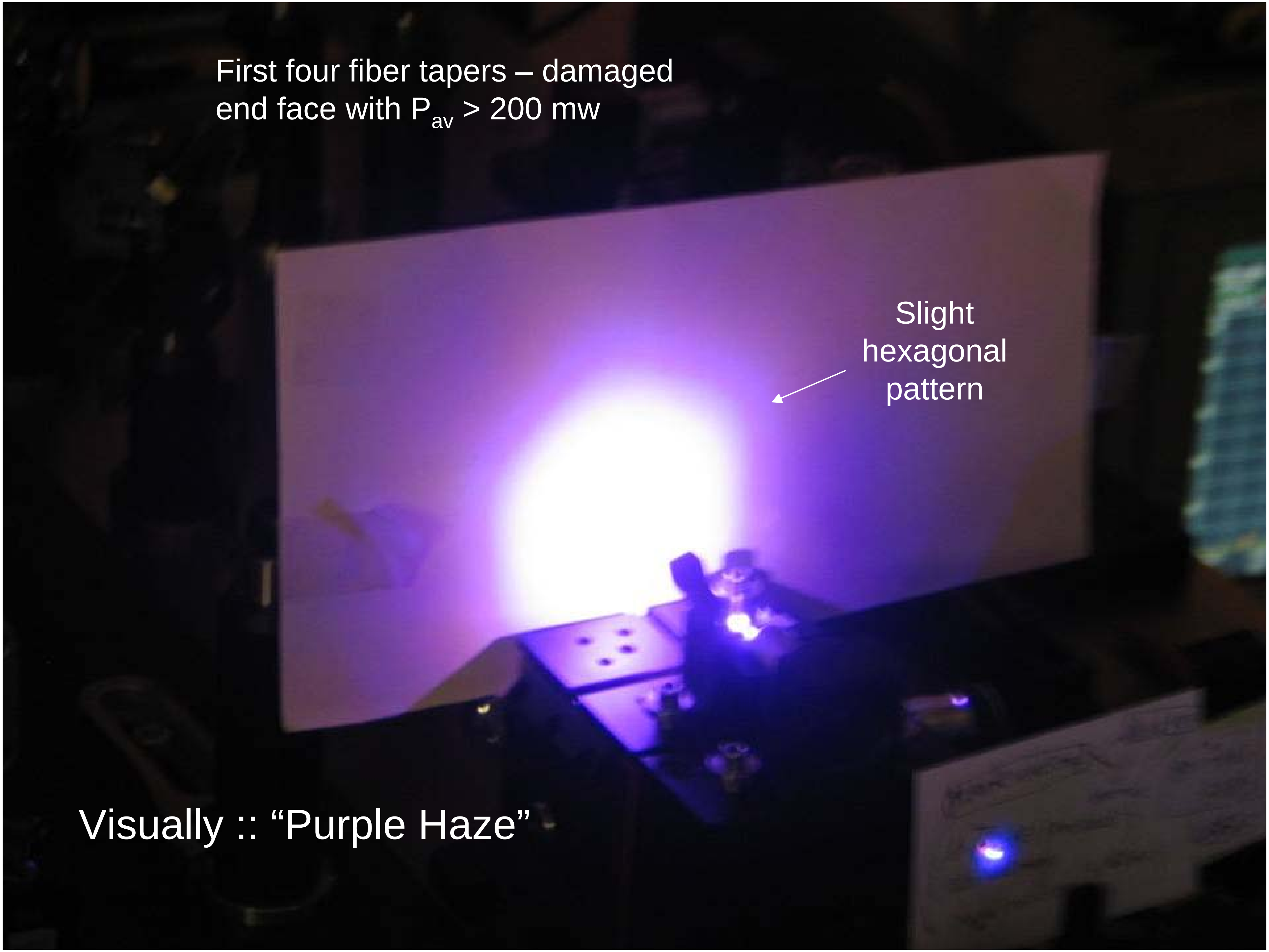


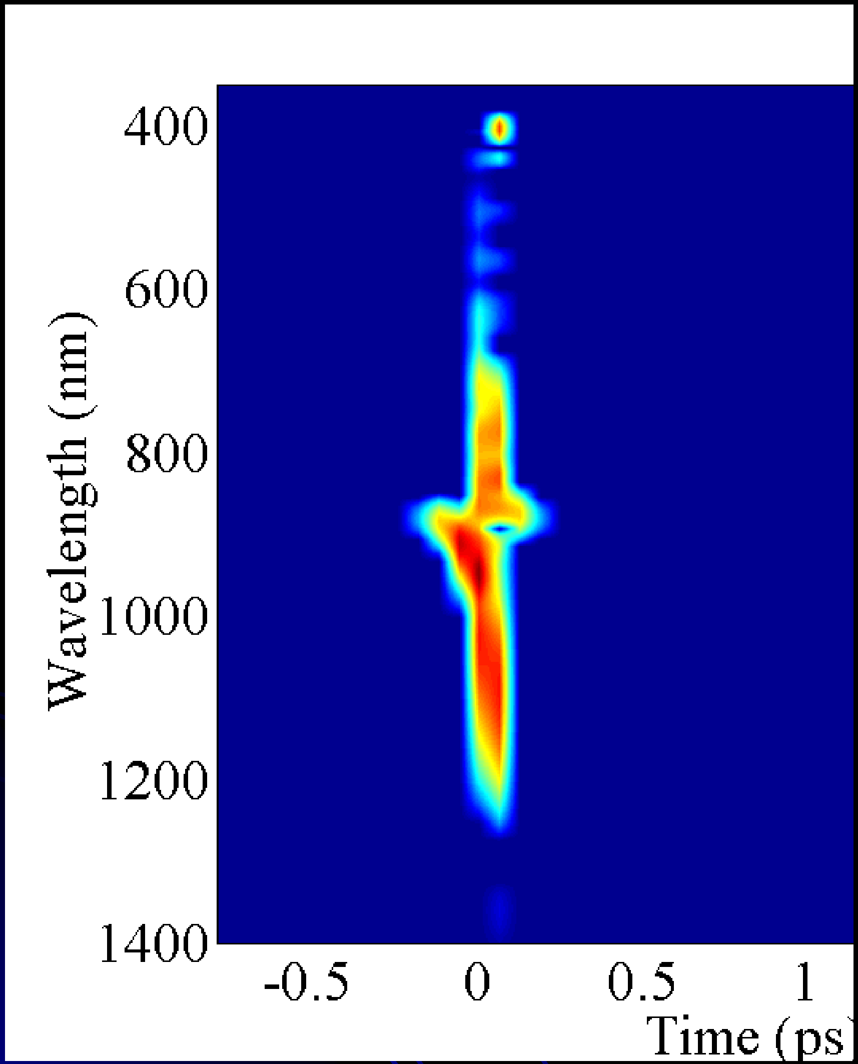


Average power: 150 mw

First experimental results




First four fiber tapers – damaged end face with P_{av} > 200 mw
Slight hexagonal pattern
Visually :: “Purple Haze”



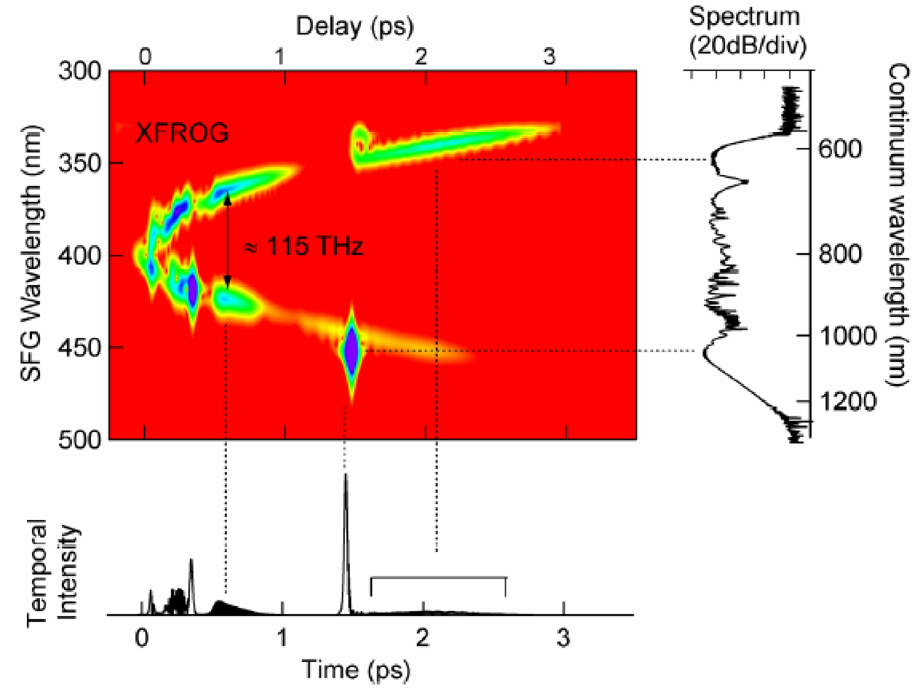
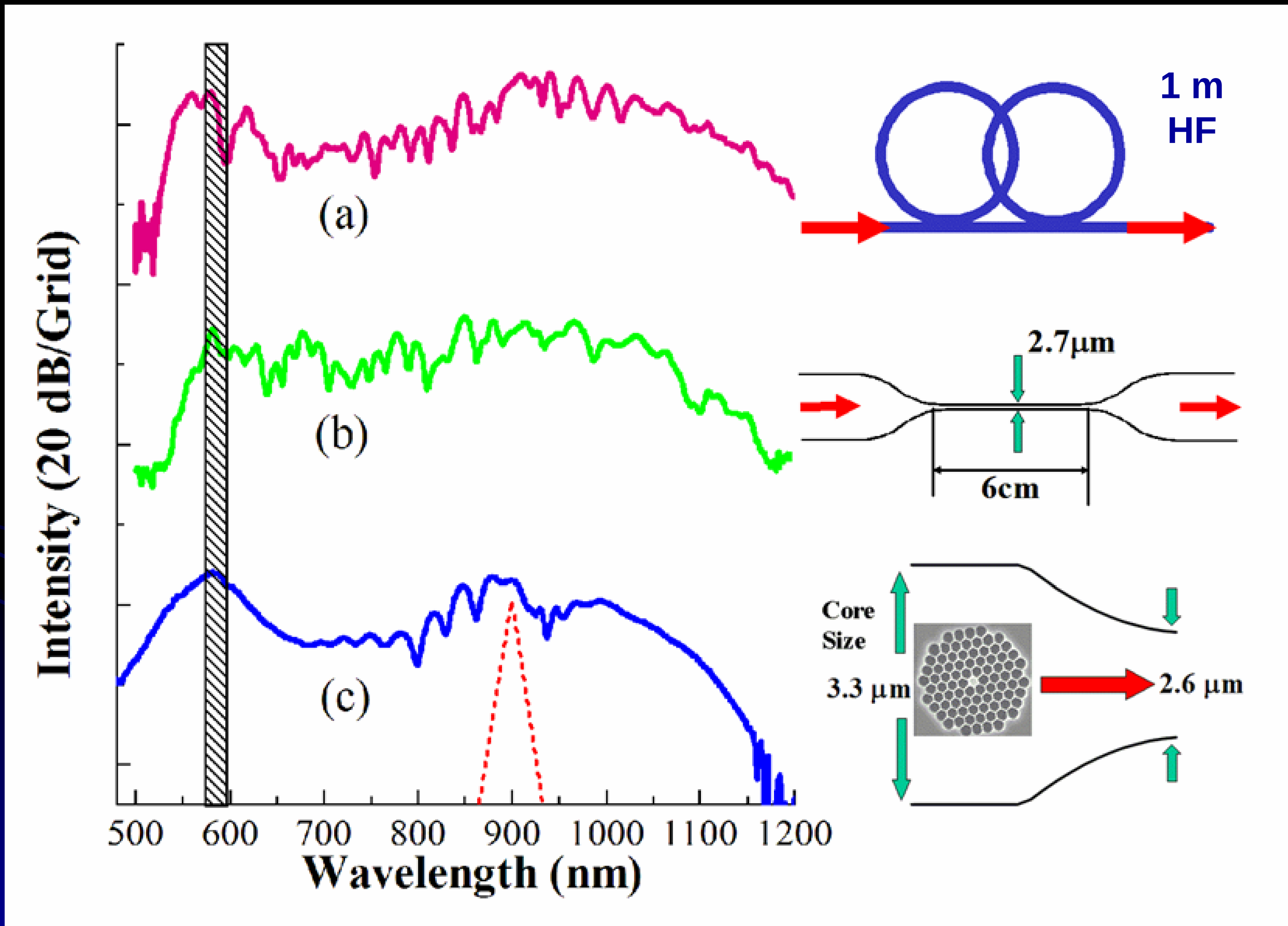
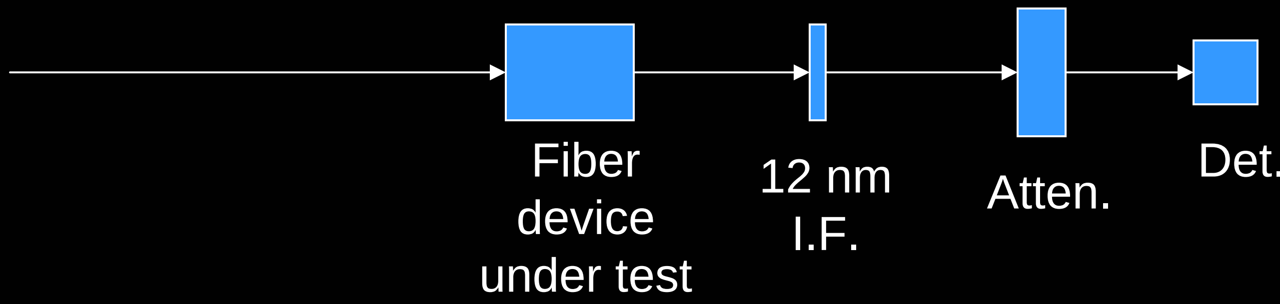


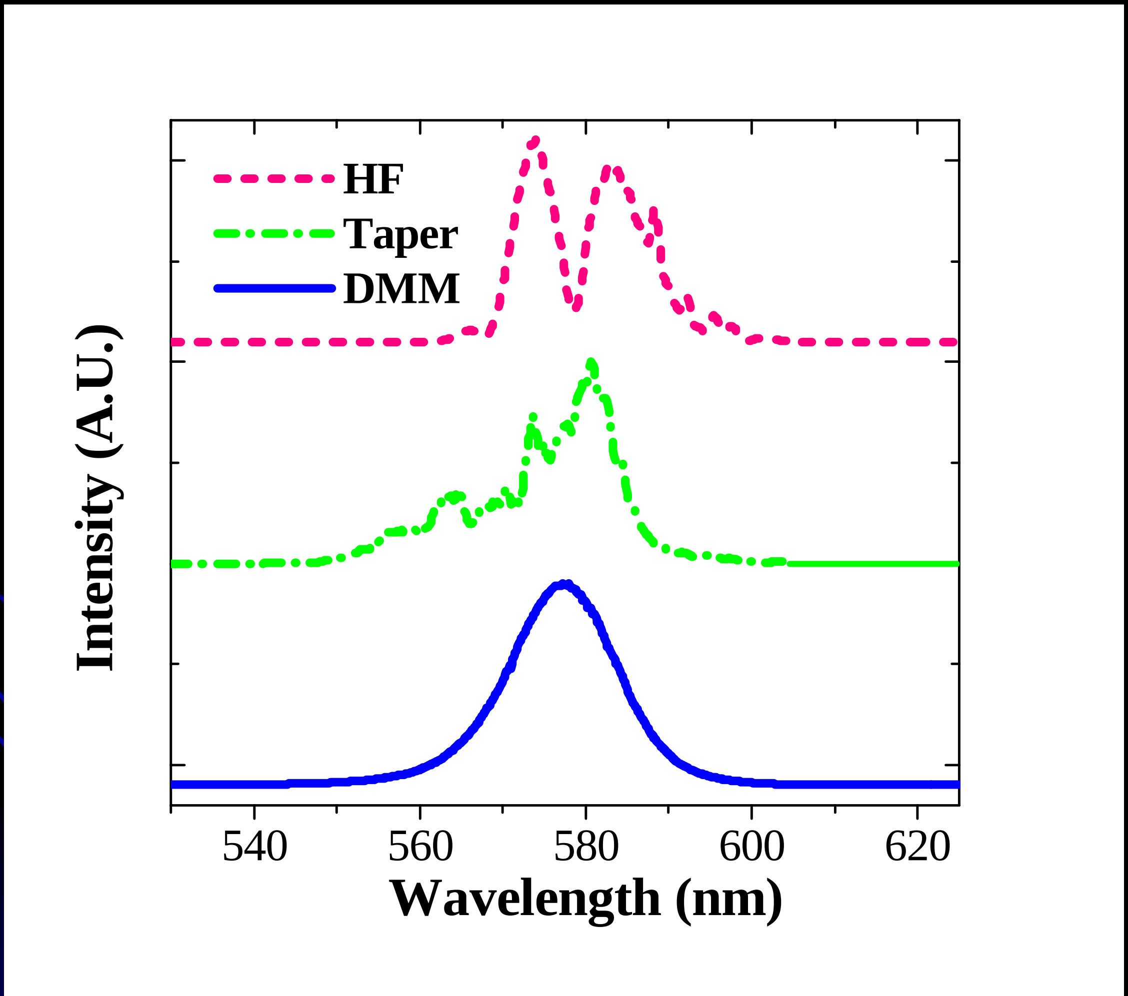
Fig. 3. (917 KB) Calculated XFROG trace with its structure correlated with the intensity and spectrum showing evolution with propagation distance. Note the nonlinear wavelength axis used in the plot of the fundamental SC spectrum.

Dudley et. al OPEX 21 October 2002 / Vol. 10, No. 21 / OPTICS EXPRESS 1215

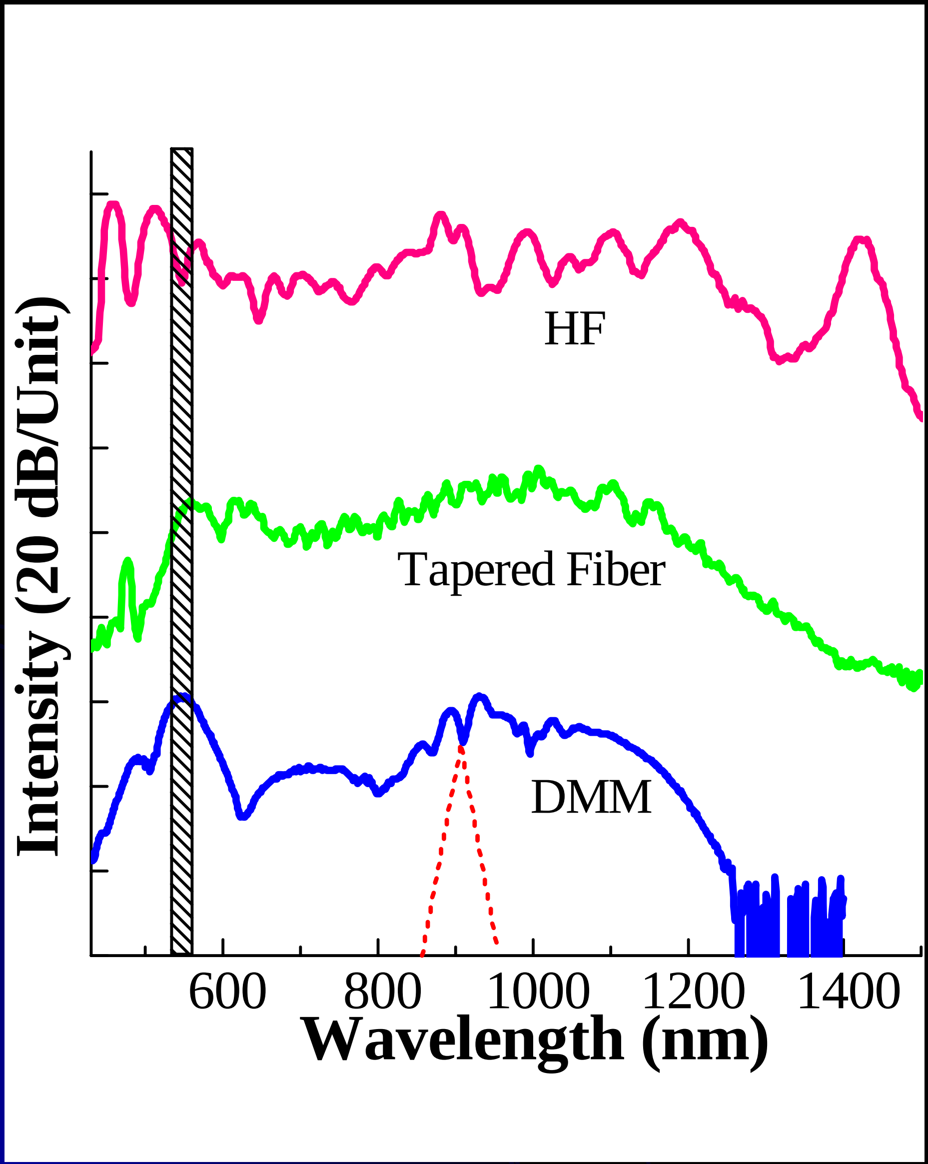
Comparison of wavelength shifting from 900 nm to 580 nm

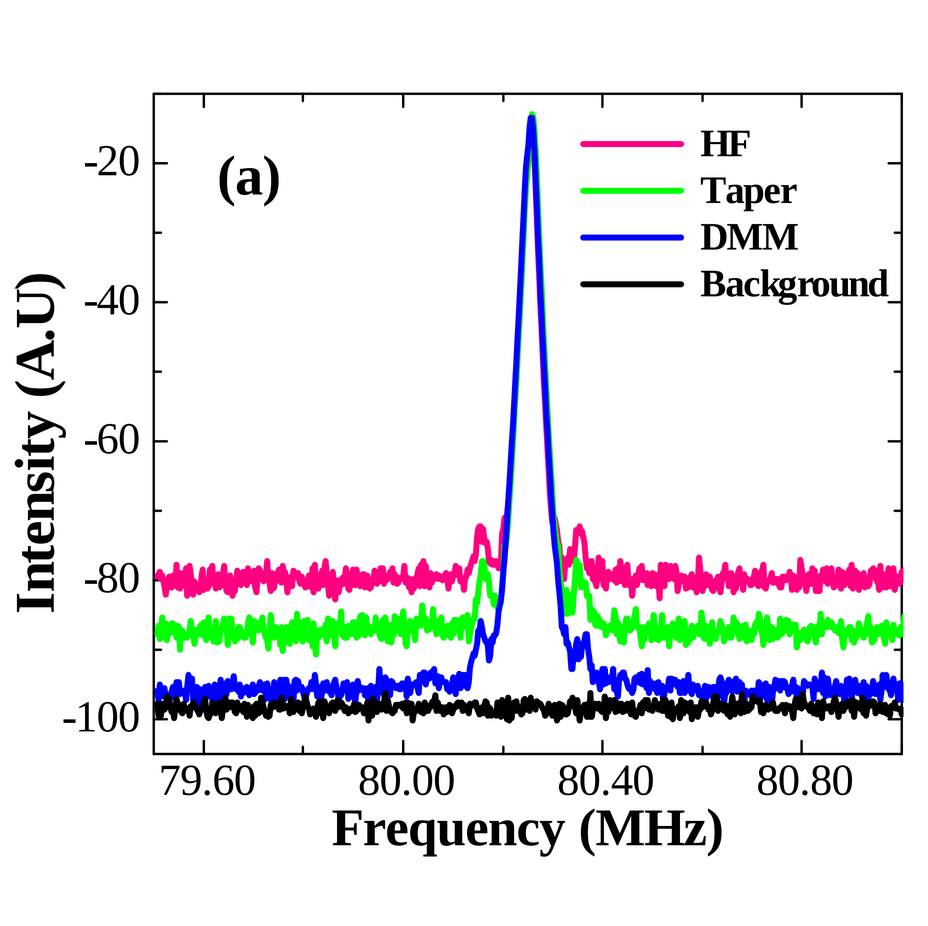



Fiber device under test
12 nm I.F.
Atten.
Det.

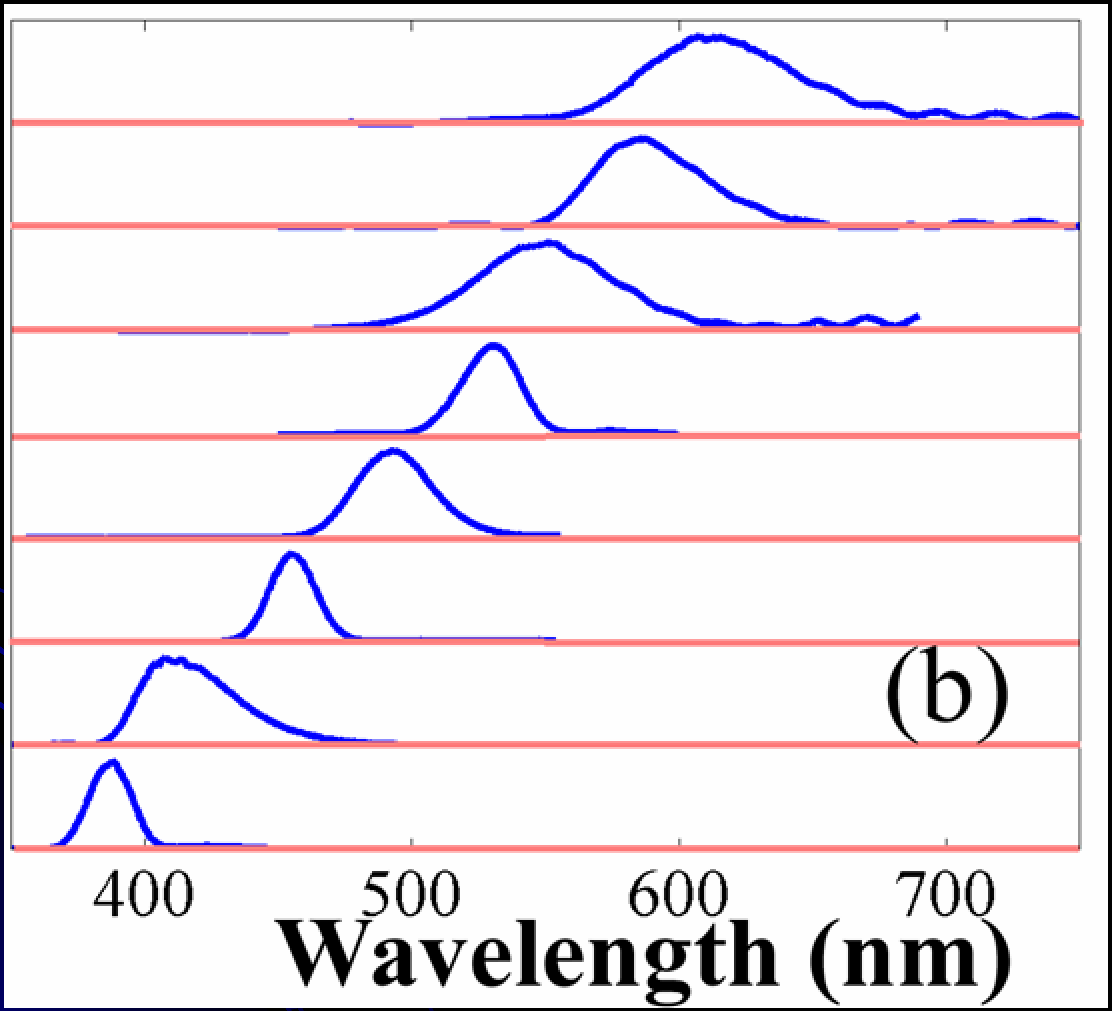

HF
Taper
DMM
Intensity (A.U.)
540
560
580
600
620
Wavelength (nm)

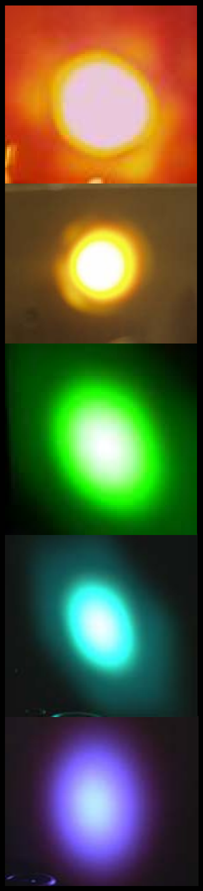
535 nm slice – RF noise comparisons





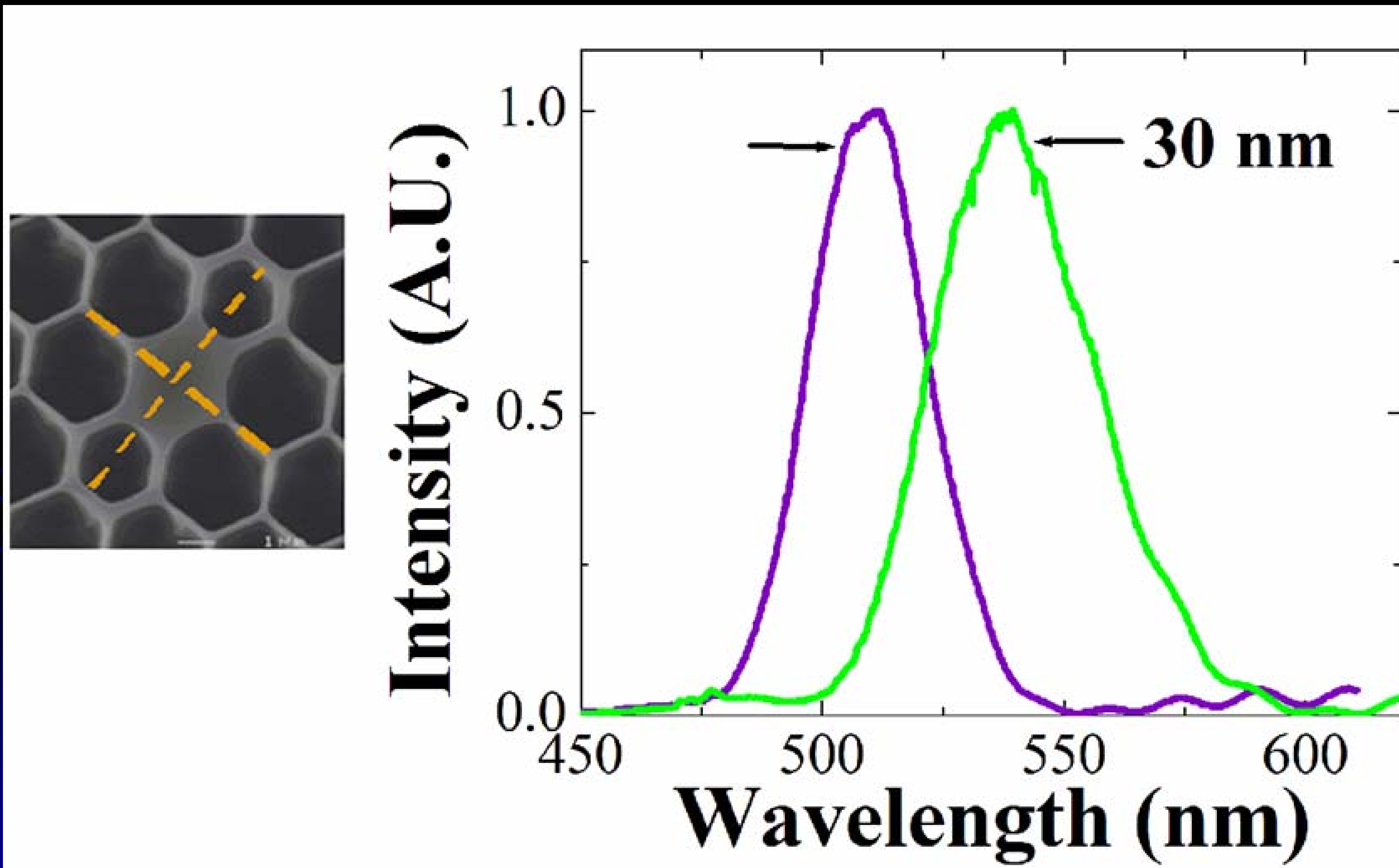
Tunability of AS feature by varying taper diameter



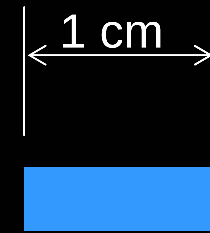


Up to 20% conversion...

Tapering PM fiber adds flexibility



Three regimes of dispersion management

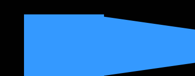


- No dispersion micro-management

  narrow AS feature, narrowband phase-matching

- “Slow” dispersion micro-management (5-10 mm)

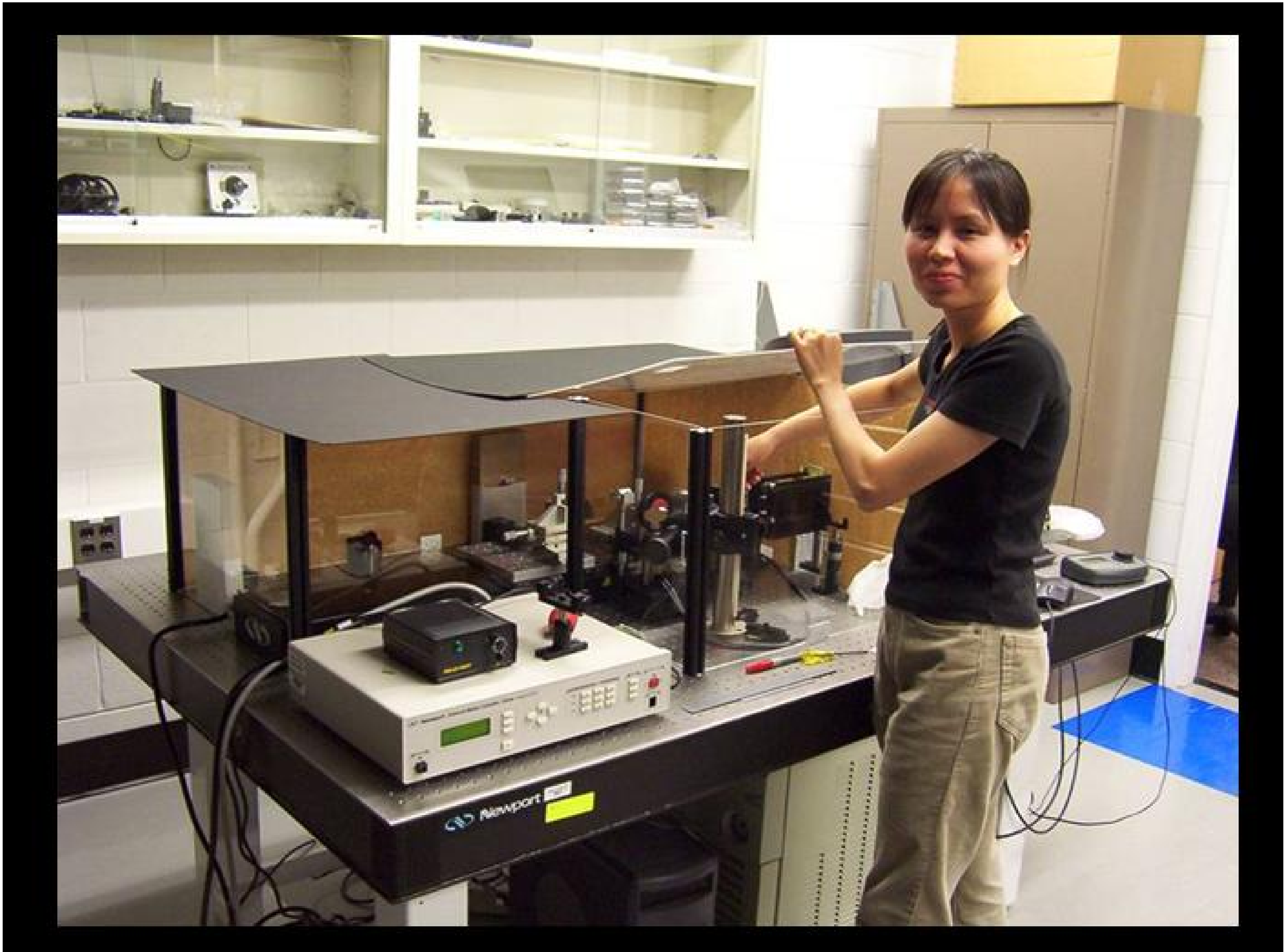
  broader AS features, broader phase-matching, but retains high coherence and low noise



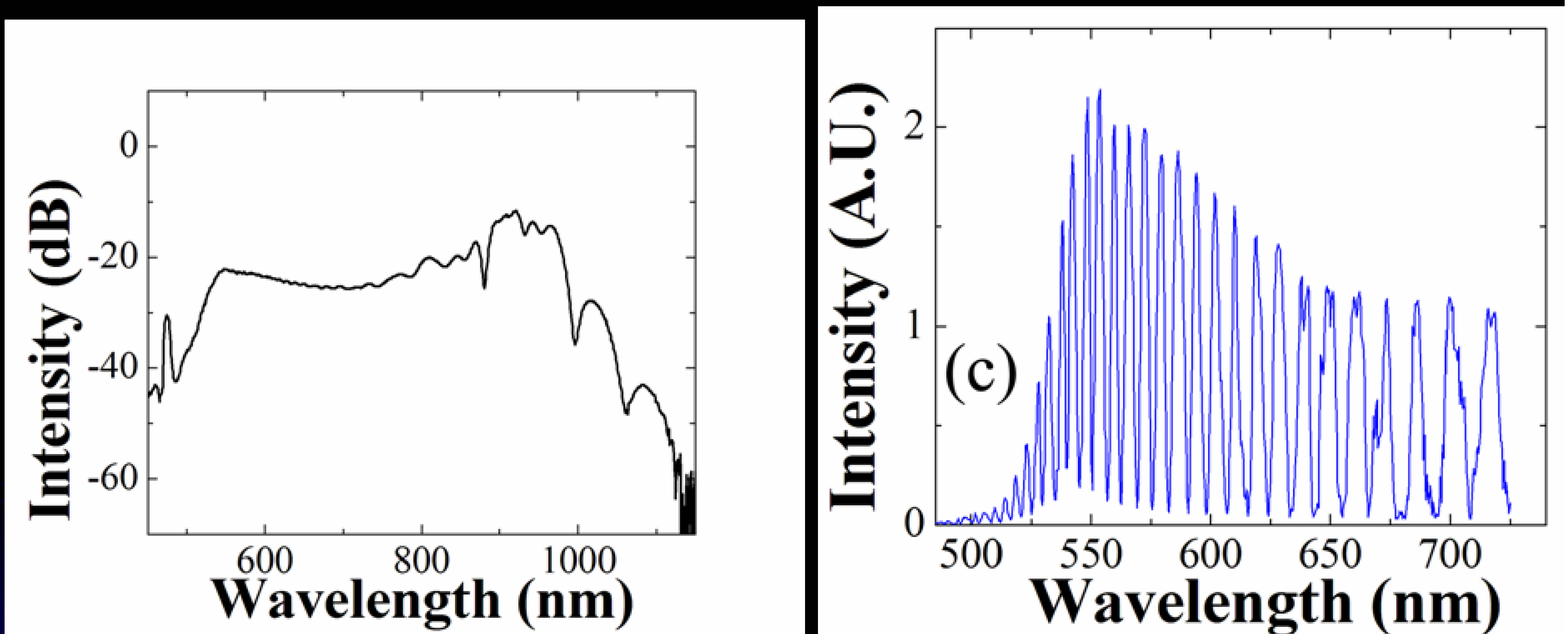
- “Rapid” dispersion micro-management (<1mm)

  can we generate broader AS features “sub-continuum” yet retain full coherence and low noise ?

(note a holy grail here........)

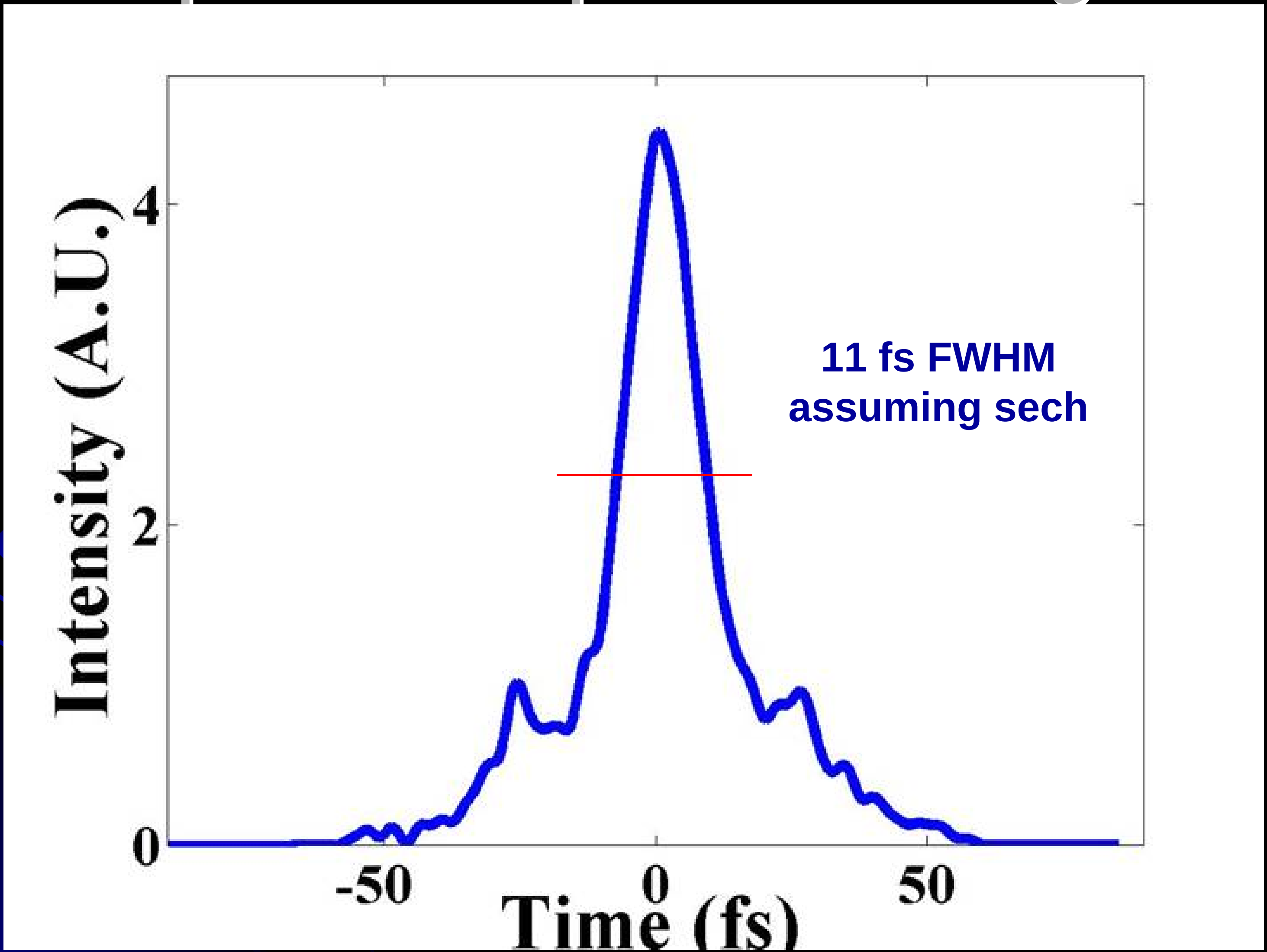

Newport

Broadband high coherence generation



- *Ultrabroad very high spectral coherence white light*
- *DMM length is <1mm*
- *Compressed to 11 fs with fused silica prism pair*
- *Fei Lu, Yujun Deng and WHK Tucson October OSA Meeting 2005*

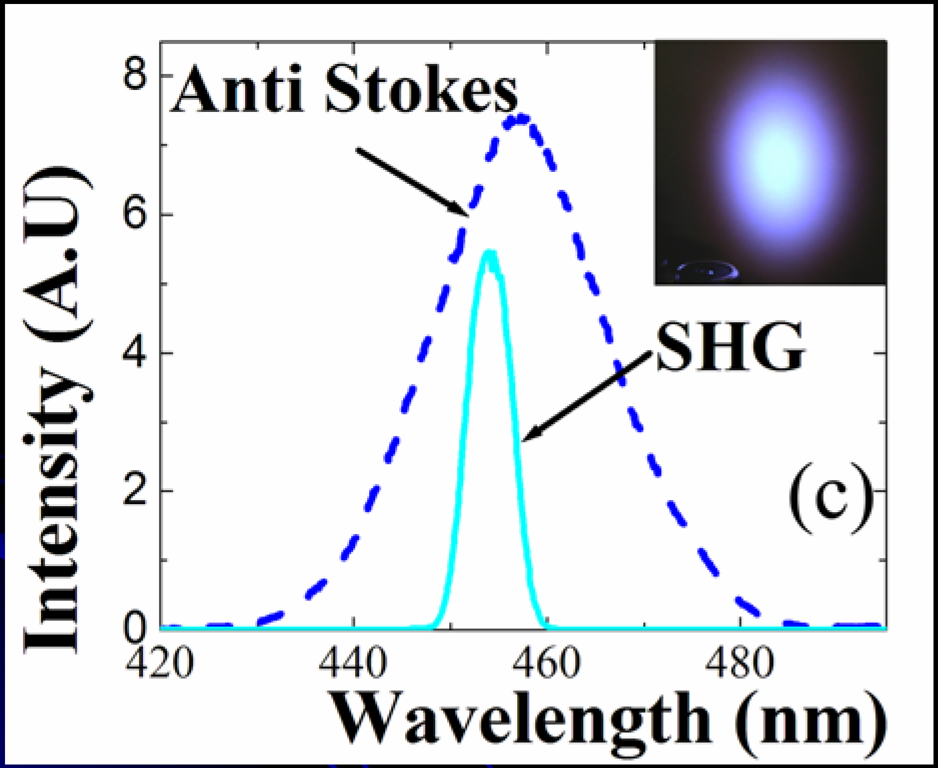
Compression of continuum with FS prism pair in “rapid DMM regime”

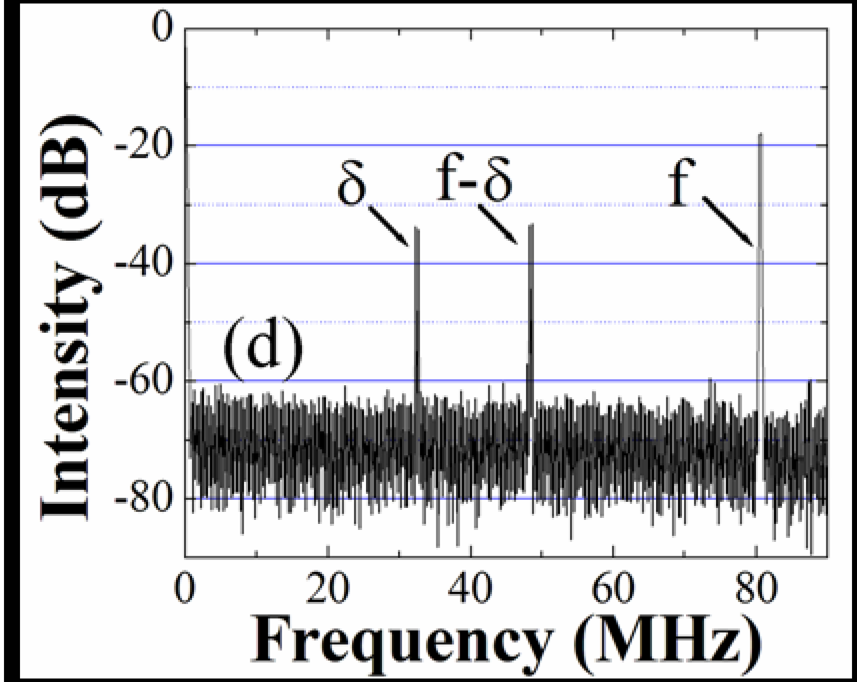


Applications

- Low noise multispectral imaging
- Spectroscopy
- OCT
- CARS microscopy
- Precision frequency measurement
- Generation of CEP-locked light

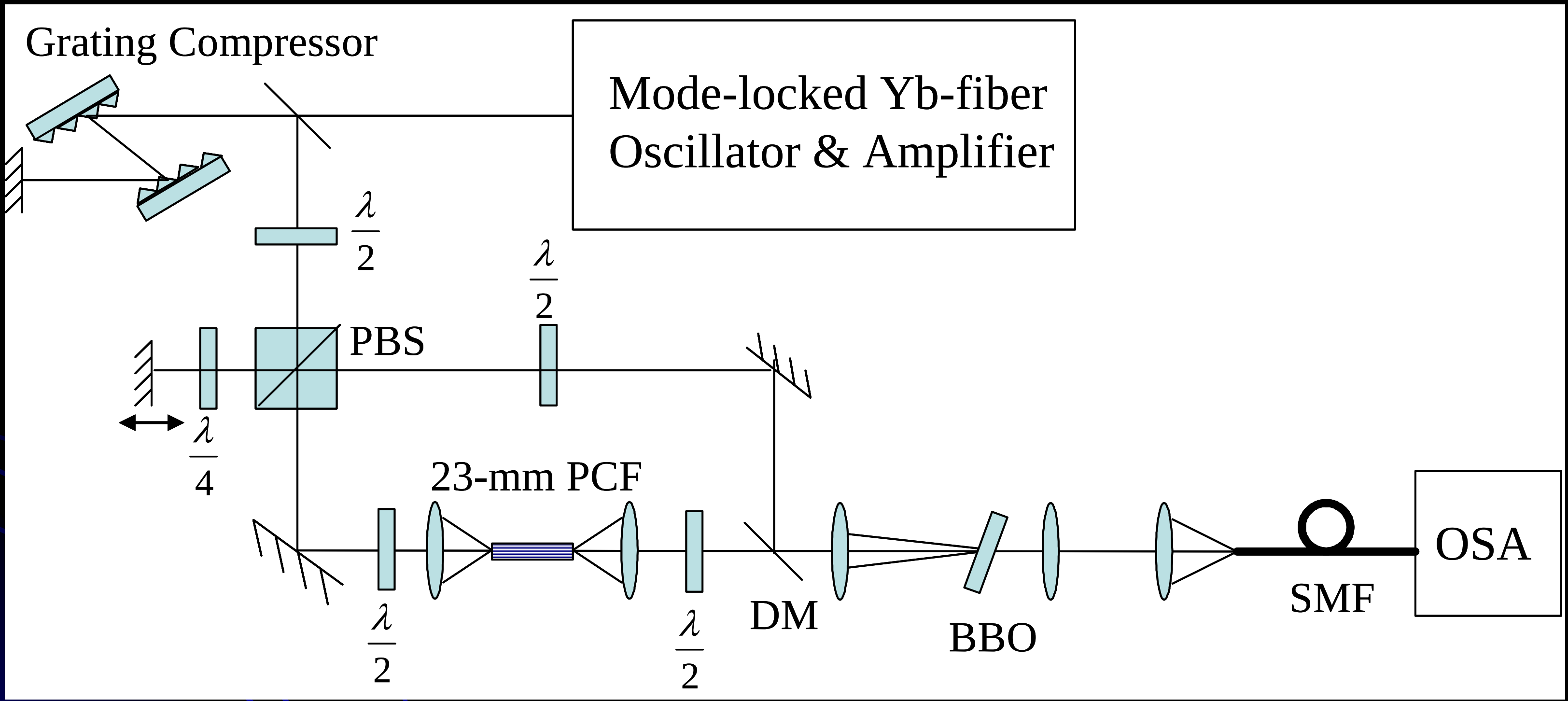
Generation of AS resonant with SHG, and RF CEP beat notes





Fiber-laser-based difference frequency generation scheme for carrier-envelope-offset phase stabilization applications

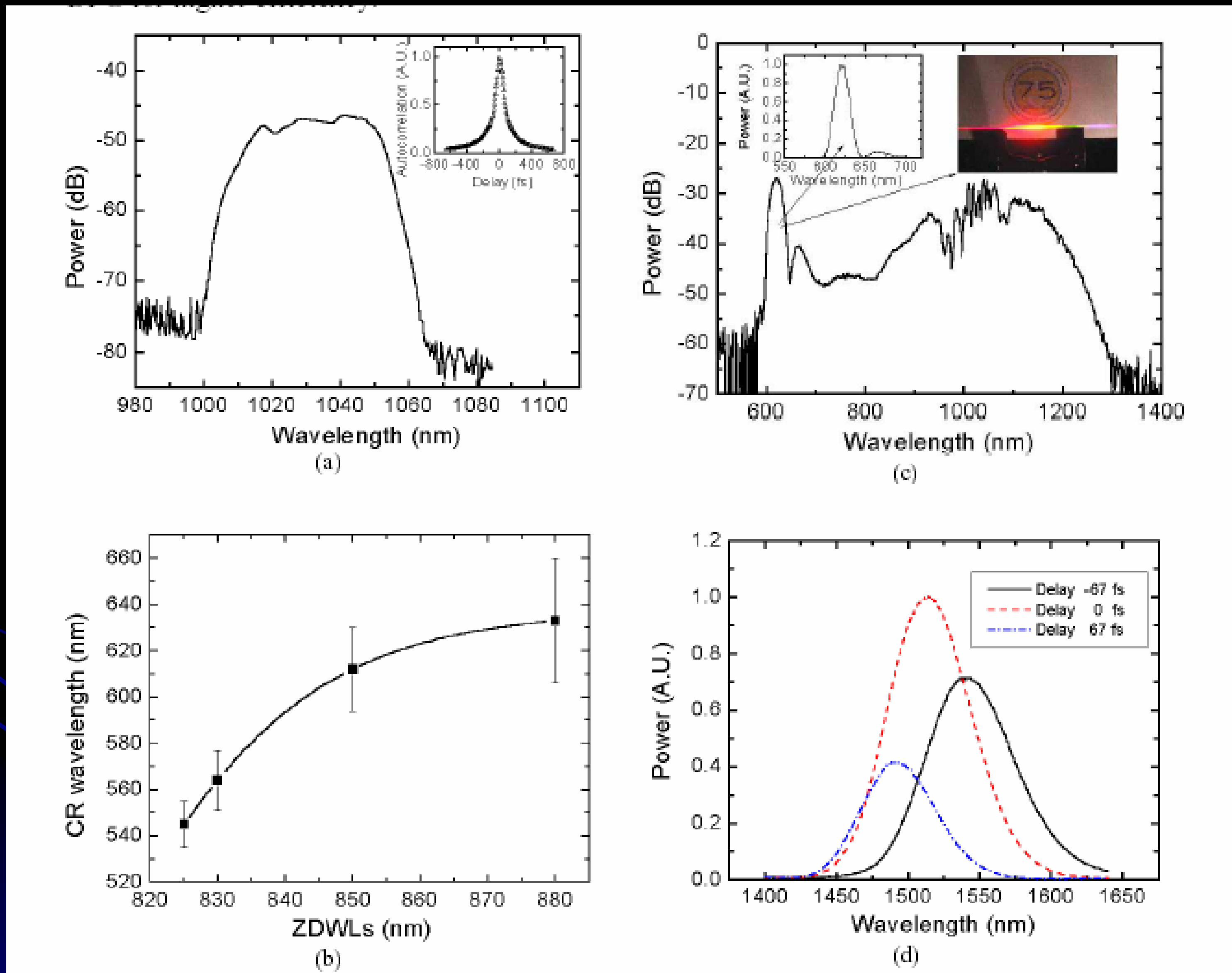
Yujun Deng, Fei Lu, and Wayne H. Knox



Received 16 May 2005; revised 31 May 2005; accepted 1 June 2005
13 June 2005 / Vol. 13, No. 12 / OPTICS EXPRESS 4590

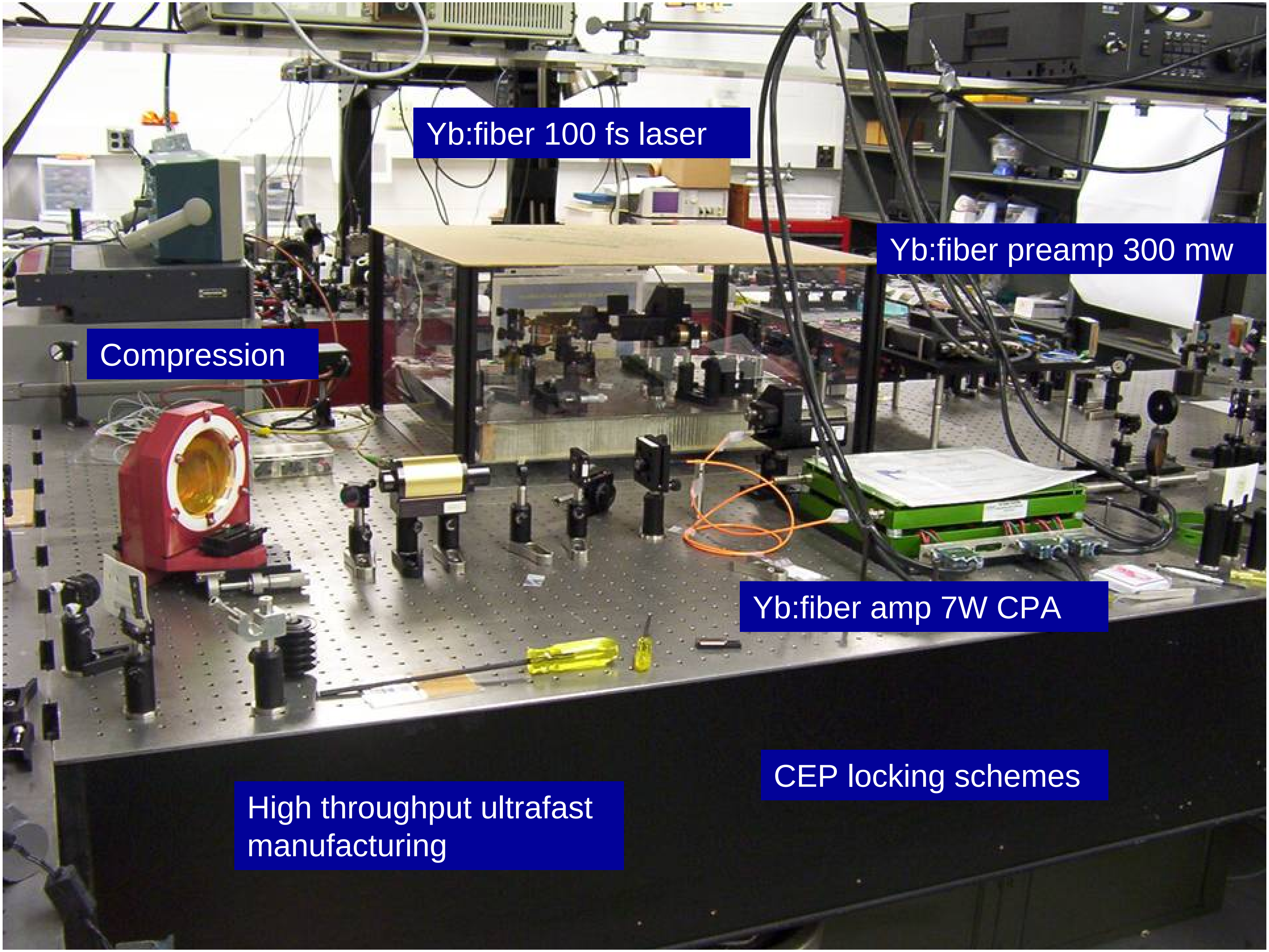
Yb:fiber laser input

Orange AS generation in 23 mm pcf

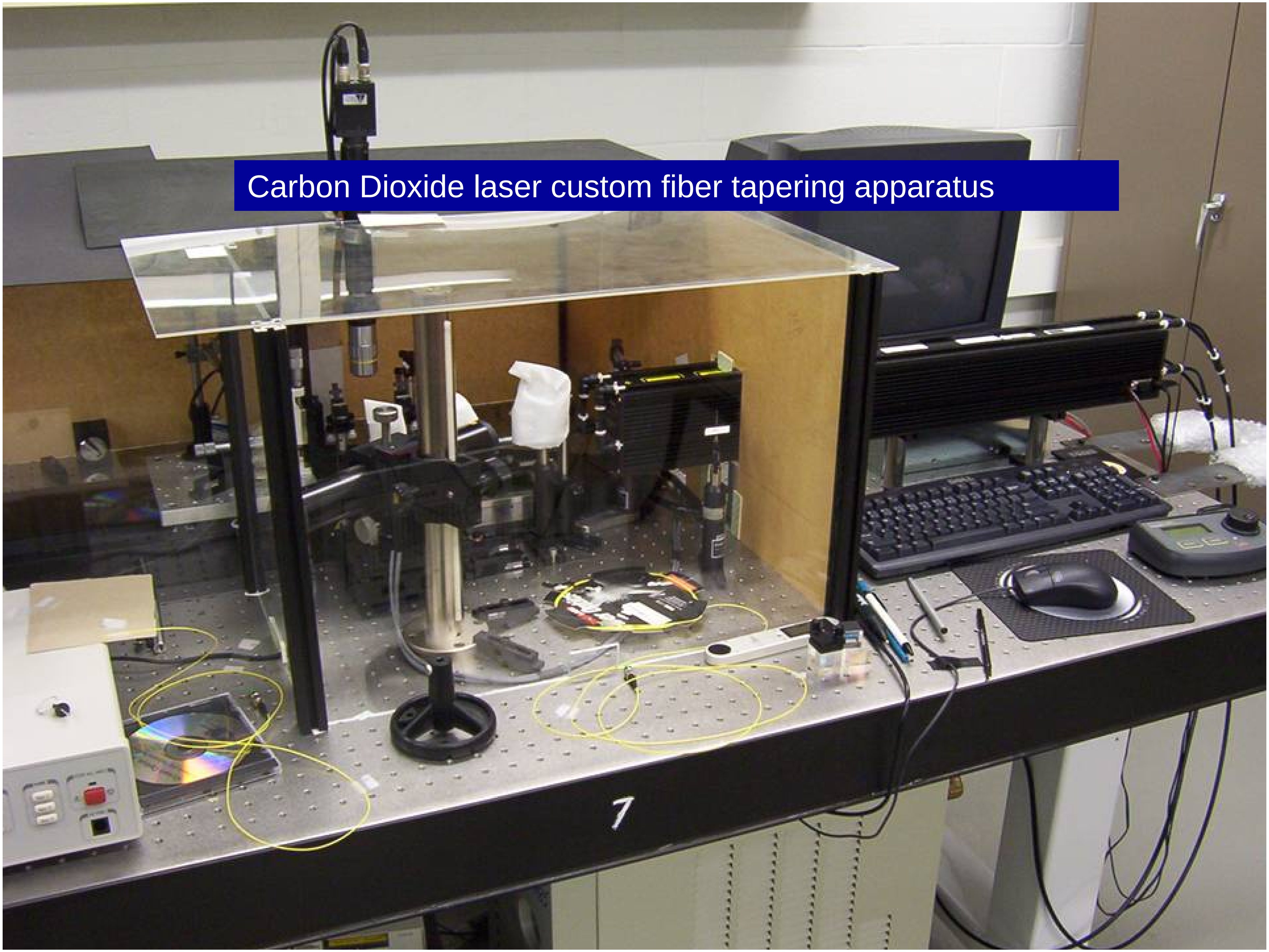


AS wavelength in four fibers

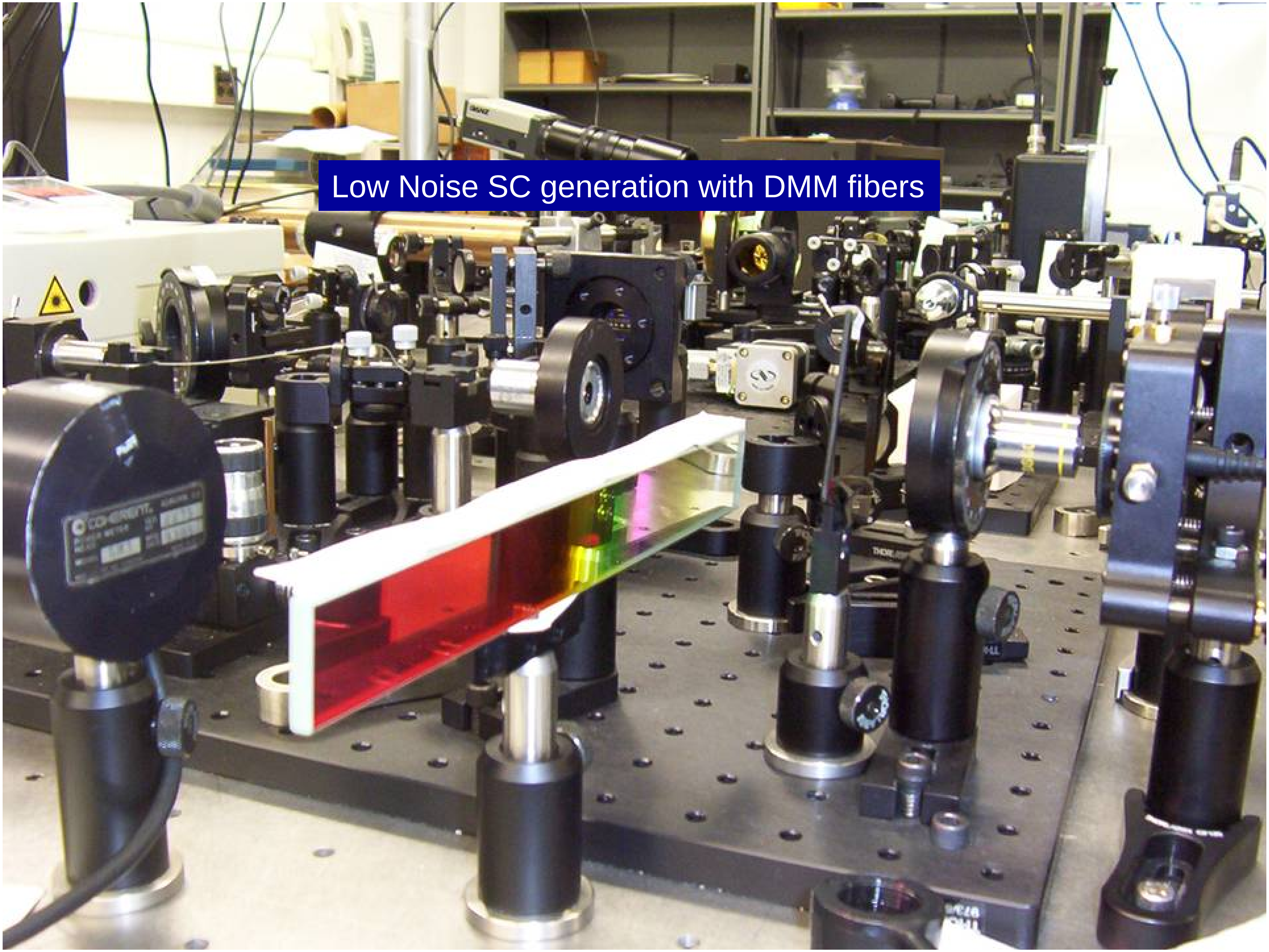
CEP-locked difference light: 2 μW

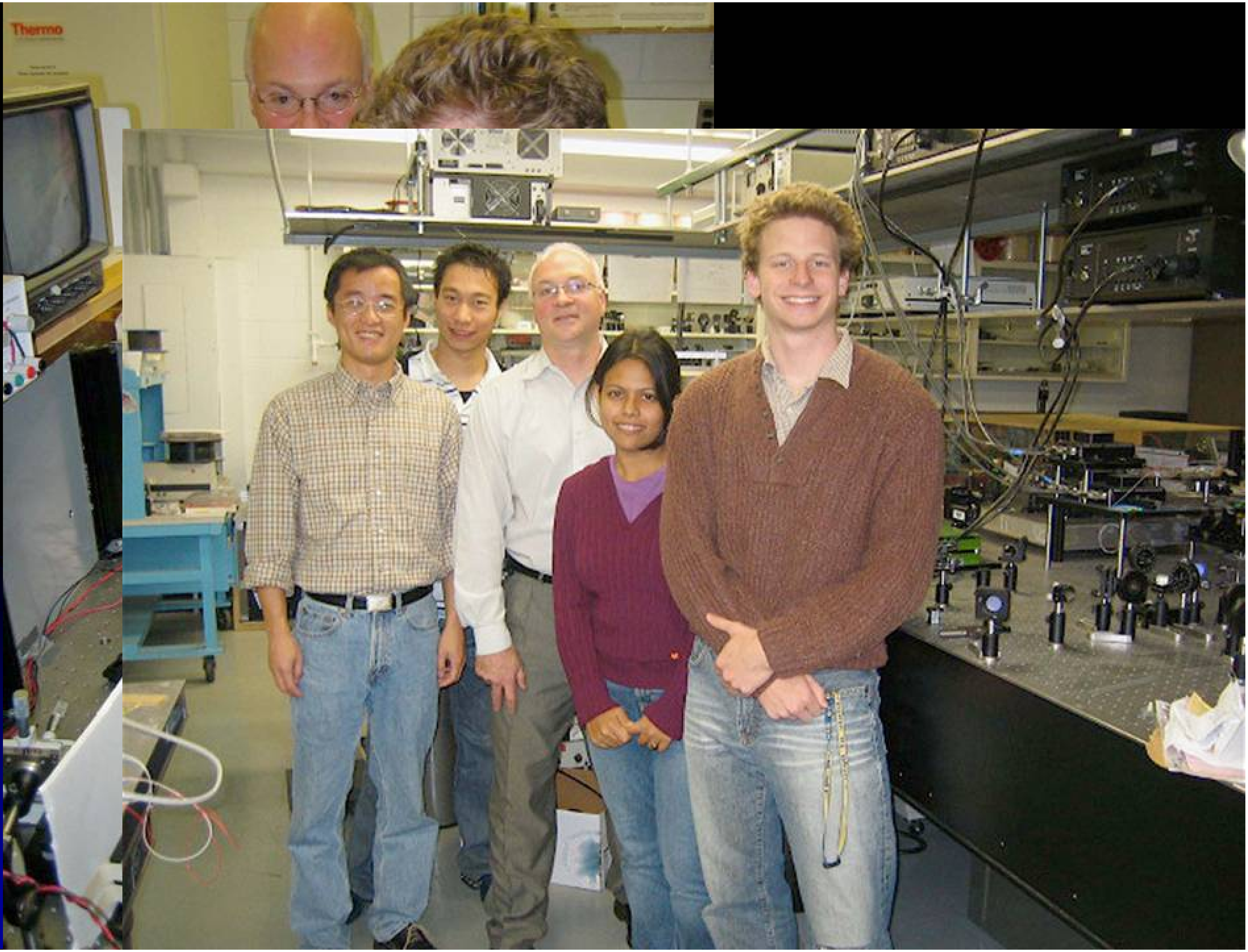

Yb:fiber 100 fs laser
Yb:fiber preamp 300 mw
Compression
Yb:fiber amp 7W CPA
CEP locking schemes
High throughput ultrafast manufacturing

Carbon Dioxide laser custom fiber tapering apparatus



Low Noise SC generation with DMM fibers

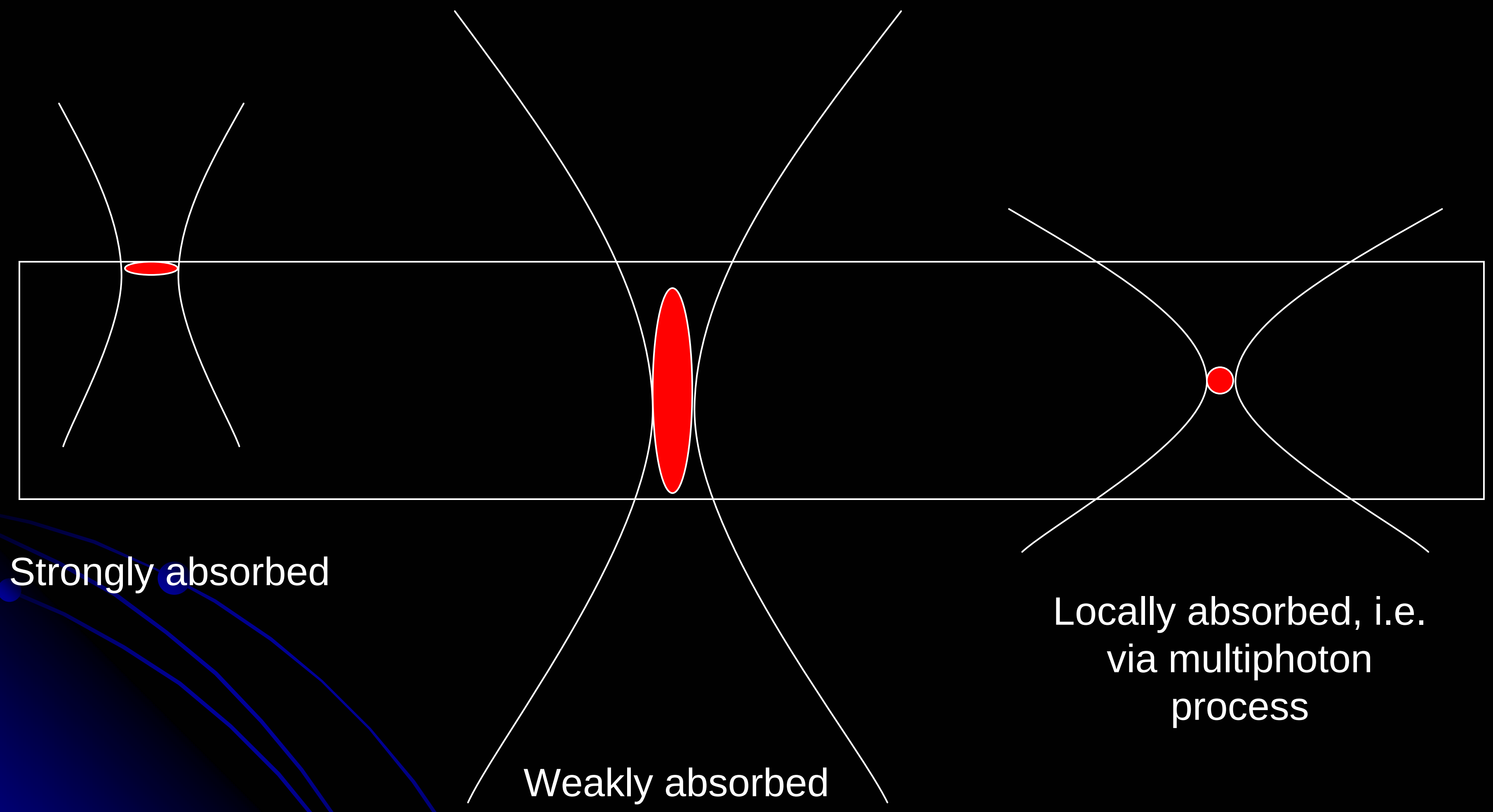



Thermo

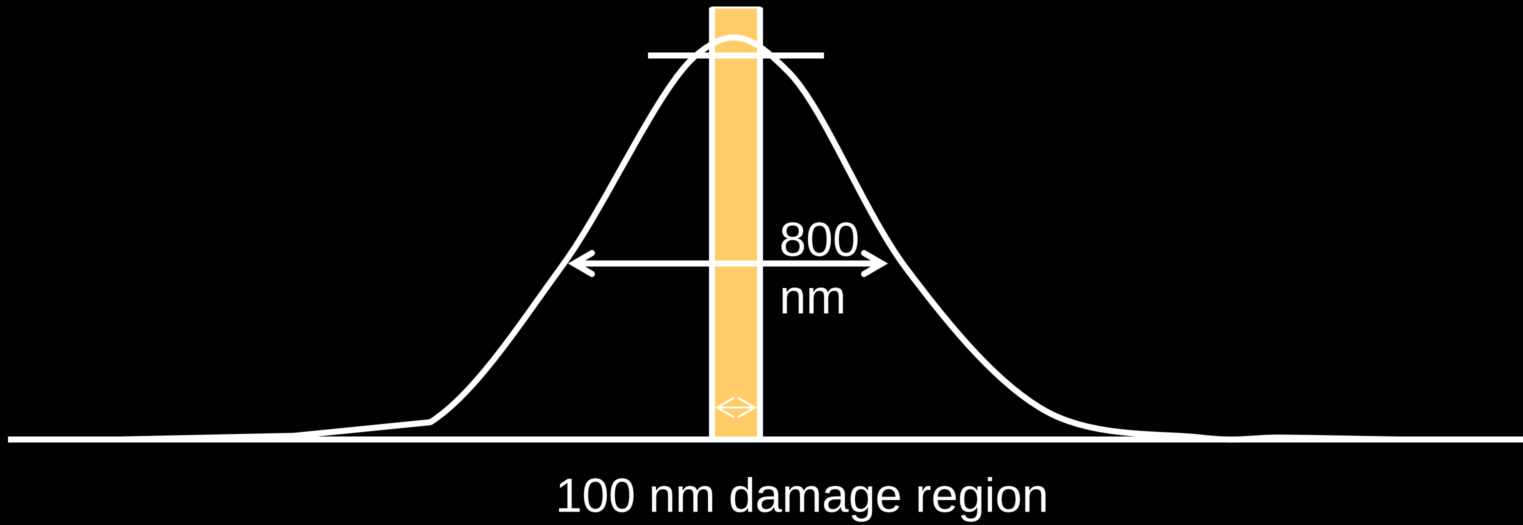
What is "Ultrafast Manufacturing"?

- Using ultrashort optical pulses (<1 ps) to:
  - Micromachine, nanomachine 1D, 2D or 3D structures in metals, transparent solids, biological tissues and hazardous materials
  - Fabricate structures by use of multiphoton absorption in photopolymers, or using materials ablated by ultrashort pulses
- Cutting, drilling, trimming, writing, adjusting, temporarily weakening…etc…
- Literally – making things with ultrashort optical pulses
  - (most literally - *that can't be made any other way*)
  - (and maybe even – *things that somebody wants !*)

Three different regimes for laser processing of materials



Ultrashort pulses can produce damage in a region much smaller than a wavelength…



- This has been demonstrated in metals, transparent solids, and biological materials
- Deterministic nature of ultrashort light-matter interaction

Machining of Sub-Micron Holes using a Femtosecond Laser at 800 nm
P. P. Pronko, S. K. Dutta, J. Squier, J. V. Rudd, D. Du, and G. Mourou
Opt. Commun. ***114****, 106-110 (Jan. 15 1995).*

Optics Express, September 23, 2002, p. 978

Fabrication of Fresnel zone plate embedded in silica glass by femtosecond laser pulses

Wataru Watanabe, Daisuke Kuroda, and Kazuyoshi Itoh

Osaka University

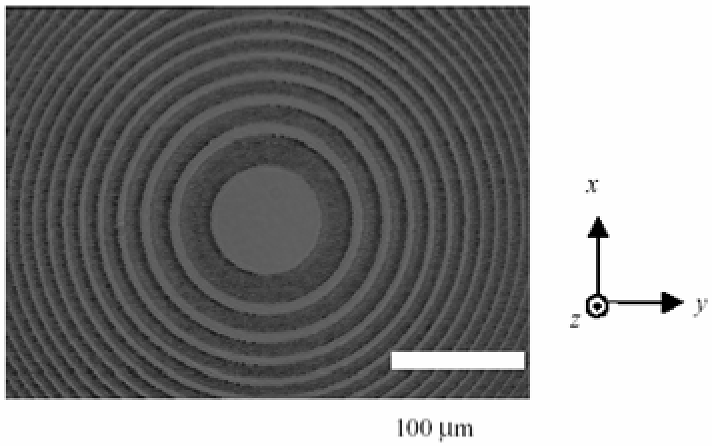
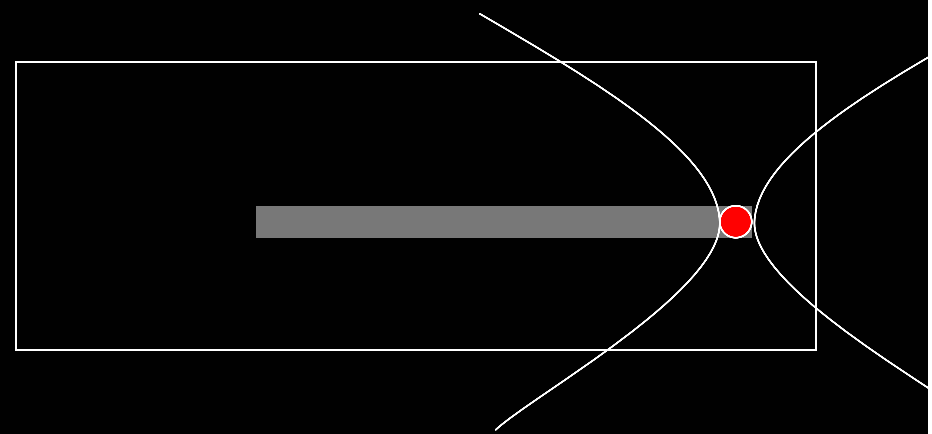


Fig. 3. Optical image of the fabricated Fresnel zone plate by embedding the two-dimensional array of voids. The image was observed under illumination by halogen lamp.



- Maskless
- Embedded inside glass block

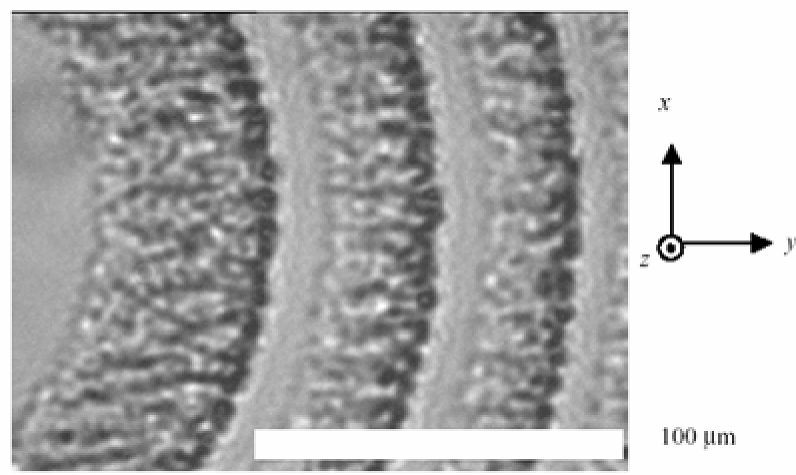


Fig. 4 Magnified image of a part of the zone plate obtained by a 50× objective.

1912 OPTICS LETTERS / Vol. 26, No. 23 / December 1, 2001

Three-dimensional hole drilling of silica glass from the rear surface with femtosecond laser pulses

Yan Li, *Venture Business Laboratory, Osaka University et al.*

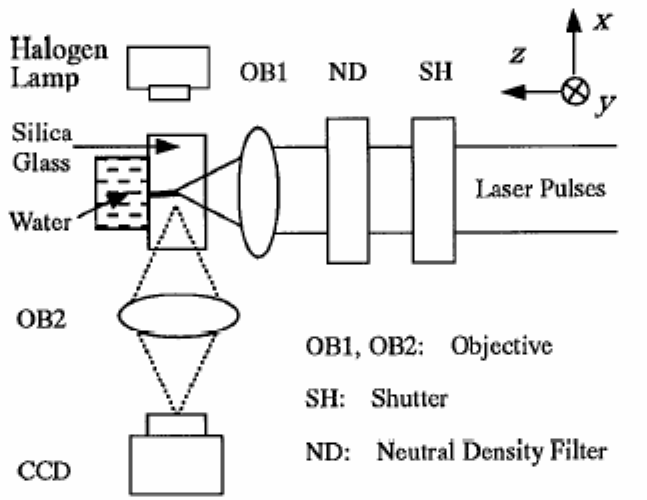


Fig. 1. Top view of the experimental setup for microdrilling of silica glass from its rear surface.

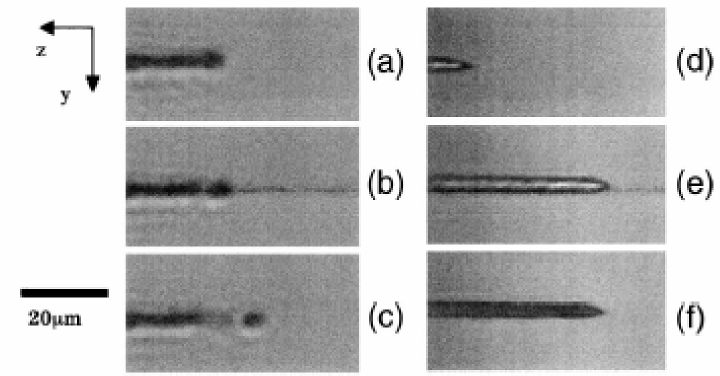


Fig. 2. Microdrilling of silica glass from its rear surface in air without and with an inflow of water into the hole. Incident energy, 1 μJ per pulse. (a)–(c) Drilling without an inflow of water; (d), (e) drilling with an inflow of water. (f) Image of (e) after the water has receded.

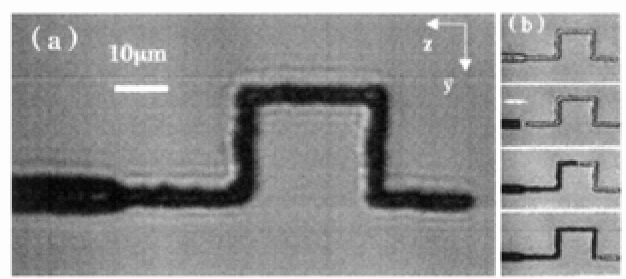
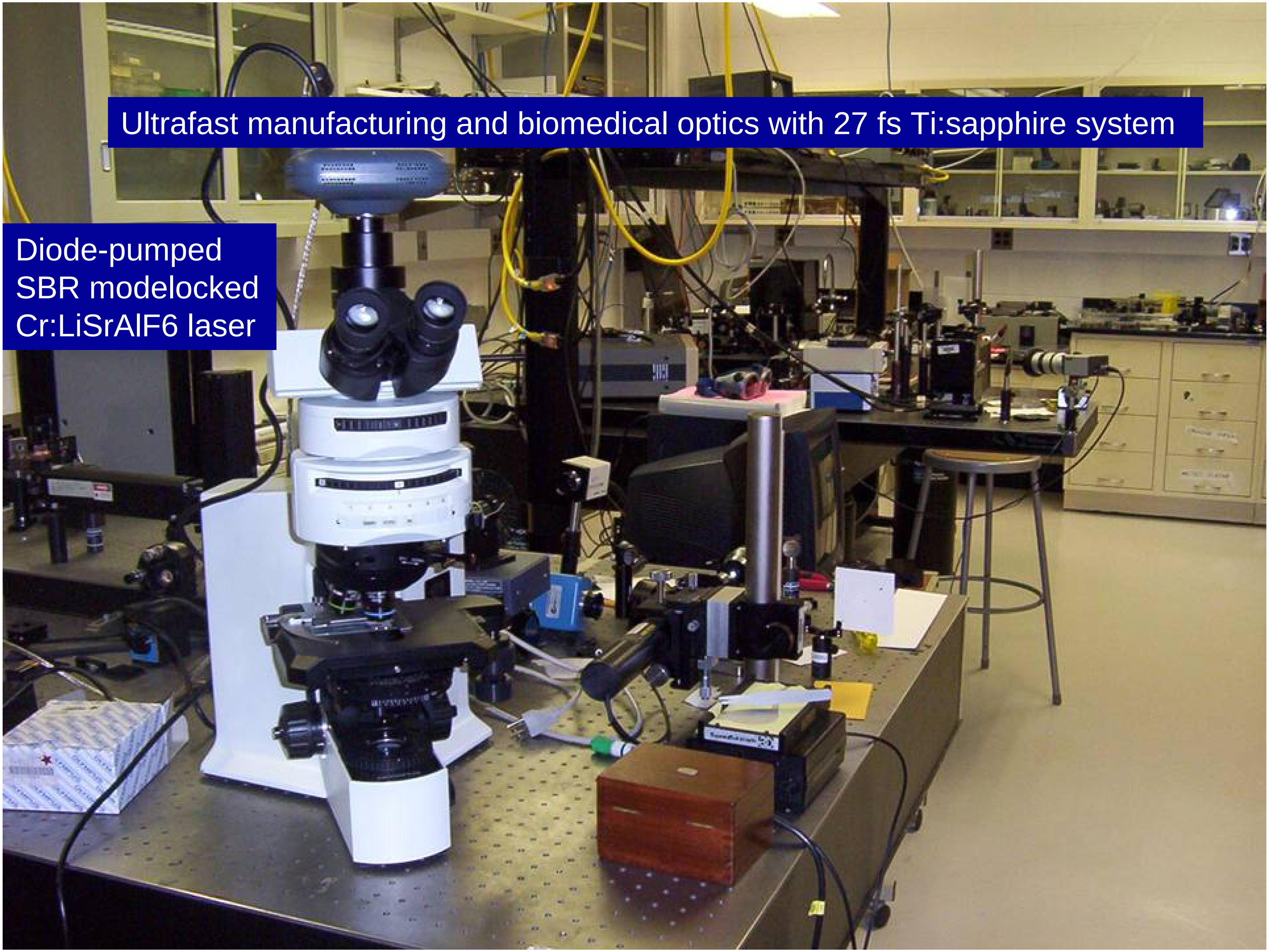
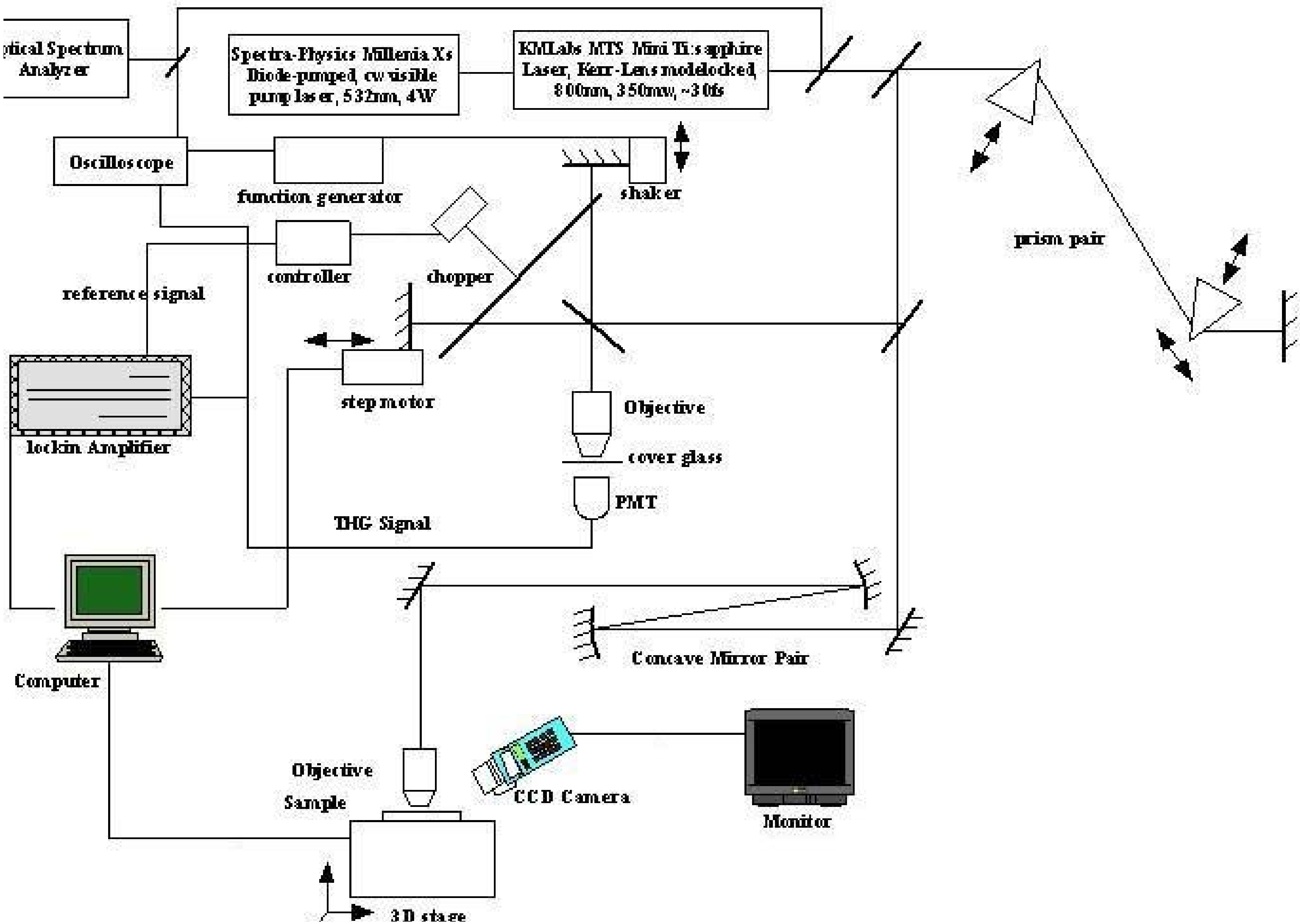


Fig. 4. Square-wave shaped hole drilled by movement of the sample in different directions. (a) The finished hole with diameters of ~7 μm (pulse energy, ~4 μJ) and ~4 μm (pulse energy, ~1 μJ). (b) Video clips of the drying process of the refilled hole.

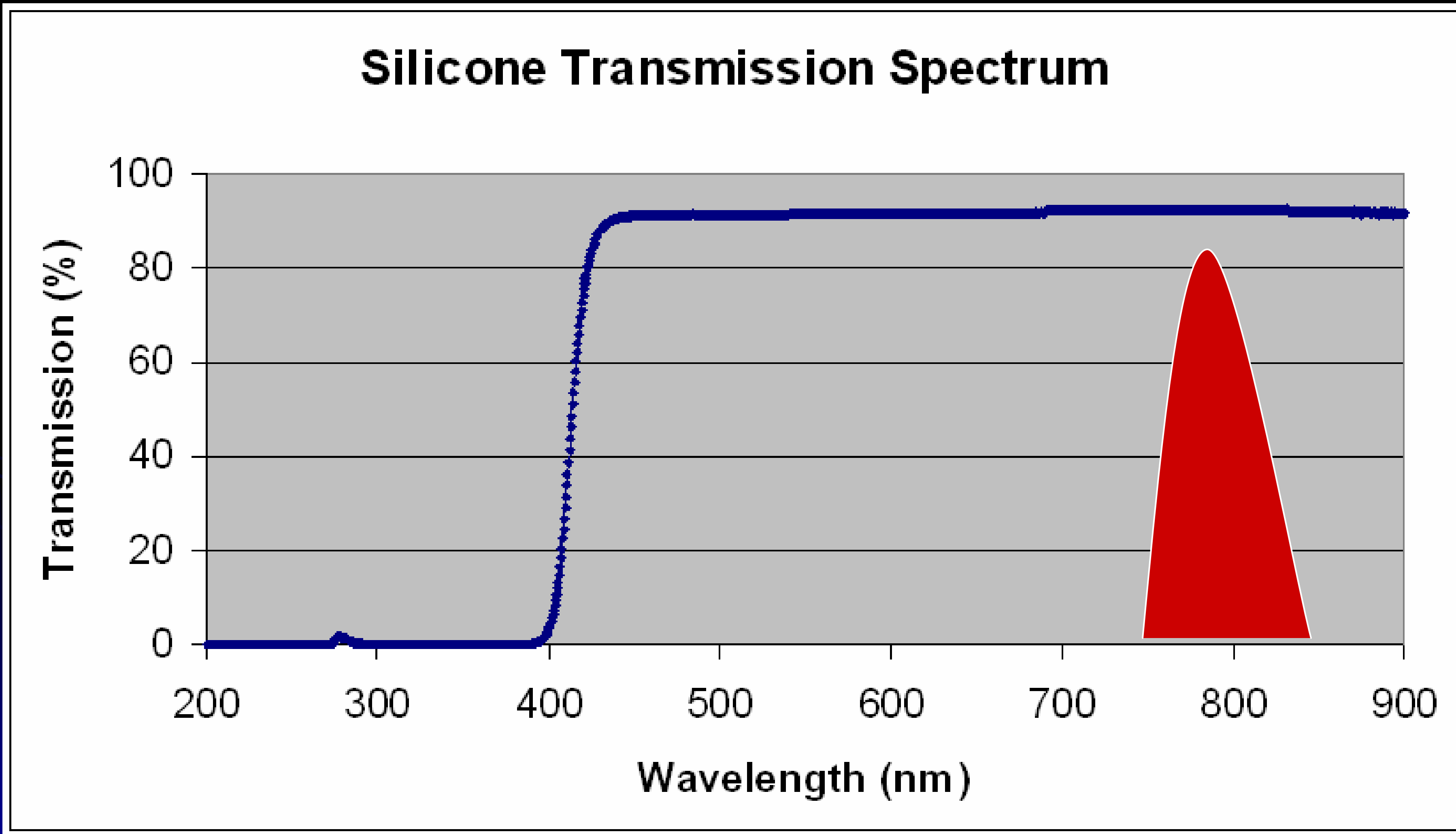
- ***Highly novel structures !***
- ***Applications in microfluidics (7 μm)***
- ***Is there any other way to do this ?***


Ultrafast manufacturing and biomedical optics with 27 fs Ti:sapphire system
Diode-pumped
SBR modelocked
Cr:LiSrAlF6 laser

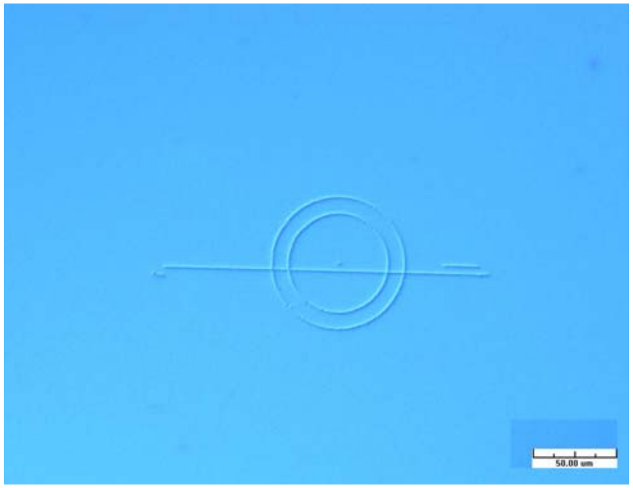


ptical Spectrum Analyzer
Spectra-Physics Millenia Xs Diode-pumped, cw visible pump laser, 532nm, 4W
KMLabs MTS Mini Ti:sapphire Laser, Kerr-Lens modelocked, 800nm, 350mw, ~30fs
Oscilloscope
function generator
shaker
prism pair
controller
chopper
reference signal
step motor
lockin Amplifier
Objective
cover glass
PMT
THG Signal
Concave Mirror Pair
Computer
Objective
Sample
CCD Camera
Monitor
3D stage

Sample Spectrum

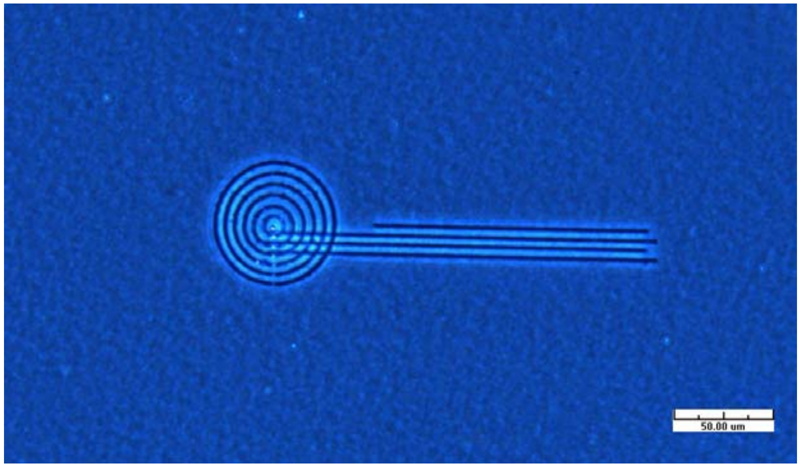


Rings



- 30 & 40 microns radii

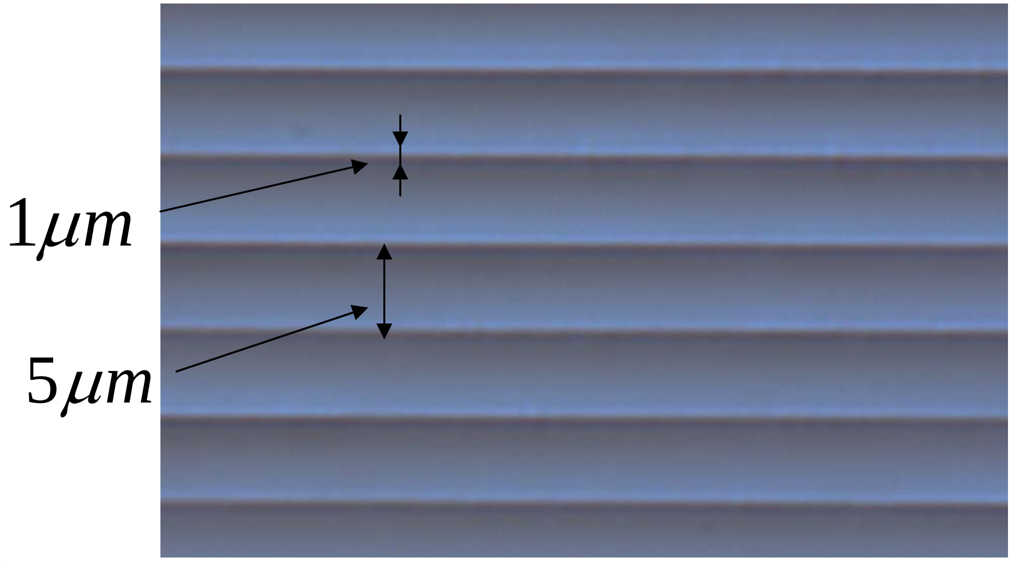
Phase Contrast Image



DIC Images

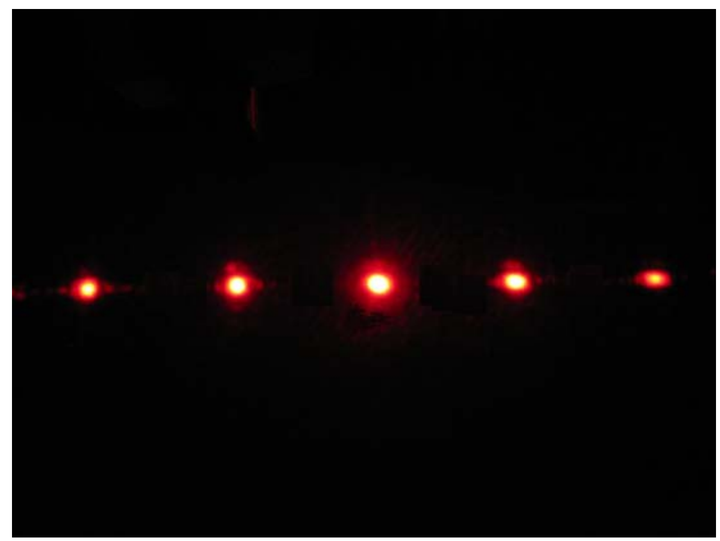
- minimum radius: 5 microns
- maximum radius: 30 microns

Gratings



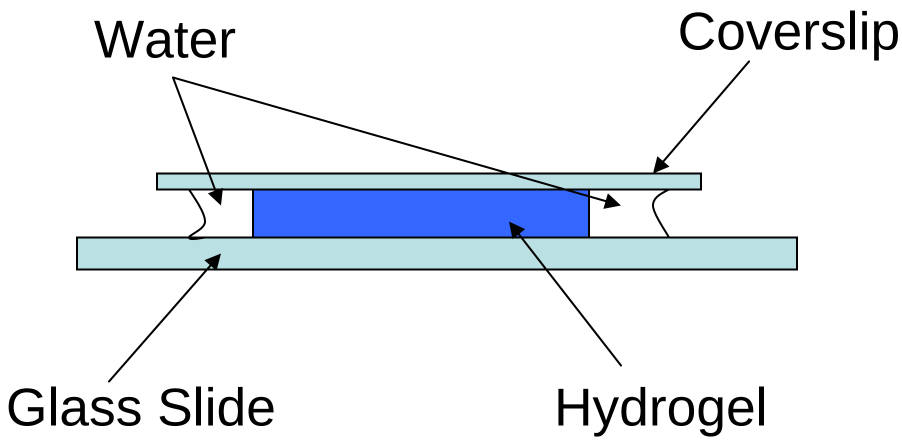
Refractive Index Change:
PV2526-164: ~ 0.06
RD1817: ~ 0.05
HEMA B: ~ 0.03

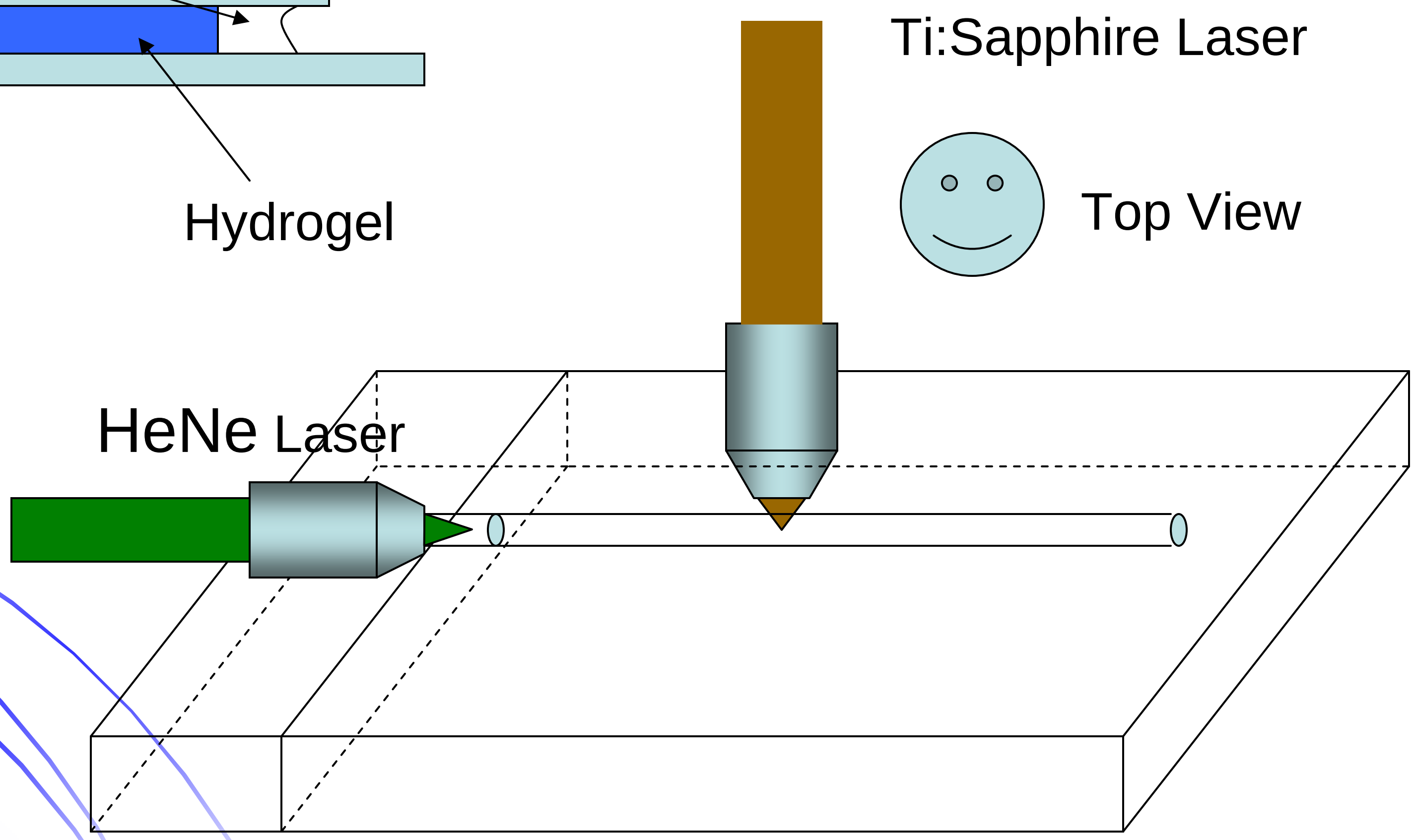
Diffraction Pattern



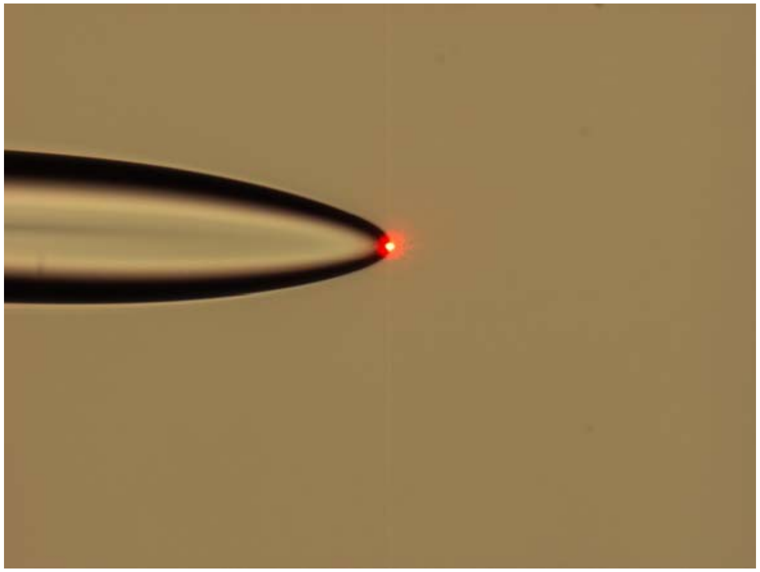
Are these refractive index changes POSITIVE or NEGATIVE?

Waveguide writing

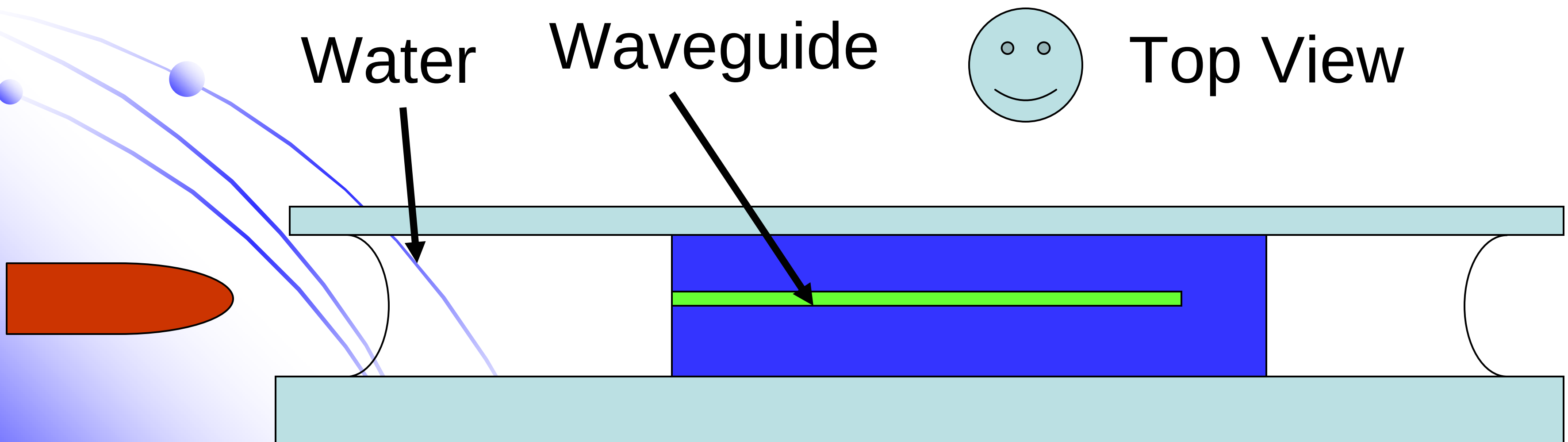


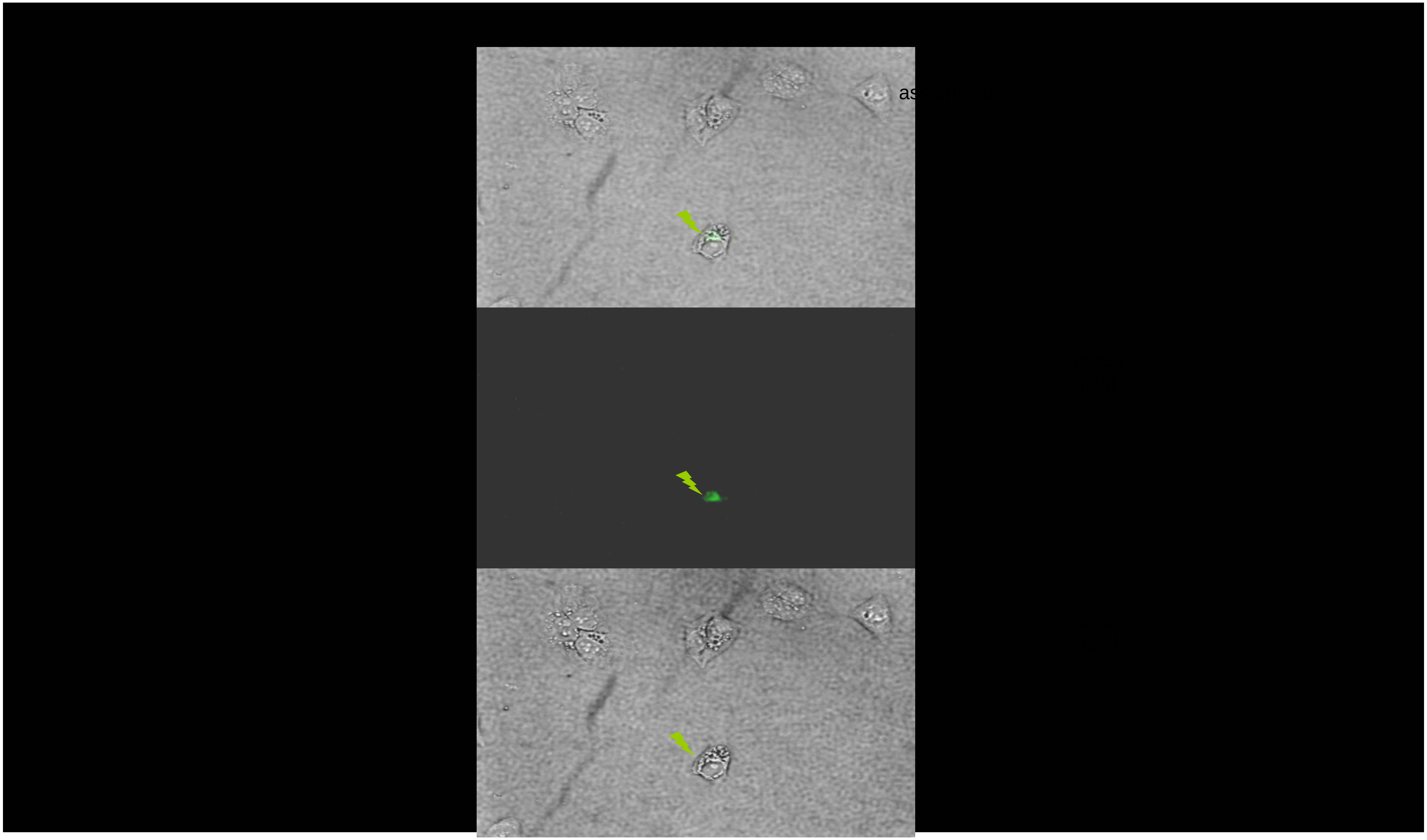


Tapered lensed fiber



Working distance: 6 microns
Spot diameter: 2 microns



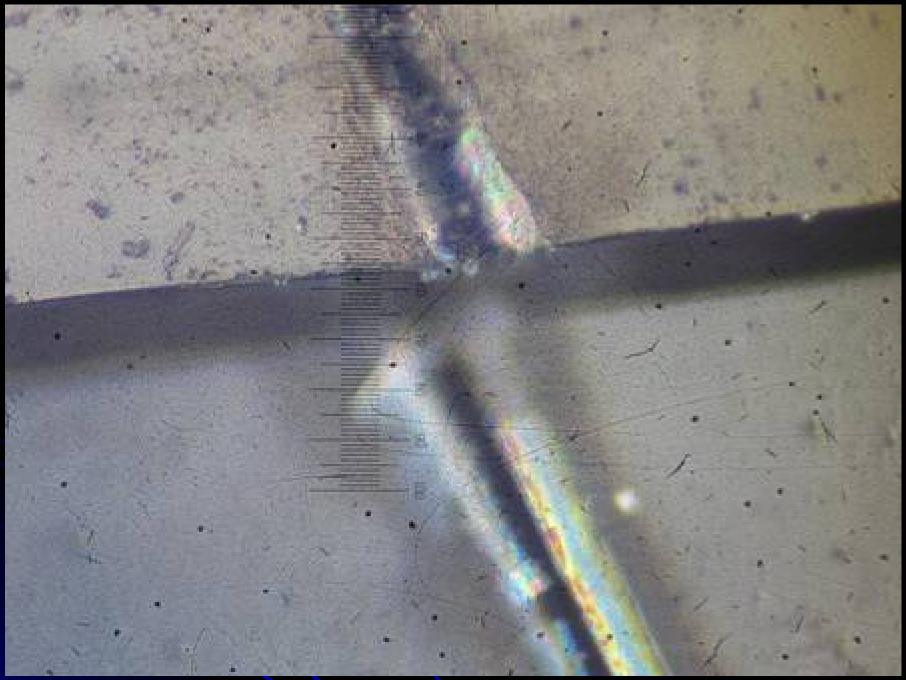


Optotransfection:

To demonstrate the feasibility of the transfection of cells by a two-photon laser at our insitute, human HA-Cat keratinocytes were allowed to adhere for 36hrs to a clean glass slide, a cunningham chamber was formed and the cells were sealed in RPMI/HEPES medium in the presence of 2.5 µg pEGFPŠCL (Clontech). The cells were targeted for 50mS with a laser at the strength of 80mW. The slide was then incubated for 7 hrs in a regular cell incubator. The exposure shown was taken on a Nikon Eclipse E600 microscope with a 40x PlanFluor lens and the B-2E/C (515-555 nm) filter for 20 sec.

Inside of Silicone

In Nitrogen Atmosphere



- Width <= 20um
  - Sub-micron features obtained !

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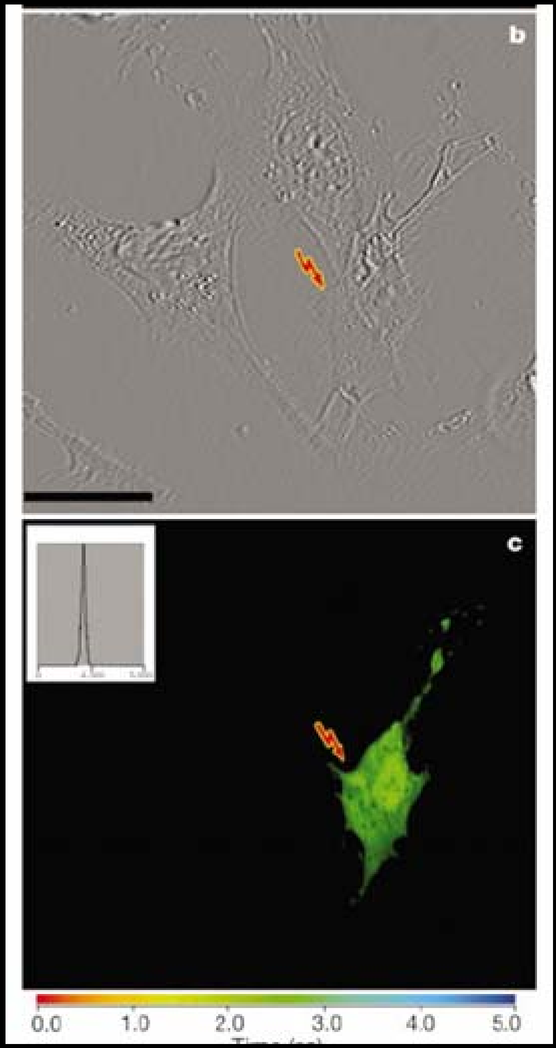
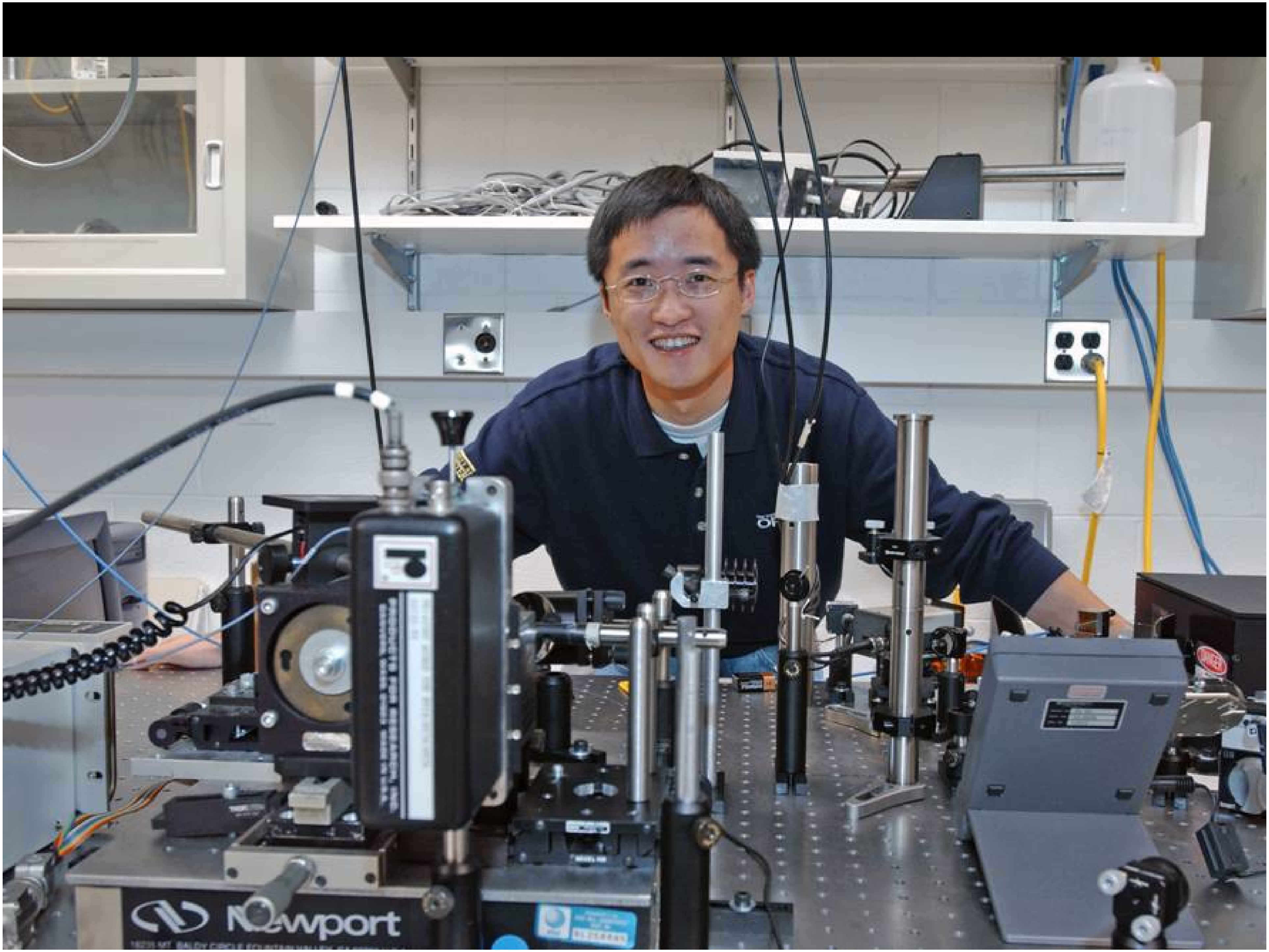
Targeted transfection by femtosecond laser

Uday K. Tirlapur, Karsten König

Laser Microscopy Division, Friedrich Schiller University, Jena, Germany

The challenge for successful delivery of foreign DNA into cells *in vitro*, a key technique in cell and molecular biology with important biomedical implications, is to improve transfection efficiency while leaving the cell's architecture intact. Here we show that a variety of mammalian cells can be directly transfected with DNA without perturbing their structure by first creating a tiny, localized perforation in the membrane using ultrashort (femtosecond), high-intensity, near-infrared laser pulses. Not only does this superior optical technique give high transfection efficiency and cell survival, but it also allows simultaneous evaluation of the integration and expression of the introduced gene.




Newport

Room for more ?

- Let’s talk !