Laser driven facility for irradiation experiments, two-photon microscopy and microfabrication

Ultrafast Beams and Applications
UBA17 04-07 July, 2017

Presenter: Arsham Yeremyan

Outline

- Parallel operation of AREAL linac and DELTA stations
  - Femtosecond laser system: specs and features
  - Beam delivery schemes, control and measurements
- Research fields and experimental capabilities
  - Laser driven microscopy and microfabrication stations
  - Fields of applications and multidisciplinary research capabilities
  - Upcoming upgrades and extensions
    - Tunable laser, THz spectroscopy, pulse-picking
- Applications
- Summary

Laser Driven Experimental Stations

2-photon microscope

DELTA

250 fs, 50 MHz
1030 nm, 20nJ

0.4--8 ps, 1—100k Hz
1030 nm, 1.8 mJ

uFAB

Osc

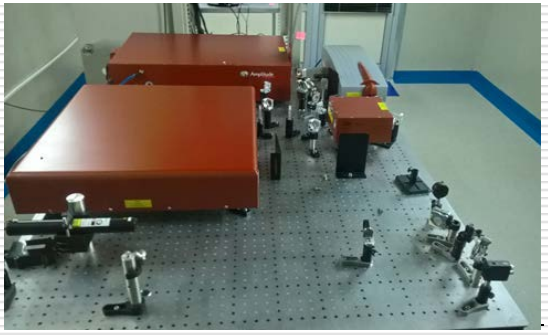
250 fs, 50 MHz
1030 nm, 25nJ

Ampl

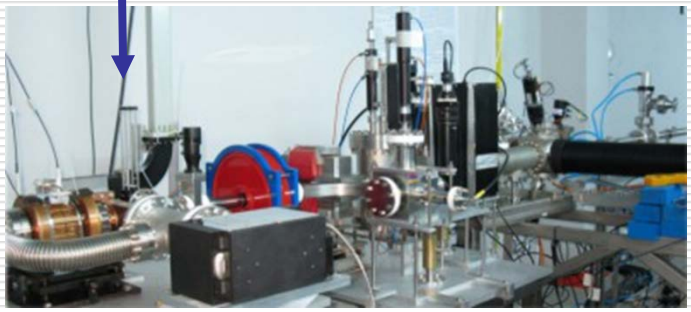
FHG

0.4--8 ps, 1--100 Hz
258 nm, 425uJ

AREAL



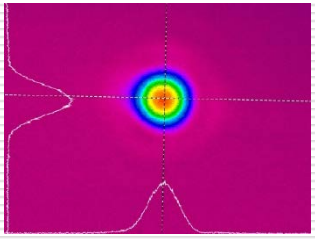
LASER

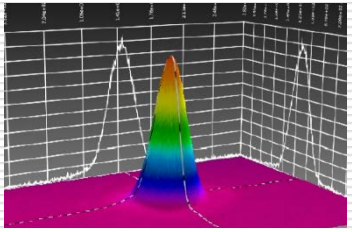


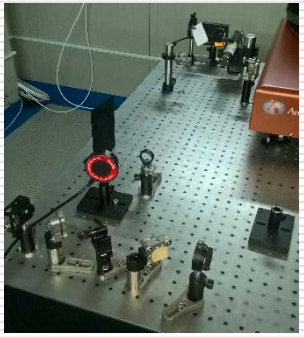
Femtosecond Laser System

Measurements and control

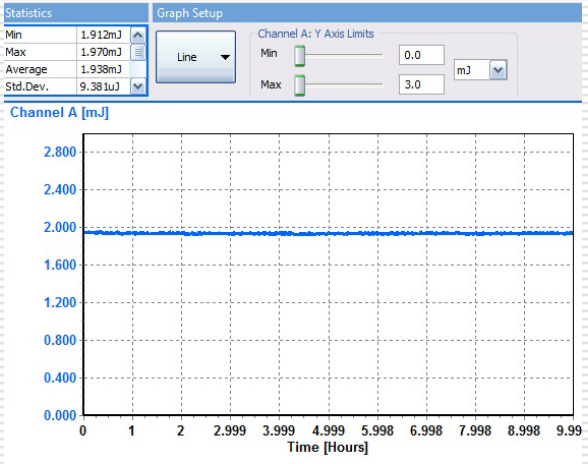
IR and UV pulse profile monitoring (Spiricon)



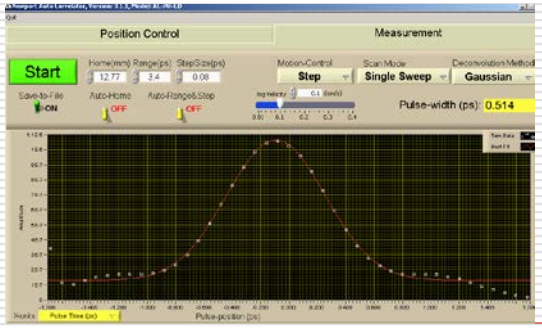




Energy/Power measurements



Pulse-width variation and autocorrelator measurement



Femtosecond Laser System

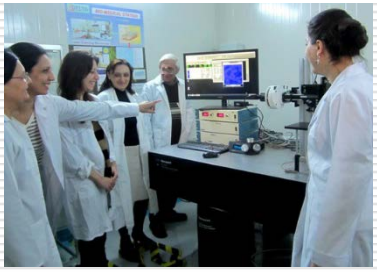
Specifications and features

	t-pulse	S-pulse	FHG	SHG*	THG*
Wavelength	1030 nm	1030 nm	258 nm	**515 nm**	**343 nm**
Pulse width	250 fs	400 fs--8 ps	400 fs --8 ps	**400 fs--8 ps**	**1—8 ps**
Rep. Rate	50 MHz	1-100K Hz	1-1K Hz	**1-100K Hz**	**1—100K Hz**
Energy/pulse	20 nJ	Up to 2 mJ	Up to 425 uJ	**Up to 1mJ**	

**** Conversion implemented in DELTA uFab***

- *Synchronization with Master Oscillator*
- *Remote control*
- *IR and UV pulse-to-pulse energy stability ~0.5 %*

Laser Driven Experimental Stations



DELTA

0.4--8 ps, 1—100k Hz
1030 nm

2-photon microscope

uFAB

234 fs, 50 MHz
1030 nm

234 fs, 50 MHz
1030 nm

Osc

Ampl

FHG

0.4--8 ps, 1--100 Hz
258 nm

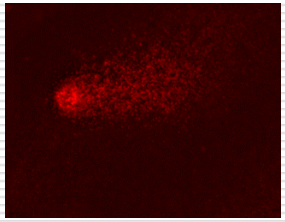
AREAL

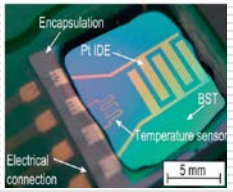
LASER

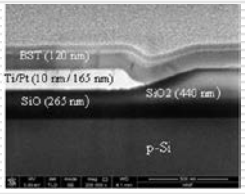
Electron irradiation experiments on AREAL linac

Experiments

Dose-rate effects on DNA, radiation-induced defects in semiconductors, dielectrics, ferroelectrics, etc.







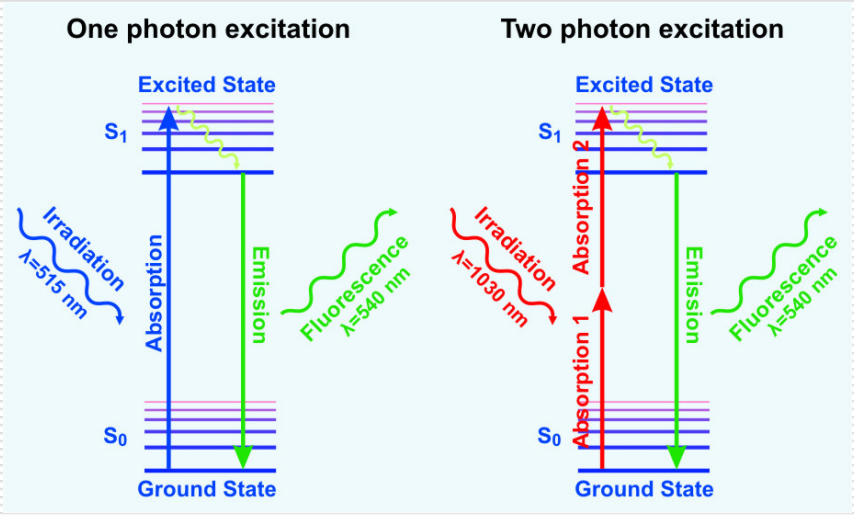
Fields

Genetics
Biology
Molecular Physics
Microelectronics
Solid State Physics
New materials

Groups

Yerevan State Univ
Polytechnic Univ.
Yerevan Phys. Inst
Inst. Mol. Biology
Inst. Phys. Research
CANDLE Institute

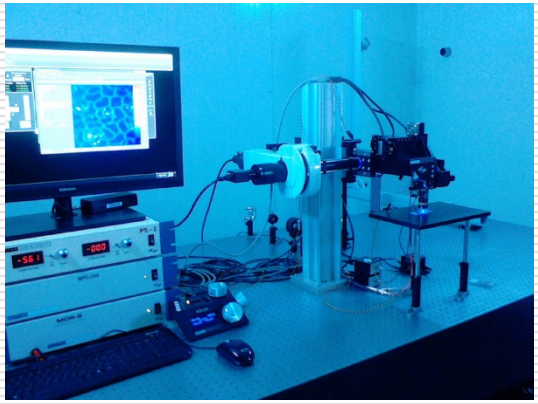
Two-Photon Microscopy: Basics



Advantages

- more sensitive than Confocal Laser Microscopy
- Longer wavelength penetrates deeper
- Higher resolution
- Better signal-to-noise ratio,
- other

DELTA Two-Photon Microscope: Features



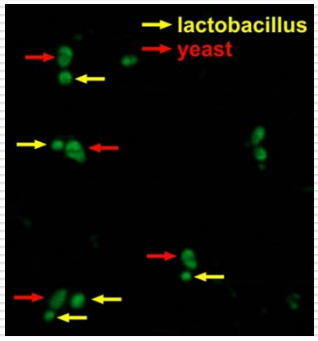
- Sutter Instruments
- Galvano-scanning system
- Multi-channel measurements with different filters and PMTs
- 3D-acquisition capability, etc.

Operating Parameters

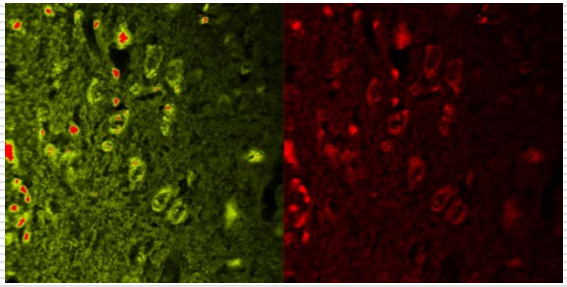
Excitation: 1030 nm
Fluorescence: >515 nm
Energy per pulse: up to 20 nJ
Pulse length: 280 fs
Intensity in focal plane: up to ~10^{13} W/cm^2

Two-Photon Microscopy

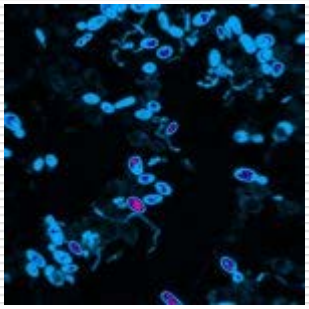
Experiments



Interaction of lactobacteria and yeast



Live brain imaging



Identification of dead and live soil microorganisms

Other….

Groups

Institute of Molecular Biology NAS RA

Yerevan State Medical University

Armenian National Agrarian University/ International Association for Human and Animals Health Improvement

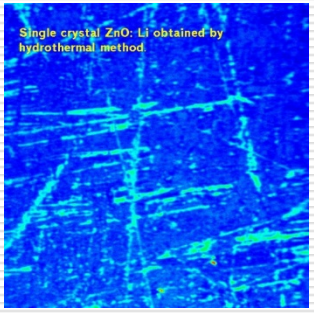
CANDLE SRI

A.I. Alikhanian National Science Laboratory (YerPhI)

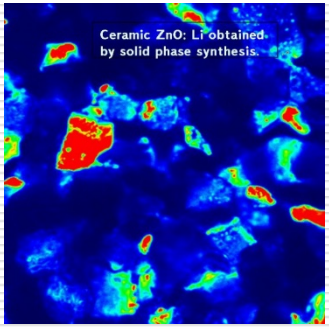
Institute for Physical Research NAS RA

Two-Photon Microscopy

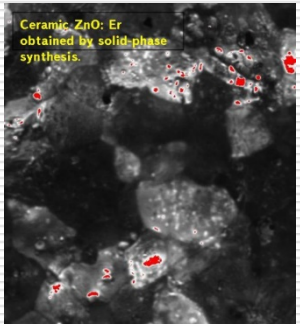
Possibility of multiphoton excitation microscopy of inorganics



ZnO:Li - hydrothermal



ZnO:Li –solid phase growth

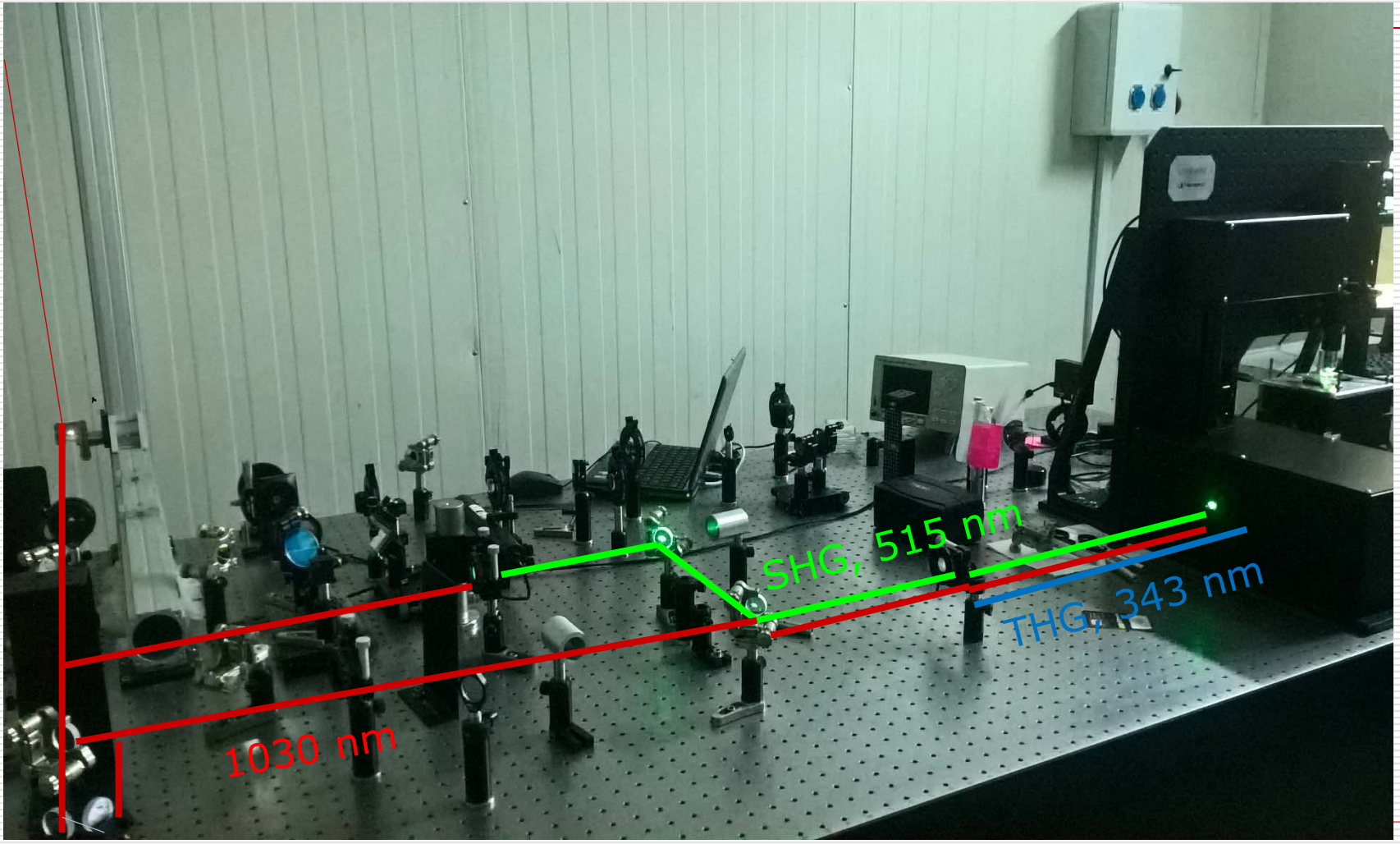


ZnO:Er –solid phase growth

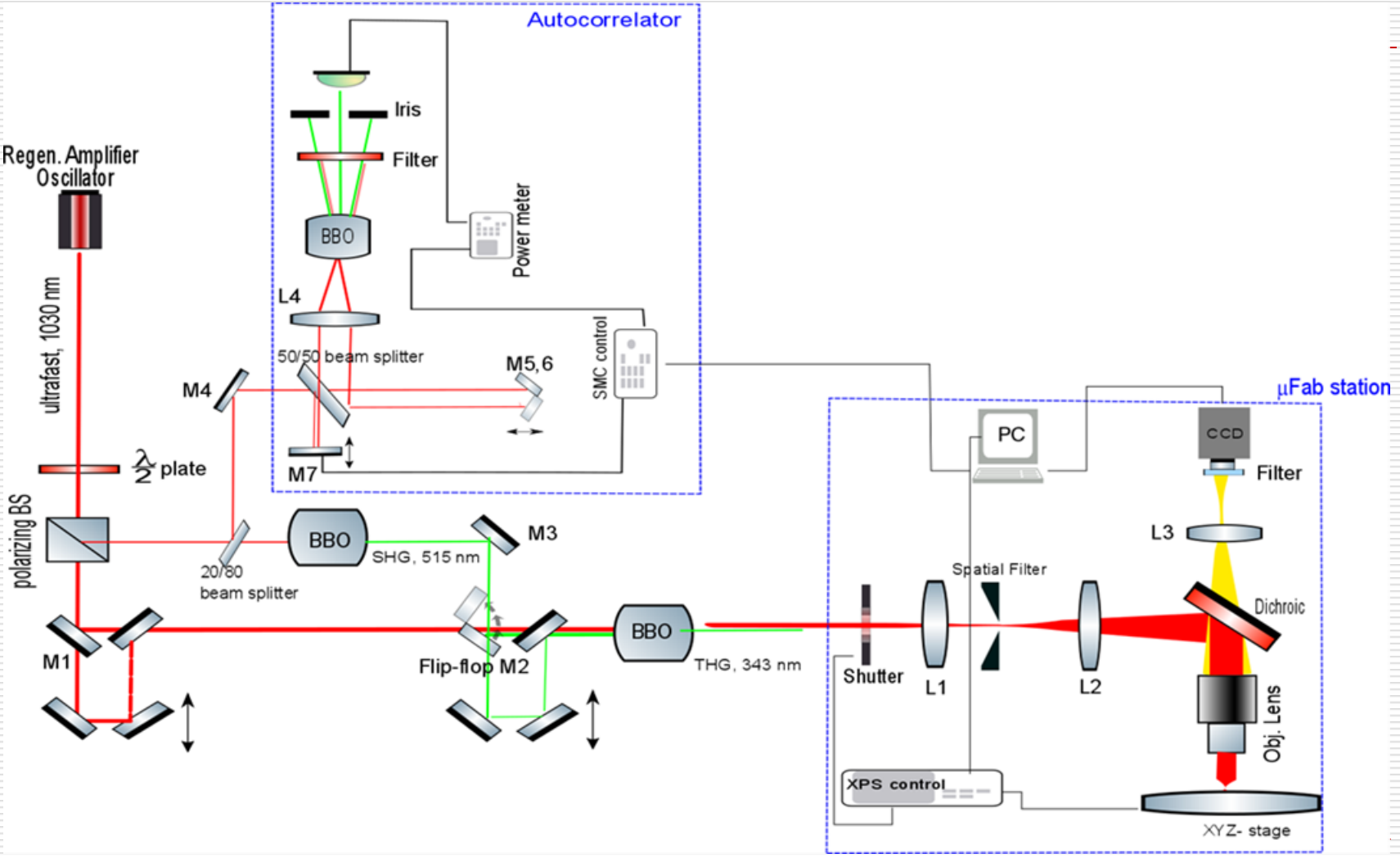
Image scale:
200 x 200 um

SHG microscopy of doped ZnO surface

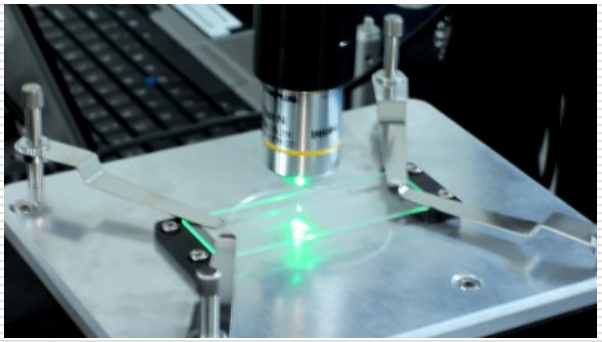
DELTA uFAB station



DELTA uFAB station



DELTA uFAB station



Operating Parameters

- Pulse duration: 400 fs –8 ps
- Repetition rate: 1 Hz –100 kHz
- Average power: up to 8 W
- Pulse energy: up to 2 mJ (1030 nm) and 1 mJ (515 nm)
- Wavelengths 1030 nm, 515 nm, 343 nm
- Sample positioning accuracy: ±50 nm
- Travel range: 100 x 100 mm (XY), 25 mm (Z)

Femtosecond laser processing of materials

- Ultrashort pulses →new mechanisms of laser-matter interactions

*Suppression of heat diffusion to surrounding regions → improvement of quality and spatial resolution for **nanoscale** fabrication*

- High peak intensities→ nonlinear absorption

Multiphoton absorption in transparent materials→both surface (2D) and volume (3D) writing of micro- and nanostructures becomes feasible

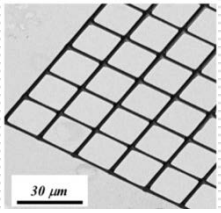
- *Processing of practically all materials: metals, semiconductors, glasses, polymers, ceramics, and biological samples*

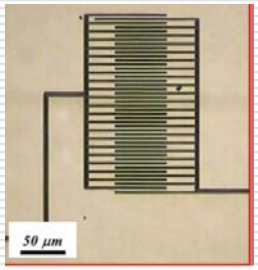
DELTA Microfabrication

Femtosecond laser processing

Typical Applications

Direct laser writing, micromachining, laser-assisted deposition, 2D patterning

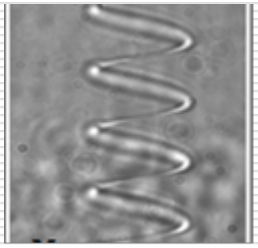


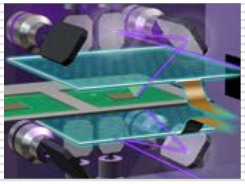


Micro- and nanoelectronics

Semiconductor technology, etc

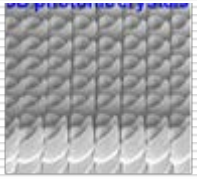
Bulk processing of transparent materials

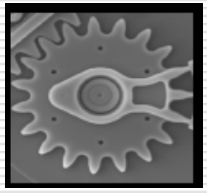


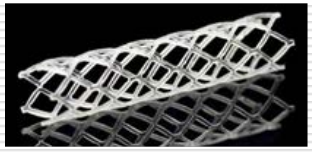


Microfluidics networks, waveguides, labs-on-a-chip

2-photon polymerization, ablation

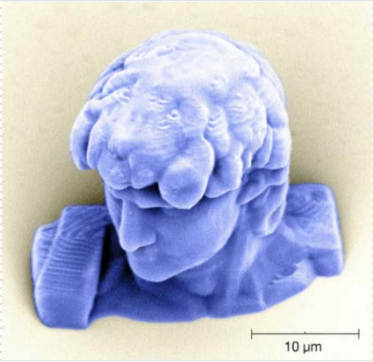






3D photonic crystals, MEMS biomedical

Other...



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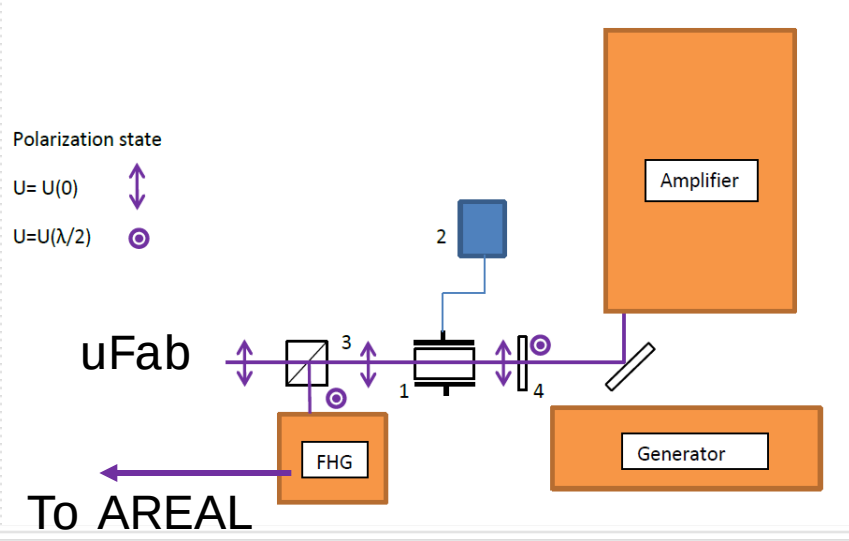
Upcoming upgrades and Extensions

Ultrafast pulse picker



1. Pockels cell 2. Driver 3. Polarizing beamsplitter 4. Waveplate

- *Designed specifically for simultaneous operation of AREAL and uFab*
- *N out of 50K pulses with switched polarization can be redirected from the train of amplifier output*
- *Sync with Master Oscillator*

Upcoming upgrades and Extensions

Tunable femtosecond laser

+Sync unit with MO

cooperation with AVESTA (Russia)

Ti:Sapphire, 750-950 nm, 100 fs, 80MHz

Applications

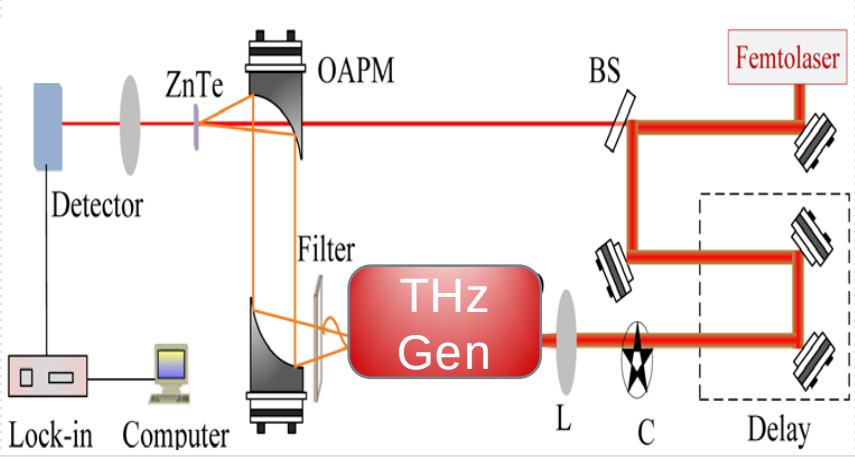
- 2P-microscopy; extended range of fluorophores
- Time-resolved experiments
- other

Upcoming upgrades and Extensions

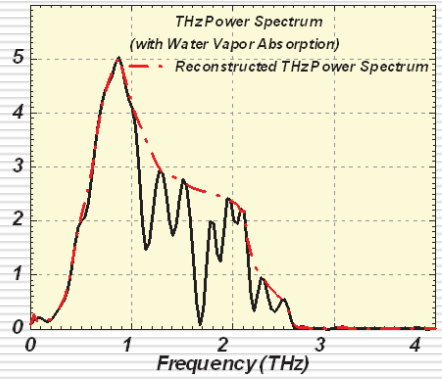
THz spectrometer

THz source + EO sampling

table-top, 1 to 100s nJ/pulse (not a FEL); 0.5-2.3 THz



Basic scheme



In cooperation with AVESTA (Russia)

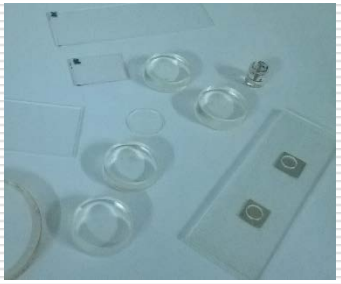
AVESTA lasers and optical systems

THz generation to be implemented at CANDLE

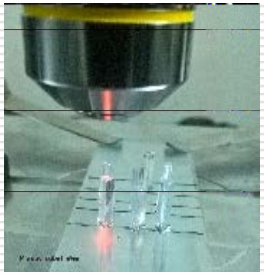
DELTA Microfabrication

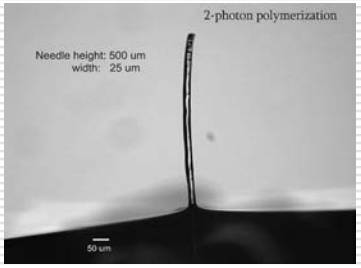
Current activities

- Fabrication of glass-based optical elements:
  Laser beam shaping elements
  "fork" gratings for optical vortex generation
  diffraction gratings

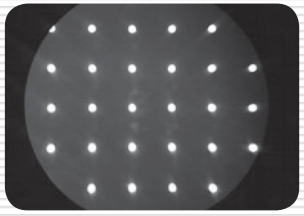


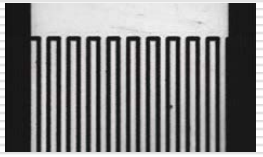
- 2-photon polymerization:
  Liquid-crystal alignment microstructures
  Micro-needles, cantilevers, microprobes





- Patterning of semiconductor and metallic surfaces:
  micro-contacts, nano-film patterning,
  photon electron beam apertures





DELTA Microfabrication

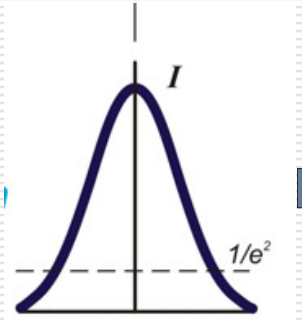
Current activities

Laser Beam Shaping

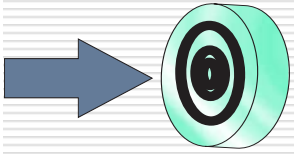
Principle

Conversion of laser irradiance distribution

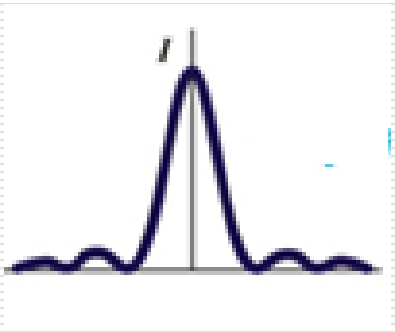
Gaussian

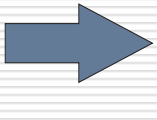


Modulation of Gaussian with a proper phase function

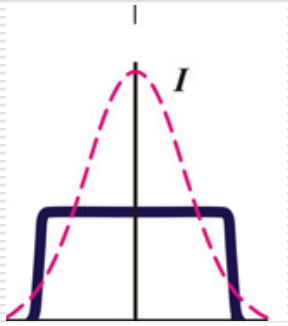


Bessinc*(r) or* “Airy disk”





Homogeneous (Flattop)



Far field (or f- plane of a lens)

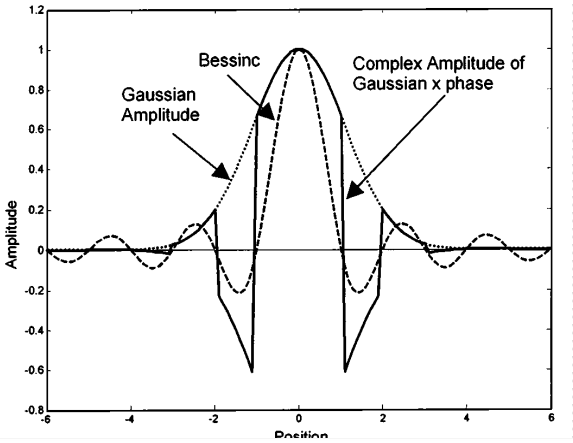
Current activities

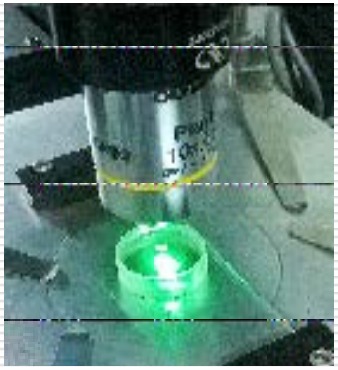
Laser Beam Shaping

Design and fabrication

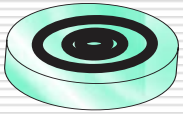
Design Parameters
Wavelength
Beam size
Traveling (focal) distance
Phase depth

(0,π) binary phase function (concentric rings) are laser-written IN/ON glass





Integrated π-Shaper

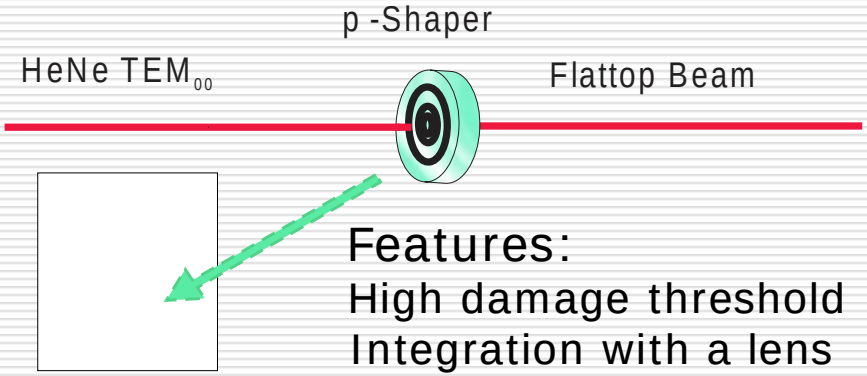


DELTA Microfabrication

Current activities

Laser Beam Shaping

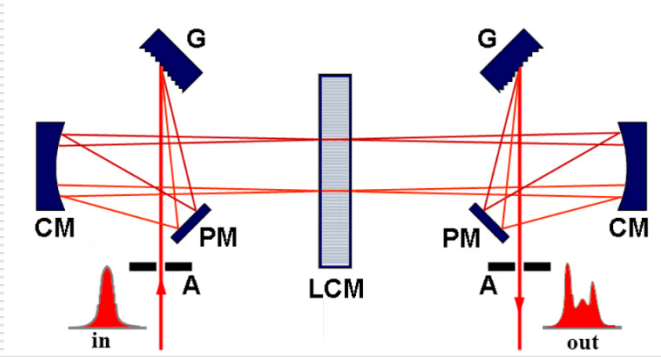
Results



Features:
High damage threshold
Integration with a lens
Efficiency >95 %

Applications

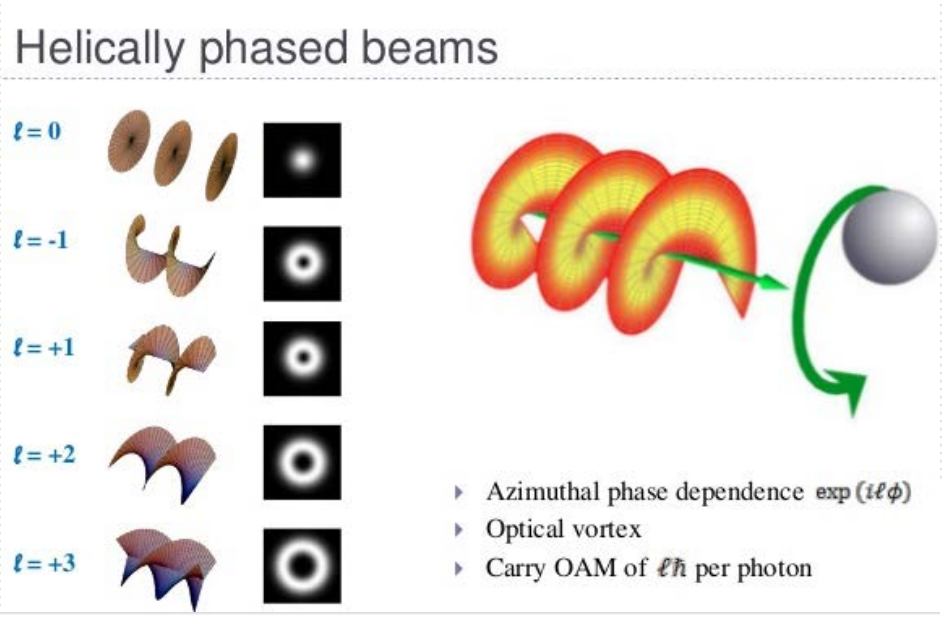
Laser fabrication technology
Spatial-temporal beam shaping
...



DELTA Microfabrication

Current activities

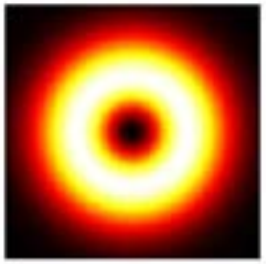
Optical Vortex Beams



Potential Applications

- Optical communications
- Coronagraphy
- Micro-particle manipulation (optical tweezers)
- Beam shaping
- STED (2P-)microscopy

Excitation beam



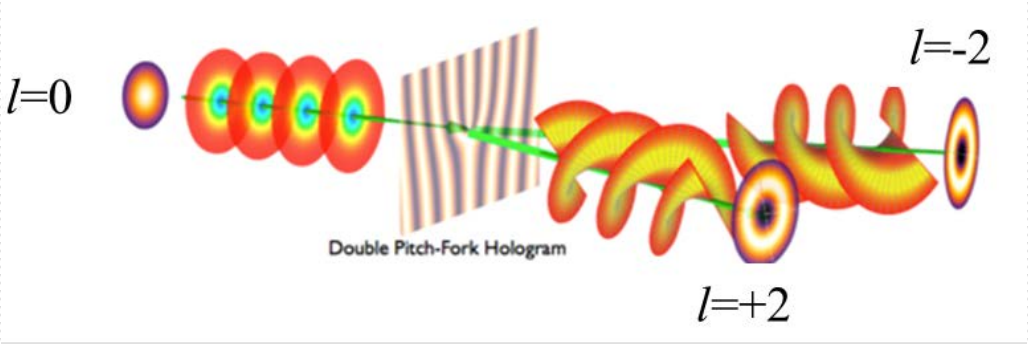
quenching beam

"Fluorescence -allowing" beam

Current activities

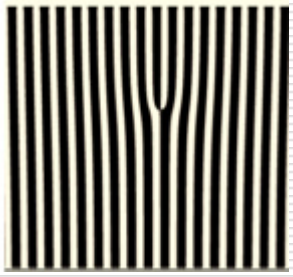
Optical Vortex Beams

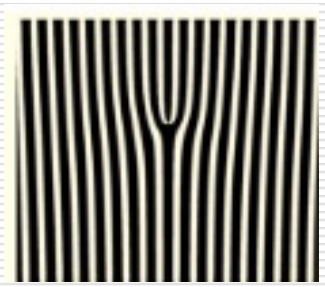
Computer-generated “Fork” holograms as a source of phase singularities

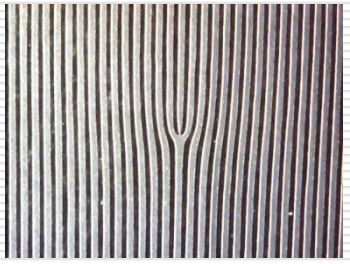


Features:

- Glass provides high damage threshold (critical with high power applications)
- Efficiency can be increased by fabrication of volume holograms







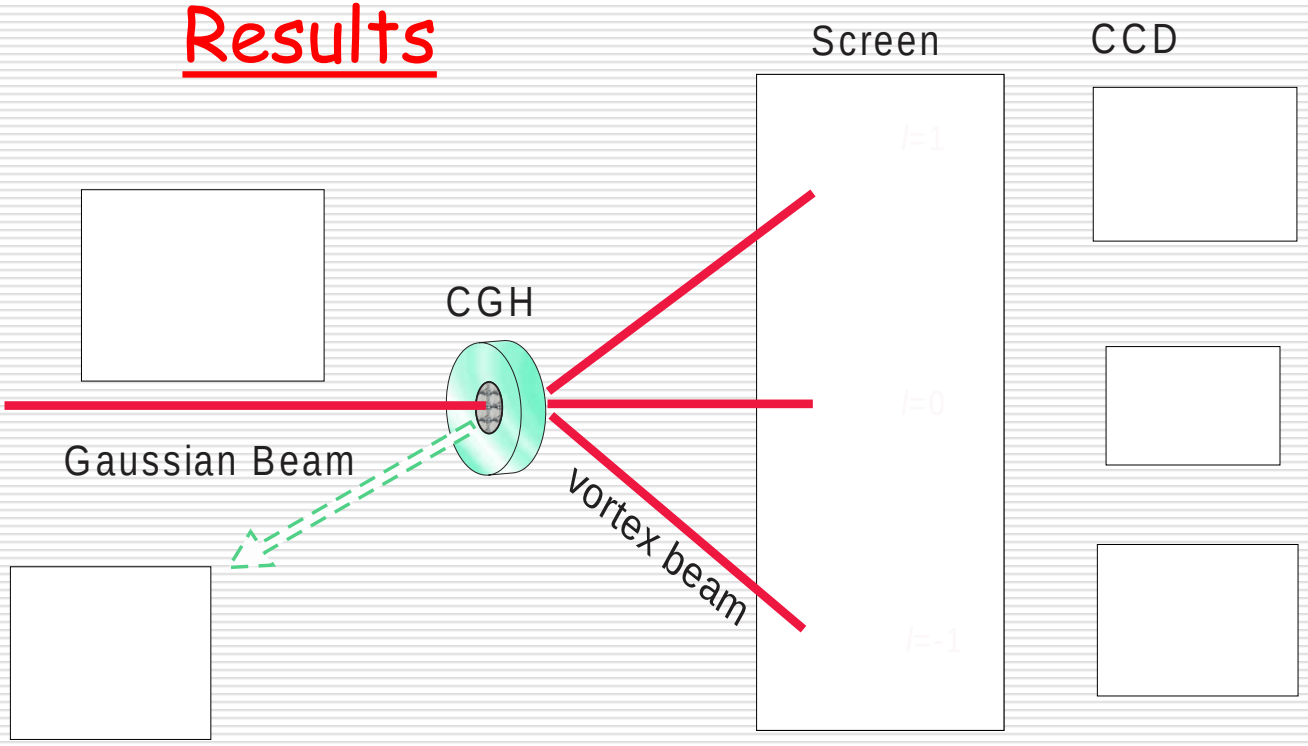
Laser-written on glass

Current activities

Optical Vortex Beams

Results

Optical vortex **generation**

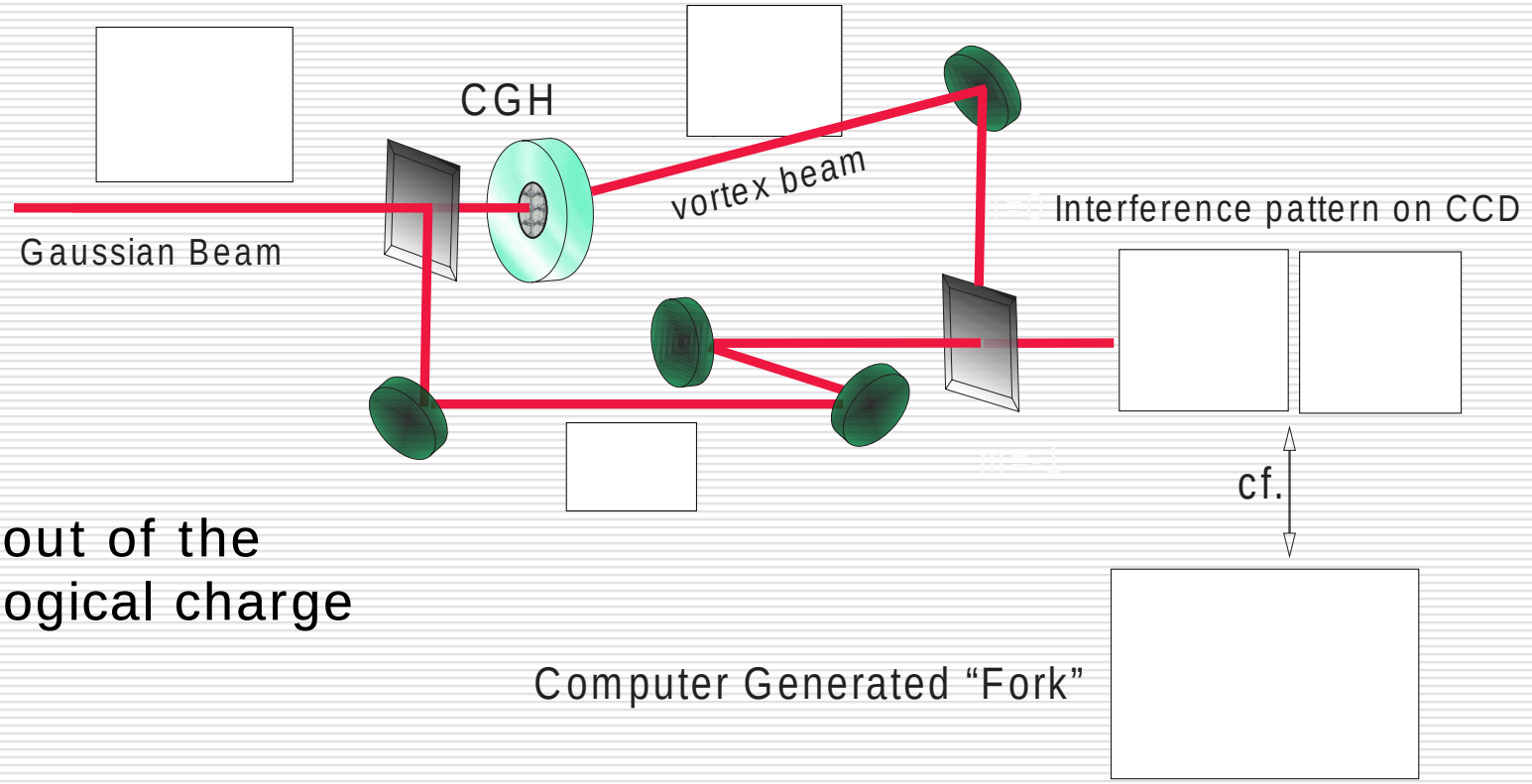


CGH-Computer Generated Hologram laser-written ON/IN glass

Current activities

Optical Vortex Beams

Results



Readout of the topological charge

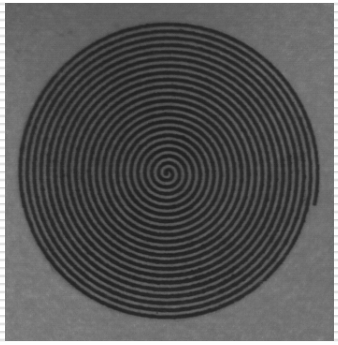
DELTA Microfabrication

Current activities

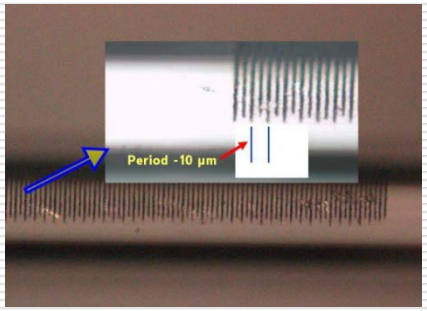
More glass-based optical elements

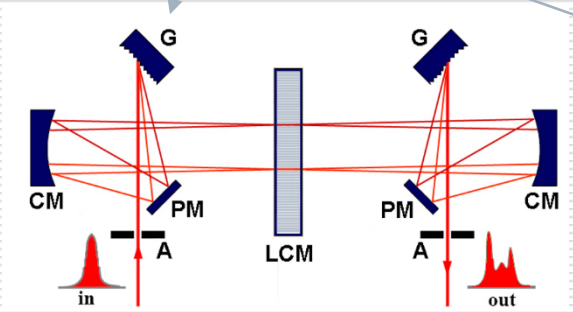
Relief diffraction gratings

spiral

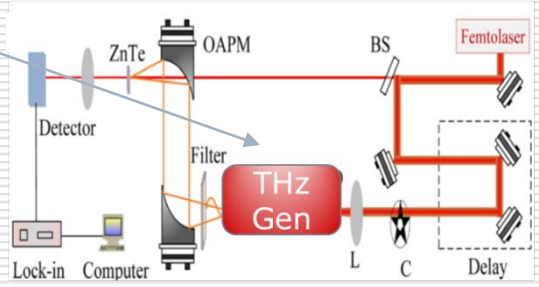


Fiber diffraction grating





Pulse shaping

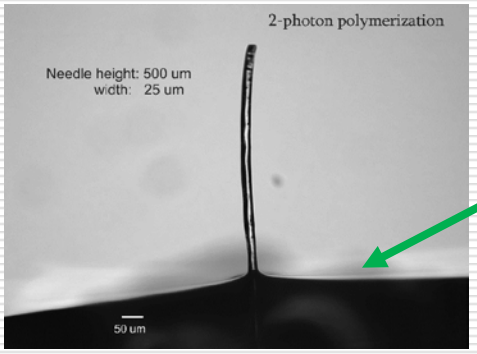


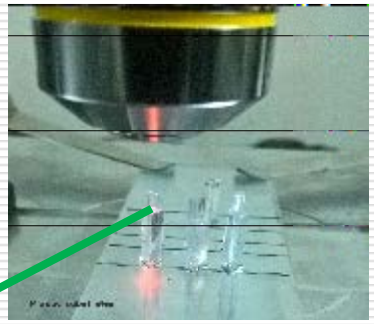
Applied to tilt the pump front for efficient THz generation

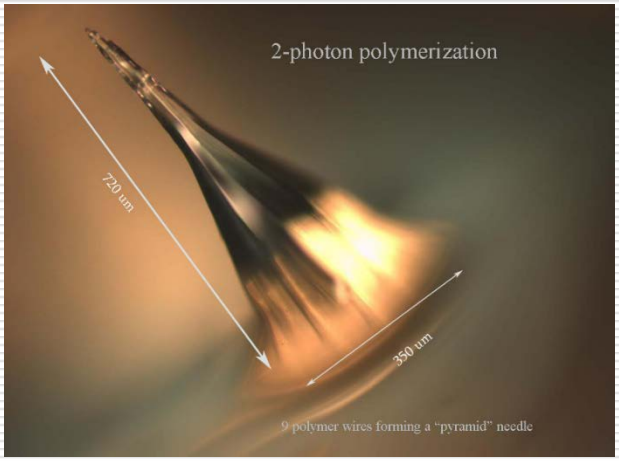
DELTA Microfabrication

Current activities

Two-photon polymerization

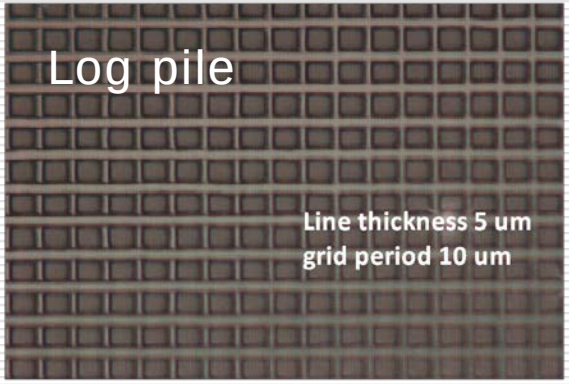






Applications

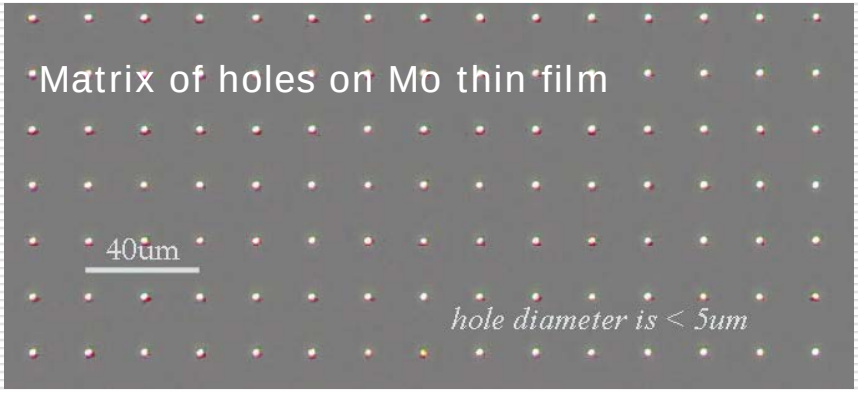
- bio-medical: micro-needles for transdermal drug delivery, microelectrodes, etc.
- 3D photonic crystals
- Liquid crystal devices
- Micro-and nano-cantilevers, sensors
- MEMS (Micro- Electro-Mechanical Systems)

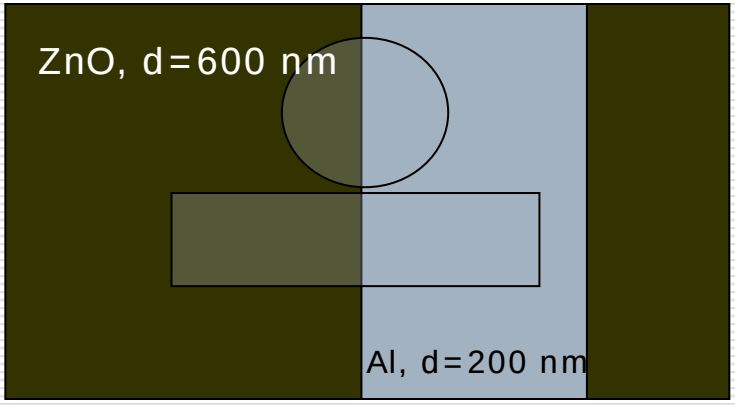


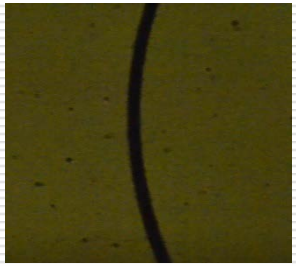
DELTA Microfabrication

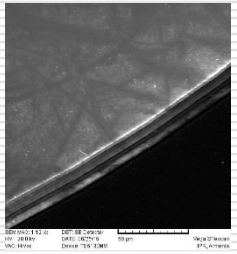
Current activities

Surface patterning



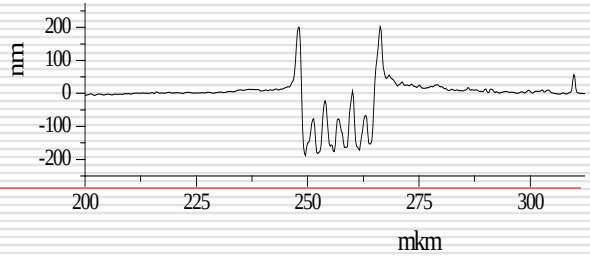






Applications

micro-contacts
nano-film patterning
photon electron beam apertures



Summary

- Fundamental, 2nd, 3rd and 4th harmonics of femtosecond laser are used for parallel operation of 2-photon scanning microscope, microfabrication and linac stations
- This provides unique capability to perform a comprehensive chain of multidisciplinary experiments using ultrafast electron and photon beams
- Forthcoming supplements and developments are highlighted which will further extend the experimental capabilities
- A summary of results to demonstrate the diversity of potential applications

Thank you