Application of tunable-delay, ultrashort double pulses for materials processing and THz generation

Ultrafast Beams and Applications

UBA-22

04-08 July, 2022

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Outline

- Tunable-delay pulse pair generation on AREAL laser

  as a tool for fundamental studies and applications

- Current Experiments
  - Generation of e-bunch pairs and application for irradiation of thin films and glasses
  - Study of dynamics of glass laser processing and microfabrication
  - Application for air-plasma THz generation experiments

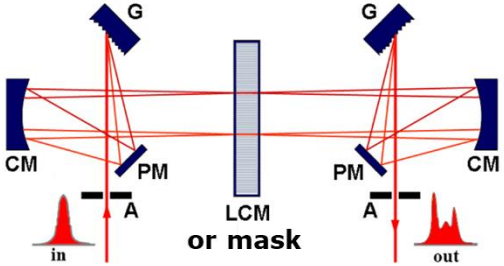
- Summary

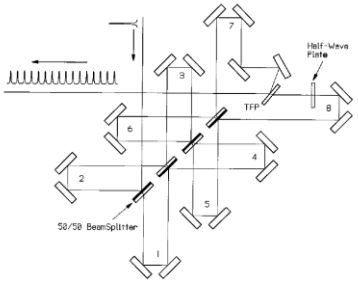
Temporal shaping of ultrashort-pulses

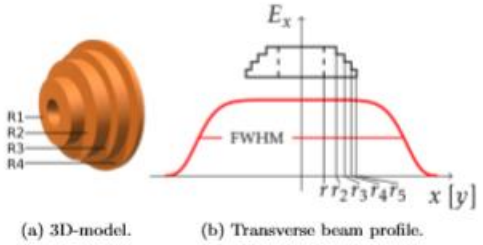
Methods for generation of waveforms are actively studied and applied in parallel with development of femtosecond laser systems

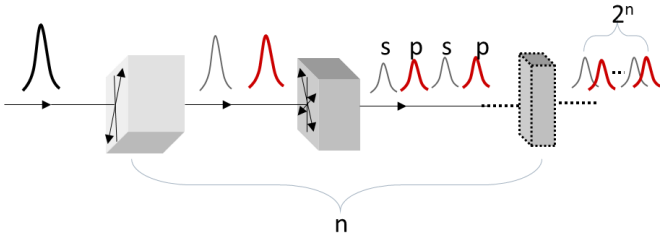
Many Techniques

Active and passive; Fourier synthesis:
Fiber and gratings (Stretching and SPM)
Fixed masks or programmable SLM+gratings
Holographic
Delay lines and interferometers
Combination with spatial beam shaping and applications etc.

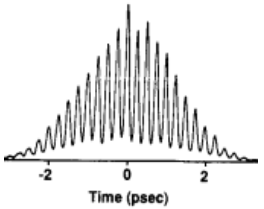


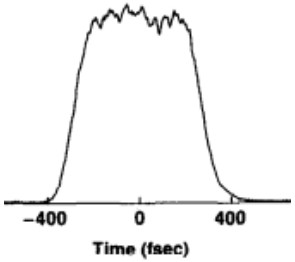


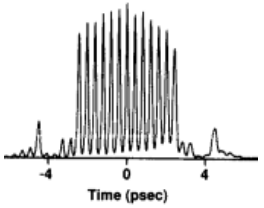


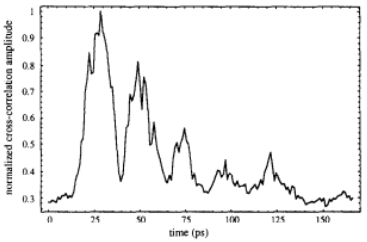


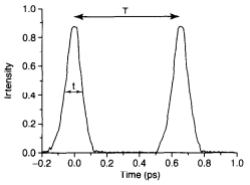
Variety of shapes



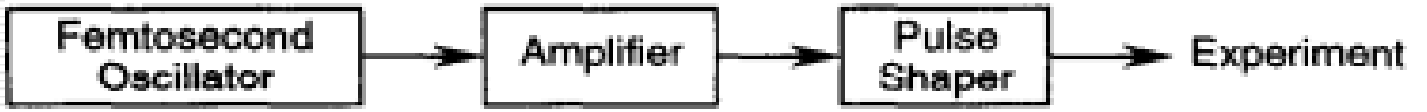




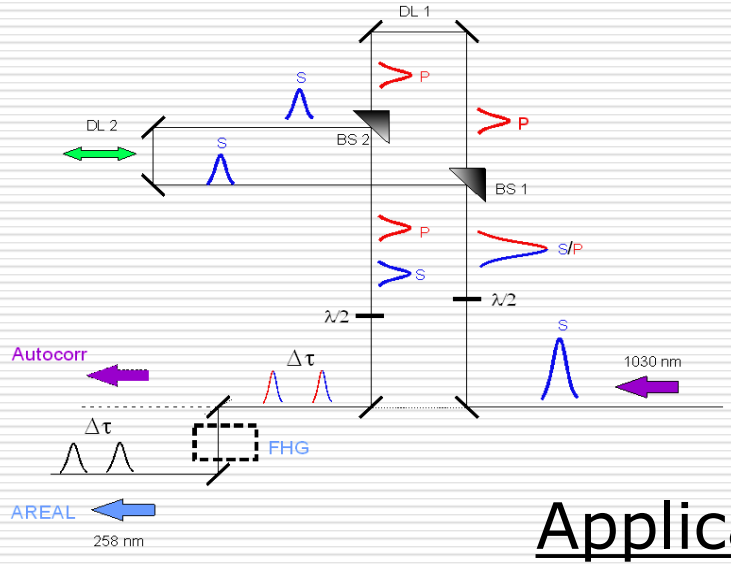


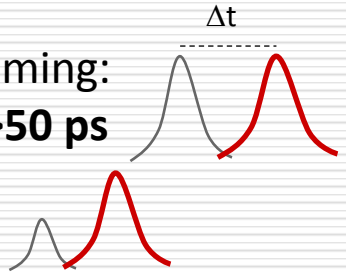


Temporal shaping of ultrashort-pulses



Delay line for pulse doubling on AREAL laser





- Tunable relative timing: **from 0 to >50 ps**
- Arbitrary contrast
- measurement/control of pulse duration and delay with autocorrelator

Applications

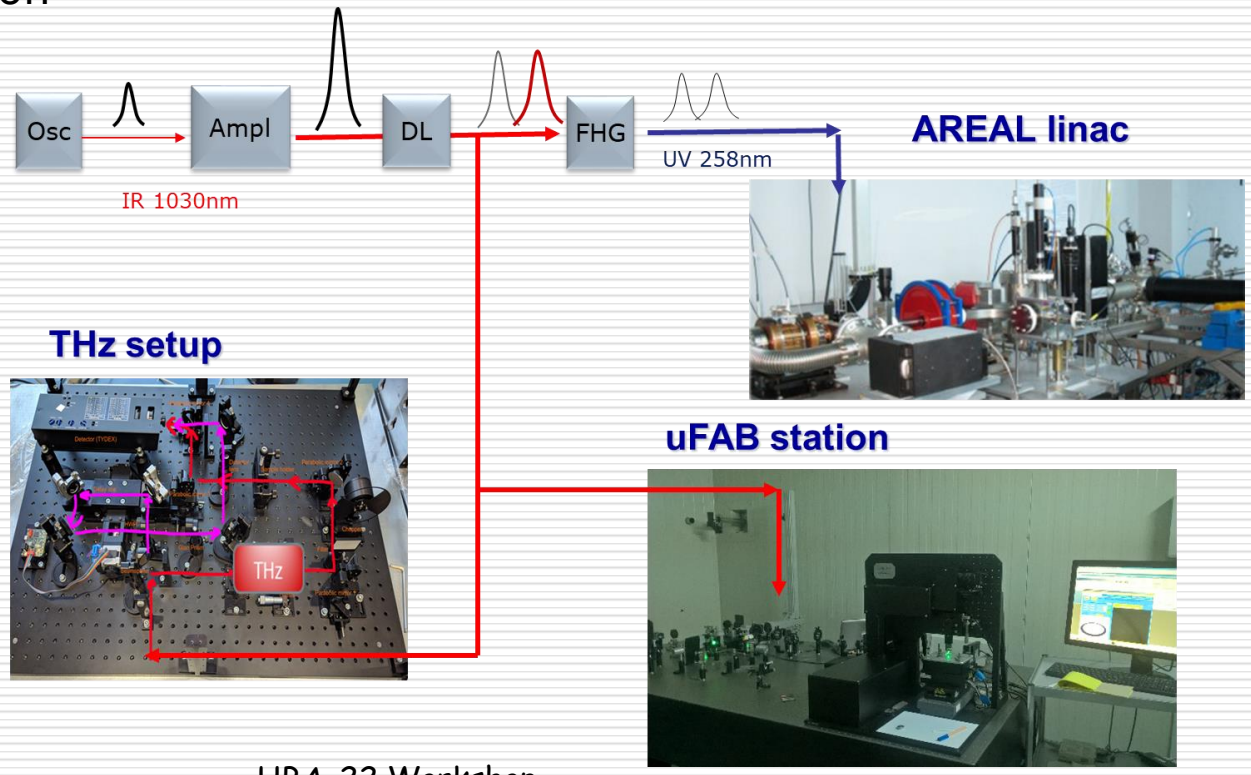
- ❑ Fundamental studies (dynamics of ultrafast processes, plasma physics…)
- ❑ Coherent laser control (atomic and nonlinear optical processes, charge motions in semiconductors, chemistry…)
- ❑ generation and applications of e-bunch doublets and structured e-bunches
- ❑ Materials processing (laser processing, irradiation…)

Other….

Applications of tunable-delay double pulses

Current experiments at CANDLE

- Generation of e-bunch pairs and structured beams; effect of irradiation on semiconductor thin films and glasses
- Study of dynamics of laser-induced modifications in glasses; Effects on 3D (bulk) micro-processing
- Driving and optimization of dynamics of laser-induced air plasma for THz generation



Generation of e-bunch pairs and structured beams; effect of irradiation on semiconductor thin films and glasses

Project: *"Effect of ultrashort electron and photon bunches on surface structure and optical properties of thin-film coatings and glasses"*

Synthesis & Experiments

Measurements & Characterization

Thin film deposition

E-beam irrad.

UV and VIS laser irrad.

Surface Microscopy

Composition

Spectral

etc.

Axio Observer 3
Carl Zeiss

SEM EVO-10
Carl Zeiss

AvaSpec-ULS3648
Avantes

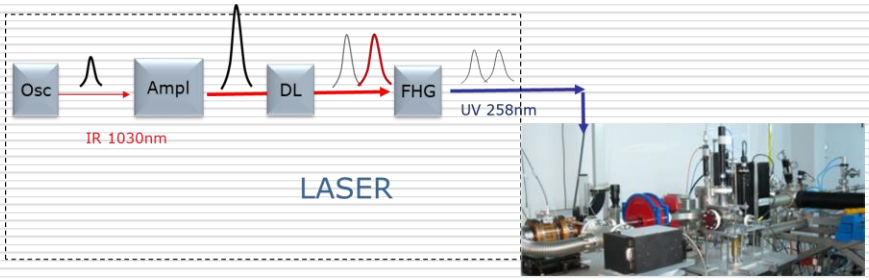
E-beam irradiation of CdS thin films on glass

Features of ultrashort-bunch electron irradiation

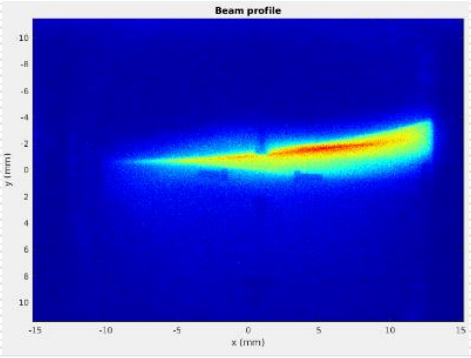
- Relative contribution from "*direct*" (close to the particle trajectory) and "*long-range*" interactions in energy-losses changes at high-flux, ultrashort-bunch irradiation: contribution from long-range interactions increases at shorter duration of e-bunch at a given flux;
- Local redistribution of formed defects and chemical bonds in the target due to the change in dynamics of different relaxation paths;
- Physicochemical reactions of the charged and excited particle occur at durations 10^{-13}—10^{-8} sec → influence of secondary effects are suppressed when irradiating with picosecond or shorter pulses

Thus, irradiation effects are expected to depend on both e-bunch duration and temporal shape (modulation)→ additional control parameter (in addition to energy and flux)

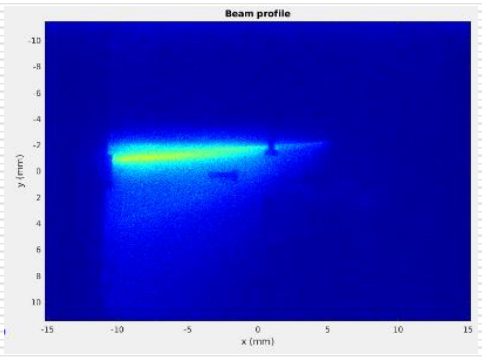
Tunable-delay e-bunch pairs



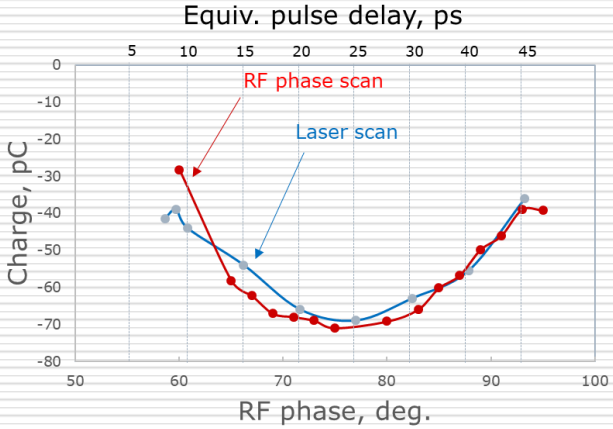
Bunch 1



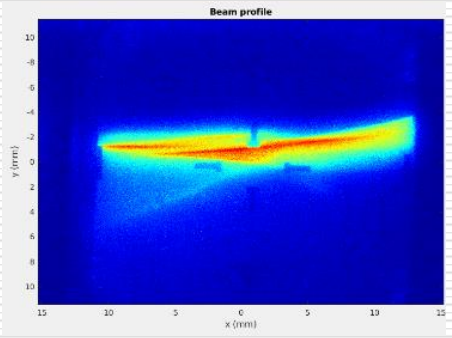
Bunch 2



phase scan by optical path variation



Bunch 1+Bunch 2



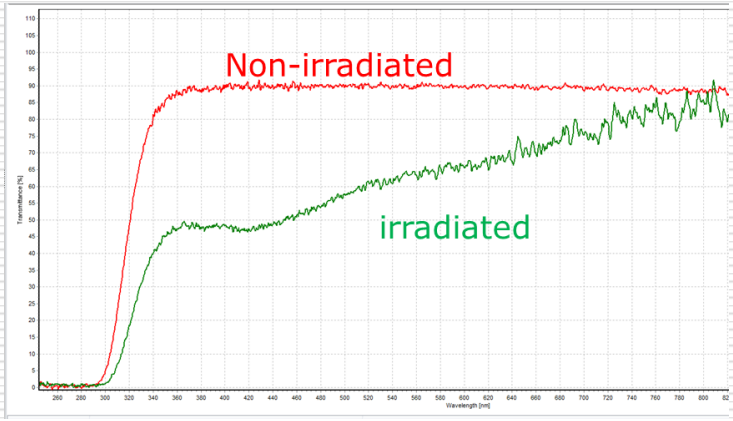
Parameter	Value
Laser pulse measured delay, t_d	20 ps
Laser pulse duration, t_1, t_2	$t_1=t_2$=550 fs
Laser pulse energies, E1, E2	40.17 μJ, 40.7 μJ (+-1%)
e-Bunch charges (optimized), Q1, Q2	83 pC, 72 pC
e-Bunch charges (optimized for Q1)	83 pC, 48 pC
Phase difference optimized for Q1 and Q2	78°-95°=-17°
e-Bunch energy (E1)	~ 2MeV

Control and reference phase with fixed laser pulse
Other technical applications?!

E-beam irradiation of CdS thin films on glass

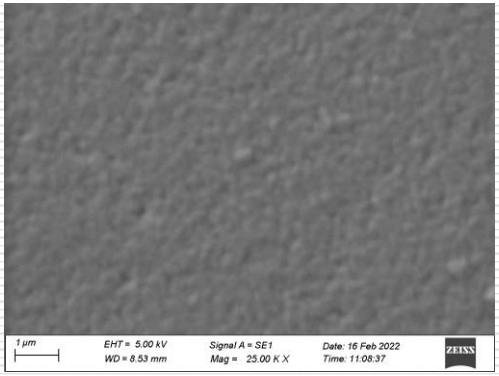
deposition/irradiation/characterization experiments

Vacuum evaporated CdS thin films on glass	
Evaporation Temp.	820 ^{0}C
Substrate Temp.	120 ^{0}C
Avg. thickness	1700 nm
Deposition time	20 min

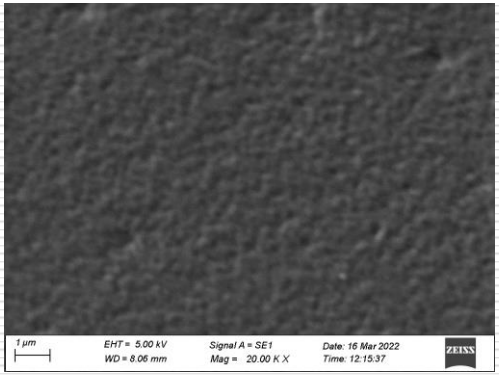


Non-shaped, single-bunch irradiation

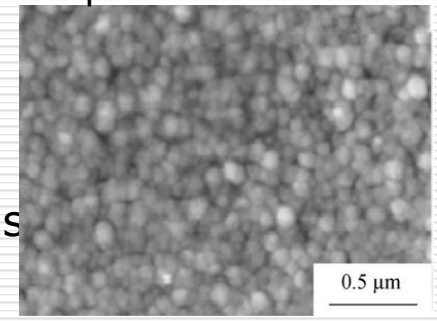
Before



After



Expected



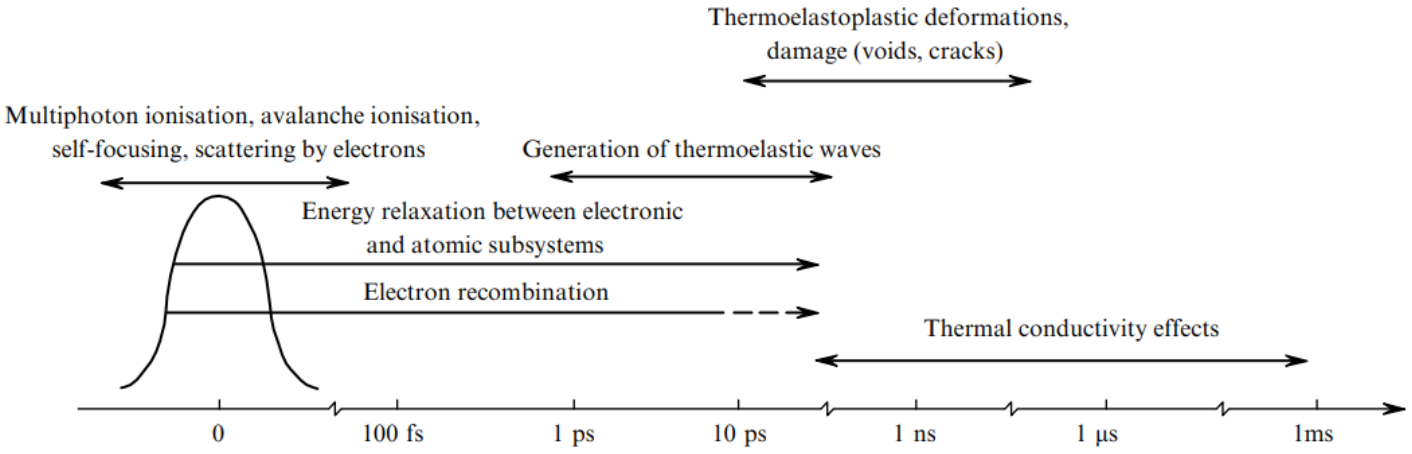
- Only a slight structural modification: *change of grain size*
- Optimal deposition regimes to be defined for homogeneous films
- Proper irrad. dose range to be defined
- Effect of bunch temporal shape

Laser processing of transparent glasses

Effect of time-domain pulse shaping

Physical mechanisms underlying glass modification during ultrashort-pulse processing are not fully understood:

- Complex excitation-relaxation dynamics, involving multitude (competing) processes in different time-scales:



Bulgakova et al. Quantum Electronics, 40 (11) p.966 (2010)

- material-dependent thermodynamic relaxation (e.g. fused silica vs borosilicate BK7)
- Pulse shaping in time domain can be exploited to adjust the energy delivery rate to the transient states; and for efficiency of energy deposition

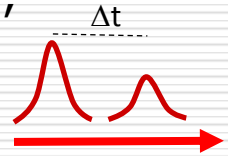
Laser processing of transparent glasses

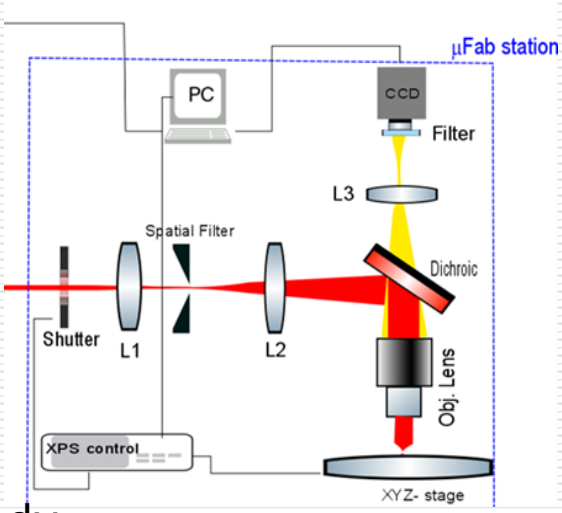
Effect of double-pulse laser irradiation

See also presentation by M. Sargsyan, this session

Experiments

- Space-selective irradiation by single doublets; variable pulse delay, different contrasts





- Study of dynamics by measuring the transmittance change after irradiation
- optical microscopy images and comparison, damage stady

Main aims

- multiphoton excitation-relaxation dynamics, laser-induced damage/breakdown mechanisms in the time-scale 1—50 ps, at near-threshold intensities
- Exploit the DL and uFAB scanning parameters as a tool for driving and optimization of micro-processing for quality fabrication

Laser processing of transparent glasses

Effect of double-pulse laser irradiation

Important observations

- ✓ Incubation effects and decrease of double-pump damage threshold compared to single-pulse treatment
- ✓ The first laser pulse induces a large concentration of defects in the material lattice that modifies the interaction with the subsequent pulse

Practical meaning

- ✓ Method for real-time determination of optical breakdown/damage threshold from transmittance measurements and optical microscopy
- ✓ Possibility of higher-resolution (smaller feature size) fabrication: Decrease of feature size due to the inhomogeneous excitation by first pulse

THz generation from laser-induced air plasma

Air plasma as a popular THz source: ponderomotive forces on photoexcited electrons due to the density gradient; transient emission depending on the dipole direction

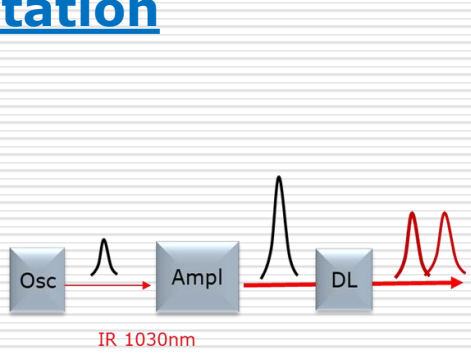
- Gas ionization at intensities > 10^{12} W/cm^2, easily achieved by current laser systems
- No limitation on pump intensities (no concern of crystal damage, etc.)
- Limited conversion efficiency (mainly, due to the electron density saturation and laser intensity clamping effects)

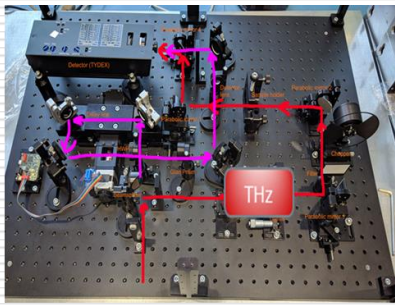
Approaches to enhance the efficiency: *two-color generation*, *HV electric bias*, etc.

See presentation by M. Sukiasyan, this session

Effect of double-pump optical excitation

- nonstationary enhancement of nonlinearity
- Relatively weaker first pulse for ionization
- Pulse delay can be optimized to get the highest signal





Summary

Tunable-delay, ultrashort double pulses as an experimental tool for materials processing and optimization of THz generation from laser induced plasma

- Temporally shaped (structured) e-bunches for irradiation experiments
- Method for fundamental dynamics studies and improvement of laser processing of glasses
- Potential application for enhancement of efficiency of THz generation from laser-induced air plasma

Thank you