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High-energy terahertz radiation source tunable in a wide spectral range

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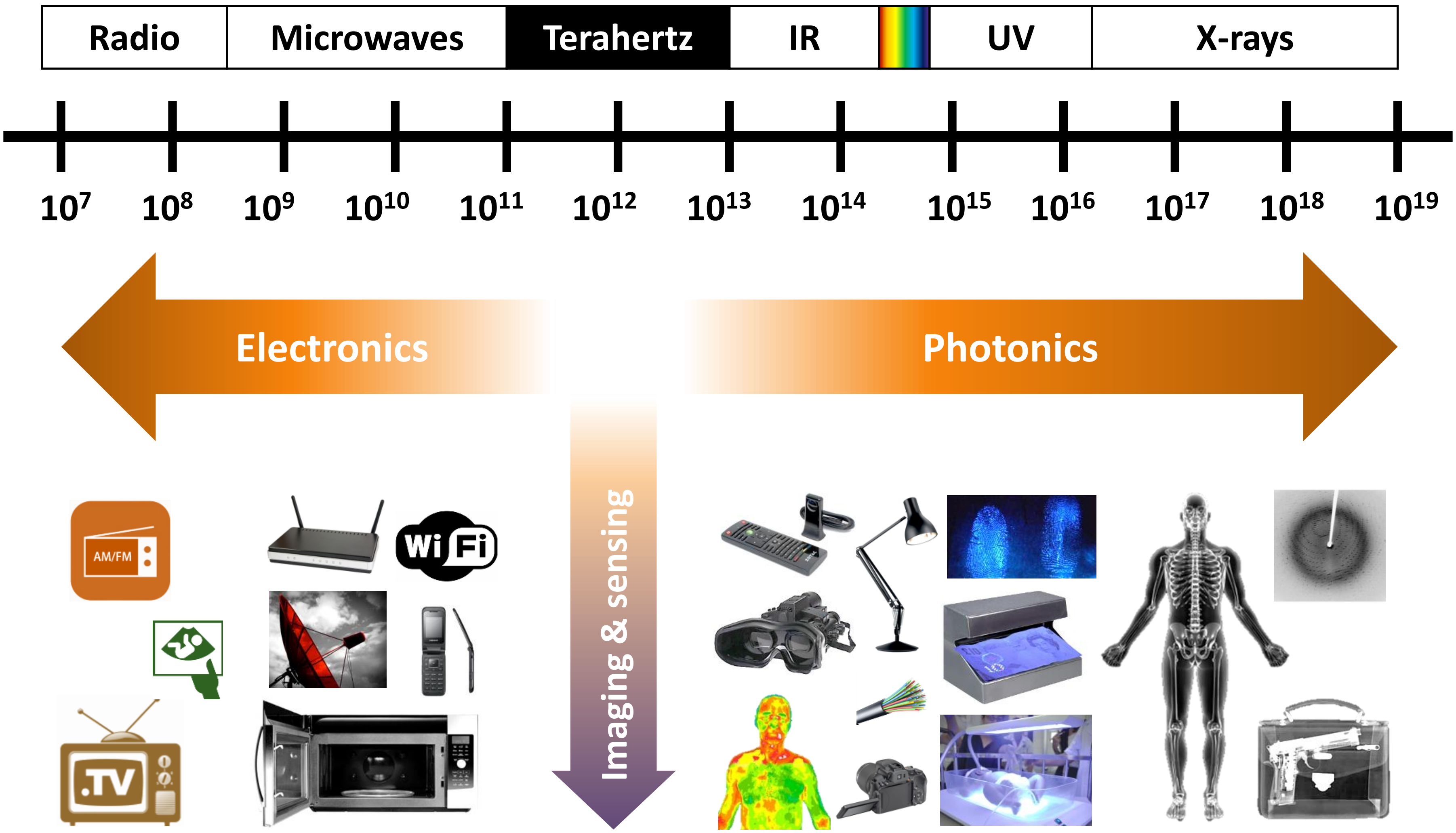
THz radiation

Frequency	Wavelength	Energy	Wavenumber
0.1 ÷ 10 THz	0.03 ÷ 3 mm	0.41 ÷ 41 meV	3.3 ÷ 333.3 cm^{-1}

1 THz = 10^{12} Hz

Frequency, ν	Wavelength, λ	Energy, ε	Wavenumber, $\check{\nu}$	Temperature
1 THz	**300 μm**	**4.14 meV**	**33.3 cm^{-1}**	**47.6 K**

The Electromagnetic Spectrum



Application Areas of THz

- Astronomy
  - Microwave background
  - Local oscillators
  - Interstellar clouds
- Earth sensing
  - Ozone
  - Climate
  - Environment
- Communications
  - High bandwidth
  - High speed
  - Wireless networking
- Chemistry
  - Catalysis
  - Reaction kinetics
  - Microscope
- Medical
  - Basal cell carcinoma
  - Cancer detection
  - Bio fluids

Application Areas of THz

- **Paleontology**
  - Fossil imaging
- **Industrial**
  - Package inspection
  - Circuit testing
  - Gas sensing
- **Security**
  - Drugs
  - Explosive
  - Terrorism
- **Biotech**
  - Genetics
  - Biochips
  - Proteomic sensing
- **Process technology**
  - Medications
  - Food analysis
  - Quality control

Properties of Terahertz Radiation

- Non-ionizing vs UV & x-ray
- Minimal health risk
- High penetration depths for many nonconductive materials
- Better spatial resolution vs mm & sub-mm waves
- Strong absorption/reflection by water, organic substances, metals
- High chemical sensitivity/selectivity, «fingerprints»

Generation of THz radiation

Electronic systems

- High power, ideal for terahertz imaging

Optoelectronic

- High bandwidth, ideal for spectroscopy

Pulsed lasers

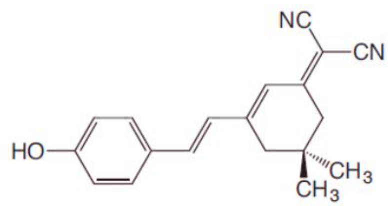
- Fast measurements, broad spectrum

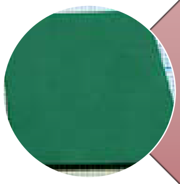
CW lasers

- Tunable, highest spectral resolution

Generation of THz radiation

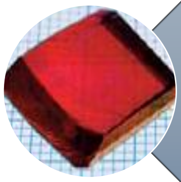
Organic crystals





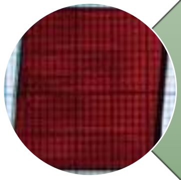
DSTMS

- Efficient terahertz generation in 0.3-15 THz range



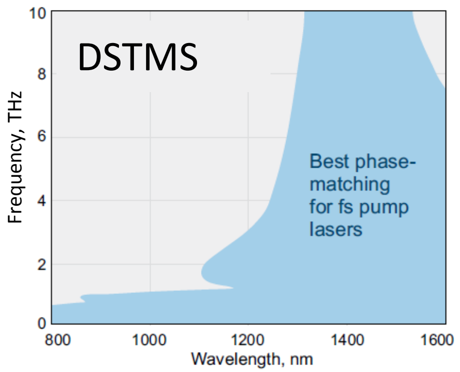
OH1

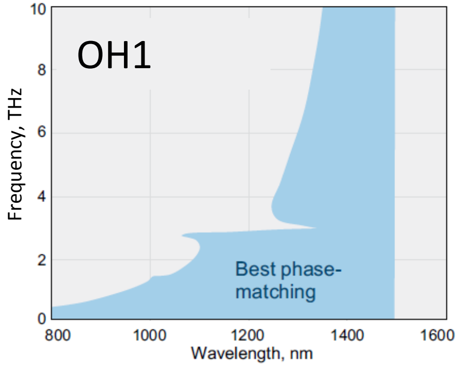
- Efficient terahertz generation in 0.1-3 THz range

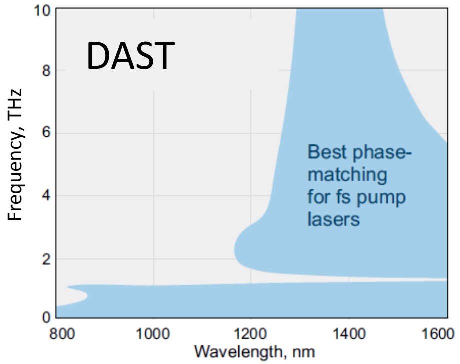


DAST

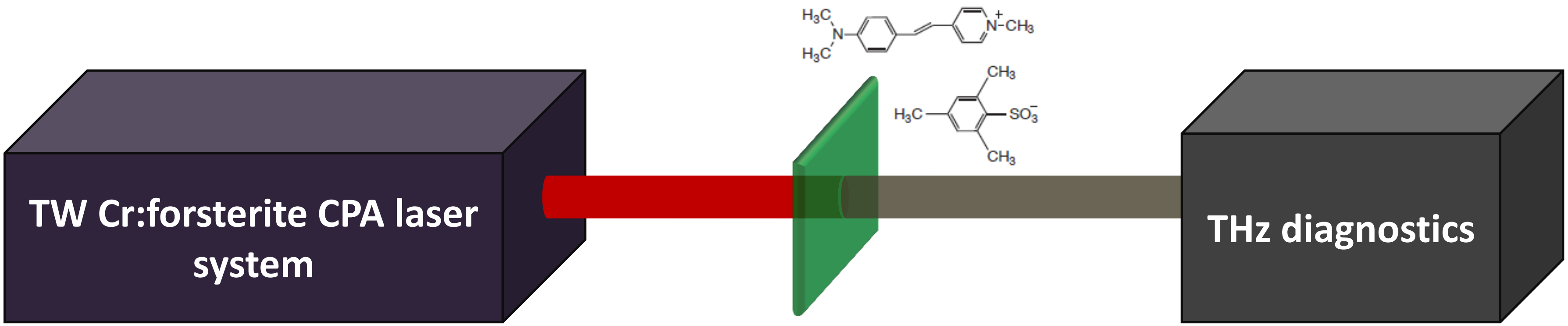
- Efficient terahertz generation in 0.1-17 THz range







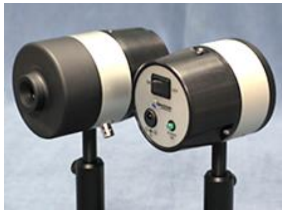
Generation of THz radiation

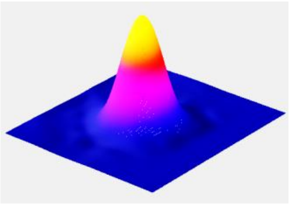


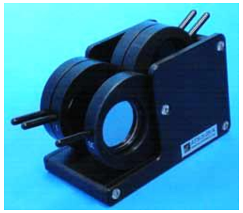
Nonlinear organic crystals

- Wavelength (1240 nm)
- Pulse duration (85 fs)
- Pulse energy (80 mJ)
- Pulse energy stability (2%)
- Intensity contrast (10^7)
- Repetition rate (10 Hz)
- $M^2 = 1.3$

- THz filters (Tydex Inc.)
- THz attenuators (Tydex Inc.)
- THz beamsplitter (Tydex Inc.)
- Golay cell (Tydex Inc.)
- THz imager (NEC Corp.)
- THz Radiometer (Gentec-EO)
- Parabolic mirrors (Janos)

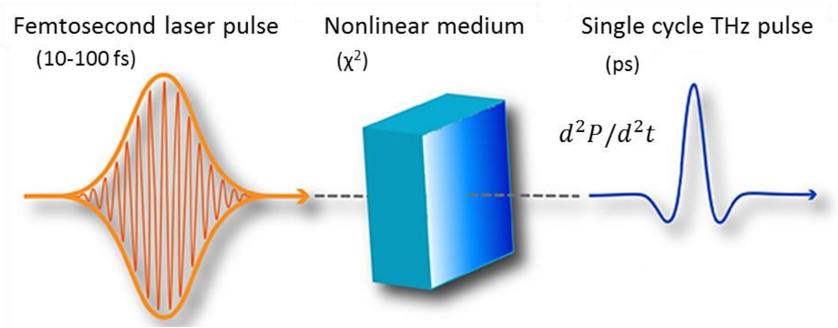



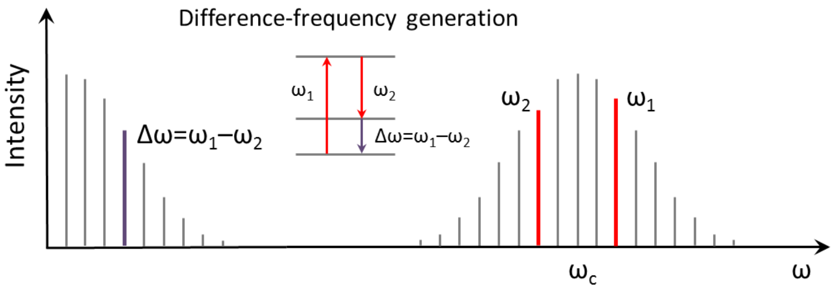





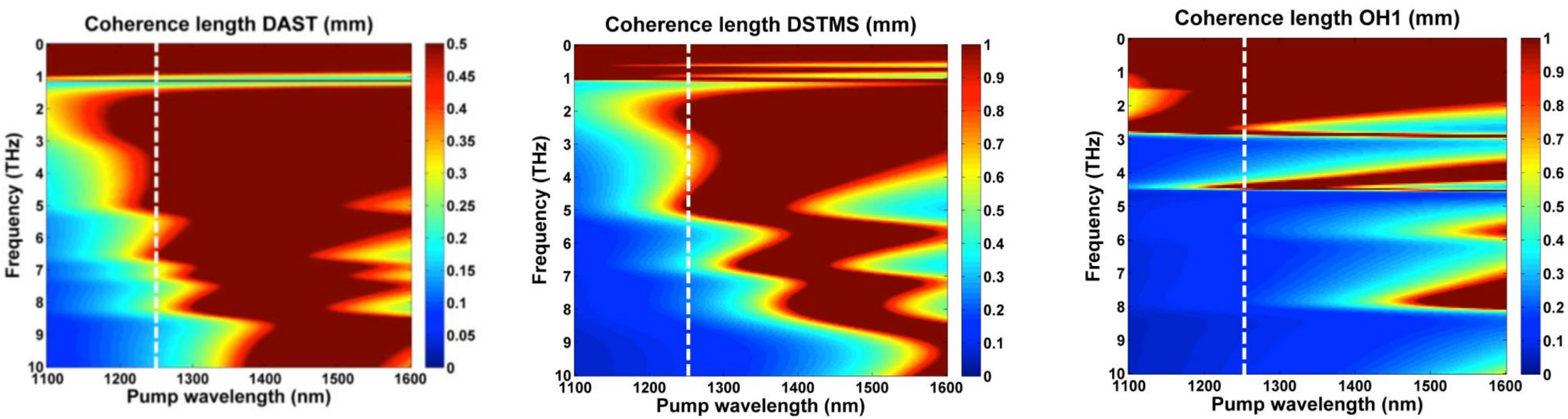

Generation of THz radiation

Optical Rectification

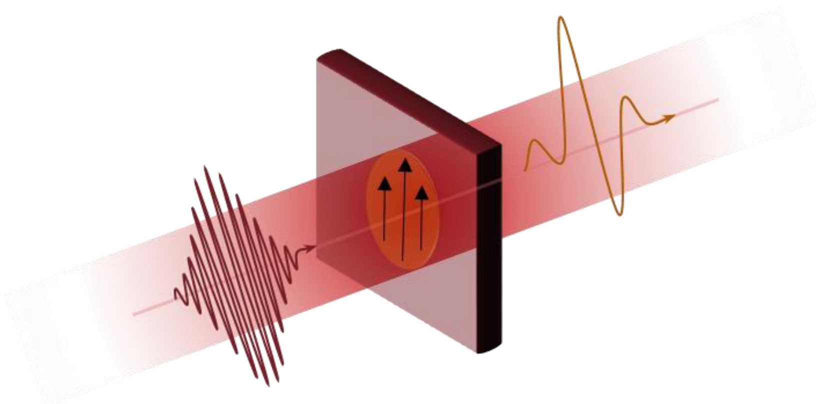




Calculated coherence length for DAST, DSTMS and OH1 at different pump wavelengths and THz frequencies



Record-breaking high-power source of coherent THz radiation of sub-picosecond pulse duration

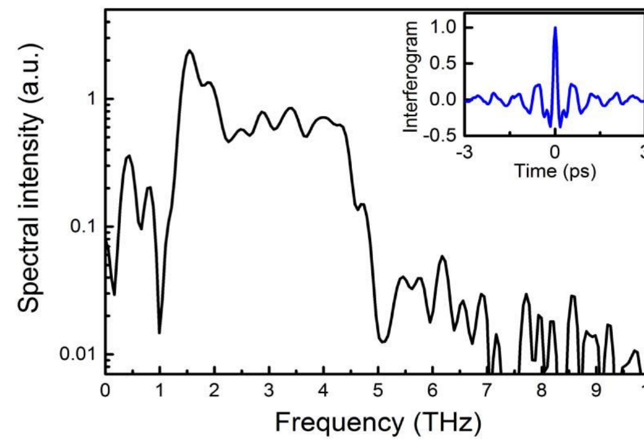


The single-cycle, phase-stable THz pulse parameters:

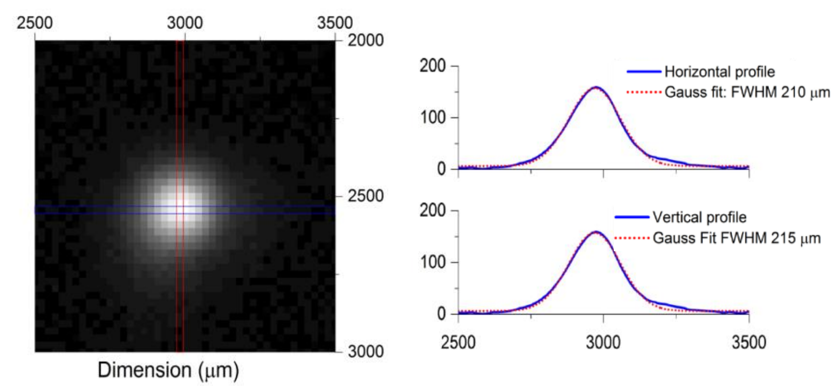
- THz pulse energy up to **1 mJ**
- Conversion efficiency > **3%**
- THz field strength **42 MV/cm**
- Frequency range **0.1 – 5 THz**
- Power up to **10 GW**

Optics Letters, Vol. 39, Issue 23, pp. 6632–6635 (2014), IF=3.2

THz spectrum retrieved by the autocorrelation using a THz Michelson interferometer

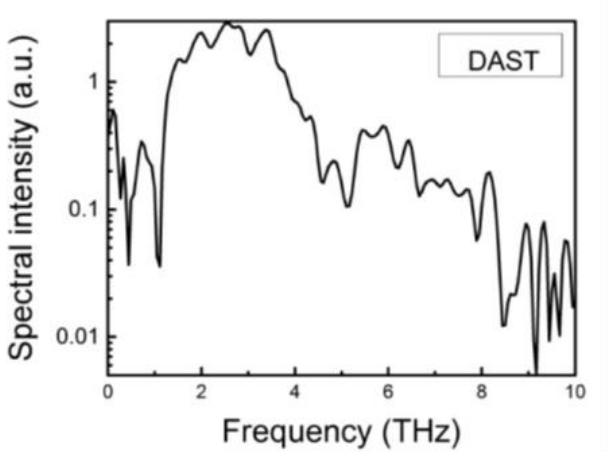


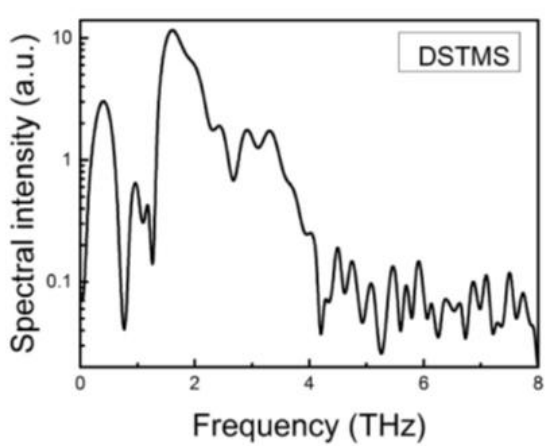
THz beam profile for DSTMS

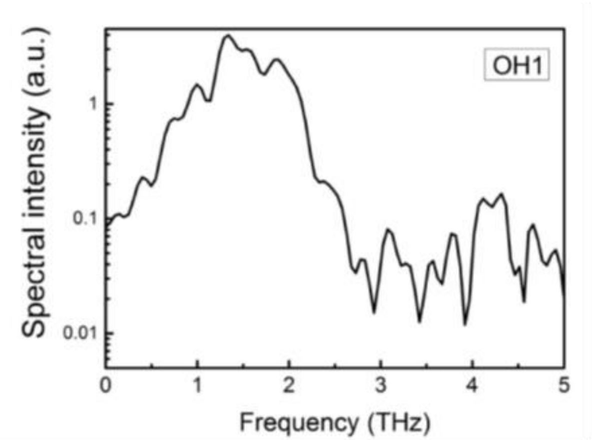


Record-breaking high-power source of coherent THz radiation of sub-picosecond pulse duration

Terahertz generation in organic crystals DAST, DSTMS, and OH1 directly pumped by a Cr:forsterite laser at central wavelength of 1.24 μm



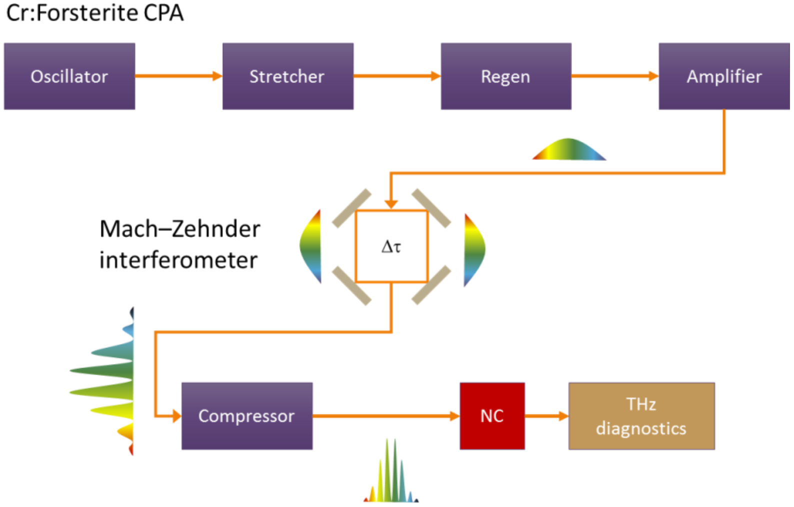




Organic crystal	Thickness-Diameter (mm)	Max. efficiency	Max. energy/ Fluence	Emitted spectrum	Focus FWHM	Electric field
DAST	0.18-5	2.1%	62 uJ/280 uJ/cm^2	0.1-10 THz	490 um	6.2 MV/cm
DSTMS	0.9-10	1.1%	150 uJ/110 uJ/cm^2	0.1-4 THz	210 um	18 MV/cm
OH1	0.44-10	3.2%	270 uJ/300 uJ/cm^2	0.1-3 THz	440 um	9.9 MV/cm

Optics Express, Vol. 23, Issue 4, pp. 4573-4580 (2015), IF=3.749

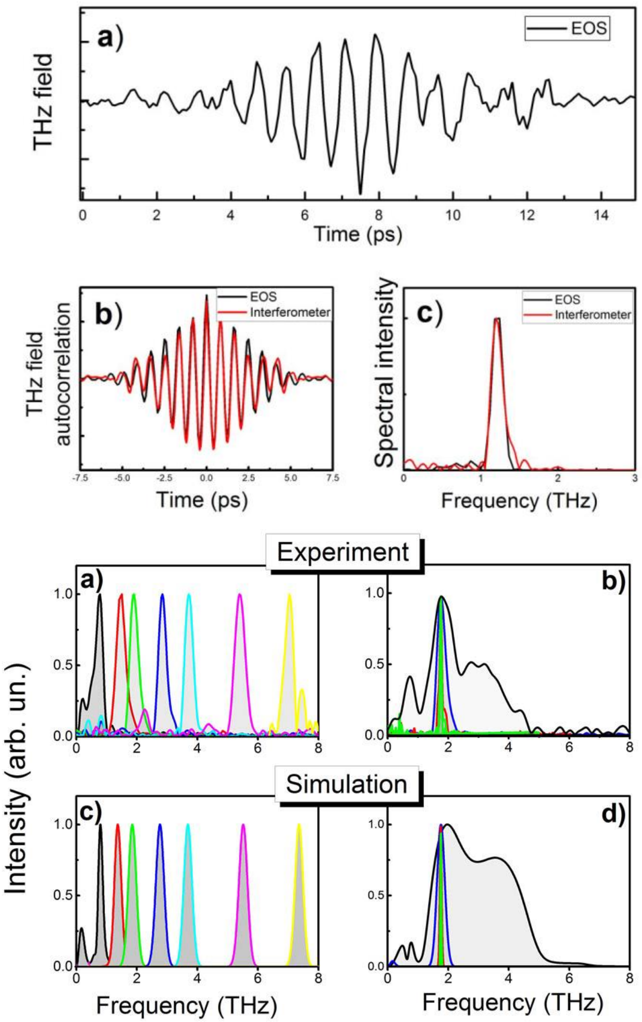
Generation of strong-field spectrally-tunable Terahertz pulses



The multi-cycle, phase-stable THz pulse parameters:

- THz pulse energy **5 - 20 uJ**
- Conversion efficiency **0.02%**
- Spectral bandwidth **< 50 GHz**
- Minimum bandwidth **30 GHz**
- Frequency tuning range **0.5-7 THz**

Narrowband/multi-cycle THz radiation



Submitted to Nature Communications, IF=11.329

Collaboration

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The Ioffe Physical-Technical Institute, St Petersburg, Russia

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Moscow Technological University (MIREA), Moscow, Russia

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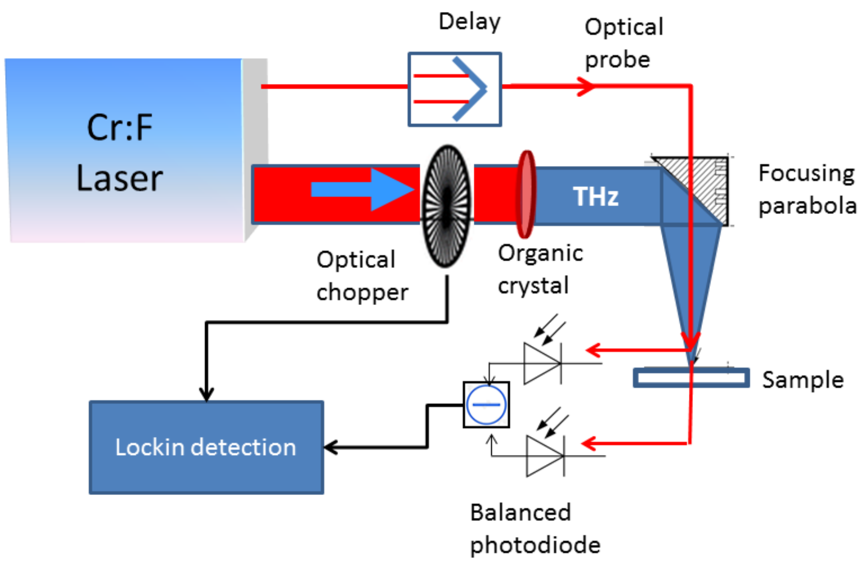
Alexey Kimel

Ultrafast light modulator driven by strong and tunable THz field

Scientific & Technological Cooperation Programme Switzerland-Russia (STCPSR) 2016 – 2017 Grant 14.613.21.0056

THz field induces distortion of the band structures (GaP, GaAs, InP, Si) with consequent shift of the absorption and changes of the optical transmission at the THz field by interband tunneling and charge carrier density modification turning the semiconductor in a metal-like transient state.

The presented scheme displays a pathway to coherently control the optical properties of semiconductors on an ultrafast time scale by a strong THz field.



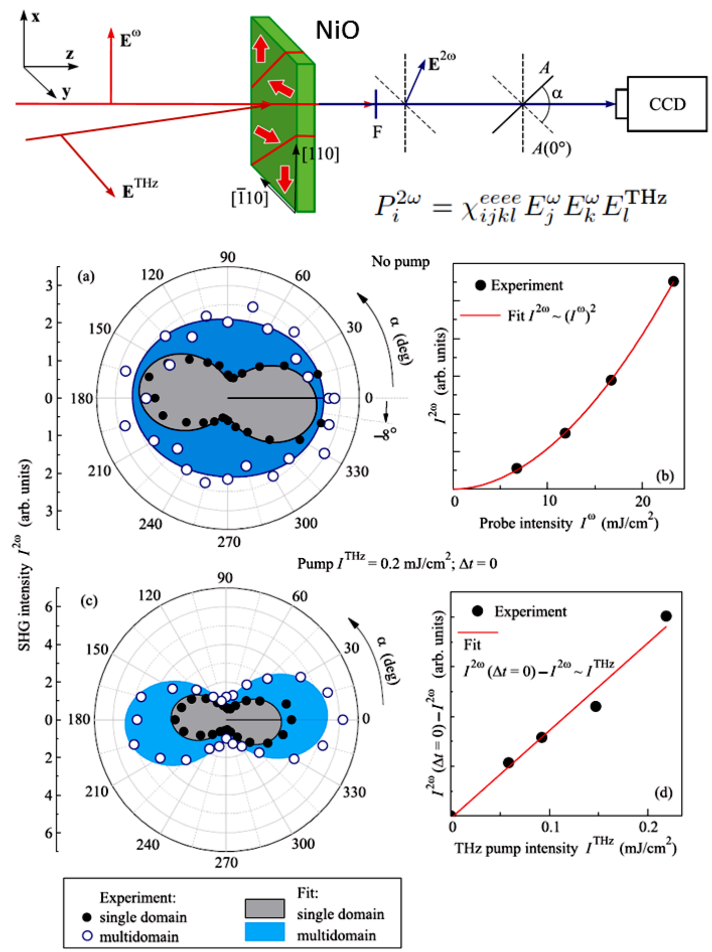
Joint work with Paul Scherrer Institute, Switzerland

Optical second harmonic generation induced by THz pulses in centrosymmetric antiferromagnet NiO

Optical SHG induced by THz pulses arises through the electric dipole mechanism of the interaction of the THz electric field with the electron subsystem of NiO.

Transient changes of SHG in 7 picoseconds after action of THz pulse also have electrodipole nature and are determined by transport effects of THz pulse in NiO plate.

Coherent oscillations of spins at the antiferromagnetic resonance frequency induced by the magnetic component of the terahertz pulse induce a relatively weak modulation of magnetic dipole optical second harmonic generation.



JETP Lett., 104, Issue 7, p.441-448 (2016)

Joint work with Ioffe Physical-Technical Institute, MIREA, Radboud University Nijmegen

THz Electric Field-Induced Second Harmonic Generation in Inorganic Ferroelectric

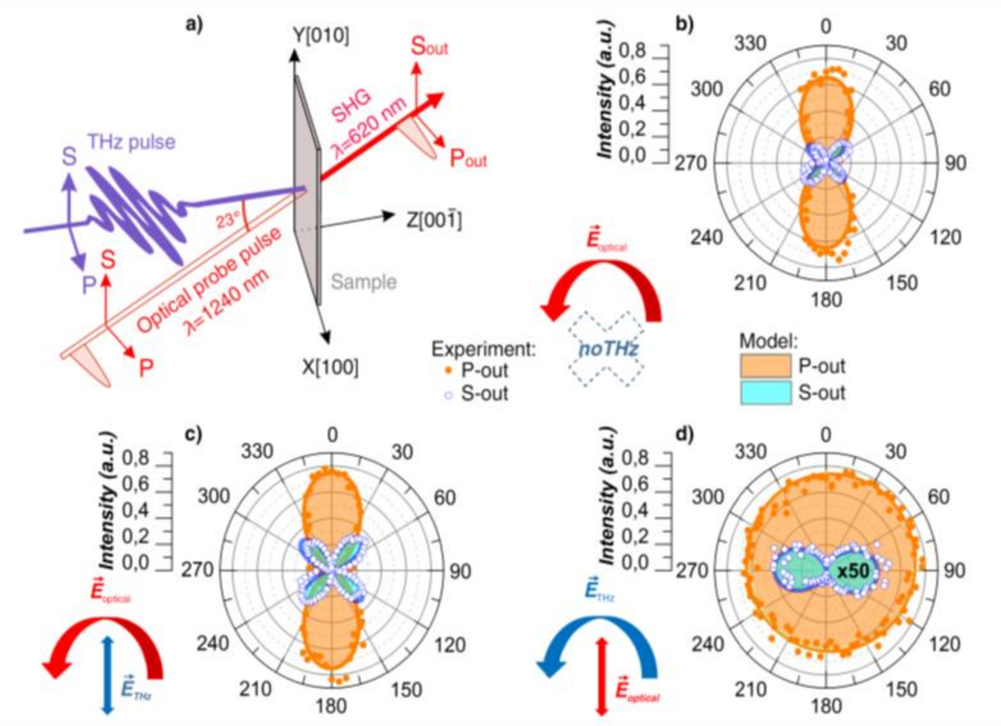
SHG induced by the electric field of a strong nearly single-cycle terahertz pulse with the pick amplitude of 300 kV/cm

As the THz pulse pumps the medium in the range of phononic excitations, the **induced polarization** is explained as a change of the **ferrolectric order parameter.**

It is estimated that under action of the THz pulse the latter acquires an in-plane component up to 3% of the net polarization.

Accepted to Scientific Reports IF=5.228

Ferroelectric $BaSrTiO_3$



Polarization dependences of the SHG intensity

Joint work with Ioffe Physical-Technical Institute, MIREA, Radboud University Nijmegen

Interaction of high-power THz sub-picosecond coherent radiation with matter

Future plans:

1. Experimental data acquisition for theoretical modelling of THz damage interaction mechanism in metals, semiconductors and dielectrics.
2. Experimental investigations of phase transitions, crystal lattice damage and surface layer modification in different materials.
3. Experimental data acquisition of matter response change in the visible range under action of extra-high-power THz pulse for different materials.