Novosibirsk ERL based FEL as User Facility

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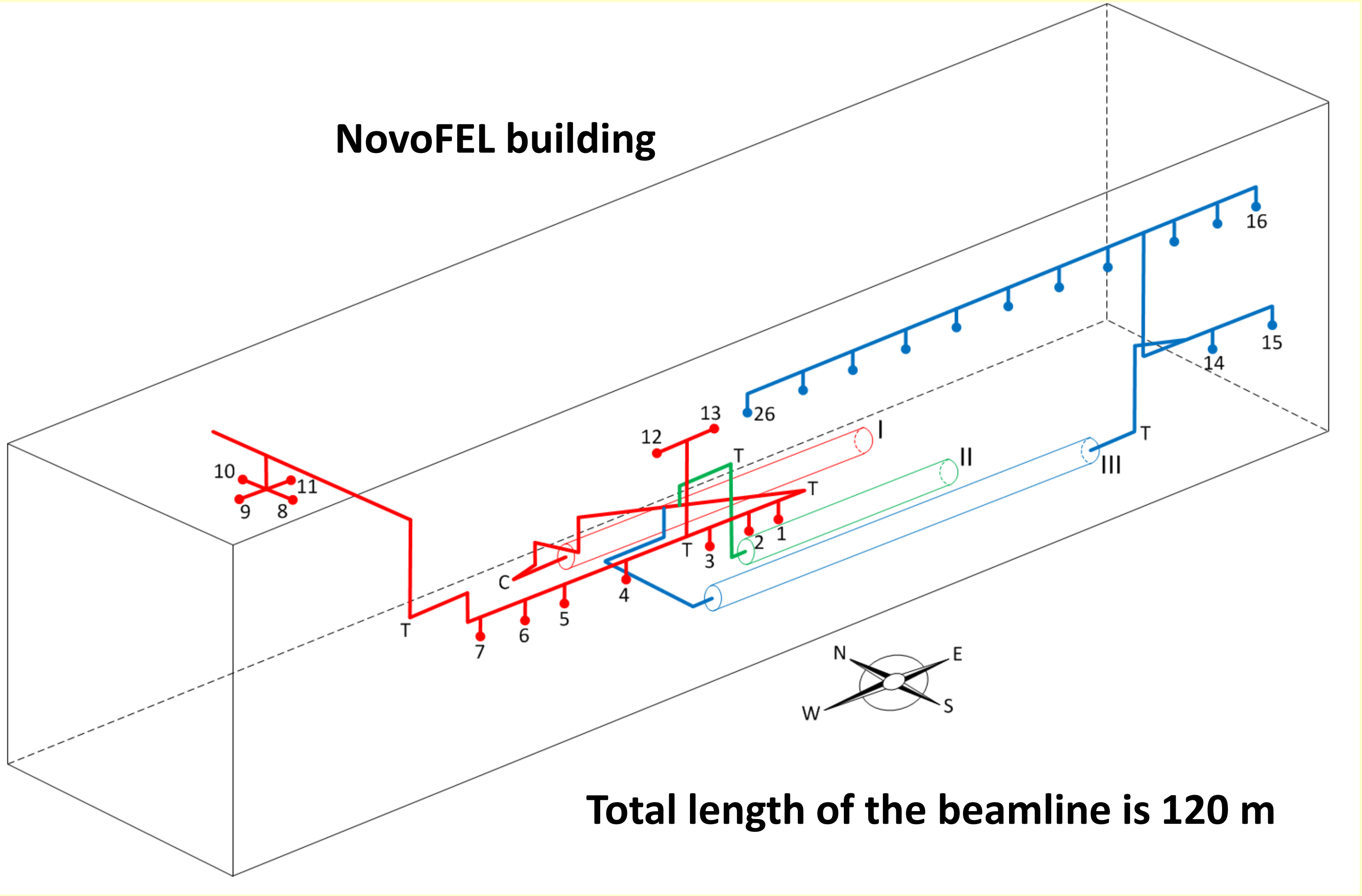
ERL-2017, 18-23 June 2017, CERN

Beamline system at NovoFEL



1, 2,…, 13 – working user stations

14, …, 26 – developing user stations

I (red) - Terahertz FEL

II (green) - Far infrared FEL

III (blue) - Infrared FEL

T – Toroidal mirrors

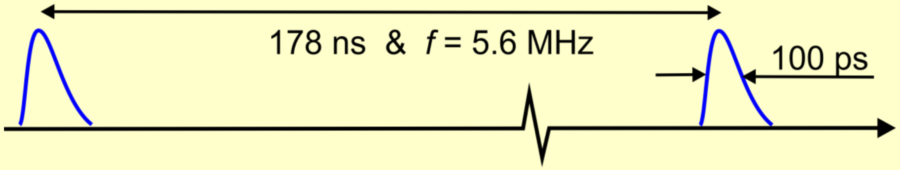
C – Spherical mirror

Other mirrors are plane

NovoFEL radiation parameters

Laser	Terahertz	Far-Infrared	Infrared
Status	In operation since 2003	In operation since 2009	In operation since 2015
Wavelength, μm	90 – 240	37 – 80	8 – 11 (7–30)
Relative line width (FWHM), %	0.2 – 1	0.2 – 1	0.1 – 1
Maximum average power, kW	0.5	0.5	0.1
Maximum peak power, MW	0.9	2.0	10
Pulse duration, ps	30 – 120	20 – 40	10 – 20
Pulse repetition rate, MHz	3.7 – 22.4		
Polarization	Linear, > 99.6 %		
Beams	Gaussian beams with diffraction divergence		

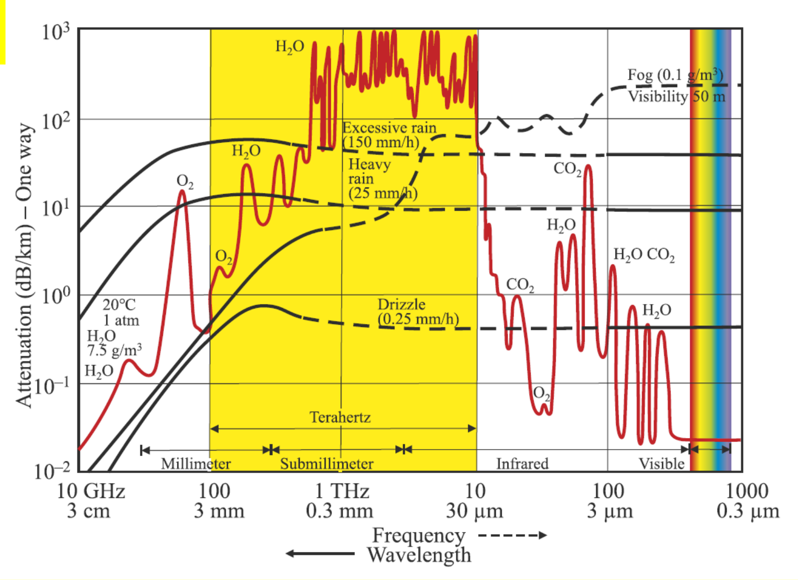
Typical radiation of THz NovoFEL - continuous train of 100 ps pulses:



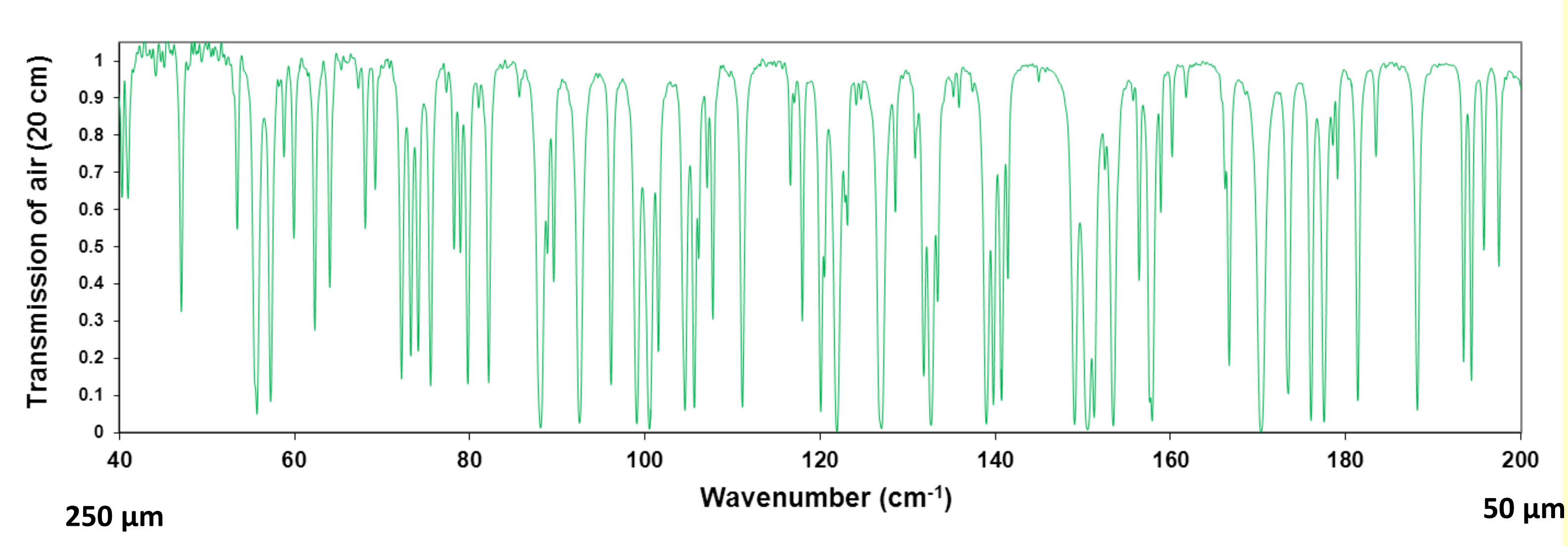
Beamline system at NovoFEL

- **Transmission line is filled with dry nitrogen/air mixture now**
- **Transmission line can easily be transformed to vacuum system**

Attenuation

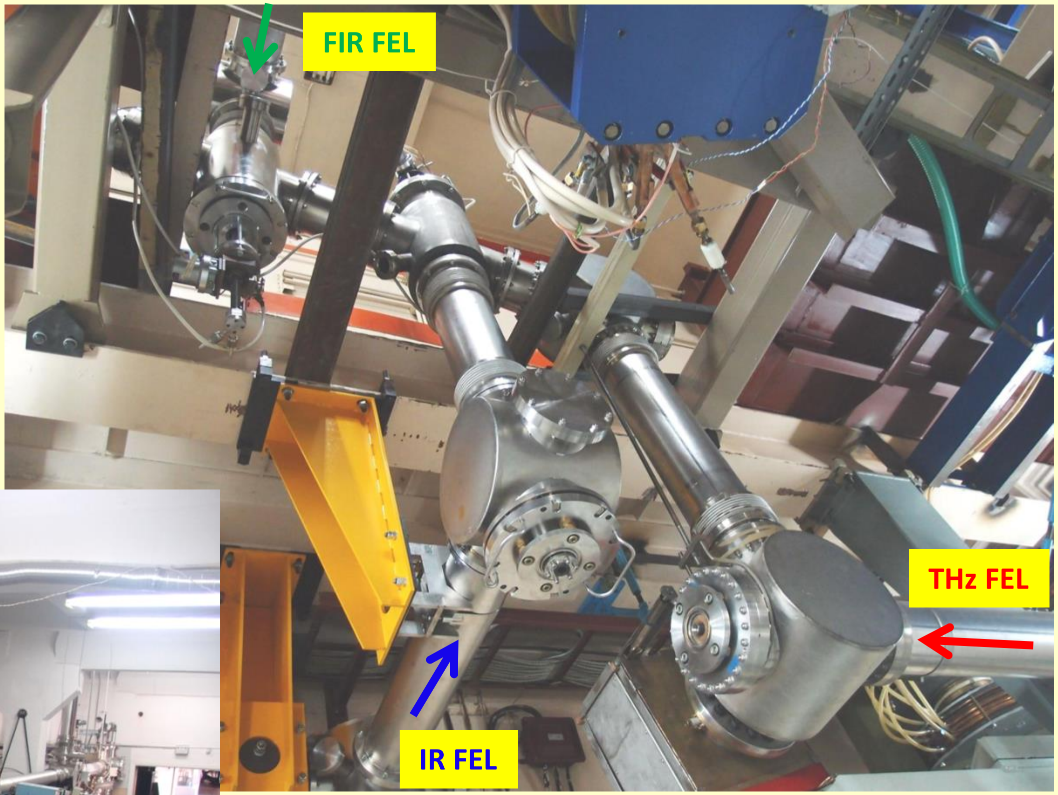


Transmission



Beamline system at NovoFEL

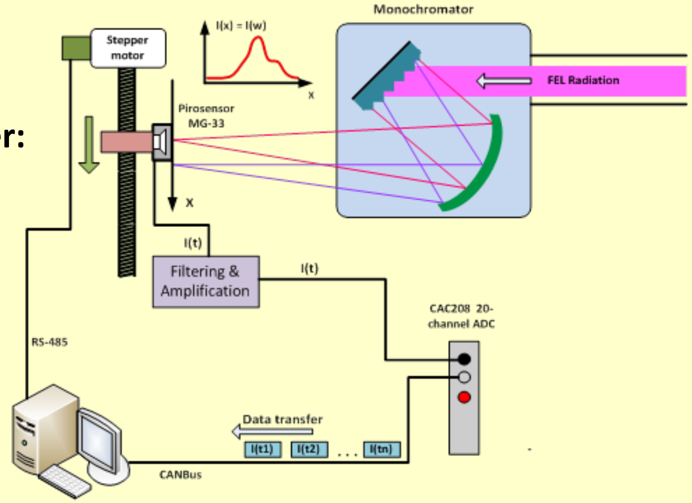
Transport channels in accelerating hall

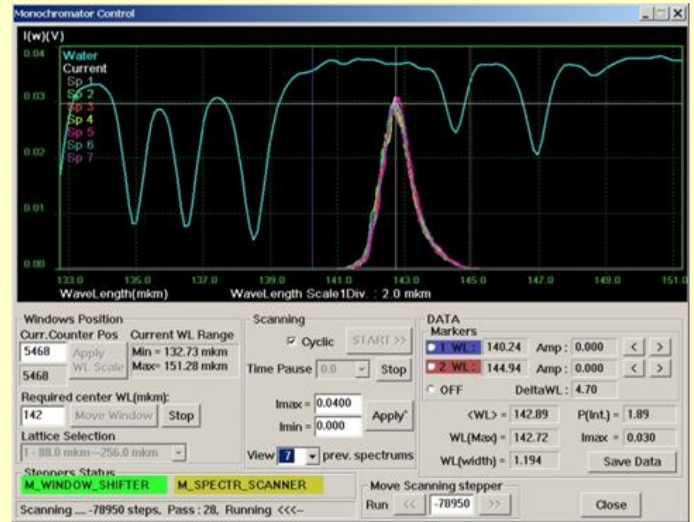


Transport channel in one of user's halls

Diagnostics of NovoFEL radiation

On-line grating spectrometer:





Diagnostics of NovoFEL radiation

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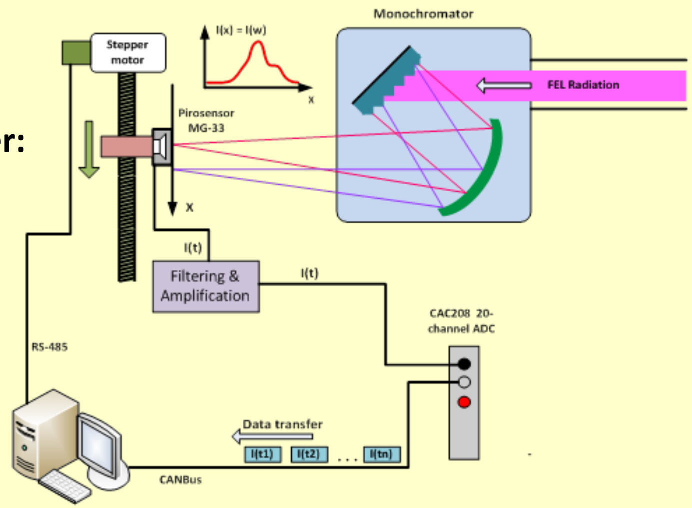
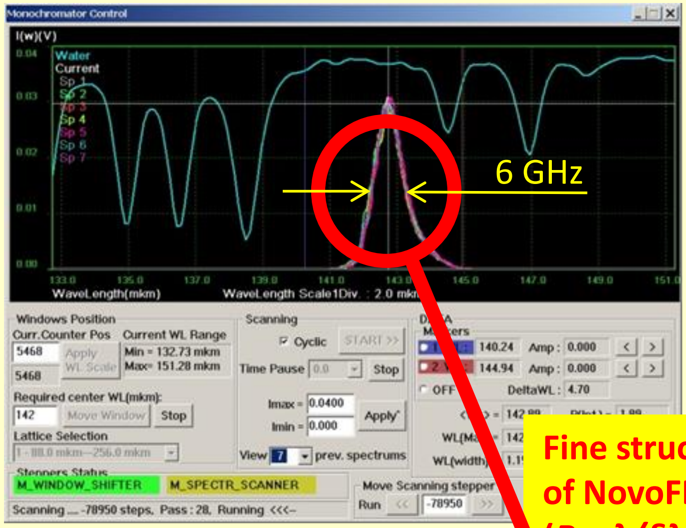
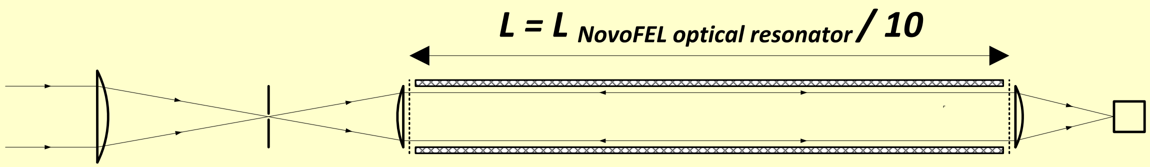
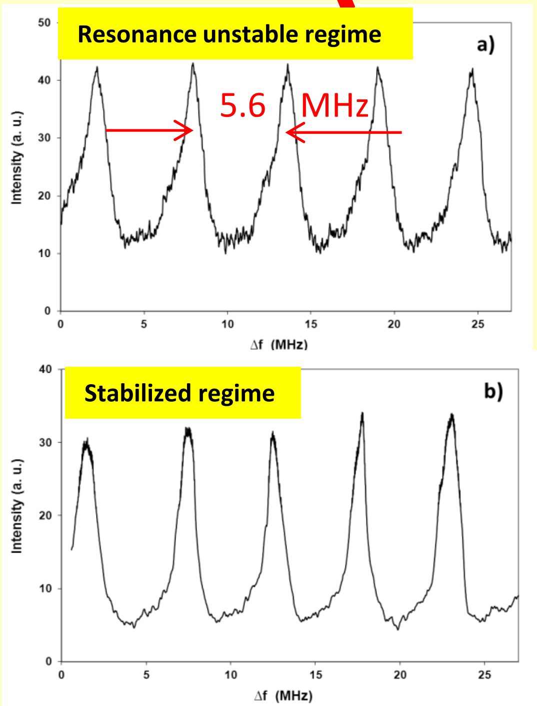




Fine structure of NovoFEL radiation ($R = \lambda/\delta\lambda = 2\cdot10^6$–$10^7$)

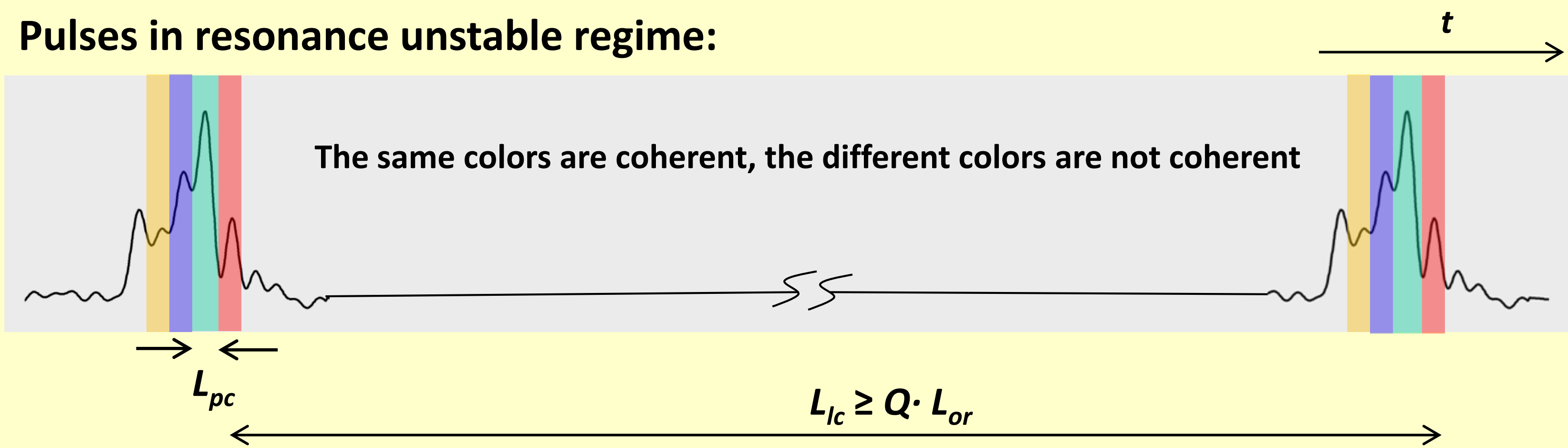
Ultra-long resonance waveguide vacuum Fabry-Perot interferometer:





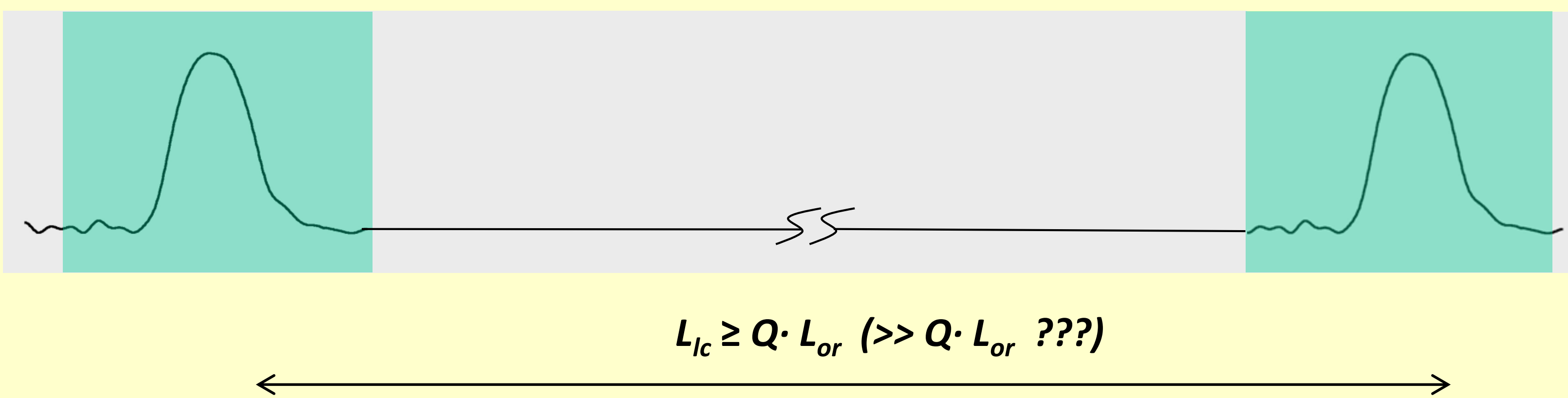
Two lengths of coherency in FEL

Pulses in resonance unstable regime:



L_{pc} – intra-pulse coherency depends on fast side-band instability. Typically L_{pc} = slippage length = $N_{und} \cdot \lambda$
L_{lc} – laser coherency depends on slow laser's instabilities. Typically $L_{lc} \geq Q \cdot L_{or}$ (L_{or} – length of optical resonator, Q – quality of optical resonator)

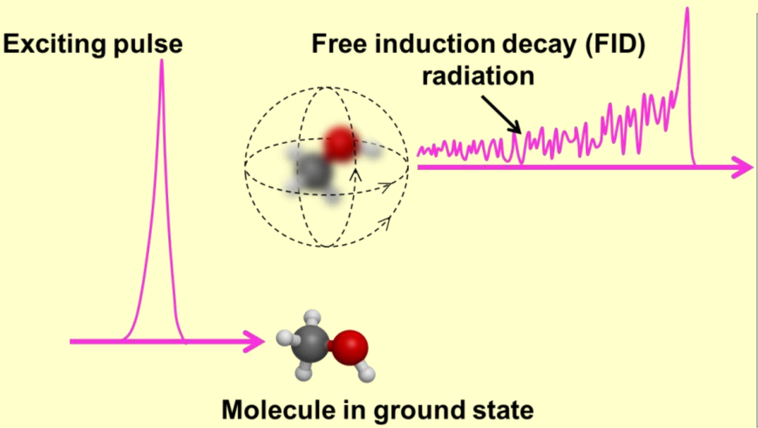
Pulses in stabilized regime (additional detuning of frequencies of electron and light pulse):



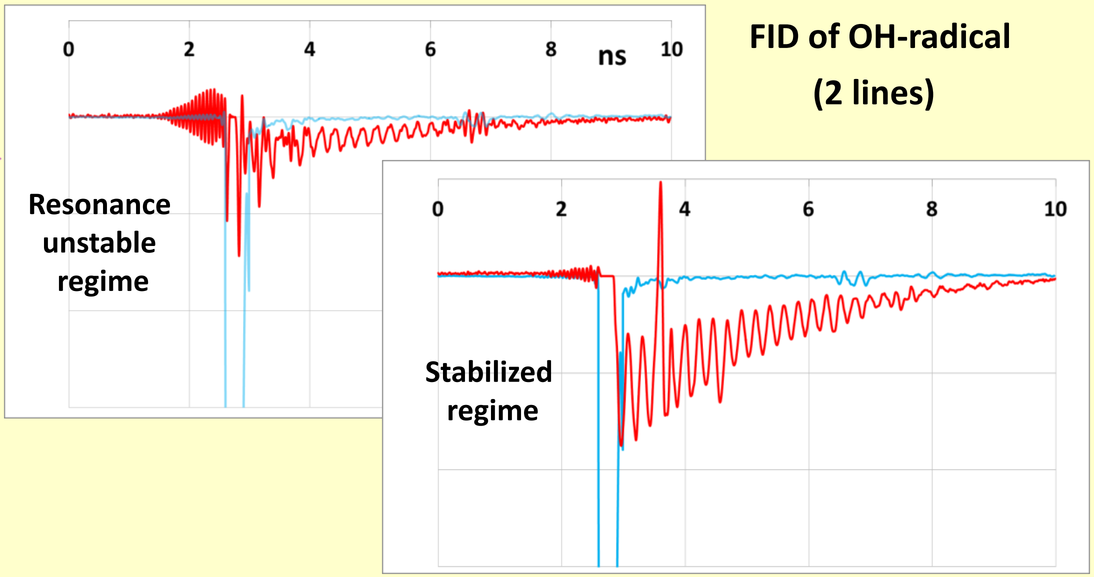
L_{lc}^{MAX} = laser limit = (Laser power/Power of spontaneous emission)$\cdot L_{or} = N \cdot Q \cdot L_{or}$ (N – number of photons in optical resonator)

Importance of radiation coherency

Intra-pulse coherency is important for spectroscopy based on free-induction decay radiation:



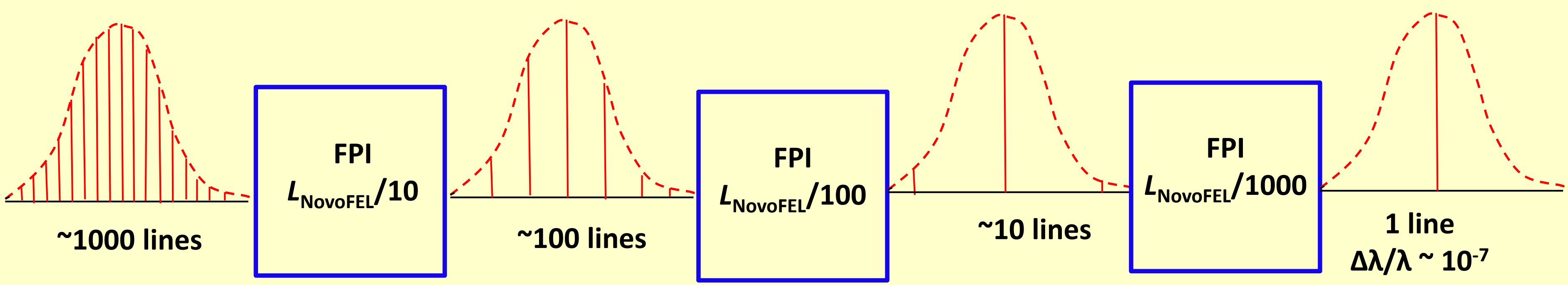
Ultrafast spectroscopy of unrepeatable (unstable, single) phenomena



FID of OH-radical

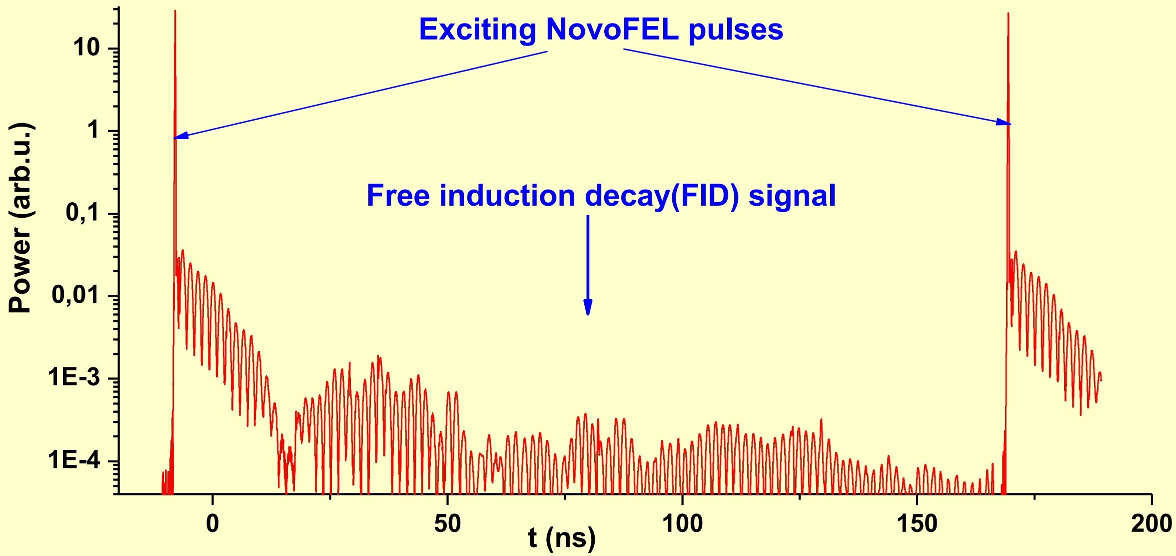
(2 lines)

Total laser coherency is important for creation effective monochromatic tunable laser source:

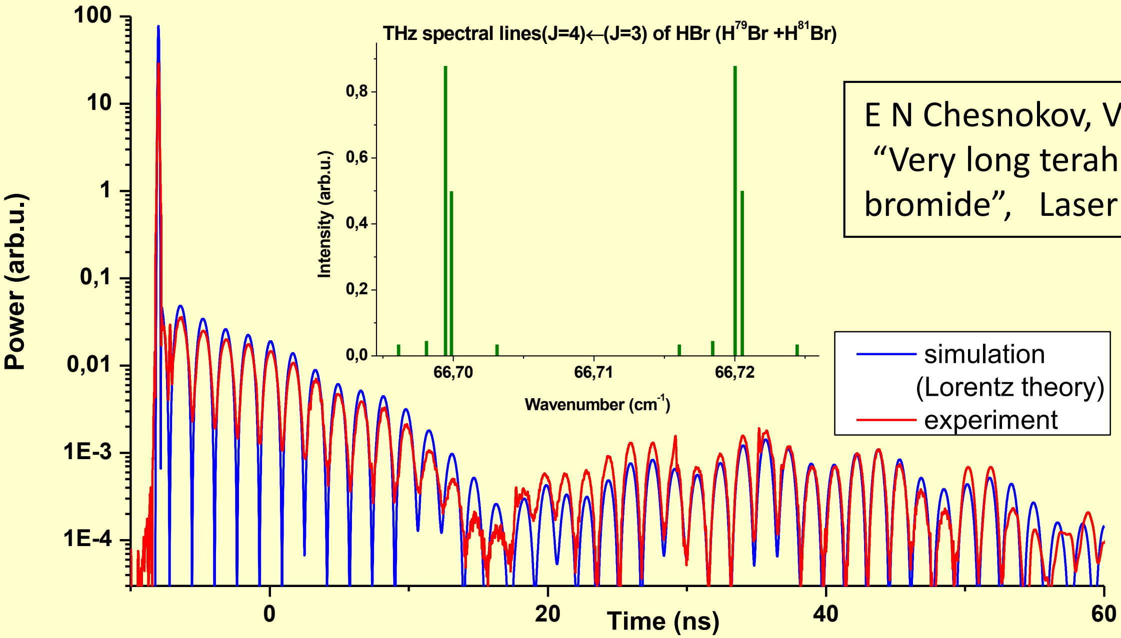


$P \sim L_{lc}$

Very long free induction decay in HBr

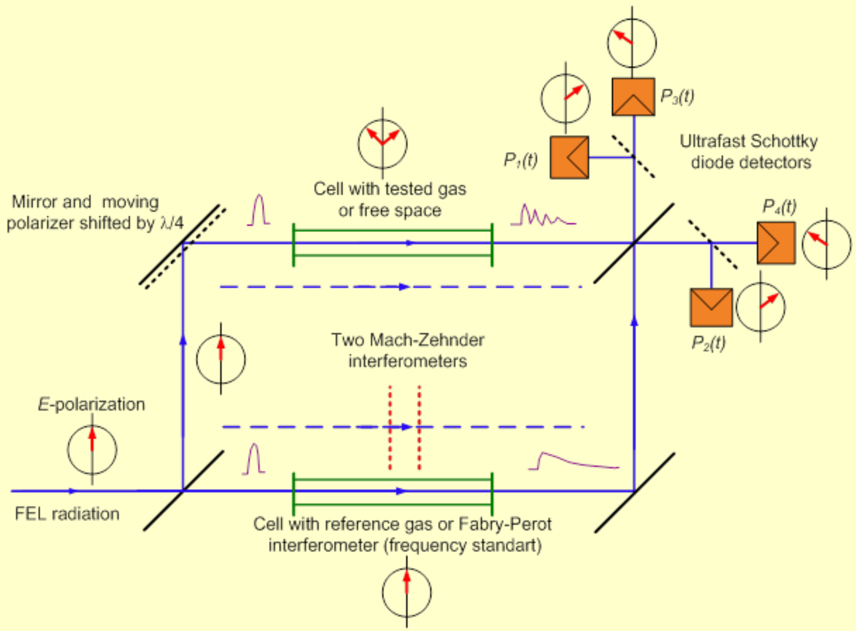


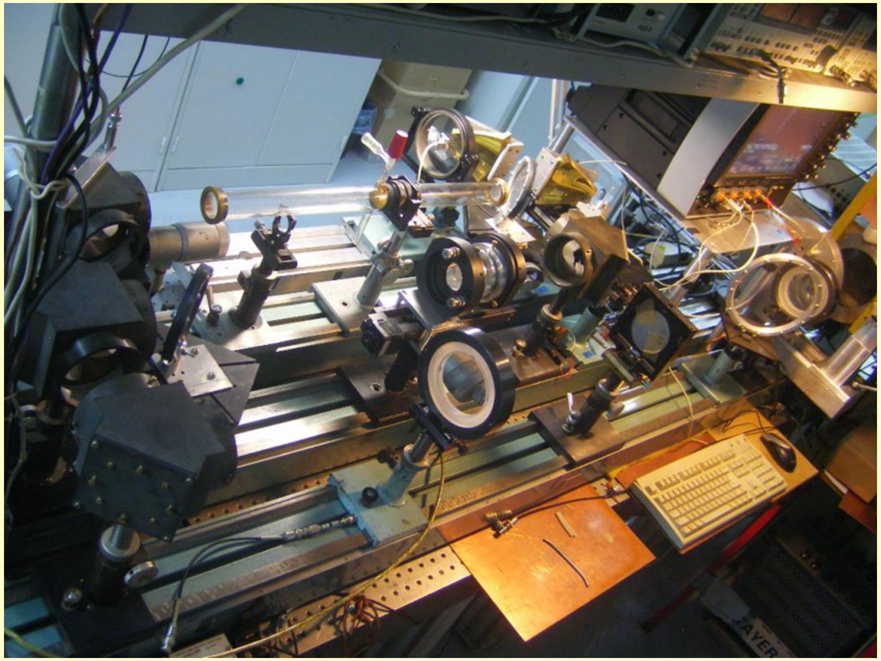
$(\Delta f / f)_{min} = (2\text{-}4) \cdot 10^{-6}$

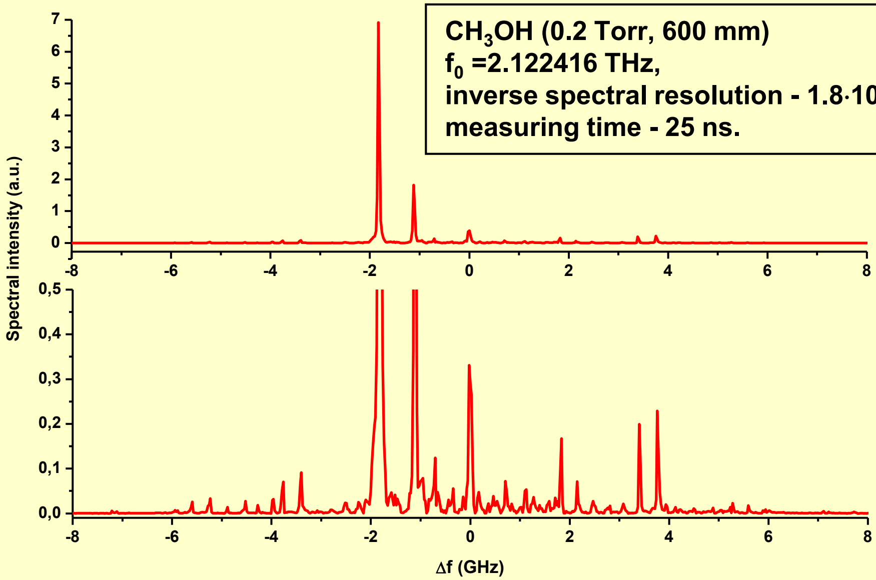


E N Chesnokov, V V Kubarev, P V Koshlyakov and G N Kulipanov, "Very long terahertz free induction decay in gaseous hydrogen bromide", Laser Phys. Lett. 10, 055701 (2013).

Ultrafast (single pulse) time-domain spectrometer

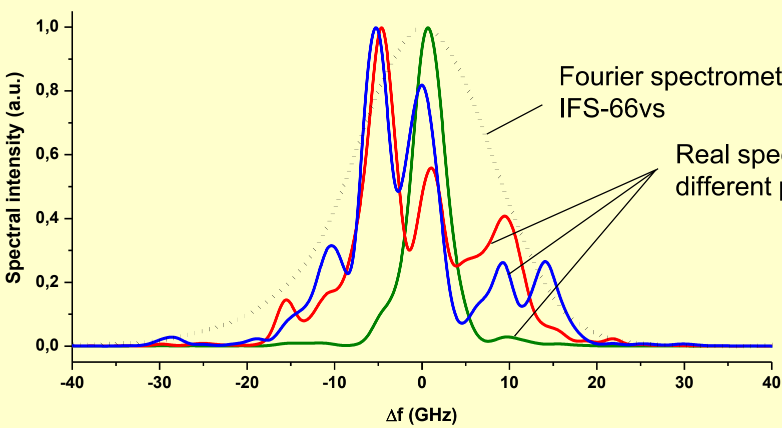




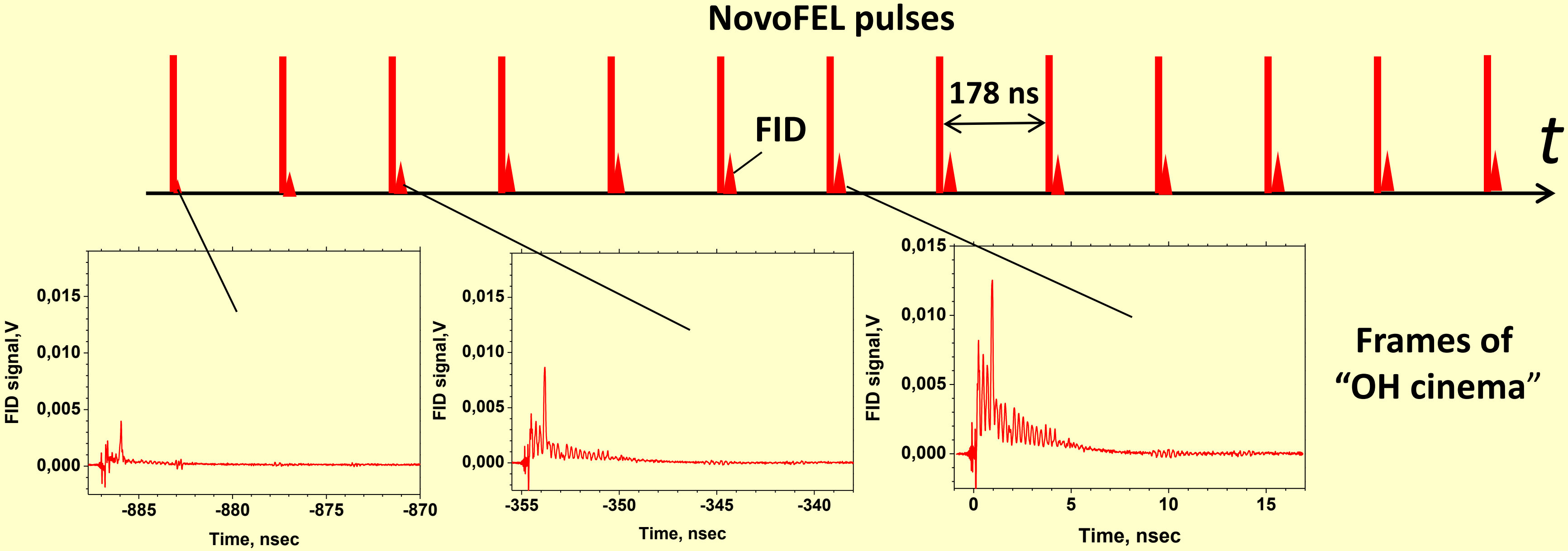


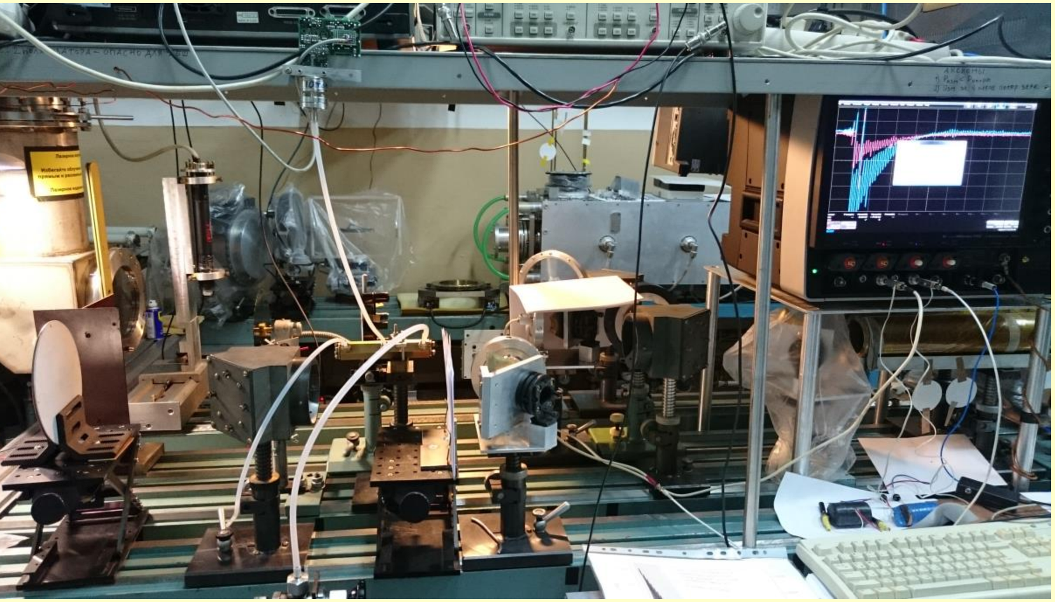
CH_3OH (0.2 Torr, 600 mm)
f_0 =2.122416 THz,
inverse spectral resolution - $1.8\cdot10^{-5}$,
measuring time - 25 ns.

NovoFEL spectra, Regime of strong SB-instability:
Integral spectral width – $9\cdot10^{-3}$ (18 GHz)
f_0 = 2.12 THz,
Inverse spectral resolution – $1.2\cdot10^{-3}$,
Measuring time – 0.4 ns.



Fast photochemistry: Dynamics of OH radical

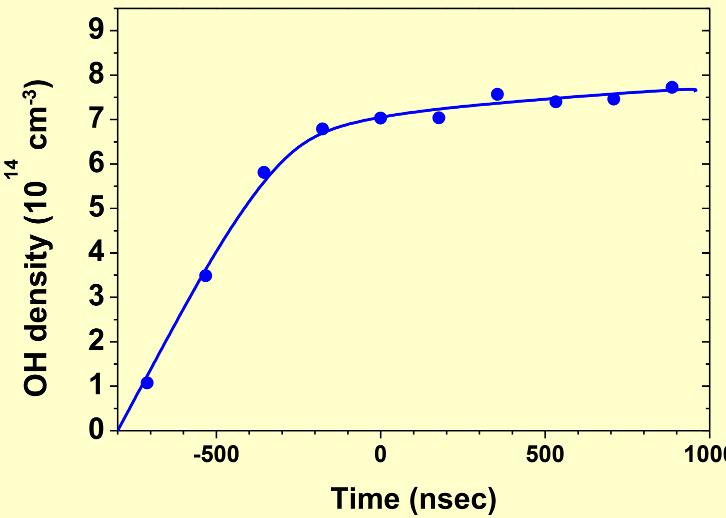




Generation of OH radicals:

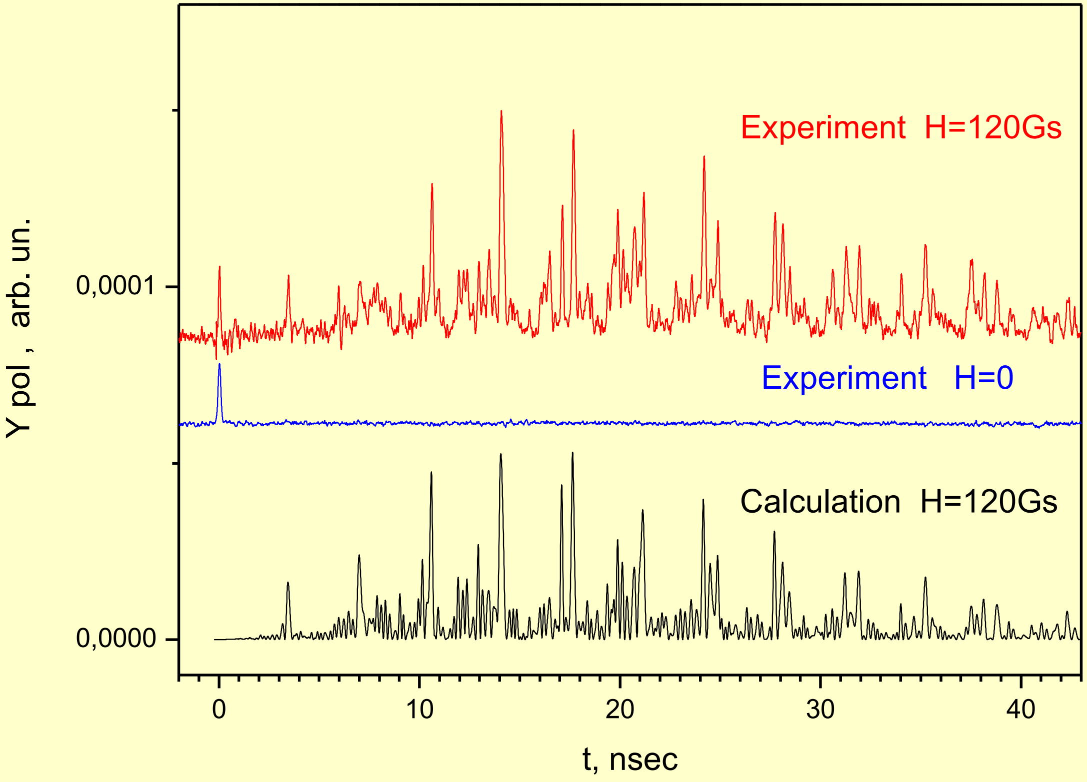
$O_3 + (h\nu = 266\ \mathrm{nm}) \rightarrow O(^1D) + O_2$

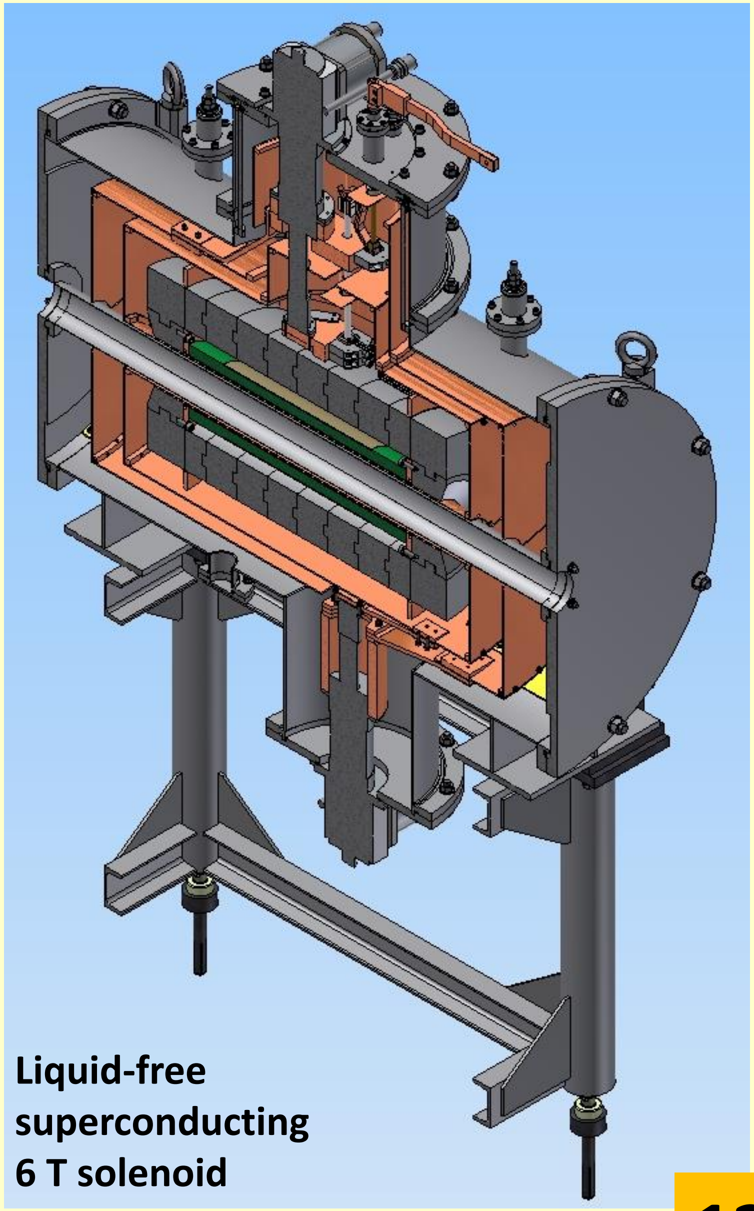
$O(^1D) + H_2O \rightarrow 2\,OH$



Sensitive FID spectroscopy in magnetic fields

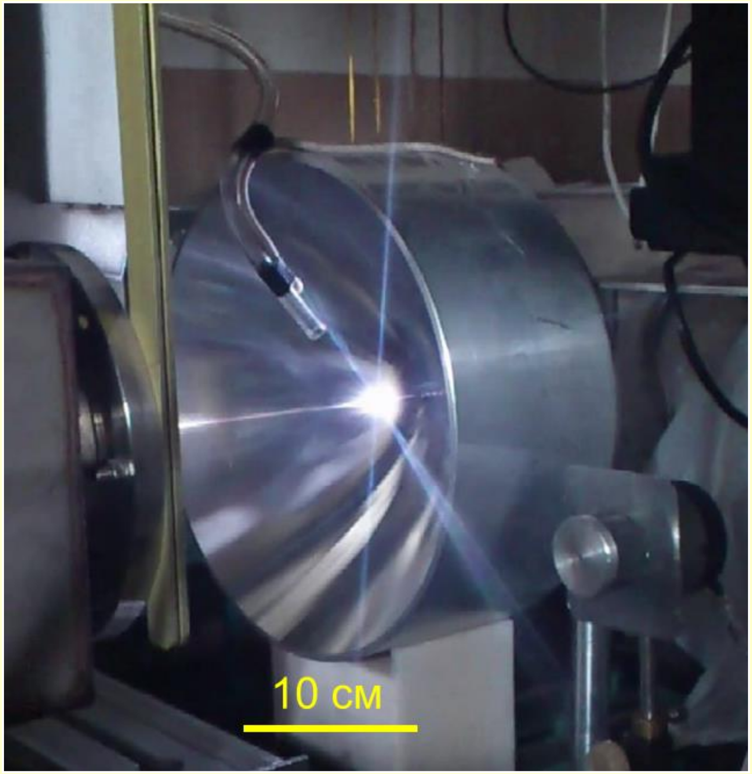
P(NO_2)= 1 Torr
L = 40 cm
Fully closed polarizer

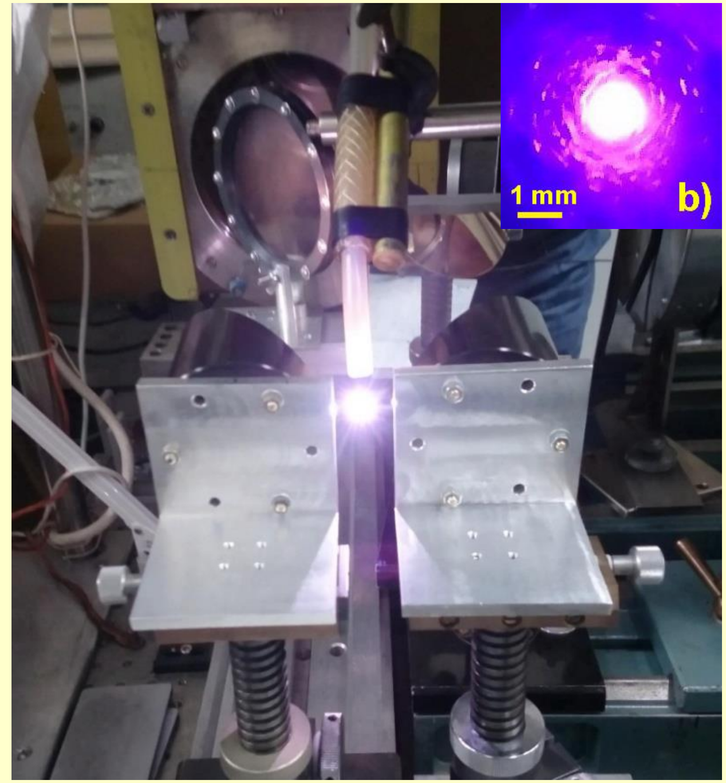




Liquid-free superconducting 6 T solenoid

Terahertz optical discharge





Intensities for ignition and quenching of CW optical discharge sustained by 66-ps pulses of NovoFEL at λ = 130 mm

Gas	Ar	He	N_2	Air	CO_2
Breakdown threshold (GW/cm^2)	1.1	1.18	1.23	1.36	1.38
Quenching intensity (GW/cm^2)	0.51	0.91	1.00	0.90	1.20

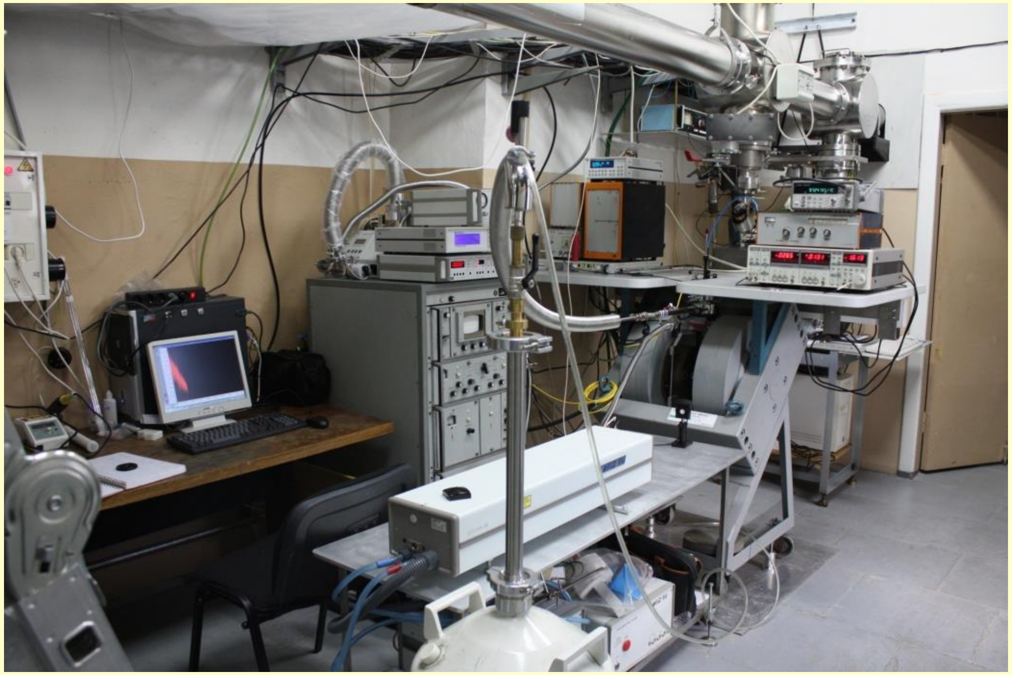
High-temterature point stabilized CW optical discharge in argon:

P = 1 atm

T = 30 000 K° (record value)

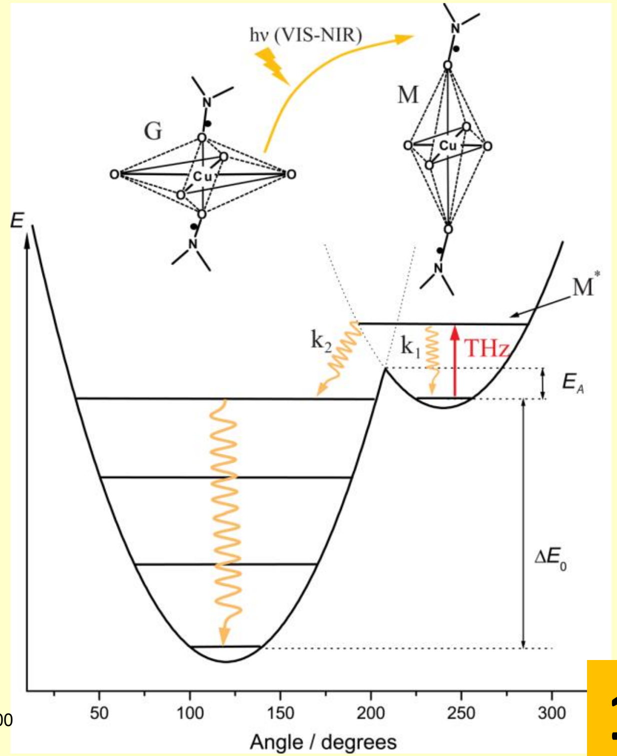
THz range is optimal for high-temperature optical discharge

EPR spectroscopy. Spintronics of magnetoactive materials

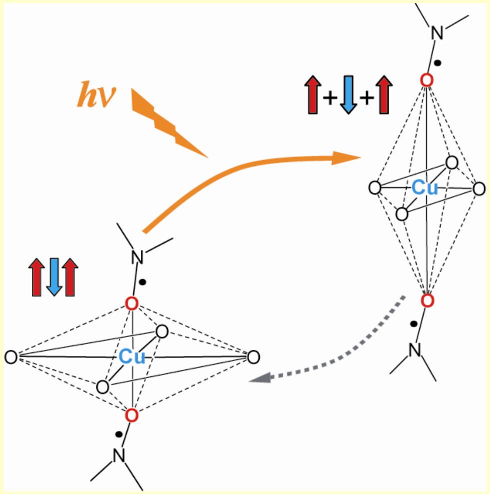


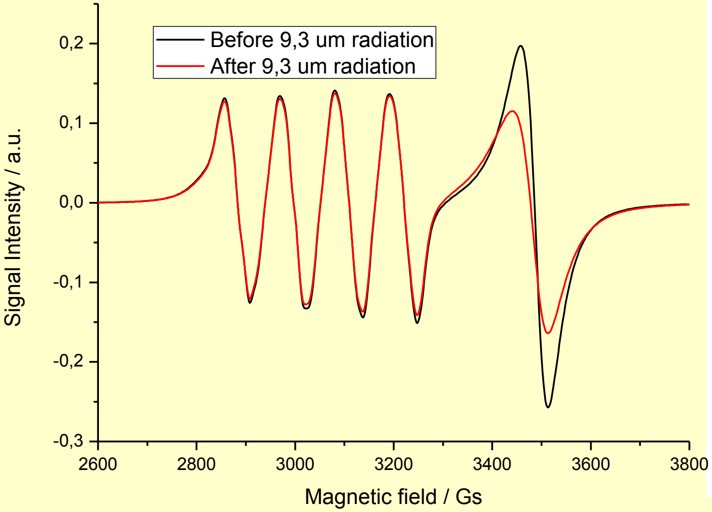
Infrared NovoFEL: switch up
Terahertz NovoFEL: switch down

THz-induced backward conversion of the metastable states in $Cu(hfac)_2L^{Pr}$



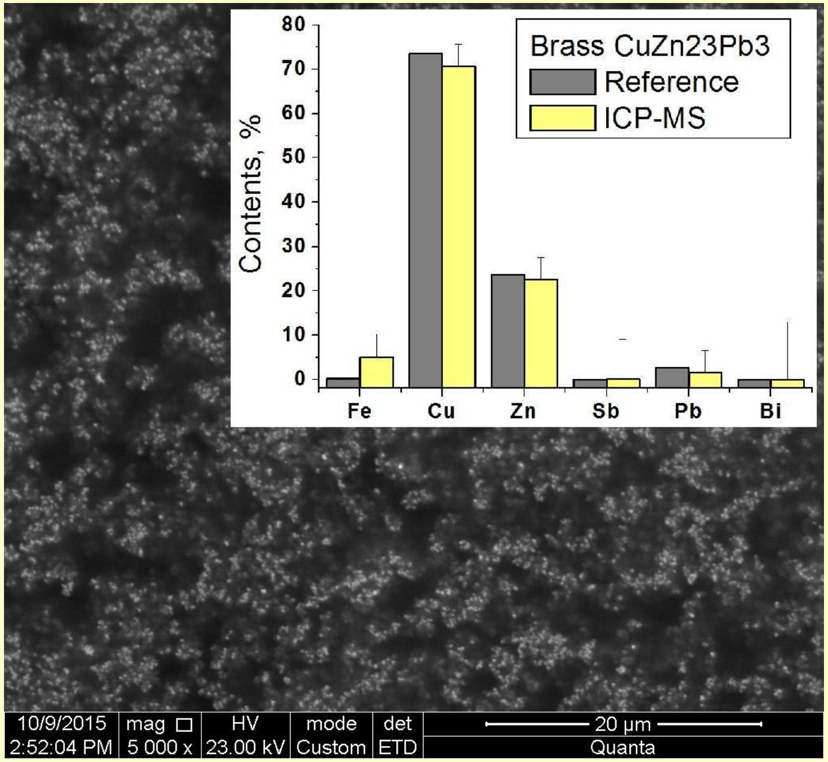
Influence of IR-light to the spin state of photoswitchable copper(II)-nitroxide magnetoactive compound $Cu(hfac)_2L^{Pr}$

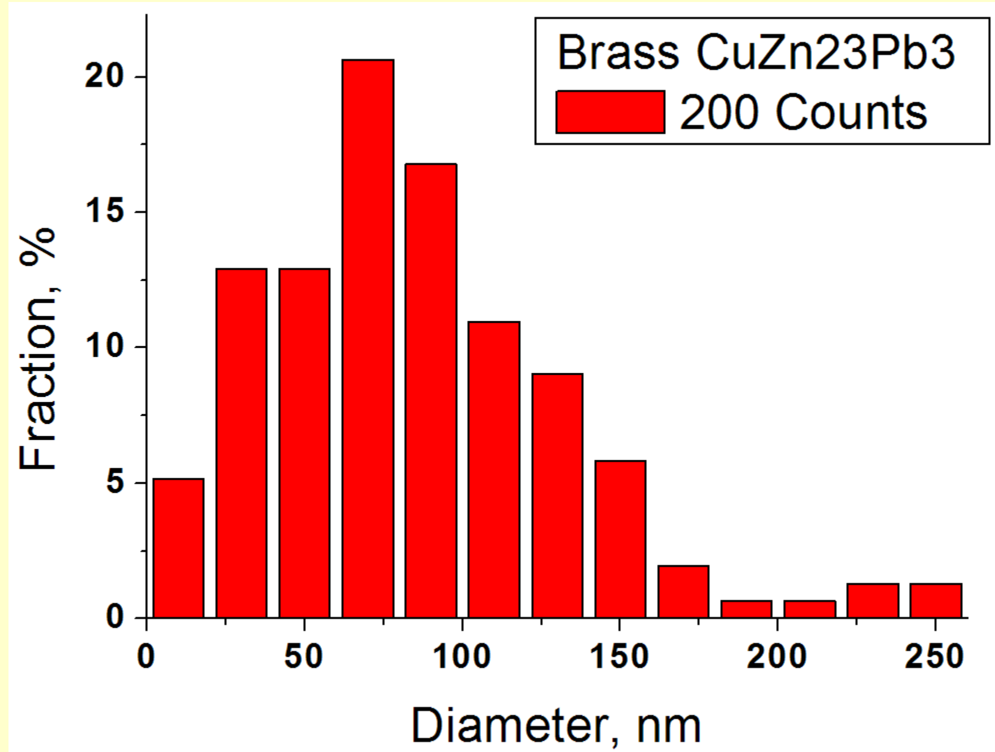




Nanoparticles. Ablation by ultra-sonic waves in water

Terahertz irradiation (5.6 MHz) of water results in formation of nanosized hydrosols of cell material



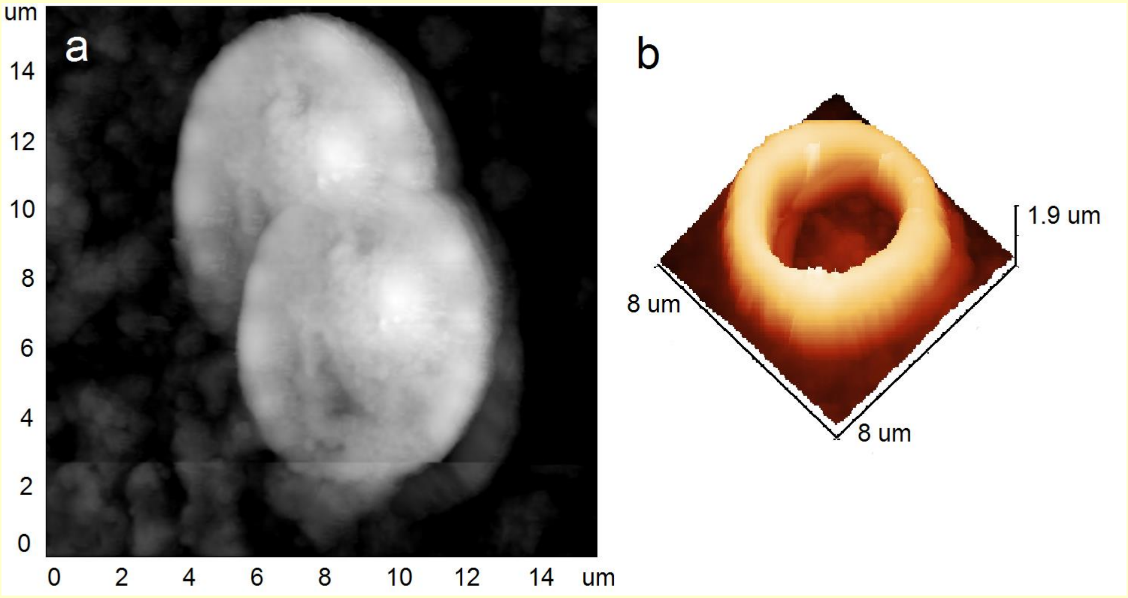


Laser: Wavelength: 130±2 µm. Average power: 20W.
Pulse power: <1MW. Pulse length: 30-100ps. Repetition rate 5.6MHz.
Exposition conditions: atmospheric pressure, room temperature. Duration: 5-10sec.
Materials: Inert alloys, ceramics, graphite, etc., distilled water: 50-100µl.
Particle diameters (N½): 50-80nm. Concentration: $<10^{10}cm^{-3}$ (1-2mg/l)

Specific damage of living systems by ultra sonic waves unduced pulse-periodical THz radiation

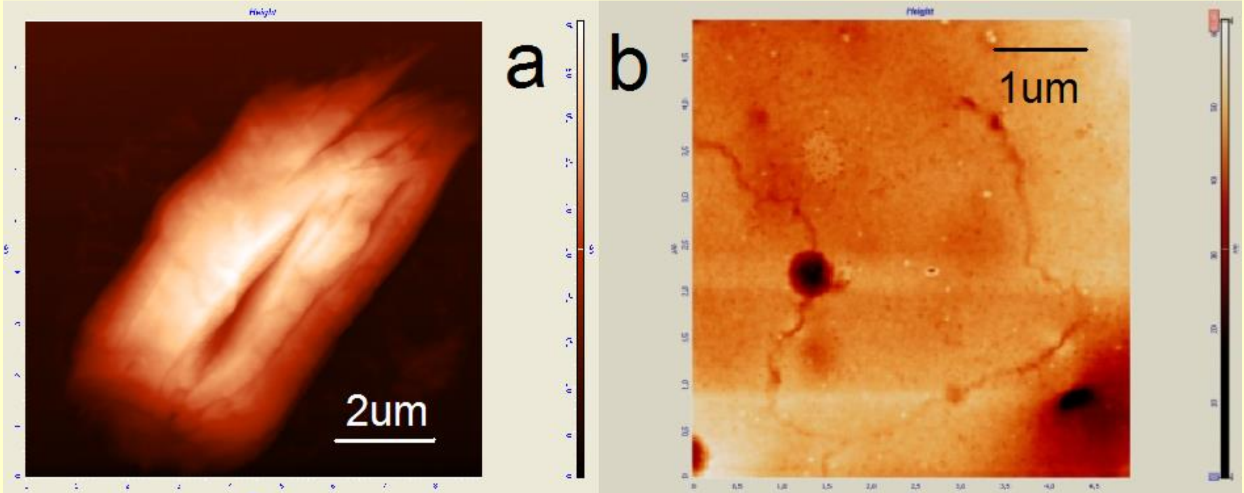
AFM characterization showed that morphological changes are completely destructive after 15-seconds of THz radiation exposition

Initial:
a - hepatocytes
b - erythrocyte

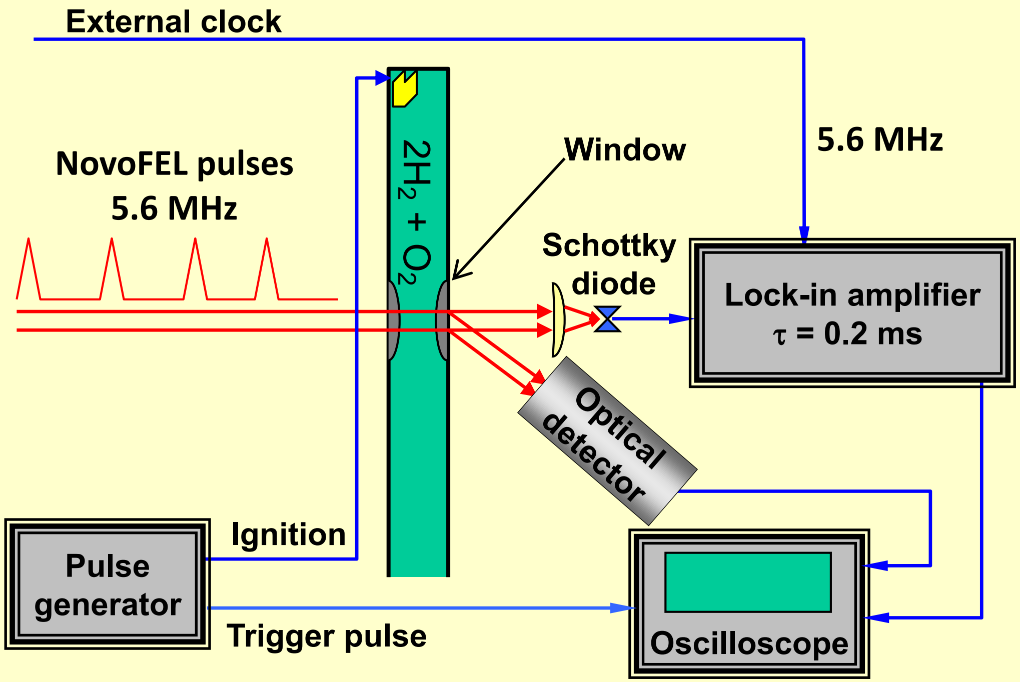


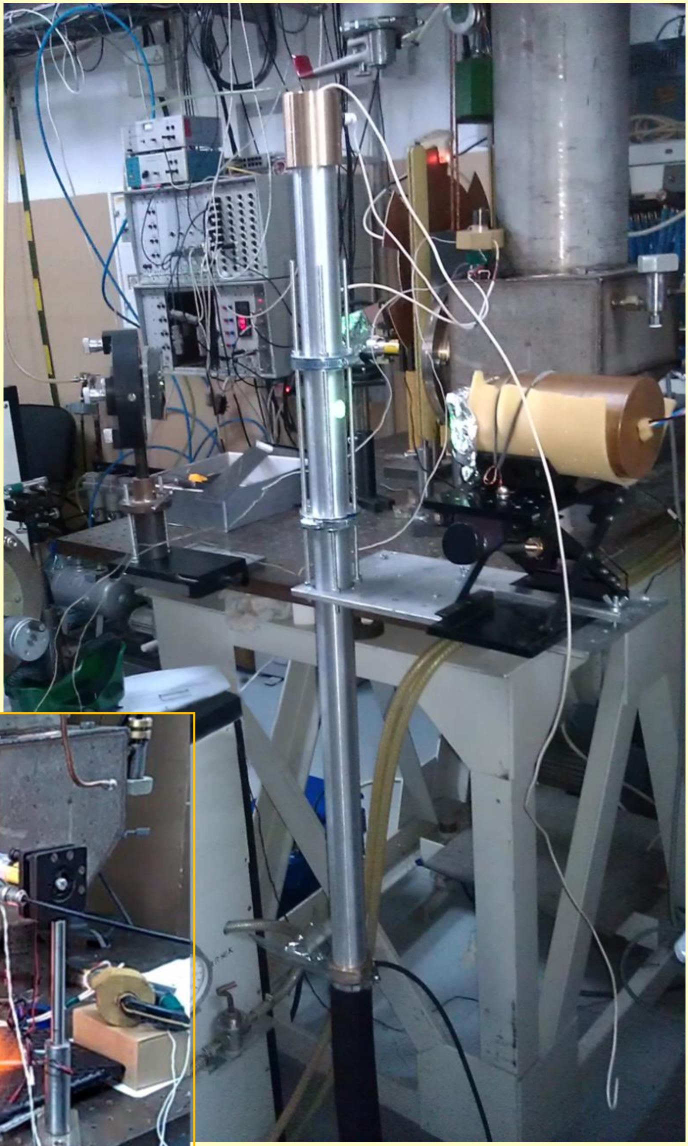
Exposed 15sec
1ml, 20W/cm^2:

Membrane pores and cracks



Dynamics of burning and detonation in hydrogen-oxygen mixture

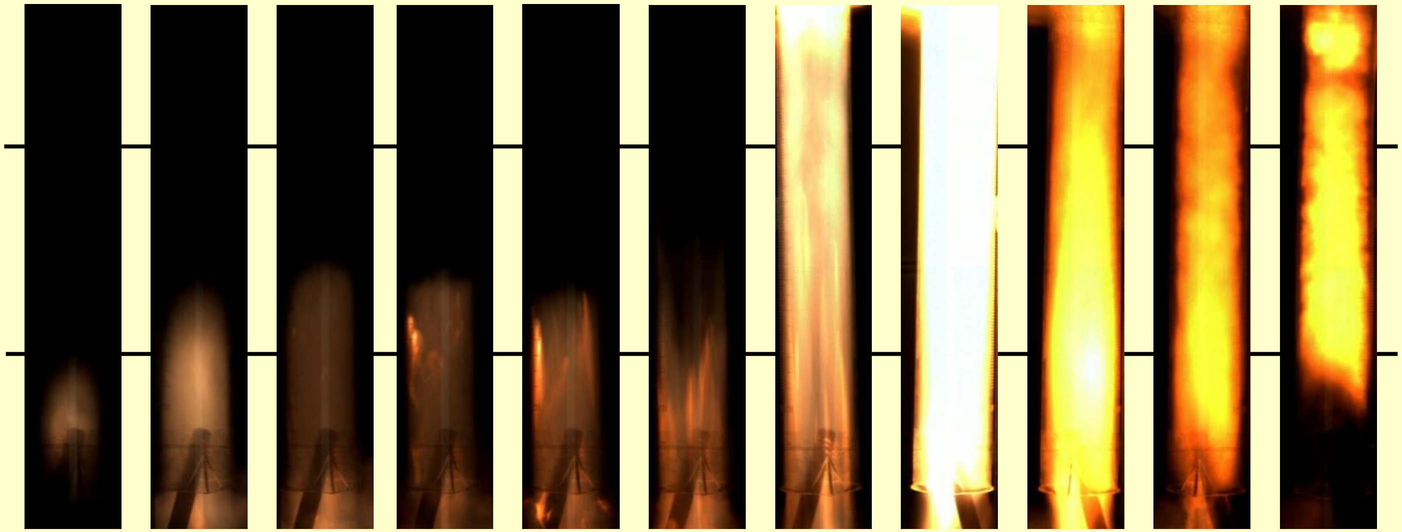




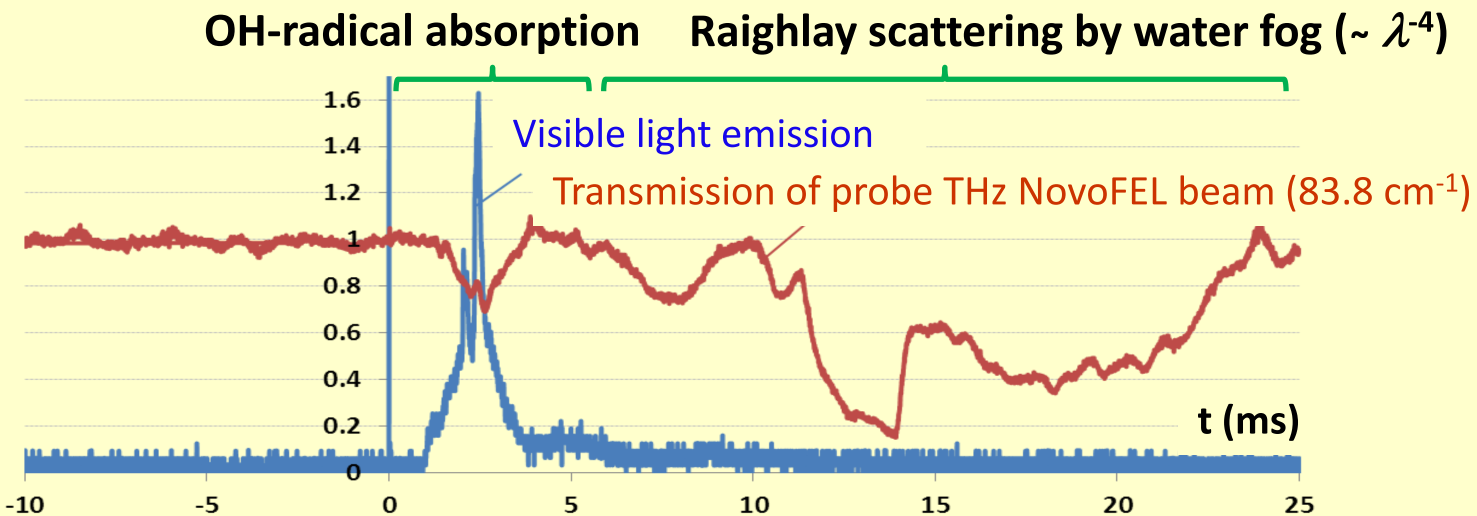
Wavelength of NovoFEL is tuned to a determined absorption line of H_2O or OH radical

Dynamics of burning and detonation in hydrogen-oxygen mixture

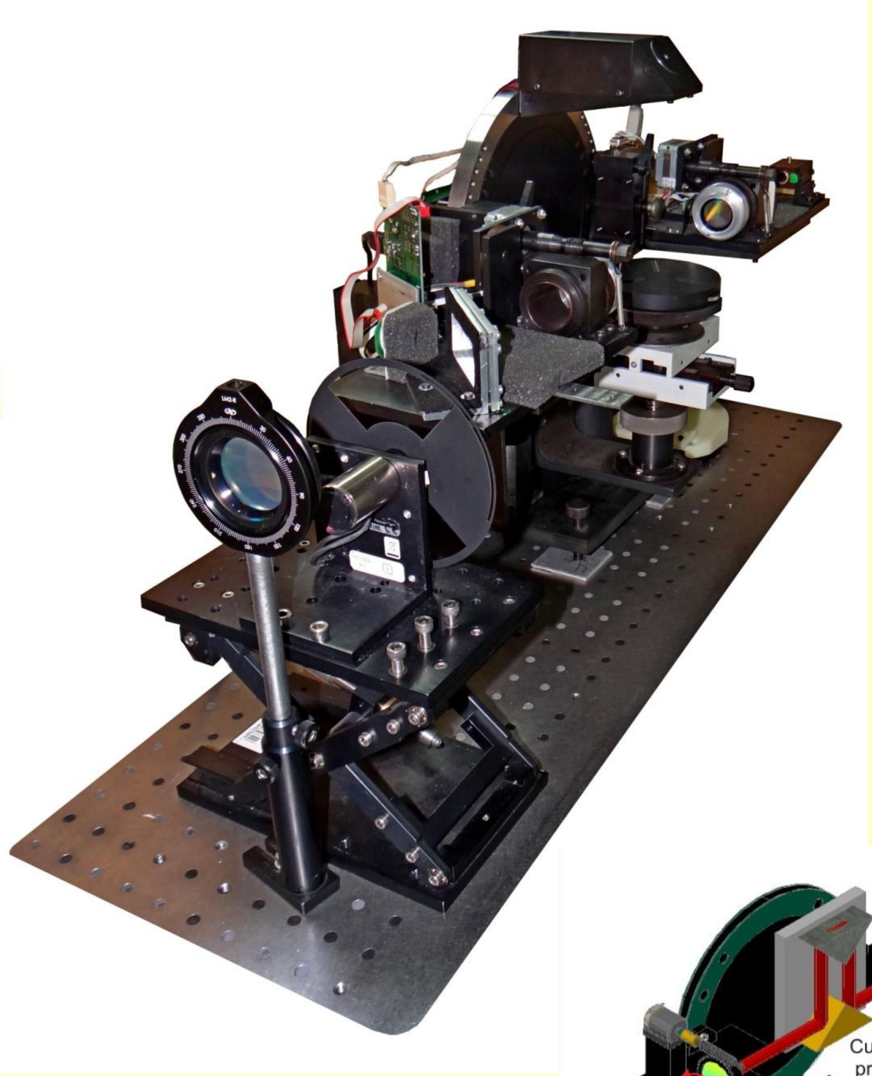
High-speed image acquisition of detonation in transparent pipe



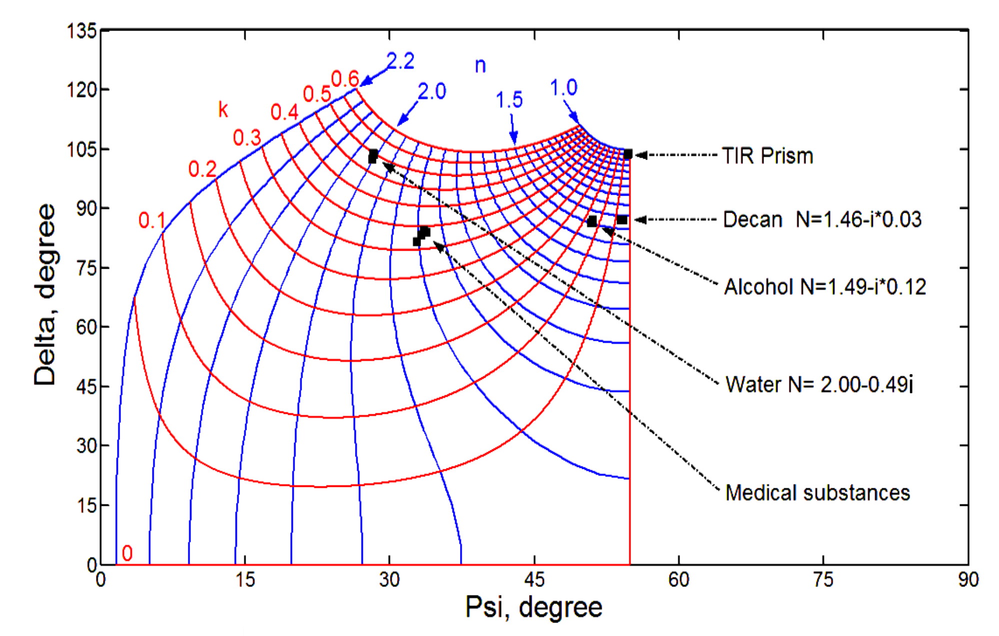
1 ms 4 ms

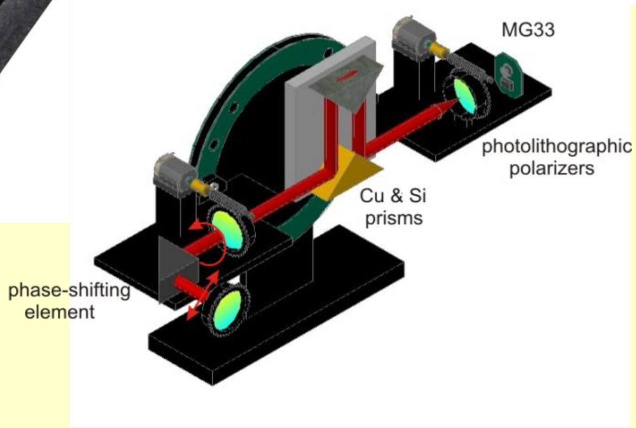


Material optical properties. THz ellipsometry

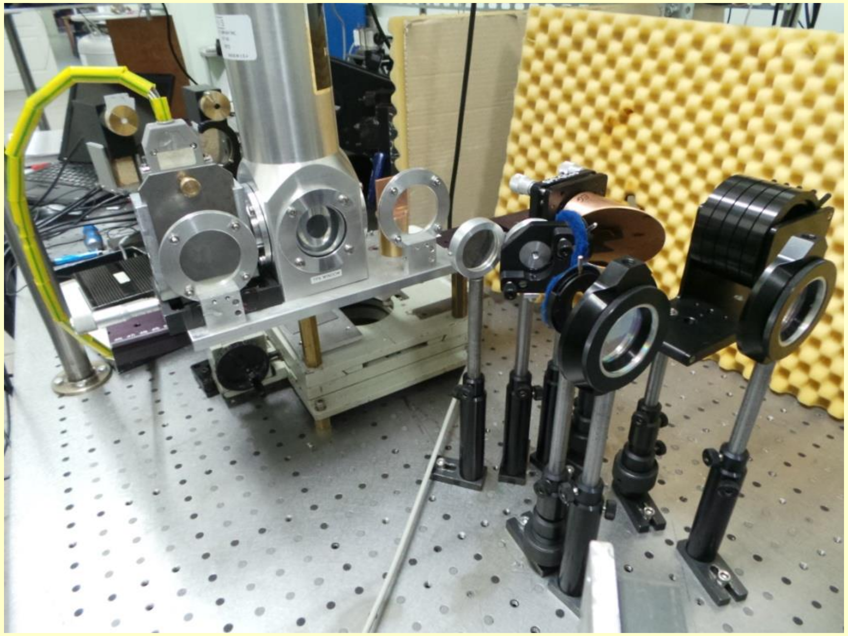


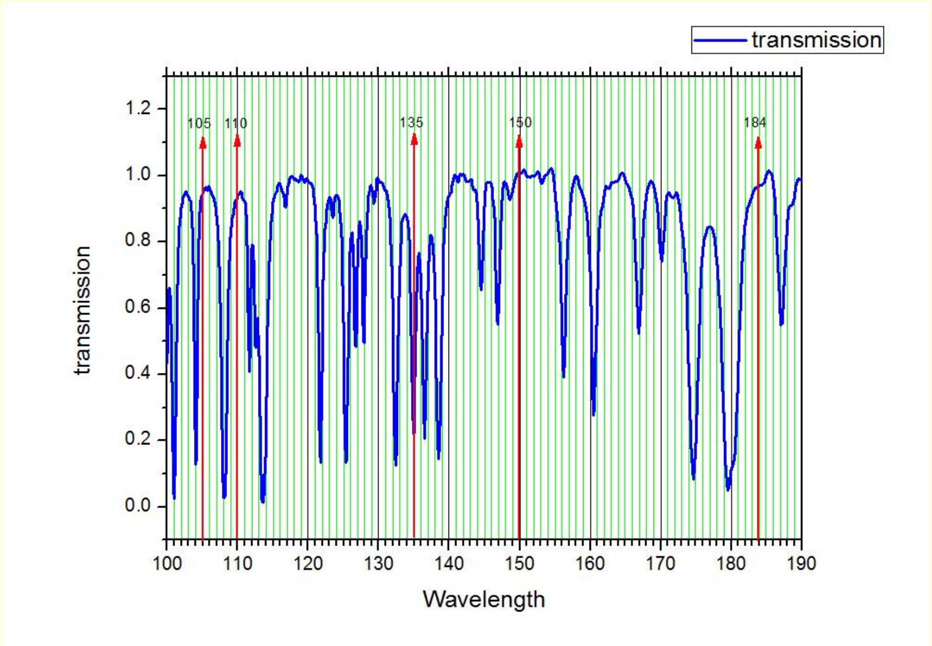
Accuracy of measurements of ellipsometric parameters is 0.5° for ψ and 0.03 for cos(Δ)

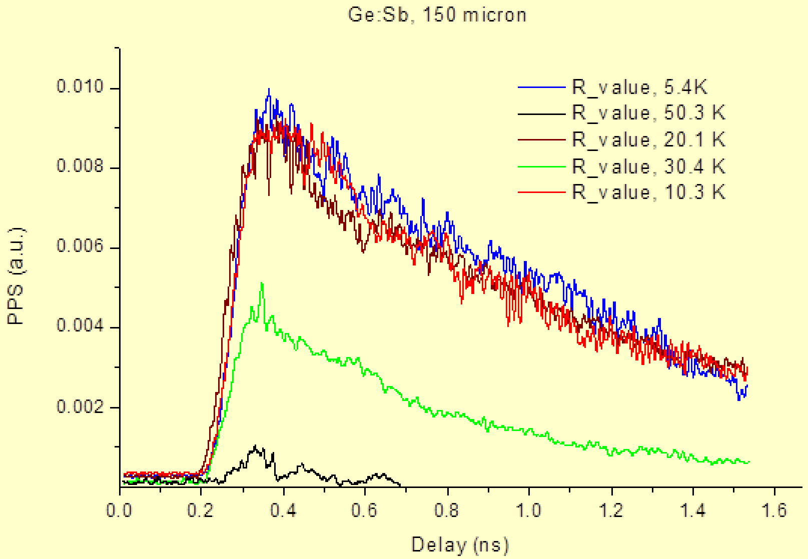


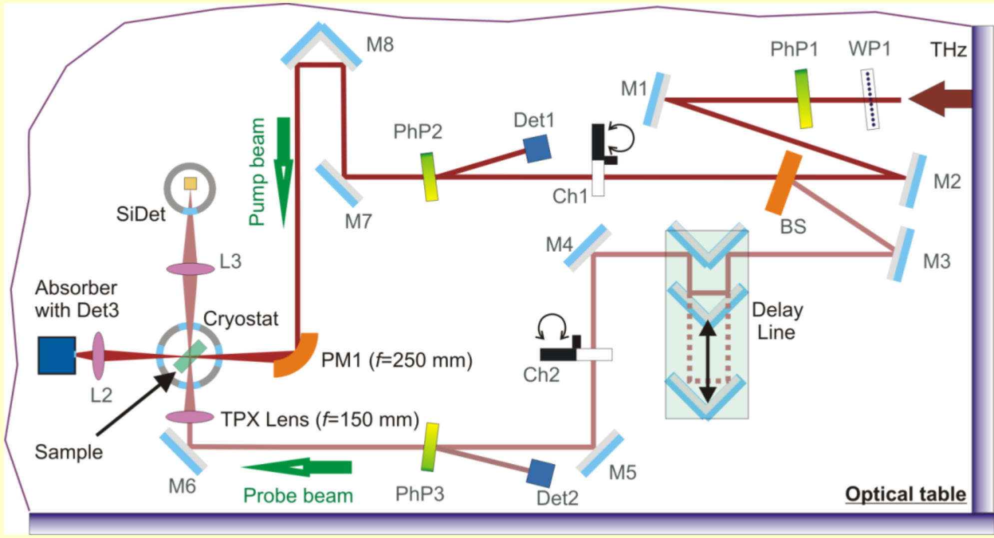


Semiconductors. One-color THz pump-probe spectroscopy



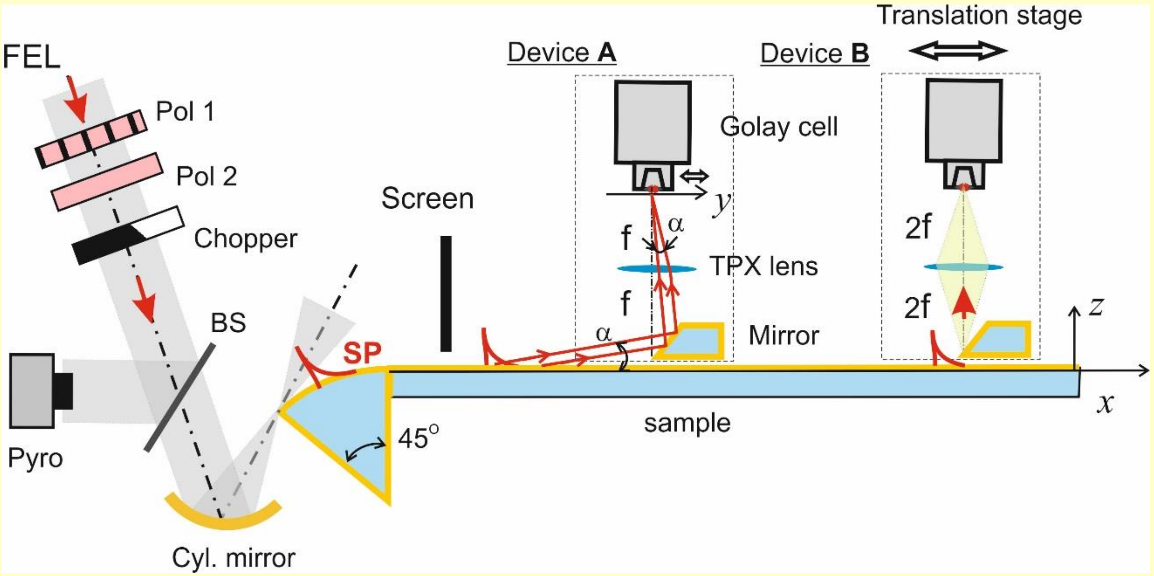




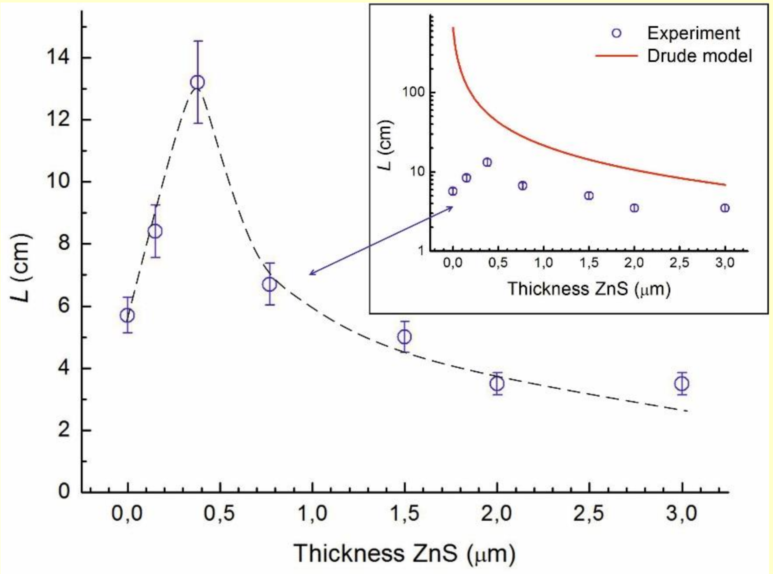


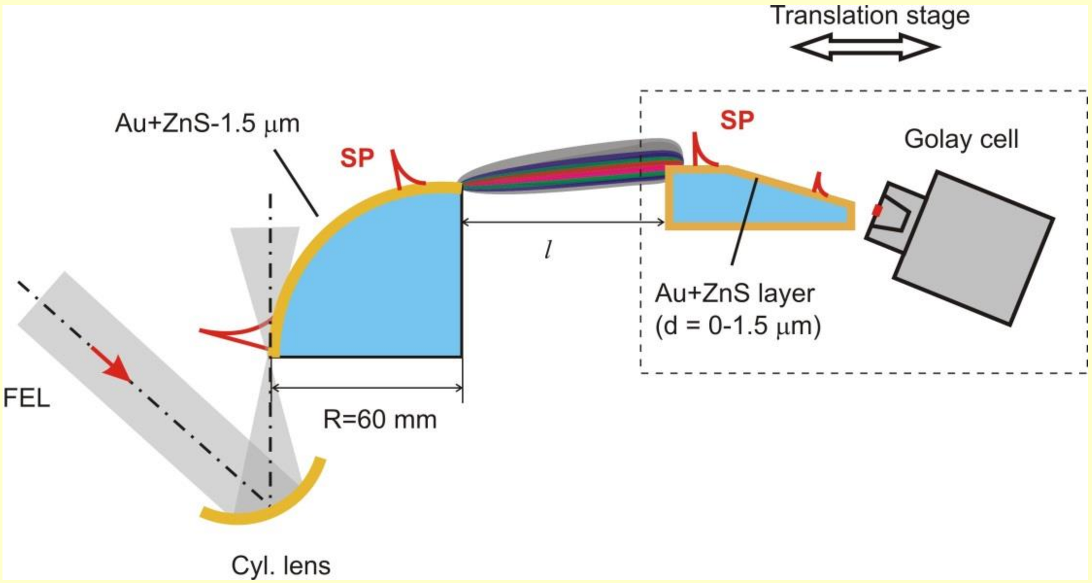
Relaxation time of excited states in GeSb (GeGa, GeAs) is important for creation of detectors and lasers

Surface plasmon polaritons (SPPs) in the terahertz range



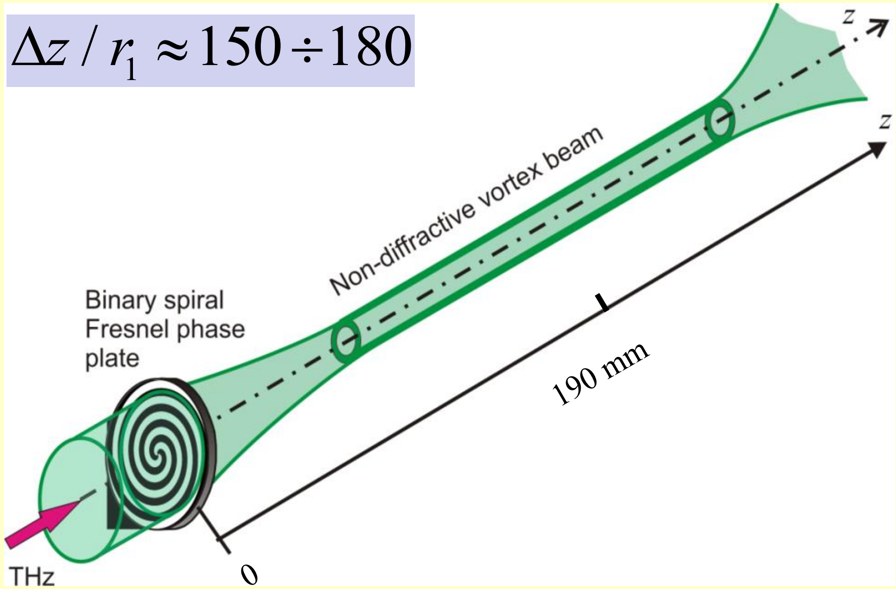
- Techniques for study SPP in the terahertz range have been developed
- Peculiarity of SPP propagation along metal-dielectric in THz

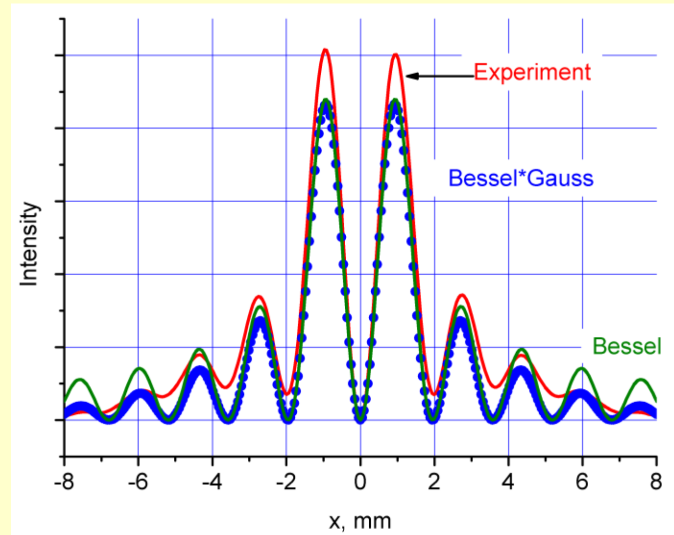




THz Bessel beams with angular orbital momentum

$$\Delta z / r_1 \approx 150 \div 180$$





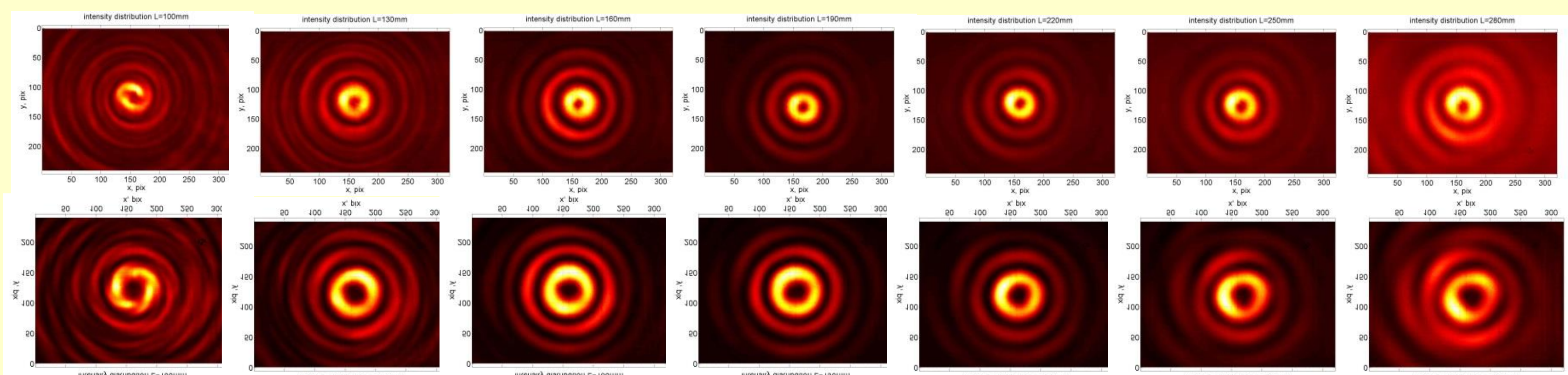
$$BG_{|l|}(r,\varphi,z=0) = J_{|l|}(\alpha_l r)\,\mathrm{e}^{-\frac{r^2}{\omega_0^2}+il\varphi}$$

Experiment:

z = 100 130 160 190 220 250 280 mm

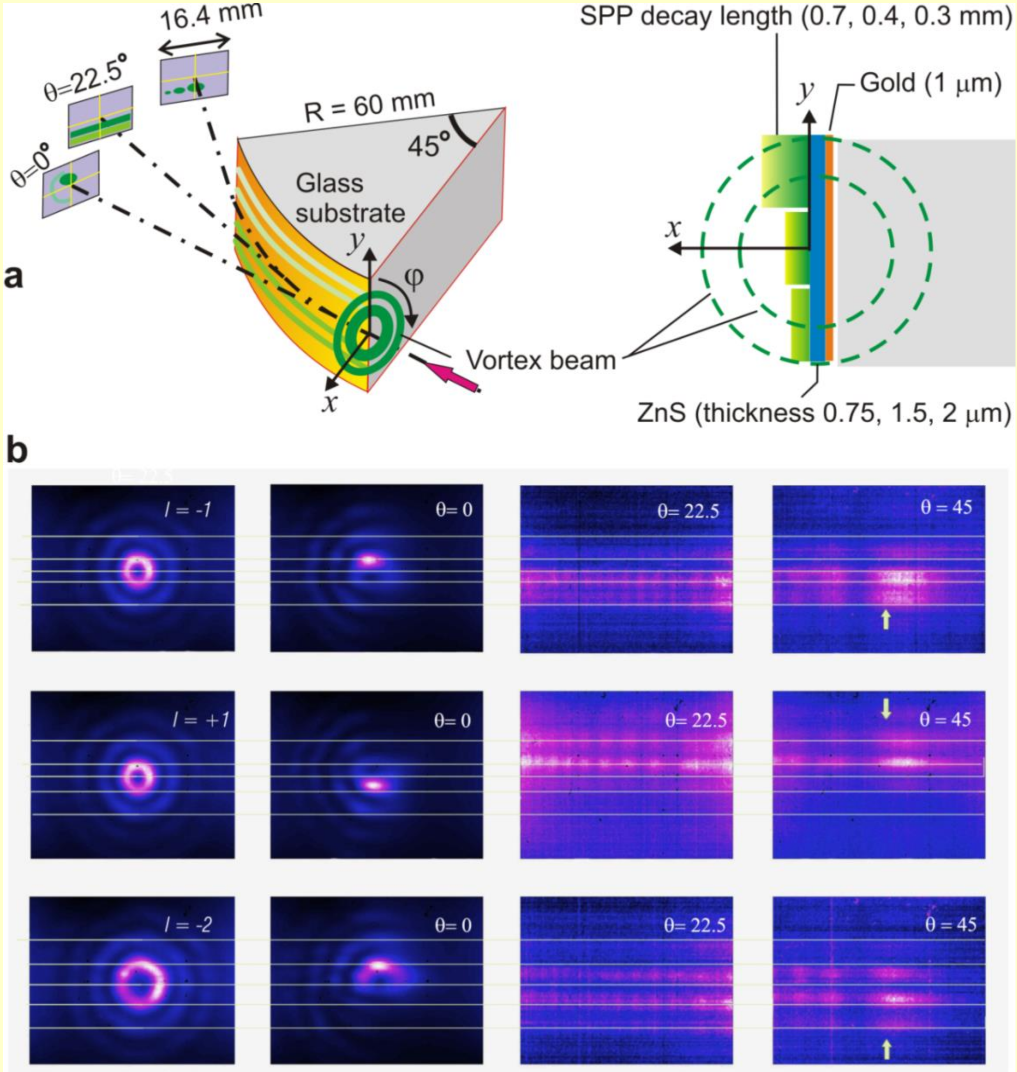
$l = +1$

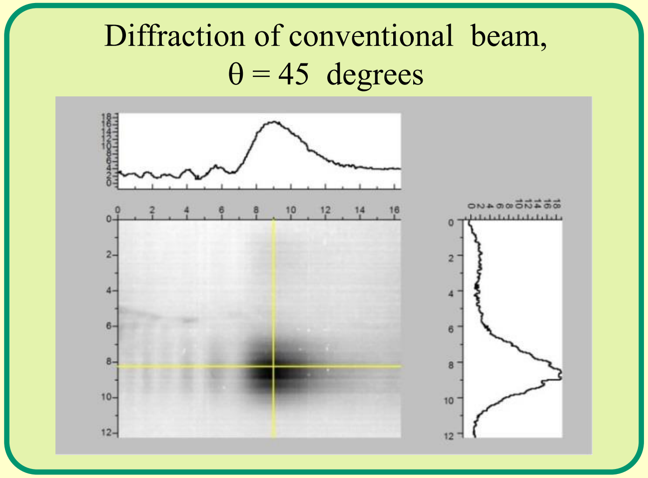
$l = +2$

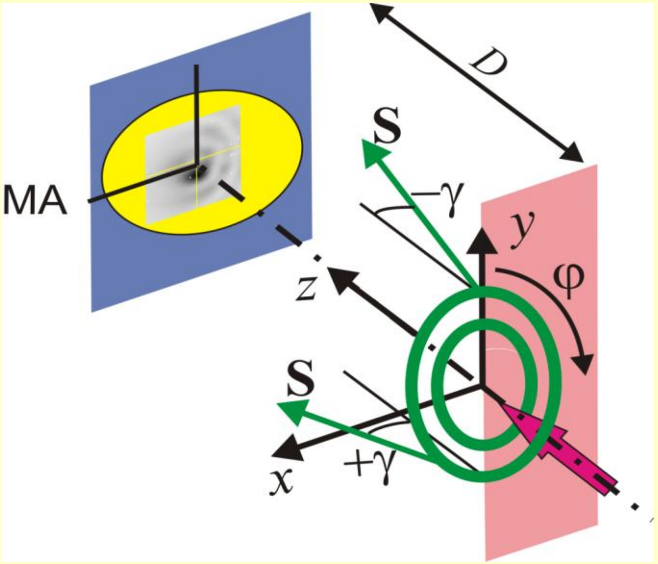


Surface plasmon polaritons and beams with angular orbital momentum

Efficiency of the generation of SPPs depends on direction of beam rotation





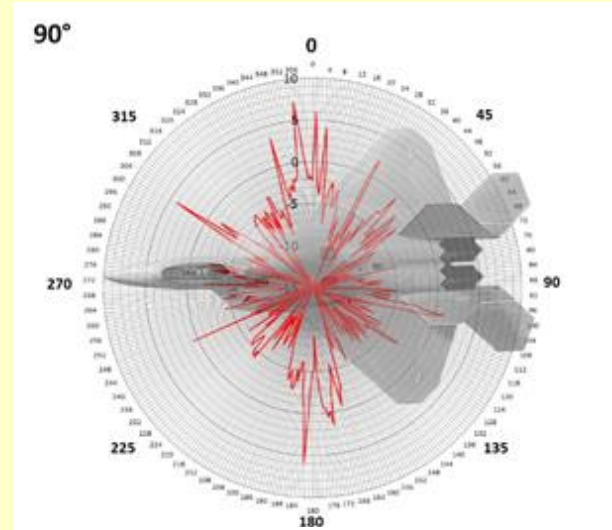


B. A. Knyazev, at al., Phys. Rev. Letters, V. 115, 163901, 2015, 5p.

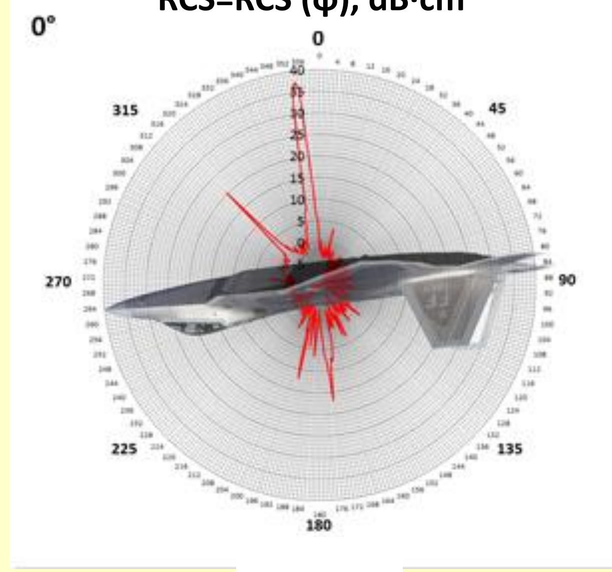
Measuring of radar cross-section (RCS)

Scale modelling: $L_0^* = \frac{\lambda_0}{\lambda_\mathrm{M}} L_M^*$; $S_0^* = \frac{\lambda_0^2}{\lambda_\mathrm{M}^2} S_M^*$;

λ_0 – GHz
λ_M - THz



RCS=RCS (φ), dB·cm²



Thank you for your attention !