PUMP-PROBE SETUP FOR FAR-INFRARED SUBNANOSECOND TIME-RESOLVED SPECTROSCOPY AT THE NOVOSIBIRSK FREE ELECTRON LASER

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PUMP-PROBE SYSTEM

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Time-resolved electronic capture in *n*-type germanium doped with antimony

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The low temperature ($T = 5$–40 K) capture of free electrons into hydrogenlike antimony centers in germanium has been studied by a time-resolving experiment using the free electron laser FELBE. The analysis of the pump-probe signal reveals a typical capture time of about 1.7 ns that decreases with pump energy to less than 1 ns while the number of ionized donors increases. The dependence on the pump-pulse energy is well described by an acoustic phonon-assisted capture process. In the cases when (i) a significant number of the electrons is in the conduction band (flux densities larger than 5×10^{25} photons/(cm^2 s), (ii) the lattice temperature is above ~20 K, or (iii) a static electric field above ~2 V/cm is applied to the crystal, the pump-probe technique reveals an additional intraband relaxation process with a characteristic time of ~100 ps, which is much shorter than that of the capture of free electrons into the antimony ground state.

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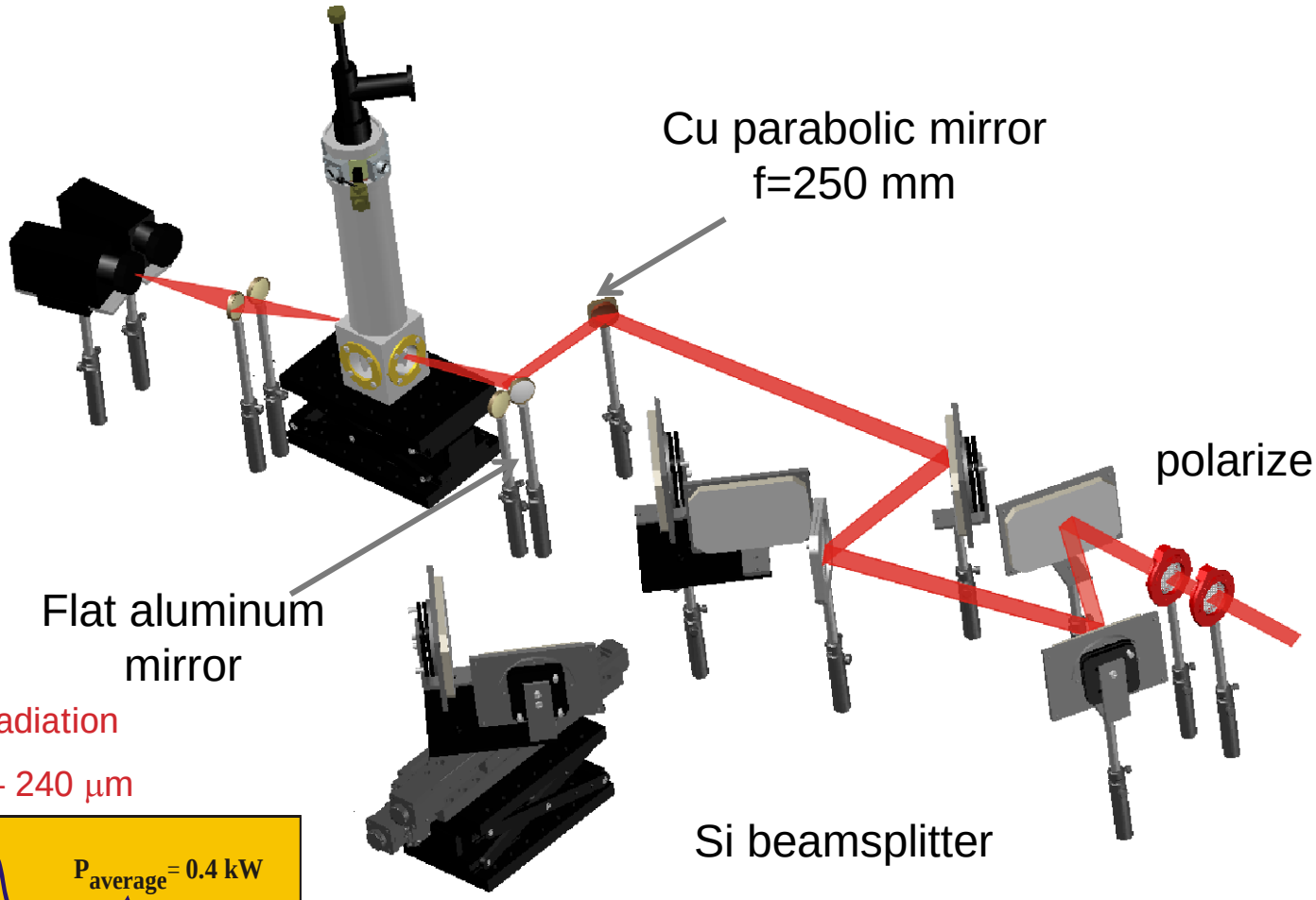
I. INTRODUCTION

Impurity centers in semiconductors such as silicon (Si) or germanium (Ge) have been thoroughly investigated over the last decades. Most of the research in the early years was devoted to the low temperature equilibrium spectroscopy of impurity states, measurements of photocurrent relaxation, and

Relaxation dynamics in undoped bulk and nanowire Ge using optical-pump with optical-probe [23] or terahertz-probe [24] spectroscopy have revealed important information about electron-hole recombination. However, relaxation dynamics of ionized centers in Ge were investigated with a considerable number of different but mainly indirect methods. These include studies of the electric field-dependent stationary

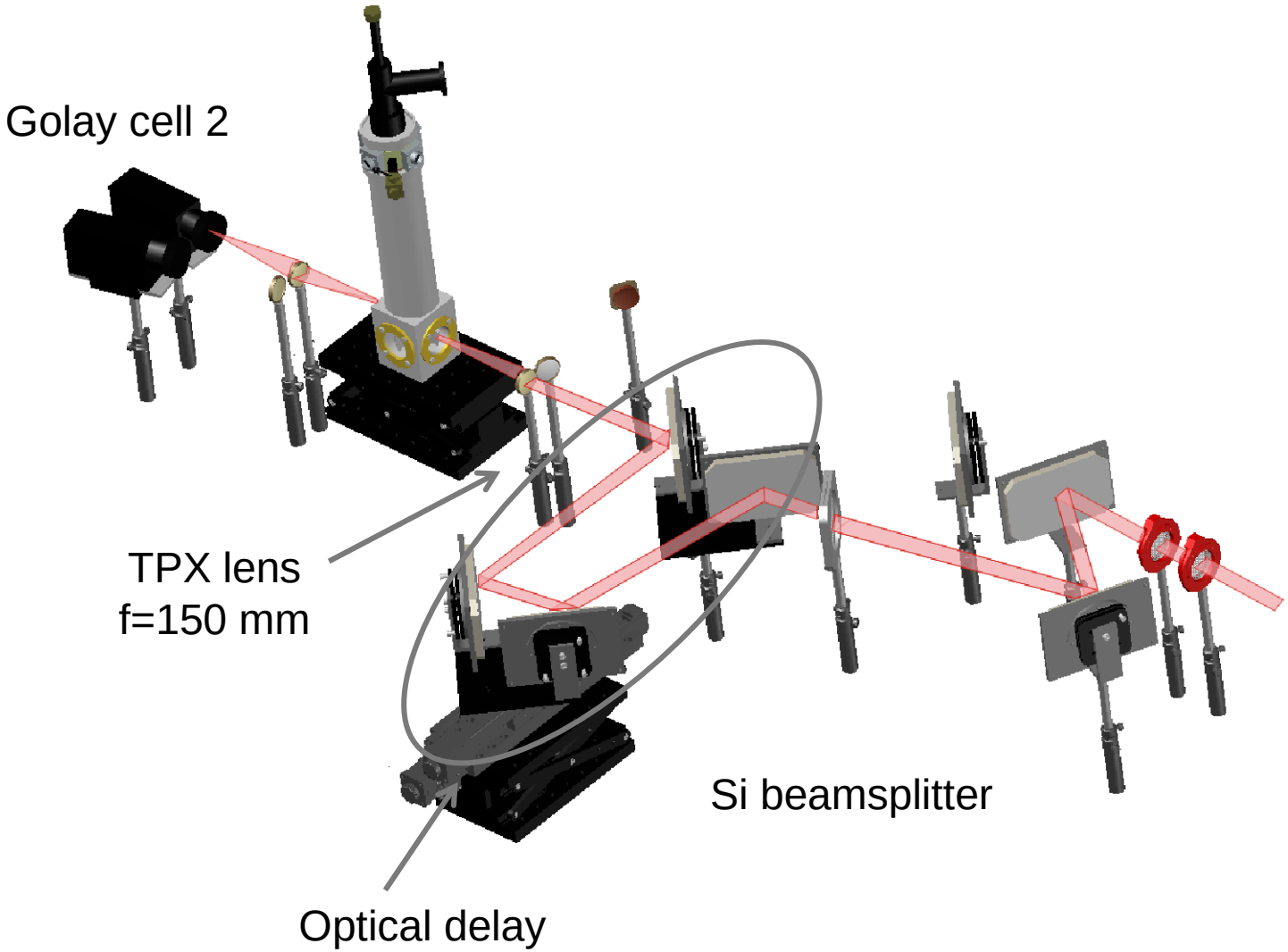
OPTICAL SYSTEM: PUMP BEAM



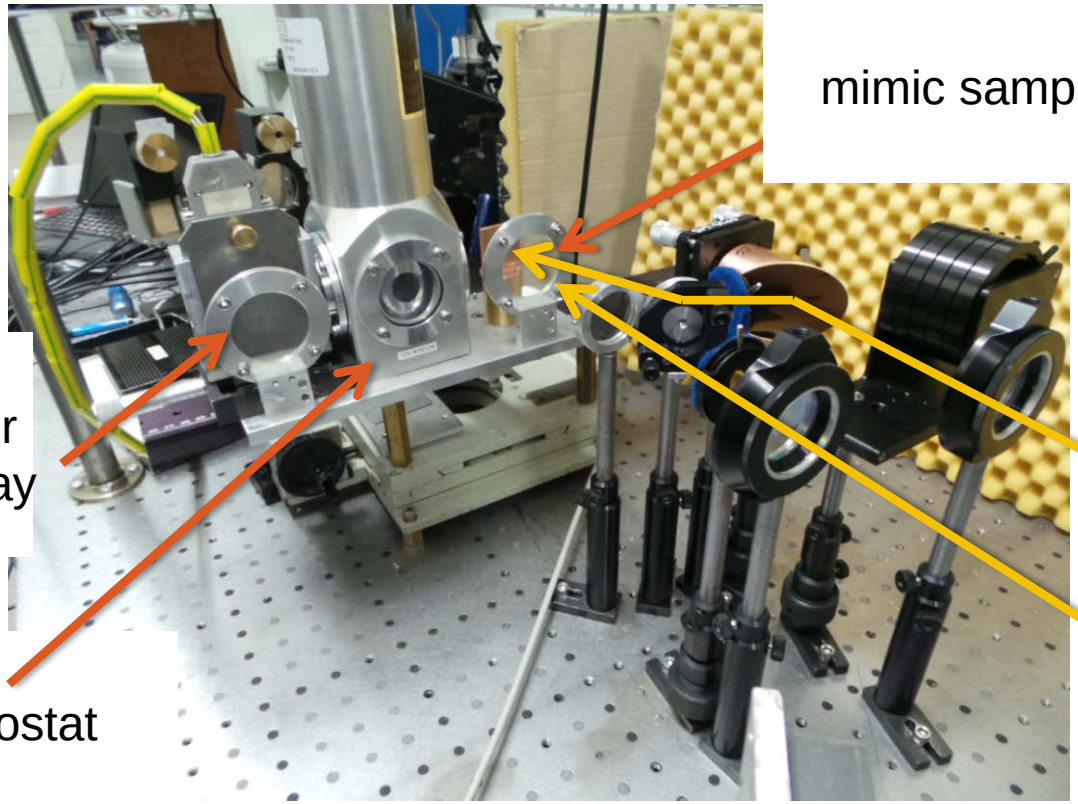
Monochromatic radiation

tunable within 5– 240 μm

OPTICAL SYSTEM: PROBE BEAM



CONTROL OF BEAMS POSITION ON A SAMPLE



mimic sample holder

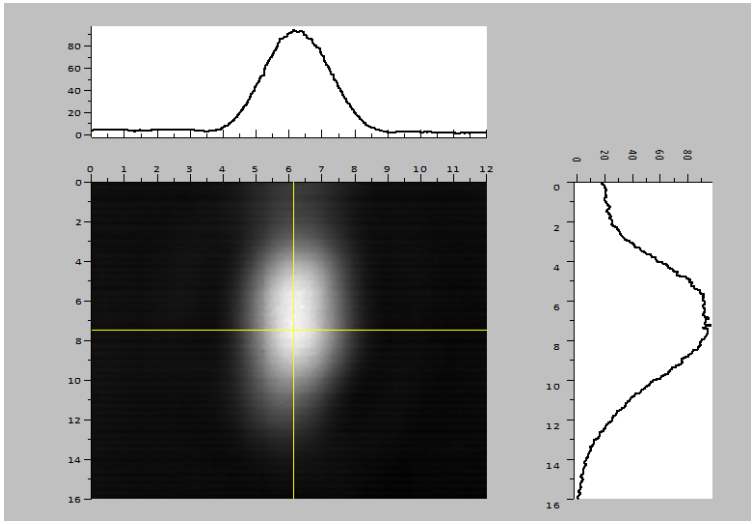
Microbolometer focal plane array

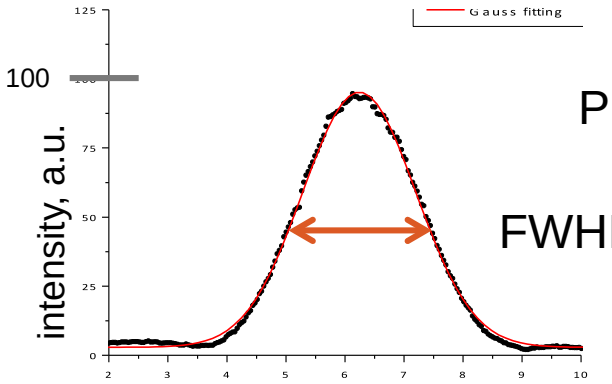
Cryostat

Pump beam

Probe beam

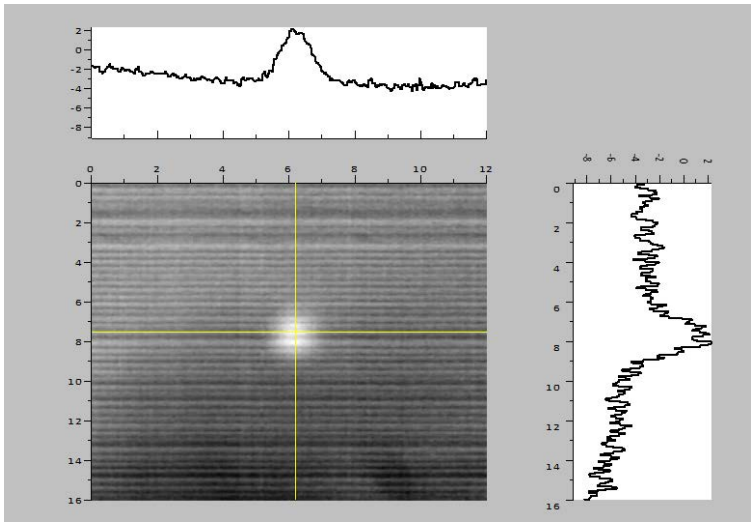
CONTROL OF BEAMS POSITION ON A SAMPLE

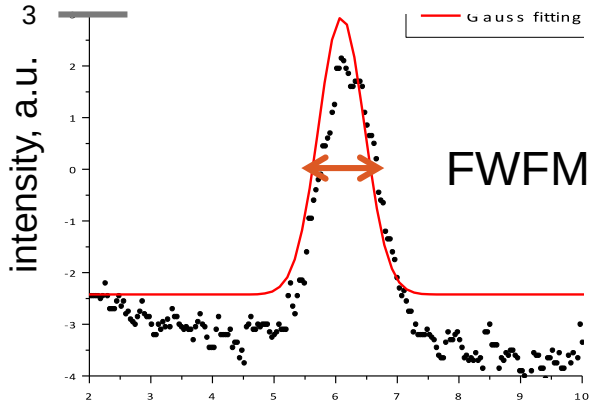




PUMP

FWHM 2.5 mm





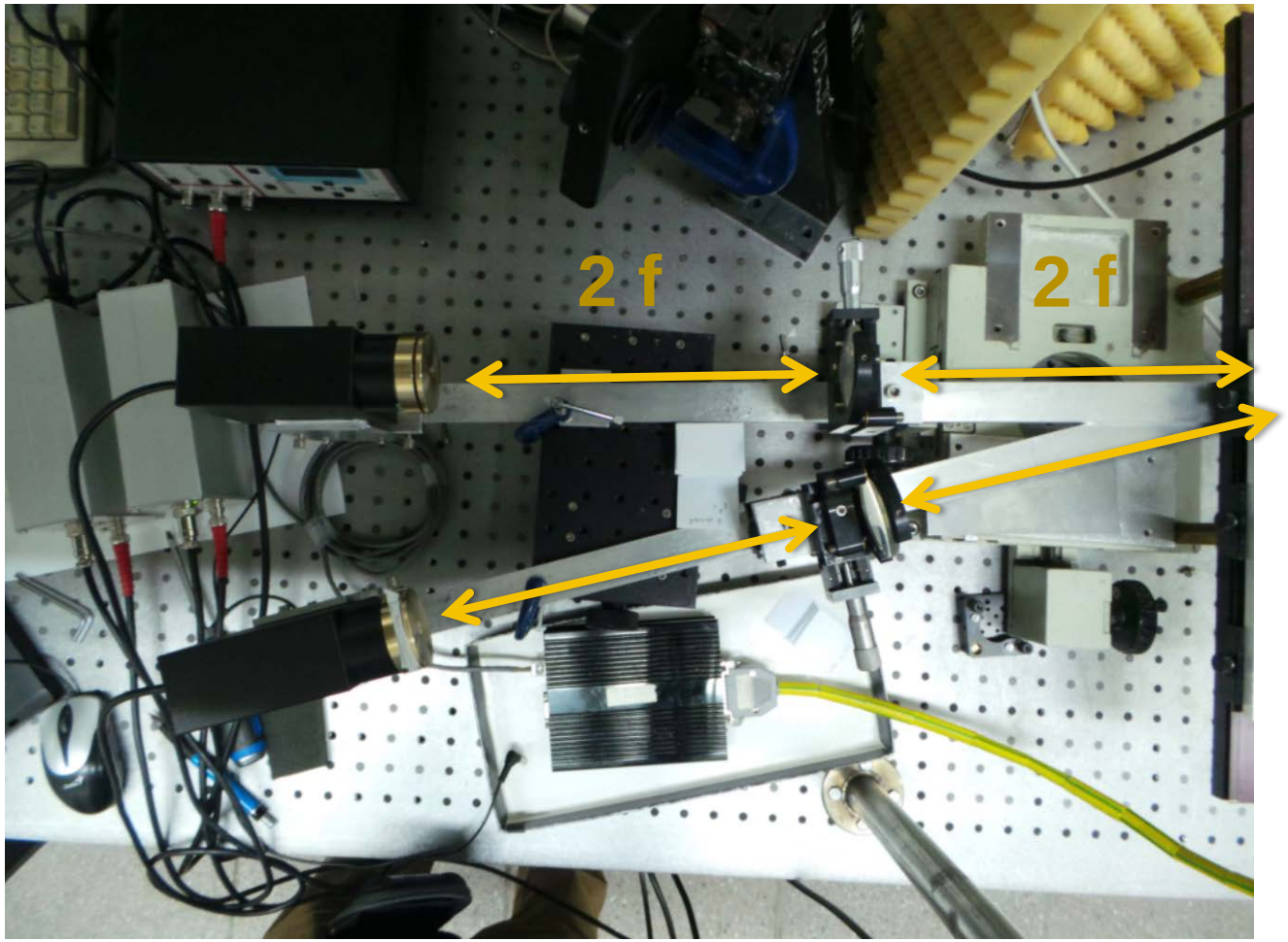
PROBE

FWFM 1 mm

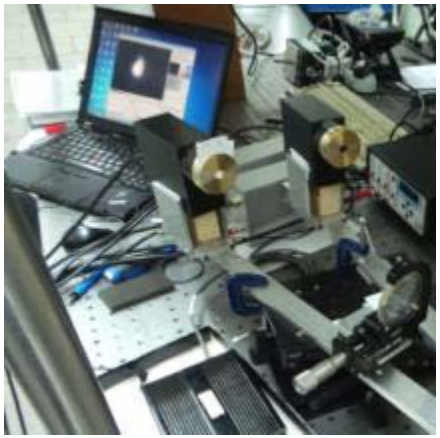
DETECTION SYSTEM

Probe beam detector

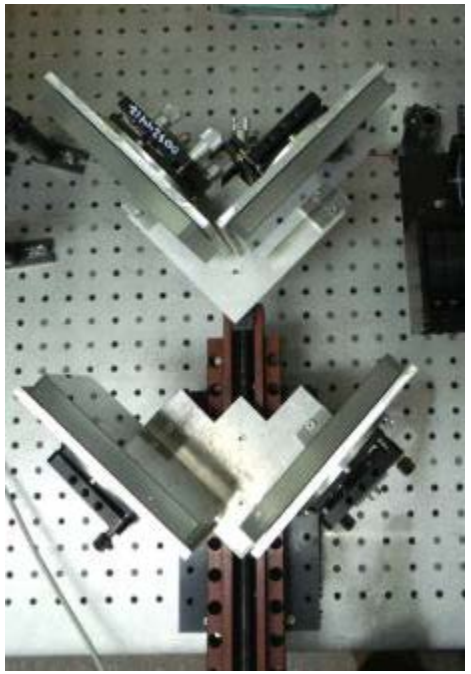
Pump beam detector



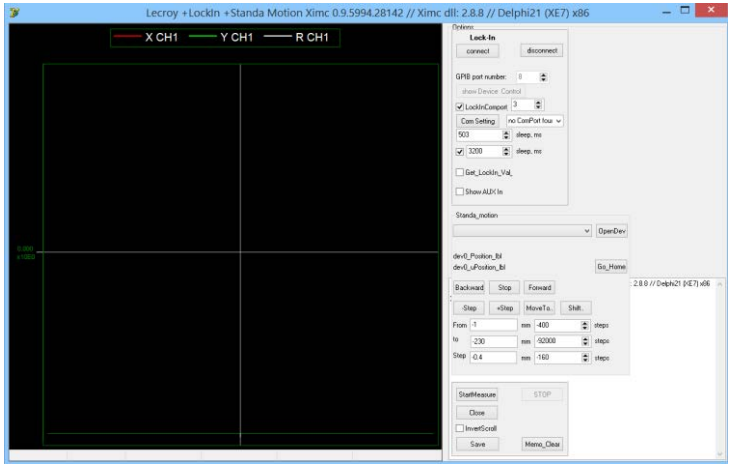
AUTOMATION OF THE MEASURMENTS



Golay detector + Lock-in amplifier
at 15 Hz pump beam modulation

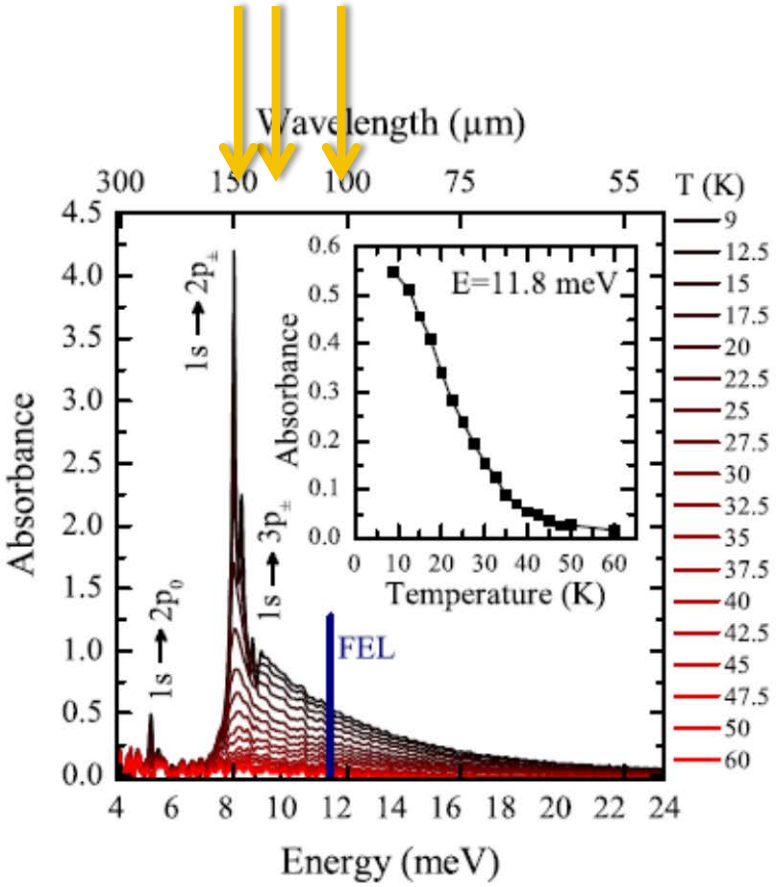


input radiation power measured with pyroelectric detector



Delay line

GE:SB STUDY



105 μm
142 μm
150 μm

FIG. 2. (Color online) Absorbance (σNd) of the investigated Ge:Sb sample as a function of the temperature, showing spectral features corresponding to intracenter (discrete lines) and impurity-band transitions (continuum at energies larger than ~10 meV). The discrete lines correspond to transitions originating from the $1s(A_1)$ and $1s(T_2)$ antimony states, which is thermally populated. Inset: Absorbance in the sample at the FEL pump photon energy of 11.8 meV (105 μm) as a function of the sample temperature.

GE:SB STUDY: RELAXATION TIME

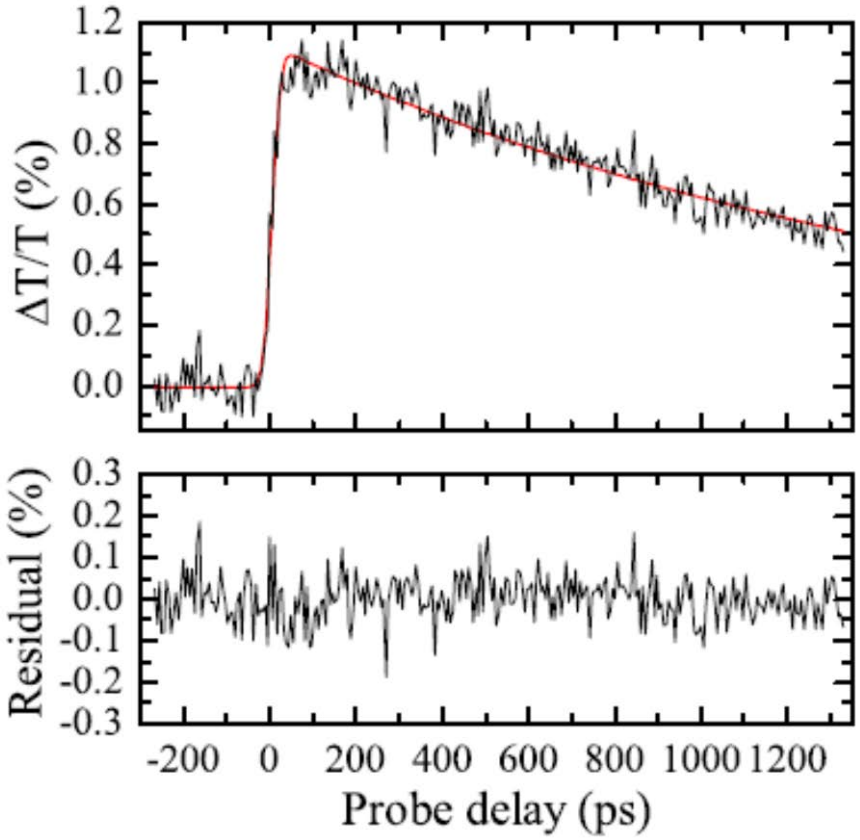


FIG. 4. (Color online) Pump-probe signal of the Ge:Sb sample at a pump-pulse energy of 0.3 nJ and a temperature of ~5 K. The straight red line is a fit using Eq. (6). The decay time is 1.7 ns. The residual is the difference between fit and measurement.

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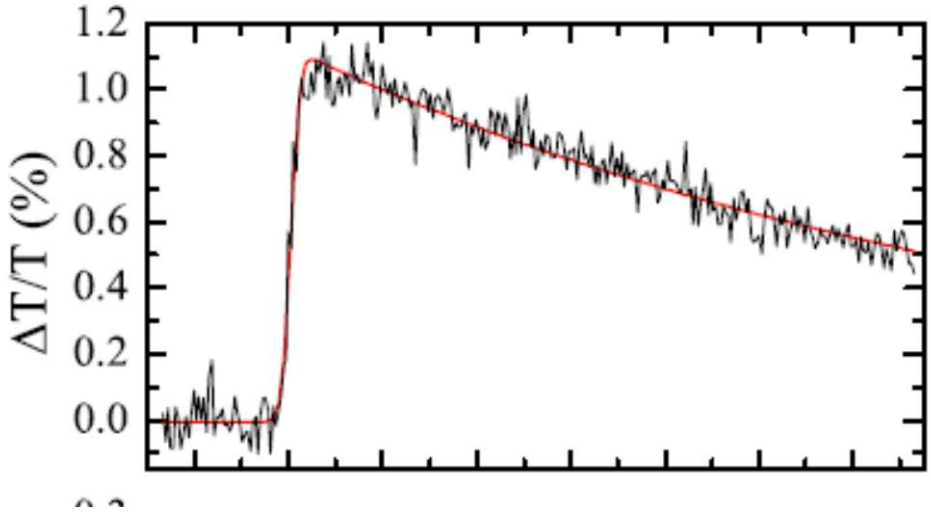
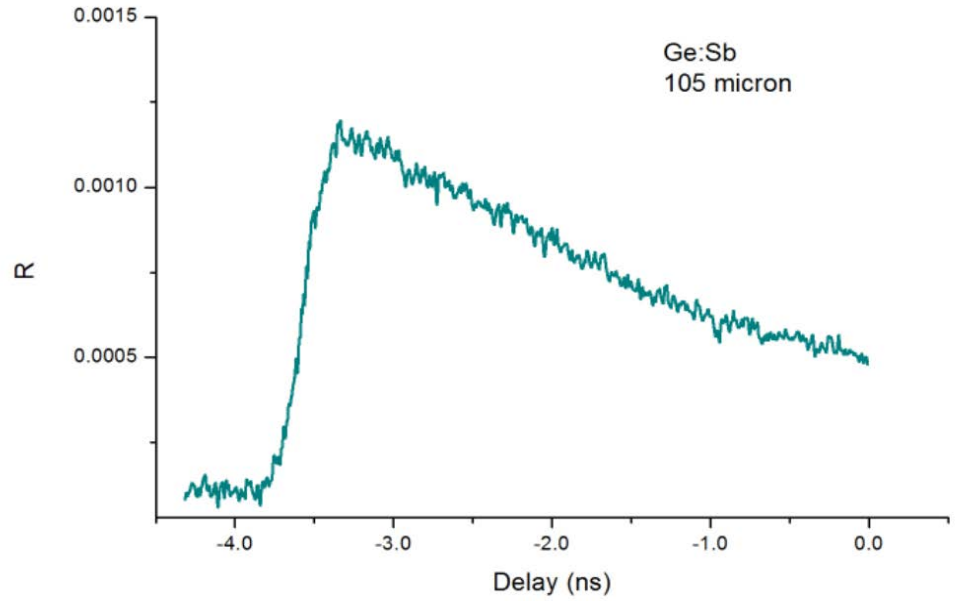
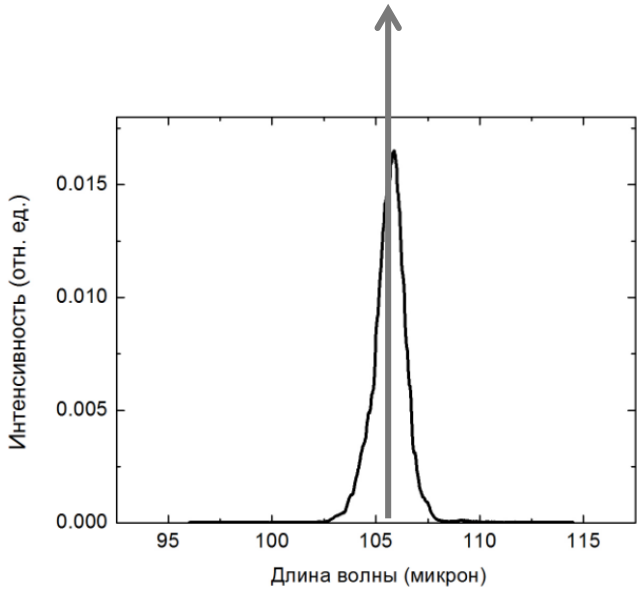
GE:SB STUDY: RELAXATION TIME



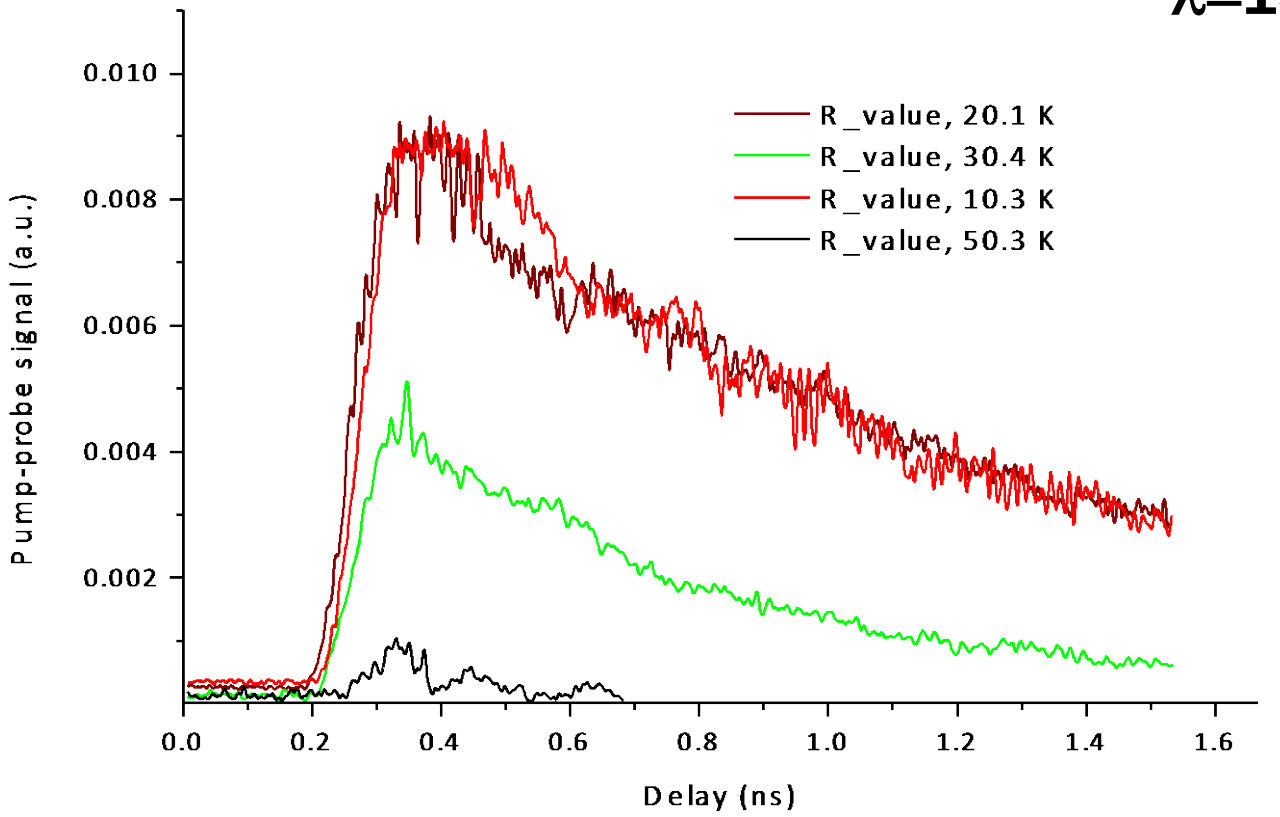


λ=106 μm



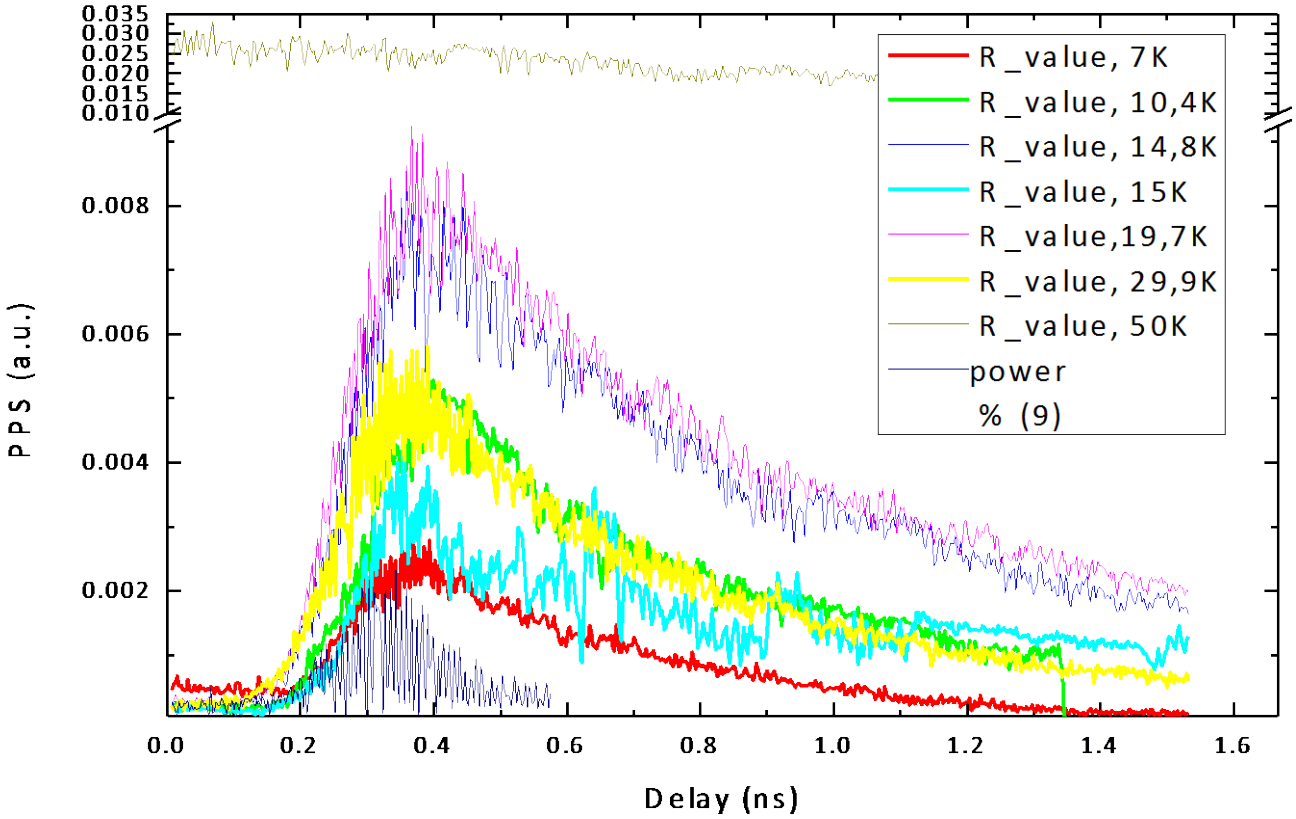
GE:SB STUDY:
2P+/- AT DIFFERENT TEMPERATURES

λ=150 μm



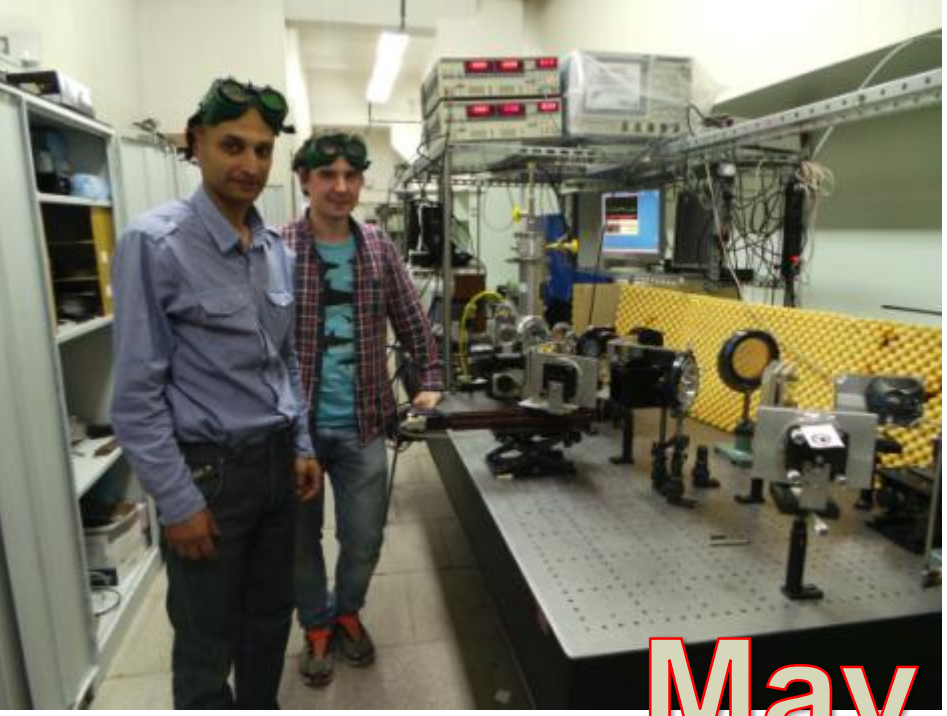
GE:SB STUDY:
3P+/- AT DIFFERENT TEMPERATURES

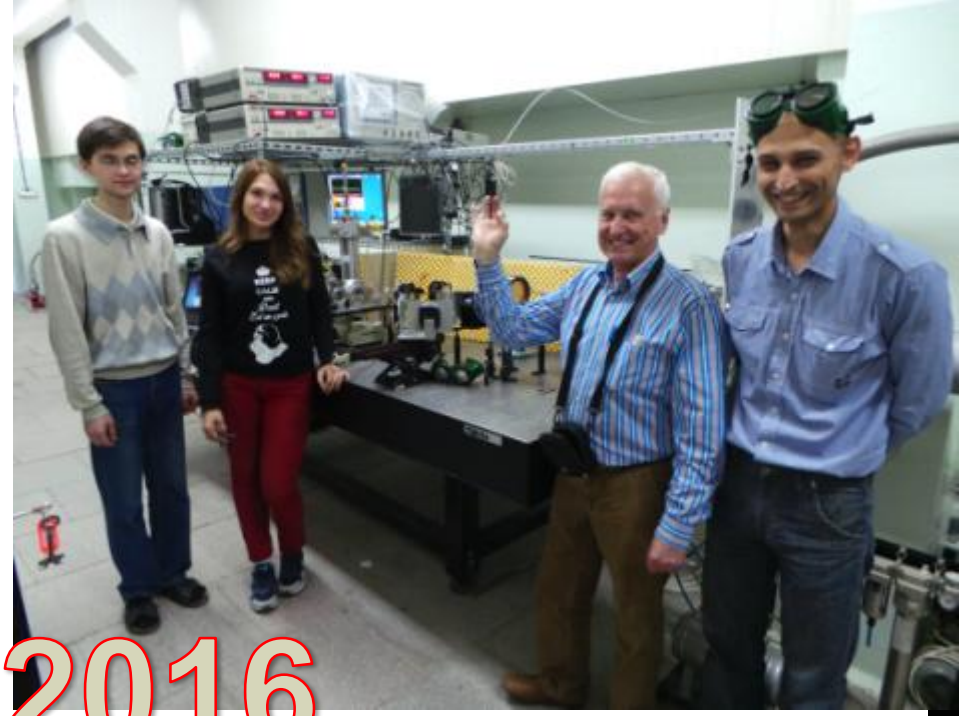
λ=142 μm



SUMMARY

- Pump-probe system at the Novosibirsk free electron laser has been comissioned
- Test experiments with the samples, which were previously studied at FELBY, have been performed and demonstrated properly work of the system





May 2016