Time resolved experiments with a laser-driven x-ray diode

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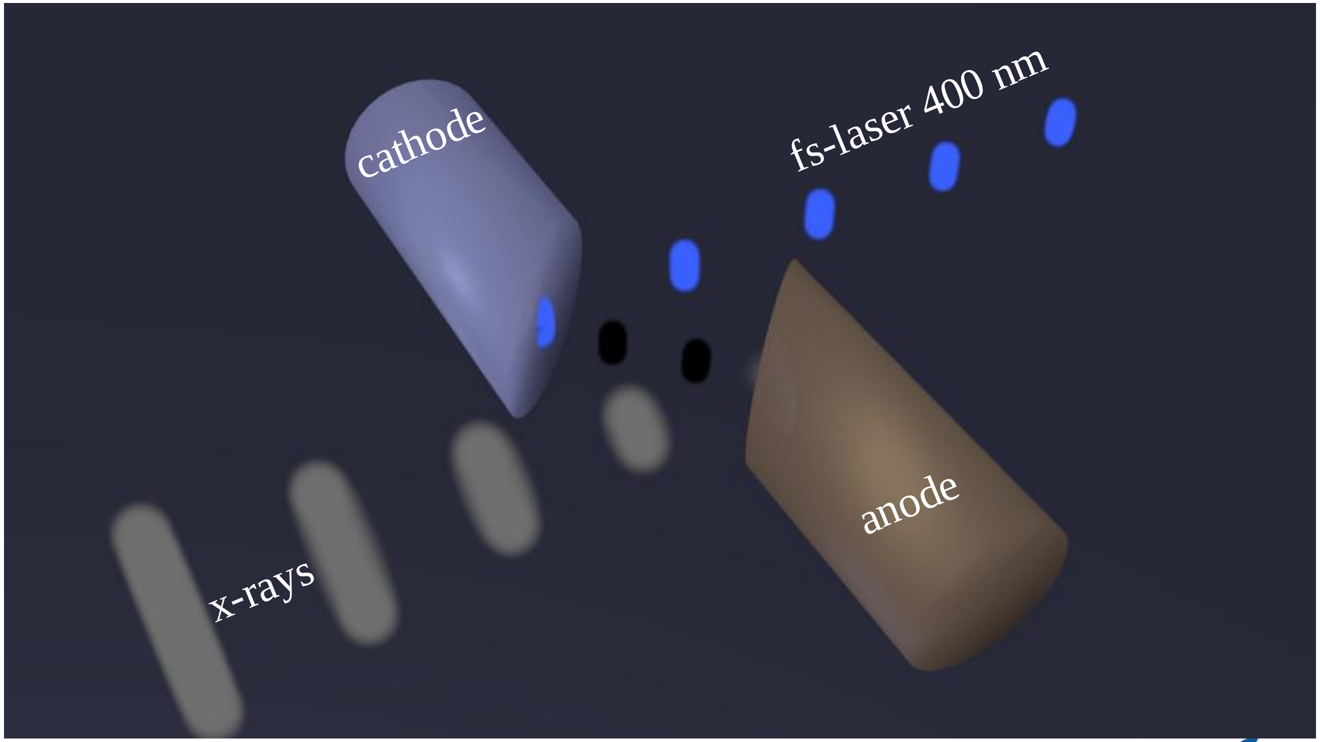
Outline

- The Laser-Driven X-ray Diode
  - Working Principle
  - Setup
  - Characterization
- Optical Phonons in Germanium
- Time Resolved X-ray Absorption Spectroscopy (feasibility study)
- Summary

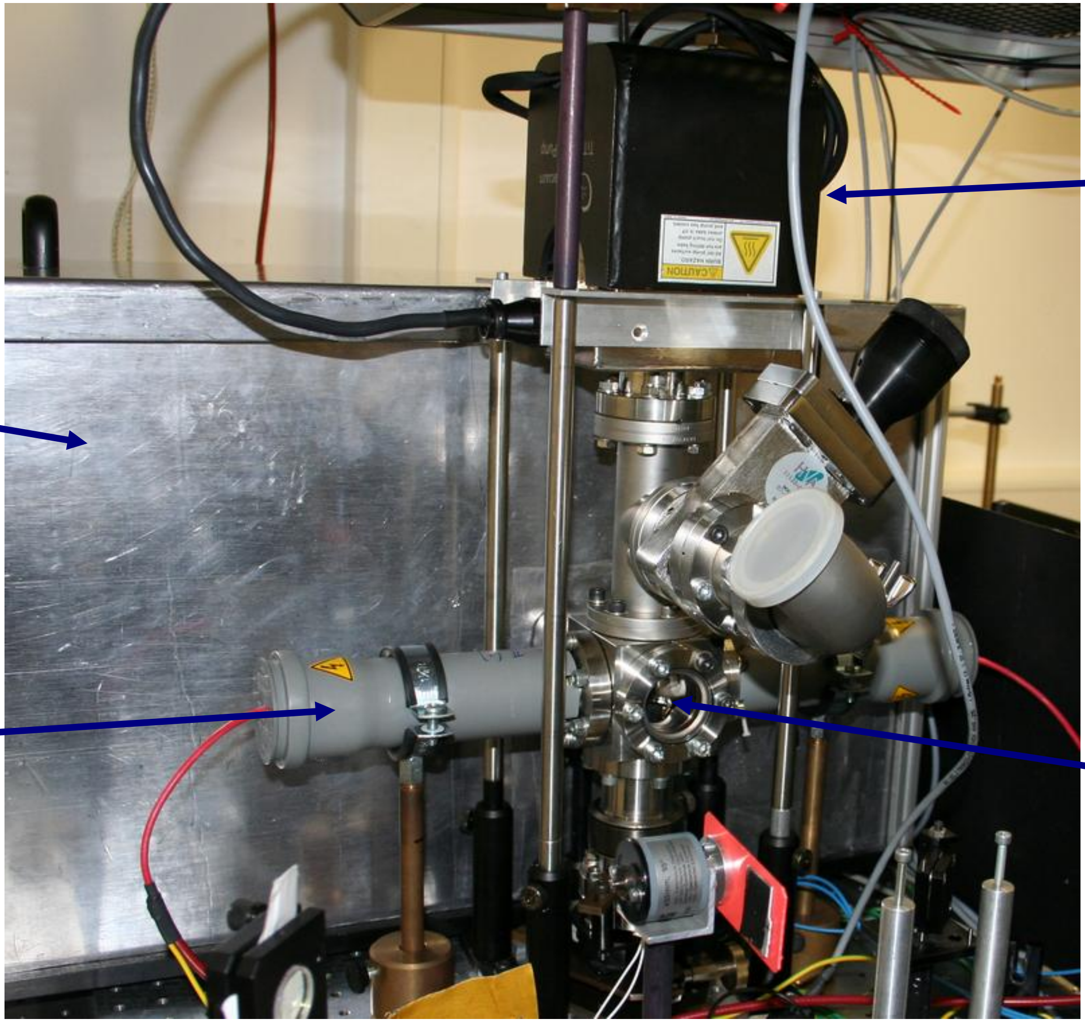
Working Principle

1. photoexcitation of electrons with fs-laser
2. acceleration of electrons to the anode

   (voltage between anode and cathode U = 0…40 kV)
3. creation of ultrashort x-ray pulses (characteristic lines + bremsstrahlung)



The Laser-Driven X-ray Source



experimental chamber

ion vacuum pump

high voltage connector

entrance window

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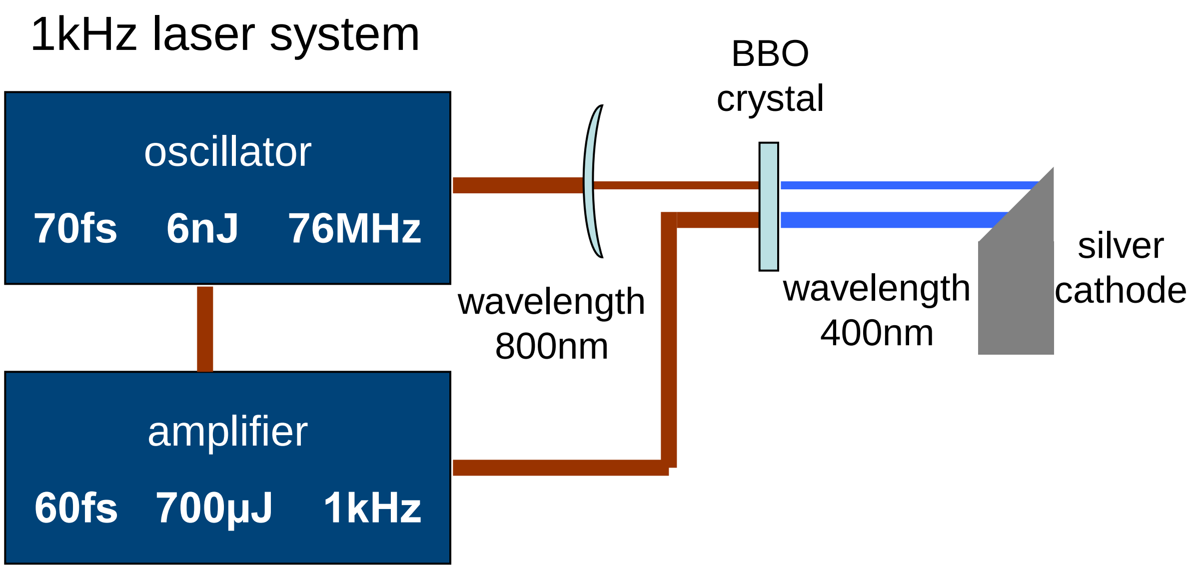
Photoemission

Silver as photo cathode:

- no oxides on surface
- stable against fs-laser pulses
- work function of 4.3eV

2-photon photoemission with the frequency doubled laser pulses (1.55eV/800nm → 3.1eV/400nm)

max. photocurrent **44 nA**
with
amplifier or oxcillator



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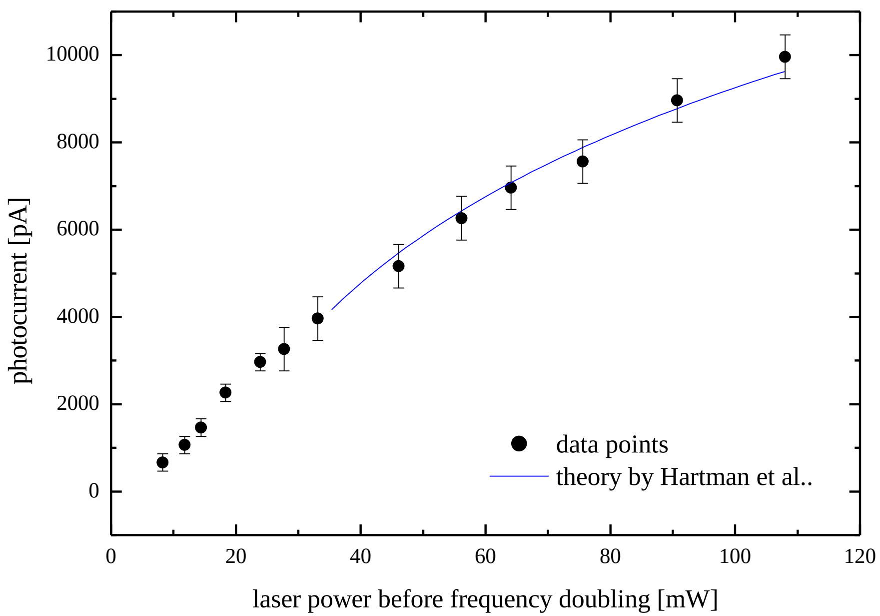
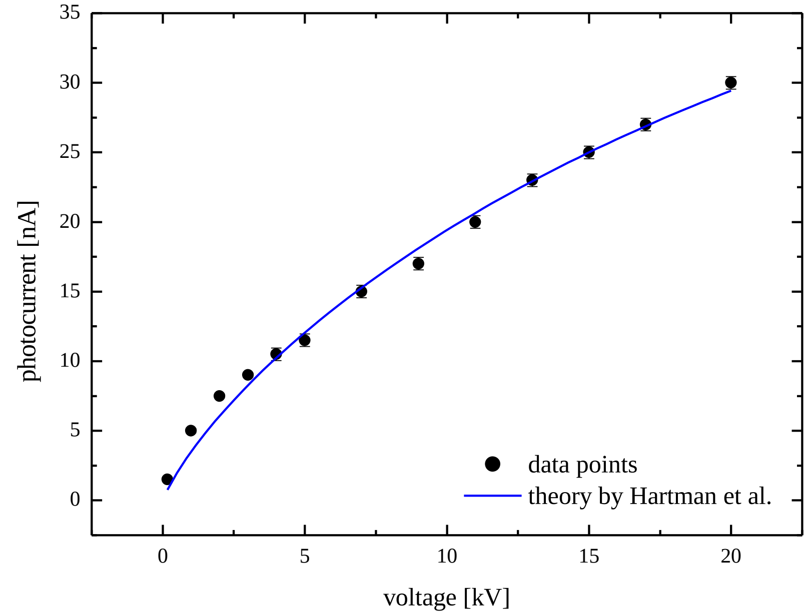
Charge Saturation

short electron pulses → space charge effects

e⁻ emission is saturated in regions of high laser intensity (mainly by using the amplifier)

→ best way to increase photocurrent is a higher repetition rate of the laser





S. Hartman, et al., Nucl. Instrum. and Meth. in Phys. Res.-Sec. A Only, 340, 219 (1994)

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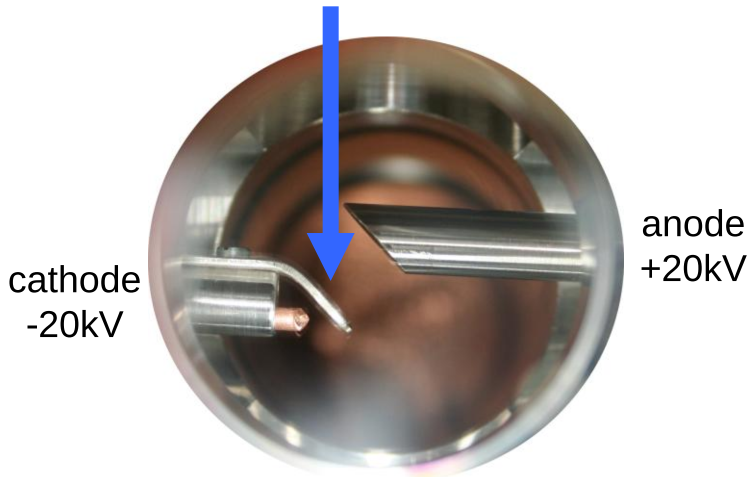
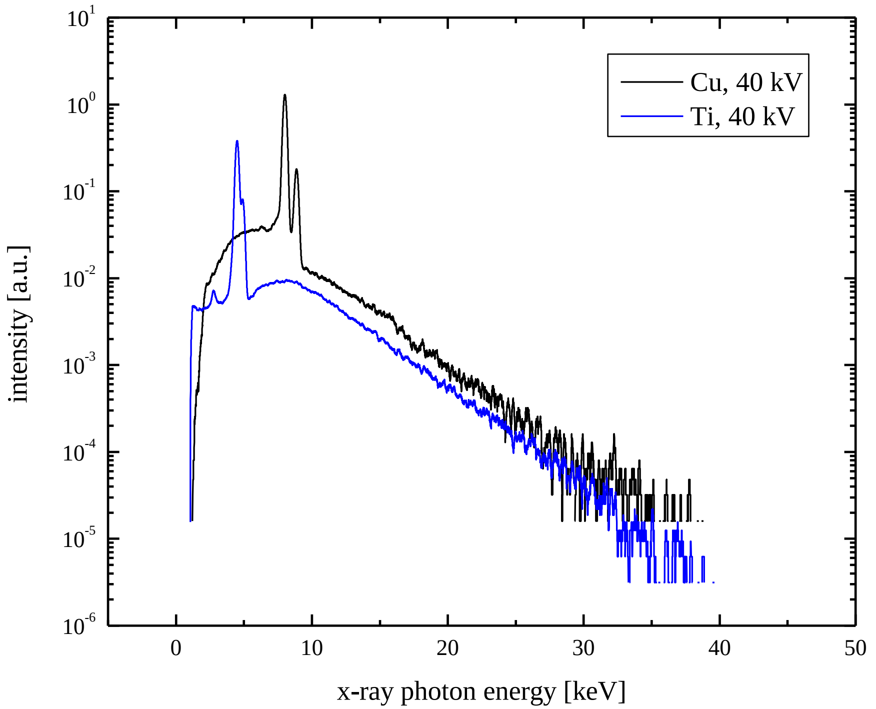
Properties of the X-ray Pulses



X-ray spectra show typical behavior of an X-ray tube



$1.4 \cdot 10^9$ Ti K_α photons per sec in 4π

$1.2 \cdot 10^9$ Cu K_α photons per sec in 4π

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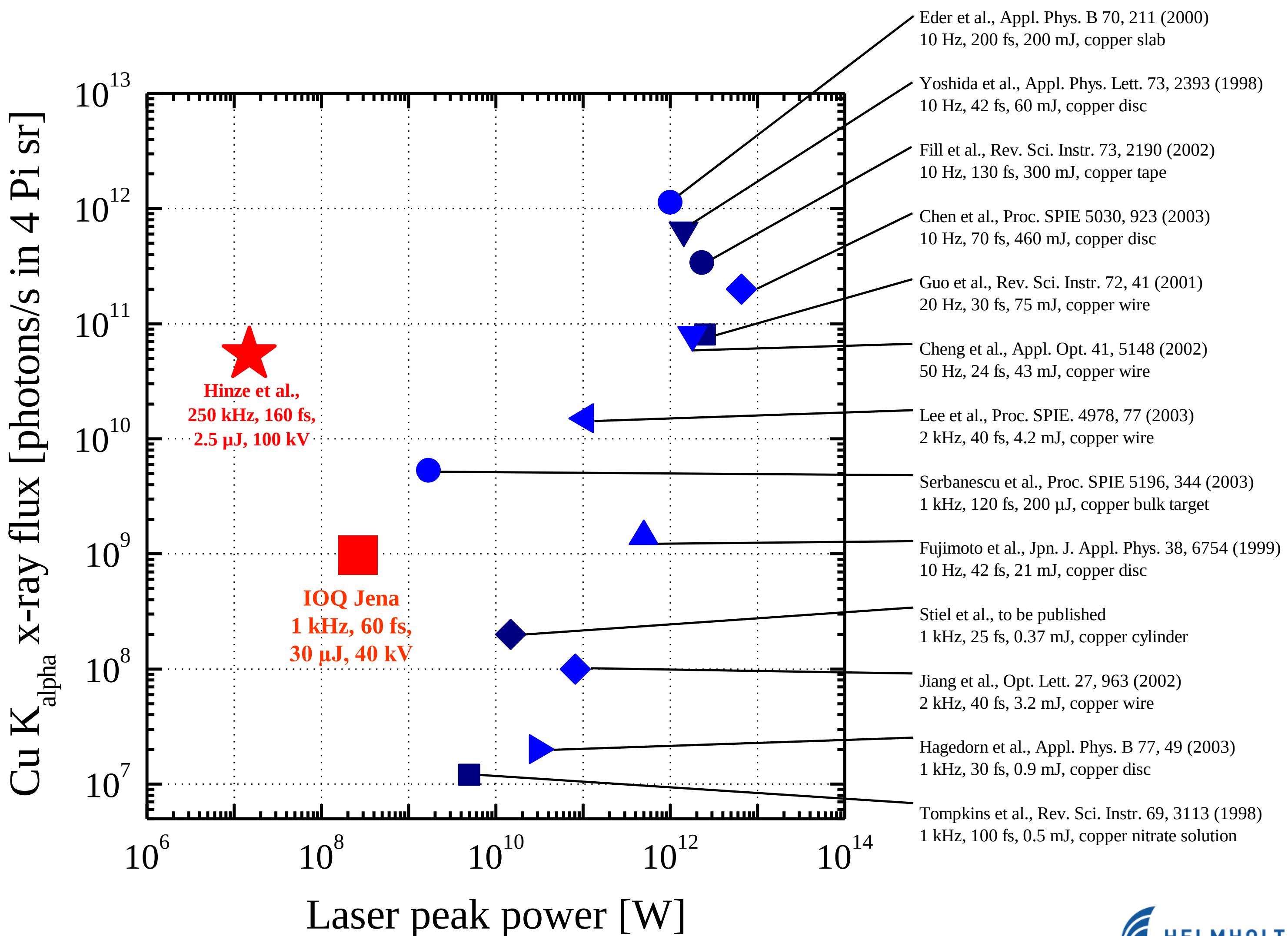
Comparison with other Laser Based X-ray Sources



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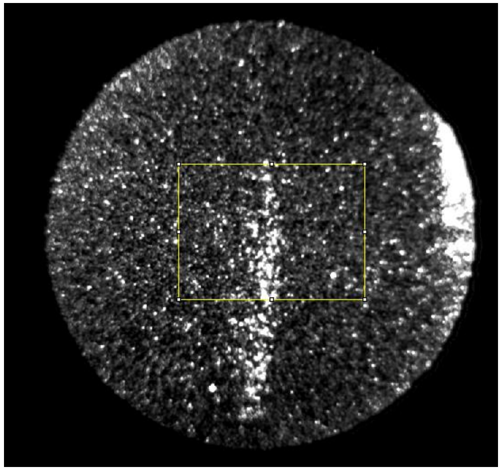
Properties of the X-ray Source

X-ray pulse duration < 26 ps
(resolution limit of our streak camera)

pulse broadening, due to:

- velocity spread of electrons
- space charge effects



streak camera image

source size on the anode ∝ laser spot size

focussing of oscillator → small source size

(ca. 70µm diameter)

→ phase contrast imaging

absorption and phase contrast image of a spider

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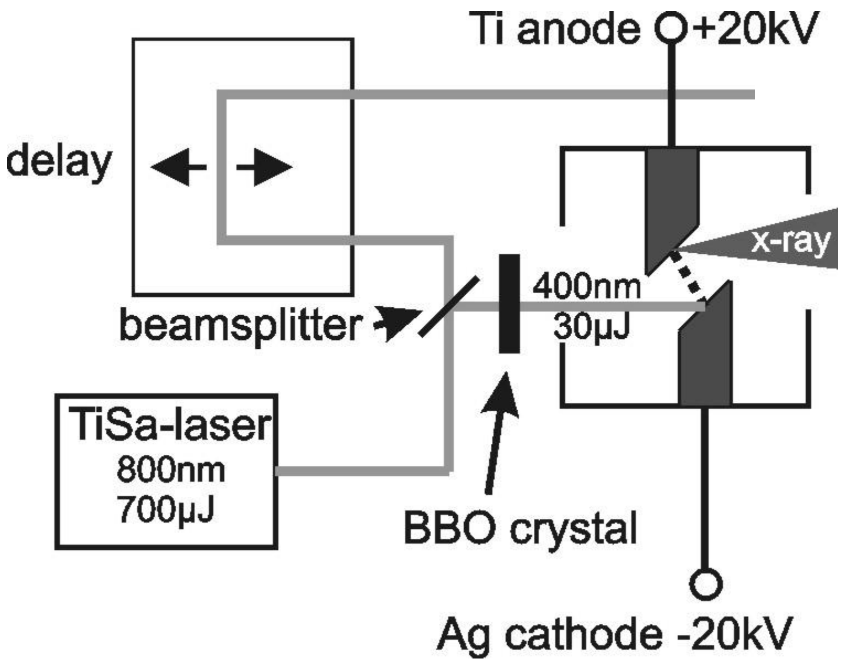
Setup for Time-resolved X-ray Diffraction

Characterization of laser-excited acoustical phonons
in germanium (Ge)



K.S. Schulze, et al. Appl. Phys. Lett. **98**, 141109 (2011)

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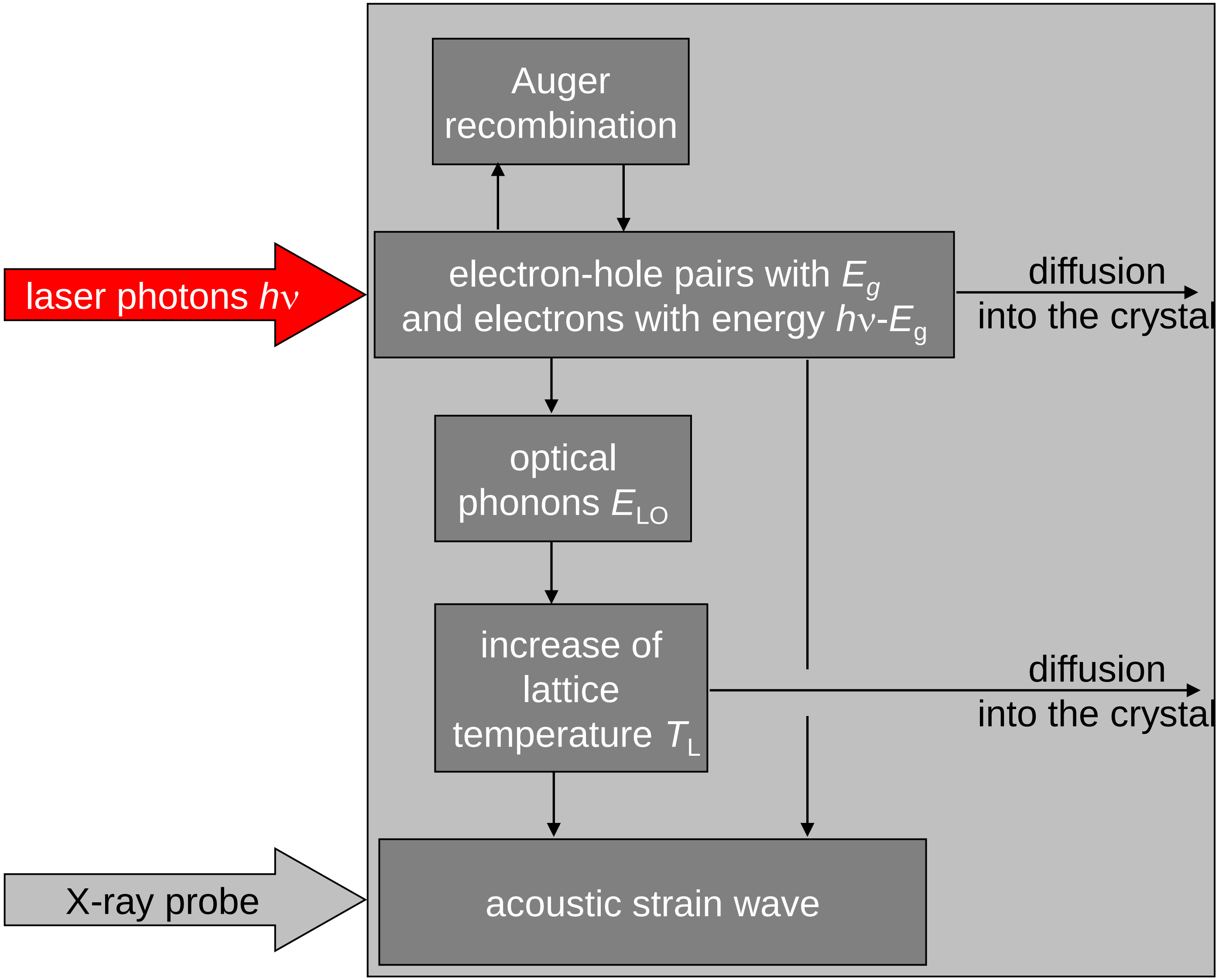
Energy Flow in a Semiconductor Sample after Laser Excitation



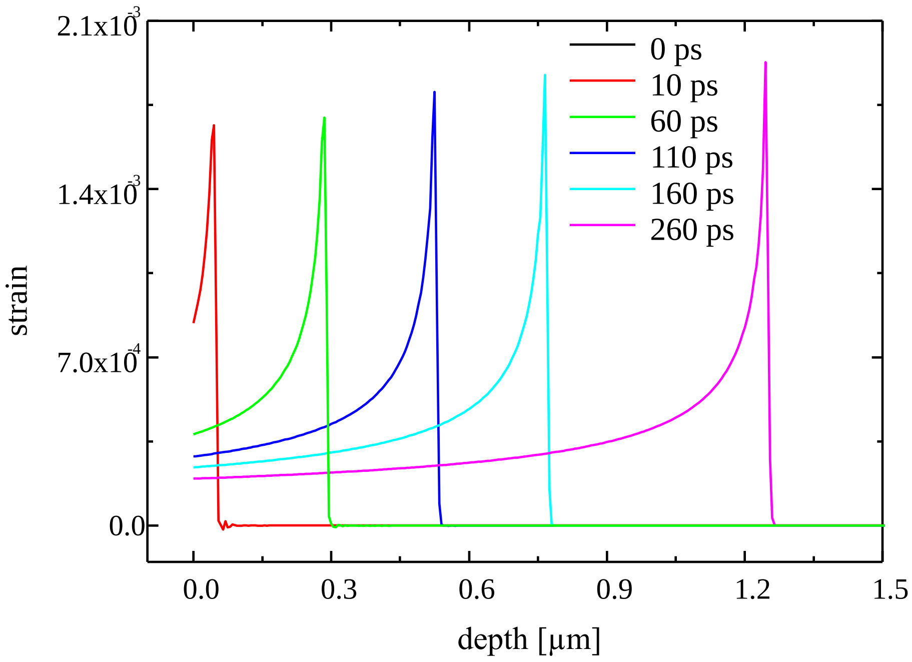
A. Morak, et al., Phys. Stat. Sol. B, 243, 2728 (2006).

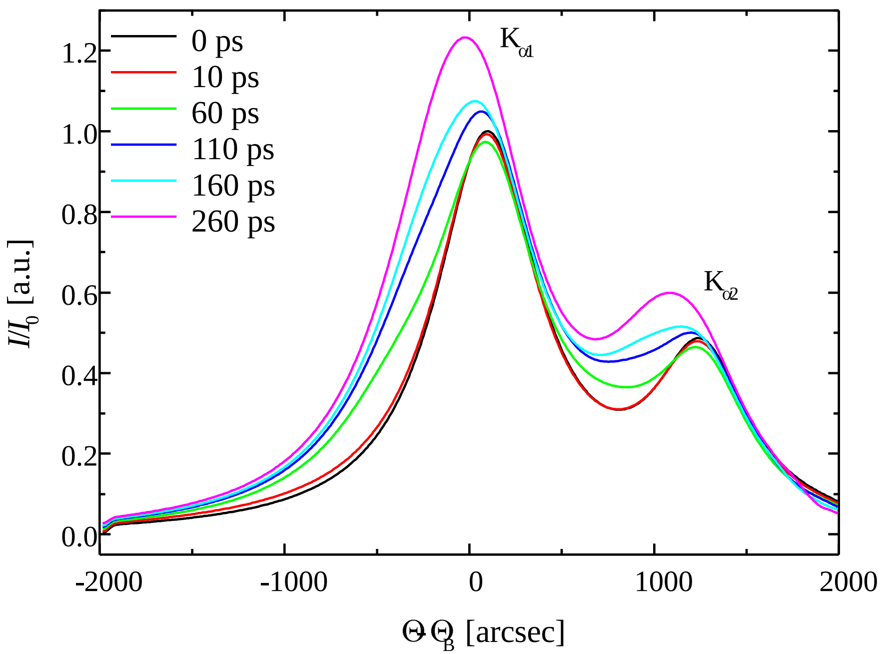
A. Lietoila and J. Gibbons, J. App. Phys., 53, 3207 (1982).

Simulation of Strain and Reflection Curve

laser excitation with 10mJ/cm^2

X-ray probe with Ti K_{α}, germanium (400) reflection





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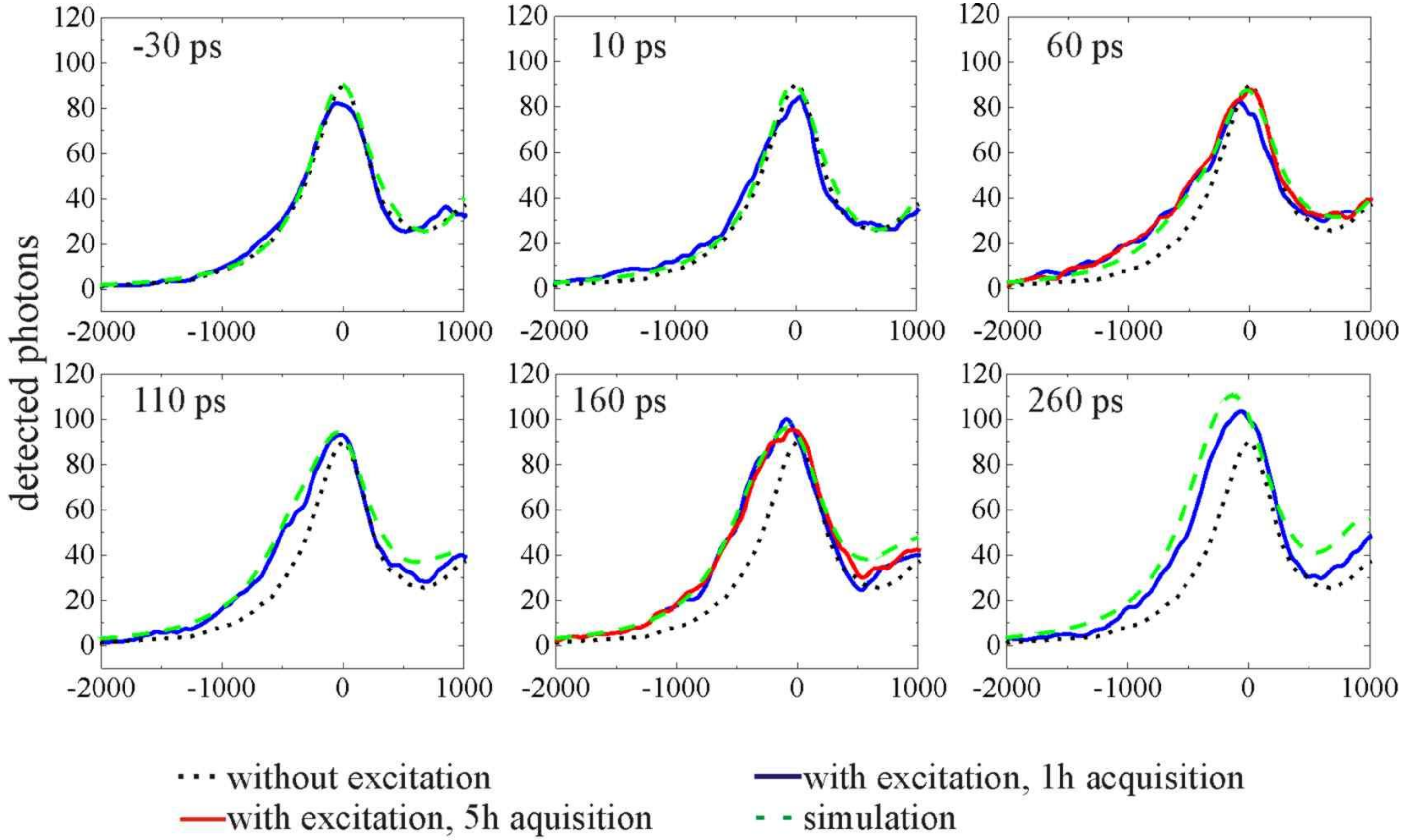
Change of the Reflection Curve after Laser Excitation

Ge-(400) reflection after excitation with 10mJ/cm^2, only Ti-K$_{\alpha 1}$ is displayed



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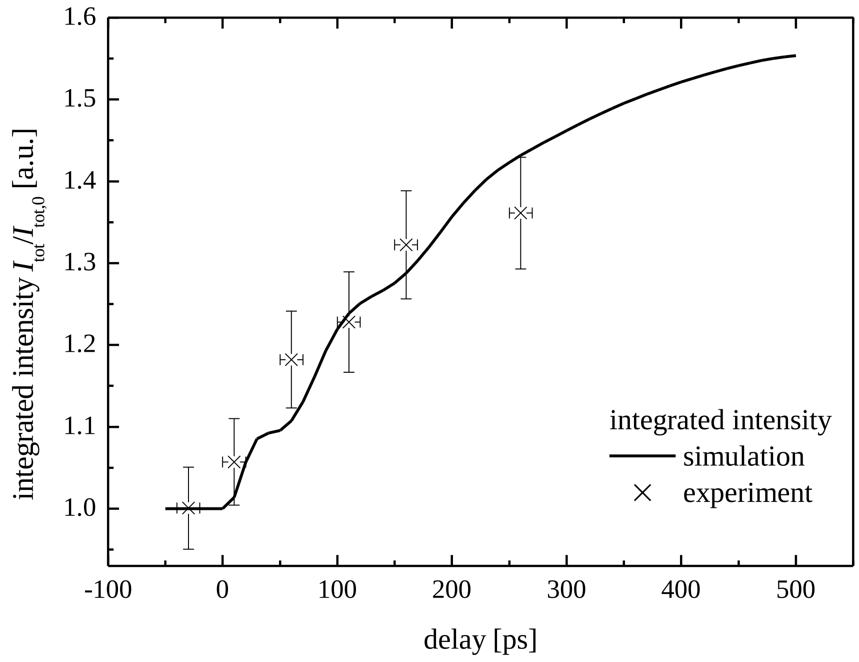
Integrated Reflectivity

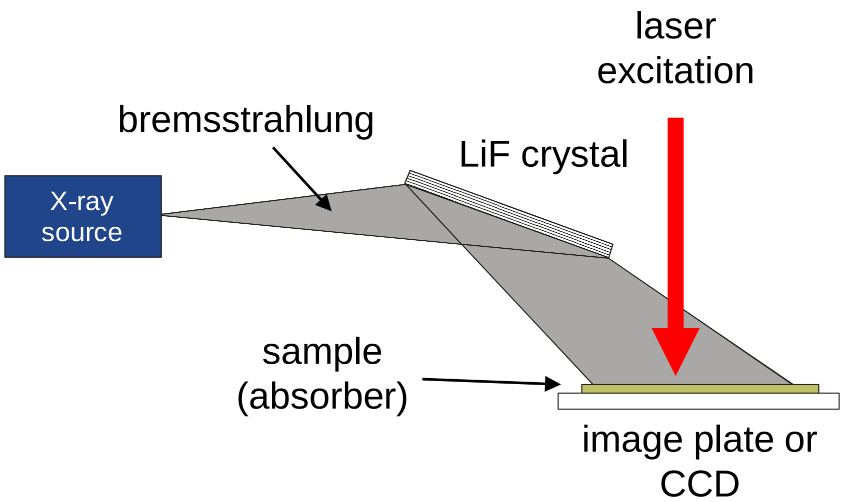
could be measured, due to the stable x-ray intensity

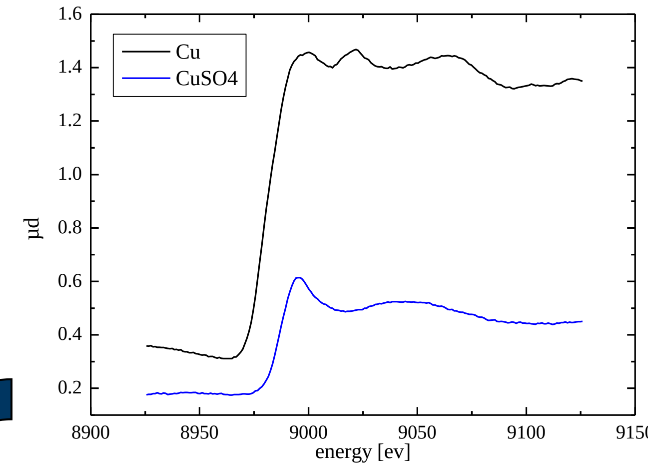


X-ray Absorption Spectroscopy with an X-ray tube

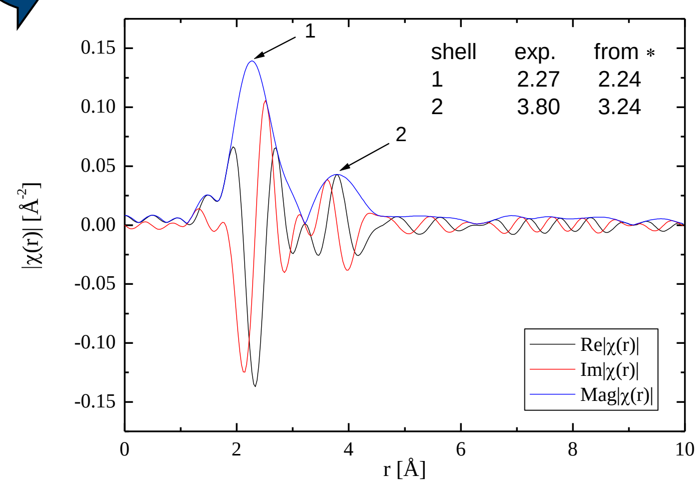
Beer Lambert law:

$$I = I_0 \, e^{-\mu d}$$





EXAFS measurement at a conventional x-ray tube (W-anode)



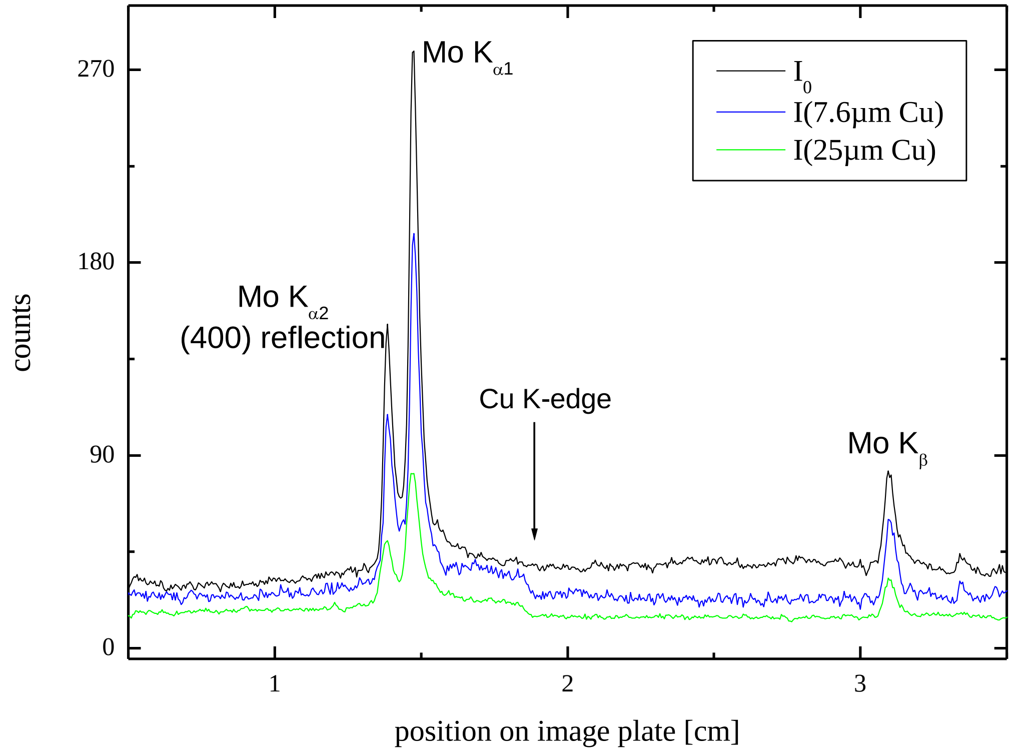
calc. distance to scattering shells

G. Bötcher, Diploma thesis, FSU Jena, 2011

∗ G. Martens et. al., Phys. Rev. B, Vol 17., No. 4, pp. 1481-1488 (1978)

Copper Absorption Edge

measured with the laser driven x-ray diode and Mo-anode, LiF (200)-reflection



acquisition time: 16h 38min

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Summary

- Laser-driven x-ray diode is a stable picosecond x-ray source
- Delivers up to 10^9 Kα-photons per sec.
- It enables laser pump/X-ray probe experiments
  (e.g. detection of strain waves in Ge)

Outlook:

- Improvement of the number of photons with another laser
- Realization of new pump/probe experiments (e.g. time-resolved EXAFS)

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