Time Resolved X-ray Diffraction

Application Note

Introduction

In the last years a new method has been developed to study the time evolution of atomic and molecular structure on the time scale of 100 femtosecond ($1 fs = 10^{-15} s$) which is the typical time scale for atomic vibration. This method will give new insights of the temporal evolution of physical, chemical as well as biological processes on the atomic scale. New developments such as new x-ray sources, femtosecond lasers, and x-ray optics were essential for this study. But without new detector development in the keV-photon range such experiments are not possible. A combination of a toroidally bent crystal optics with a CCD camera can provide the simultaneous measurement of transient crystal diffraction curves (ref. 1).

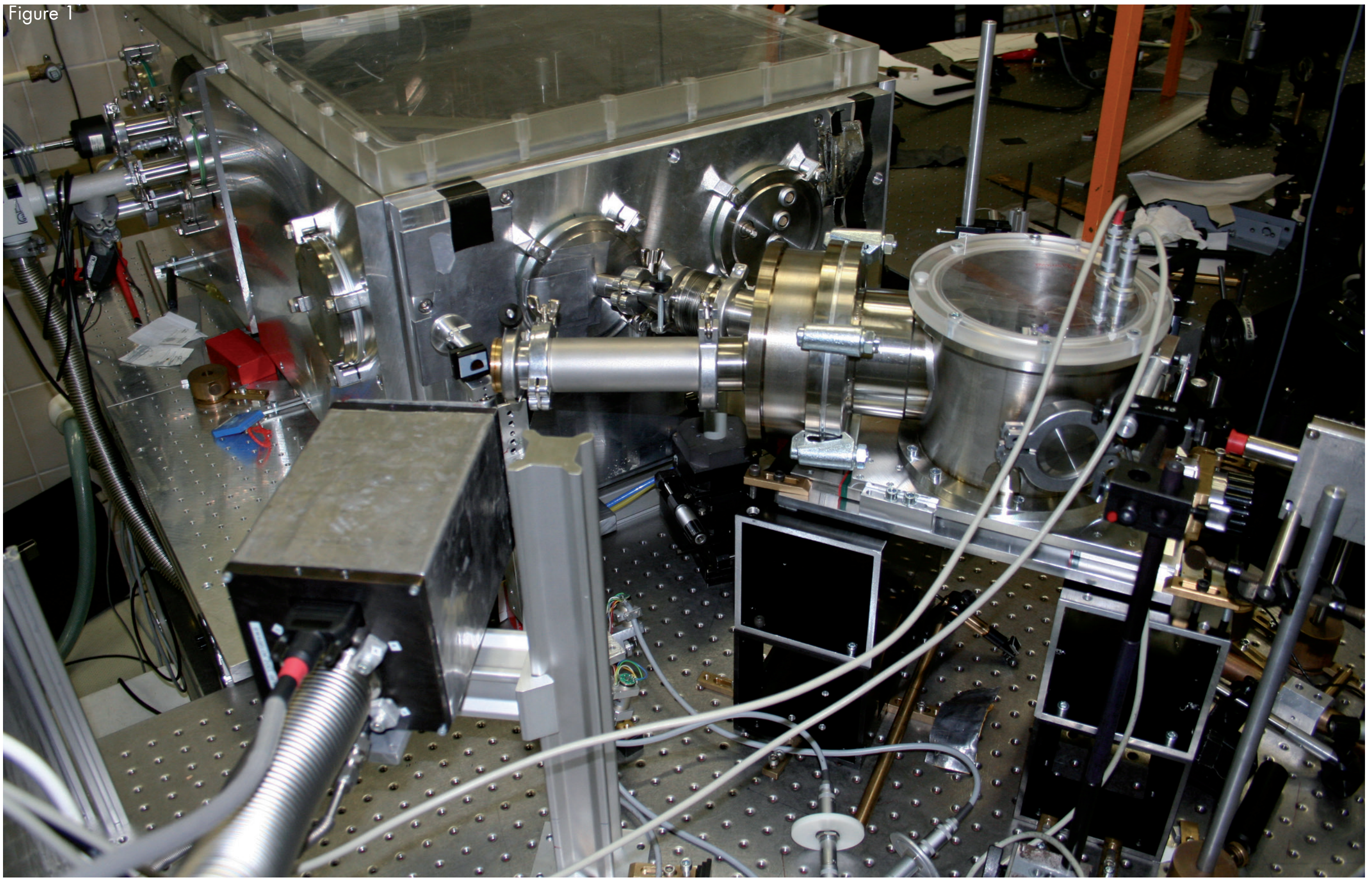
Time resolved x-ray diffraction by using a pulsed femtosecond x-ray source at Institut für Optik und Quantenelektronik Jena

A typically set up for time resolved diffraction is shown in Figure 1. The interaction of short intense laser pulses ($t = 100$ fs, $I > 10^{15}$ W/ cm^2) with solid matter create a thin dense plasma layer where electrons can be efficient accelerated to keV or MeV energies. Such electrons can produce short x-ray pulses when interacting with a solid. The x-ray source is slightly larger then the laser focus, typically some tens of micrometer. Intense line radiation from the laser based x-ray source like Kα lines are focussed with toroidally bent crystals onto the samples which are investigated. Then a spherical monochromatic wave is falling on the sample. The diffracted x-ray signal from the sample (Figure 2a, page 2) is recorded by an Andor back-illuminated deep depletion X-ray CCD camera DX420-BR-DD with 1024 x 255 pixels providing i.e. the rocking curve in case of a single crystal sample (Figure 2b, page 2). Excitation of the sample by a second laser pulse with a certain delay before the x-ray probe pulse allows to follow the temporal response of the diffraction signal by varying the delay of both pulses (ref. 2).

Properties of X-ray CCD cameras

Important properties of back-illuminated deep depletion CCDs have following advantages compared to other x-ray detectors (ref. 3):

Figure 1



- They can accumulate photons over a various time (typically 1 s... 1000 s) by using a chip temperature of –70°C.
- They can detect single photon events in the keV-photon-energy range. More then 250,000 single solid state detectors, each pixel, record simultaneously the signal.
- Such CCDs have a high detection efficiency, more than 90% for 4.5 keV photons.
- There exists an excellent linearity between photon energy and detected charge.
- The photon energy can be reconstructed even the charge of one photon is split to four pixels.
- The CCD cameras can be used in a vacuum experiment as well as in a small flexible vacuum housings (see Figure 1) by using a pressure of 10-5 mbar.
- They have relatively low mass, and can be easy translated and rotated.

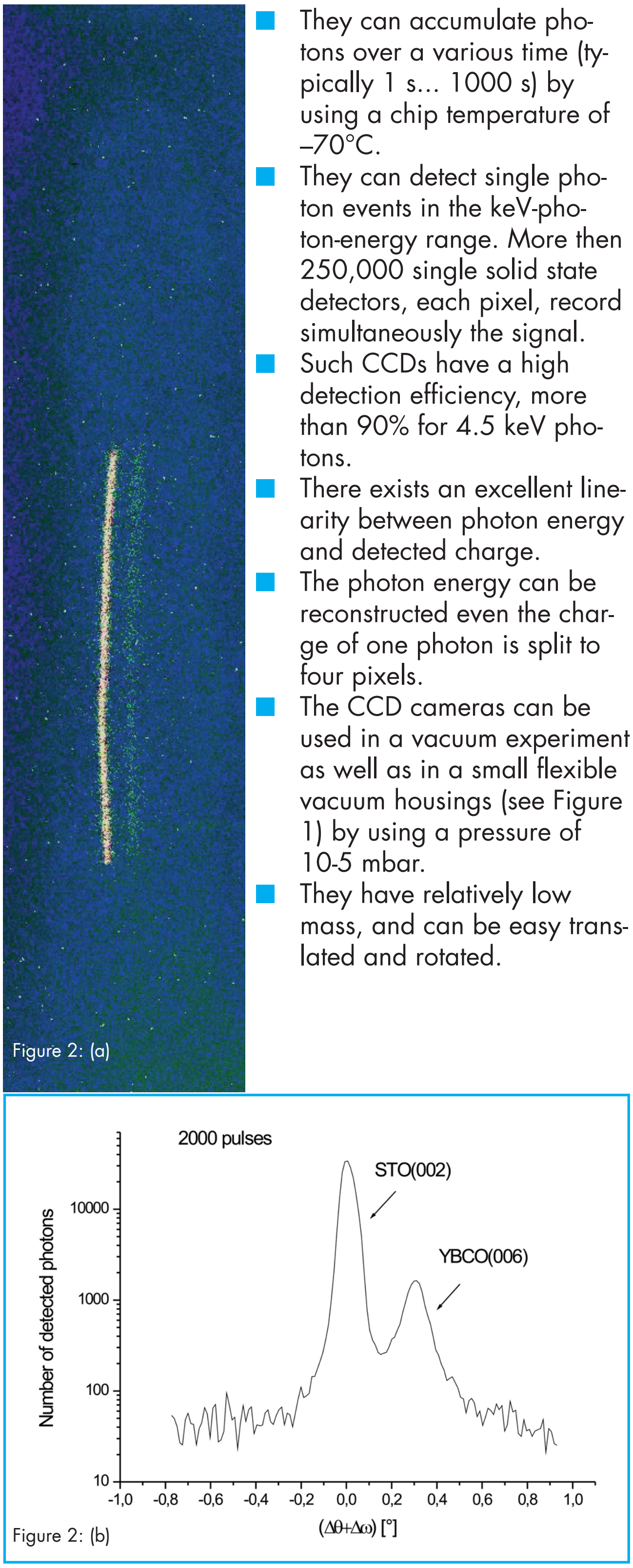


Figure 2: (a) X-ray image recording the transient rocking curve of a YBCO superconducting layer on a strontiumtitanate crystal, (b) Rocking curve reconstructed from the x-ray image shown in Figure 2a.

Application for time resolved experiments

Such kind of experiment require significant properties of the detectors to record successfully reasonable data. One of the most important parameter for these experiments is the time average x-ray photon flux. But especially a high detection efficiency reduces the extreme high cost for a high average power of the femtosecond laser driving the x-ray source.

X-ray CCDs are applied in various steps of these experiments:

- They are used as a recording x-ray spectrometer in the single photon counting mode (line spectra and Bremsstrahlung), for laser based X-ray source optimization,
- With those detectors online alignment of the x-ray optics (i.e. toroidally bent crystals) are done, i.e. like Bragg angle rotation, crystal azimuth rotation and focus alignment.
- Finally the crystal rocking curves, transient or static, are recorded from crystal samples.

Advantages for data analysis by using back-illuminated deep depletion X-ray CCD are:

- Diffracted single photons can be located with a precision of one pixel. This corresponds to an angular resolution of typical 0.5 arcminute in diffraction experiments.
- The background level given by the CCD temperature can be subtracted relatively easy.
- Scattered hard photons not contributing to the diffracted signal, but disturbing the measurement can be easily removed if single photon counting mode is used.
- The reconstruction of the rocking curve from the two dimensional CCD image (Kossel cone in Figure 2a).
- One can record large solid angles diffracted by the samples due the large detector area.

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References:

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