ESRF

Experiment title:

Time resolved diffraction near the X-ray acoustic resonance

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Report:

The diffraction properties of an ideal crystal are well described within the theory of dynamical diffraction. It predicts a narrow line width and weak intensity for the Bragg peak even in case of thick crystals, Any internal strain will increase the diffracted intensity and widen the rocking curve of the Bragg peak, where the shape of the rocking curve becomes a very sensitive probe for the strains present.

A crystal excited by longitudinal ultrasonic waves has strain which varies rapidly in space and time. Depending on the local strain from the sound wave, the diffraction behavior of part of the crystal changes from a dynamical scatterer with low intensity towards the diffraction behavior of a kinematical scatterer with largely increased intensity, The details of the internal stresses are thus revealed by diffraction in a very direct and sensitive way. In particular, a true standing wave creates well defined locii of zero strain, and in between them develop regions where the strain varies with the sound frequency. Note that the entire crystal is strain free twice during one vibration period. For a non-stationary sound excitation each part of the crystal will become strained during a vibration period.

We intended to determine the momentary stress in an ideal Si single crystal excited by ultrasound waves in the MHz range via a measurement of its time-resolved diffraction profile with a time resolution of about 1/10 of the vibration period.

High energy X-ray diffraction of some 100 keV is perfectly suited to access the internal strain in a massive Si crystal because the absorption length is some *20* mm. We also note that at the same time the extinction length of the -351 reflection used is about *0.44* mm. We fixed a longitudinal $LiNbO_3$ transducer with a base frequency of *2.5* MHz on a Si 111 crystal of 10 mm thickness. Because one vibration period corresponds to *400* ns, we aimed for a time resolution better than *40* ns. We used a standard 3 cm thick Ge detector for high efficiency, but fast electronic triggering and signal processing to achieve a final time resolution of some *20* ns. As an demonstration of a time resolution we show in fig. 1 the current in the ring measured via the time resolved Bragg intensity from our crystal. The fig. shows that the synchrotrons was running in the hybrid mode. Note that the single bunch is perfectly suited for a calibration of our time resolution and that the observed intensity modulation of the grouped bunches is real.

For the measurements we first recorded rocking scans to determine resonance conditions of the sound excitation via the broadening and the intensity gains of the Bragg peaks. Examples are shown in fig 2. Without sound excitation we observe a rocking curve with a full width at half maximum of 0.2", which agrees with the theoretical width. With increasing excitation the peak intensity first doubles, and then the rocking width increases. At still higher excitation levels the width continues to increase while the peak intensity becomes reduced. The peak shapes can be explained quantitatively by invoking the strain distribution by the sound wave in the crystals and invoking primary extinction. It should be noted that the width of the rocking curve represents directly the strain and the atomic displacements in the crystal. For the main part of the experiment we triggered the counting electronics by the ultrasonic wave and the Bragg diffracted intensity was recorded for various conditions of sound excitation in a two dimensional field of rocking angle and time. Fig. 3 gives two examples . Fig. 3a shows an excitation with a purely standing wave in the Si crystal, whereas fig. 3b corresponds to an excitation with a standing wave in the transducer. Note, that this condition produces an excitation in Si which has a traveling wave contribution in the Si crystal.

The present data provide a unique access to visualize the dynamics of strain in a crystal, and under what conditions pure stationary excitations with well defined resonance conditions develop, Actually, we have made a movie that shows the heart beat of a crystal. At a given moment of time when the atomic amplitudes are zero it behaves as a dynamically scattering crystal, and 100 ns later when the atomic displacements are at their maximum this crystal scatters kinematically.

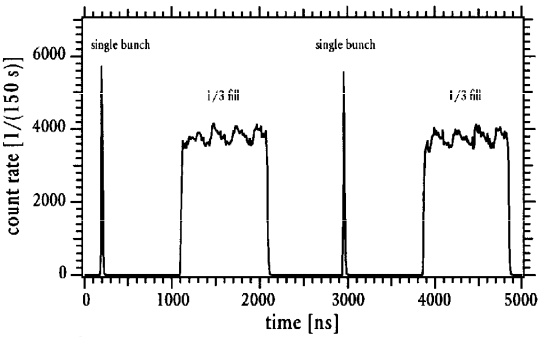

Fig. 1: Current in the synchrotron ring monitored by the time-resolved Bragg intensity from our crystal. This setup was used for the time calibration.

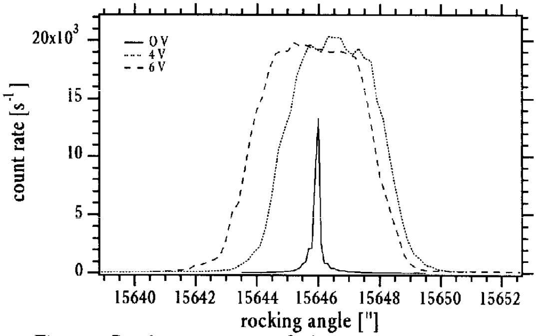

Fig. 2: Rocking curves of the -351 Bragg peak for various levels of ultrasonic excitation

Fig. 3: Contour maps of the Bragg intensities in rocking angle-time planes. The upper graph shows a pure standing wave whereas a propagating wave component is superimposed to the lower plot. The time scale corresponds to 3 and 2 vibration periods in a) and b), respectively.