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Report:

The combination of the laser pumping techniques with X-ray probe methods opens an enormous field of investigation for the study of time resolved processes. In particular acoustic shock waves are relatively easy to obtain by intense laser pulses while high resolution X-ray diffraction together with the elevated photon energies and intensities at ESRF is a unique probe for the atomic arrangements during the wave propagation. The far aim is to observe the mechanics of a phase transition during the pressure increase at the front of a shock wave.

Here we have studied the acoustic response to laser impacted perfect silicon analyzed by time resolved high energy X-ray diffraction on the triple axes diffractometer at ID15A. A commercial, Q-switched Nd-YAG laser (Quantel Big Sky Laser) with a wavelength of λ_o = 10640 Å and an energy of 50 mJ within a shot of 7 ns, 25 Hz repetition rate was used to shock the silicon crystal. The sample as shown in figure (1) is made from a perfect silicon crystal. Its geometry is rotational symmetric along the [111] axis and consists of a 5 mm thick plate of 30 mm diameter with a long, cylindrical rod of either 3 mm or 10 mm sticking out on one side. It was glued at the edge of the plate to the sample holder. The focused laser beam impacts the sample centrosymmetric either on the plate or on the face of the rod.

We used the Si 333 reflection with a scattering vector parallel to the sample axis. It matches ideally to the Si 511 reflection of the monochromator which allows to work in the non-dispersive diffractometer mode and to get rid of most harmonics. Photon energies were at 113 keV or 170 keV which results in relatively small diffraction angles and thus with a beam size of typically 0.1 x 0.1 mm^2 allows for good spatial resolution along the sample axis. Time resolution is obtained by the synchronization of photon events to the bunch clock in 16-bunch mode and compared to the external trigger signal of the laser Q-switch. Data were acquired stroboscopically [2].

Typical time patterns slightly off the center of the reflection curve are given in figure (2) top and bottom for impact on the plate or on the rod face, respectively. Although they look qualitatively different they both start with a sharp raising edge, the shock front, and they have a superimposed ringing with 300 ns periodicity. The impact of the plate side results in a rapid and a delayed pulse of phonons which we attribute to a bunch of compression and surface coupled waves, respectively. The arrival time as a function of the position in the crystal is compiled in figure (3) and the sound speeds of 10066 m/s and 3390 m/s correspond well to the expected values.

The laser impact creates both longitudinal shock waves into the volume and surface waves traveling perpendicular to the former. The volume waves travel with a sharp shock front directly to the rod while the surface waves are not only slower but have to travel around the plate. Since the geometry is rotational symmetric, all surface waves are in phase when arriving and traveling along the rod and results in periodic growing or shrinking of the cylinder section. This, however, describes a standing longitudinal wave perpendicular to the cylinder axis. The cylinder thickness together with the longitudinal sound speed gives the observed ringing time of 300 ns = 3 mm / 10 km/s. When impacted on the rod edge there is no time delay between the surface and the volume waves and the ringing occures immediately and much stronger.

At present state, the data are not fully analyzed. In particular we are interested to evaluate the shock front, its raising time and an estimation for its amplitude. The experiment is made with so far highest resolution in reciprocal space and high energy X-rays suitable to probe the volume of thick and heavy samples. For its realization the beamline was equipped with the appropriate safety system holding for any laser experiment and the path towards physically more interesting samples where one approaches a structural phase transition is prepared.

Acknowledgments

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References

[1] QUANTEL, 17 avenue de l'Atlantique - BP 23 - 91941 Les Ulis cedex, France, http://www.quantel.fr/

[2] K.-D. Liss, A. Magerl, R. Hock, B. Waibel, A. Remhof, *"The investigation of ultrasonic fields by time resolved X-ray diffraction"* Proceedings of SPIE, (1998). **3451**: p. 117-127.

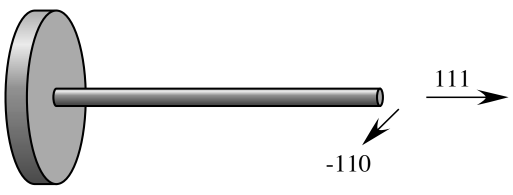

Figure (1): Sample Geomtry. The laser light hits the sample axially either on the left side with the plate or on the right on the rod.

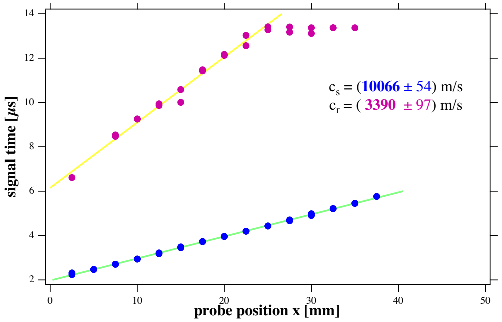

Figure (3): Propagation of the fast volume shock wave and the surface acoustic waves. After the surface waves reach the back tip of the rod they scatter and the wave packet spreads leading to the kink in the graph.

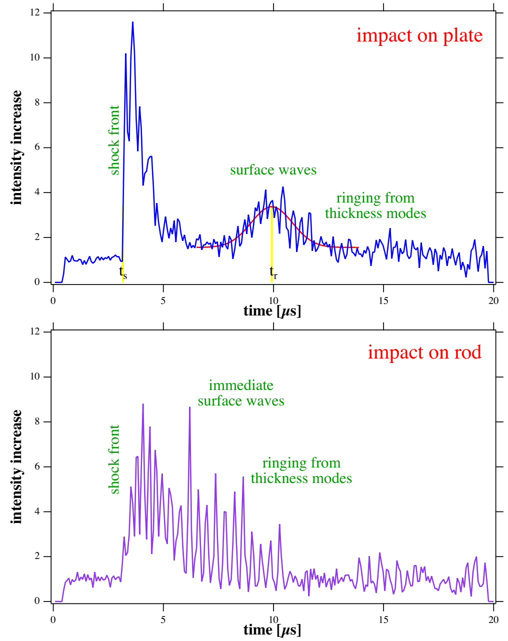

Figure (2): Time patterns of the intensity increase off the center of a rocking curve with impact to the left (top) and right side of the sketch figure (1) (bottom). The plate delays the surface acoustic waves with respect to the volume waves.

http://www.esrf.fr/exp_facilities/id15a/science/science.html