X-ray Diffractometry with Synchrotron Radiation for Exploration of Fast Processes in Solids with Nanosecond Time Resolution

B.P.Tolochko, O.V.Evdokov

Institute of Solid State Chemistry and Mechanochemistry Siberian Branch of Russian Academy of Sciences, 630128 Novosibirsk, 18 Kutateladze str.

e-mail address: B.P.Tolochko@inp.nsk.su

K.A.Ten, I.A.Rubtsov, E.R.Pruuel, A.O.Kashkarov

Lavrentiev Institute for Hydrodynamics Siberian Branch of Russian Academy of Sciences, 630090 Novosibirsk, 5 Lavrantev str.

A.S.Arakcheev, V.M.Aulchenko , A.V. Burdakov, A.D. Chernyakin, G.N.Kulipanov, A.A.Kasatov , A.V. Kosov , P.A. Piminov, S.V. Polosatkin, V.A. Popov, L.I. Shekhtman , A.A. Shoshin, D.I.Skovorodin, A.A. Vasilyev , L.N. Vyacheslavov, V.V. Zhulanov, K.V.Zolotarev

Budker Institute of nuclear Physics Siberian Branch of Russian Academy of Sciences, 630090 Novosibirsk, 11 Lavrantev str.

Abstract: The report is reviews the principles of nanosecond X-ray diffractometry with using synchrotron radiation and requirements to object, equipment and detectors. Investigation of pulsed laser radiation and shock waves impact on the substance was made.

The technique of X-ray diffraction with time resolution has shown tremendous progress recent years. This is due to the development of the accelerator technology, methods of generation of synchrotron radiation (SR), and fast X-ray detectors. The report reviews the main principles of time-resolved X-ray diffractometry and requirements to the object, equipment and detectors. Considered are the basic parameters of the diffraction installations at BINP, SLAC, and EuXFEL.

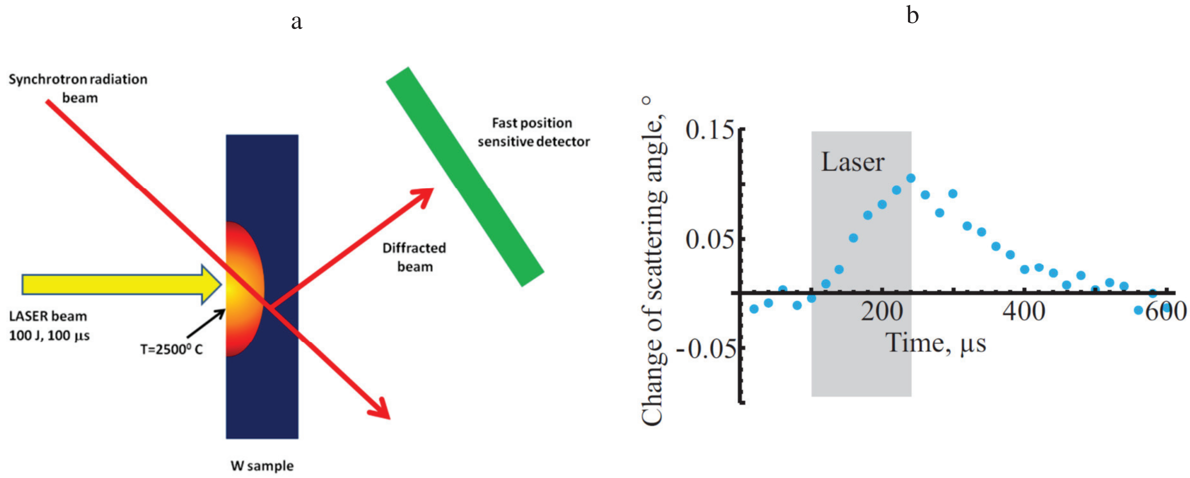

Fig. 1. a) Scheme of fast 100 J laser heating experiment. The laser beam heats the surface of the sample up to 2500 C, which gives rise stresses around the heating zone. Synchrotron radiation allows to measure the dynamics of the stress developing and the dynamics of their relaxation.
b) The time dependencies of the change of the X-ray diffraction angle during 1 J laser heating caused by stress. The grey background marks the time interval of the laser heating.

To obtain the best experimental parameters it is necessary to minimize the duration of the SR flash and the divergence of the primary beam, as well as increasing its intensity and monochromaticity. Unfortunately, currently it is impossible to improve all the parameters simultaneously, so the experimenters have to compromise. For example, they increase the flux of photons at the expense of deterioration of the monochromaticity (BINP and APS/ANL) and carry out experiments in the "pink" spectrum. Or they increase the exposure time at the expense of summation of photons from a few bunches. This mode was applied to investigation into the dynamics of nucleation and growth of nanodiamonds in a shock-wave impact on hydrocarbons. Possible options of development of time-resolved X-ray diffractometry installations at BINP are considered.

Now we are preparing an experiment to study the behavior of the crystal lattice of the material of the fusion reactor first wall during a plasma discharge on the diverter. A fast one-coordinate X-ray detector was developed for this experiment. The detector enables fast recording of 100 diffraction frames with an exposure time of 73 ps and a periodicity of 100 ns. Thus, we can record X-ray "movies" with high time resolution, which store information about the dynamics of plasma interaction with the structure of the crystal surface in a plasma discharge (100 μs in the ITER).

To solve this problem we are developing an installation to work on beams of synchrotron radiation of VEPP-4 (BINP SB RAS). The installation will enable obtaining information about what is happening to the crystal lattice when the plasma of the ITER reactor interacts with the wall for a short period of time. The plasma discharge parameters in the ITER are as follows: an energy of 100 J for 100 μs on an area of 1 mm2. We conducted first successful test experiments, having recorded changes in the crystal lattice of W, using a laser with a power of 1 J and a pulse width of 100 μs. Now diffraction patterns with a time resolution of 73 ps can be recorded.

Installation scheme is shown in Figure 1-a. Specificity of the experiment is that 100 J laser heats a very thin surface layer, and as result at the heat front the internal stresses appears. As heat front move into the sample and the stress distribution in the sample is changing. A narrow beam of synchrotron radiation with an energy of 80 keV allows to probe the region of interest of the sample and obtain information about the distribution of stresses during laser heating of the sample. Experimental results are presented in Figure 1-b

The same method will be used for investigation the behavior of the crystal lattice of space materials under the impact of shock waves and meteorites, flying with speeds of up to 11 km/sec. For this experiment, a gun launching small pellets with such speeds has been designed.

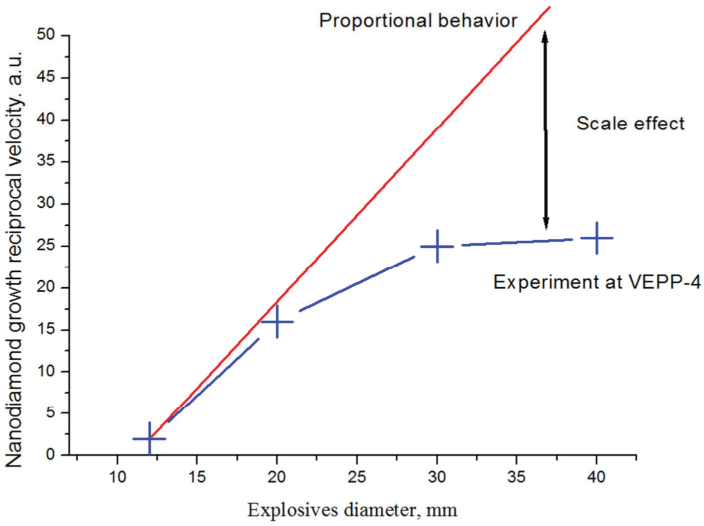

Fig. 2. The dynamics (velocity) of nanodiamonds mass during detonation (+). The curve is a non-trivial, non-linear dependence versus the mass of explosives (explosive diameter).

Our group has more than 15 years investigate the dynamics of nanodiamonds formation during detonation and shock wave effects. In recent experiments obtained reliable experimental data showing the growth dynamics of nanodiamonds during detonation of TNT. This is a unique result, since similar experiments conducted in Advance Photon Source (US, Argonne National Laboratory) have not detected an increase the size of the diamond. The data obtained allow to plan experiments in which the authors hope to grow diamond with micron sizes.

In the study of the dynamics of formation of nanodiamonds during detonation was received scale effect - a non-trivial, non-linear dependence of the all diamond mass in the reaction zone versus the mass of explosives (explosive diameter, Fig.2.).