Current status of the studies of X-ray diffraction on tungsten during pulsed heat loads at the scattering station «Plasma» at the VEPP-4 source of synchrotron radiation

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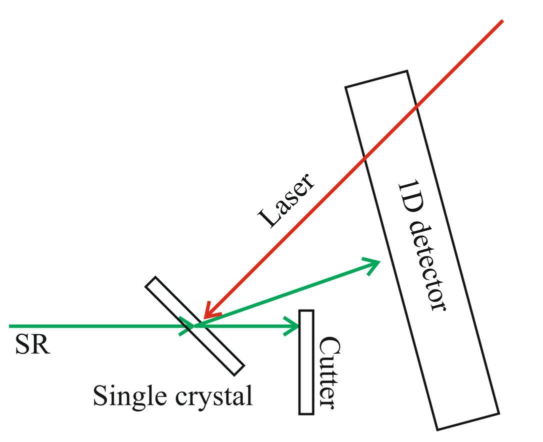
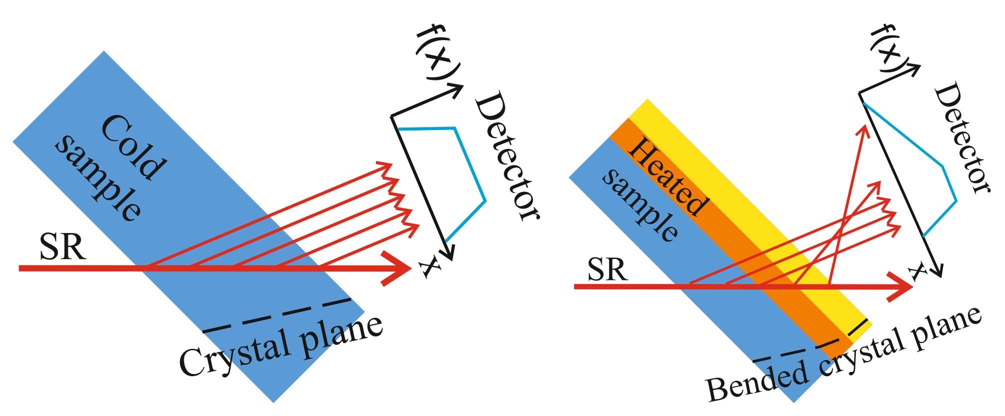
Motivation

Fusion plasma confinement at facilities based on a tokamak geometry of the magnetic field includes periodical transient heat loads to divertor plates. The divertor plates of ITER are seem to be covered by tungsten. The tungsten tends to crack in case of the pulsed heating. The reasons of the crack formation are deformations and mechanical stresses caused by the sharp rise in temperature of thin surface layer. The X-ray scattering station «Plasma» at the beamline 8 at the VEPP-4M source of synchrotron radiation was developed for dynamical measurements of deformations and mechanical stresses in tungsten during pulsed heating simulating by laser radiation.

Dynamical measurements of deformations

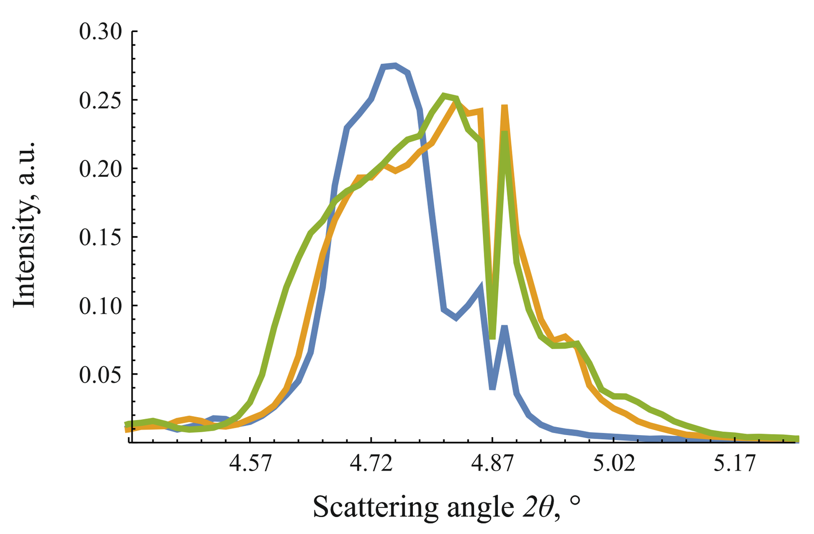


The scheme of the experiment. Polychromatic SR was used. In the first experiments single crystal tungsten was used as the sample.

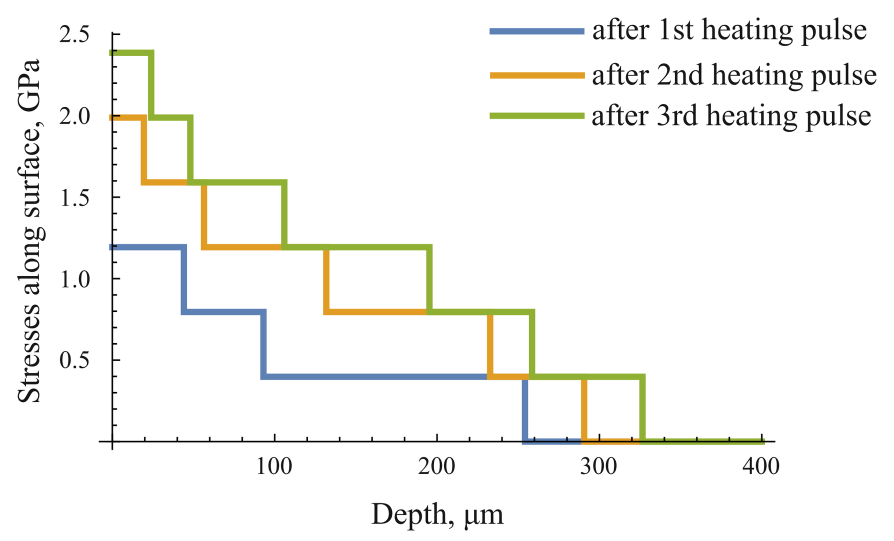


The scheme of the relation between the deformation distribution and the shape of the diffraction peak.

Pulsed heat load leads to compression and stretching of surface that as a result is expressed in rotation of the "reflecting" atomic lattice plane, which leads to the changes in the shape of the diffraction peak. After finishing the pulsed heat load, the sample cools and the diffraction peak begin to shift to it's original position. If the diffraction peak change it's shape and position between cooling-heating cycles, it means that residual stresses were occurred.



Static diffraction peaks after consecutive heating pulses.

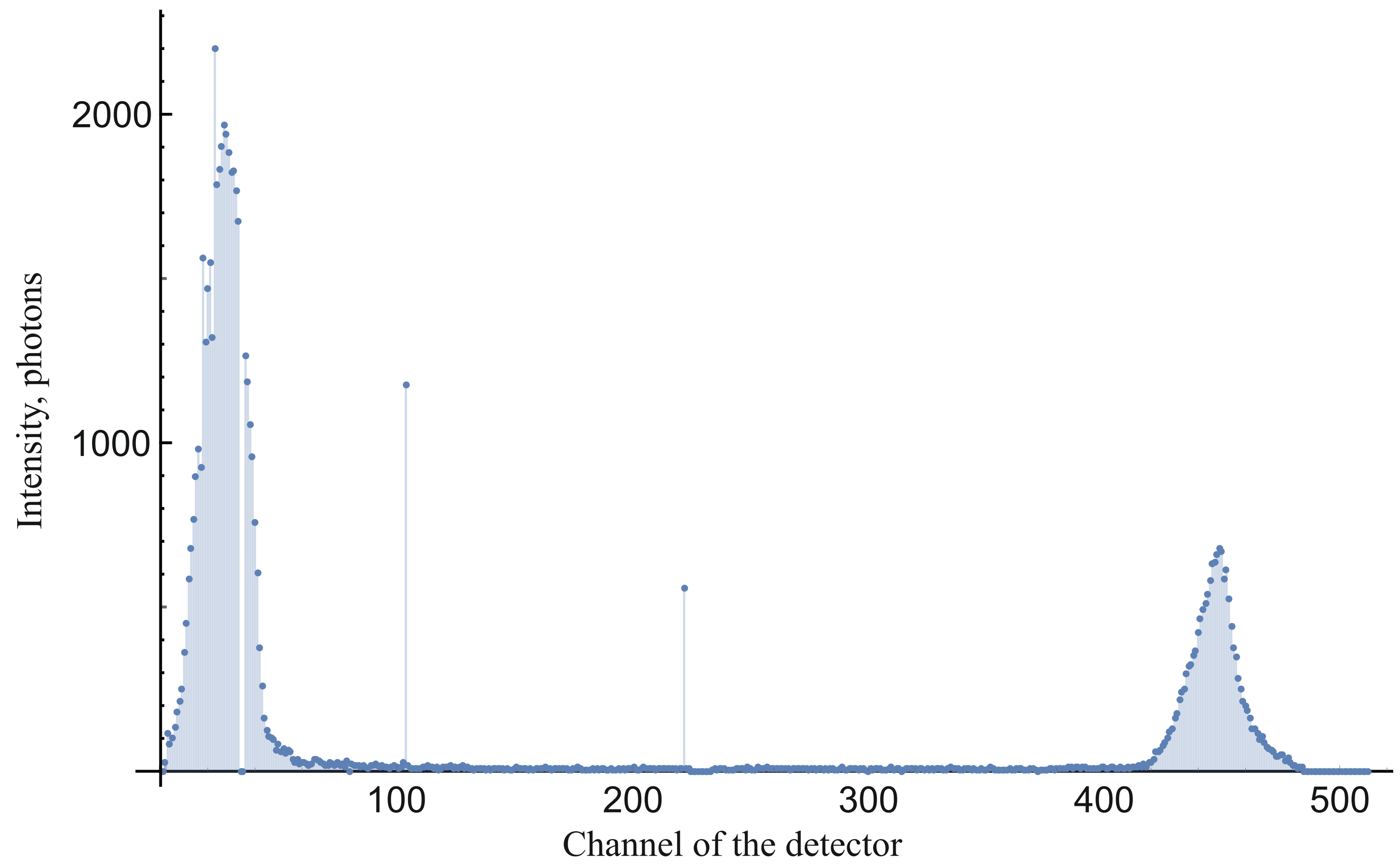


Deconvolution of residual stress distribution in the sample according to measured static diffraction peaks.

Consecutive heating pulses lead to the consistent shift towards larger scattering angles, which means that each pulse leads to an increase in plastic compression along the surface.

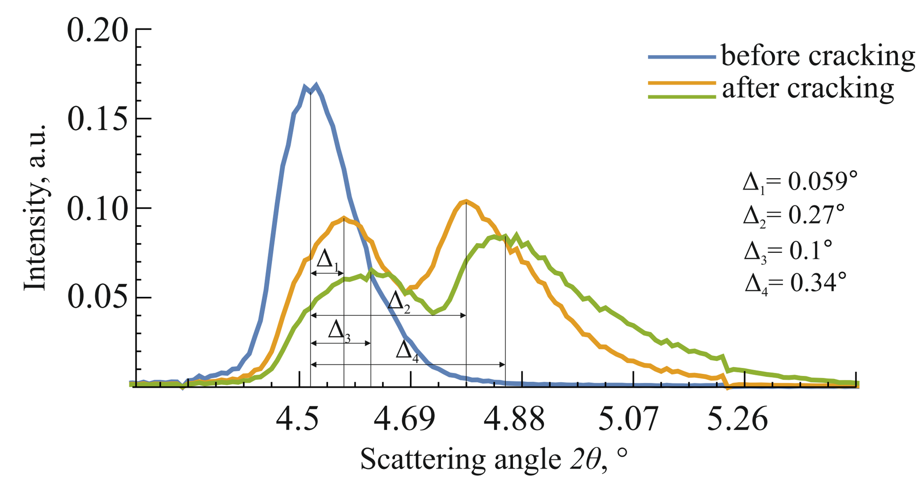
Polycrystalline diffraction

Test experiments were carried out to measure X-ray diffraction on a polycrystalline tungsten. The measurements were carried out on monochromatic radiation with energy about 50 keV. The total measurement time was 150 ms (1000 films of 30 frames with a duration of 50 μs). To obtain the final diffractogram, each frame was processed separately: the presence of a signal significantly exceeding the noise corresponding to the absorption of a photon in this channel of the detector was checked in each channel.

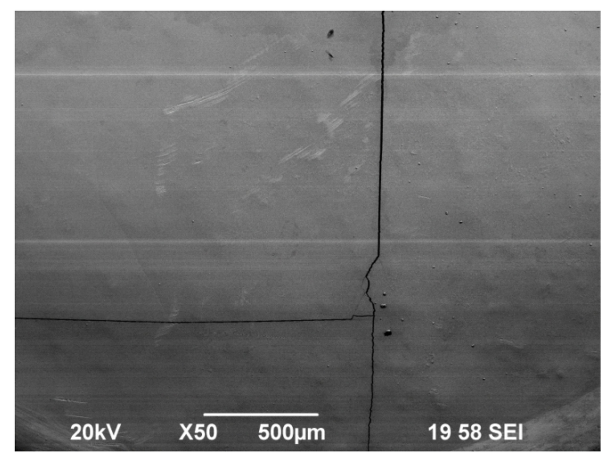


Incident SR beam (the left peak) and diffraction beam 110 (the right peak).

Observation of cracking

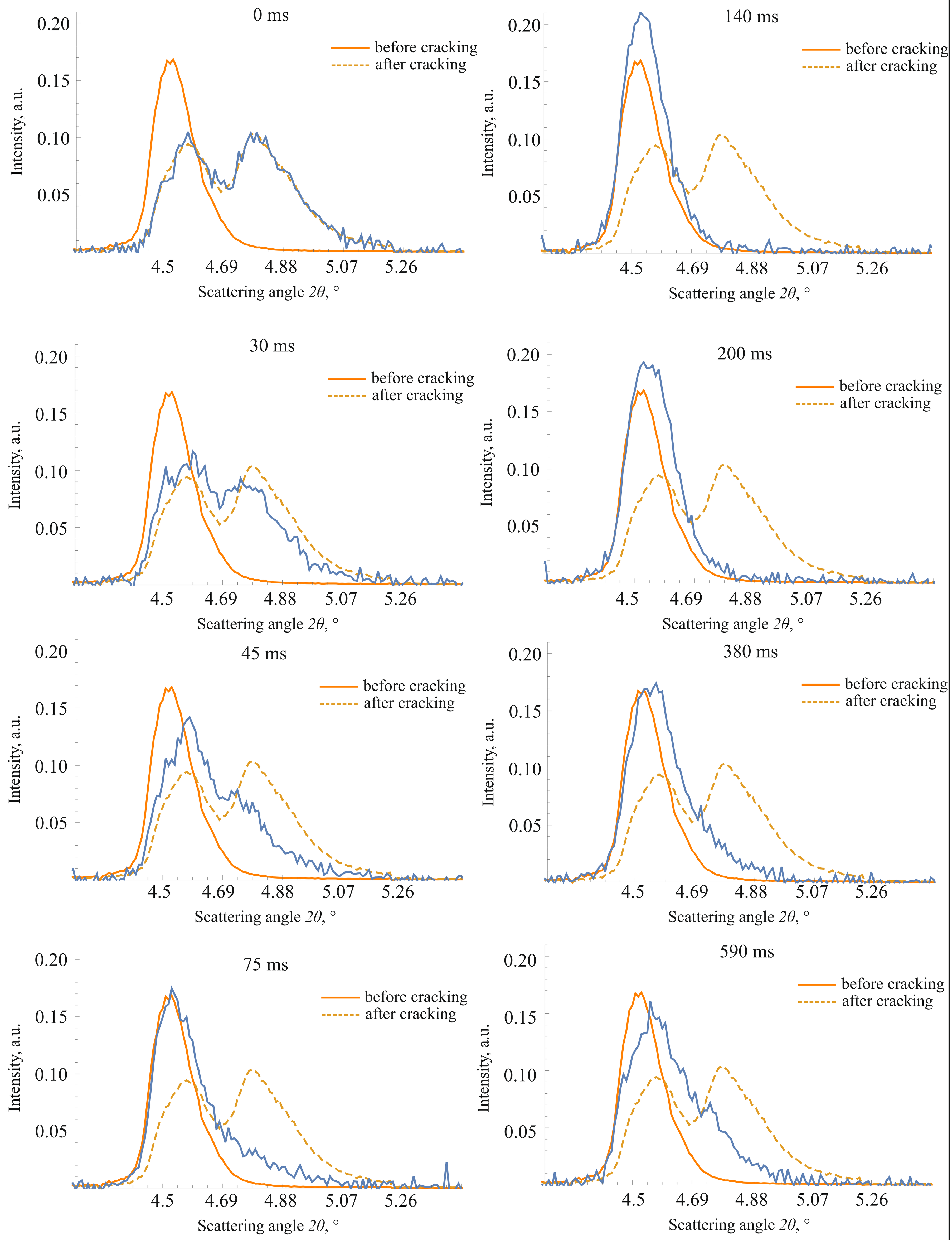


Static diffraction peaks before and after cracking of the sample during consecutive heating pulses.



Cracks on the surface of the sample

Cracking of the sample and bifurcation of the diffraction peak were detected between consecutive heating pulses. Cracking was occurred with a delay after the last heating pulse before cracking.



Dynamics of the diffraction peak during pulsed heating after cracking. Heating pulse duration is 140 ms.

During pulsed heating, the thermal expansion of the sample leads to the convergence of the crack and returning of the diffraction peak to its original position before cracking. After cooling, double diffraction peak appears again.

Conclusion

- First results with polycrystalline sample were found to be satisfactory. The development of a project of an experiment to measure the dynamics of stresses on the surface of polycrystalline tungsten during pulsed heating has begun.
- Theoretical discussion of the behavior of dynamics of diffraction peak from the cracked sample has begun.