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Phase transitions in solids under irradiations with x-ray free electrons lasers – characteristic time scales

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The presentation is related to the development of presently most sophisticated 4th generation synchrotron radiation sources – the short-wavelength free electron lasers (FELs). With the advent of the XFEL sources, a unique combination of radiation properties created new research possibilities. Radiation intensity produced in FELs, reaching the values of 10^{20} W/cm^2, exceeds by many orders of magnitude intensities available from other monochromatic X-ray sources, thus making it possible to excite a solid material through phase transition points up to, so called, warm dense matter condition. As typical pulse duration, on the order of femtoseconds, is shorter than most of the time constants related to structural transformations and to the energy transfer, it is possible to separate the processes from influence of radiation absorption during the pulse duration. Moreover, the photon energies, larger than value of energy gap in any material makes it possible to avoid nonlinearities in absorption what radically simplifies the modeling of the subsequent physical processes. Thus systematic studies of structural changes in materials, their electronic properties, as well as transition dynamics and energy transfer processes are possible. They can lead to better understanding of the material's properties like radiation hardness and to validation of the existing theoretical models of the energy transport in solids (see Figure 1).

However, properties of the intense FEL beam create, apart from new experimental opportunities, the extreme demands to optical elements applied in the experimental equipment. The radiation load imposed on optical elements served for beam diagnostics, controlling and shaping can lead to their damage. Such materials are of special interest for studies of radiation hardness. It has been shown that optical coatings are destroyed by single FEL pulses if the beam's intensity/fluence exceeds a critical level – single shot damage threshold [1-3]. At such a fluence the temperature of the material reaches phase transition point. Secondly, for a high repetition sources, like in the lithographic applications, the heat load on optics may reach kW level. This leads to the optics heating and its destruction, e.g. due to the enhanced atomic diffusivity in multilayer reflecting coating. Furthermore repeatable irradiations of optics may cause multi shot damage, e.g. related to thermal stresses. Moreover a rapid deposition of EUV pulse energy at the optics surface causes its hydrodynamical deformations what results in wavefront distortions for the proceeding pulses [4].

In my talk dominant processes that lead to the structural and electronic changes of solid materials under irradiations with intense femtosecond pulses of X-ray radiation will be presented. Characteristic time scales of these processes in a relation to the main materials nad radiation paremeters like pulse intensity, photon energy, radiation absorption depth, repetition rate of the source etc. will be discussed.

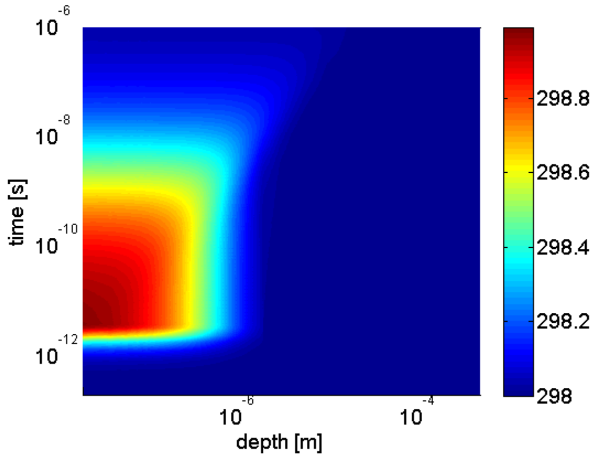

Figure 1. Simulations of the heat diffusion in Si sample irradiated with 1 ps pulse of XUV radiation at normal incidence. Plot shows temperature color-map as a function of depth and time.

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