P-40

Energy transport by hot electrons in c-Si irradiated with 5.5 and 12 keV photons

R. Sobierajski[1], A. Aquila[2], D. Klinger[1], I. Yatsyna[1], T. Burian[3], J. Chalupský[3], P. Dłużewski[1], V. Hájková[3], Y. Inubushi[4], M. Klepka[1], T. Koyama[5], H. Ohashi[4,5], C. Özkan[2], K. Tonoe[5], M. Yabashi[4] and J. Gaudin[2,6]

[1]*Institute of Physics, PAS Al. Lotników 32/46, Warsaw, PL-02-668, Poland*
[2]*European XFEL GmbH, Albert-Einstein-Ring 19, Hamburg, D-22671, Germany*
[3]*Institute of Physics, ASCR, Na Slovance 2, Prague 8, 182 21, Czech Republic*
[4]*RIKEN/SPring-8 Kouto 1-1-1, Sayo, Hyogo, 679-5148 Japan,*
[5]*Japan Synchrotron Radiation Research Institute (Japan)*
[6]*Univ. Bordeaux, CEA, CNRS, CELIA (Centre Lasers Intenses et Applications) UMR5107, F-33405 Talence, France*

Keywords: free-electron laser, energy transport, phase transitions in solids

The rapid development of a new generation of X-ray radiation sources providing ultrashort (from atto- to femtoseconds) pulses creates unique possibilities for generating high energy density states of matter. Instruments, like free-electron lasers (FELs) produce pulses of very high intensity and allow to extend the optical studies of radiation induced phase transitions of solids. The excitation of solid materials with x-ray femtosecond pulses offers a number of advantages over irradiation with femtosecond optical lasers. First of all the energy deposition process is not influenced by optical nonlinearities i.e. multiphoton absorption and free carrier absorption. Moreover the absorption depth can be varied over many orders of magnitude. E.g. for silicon it changes from a few nanometres up to hundreds of microns. Therefore, ultrashort X-ray pulses allow the preparation of well-defined excitation conditions in variable sample volumes and thus to study the energy transport processes.

Single shot irradiations of the Si flat mirror were performed at SACLA FEL facility at 5.5 and 12 keV photon energies, at grazing angles below and above critical angle. Similar morphology of the exposed spots was observed for all irradiation conditions. TEM images of the cross-section show that the radiation induced structural modification of materials is related to melting of Si and its resolidification. The observed structural modifications have threshold nature. The experimental damage thresholds in case of the irradiations above the critical angle [1] are close to the energy density required for melting of Si (approx. 0.9 eV/atom). The energy transport by hot electrons does not significantly influence the energy density distribution over the sample depth due to relatively high excited volume.

The experimental damage thresholds are the highest in case of the irradiations below the critical angles. In these cases the energy density of the radiation absorbed at the sample's surface can reach above a melting threshold without any structural modification. This may be explained by the transport of the energy out of the excitation volume (limited to the absorption skin depth) by hot electrons on the time scales shorter than the one typical for the electron-phonon coupling (~2 ps for Si). Modelling of the energy transport by ballistic electrons has been performed by means of the PENELOPE simulation code.

Acknowledgments: The authors wish to thank the staff of SACLA, Japan for all the help during experimental beam time. This work was partly supported by the Polish National Science Center (Grant No. DEC-2011/03/B/ST3/02453)

[1] T. Koyama et al., *Optics Express* **21** (2013) 15382.