Ultrafast X-ray science—probing transient structures in condensed matter

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Structural dynamics of condensed matter is connected with changes of the spatial arrangement of atoms. The geometry on an atomic length scale may change in a fully reversible way such as, e.g., for phonon excitations in crystals or may be transformed in an irreversible fashion by, e.g., phase transitions and/or chemical transformations. The elementary steps of such processes occur on femto- to picosecond time scales set by translational, rotational or vibrational motions of key structural units.

X-ray diffraction and absorption are highly sensitive probes of microscopic structure. Their extension into the ultrafast domain allows for probing structural dynamics most directly and in real-time. These fascinating perspectives are driving strong research efforts worldwide, aiming both at new schemes for generating and applying ultrashort X-ray pulses and at elucidating structural dynamics in a broad range of systems.

Over the last six years, the Deutsche Forschungsgemeinschaft has supported research in this area through the Priority Program 1134 ‘Transient structures in condensed matter investigated by ultrafast X-ray techniques’, bringing together leading German groups for joint research. In this special issue, key results are presented in a series of reviews by the participating groups. The priority program covered the following areas of research:

- Theory of photoinduced structural dynamics and phase transitions [1–16]
- Generation of ultrashort hard and soft X-ray pulses, X-ray optics, imaging, and detection [17–45]

- Femtosecond X-ray diffraction to study structural dynamics in crystalline materials, including semiconductors, ferroelectrics and other materials displaying strong electronic correlations [46–62], as well as organic solids [63, 64]
- Ultrafast X-ray absorption and photoelectron spectroscopy to investigate transient structures in crystals and disordered materials including liquids [65–71]

Both laser-driven and accelerator based X-ray sources were applied in the experiments and the program has established new links between those communities. The priority program was successful in creating highly visible results by joint research, as documented in a large number of joint publications. It fostered intense collaborations among the participating groups and beyond and was instrumental for the training of young researchers. New technology for X-ray sources and optics was developed within and/or in cooperation with the priority program and led to new products.

I would like to thank the Deutsche Forschungsgemeinschaft for the generous, continuous and efficient support of this program, and look forward to seeing a rapid progress and many new applications of ultrafast X-ray science.

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