X-ray Free Electron Lasers: Overview, Common Applications and Novel Scientific Opportunities

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Functional materials are becoming increasingly important to key societal challenges. These materials are often developed based on trial-and-error approaches, leaving doubts about the microscopic processes involved. Many of these processes are based on transitions between electronic or atomic states, taking place on time scales of femtoseconds to nanoseconds, where time-resolved studies are challenging. X-ray Free Electron Lasers (XFELs) provide femtosecond-long pulses of X-rays, enabling the investigation of functional materials in the time domain and with microscopic resolution.

In this presentation, the fundamental principles in the operation of Free Electron Lasers are described. The key properties of their radiation and the related measurement techniques are summarized. They are essential for obtaining high-resolution, low-noise data. At the same time, they can enable novel approaches to performing measurements, some of which are described here.

To obtain highest temporal resolution, pump-probe schemes are commonly applied, using femtosecond optical pulses in the UV, visible or IR spectrum to stimulate (“trigger”) electronic or lattice excitations. The transformation and relaxation pathways following these excitations can then be probed using X-ray techniques. With the availability of THz-sources at XFEL instruments, also electrical excitations are now becoming possible with peak field strengths exceeding 100 kV/cm,

Commonly applied X-ray techniques such as X-ray scattering and X-ray spectroscopy at XFELs are reviewed with an emphasis on single shot wide-angle X-ray scattering (WAXS) experiments. The latter is a novel technique that is only possible at XFELs and can be used to study irreversible phase transitions on unprecedented time-scales and excitation levels.