Imaging ferroelastic domain dynamics with nanoscale X-ray diffraction at the MAX IV synchrotron

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Metal halide perovskites (MHPs) have shown impressive results in solar cells, light emitting devices, and scintillator applications, but basic questions regarding its complex structure are still open [1]. The low symmetry of MHP crystal structures allows the formation of ferroelastic domains, whose ferroelectric nature is debated. Ferroelastic and ferroelectric materials show nanoscale domains with typical sizes ranging from 10 to 1000 nm. Imaging dynamics of ferroic domains require an experimentally challenging combination of high spatial resolution, strain sensitivity and long penetration depth.

We have developed nanoscale X-ray diffraction methods to study the dynamics of ferroelastic domains within MHP nanostructures, made available by recent developments in X-ray optics and synchrotron sources. $CsPbBr_3$ nanowires were imaged across the orthorhombic to tetragonal crystal phase transition using in situ temperature-dependent nanofocused scanning X-ray diffraction, with the 60 nm beam at the NanoMAX beamline, MAX IV [2]. The formation of highly organized domain pattern near 80 °C revealed the ferroelastic nature of the domains. To achieve improved temporal resolution, we used the newly developed Full-Field Diffraction X-ray Microscopy technique, available at the ID01 beamline, ESRF, France, to probe the domain evolution at 6 s time resolutions [3] . Twinned ferroelastic domains in single 500 nm $CsPbBr_3$ particles were studied with 3D Bragg coherent x-ray diffraction imaging [4]. A preferential double-domain structure was revealed, with one domain oriented along the [110] and the other along the [002] direction. These results demonstrate that X-ray methods now offer sufficient spatial resolution to image ferroic domains, allowing for in situ studies of their formation and dynamics in realistic conditions.

Finally, I will give an update of the status of the 4th-generation synchrotron MAX IV in Lund, Sweden (https://www.maxiv.lu.se/).

References

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Visualizing Spin Currents with X-ray Microscopy

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Today's magnetic device technology is based on complex magnetic alloys or multilayers that are patterned at the nanoscale and operate at gigahertz frequencies. To better understand the behavior of such devices one needs an experimental approach that is capable of detecting magnetization with nanometer and picosecond sensitivity. In addition, since devices contain different magnetic elements, a technique is needed that provides element-specific chemical information about not only ferromagnetic but antiferromagnetic materials as well. Finally, instead of manipulating devices with external magnetic fields one now often makes use of so called *spin currents*. Pure spin currents or electrical currents with a net magnetic spin moment are fascinating from a fundamental as well as applied perspective. Their effects on the magnetization of a second magnetic layer in a device have been studied intensively using transport and other macroscopic tools. However, from a fundamental point of view it is also often interesting to directly "see" the currents directly on a microscopic scale.

To answer all these questions soft x-ray microscopy is an excellent tool, because a synchrotron produces tunable and fully polarized X-rays with energies between several tens of electron volts up to tens of kiloelectron volts. The interaction of tunable X-rays with matter is element-specific, allowing us to separately address different elements in a device. The polarization dependence or dichroism of the X-ray interaction provides a path to measure a ferromagnetic moment and its orientation or determine the orientation of the spin axis in an antiferromagnet. The wavelength of X-rays is on the order of nanometers, which enables microscopy with nanometer spatial resolution. And finally, a synchrotron is a pulsed X-ray source, with a pulse length of tens of picoseconds, which enables us to study magnetization dynamics with a time resolution given by the X-ray pulse length in a pump-probe fashion.