Nowadays, magnetic nanostructures are widely used in modern data storage technology. An investigation of these structures requires a high spatial and temporal resolution to resolve magnetization dynamics on its fundamental length- and time-scales. A better understanding of the temporal magnetization evolution in nanostructured samples has the potential to greatly contribute to novel storage devices as well as spintronic computer concepts.

The P04 beamline at the high-brilliance synchrotron source PETRA III delivers monochromatized soft X-ray radiation at the transition metal L edges featuring a wavelength in the nanometer regime. This enables setting up a full-field transmission X-ray microscope for direct imaging of magnetic nanostructures with sufficient spatial resolution [2] in line with detecting the magnetization of the sample via the X-ray magnetic circular dichroism (XMCD) effect [5, 3, 1]. Due to the pulsed character of the synchrotron radiation, the transient evolution of the sample magnetization can be traced in a stroboscopic pump-probe approach with a picosecond temporal resolution given by the PETRA III pulse duration.

We have constructed a new endstation to capture the magnetization dynamics in 30 nm thin nanostructured permalloy (Ni$_{80}$Fe$_{20}$) samples. Figure 1 shows the setup consisting of a grating condenser [4] for homogeneous sample illumination within a spot of 20 µm diameter. A micro zone plate images the transmitted light with < 65 nm spatial resolution onto an in-house developed fast gateable X-ray detector to isolate the dynamic information contained in single synchrotron bunches [6, 1].

Figure 1: Transmission X-ray microscope consisting of grating condenser, sample, micro zone plate and a gateable detector. An excitation of the sample can be achieved through a current pulse transporting a magnetic field $\vec{H}_{\text{pulse}}$ to the permalloy sample structures.
Applying current pulses through a narrow conductor of a coplanar waveguide (CPW) on the sample enables the manipulation of the magnetization in the permalloy structures located in the vicinity of the waveguide which are exposed to the magnetic Oersted field curled around the conductor. Figure 2 demonstrates the capability of the instrument to resolve the spatial magnetization distribution in the sample and shows a typical Landau flux-closure pattern consisting of four domains represented by the different gray levels in the depicted permalloy square.

The ability to record transient magnetization states with the setup is presented in figure 3. The image shows an XMCD magnetization map of modulated permalloy nanowires of 400 nm width at three different delay settings between the pump current pulse and the soft X-ray probe pulse. The dark background in the left side of the images represents the waveguide conductor that transports the current with the accompanied magnetic Oersted field pulse $\vec{H}_{\text{pulse}}$. An additional external static magnetic field commonly aligns the magnetization in the nanowires along the field lines which is represented by a light contrast in the images before and after the excitation pulse has arrived. During the pulse, the XMCD contrast of the elements in overlap with the waveguide conductor changes to a darker gray value representing an opposite magnetization alignment due to the pulsed field in the center image of figure 3.

This measurement demonstrates the achievement of temporal overlap between pump and probe pulses and furthermore shows that the instrument is ready to record movies of magnetization dynamics in nanostructures with a spatial resolution $< 65$ nm and a temporal resolution fundamentally limited by the PETRA III pulse duration of 90 ps FWHM [2, 7]. Real time tracing of domain pattern destruction and recovery in permalloy samples has been observed in recent experiments [6].

References