Nanoscale dynamics of magnetic domain walls with x-ray speckle

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Introduction

We present a study the quantum spin dynamics of magnetic domain walls with sub-micron spatial resolution by using X-ray Photon Correlation Spectroscopy (XPCS), based on observations of coherent x-ray speckle intensity fluctuiations.

Chromium is an archetypical spin-density wave (SDW) antiferromagnet. The spin-density wave structure arising from nesting of fermi surface forms along one of the three equivalent crystallographic directions of BCC chromium, resulting in formation of complex domain structure, with nanoscopically thick domain walls separating the regions with different orientation of spins (S-domains) or spin density wave-vectors (Q-domains). Spin-density wave in Chromium is accompanied by charge density wave (CDW), consisting of modulations of itinerant electron distribution and lattice strain.

Methods and Materials

Measurements were performed at beamlines 34-ID and 8-ID of Advanced Photon Source. Coherent portion of the x-ray beam was selected with a spatial filter (either a 10 micron pinhole, or a set of slits 10 microns horizontally by 40 microns vertically), resulting in 15% coherence factor. Chromium [111] sample was mounted inside low-drift (<1μm/hr) He flow cryostat, which allowed varying the temperature of the sample from 300K down to 4K. Coherent x-ray speckle diffraction pattern (see Fig. 1) was collected with a Princeton Instruments LCX-1300 CCD camera 2 meters away from the sample in reflection geometry, tuned to either a structural [200] Bragg reflection, or [2-2δ, 0, 0] Charge Density Wave Satellite.

XPCS is an extension of dynamic light scattering techniques that has been routinely used by laser community. Applied in x-ray regime, it provides an advantage of being able to probe structures deep within the bulk of materials otherwise not accessible with visible light. Additionally, spatial resolution of visible light (laser-based) PCS is severely limited to lengthscales on the order of a micron and larger, due to diffraction limit. X-ray PCS, however, is capable of achieving nanoscale spatial resolution.

By following the time-resolved evolution of speckle pattern we were able to obtain direct measure of nanoscale dynamics of magnetic domain wall fluctuations in Cr.

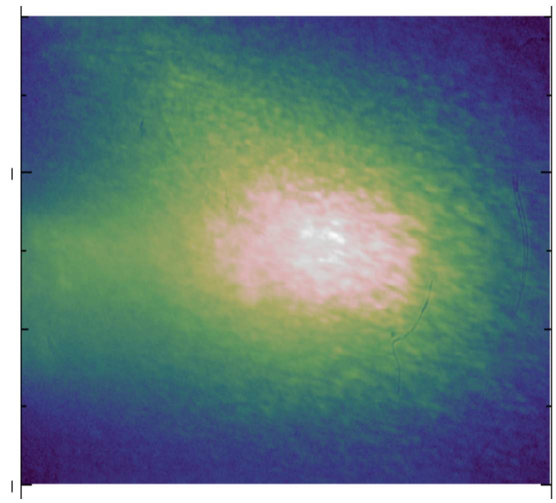

Fig. 1.: Typical X-ray Coherent Speckle Pattern. Grainy intensity distribution across the image are due to coherent properties of the x-ray beam. Intensity fluctuations of the image provide a measure of dynamics within the bulk of the sample.

Results

Speckle measurements for Bragg reflection condition were used to test the stability of diffractometer, the beamline components as well as crystalline structure of the Chromium sample. This speckle pattern was observed to be quasi-static (less than 1% change of coherence) over 4 hours of measurements.

Charge Density Wave satellite speckle, however, has been evolving with characteristic timescale that varies with temperature in good agreement with thermally activated theory of domain wall motion. At low temperatures the timescale has been shown to be temperature-independent, possibly due to quantum-mechanical tunneling mechanism for domain wall fluctuations.

Discussion

XPCS serves as a powerful technique in studies of materials characterized by complex disorder, in this particular case consisting of irregular distribution of spin-density wave magnetic domains.

We observe a cross-over behavior from thermally activated domain wall fluctuations at high temperature regime to quanum tunneling mechanism at low temperatures. Possible implications of these measurements will be discussed.