

# X-ray Ptychography of Charge-Order Domains in High Temperature Superconductors

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Thermally driven critical fluctuations are expected near a classical second-order phase transition, which should slow down as the transition is approached. Coherent imaging with single pulses of X-rays should be able to freeze these fluctuations and make a movie of them. It is expected that in place of diffuse scattering associated with the transition, there would be “speckled” diffraction indicative of critical domains associated with the fluctuations. Observing these fluctuations is one of the science goals of the MID station, however with only limited temperature control, it was decided to investigate a transition near room temperature. We chose to look at a sample of  $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$  (LSCO) for which the phase transition between the high temperature tetragonal (HTT) phase and the low-temperature orthorhombic (LTO) phase can be adjusted with the composition variable,  $x$ . We measured a high quality epitaxial thin film of LSCO,  $x=0.07$ , which has its HTT-LTO transition at around  $70^\circ\text{C}$ , at MID over two beamtimes in 2019 and 2020. LSCO is the original High Temperature Superconductor material discovered by Bednorz and Muller in 1986.

We found the sample was undamaged by the full SASE2 monochromatic beam, even close to the 200nm focus of the “nafo” CRL optics, provided 30% attenuation was retained. This surprising radiation immunity may have arisen from the presence of a thin 200nm gold film electrode covering the sample, which could redistribute photoelectrons and reduce charging effects; previously ferroelectric thin films were found to damage easily in a focussed XFEL beam. High-visibility speckled diffraction patterns were clearly recorded in single shots showing that any fluctuations were sufficiently frozen during the pulse. But the patterns were found to differ on every shot, suggesting that the beam/sample positioning was unstable. At all temperatures, the patterns repeated at random intervals suggesting this is not due to sample fluctuations. Patterns which showed high correlation were averaged together to improve statistics and the resulting partially-correlated groups could be assigned an overlap distance using modelling as phase domains. This could lead to a ptychographic reconstruction of the domains, despite having no information about the probe positions. Ptychographic images of related materials, measured with coherent soft X-rays, show that the method works for charge-density wave domains.

At the end of this presentation, we will introduce the possibility that the speckle inversion “phase problem” may be amenable to Machine Learning approaches in the future. A large team of researchers helped with the experiment and contributed to the progress towards this common goal of visualising domain fluctuations in crystals [1].

[1] L. Wu, T. A. Assefa, M. P. M. Dean, E. S. Bozin, Y. Cao, H. You, D. Sheyfer, S. Rosenkranz, P. G. Evans, S. Marks, J. Diao, L. Gelisio, S. Banerjee, D. A. Keen, J. Hallmann, U. Boesenberg, M. Scholz, J. Moeller, A. Madsen, I. Bozovic and I. K. Robinson to be published

