Ultrafast coherent X-ray diffraction to study magnetic domain dynamics

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Magnetism is an important form of long-range order in condensed matter materials, which has a profound influence on their transport properties and a host of relevant applications, whose speed can be a limitation. Below 240K, Mott insulator Sr_2IrO_4 forms an ordered antiferromagnetic (AFM) state where the spins are locally aligned in opposite directions with zero net magnetic moment. In crystals, this results in a lower symmetry described by a supercell structure, leading to additional unique magnetic Bragg peaks in diffraction. We studied the (106) magnetic Bragg peak of Sr_2IrO_4 at 100K with laser pump-probe time-resolved resonant coherent magnetic X-ray diffraction imaging, to measure the migration velocity of its antiferromagnetic domain walls using an X-ray Free Electron Laser (XFEL). During the laser-induced demagnetization, we observe X-ray images of micron-sized clusters of magnetic phase domains which reconfigure within 100 fs following excitation by an optical laser, with their boundaries moving at 3×10^6 m/s. This is closer to a typical Fermi velocity, than the speed of sound, implying an electronic mechanism. The return relaxation is slower, taking longer than 10 ps, suggesting that lattice coupling may be involved. We also show that domains regrow in the same location every time. Fundamentally, this behavior is understood to arise from a purely electronic spin contribution to the magnetic structure without any role for coupling to the crystal lattice.

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