Antiferromagnetic (AF) materials offer a route to realising high-speed, high-density data storage devices that are robust against magnetic fields due to their intrinsic dynamics in the THz-regime and the lack magnetic stray fields. The key to functionality and efficiency is the control of AF domains and domain walls. Although AF domain structures are known to be sensitive to magnetoelastic effects, the microscopic interplay of crystalline defects, strain and magnetic ordering remains largely unknown. Here, we reveal, using photoemission electron microscopy combined with scanning x-ray diffraction microscopy and micromagnetic simulations, that the AF domain structure in CuMnAs thin films is dominated by nanoscale structural twin defects, which determine the location and orientation of 180° and 90° domain walls. The results emphasise the high sensitivity of the AF domain structure to the crystallographic nanostructure and provide a route to optimising device performance.

Index Terms—Antiferromagnetism, Domain Walls, Photoemission Electron Microscopy, Scanning X-ray Diffraction Microscopy

I. INTRODUCTION

Antiferromagnetic (AF) materials are promising candidates for high-speed, high-density data storage devices that are robust against magnetic fields, since they exhibit intrinsic dynamics in the THz-regime, lack magnetic stray fields and can be switched electrically. Most promising for high-speed applications is electrical switching via current induced bulk Néel spin-orbit torque, which has been predicted to exist in MnAu and CuMnAs [1],[2]. Experimentally, 90° domain reorientations induced by orthogonal current pulses and current-polarity dependent switching of AF order has been demonstrated [3]-[6].

In spintronics, the efficiency of a device is directly related to the domain structure, which is only poorly understood in fully compensated AFs. For thin films, it is known that the domain morphology can vary considerably with thickness and high-resolution AF domain imaging has revealed pronounced non-uniformities and pinning effects during domain switching [3]-[6]. This emphasises the need to understand AF domain formation at the nanoscale to realise high-performance spintronic devices.

Here [7], we show that the AF domain structure in CuMnAs films, a most important material in AF spintronics research, is largely governed by nanoscale twin defects. The 50nm-thick CuMnAs(001) films are epitaxially grown fully strained with low mosaicity on GaP(001) The CuMnAs layer is a collinear antiferromagnet with a Néel temperature of 485 K [8] and a tetragonal crystal structure. A large magnetocrystalline anisotropy confines the spin axes in the (001)-plane, i.e., within the film-plane [8].
ray magnetic linear dichroism (XMLD), yielding maximum contrast between regions with the local spin axis aligned perpendicular and parallel to the x-ray polarisation $\vec{E}$. This allows to achieve contrast on the domains or on the boundaries, depending on the orientation of $\vec{E}$.

Figure 1A shows an approximately equal population of dark and light areas, corresponding to AF domains with the local spin axis parallel to [110] or [1-10]. The domains typically exceed several micrometers in lateral size and have serrated edges. Figure 1B shows the corresponding domain boundaries. 90° domain walls appear as well separated black or white lines, depending on the average direction of the spin axis across the domain wall, and 180° domain walls show up as adjacent black and white lines. Figure 1C and D show high-resolution XMLD-PEEM images of an area, which contains examples of all characteristic domain and domain wall features. Figure 1E shows the same area imaged with x-ray linear dichroism (XLD) – PEEM, which indicates local crystallographic variations. We observe a pattern of thin lines running parallel to the [110] or [1-10] crystallographic directions. The composite image, (Fig. 1F), reveals that the local AF spin axis is always oriented collinear with the defect lines. Long, straight 180° domain walls are found to be confined between two parallel defects and can become highly constricted as seen in the middle of Fig. 1F. Defect T-junctions, e.g., in the bottom half of Fig. 1F, lead to 90° domain walls with pinch-points at the junctions which leads to the serrated edges. Such a strong direct correlation between defects and domains is observed across all areas of the film.

III. CRYSTALLOGRAPHIC STRUCTURE OF THE DEFECTS AND COUPLING MECHANISM

Using scanning x-ray diffraction microscopy (SXDM), we have been able to identify the defects as microtwins, which had previously been identified as characteristic defects in CuMnAs using high-angle annular dark field-scanning transmission electron microscopy (HAADF-STEM). They are nanoscale slabs of a microtwinned phase, in which the lattice is rotated so that the c-axis is tilted away from the film normal by ~82°. The slabs extend over most of the film thickness and produce the characteristic rectangular pattern at the surface. The 3d crystallographic structure yields an intuitive argument for the observed alignment of the AF spin axis parallel to the defect line on the surface. As illustrated in Fig. 2, the magnetic easy planes of twin and surrounding lattice share only one common axis. This is thus the easy of the area and parallel to the microtwin surface termination. Hence, the Néel vector (the difference of the sublattice magnetisations) aligns along the defect line. For adjacent microtwins, the local Néel vector can align either parallel or antiparallel. Antiparallel alignment results in 180° domain walls. For parallel alignment of the Néel vector, the area between the microtwins is magnetically homogeneous and can extend over several micrometers. Perpendicular alignment of two defects gives rise to 90° domain walls.

IV. MICROMAGNETIC SIMULATION

Including the effects of microtwins in micromagnetic simulations is sufficient to fully explain the experimentally observed AF domain structures, as shown in Fig. 3.

![Fig. 3. A-D Micromagnetic simulations of the AF domain structure for different microtwin distributions (dashed yellow lines). E-G Composite images of experimentally observed XMLD-PEEM images and microtwin configurations. The color wheel shows the local spin axis. Adapted from [7].](image)

V. CONCLUSION

Our results highlight the role of crystallographic defects for AF domain structures in CuMnAs thin films. The concentration and distribution of these defects may be engineered by varying the growth parameters. This provides a means for tailoring the AF domains and domain walls for specific functionality.

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