Multiferroic materials, displaying simultaneously ferromagnetism and ferroelectricity, have recently attracted growing interest due to their intriguing physical properties and potential applications. In this presentation, we show our transmission electron microscopy results of RMnO$_3$ multiferroic materials. Using state-of-the-art aberration-corrected annular-bright-field and high-angle annular-dark-field scanning transmission electron microscopy, we investigated the structure of multiferroic vortex domains in YMnO$_3$ at atomic scale. Two types of displacements were identified among six domain walls; six translation-ferroelectric domains denoted by $\alpha^+$, $\gamma^-$, $\beta^+$, $\alpha^-$, $\gamma^+$, and $\beta^-$, respectively, were recognized, demonstrating the interlocking nature of the anti-vortex domain. We found that the anti-vortex core is about four unit cells wide. We reconstructed the vortex model with three swirling pairs of domain walls along the [001] direction. Two types of 180 degree domain walls, i.e., the transverse and the longitudinal domain walls are identified, which is in consistency with the interlock between ferroelectric and structural translation domain wall predicted previously. These wall structures are different from the polarization inversion in conventional ferroelectrics. These results are very critical for the understanding of topological behaviors and unusual properties of the multiferroic vortex. In addition, we found a new ferroelectric phase induced by oxygen vacancy ordering. We proposed a proper structure model and examined its correctness.

References

Acknowledgement: This work was supported by 973 (2012CB932302) and NNSF of China (11174336). The sample was from Pengcheng Dai’s group at UT/Rice supported by the US DOE, BES (DE-FG02-05ER46202).
Fig. 1: HAADF image of the anti-vortex domains. The domain walls are marked by red dotted lines and the red circle is used to mark the region of the vortex core.

Fig. 2: The reconstructed model of the vortex domains along [001] direction. The red dotted lines and the circle indicate the locations of domain walls and the core of the vortex, respectively. The yellow circles with a dot and the blue circles with a cross represent $Y_{up}$ and $Y_{down}$ atoms. The green circles represent $Y$ atoms at the paraelectric position.

Fig. 3: Type-I and type-II domain walls along the [010] direction including all the four kinds of domain walls.