Substrate-Dependent Bonding Anisotropy of Epitaxial Multiferroic $DyMnO_3$ Thin Films

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We investigated the substrate-dependent electronic structure and anisotropic bonding of the Mn $3d$ states in $DyMnO_3$ thin films on $SrTiO_3(001)$ and $LaAlO_3(110)$ substrates using polarization-dependent x-ray absorption spectroscopy (XAS) at O K-, Mn L- and Mn K-edges for three polarizations, E ∥ a, E ∥ b and E ∥ c. Polarization-dependent x-ray absorption spectra at O K-, Mn $L_{2,3}$- and Mn K-edges of orthorhombic $DyMnO_3/LaAlO_3(110)$ thin films show a strong polarization dependence, whereas orthorhombic $DyMnO_3/SrTiO_3(001)$ thin films show nearly isotropic spectral structure. The main peak in polarized Mn $L_{2,3}$-edge XAS spectra of $DyMnO_3/LaAlO_3(110)$ thin films for the E ∥ b polarization lies at a lower energy than for polarizations E ∥ a and E ∥ c. This indicates a great anisotropy in Mn $3d$-O $2p$ hybridization, reflecting an orbital ordering and a highly anisotropic coplanar Mn-O bonding in $DyMnO_3/LaAlO_3(110)$ thin films. Orbital ordering of e_g-orbital and the highly anisotropic in-plane Mn-O bonding is an indispensable factor to the formation of complicated incommensurate modulated magnetic structures observed in orthorhombic $DyMnO_3$. The present results provide important implications for the microscopic understanding of the multiferroic $DyMnO_3$.