Supplemental Materials

Effect of strain on voltage-controlled magnetism in $BiFeO_3$-based heterostructures

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Supplemental text

Shown in figure S1(a) is the phase diagram of λ_S and h_{DM}^0 constructed for different voltage-induced magnetic domain switching behaviors based on phase-field simulations. Typical magnetic and ferroelectric domain structures in different phase regions before and after reversing the in-plane average polarization $\mathbf{P}_{100}$ are shown in figure S1(b). It can be seen from figure S1(a) that the range of critical value of h_{DM}^0 for voltage-induced 180° magnetization reversal can be tuned by modulating λ_S. For instance, when h_{DM}^0 =100 Oe (as measured by experiment [1]), the 180° reversal should take place for the λ_S ranging from -7 ppm to -20 ppm. Furthermore, the region of 180° full reversal gradually shrinks with decreasing h_{DM}^0, and vanishes when h_{DM}^0 is smaller than 70 Oe. In addition, there is no 180° magnetization reversal upon a positive λ_S, in which case the contributions from the $\mathbf{H}_{DM}$-field

and strain are not against each other.

Reference

[1] Trassin, M. et al. Interfacial coupling in multiferroic/ferromagnet heterostructures. Phys. Rev. B 87, 134426 (2013)

Supplemental Figures

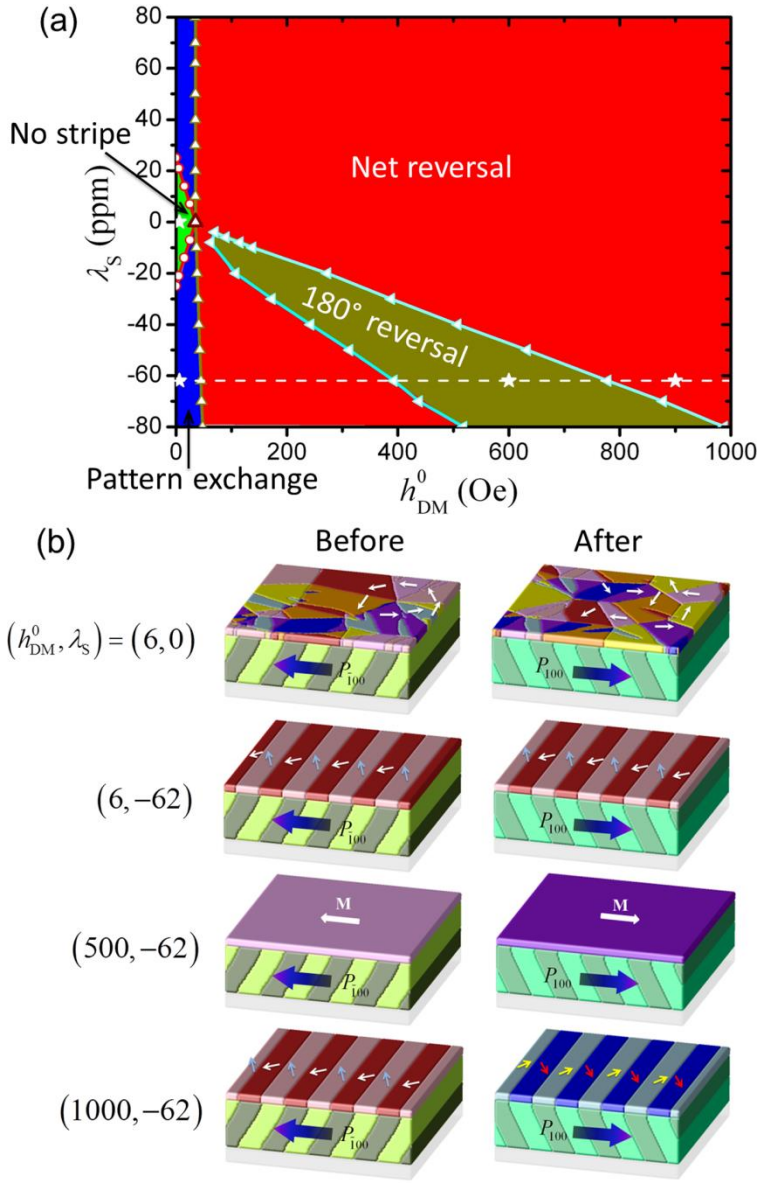

Figure S1 (a) Phase diagram of the saturation magnetostricton coefficient λ_S and the magnitude of $\mathbf{H}_{DM}$-field h^0_{DM} for various voltage-induced magnetic domain switching behaviors, including pattern exchange of magnetic striped domain, net magnetization reversal, and full 180° reversal. The *"no-stripe"* region indicates the magnetization can neither be stabilized as striped domains nor be reversed. (b) Typical magnetic and ferroelectric domain structures for these different phase regions before and after reversing the in-plane average polarization $\mathbf{P}_{100}$. Corresponding values of λ_S and h^0_{DM} are marked by stars in the phase diagram.

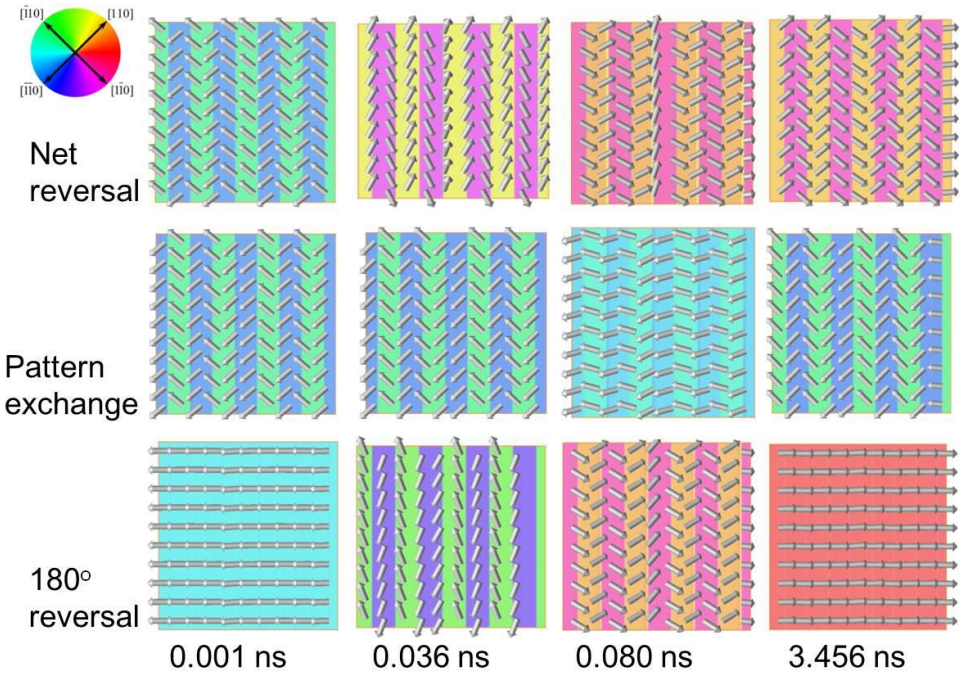

Figure S2 Vector diagrams of local magnetization distributions at time stages of 0.001 ns, 0.036 ns, 0.080 ns, and 3.456 ns for different voltage-induced magnetic domain switching paths shown in figure 4. The background color indicates the orientation of the local magnetization vectors (see the color wheel). The magnitudes of $\mathbf{H}_{\mathrm{DM}}$-field (h_{DM}^{0}) are taken as 6 Oe, 500 Oe, and 1000 Oe for pattern exchange, net magnetization reversal, and 180 ° full magnetization reversal, respectively.