Supplementary Material

Giant magnetoelectric effect in perpendicularly magnetized Pt/Co/Ta ultrathin films on a ferroelectric substrate

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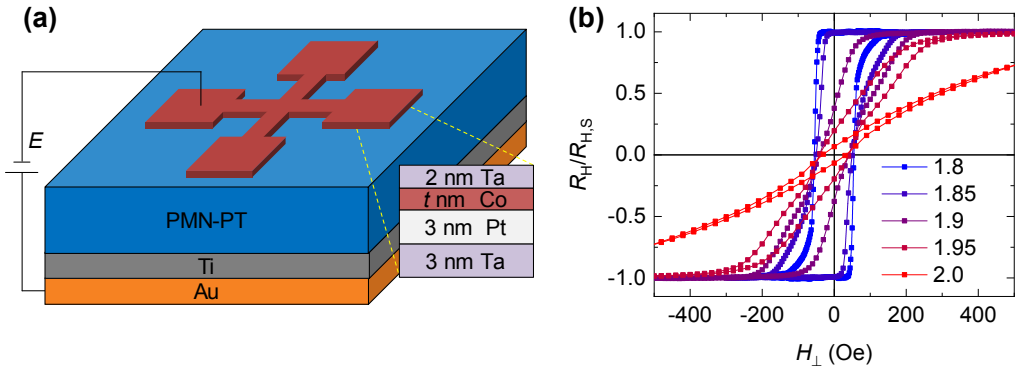

Fig. S1 (a) Schematic of the sample structure and the experimental configuration. A Hall bar was patterned to measure AHE. The electric field was applied on the PMN-PT substrate to generate strain via converse piezoelectric effect to modulate the magnetic property of the Pt/Co/Ta ultrathin films; a positive electric field was defined as pointing from PMN-PT to Pt/Co/Ta. (b) AHE curves of Pt/Co/Ta ultrathin films with various thicknesses of Co layer.

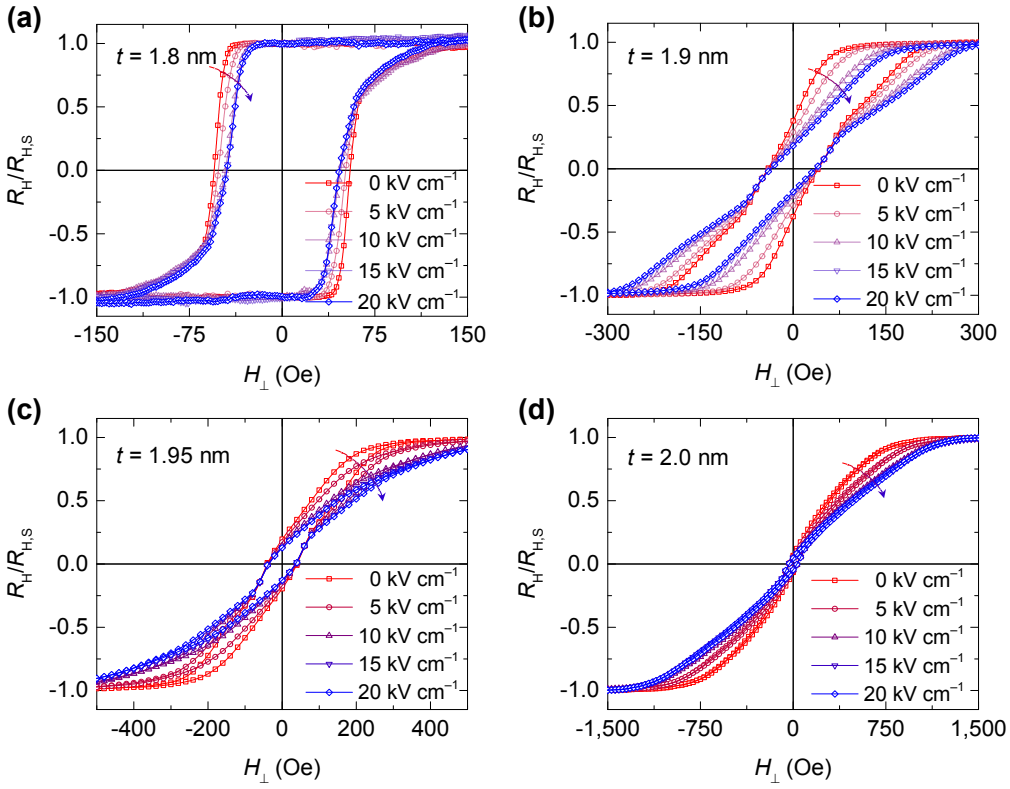

Fig. S2 In situ AHE curves measured under electric fields for perpendicularly magnetized Pt/Co/Ta samples with various Co thicknesses: (a) 1.8 nm, (b) 1.9 nm, (c) 1.95 nm and (d) 2.0 nm. The arrows clearly show that the AHE curves, for all samples, had a remarkable change when applying electric fields. As electric fields increased, the coercive field H_C in (a) decreased, and the saturated field in (b), (c) and (c) increased, indicating a reduction of PMA by the electric fields.

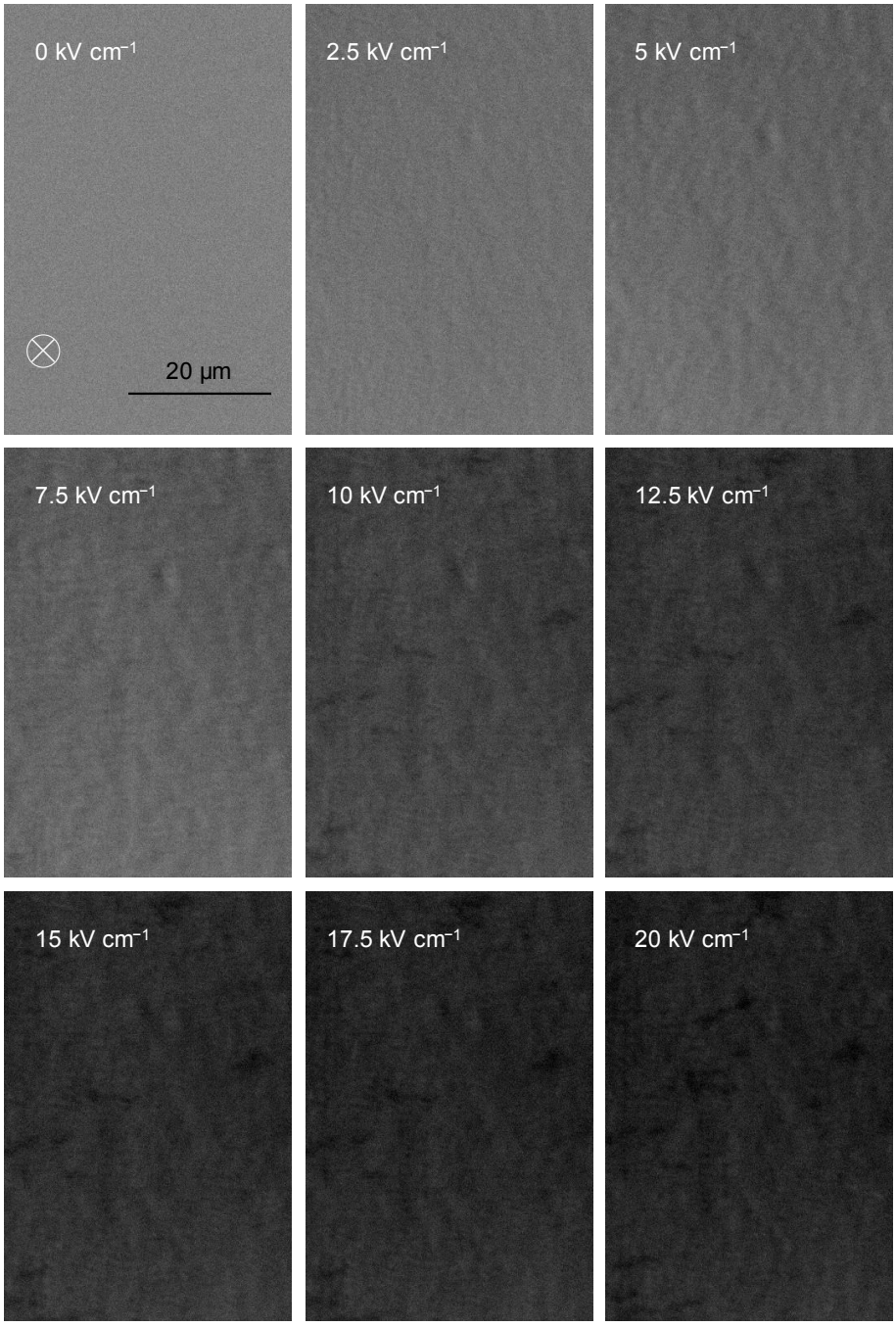

Fig. S3 Kerr images taken at zero magnetic field after applying sequential electric fields. The background gradually became darker because of the applied electric field; we subtracted the background to obtain the magnetic domain signal, as shown in Fig. 3.

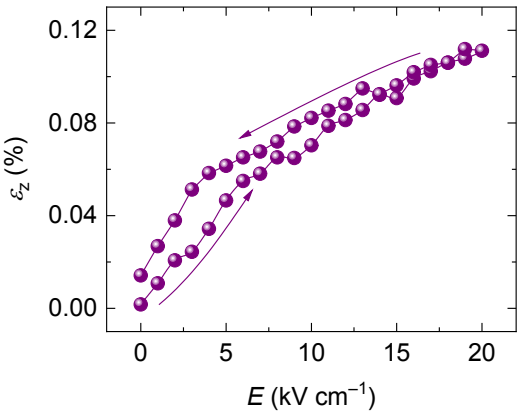

Fig. S4 Tensile strain along the *z* axis induced by electric fields, which was estimated based on the shift of the (022) peak in Fig. 4a.

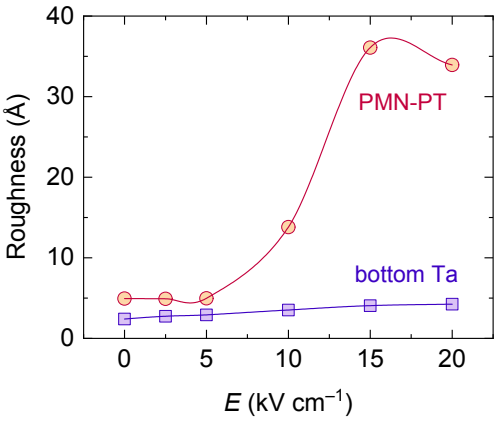

Fig. S5 Dependence of PMN-PT and bottom Ta interface roughness on electric field, which is deduced from Figure 4b by fitting XRR spectra. In the above figure, we clearly see that the electric field induced a large roughness variation of the PMN-PT substrate and this large substrate roughness variation can be largely suppressed by inserting a 3 nm Ta thin layer.