

Controlling interface anisotropy in CoFeB/MgO/HfO₂ using dusting layers and magneto-ionic gating

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I. Thickness difference for dusting layers

Thin film samples with different dusting layers were deposited using a sputtering system. The thicknesses of dusting layers used here are: 0.08 nm for Ta and W and 0.09 nm for Pt. This difference in thickness is due to the deposition rates of each element and the number of rotations required to achieve the desired thickness. Each heavy metal element is first deposited with a higher thickness of 20 nm or 30 nm. Once we have parameters for these thicknesses, we tune down the parameters to achieve our desired thickness. One of the parameters is the number of rotations for the sample stage in order to obtain a homogeneous thickness over the complete area of a sample. For Ta and W, it was possible to have certain number of full rotations to achieve 0.08 nm of thickness, whereas in the case of Pt, it required half a rotation for this thickness, which is not possible in our sputtering system. Since we can only have full rotations, the thickness used here for Pt is 0.09 nm.

II. Pt and W- bottom dusting layer

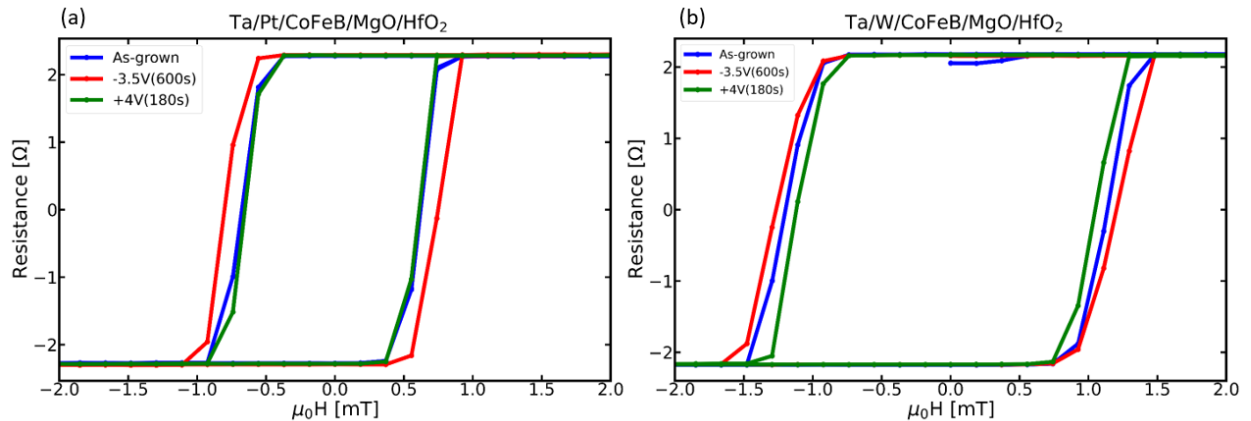


FIG. S1. (a) Ta/Pt(0.09)/CoFeB/MgO/HfO₂ and (b) Ta/W(0.08)/CoFeB/MgO/HfO₂ plots showing the variation of coercivity.

The obtained change in coercive field values are about 20 % for Pt and Ta bottom dusting layers whereas only a 6 % change is observed for W. Figure S1 shows the same plots as in the main text, in a smaller magnetic field scale.

III. Remanence cycles for Ta/CoFeB/Pt(0.09)/MgO/HfO₂

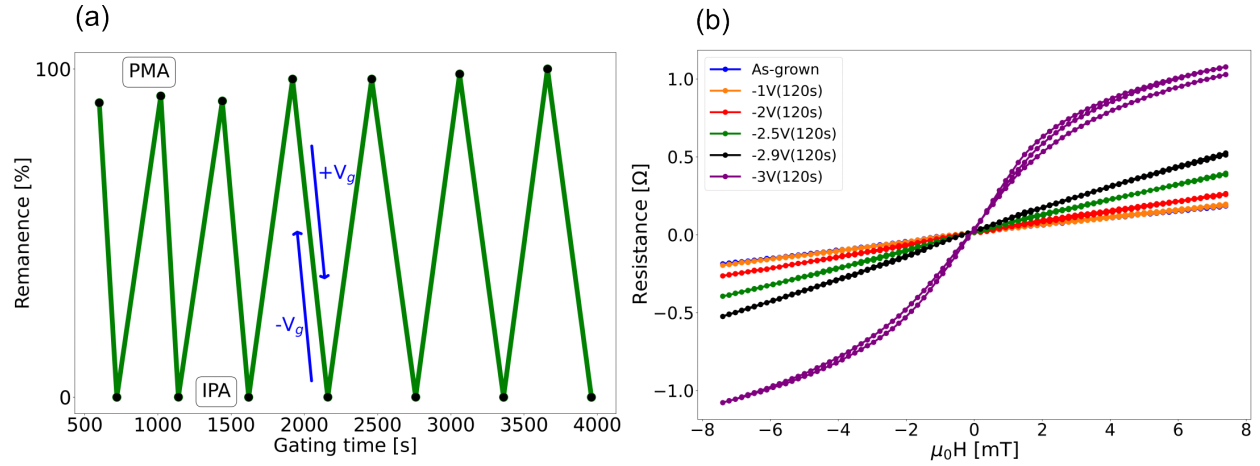


FIG. S2. (a) Remanence as function of reversibility cycles of Ta/CoFeB/Pt(0.09)/MgO/HfO₂. (b) AHE hysteresis loops measured with lower gate voltages showing that the transition towards PMA starts to appear at -3 V.

In fig.S2(a), we show the variation in remanence for seven cycles between the in-plane anisotropy (IPA) state represented as 0% and PMA as 100%. Fig.S2(b) shows that below -3 V, Ta/CoFeB/Pt(0.09)/MgO/HfO₂ stays in an IPA state, it starts to transition to PMA from -3 V onwards. This sample requires an initial activation to transition to PMA. Once the sample is activated at -3 V, it requires -3.5 V for 600 s to attain a PMA state for the first cycle, while for all subsequent cycles a shorter time of 300 s is sufficient for the transition to occur. However, for transitioning back to the IPA state, we observe that with each cycle the magnitude of the applied +V_g as well as the duration of gating time increases by 60s to 120s.

IV. Pt-dusting layer with 1 nm thickness

A continuous Pt layer with a thickness of 1 nm was deposited at the CoFeB/MgO interface. The sample shows in-plane magnetisation in the as-grown state and remains unaffected by the application of gate voltages. This indicates that a higher concentration of Pt at the top interface completely blocks the interaction between oxygen species and CoFeB which results in a stable IPA state.

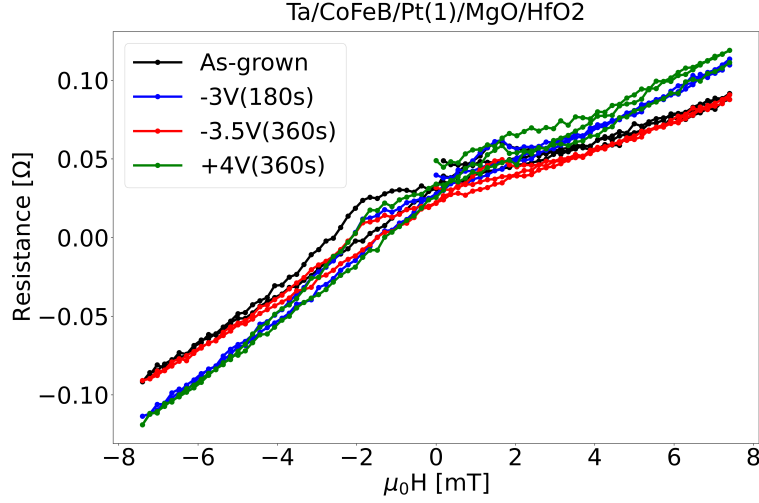


FIG. S3. AHE hysteresis loops measured for Ta/CoFeB/Pt(1)/MgO/HfO₂.

V. AHE loops for TEM

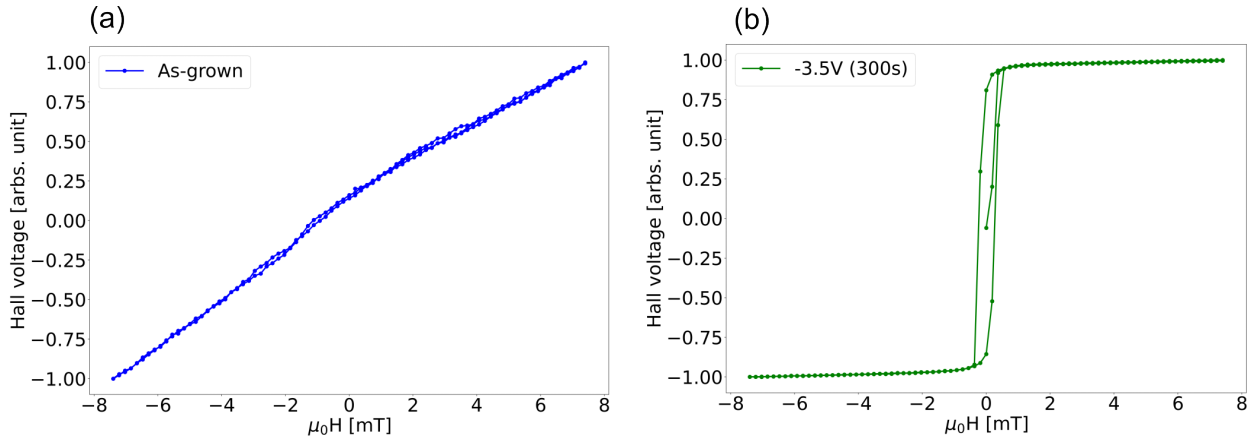


FIG. S4. AHE hysteresis loops measured in the samples investigated with TEM: (a) As-grown state and (b) after voltage state.

The AHE loops in Fig. S4 correspond to the as-grown and after voltage samples investigated with TEM. In the as-grown state the sample is in-plane magnetised (a), while the sample after voltage exhibits PMA (b).