C2N

Soutenance de thèse

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Strain modulation of magnetic domain wall motion in CoFeB systems

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Abstract :

Strain-induced modification of magnetic properties in hybrid piezoelectric/ferromagnetic heterostructures is being intensively investigated due to its potential for low-power spintronics applications based on magnetic domain wall (DW) motion. Materials with in-plane magnetic anisotropy (IPA) and perpendicular magnetic anisotropy (PMA) have been used to study strain-induced magnetization variations in hybrid piezoelectric/ferromagnetic heterostructures. However, from a fundamental perspective, a comprehensive understanding of the magnetic DW velocity dependence on various strain configurations (such as uniaxial, biaxial, and shear strains) and geometries is still lacking, particularly in PMA materials. Therefore, more fundamental research is needed to understand the role of electric field-tuned piezoelectric and ferromagnetic coupling and its impact on magnetic DW motion for the development of energy-efficient strain-induced devices. This thesis aims to investigate the effect of different strain configurations and geometries on magnetic DW motion in PMA materials. This work investigated the influence of piezoelectric strain on magnetic DW motion in PMN-PT (011)/Ta/CoFeB/MgO-based devices through two distinct approaches. The first approach studied the effect of biaxial in-plane strain and out-of-the-plane polarization on DW motion in continuous magnetic films on top of piezoelectric substrates. In contrast, the second approach explored the impact of local uniaxial in-plane strain on DW velocity modulation in patterned devices. The first results presented in this thesis show that, in PMN-PT (011), the application of a voltage along the sample's out-of-plane (OOP) direction leads to a non-volatile polarization state, as confirmed by piezoresponse force microscopy. In this configuration, we observe a non-volatile decrease in the DW velocity during the creep regime in the poled state with respect to the unpoled state. This response can be linked not only to a strain-control of magnetic anisotropy but also to a strain-controlled change in the homogeneity of the magnetic landscape. Such interface modulations result in additional pinning sites in the poled state compared to the poled state, as confirmed by our creep dynamics analysis. This can significantly affect DW nucleation/depinning fields, which opens the door to using strain to control magnetic disorder. The second result of this thesis explores the effect of annealing on hybrid piezoelectric/ferromagnetic heterostructures, revealing significant impacts on DW velocity and anisotropy modulation. Despite the strain relaxation in the PMN-PT layer, our measurements showed a significant reduction in the DW velocity in the creep regime after annealing. This reduction in velocity was attributed to the increased effective anisotropy in the annealed state, which resulted from the improvement of the crystalline structures of CoFeB and MgO induced by the high annealing temperature. Our FMR measurements confirmed that this partial crystallization enhanced the PMA compared to the as-grown state. Therefore, our results showed that recovering the magnetic DW velocity to its original as-grown state was impossible after annealing. Additionally, a DW velocity modulation of up to 50% in the presence of local in-plane strain was observed, which was attributed to anisotropy modulation at the local scale. Finally, in the last part of the thesis, micromagnetic simulations were performed to validate and interpret our observed experimental results on strain-influenced DW dynamics modulation beyond the creep regime in continuous magnetic films on top of piezoelectric substrates. In summary, this study offers significant contributions toward understanding the behavior of magnetic DWs in response to different strain configurations. Multiple strain configurations in piezoelectric/ferromagnetic hybrid structures can open new opportunities for the electrical manipulation of DW dynamics.

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