Surface artificial grooving and engraving for magnetic anisotropy texture patterning

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In this work, we investigate the induction of in-plane uniaxial magnetic anisotropy in permalloy thin films through Surface Artificial Grooving and Engraving (SAGE), a technique that involves the controlled nanoscale scratching of the film surface using atomic force nanolithography. This process generates a well-ordered groove array resulting in a strong uniaxial anisotropy with the easy axis aligned along the groove direction. The strength of this anisotropy is found to increase for small period and deep engraving. This approach is applied to patterned Py structures, enabling the mastering of domain arrangement and domain-wall motion. In particular, we demonstrate the control of vortex-state chirality in ferromagnetic disks and the direction of spin wave propagation in corrugated permalloy waveguides.

1. Introduction

Uniaxial magnetic anisotropy can be induced in permalloy through substrate corrugation, as previously demonstrated in corrugated Si systems [1]. This finding motivated further exploration of anisotropy control at the micron scale through direct structuring of the ferromagnet itself. Here, we present a method for tailoring magnetic anisotropy using the Surface Artificial Grooving and Engraving (SAGE) technique, where the periodicity and depth of grooves dictate the anisotropy strength. Beyond the control of anisotropy, this approach enables the manipulation of domain walls, tuning the magnetic disk chirality [2] and the excitation of zero-field spin waves [3]. The technique further opens pathways for engineering multidomain magnetic architectures and guiding spin wave propagation in corrugated ferromagnetic media [4].

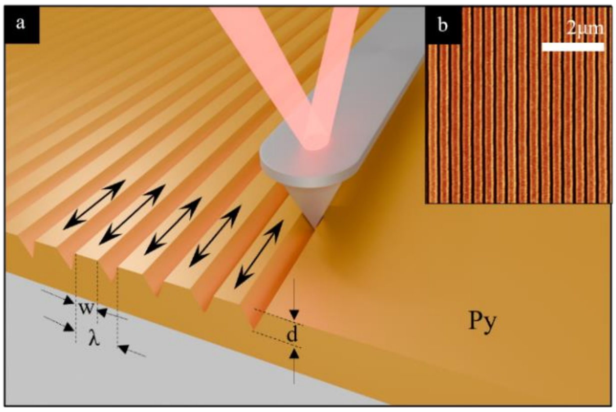

Figure 1: (a) Schematic representation of the SAGE technique via atomic force nanolithography. (b) Atomic Force Microscopy image of a SAGE-patterned region.

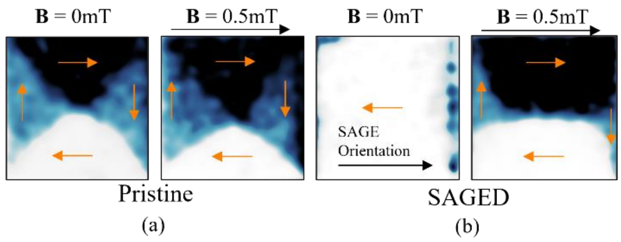

Figure 2: (a) MOKE images of a pristine 30 nm thick Py square in the remanent state (left) and under a 0.5 mT applied field (right). (b) MOKE images of a SAGED Py square (with SAGE orientation along the indicated direction) in the remanent state (left) and under a 0.5 mT field (right) highlighting the emergence of uniaxial anisotropy. The orange arrows in the samples indicate the direction of magnetization (**M**).

2. Results and discussion

A series of 30 nm-thick, 25 μm-wide square permalloy samples were patterned using atomic force nanolithography, employing the SAGE technique. Corrugations were introduced across the entire structure, with systematically varied depth and periodicity to investigate their impact on the magnetization reversal mechanism. The coercive field was found to scale linearly with groove depth, while an increase in periodicity resulted in an inverse relationship with coercivity. These findings highlight the tunability of magnetic anisotropy through controlled nanoscale structuring.

A further extension of this concept was applied to local corrugation in a Py waveguide to investigate its impact on spin wave propagation. The findings revealed that the structured waveguide supported zero-field spin wave propagation with an enhanced amplitude compared to its non-corrugated counterpart. Additionally, it was observed that local corrugation played a crucial role in controlling the vortex chirality in ferromagnetic disks, enabling switching between chiral states under an applied field. Furthermore, the introduction of corrugation enabled the tuning of magnetoresistance in magneto-resistive Py stripes, resulting in an improved linear response in MR devices and offering an alternative approach to the traditional barber pole configuration [5].

References

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