DOMAIN WALL DEVICES FOR INFORMATION STORAGE

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I. INTRODUCTION

Hard disk drives, which have been fulfilling the majority of the storage requirements are reaching a saturation in the areal density growth. Alternative technologies are being sought for supplementing the storage needs. In this connection, domain wall memory plays an important role. In such devices, the domains store information and they are moved around by a spin torque current while reading and writing information (Figure 1(a)). An understanding and precise control of domain wall displacement in nanowires is essential for memory and logic device applications. Currently, domain walls are pinned by creating topographical notches (Figure 1(b)) fabricated by lithography [1]. Stepped nanowires, in which the domains are pinned at corners, has also been proposed as a potential technique to pin the domain walls [2]. In our group, we have been investigating spin textures in ferromagnetic nanowires as a method for pinning domain walls [3]. In one approach (Figure 1(c)), we use annealing induced mixing to form pinning sites as a non-topographical approach. In another approach, we use controlled ion-implantation through the masks as a potential method to form pinning sites for domain wall memory. Recently, we have also been investigating exchange coupled cross-bar layers to form pinning sites. This talk will provide examples of these three approaches.

II. EXPERIMENTAL DETAILS

Magnetic films and multilayers of various types were fabricated by dc magnetron sputtering. Domain wall devices were fabricated by a combination of lithography. An array of characterization techniques such as magnetometry, X-Ray diffraction, X-Ray photoelectron spectroscopy (XPS), Ferromagnetic resonance (FMR), and anisotropy magnetoresistance (AMR) measurements were carried out to understand the properties of films and devices.

III. RESULTS AND DISCUSSION

As our first investigation, we carried annealing induced diffusion to form compositionally modified regions, which form the pinning sites. At first, we fabricated permalloy ($Ni_{80}Fe_{20}$) films coated with different capping layers such as Ta, Cr, Cu and Ru. We investigated the magnetic and magnetodynamic properties through FMR, and AMR measurements before and after annealing the samples at different annealing temperatures. We found that the saturation magnetization of permalloy film decreased from 724 emu/cc to 350 emu/cc, and damping constant increased by 246% while the annealing temperature (T_{an}) was changed from 100 °C to 500 °C. XPS results confirmed increased diffusion of Cr into the middle of permalloy layers with T_{an} (Figure 1(d-e)). We fabricated domain wall devices with and without Cr cross bars (Figure 2(a-b)). We carried out resistance versus field measurements to understand the domain wall pinning (Figure 2(c-d)). The results pointed out that annealing induced local diffusion helps to control critical magnetodynamic properties of ferromagnetic nanowire properties and this intermixing helps to pin domain wall at a precise position. Novel minor R-H loops helped to understand the pinning strength.

In another approach, localized modification of magnetic properties in Co/Pd multilayers based devices by means of ion implantation was investigated. Masks were created using electron beam lithography and B^+ implantation was carried out through the masks. The results from magnetization measurements and X-Ray diffraction measurements at the thin film level indicated that the ion-implantation is effective in changing magnetic anisotropy (Figure 2e-f). The domain images observed by Kerr microscope and MFM indicate that the stripe domain, a signature of perpendicular magnetic anisotropy, is lost after the implantation. Kerr images of the devices at different values of applied field show that the domain walls stop at the pinning centres formed by B^+ ion diffused regions (Figure 3). These results show that localized compositional modification using ion-implantation helps to pin domain walls at precise positions.

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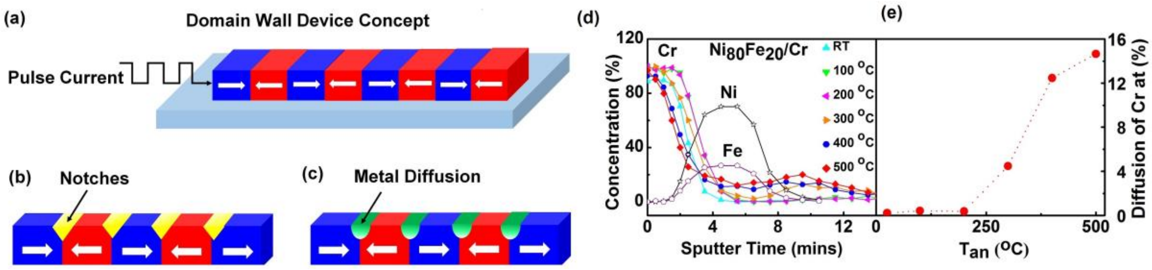

Figure 1. Schematic view of the domain wall concepts and the results of the study. (a) Domain wall device concept, wherein a pulse current is used to move the domain walls (b) Domain wall devices with notches, where physically modified regions act as pinning centres and (c) the devices under this study, where metal diffusion from the crossbars is used to form pinning sites. (d) Concentration of different elements at different depth of the films and (e) the diffusion of Cr at various annealing temperatures.

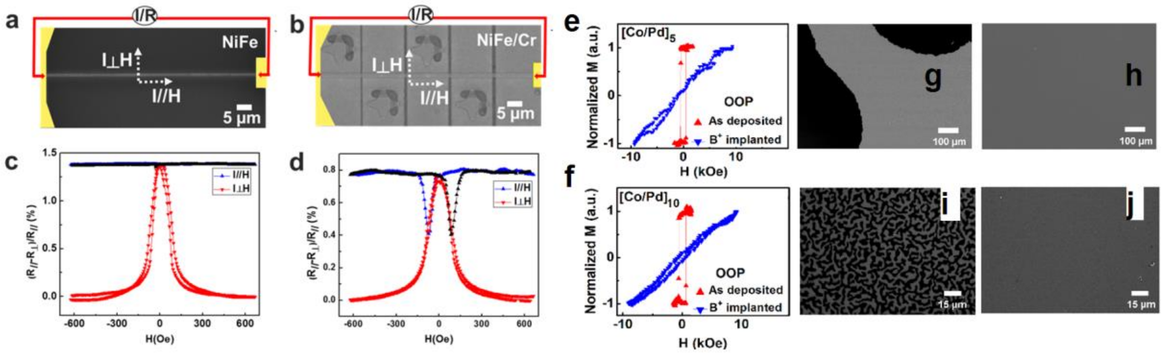

Figure 2. Domain wall devices and the pinning effect. (a) Domain wall devices without Cr crossbars and (b) with Cr crossbars, where Cr diffused regions act as pinning centres; (c) The R-H curves of devices without Cr crossbars and (d) with Cr crossbars, which show a peculiar drop in resistance at fields much larger than the coercivity, indicating the formation of regions with a magnetization orthogonal to the current direction; (e and f) Out-of-plane (OOP) hysteresis loops of Co/Pd multilayers (with 5 and 10 bilayers respectively) before and after B^+ ion-implantation. (g and i) domain images of Co/Pd multilayers before ion-implantation and (h and j) domain images of Co/Pd multilayers after ion-implantation.

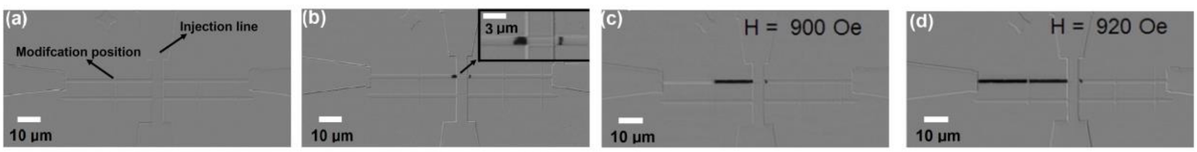

Figure 3. Domain wall pinning effect in Co/Pd multilayer based devices, as observed using Kerr microscopy. (a) Kerr signal from domains after saturation (b) Nucleation of reversed domains (black dots) at the middle of the image, observed after sending an electric-current through injection line to produce magnetic-field. (c) domains observed after the application of a reversal field (900 Oe). The domain has propagated and stopped at the region, where the implantation was carried out; (d) further increase in reversal field (920 Oe) leads to depinning and movement of the domain wall.