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Microscopy and Magnetoresistance studies in zigzag and semi-circle-in-series Permalloy wires

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In recent years there is a growing interest in both theoretical and practical researches about the nanostructured materials. Atomic force microscopy (AFM), magnetic force microscopy (MFM) and Magnetoresistance (MR) due to domain wall scattering in ultra-thin wires can be well controlled by the shape, thickness and size of the wires.

In this study, a field emission electron-beam lithography (Hitiachi 4200) and lift-off process was used to prepare $Ni_{80}Fe_{20}$ zigzag and semi-circle-in-series wires on Si(100) with 100nm SiO_2 buffer-layers. PMMA and copolymer was spin coated onto the substrate under a proper speed and baked at 135^{o}C. After the e-beam writing process, MIBK:IPA and IPA were used to develop the patterns. $Ni_{80}Fe_{20}$ films were deposited by thermal evaporation with a base pressure of $1x10^{-6}$ torr. Zigzag wires with a pitch of 4μm was zigzagged between two gold pads separated by 50μm. Samples with the same line width of 500nm and different thickness were fabricated. The total length of these wires are nearly the same, L= 73 ± 1 μm. Therefore, the number of corners for the wire is 25. MR measurements were made by four-point method in a variable temperature and magnetic field platform (PPMS, Quantum Design Model 6000) in the temperature range 10-300K. The magnetic field was applied in the plane and the field angle is measured with respect to the transverse direction. Resistance at 20kOe was used as the reference when calculating MR percentage, and detailed investigation was performed from –1500 Oe to 1500 Oe.

Magnetic domain observation was made by magnetic force microscopy (MFM, NT-MDT Slolver P47) and the field was applied in the longitudinal or transverse directions before measurement. The semi-circle wires with diameter of 4 μm were patterned between two gold pads separated by 60μm. The total length of these wires were 94 ± 1μm, and there were 15 corners in samples. In longitudinal (transverse) direction, we observed a negative (positive) MR of roughly 0.15 (0.34%) and 0.10% (0.11%). The MR in semi-circle samples attributes to the additional domain walls which accumulated near the 15 corners. In zero magnetic field, when decreasing T from 100 to 10 K, the electrical resistance was monotonically decreased from 755 to 720 ohms ohms. This could be understood due to non-magnetic scattering. In general, Domain wall MR was insensitive to the temperatures, and the magnetic switching field decreases with increasing T. The negative and positive MRs near zero magnetic field are attributed to the domain wall motion. Their values are almost temperature independent. In general, for negative MR, when the positive applied field decreased from saturation, the magnetization began to rotate toward the direction parallel to the wire edge due to the shape anisotropy. As the magnetic field was reversed and increased in magnitude, the magnetization became unstable. At roughly -80 Oe, the magnetization switched simultaneously toward the stable state aligned to the wires in the negative direction, resulting in a jump in resistivity. For positive MR, near zero magnetic field there was a plateau shape positive MR and no abrupt change when the magnetization reversed. We can interpret this effect by the mistracking effect caused by the domain structure. In other word, antiparallel domains and a 180 degree domain wall at the overlap region. The MR started to increase at roughly 40 Oe before the magnetic field was reversed.

For AFM and MFM studies, as an example, Fig. 1 shows AFM (up part) and MFM (down part) images of a zigzag wire consists of 26 straight segments, alternating black and white areas were observed at the corners of the zigzag wire in its remanent state after a magnetic field was applied in the transverse direction of the wire. This indicates that a multi-domain magnetic structure is induced by the shape anisotropy of each segment. The influence on domain wall MR with different film thickness can be elucidated by the difference of domain wall type in different film thickness. The thickness of Bloch wall and Neel wall as function of thickness of Permalloy film has been studied before. According to $Ni_{80}Fe_{20}$ domain wall phase diagram, different type of domain wall dominates at different $Ni_{80}Fe_{20}$ film thickness. For very thick Permalloy films the domain wall is dominated by Bloch-type in the film center and terminated by N'eel caps at the film surface. When reducing the film thickness, the domain wall turns into an asymmetric Bloch wall (vortex wall), then into a complex cross-tie wall and finally for very thin films into a symmetric N'eel wall.

For zigzag wires with 100nm film thickness, asymmetric Bloch wall was dominated and with the calculated wall width 50nm. The wall width (50nm) is smaller than the wire width (500nm) and film thickness (100nm). As a result, domain wall density is highly at corners. Therefore, domain wall scattering was significantly in this film. The domain wall MR is sensitive to the variation of temperature in the wire with 100nm film thickness. As a result, effective anisotropy of zigzag wires is a function a film thickness.

In summary, domain wall resistivity was discussed by zigzag and semi-circle wires that can control the domain configuration well. From AFM, MFM and MR studies, we have shown that in ultra-thin wires both magnetic domain and magnetoresistance can be well controlled by the shape, thickness and size of the wires. Dependence of the domain patterns and domain wall resistivities on film thickness and temperature has been experimental reported. By ameliorating the edge smoothness and linewidth to diameter ratio, the semi-circle-in-series permalloy wires can have very stable and reproducible domain and MR response. For application purpose, the wires studied can be used on spin valve giant magnetoresistance and tunneling magnetic structures to make stable sensors.

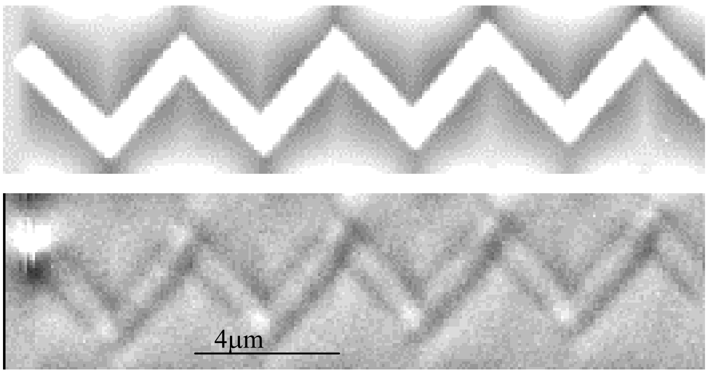

FIG. 1 The atomic force microscope and magnetic force microscopy images of a $Ni_{80}Fe_{20}$ zigzag wire.

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