Critical Phenomena of Roughness with Respect to External Magnetic Field in Ultrathin Ferromagnetic Film

Lee, Kang-Soo*, Lee, Chang-won[1], Cho, Young-jin[1], Seo, Sunae[1], Choe, Sug-Bong
Center for Subwavelength Optics and School of Physics and Astronomy, Seoul National University, Seoul, Korea, South
[1]Samsung Advanced Institute of Technology, Suwon, Korea, South

In ultrathin ferromagnetic films, magnetic domain wall motions can be simply described by one-dimensional strings, which move through two-dimensional random potential. Such randomness makes the system have scaling properties and critical phenomena. Previous works demonstrated that the magnetic domain wall actually exhibits the scaling properties, of which the roughness exponent was probed to be 2/3 in accordance with the theoretical prediction [1,2]. In this work, we test the field-strength dependence of the roughness of driven domain interfaces in CoFe/Pt multilayers. Interestingly, it is found that, whereas the roughness exponent is invariant, the roughness amplitude is very sensitive on the strength of the applied magnetic field. This phenomenon was mentioned in ref [3]. But the detail dependence have not been revealed yet.

For this study, we prepared 50-Å Ta/25-Å Pt/5-Å $Co_{90}Fe_{10}$/10-Å Pt film, deposited on Si substrate with natural SiO_2 layer by dc-magnetron sputtering in ultrahigh vacuum environment. The domain walls are observed by a magneto-optical Kerr-effect microscope. Domain walls are propagated over sufficient distance (We propagated domain walls sufficiently far (4~5 mm) to saturate the roughness at given field) with different magnetic field, then stop with ~5ms field falling time and we immediately capture several images of the domain walls. From these images, the roughness width and roughness exponent are measured at those fields.o

Figure 1 shows the log-log plot of the roughness with respect to the domain wall segment length. The scaling behavior is clearly seen from the figure. The saturation at high L is due to the finite size of our domain wall images. From the slope in the log-log plot, the roughness exponent is invariant being about 2/3, irrespective to the external magnetic field. The fitting values with L less than 10 µm are 0.665±0.036. However the roughness itself is changed as the external magnetic field increases (so velocity increases). As shown in Fig 2, the roughness width exhibits two distinct regimes－it is decreased with increasing magnetic field and then saturated. The threshold field between the two distinct regimes is closely related with the quenched random pinning strength, since the roughness is determined by balancing the quenched random friction with the tension (which originates from domain wall energy tending to shorten the walls) and Zeeman Force. This will be another characteristic field index of quenched pinning strength of films like the one in the field-velocity relation. (In the field vs velocity relation at zero temperature, there is also critical threshold field at which domain walls start to move.)

References:

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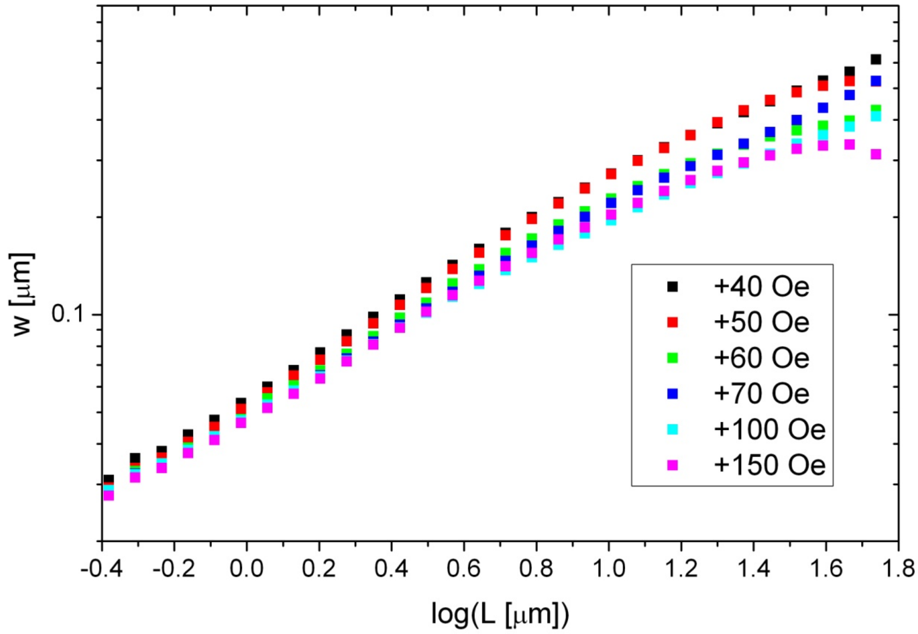

Fig 1. The log-log scaling plot of the roughness w with respective to the domain wall segment length L. Each data is collected after sufficient (a few mm over) propagation with different external field. The slope which is called roughness exponent corresponds theoretically predicted 2/3. However the offset, or the roughness widths at given L seem to be discrete depending on the applied field strength.

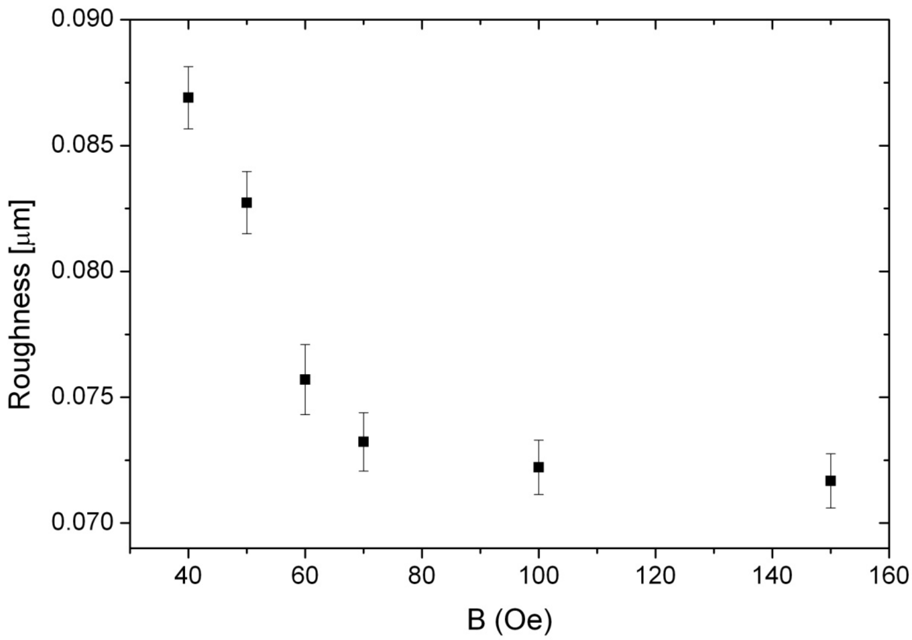

Fig 2. The roughness width of the domain walls at domain wall size 1.9 μm in [25-Å Pt/5-Å Co90Fe10/10-Å Pt] PMA film. This graph shows that the roughness width becomes smaller as the applied magnetic field increases until some critical field (about 75 Oe). After the critical field, the roughness of the domain walls seems to be saturated.