Journal of Magnetics 11(2), 83-86 (2006)

Simulation of the Effect of Soft Underlayer Domain Wall Structure on Output Signal in Perpendicular Magnetic Recording

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(Received 28 March 2006)

Controlling magnetic domains in soft underlayer (SUL) of perpendicular magnetic recording (PMR) is an important issue for the application of PMR in HDD. We studied the magnetic domain structures in SUL using the finite element based micromagnetic simulation (FEMM) for the SUL models with different thicknesses. The purpose is to simulate the magnetic domain wall noise when the SUL thickness and saturation magnetization are changed. The simulation results show that a 15 nm SUL forms simpler Neel wall domain wall pattern and 40 nm SUL forms complex Bloch wall. To visualize the effect of these domain walls stray field at a read sensor position, the magnetic stray field of the domain walls at air bearing surface (ABS) which is 50 nm above the SUL was simulated and the results imply that Bloch walls have stronger stray field with more complicated field patterns than Neel walls and this becomes a significant noise source. Therefore, the thickness of the SUL should be controlled to avoid the formation of Bloch walls.

Key words : FEMM (Finite Element Micromagnetic Model), micromagnetics, PMR (Permendicular Magnetic Recording), soft underlayer, domain wall

1. Introcuction

The rapid increase in areal density of hard disc drive (HDD) has been slowed down recently due to the saturation of longitudinal magnetic recording technology. Transition from longitudinal to perpendicular magnetic recording (PMR) mechanism will be able to sustain the areal density growth. A critical requirement for PMR application is the media structures that consist of a recording layer and soft magnetic underlayer (SUL). The SUL is essential to conducts the magnetic flux from the write head and also helps to enhance the write field during the writing process. However, the stray field from magnetic domain walls in the SUL becomes one of the main sources of noise during the reading process. There are a lots of efforts to try to eliminate the SUL domains formation [1, 2].

Domain wall structure in the SUL depends on the magnetic properties and thickness of the SUL. The SUL thickness has to be optimized such that it is thick enough to conduct flux and thin enough to reduce magnetic noise. In this study, we simulate the remanent magnetization state of the SUL with different thicknesses and magnetic properties and compare the simulated domain wall structures and their stray field patterns.

2. Modeling

We use the finite element micromagnetic method to compute the remanent magnetization state of the magnetic thin film models by solving the Landau-Liftshitz equation. Starting from the finite element discretization of the total energy, the effective field can be evaluated using the box method [3]. Each node has its magnetic moment and its effective field. The demagnetizing field is calculated using the hybrid finite element boundary method.

The size of our simulation model is 700 nm × 500 nm with two thicknesses, 40 nm and 15 nm. The reason is that we want to create two types of domain wall, Neel and Bloch wall. Neel wall forms in film thickness less than 20 nm, while Bloch wall forms in thickness above 30 nm.

We mesh our model using a 5 nm mesh size, which is

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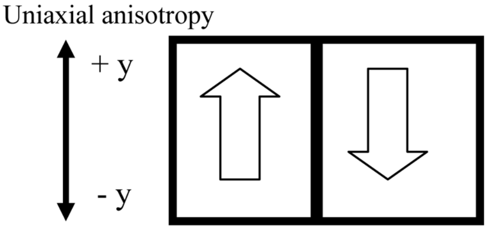


Fig. 1. Schematic drawing of the domain wall creation methods. Arrows indicate the magnetization direction.

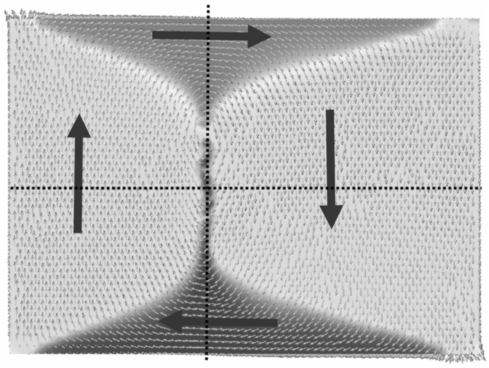


Fig. 2. The remanent state of the model in equilibrium flux closure state.

sufficiently small as compared to the exchange length. This leads to more than 21000 total numbers of nodes.

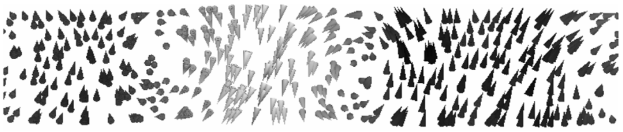
In order to create a domain wall, we deliberately assign a large uniaxial anisotropy energy ($K = 1 \times 10^5$ J/m^3) along the y-axis, as shown in Fig. 1. We set the initial magnetization direction of a half of the film in the +y direction and the other half in the –y direction. Finally, we let the system relax to an equilibrium state. At the equilibrium state, the magnetization turns into a 4-state flux-closure formation with a reduced domain wall size at the centre, as shown in Fig. 2.

Next, we compute the magnetic stray field from the magnetic films at a distance of 50 nm above the film. This is a typical distance from the writing pole to the SUL in an actual PMR system. The stray field, in particular the perpendicular component of the stray field represents the domain wall noise from the SUL. We also compute the domain wall noise by changing the saturation magnetization ($4\pi M_s$) of the film from 1.0 T to 2.0 T.

3. Simulation Results

All the simulated equilibrium magnetization states of SUL form the similar 4-state domains structure regardless of thickness and saturation magnetization variation. The main difference lies in the domain wall structure which separates the domains. The domain wall structures depend on the thickness of the magnetic layer. Fig. 3. shows the cross-sectional views of magnetization state inside the domain walls in the SUL. Fig. 3(a) shows the formation of a Bloch wall in 40 nm SUL. The magnetization in the domain wall points out-of-plane. However, the magnetization of domain wall in 15 nm SUL aligned in-plane and hence forms a Neel wall

The formation of Bloch and Neel walls can be understood in term of magnetostatic energy minimization. When the magnetic layer is thick, it is more favorable for the magnetization to point vertical to the film plane because the energy is minimum. When the film thickness



(a) t = 40nm, Bloch wall

(b) t = 15nm, Neel wall

Fig. 3. The cross-sectional view of the remanent state of SUL across the domain wall.

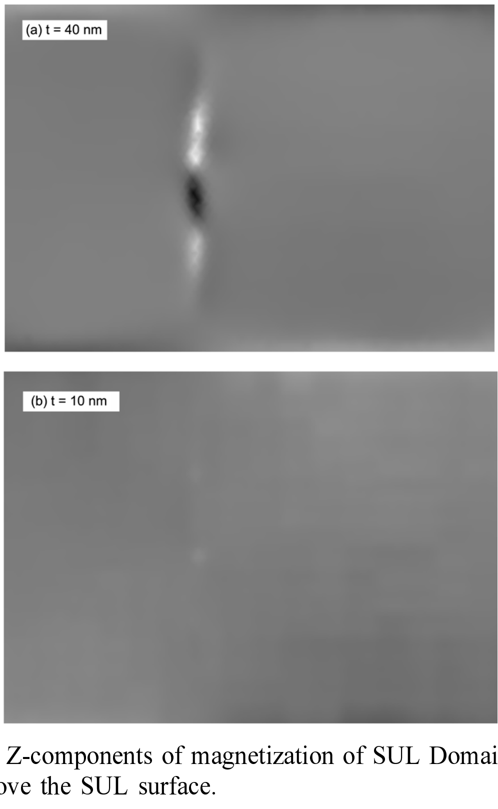


Fig. 4. Z-components of magnetization of SUL Domain at 50 nm above the SUL surface.

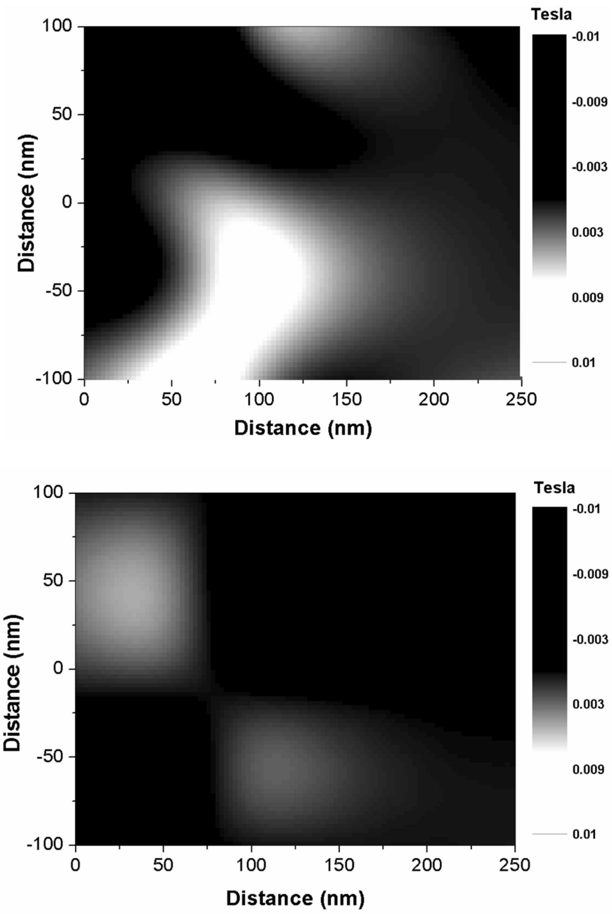


Fig. 5. (Top) Stray field from the Bloch wall of 40 nm SUL and (Bottom) Stray field from Neel wall of 10 nm SUL.

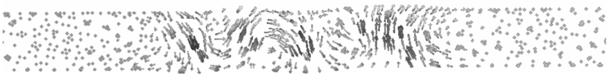
is reduced, Bloch domain wall energy increases because the top and bottom surface magnetic charges are closer. If the film thickness is sufficiently thin, the magnetization in the domain wall is forced to point in-plane to reduce magnetostatic energy, hence the Neel wall forms (Fig. 3(b)).

Out-of-plane magnetization (Mz) is plotted in Fig. 4 for both film thicknesses. The Mz component is clearly visible in Fig. 4(a) while nearly no Mz component in Fig. 4(b).

The black and white strip in Fig. 4(a) shows the magnetization component point +z and –z direction. This indicates the formation of vortices which we will discuss later.

The z-component of stray field strength (Hz) 50 nm above the surface of the SUL is computed and is shown in Fig. 5. The SUL with Bloch wall generates complicated Hz field and the field strength is quite large, about 100 Oe. The black and white shading shows the strength of stray field, Hz in opposite direction. On the other hand, the stray field from Neel wall is relatively weak, less than 50Oe. Therefore, in this case, magnetic domain wall noise from Neel wall is half of the noise comes from Bloch wall.

(a) $4\pi M_s = 1.0$ T



(b) $4\pi M_s = 1.5$ T

(c) $4\pi M_s = 2.0$ T

Fig. 6. The cross-sectional view of the equilibrium magnetic state of SUL along the Bloch walls for different $4\pi M_s$.

The complexity of the stray field is a result of complicated domain wall structure formed within the Bloch wall. This complicated domain wall structure can be seen when we change the saturation magnetization value of the 40 nm thick SUL.

Fig. 6 shows the cross-sectional view inside the domain walls. It shows the strong correlation between domain wall patterns and the $4\pi M_s$ of the film. The first observation is that domain wall size and its out-of-plane magnetic moments decreases with increasing 4πMs, but still the stray filed at ABS is increased with increasing 4πMs. This is due to the increase in demagnetization energy when the magnetic moment pointing vertically. Since the demagnetization energy is proportional to the z-component of magnetization, the minimization of demagnetizing energy prevents the out-of-plan magnetization component from forming. The second observation is the simpler Bloch wall structure in higher 4πMs film. The tendency for vortex formation within Bloch wall is suppressed as Ms is increased.

4. Conclusion

We simulated the magnetic domain structure and its stray field patterns for two different SUL thicknesses and three different saturation magnetization. Our results show that 40 nm SUL is sufficient to form Bloch wall and generates strong and complicated stray field at ABS. The stray field can be a strong source of magnetic noise. The complexity of vortices formed within Bloch wall depends on the magnetic layer saturation magnetization. On the other hand, a 15 nm thick SUL suppress the formation of

Bloch wall to Neel wall. The direct consequence of this is a much simplified domain wall structure and reduced stray field noise.

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