Control of magnetic skyrmion: Theoretical design of skyrmion device

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The key to develop the magnetic memory devices is nothing more than the control technique of the magnetic texture by external fields. The recent studies reveal that skyrmion,[1] the nano-sized magnetic texture, is driven by a much smaller electric current density than that for the magnetic domain wall motion, and hence, the potential application of the skyrmion has attracted much attention. To utilize the skyrmion for device applications, the control technique for creation (write), annihilation (erase) and motion (transport) must be established. We theoretically study the creation, annihilation and current-driven motion of skyrmion in the chiral and dipolar magnets in two dimensions, by numerically solving Landau-Lifshitz-Gilbert equation. By the numerical study, we explore the optimal condition to control the skyrmion in the ferromagnetic background.[2]

Figure 1 shows the schematic figure of the magnetic skyrmion in the thin-film system. In Fig.1 (a), the vortex like structure is in the ferromagnetic background and the magnetic moments wind perpendicular to the radial direction of the circular magnetic texture. This is the Bloch skyrmion and is often observed in the chiral magnets. In Fig.1 (b), on the other hand, the winding plane includes the radial direction. This is the Néel skyrmion and is often found in the artificially composed super-lattice magnet. The Bloch and the Néel skyrmions are in the same topological class: The topology of the skyrmion is characterized by the skyrmion number which is defined by the wrapping number of a sphere by the magnetic moments. The skyrmion number of the perfect ferromagnetic state is zero but it is -1 for the skyrmion in the ferromagnetic background. Because of the difference in topology, the skyrmion cannot be reached from the perfect ferromagnetic state within the continuous deformation of the magnetic texture. As a result, the skyrmion carries a (meta-) stability and is protected by a potential barrier. To overcome this barrier, a large energy enough to destroy the magnetic ordering is needed. However, the spatial discontinuity gives a favorable environment to change the topology of magnetic texture and the stability is reduced. For example, the skyrmion is created rather easily at the edge of a magnet in comparison to the deep inside of the system. Also the local heating provides the hot spot where the skyrmions are nucleated.

The topology of the skyrmion is of crucial importance for the current driven motion: Because of the vorticity of the swirling magnetic texture, a Magnus effect occurs along with the motion of the skyrmion. By utilizing this effect, the large spin-transfer-torque effect appears and moving velocity of the skyrmion is enhanced compared to the domain wall motion.

We show the numerical results of the real-time dynamics of the magnetic textures induced by external stimuli and discuss the creation, annihilation and current-driven motion of skyrmion(s) for the theoretical design of the skyrmion memory devices.

References

1) As a review: N. Nagaosa, and Y. Tokura, Nat. Nanotechnol., **8** (2013) 899.
2) W. Koshibae, Y. Kaneko, J. Iwasaki, M. Kawasaki, Y. Tokura and N. Nagaosa, Jpn. J. Appl. Phys., **54** (2015) 053001.

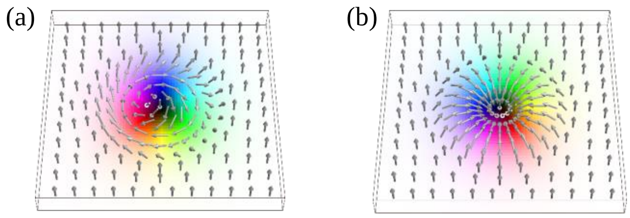

Fig. 1 Shematic figure of the magnetic skyrmion.
(a) Bloch skyrmion. (b) Néel skyrmion. (see text)