

MAGNETIC SKYRMION LOGIC GATES

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I. INTRODUCTION

Magnetic skyrmions, which are topological particle-like excitations in ferromagnets, have attracted a lot of attention recently. Skyrmionics is an attempt to use magnetic skyrmions as information carriers in next generation spintronic devices. Proposals of manipulations and operations of skyrmions are highly desired. It has been demonstrated that a skyrmion can be generated by converting a domain-wall pair at a narrow-wide junction [1]. In this work, we show that the conversion, duplication and merging of isolated skyrmions with different chirality and topology are possible all in one system. We also demonstrate the conversion of a skyrmion into another form of a skyrmion, i.e., a bimeron. We design spin logic gates such as the AND and OR gates based on manipulations of skyrmions. These results provide important guidelines for utilizing the topology of nanoscale spin textures as information carriers in novel magnetic sensors and spin logic devices.

II. RESULTS

We investigated the skyrmion conversion between different magnetic materials. The results are shown in Fig. 1. Fig. 1a shows the reversible conversion between a domain-wall pair and a skyrmion, which has been report in ref. 1. For Fig. 1b, we have assumed the sign of the DMI is positive in the left input region, while it is negative in the right output region. The helicity is determined by the DMI. The helicity of skyrmion in the left region is 0 while 1 for the skyrmion in the right region. Fig. 1c shows the skyrmion conversion when the magnetization between the left and right side with the same DMI. The stable skyrmion in the left region is a skyrmion while an anti-skyrmion in the right region. And the helicity is also reversed. Fig. 1d shows that skyrmion conversions when both the sign of the DMI and the direction of the magnetization are opposite between the left and right region. The skyrmion with the helicity of 0 is converted into an anti-skyrmion with the helicity of 0.

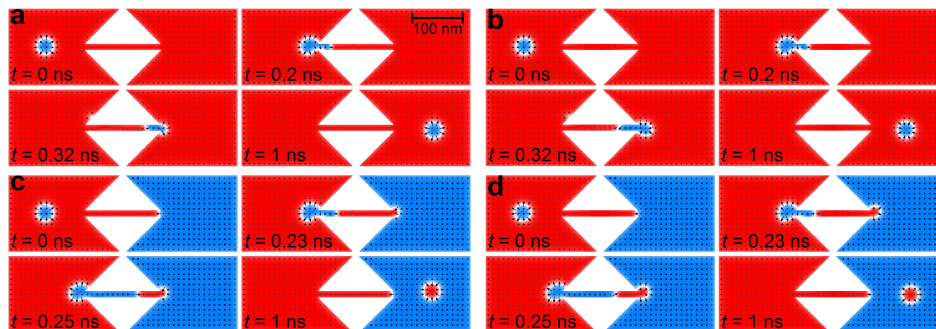


Fig. 1 Conversions between skyrmions and anti-skyrmions. a) Conversion between a skyrmion and a skyrmion with identical out-going helicity. b) Conversion between a skyrmion and a skyrmion with opposite in-going helicity. c) Conversion between a skyrmion and an anti-skyrmion with opposite in-going helicity. d) Conversion between a skyrmion and an anti-skyrmion with identical out-going helicity.

The conversion between a skyrmion and a bimeron has been demonstrated in this work. For the skyrmions in the materials with perpendicular magnetic anisotropy (PMA), the tail must be up or down direction. In the easy-plane sample, the tail must be in-plane. Then, in the right output region, a skyrmion is converted into a bimeron, which is a pair of merons. A bimeron (anti-bimeron) has a skyrmion number of 1 (-1) and is another form of a skyrmion which exists in easy-plane sample.

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Based on the reversible conversion between skyrmions and domain-wall pairs, we design the logical OR and AND operations, as shown in Fig. 2. In the skyrmion-based logic gates, binary 0 corresponds to the absence of a skyrmion and binary 1 corresponds to the present of a skyrmion. The OR ($0+0=0$, $0+1=1$, $1+0=1$, and $1+1=1$) and AND ($0+0=0$, $0+1=0$, $1+0=0$, and $1+1=1$) gates can be realized by using skyrmions in the designed devices. For the process of $0+0=0$, there is no output when there is no input.

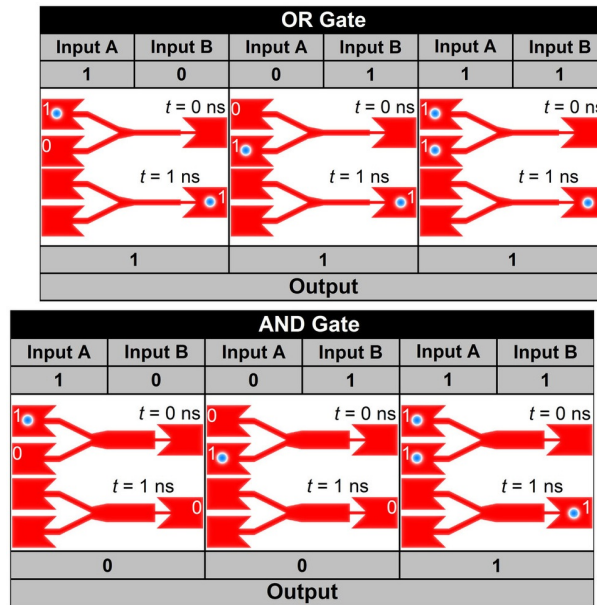


Fig. 2 Skyrmion-based logical OR and AND operation.

REFERENCES

- 1) Y. Zhou and M. Ezawa, "A reversible conversion between a skyrmion and a domain-wall pair in junction geometry", *Nat. Commun.* 5, 4652, (2014).