Detection of paired domain walls in a ferromagnetic ring by a bend resistance measurement

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Abstract

We have investigated dynamics of paired domain walls in a microfabricated ferromagnetic ring by using a ballistic transport character of a two-dimensional electron gas (2DEG) microcross. The stray field from the domain walls results in a change in the bend resistance of the 2DEG cross lying beneath the ferromagnetic ring depending on the positions of the domain walls. The measurements for different directional angles of the applied magnetic field reveal that the domain wall behavior is strongly affected by identical local defects in the ring. We have also studied a response of paired domain walls under a pulsed magnetic field. We find that the paired domain walls switch the positions without annihilation under a pulsed magnetic field with a short rise time.

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1. Introduction

Study for manipulation of domain walls inside a microfabricated ferromagnet is an important research topic for developing a future magnetic device based on domain wall motion. We can detect a local stray field from a tiny individual ferromagnet placed above a two-dimensional electron gas (2DEG) cross by local Hall effect\cite{1,2}. The Hall resistance is roughly proportional to the net magnetic flux of the stray field from the ferromagnet inside the 2DEG cross. For detection of a domain wall, the Hall signal shows different signs between head-to-head (H–H) and tail-to-tail (T–T) domain walls\cite{3} and is less sensitive to the position of the domain wall. By contrast, a bend resistance reflects a spatial distribution of the stray field\cite{4–6} and, therefore, contains an information of the position of the domain wall. In the present study, we have investigated dynamics of paired domain walls in a ferromagnetic ring by the bend resistance measurement. The ring structure is suitable for investigating domain wall behavior since paired domain walls (H–H and T–T domain walls) are easily stabilized in the ring, which is called an onion state\cite{7,8}. When the paired domain walls collide, the magnetic state becomes a flux-closure vortex state without domain walls.

2. Experimental

We fabricated a NiFe ring with diameter of 1 \( \mu \)m on a GaAs/AlGaAs 2DEG cross as shown in Fig. 1(a). We can apply an in-plane magnetic field \( B \) for any directional angles \( \phi \) by an electromagnet and a pulsed magnetic field \( B_p \) by injecting a pulsed current into the Ti/Au RF transmission line between the ferromagnetic ring and the 2DEG cross. We can monitor the magnetic state in the ring by measuring the bend resistance obtained by the current–voltage configuration illustrated in Fig. 1 (a). We carried out the measurements at \( T \sim 4\) K.

3. Results

Fig. 2(a) shows the bend resistance with sweeping in-plane magnetic field \( B \) in the \( y \) direction (\( \phi = 90^\circ \)). We can...
clearly distinguish the magnetic state between the onion state and the vortex state. We plot the bend resistance in remanent state (zero field) $R_0$ as a function of directional angle of the initially applied in-plane magnetic field in Fig. 2(b). The signal changes with the directional angle since the remanent state is the onion state where the paired domain walls are roughly aligned in the direction of the initial field. The bend resistance is dependent on the positions of the paired domain walls [5]. The inset of Fig. 2(b) shows a detailed observation of change in the bend resistance near $90^\circ$. We can see discrete jumps in the trace which implies that the paired domain walls are stabilized in the local pinning sites near the initial positions determined by the applied field. The resolution of the shift due to the local defects is less than $1^\circ$, which means that we can detect a slight shift of the domain walls even in a nanometer scale by the bend resistance measurement, which is more sensitive than by the local Hall resistance measurements.

Figure 2(c) shows switching fields $B_{c1} \sim B_{c4}$ between the magnetic states as a function of directional angle of the in-plane magnetic field. The distribution for the onion-vortex transition widely spreads comparing with the vortex-reverse onion transition. The onion-vortex transition results from a domain wall depinning process, which is strongly dependent on the identical local defects near the domain wall. By contrast, the vortex-reverse onion transition is accompanied with a nucleation of domain walls, which is less sensitive to the local defects [9].

We have also investigated dynamics of paired domain walls under a pulsed magnetic field [10]. Here we demonstrate a controlled depinning of the domain walls depending on the rise time of the pulsed magnetic field. The static in-plane magnetic field is fixed $70$ mT in the $y$ direction, which is a little smaller than the switching field for the onion-vortex transition (see Fig. 2(a)). Under the static field, we applied a pulsed magnetic field with a variable rise time in the $x$ direction which depins the domain walls and controls the direction of the domain wall propagations illustrated in Fig. 3. The paired domain walls have different depinning fields for the pulsed field due to the local defects, $B_{d1} \sim 3$ mT and $B_{d2} \sim 17$ mT. After the depinning from the initial position, the domain wall propagates along the half path of the ring toward the opposite side.

The magnetic state after the application of the pulsed magnetic field whose amplitude is higher than the both depinning fields depends on the rise time of the pulsed field.

Fig. 1. (a) SEM image of the device. The magnetic state in the NiFe ring is controlled by applying a static in-plane magnetic field $B$ or a pulsed magnetic field $B_p$, whose change is detected by measuring the bend resistance of the 2DEG cross lying beneath the ring. (b) SEM image of the NiFe ring. Diameter: $1$ μm; line width: $70$ nm; thickness: $30$ nm. (c) Schematic illustration of the cross-section of the device.

Fig. 2. (a) Bend resistance as a function of in-plane magnetic field $B$. The switching between the onion states and the vortex states is clearly seen in the trace. (b) Zero field bend resistance as a function of directional angle $\phi$ of the initially applied magnetic field. Inset: detailed measurements for $\phi = 80^\circ \sim 100^\circ$. (c) Switchings field distribution as a function of directional angle $\phi$ of the in-plane magnetic field.
There is a time delay $\Delta t_d$ between the depinnings of the paired domain walls because of the unavoidable difference of the depinning field. We can avoid an annihilation of the paired domain walls and can switch the positions of the paired domain walls if the time delay $\Delta t_d$ is smaller than the time of the domain wall displacement $\Delta t_{pr}$ along the half path of the ring. The threshold of the rise time is about 5 ns, which is comparable to the time of the displacement calculated by a micromagnetics simulation [11].

4. Summary

We have investigated dynamics of paired domain walls in a ferromagnetic ring driven by a static magnetic field or a pulsed magnetic field. The change in the magnetic state clearly appears in the bend resistance of the 2DEG cross lying beneath the ring, which implies that the bend resistance magnetometry is useful for detecting a slight change in a spatially varying magnetic field even in a nanometer scale.

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References