Microscopic View on a Single Domain Wall
Moving through Ups and Downs of an Atomic Washboard Potential.

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Introduction

It is the intrinsic structure and the dynamical properties of the domain walls in ferromagnetic materials, which determine the major properties of the most ferromagnetic samples. Semi-classical, continuous model of a domain wall gives good agreement with most experiments. However, it was shown that for the narrow domain walls, the discrete nature of spin should be taken into account. This effectively leads to an additional term in the energy: the Peierls potential that has the periodicity of the crystal lattice. Although very rich dynamic properties were predicted for a domain wall moving in such a potential (for example, a new type of elementary topological excitations – kinks and breathers are possible in this system) all the previous experiments have failed to detect the presence of the Peierls potential, since the sensitivity required is very high (one needs to be able to detect a domain wall propagation on the sub-atomic scale).

Here we use ballistic Hall probes made of a 2DEG to investigate the motion of very narrow domain walls in garnet films at the helium temperatures. Very high sensitivity of our probes allows detecting the transitions of a domain wall between the adjacent Peierls valleys as well as the dynamics of the wall within the Peierls valley.

Experimental Technique and Samples

Ballistic Hall probes 2 μm × 2 μm in size, made of high-mobility 2DEG (Fig.1a), were used to study the propagation of the domain walls in a uniaxial garnet film (Fig.1b). The garnet film was a single-crystal, multi-domain sample with magnetization perpendicular to the surface ([111] direction). The thickness of the garnet film is ~20 μm, characteristic domain width ~14 μm, the width of the domain walls at helium temperatures is ~10 nm. The film was pressed against the surface of the Hall probe, and the estimated distance between the surface of the garnet and the surface of the probe is less than 100 nm. Most of our experiments were done at low (below 77 K) temperatures.

When a magnetic field is applied perpendicular to the surface of the sample, the domains with preferable orientation start to grow, and those with unfavorable orientation start to shrink. This effectively causes domain walls to move, and eventually one can get right underneath of the Hall probe. As the domain wall passes underneath of the Hall probe, it changes the average magnetic field in the sensor area. It was shown previously, that the Hall response of the ballistic hall magnetometers is directly proportional to the average magnetic field in the central area. Thus, taking in to account that the domain walls in this material moves as rigid planes by parallel shifts to itself, changes in the Hall signal can be translated into the domain wall displacements.

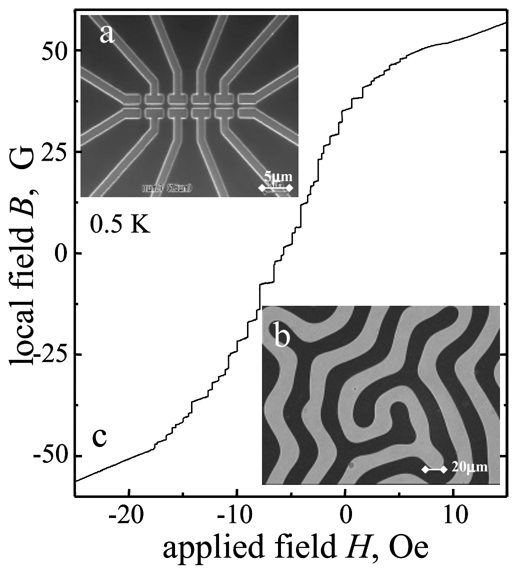

Fig.1 SEM micrograph of one of our devise with 5 Hall crosses (a). A micrograph of a garnet film, taken in transmitted polarized light. Domains of different orientations are visible due to Faraday effect (b). Local magnetic field under one of the Hall crosses (c).

Experimental Results and Discussion

Typical example of the measurements of a domain wall propagating underneath of the Hall probe is presented on Fig. 1c. For H<-18 Oe and for H>8 Oe the domain wall is far away from the cross, so only linear signal from the external magnetic field is measured. However, as the domain wall passes underneath of the Hall probe (-18 Oe < H < 8 Oe), a step-like signal is detected. This is usually called the Barkhausen jumps, which are due to pinning and de-pinning of the domain wall on individual pinning centers.

The jumps on Fig. 1c correspond to domain wall propagation on the level from 10 nm to 100 nm. However, if the domain wall was relaxed just before the measurements by exposing it to AC magnetic field of decreasing amplitude, than even smaller jumps could be detected (Fig. 2a). These jumps are of constant size 1.4 ± 0.1 nm, which corresponds with a good precision to the distance between {-110} atomic planes (1.47 nm) in garnet, which are the easy planes.

The monoatomic steps like in Fig. 2a were detected routinely, independently of the specific place on our sample. We note that this is the first observation of the domain wall propagation between the adjacent Peierls valley.

To get better a physical insight into dynamics of transitions between adjacent Peierls valleys, AC susceptibility at different excitation amplitudes was measured (Fig. 2b,c). Zero excitation corresponds to the relaxed state of the domain wall (located at the bottom of a Peierls valley). Any nonzero AC excitation causes the domain wall oscillating inside the Peierls potential, and the oscillation amplitude increases as the excitation signal increases.

A number of characteristic features can be noticed on these curves. The amplitude of the AC susceptibility remains zero until the AC excitation amplitude reaches a certain critical level H^*. At the same time a pronounced jump is measured at H^* in the imaginary part of AC susceptibility (imaginary part corresponds to the dissipations in the system). The level of dissipation stays constant until the next jump occurs (both in real and imaginary parts of AC susceptibility). This jump corresponds to the domain wall moving to the adjacent Peierls valley.

These observations are consistent with a model of "kinks", topological excitations, which can arise in a system, with a periodic underlying potential. A kink is an object that consists of two parts of a domain wall shifted by one interatomic distance with respect to each other. A pair of kinks is shown in Fig.2d. The bigger the size of the shifted part the higher the AC susceptibility signal. However, only kinks of finite size are stable. Magnetic field H^* corresponds to the generation of stable kinks, which can then propagate through the domain wall. Propagation of a kink through the whole sample corresponds to a domain wall shift by one interatomic distance. At this moment the second jump in AC susceptibility occurs.

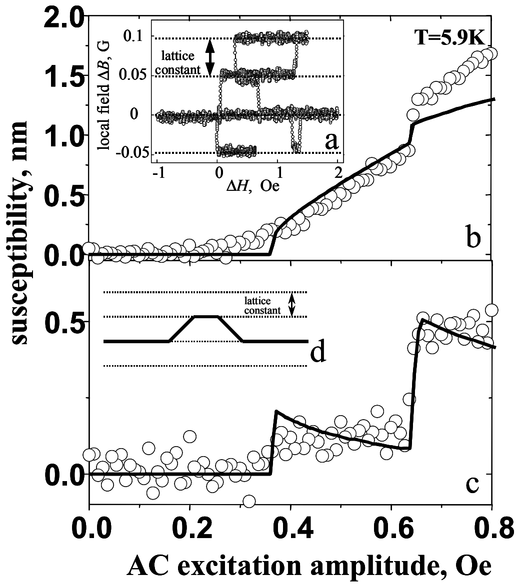

Fig. 2 Domain wall jumps between adjacent Peierls valleys (a). Amplitude (b) and imaginary part (c) of AC susceptibility vs the excitation amplitude, measured in units of domain wall propagation. Schematic representation of kinks (d).

Conclusions

For the first time, the motion of an individual domain wall in the Peierls potential was observed. The high sensitivity to local displacements of a domain wall was achieved due to low intrinsic noise of ballistic Hall probes. The dynamics of domain walls is discussed within a model of kinks, topological excitations, which gives good quantitative agreement with the experimental observations.