CURRENT-INDUCED DOMAIN WALL DYNAMICS

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When combining transport with magnetic materials on the nanoscale, a range of exciting and novel phenomena emerge. Due to the interaction of the current with the magnetization, the spin transfer torque effect leads to current-induced domain wall motion (CIDM) [1-3], which we study in detail. In CIDM, electrons transfer angular momentum and thereby push a domain wall [1-3]. We have comprehensively investigated this effect and observed that this interaction is strongly dependent on the temperature [3] and the wall spin structure [2]. So far, primarily current pulses have been employed to investigate domain wall displacements and strongly stochastic behaviour has been observed.

More reproducible behaviour is found if AC currents are used to excite domain wall oscillations, which are inherently reproducible. To generate a domain wall oscillator a restoring force is necessary, which can be provided by a constriction that generates an attractive potential well for a domain wall, which then acts as a quasiparticle [4]. The depth of the potential well, was found to increase with decreasing constriction width, and the well width was found to extend far beyond the physical size of the constriction [4].
To fully characterize the pinning potential, the curvature has to be determined in addition to the width and the depth. To study the curvature, the resonance frequency of the domain wall has to be ascertained and to this end, we inject AC currents with variable frequency into the structure shown in Fig. 1 (a) [5]. We then measure the depinning field as a function of the injected microwave frequency as shown in Fig. 2 (a) (blue squares) for a transverse wall (Fig. 1 (b)). We observe a dip of the depinning field at a resonance frequency of about 1.3 GHz even for low current densities of 10E10 A/m^2 and the eigenmode consists of the whole wall moving. Next we consider a pinned vortex wall (Fig. 1 (c)) and a strong dip in the depinning field is observed at around 800 MHz (Fig. 2 (b), blue squares). Here the eigenmode consists of the vortex core oscillation. To obtain the resonance frequencies at variable fields we employ a DC homodyne detection scheme:
As the domain wall oscillates, the resistance of the magnetic structure is modulated due to the anisotropic magnetoresistance in phase with the domain wall position. If the quasiparticle happens to be excited at the resonance frequency, the varying resistance will rectify the injected high frequency current and a DC voltage is developed across the structure. We plot the DC response for the vortex wall pinned at the constriction in Fig. 2 (b) (red line). We see a dispersion-like signal with a change in the sign exactly at the resonance frequency, which allows us to determine the resonance from the DC signal. For the transverse wall the expected signal is much weaker since the oscillation has a smaller amplitude, as visible from the smaller change in the depinning field compared to the vortex wall and this is also reflected in the smaller DC signal (Fig. 2 (a) (red line)).
The domain wall resonance frequency was measured for different external magnetic fields and was found to increase with increasing field so that we can conclude that the potential well curvature can be engineered by varying the external field [5].
To directly determine the potential U(x) we can use the power dependence of the resonance frequency [5]. From the resonance frequency as a function of the power, we obtain the oscillation period and, since the energy of an oscillator is proportional to the square of the driving force, also as a function of the energy in the system. From the energy dependence of the oscillation period we can for the first time directly determine U(x) as shown in Fig. 2 (c) with the absolute width of the potential well determined as described in [4]. The blue dots are calculated from the measured oscillator periods and the red line indicates the parabolic part of the potential well. As expected the domain wall potential flattens far away from the origin, indicating a non-harmonic (non-linear) contribution [5].
Very recently the relation between the non-adiabaticity parameter β and the damping constant α were investigated using pulse-induced wall displacement and periodic transformations between vortex and transverse walls were observed, which yield that β does not equal α.

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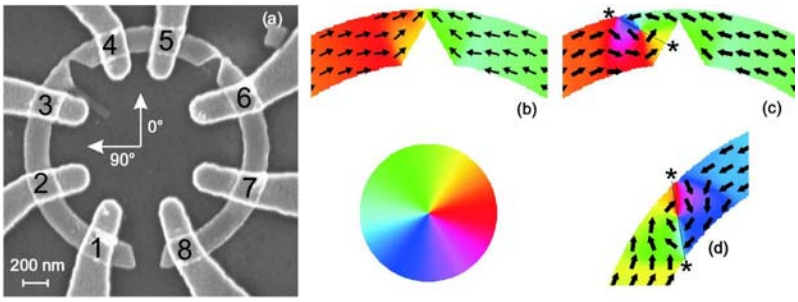

Fig. 1: (a) SEM image of the device used with the AC current injected between contacts 3 and 4. Micromagnetic simulations of a pinned transverse wall (b), pinned vortex wall (c) and a free vortex wall (d).

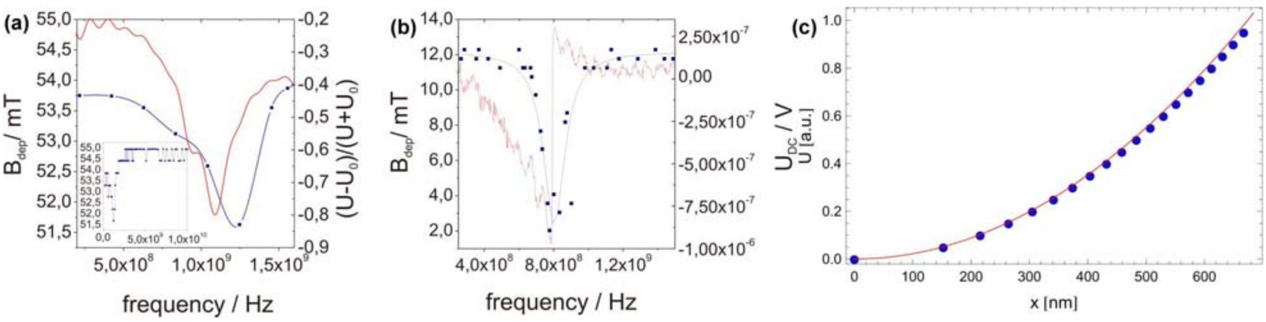

Fig. 2: Depinning field (blue squares) and DC signal (red line) for a transverse wall (a) and a vortex wall (b). In (c) the potential U(x) is directly determined and a non-harmonic contribution is found.