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How well-defined are closure domains?

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Abstract

The character of closure domains was investigated by numerical micromagnetic methods for different anisotropy functionals. Closure domain walls are undefined in the classical sense, but sharp wall-like transitions can be formed if the anisotropy functional is stationary in the center of the closure domains. © 1999 Elsevier Science B.V. All rights reserved.

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To adjust to the conflicting requirements of stray field and anisotropy, strongly misoriented soft magnetic samples form the so-called closure domains which are magnetized more or less parallel to the surface. They carry a higher energy density than the basic domains because a misoriented surface contains by definition no easy direction. The walls separating them can for this reason never exist in local equilibrium as pointed out first by Privorotskii [1]. Only a calculation of the domain pattern as a whole can answer the question whether closure domains exist at all, or whether they are in reality only a convenient representation for a continuously rotating magnetization zone with no distinct domain walls. We investigated the character of closure domains for Landau-type domain models [2] as shown in Fig. 1 with rigorous numerical simulations in two dimensions based on the procedures of Ref. [3]. A reduced uniaxial anisotropy of $Q = K_u/K_d = 0.04$ (A = exchange stiffness constant, K_u = uniaxial anisotropy constant, $K_d = J_s^2/(2\mu_0)$ = stray field energy constant) with a perpendicular easy axis was used throughout. Other anisotropies were added to study their effect. The plate thickness was chosen mostly as $D \geqslant 20\Delta$ ($\Delta = \sqrt{A/K_u}$), which is well above the critical thickness for stripe domain formation. To compare the structures we used the exchange energy density which should be concentrated for regular domain patterns in the domain walls, while becoming virtually zero in the domains (compare Fig. 2). Only the characteristic central upper sections of the complete calculated structures are shown. For pure uniaxial anisotropy distinct closure domains are not found (a). Typical closure domains are seen if the anisotropy functional is modified by adding the cubic term in (b) with $K_c/K_u = 4$. Interesting is case (c) of a planar anisotropy which induces well defined surface domains, but more continuous transitions in subsurface zones ($K_p/K_u = 1$). For strong planar anisotropy ($K_p/K_u = 4$) again marked domains are obtained (d), analogous to the case of ideally soft thin film elements [4]. To see the wall character quantitatively we evaluated the magnetization angles φ and θ on circular paths around the wall junction as indicated in Fig. 3 (radii 1/4, 1/2 and 3/4 of the distance from the wall junction to the surface). Most clearly the differences appear in the magnetization angle φ on the upper half circle which passes through the two closure domain walls. Doubling the plate thickness to 40 Δ we found that pure uniaxial anisotropy apparently induced a domain pattern by geometry only (Fig. 4a). However, already a slight tilt of the easy axis (Fig. 4b) or the application of a moderate field along the z axis (Fig. 4c) again lead to continuously rotating closure zones. For larger thicknesses (60 and 80 Δ) no further changes in character were observed.

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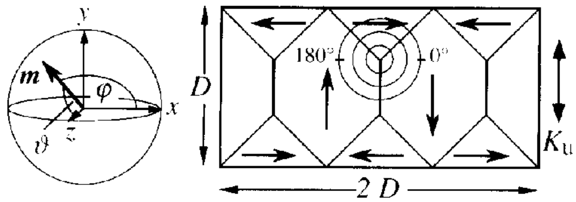

Fig. 1. Sketch of the typical closure domains structure with aspect ratio 2 : 1 used for the numerical calculations. The circles indicate the paths where the magnetization angles were evaluated (see Fig. 3). Additionally the cartesian and spherical coordinate systems used are indicated.

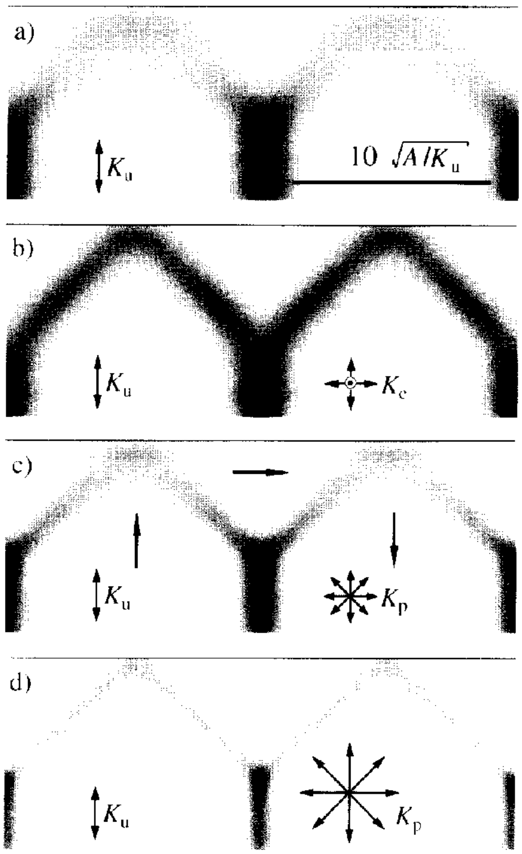

Fig. 2. The square root of the exchange energy density (normalized to the maximum value in the basic walls) is plotted as grey-shade images to indicate the walls. (a) Pure perpendicular anisotropy. Superimposed cubic (b) and weak (c) and strong (d) planar anisotropies. $\sqrt{A/K_u}$ is the wall width parameter.

Altogether, distinct closure domains form only if the anisotropy is at least stationary in the middle of the closure domain. Otherwise a more or less continuous rotation zone develops. A detailed discussion of closure domains and related structures can be found in Chap. 3.7.4 of Ref. [5].

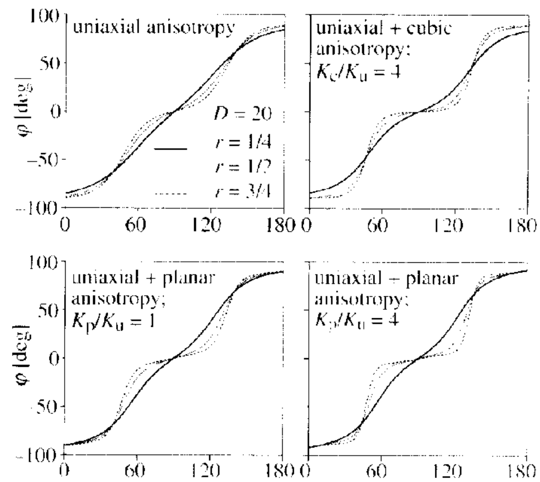

Fig. 3. Magnetization angle φ on the upper half circular path from 0° to 180° indicated in Fig. 1 for the four different anisotropy functionals (plate thickness 20 Δ).

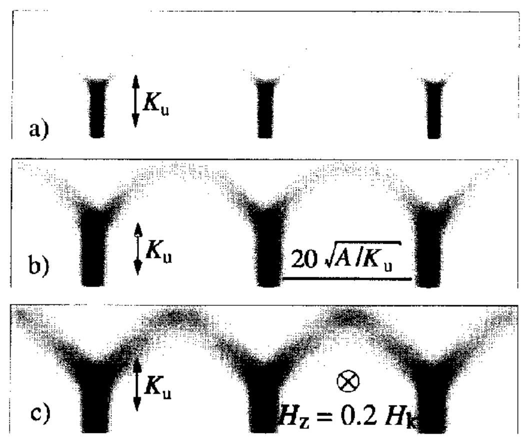

Fig. 4. Comparison of grey scale plots of the exchange energy density for a thickness of 40 Δ with the easy axis oriented exactly along the y-axis (a), for a tilting angle of 20° (b) and for a field of 0.2 times the anistropy field H_k along z (c).

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