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On the Toroidal Arrangement of the 180° Domain Walls in Ring Polycrystalline Soft Ferrites

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Abstract : According to an assumption proposed by Globus in 1976, special ring-shaped polycrystalline soft ferrites could have a toroidal arrangement of their magnetic domains (so-called "magnetic ring" concept). Experiments in the past have shown that this property must be restricted to the defect-free grain microstructures. This paper gives two examples of investigations which confirm the good validity of the concept. The first example is concerned with the magnetoelastic effects of the mechanical compression applied along the circumferences of the ring sample. λ being negative (YIG), the spins are forced to align in the stress direction leading to a more or less marked increase of the initial susceptibility (measurement is made in the same direction as the stress applied) according to the aptitude of the sample investigated to obey the above concept. In the most favourable cases, the axial direction (the revolution axis of the ring), can be then approached as a true "hard magnetization" axis, so that it becomes possible to interpret the magnetization in this direction as an irreversible rotational process. The second investigation is thus the analysis of the magnetization in this so-called "hard" direction. Comparisons with a theoretical development of the hysteresis of rotation are made which lead to good agreements.

In 1976, Globus et al. [1] postulated that ring-shaped polycrystalline soft ferrites of high microstructural quality, could show a ring-like distribution of the 180° domain walls so that, respecting at best the magnetic flux continuity from grain to grain, they also guarantee the flux closure throughout the sample (Fig.1-a). Obviously, the ability of a given ring sample to follow this so-called "magnetic ring" concept, strongly depends on its microstructure, and experiments in the past have well taken notice of this point [2]. Significant differences in microstructures can easily be achieved by voluntary changes of the sintering conditions so that it has been possible to work on two opposite categories of ferrites of the same chemical composition: 1) The type-T samples (T for toroidal domain wall arrangement) characterized by a quasi perfect grain structure (defect-free grains and regular distribution in sizes) - 2) The type-D samples (D for dispersed configuration) characterized by a visible intragranular microporosity. By another way, it is known that directional stresses act on the domain wall positions provided the next domains show non-antiparallel magnetizations. Indeed, if the stress has no action on the 180° domain wall (which contribute to the major part of the total magnetization), on the contrary, it greatly influences the closure domains. Since the latter are attached to the defects of structure, it is logical that the magnetoelastic effects will be especially encountered in D-materials, whereas they will be rather low in T-materials. It has been taken advantage of this interesting property of selectivity by stress, to test the validity of the "magnetic ring" concept. A special high pressure cell has been used to apply the adequate directional compressions along the circumferences of the sample, namely in the same direction as the susceptibility measurement (transformer method). Fig.1-b gives an example in which the T-sample is almost insensitive to the ring compression (σ) whereas the D-sample shows a large increase of susceptibility coming from a better alignment of the moments [2]. It must be remarked in the cases investigated (YIG) that the stress magnitude (0-12 MPa) leads to equivalent anisotropy fields ($H\sigma = 3\lambda\sigma/2\mu_0 M_s$) negligible (0.14 kA/m) with regard to the magnetocrystalline anisotropy field (12 kA/m), so that, the easy axes remain certainly those of the crystal structure. However, if any slight difference in energy initially exists between these axes, the magnetoelastic contribution (σ) may be then sufficient to change the domain orientation significantly. An experimental evidence has been published at ICF6 in 1992 [3]. Figs.1-(c,d) give a further illustration of the difference between T and D materials [4]: In the example, the ring susceptibility is investigated as a function of a continuous field H_0 applied in the perpendicular direction (axis of revolution). The D-samples reveal a rather smooth decreasing as H_0 is increased, with an usual hysteretical character in the field removal phase. On the contrary, the T-samples show a very sharp curve outline associated to a curious "hysteretical" behaviour resetting the susceptibility to the exact initial value, as a true demagnetization will do. This property is probably connected to a break phenomenon occurring in a well organized domain wall arrangement since a certain threshold of field is overcome [5]. The "magnetic ring" concept suggests that the ideal T-ring sample has all the moments aligned along the circumferences. It is thus

possible that the perpendicular field magnetizes the sample by a purely rotational process. As in the above situation (stress effects), the actual behaviour will differ according to the type (T or D) investigated. Fig. 2-a reminds the conditions of calculation for both the reversible and irreversible rotational magnetizations [6]. Fig. 2-b gives theoretical magnetization shapes in well known situations (note the coercivity increases as the angle α_0 decreases). Experiments have been realized to magnetize ring samples T and D in the axial direction in order to examine the exact nature of the magnetization process. Flat samples have been accurately inserted in the air-gap of an alternating electromagnet. Magnetizations have been measured by an usual flux method (sensing coil mounted on the outer lateral surface of the sample). Fig. 3 is a comparison between 3 cases: 1) The first (Fig. 3-a) corresponds to a T-sample. The theoretical loop was adjusted from the experimental loop tips (reversible parts). Note that the agreement is kept anywhere else showing that, in this case, the magnetization is probably purely rotational. - 2) The second (Fig. 3-b) corresponds to a D-sample (the same as in Fig. 1-b). The same procedure of adjustment has been applied and shows that the magnetization has not the same origin as in the previous case. The lowered coercivity indicates the existence of a domain wall contribution. - 3) The third case (Fig. 3-c) is still more convincing. Similar experiments have been realized on many other spinel samples which have led to the same conclusions.

Fig. 1- a : The "magnetic ring" concept : the domain walls have a toroidal distribution - b : Experimental confirmation of the concept. A compression applied along the circumferences does not change the susceptibility in materials (type T) obeying the above concept. On the contrary, isotropic materials (type D) generally show an increase due to an improved alignment of the domains in the measurement direction - c : The action of an external anisotropy (continuous field H_0) applied in the axial direction induces a rather smooth effect in D-materials, and on the contrary, a very sharp effect in T-materials (note the anomalous aspect of the hysteresis in this case).

Fig. 2 - a, b : Theoretical description of the magnetization due to spin rotations.

Fig. 3 - a : Good agreement between theory (Fig. 2) and experimental loops in T-materials showing that they probably magnetize by spin rotations in the axial direction (The sample is the same type-T as in Fig.1-b) - b : Isotropic materials (type-D) have a domain wall hysteresis with a coercivity smaller than predicted by the theoretical analysis - c : The previous conclusion is still more evident when the sample becomes very thick, so that, the axial direction can no longer be considered as a true hard direction of magnetization.

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