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Modified Model of Initial Magnetic Permeability of Polycrystalline Ferrites

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Abstract. A modified model of the initial magnetic permeability (IMP) is offered for a wide class of polycrystalline ferrites (PF): Ni and NiZn ferrites, YIG. Within the scope of this model, IMP and other structure-dependent properties of normally sintered ferrites are explained by two pinning mechanisms of the displacing flat domain walls (DW). The main mechanism is due to the interaction between DW and the inhomogeneous microstresses in the immediate vicinity of the grain boundaries (GB). The second mechanism occurs due to the closure domains.

1. INTRODUCTION

A great body of data is available about IMP and other characteristics of PF. However, until now insufficient attention has been paid to models that are able to explain variety of IMP data, such as: wide range of numerical values, temperature and frequency dependence of IMP. The commonly used Globus's model (bending DW is fixed on GB) gives the temperature dependence of IMP which is sometimes in disagreement with the experiment. It also cannot explain the wide range of DW resonance frequencies. In this work we consider the materials, in which IMP is determined by DW displacement. The domination of DW displacement over the rotation processes in such materials follows from the results of the investigations of magnetic spectra. In this case IMP depends on two groups of factors: the domain structure (DS) and the hindrances to DW motion (DW pinning mechanisms). The microstructure of PF also plays an important role, and the density of the magnetic poles on GB determines DS. The major hindrances to DW motion are concentrated in the immediate vicinity of GB. The understanding of these factors influence on IMP is associated with the properties of PF as sintered materials.

The normal grain growth, determined by the migration of GB, takes place at the last phase of sintering [1]. The crystallite region that remains behind migrating GB contains a few defects (has nearly perfect structure). Such a feature of the microstructure of PF determines the first property of the hindrances to DW motion: they are located near the GB.

For the interpretation of IMP as a structure dependent parameter, it is important to take into account the role of the structural length scales of the material. Together with the grain size, some other scales, which are sufficient for the microstructure and magnetic structure, may be determined. The smallest of them is the crystal lattice parameter. Other characteristic length is determined by the structure of GB which consists of the regions of better and worst coincidence [2]; their sizes Δr are 5...10

nm [3]. The magnetic nature length scale - parameter of DW width $\delta = (A/K_1)^{0.5}$, where A - exchange constant, K_1 - crystallographic anisotropy constant, is sufficient for DS and for the pinning forces. For materials mentioned here $\delta \approx 0,15... 0,4$ μm [4]. All considered scales give the hierarchy of the characteristic lengths for PF: lattice parameter - 1nm, size of the region of better and worst coincidence on GB - 10 nm, DW width - 0,1 μm , grain size - 1...10 μm .

There are inner microstresses in all PF. Universal mechanism of these stresses in PF has been proposed by Pascard and Globus [5]. They are determined by the disorientation of the crystal lattices of the neighbouring grains and by volume and linear magnetostriction. The manifestation of the stresses is the total anisotropy K [5]. Here we consider the ferrites with IMP values from several tens to several thousands. They have some common properties: approximately identical anion lattices and GB structures, approximately equal microstructure parameters, values of δ , that differ not more than 3 times.

2. THE PINNING MECHANISMS FOR DOMAIN WALL

In [7] the main pinning mechanism of DW has been proposed: interaction of DW with the microstresses in the vicinity of GB. The stresses described in [5] were considered as almost constant in the volume of the grain. The proposed model is based on the assumption that they have a component that varies with the spatial coordinates along GB. The microstresses origin is due to the disorientation of the magnetic axes of the grains, and their sources are located on GB. As a result of the alternation

of the regions with best and worst coincidence on GB, the magnetostrictional deformation creates the inhomogeneous stresses along GB. Thus DW is linked near GB with the regions of the increased anisotropy $\Delta K \approx (|K| - |K_1|)$. The spatial period and their sizes is Δr . The location of DW will be determined by the condition, that DW near GB contains the minimal number of regions with increased anisotropy. This model of the hindrances is related with Neel's model of non-magnetic inclusions with sizes less than DW width [6]. For a material with single DW in the grain (Fig. 1.a) our model gives

$$\mu_a - 1 \approx A |K| \left(\lambda_{100} / \lambda_{111} \right) D_a / |K| (|K| - |K_1|) \quad (1)$$

where λ_{100} , λ_{111} - magnetostriction constants, D_a - mean grain diameter. This model gives satisfactory coincidence with the experiment [7] for IMP temperature dependences of Ni ferrite and YIG sintered by Globus's method [8]. The function $\mu_a(D_a)$ for ferrites manufactured by traditional technology is more complicated [9]. The rate of the IMP change decreases above grain sizes 2...3 μm . This bend cannot be explained by the

Figure 1: DS in PF grains

assumption that there are two 180° DW in the grain. If the pinning mechanism not changes by the appearance of the next DW, the IMP must increase. If we assume that in materials with $D_a > 2 \mu\text{m}$ may be DS with closure domains (CD) (Fig.1.b), the second pinning mechanism is possible: external force displacing CD with non- 180° DW creates the elastic deformations that oppose to the displace of CD and the linked strained region. If this is the only pinning mechanism, then IMP is [10]:

$$\mu_a - 1 \approx (32\pi/3) M_s^2 D_a / C_{11} \lambda_{111}^2 l \quad (2)$$

where M_s - saturation magnetization, C_{11} - elastic modulus, l - size of CD. It must be noted that the two pinning mechanisms have different temperature dependences: equ.(1) gives IMP increases with temperature, equ.(2) - the one that decreases. If the both pinning mechanisms take place, IMP follows from the relation $\mu_a - 1 \approx M_s^2 / (a_1 \alpha_1 + a_2 \alpha_2)$ where α_1, α_2 - quasi-elastic coefficients of DW; a_1, a_2 - weight factors. For some materials [11] various temperature dependences of IMP (including the weak dependence) over a wide range of their change may be interpreted by the variety of the weight factors.

DS with CD allows a unified interpretation of many additional effects in PF. The bend on the curve $\mu_a(D_a)$ and the variety of IMP temperature dependences have been noted here. The other results are: temperature changes on the magnetic spectra of NiZn [12] and MnZn [13] ferrites, the change of the intensity of the ΔE -effect in a ferrite after the additional annealing [14] and others [10]. The model of the acoustic emission mechanism in PF has been formulated in [10]. It is found on the assumption of CD existence and is able to explain the sufficient properties of this effect. The essential arguments in favour of this hypothesis are the results of experimental investigations of the ΔE -effect dependence on the magnetization in NiZn ferrite [14], where DW displacement and magnetization rotation processes are separated. The component of ΔE -effect due to DW displacement increased after the additional heat treatment, which gives the consequent grain growth. Then the assumption that CD exists explains the increasing intensity of the ΔE -effect.

The DW pinning mechanism proposed here can be attributed also to the MnZn ferrites with D_a values greater than some μm .

Conclusions. The main features of the proposed model for IMP: a displacing flat DW is held in a defective layer near the GB by small regions of internal microstresses (main pinning mechanism) and by stresses in the area of CD.

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