BREAK-CROSS-TIE DOMAIN WALLS IN THIN PERMALLOY FILMS ABOVE 80 nm

By J. Białoń

Institute of Physics, Silesian Technical University, Gliwice*

and B. Wysłocki

Institute of Physics, Technical University of Częstochowa, Częstochowa**

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The influence of film thickness of 80Ni20Fe thin films in the thickness range from 80 to 110 nm on the domain walls structure has been investigated. It was found that the transition of cross-tie walls into Bloch walls is accompanied by the formation of new domain walls, called break-cross-tie walls. It was demonstrated that the formation of break-cross-tie walls is influenced by film thickness. Also, the increase of angular dispersion of anisotropy favours the formation of break-cross-tie on longer intervals of the main wall.

1. *Introduction*

Developing an adequate model of a domain wall in ferromagnetic thin films represents serious theoretical problems (see review papers [1–4]). In spite of an undoubtly great number of experimental papers dealing with the structure of a cross-tie wall, the up-to date existing models of this wall are oversimplified [5–10]. Among these works the results of Middelhoek [10] should be distinguished from which it follows that at film thickness of about 80 nm the transition of cross-tie walls into the Bloch walls should occur, as was previously observed by Methfessel, Middelhoek and Thomas [11, 12]. It seems however that the existing descriptions of these transitions are not complete. According to existing opinions with increasing thickness of permalloy thin film above 80 nm the circular Bloch line lengthens, forming the Bloch wall and lengthening the distance between cross-tie. Further increasing of the film thickness (from 90 to 100 nm) causes contraction of the Néel segments, and as a consequence the Bloch wall is formed.

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* Address: Instytut Fizyki, Politechnika Śląska, Krzywoustego 2, 44-100 Gliwice, Poland.
** Address: Instytut Fizyki, Politechnika Częstochowska, Deglera 35, 42-200 Częstochowa, Poland.

Since only a relatively few experimental papers have been published on the problem of the transition of cross-tie walls into Bloch walls and due to the discrepancy in the presented results, it was decided to carry out observations of these transitions in the thickness range from 80 to 110 nm.

2. *Experiment*

2.1. Investigated samples, methods of investigation

The investigations were performed on thin 80Ni20Fe films obtained by evaporation in a vacuum of 6×10^{-6} N/m^2 on glass-pyrex substrates in the presence of a constant magnetic field of 7×10^3 A/m. Substrates have been cleaned using the ultrasonic method. The rate at which the thickness of films increased was from 3 to 4 nm/s. The film thickness has been controlled during the evaporation using the quartz thickmeter. After evaporation the film thickness was determined by the multiray interference method (measurement error ± 4 nm). Fluctuations in thickness of any measured film are within the measurement error of ± 4 nm. The uniformity of composition has been tested using the X-ray microanalyser. From the point analysis of the chemical composition of a film it follows that the variations of Ni and Fe concentration are within the limits of a standard deviation of one sigma ($\pm 2\%$). The magnetic properties of films (anisotropy field, coercive force) were measured by means of a hysteresigraph. The angular dispersion of anisotropy has been estimated on the basis of hysteresis loop form. The coercive force of the investigated films was 135 ± 15 A/m, anisotropy field varying from 180 to 240 A/m, and angular dispersion of anisotropy α_{90} from 4 to 1°. The observations of domain structure have been made with the powder pattern method and by means of Lorentz microscopy.

2.2. Results

In Fig. 1 a typical cross-tie wall in an 80Ni20Fe thin film of 80 nm thickness is shown. With increasing thickness (about 5 to 10 nm) a gradual change of domain wall structure can be seen. The circular Bloch line is lengthening, the Néel segments become shorter, and some of them vanish altogether, causing the disappearance of the Bloch cross lines (Fig. 2). The new wall has in actuality cross-ties which are inclined with respect to the main wall. They are formed at only one side of the remaining Néel segment. The type of wall presented (Fig. 2) has been observed by Feldtkeller [13, 14] and Kolano [15]. The disapearance of the cross-tie type wall is connected with the creation of a new type of wall, as follows from our observations (Fig. 3a, b). The model of such a wall called break-cross-tie wall, is presented on Fig. 3c. On the main line of the wall between the Bloch and the Néel segments one can distinguish the so called 90°-lines. Depending on the manner of magnetization direction change in the vicinity of those lines they will or will not be accomplished with the inclined Néel segment (break-cross-tie). Following the nomenclature of Feldtkeller [14] it will occur near the so called "L_--line". The influence of the external magnetic field directed perpendicularly to the main wall on the break-cross-tie wall structure is shown on Fig. 4a, b. From the presented pictures it follows that the polarization of the Néel segments is the same.

This structure of wall indicates that the direction of the magnetization vector in a domain is not parallel to the wall, forming the low angle with this wall. As a consequence in the neighbouring walls the broken segments are inclined in opposite directions, and the Néel segments in both walls have the same polarization (see Fig. 5a and model Fig. 5b). In the nonparallel walls the broken segments have the same directions in both walls, and the Néel segments have opposite polarization (see Fig. 6a and model Fig. 6b). Due to their specific structure the break-cross-tie walls in their clear nondisturbed form appear only at definite intervals. The "undulation" of the magnetization vector favours the break-cross-tie walls appearance, but at the same time disturbs locally their uniform structure.

At film thickness of above 100 nm break-cross-ties are occurring singly or in couples at very great distances (Fig. 7). They now have very short Néel segments.

In films with greater anisotropy field (above 240 A/m) and low angular dispersion of anisotropy ($\alpha_{90} < 4°$) the elements composed of the Néel segments and break-cross-tie occur simultaneously with typical cross-ties having the Bloch cross lines (see the pictures in [13, 14] or Fig. 2 in this work).

3. *Discussion*

The determination of the conditions under which the break-cross-tie walls occur and the examination of the effect of external magnetic fields on these walls needs further observation.

From the observations presented of domain walls in permalloy films of thickness above 80 nm it follows that the former description of the structure of these intermediate walls between cross-tie and Bloch walls seems to be incomplete. Namely, it does not take into consideration the fact that this transition wall between the cross-tie wall and the Bloch wall is very susceptible, contrary to other walls, even to small changes in some film parameters, as e. g. angular dispersion of anisotropy. The increase of angular dispersion of anisotropy ($\alpha_{90} > 4°$) at low anisotropy fields ($H_K < 200$ A/m) leads to the creation of quite a new wall structure. High angular dispersion of anisotropy may be, in our case, ascribed to the series of structural defects in the film [16]. The low uniformity of chemical composition and local stresses are of importance too. Moreover, it seems that the appearance of the ripple wavelength [16, 17] which is comparable with the dimensions of the Bloch walls and the Néel segments is the important factor influencing the wall structure just in films with thicknesses 80 to 100 nm.

Many experimental facts suggest an anomalous course of both creeping [18] and domain walls movement influenced by magnetic fields exceeding the starting field of the wall in the film thickness range from 80 to 100 nm [19–22]. Among the factors which give rise to such a course of both creeping and domain walls movement could be quoted the formation of break-cross-tie walls besides of the lengthening of the Bloch segments.

Recapitulating, the two following conclusion can be drawn:

— the film thickness is the main factor influencing the formation of break-cross-tie walls,

— the increase of angular dispersion of anisotropy favours the formation of break-cross--ties on longer intervals of the main walls.

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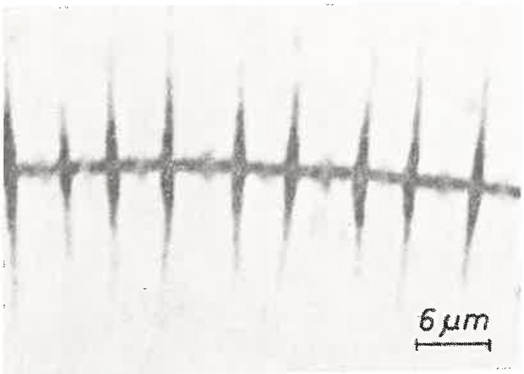


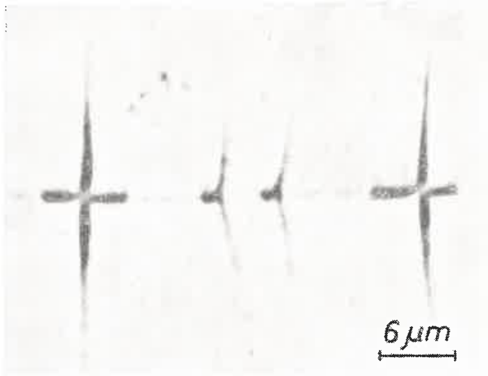


Fig. 1 Fig. 2

Fig. 1. Typical cross-tie-domain wall in 80Ni20Fe thin film 80 nm thick

Fig. 2. An example of a domain wall in 80Ni20Fe thin film 85 nm thick. Besides cross-tie appear new elements having the Néel segments at one side only. Anisotropic field $H_K = 240$ A/m, angular dispersion of anisotropy $\alpha_{90} \approx 2°$

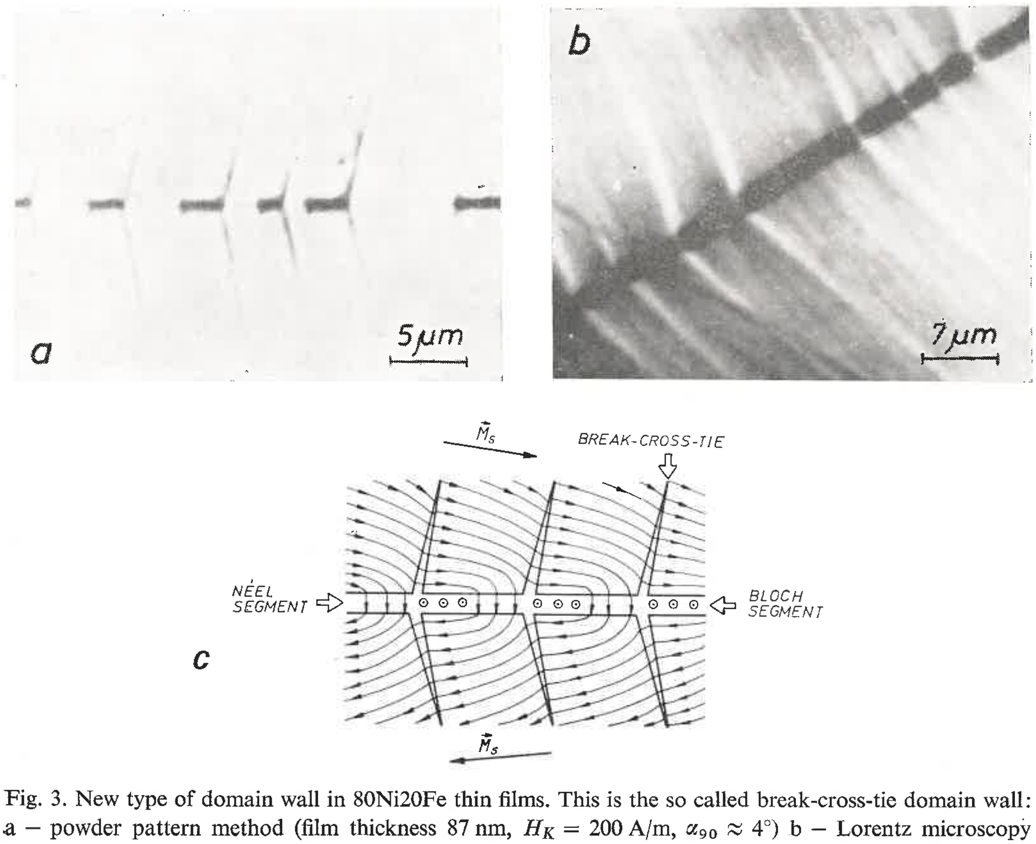


Fig. 3. New type of domain wall in 80Ni20Fe thin films. This is the so called break-cross-tie domain wall: a – powder pattern method (film thickness 87 nm, $H_K = 200$ A/m, $\alpha_{90} \approx 4°$) b – Lorentz microscopy technique (film thickness 93 nm, $H_K = 180$ A/m, $\alpha_{90} \approx 4°$), c – model of this domain wall

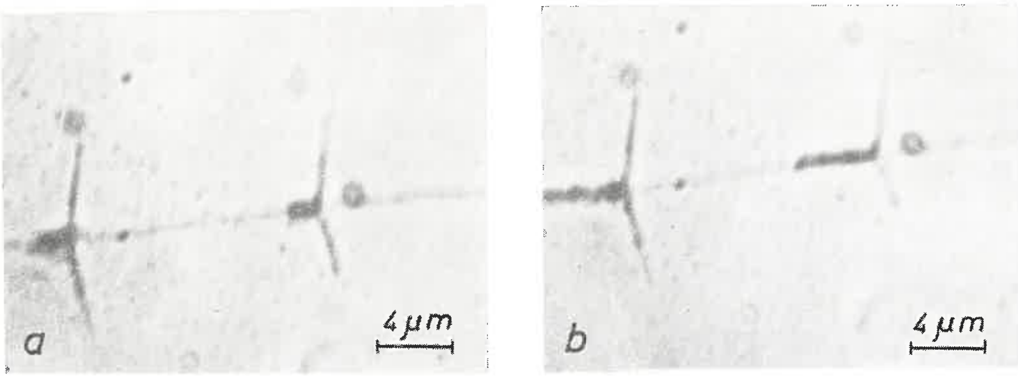


Fig. 4 Influence of a constant external magnetic field perpendicular to the main wall on the domain wall structure of 80Ni20Fe film 89 nm thick ($H_K = 190$ A/m): (a) $H = 0$, (b) $H = 60$ A/m

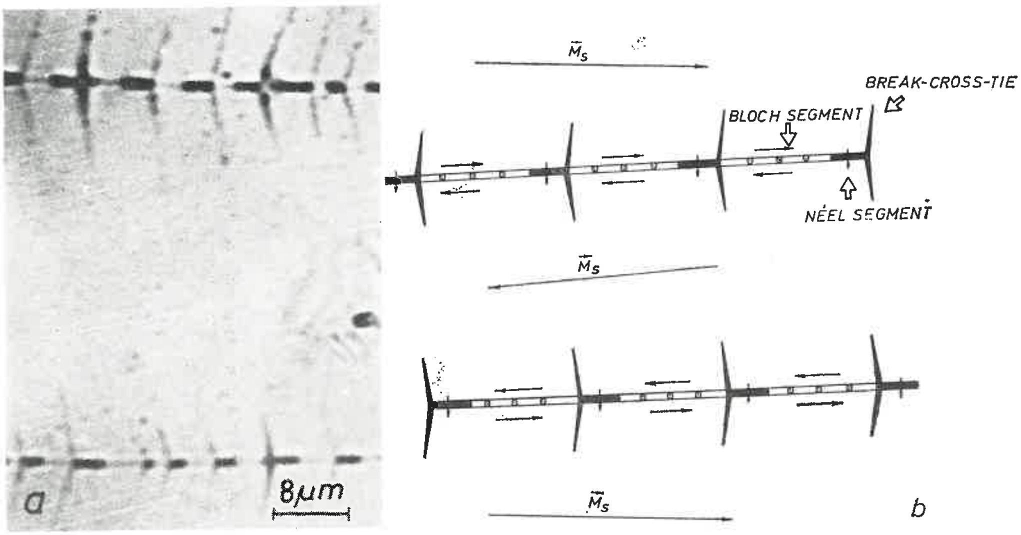
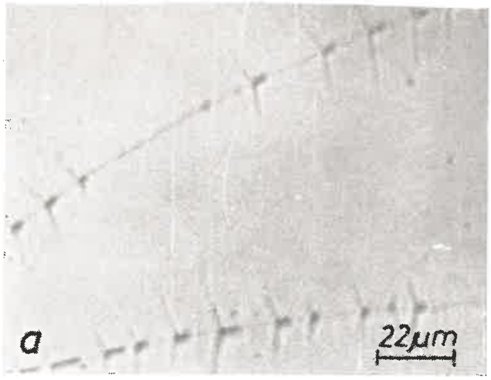


Fig. 5. Two parallel break-cross-tie domain walls (a) in 80Ni20Fe film 87 nm thick ($H_K = 200$ A/m), and simplified model (b) of this structure



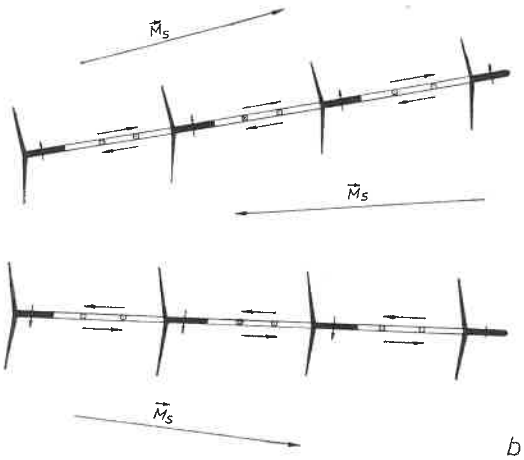


Fig. 6. Two nonparallel break-cross-tie domain walls (a) in 80Ni20Fe film 88 nm thick ($H_K = 190$ A/m), and a simplified model (b) of this structure

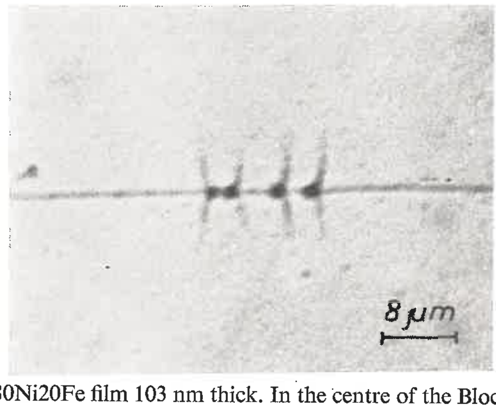


Fig. 7. The domain wall in 80Ni20Fe film 103 nm thick. In the centre of the Bloch wall are seen the remains of a break-cross-tie domain wall ($H_K = 210$ A/m)