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АННОТАЦИЯ

Показан эффект трансверсальной индукции /эффект Прокопью/ на ленте металлического стекла $Fe_{83}B_{17}$, и предложена теоретическая модель, основанная на тензоре проницаемости. Измерена интенсивность трансверсальной индукции в зависимости от возбуждающего переменного поля, постоянного напряжения смещения и примененного растягивающего напряжения. В результате этих исследований предложен новый метод для быстрого испытания материалов с целью определения аморфного характера образцов, подвергнутых различным термическим отжигам.

KIVONAT

A tranzverzális indukció (Procupiu effektus) jelenségét mutatjuk be $Fe_{83}B_{17}$ fémüveg szalagon és egy elméleti modellt javaslunk, ami a permeabilitás tenzor jellegén alapszik. Megmértük a tranzverzális indukció intenzitását a gerjesztő váltakozó tér, az előfeszitő állandó tér és az alkalmazott húzófeszültség függvényében. Ezen vizsgálatok eredményeképpen egy gyors anyagvizsgáló módszert javaslunk a különbözően hőkezelt minták amorf jellegének vizsgálatára.

ABSTRACT

The transversal induction phenomenon (Procupiu effect) is presented on $Fe_{83}B_{17}$ amorphous ribbons and a theoretical model is proposed based on the permeability tensor. The intensity of transversal induction was measured as a function of the exciting a.c. field, the biasing d.c. field and the externally applied tensile stress. As a result of these investigations a rapid testing method is proposed for testing the amorphousness of the samples after different heat treatments.

Transversal induction takes place when the exciting and detecting directions are perpendicular to each other. In the common induction experiments parallel arrangements are applied (cylindrical or toroidal).

Practically two transversal arrangements can be used, which are called in the literature Procupiu and Matteucci effects (Fig. 1). The Procupiu effect [1] consists in the induction of an e.m.f. in a coil which surrounds a ferromagnetic specimen carrying an alternating current (Fig. 1a). On the other hand, in the case of Matteucci effect [2] the alternating field is produced by a solenoid and the e.m.f. is induced in the ferromagnetic sample itself.

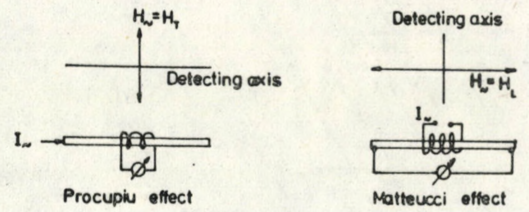

Fig. 1. Transversal induction arrangements

In present work the Procupiu effect has been investigated on amorphous alloys. In Fig. 2 the longitudinal and transversal inductions are compared for a $Fe_{83}B_{17}$ amorphous ribbon. Subtracting

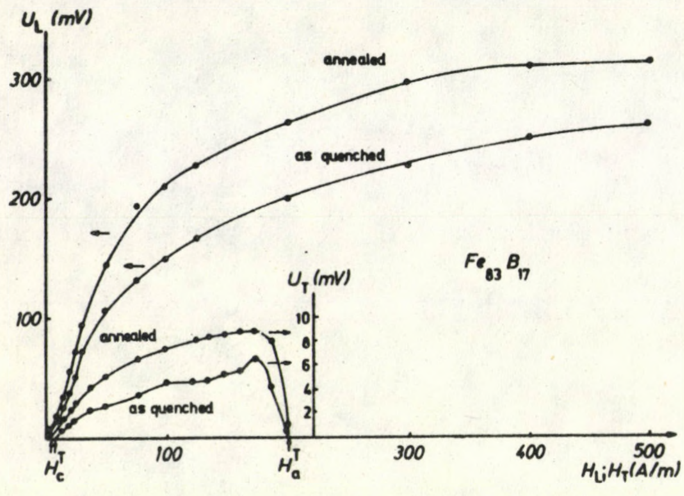

Fig. 2. *Comparison of the longitudinal and transversal induction measurements*

the direct induction of exciting field, the longitudinal induction as a function of H_L is proportional to the usual unhysteresis curve. The transversal induction behaves quite differently. It starts at a "transversal coercive force", H_c^T and suddenly disappears at a given field (H_a^T). This vanishment of U_T was not observed for a thin layer of permalloy deposited on copper wire with a monodomain structure. The transversal induction on amorphous ribbon could be detected without applying any other magnetic or mechanic solicitations. These facts suggest a domain wall origin of U_T. Although the domain patterns were not investigated in the present work, it is plausible to suppose a randomly distributed domain structure [3]. If this is the case, the applied transversal magnetic field can displace some domain walls. The Procupiu signal is induced by the longitudinal component of the magnetization changing due to the domain wall displacement (Fig.3).

In order to compute the induced e.m.f., a tensorlike magnetic susceptibility is used corresponding to the randomly distribution domain structure:

$$\vec{M} = \overline{\overline{\chi}}\vec{H} \qquad (1)$$

In a cylindrical coordinate system the field components given below correspond to the Procupiu arrangement:

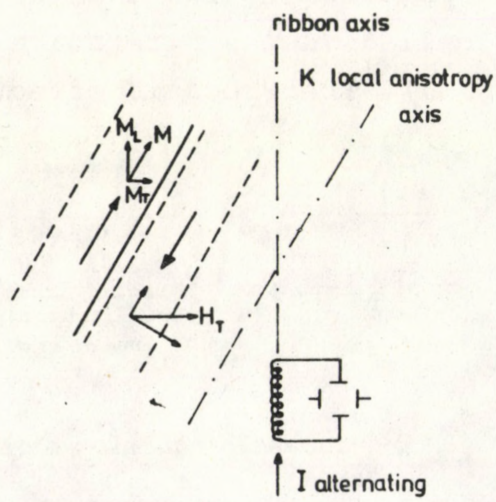

Fig. 3. *Sketch of local domain structure participating in the transversal induction*

$$H_z = H_L = \text{constant}, \qquad H_\varphi = H_T \sin t, \qquad H_r = 0 \tag{2}$$

Consequently:

$$M_z = \chi_L H_L + \chi_T H_T \tag{3}$$

and the induced signal

$$U_T \sim \frac{\partial M_z}{\partial t} . \tag{4}$$

From (4) one can obtain:

$$U_T = -2\pi\mu_o S\omega\left[\frac{H_L \cdot H_T^2}{2H}\cdot\frac{\partial \chi_L}{\partial H}\cdot\sin 2\omega t + \left(\chi_T + \frac{H_T^2}{4H}\,\frac{\partial \chi_T}{\partial H}\right)H_T\cos\omega t - \right.$$
$$\left. - \frac{H_T^3}{4H}\,\frac{\partial \chi_T}{\partial H}\cdot\cos 3\omega t\right] \tag{5}$$

where S is the cross section of the ribbon, $H^2 = H_L^2 + H_T^2 \sin^2 \omega t$ is the applied magnetic field.

It should be emphasized that one can obtain Procupiu signal even in zero applied longitudinal field in the case of randomly oriented domain walls due to the transversal component of magnetic susceptibility, and also in the case of uniaxial anisotropy, when $\chi_T = 0$, due to the simultaneously applied stationary longitudinal and alternating transversal fields.

Althouth the transversal induction is 10-100 times smaller than the longitudonal one, it is more sensible to deformations and magnetic fields. For this reasons, special care must be taken to avoid the influence of the Earth's magnetic field or other stray fields, and of external stresses introduced by improper handling and contacting.

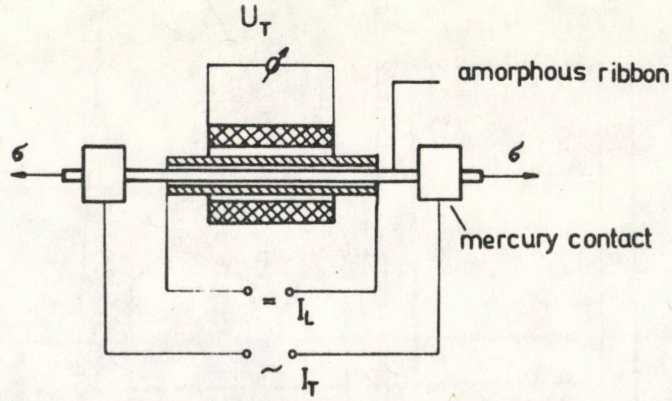

Fig. 4. The sketch of the experimental arrangement

In Fig. 4 the sketch of the experimental arrangement is shown. The mercury contact does not introduce any appreciably external stress. The current induced alternating transversal field was computed by integration over the rectangular cross section of the ribbon starting from the differential form of the Biot-Savart law. The in-plane component, H_x, in the middle of the surface of the ribbon was taken as the amplitude of the transversal exciting field:

$$H_T = \frac{I}{4\pi a}\left[\frac{\pi}{2} + \text{arctg}\,\frac{a}{2b} - \text{arctg}\,\frac{2b}{a} - \frac{a}{2b}\ln\frac{a^2}{4b^2+a^2}\right] \qquad (6)$$

where a is the halfwidth = $(\frac{D}{2})$, and b is the halfthickness = $(\frac{d}{2})$. For the ribbons used here a>>b, so the last two terms can be neglected and we obtain

$$H_T \sim \frac{I}{4a} = \frac{I}{2D}.$$

RESULTS

Two characteristic magnetic fields can be defined on the U_T versus H_T plot (Fig. 5) - a transversal coercive force $H_c^T \sim 10$ A/m of the same order of magnitude as the usual longitudinal coercive field and an annihilating field $H_a^T \sim 2000$ A/m, at which the U_T signal disappears. H_c^T does while H_a^T does not depend on the applied longitudinal field of the order of 10^2 A/m.

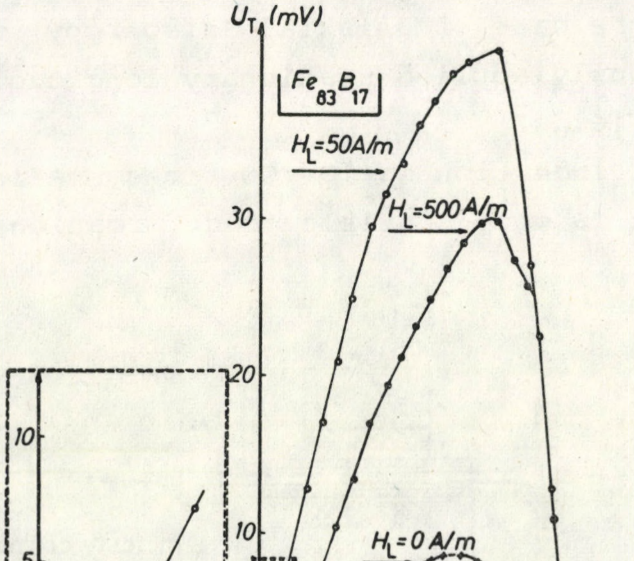

Fig. 5. Transversal induction as a function of the exciting magnetic field H_T at different biasing d.c. fields /H_L/.

The Procupiu signal can be increased by an order of magnitude applying low dc. biasing fields. At higher H_L the signal amplitude decreases proportionally to H_L^{-2}. The shape of induced e.m.f. changes continuously from symmetric spikes to tangential, sawtooth and sinusoidal signals as the static field increases.

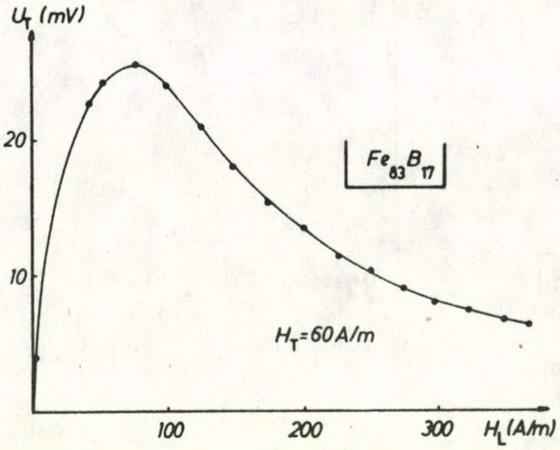

Fig. 6. Transversal induction as a function of the static magnetic field H_L

The transversal induction annihilates also at a tensile stress σ_a = 40-50 N/mm^2 well below the elastic limit (Fig.6).

The dependence of U_T versus applied tensile stress depends on the biasing longitudinal dc field. Considering the applied stress equivalent to a longitudinal magnetic field $H = \frac{3}{2}\lambda\frac{\sigma}{2K}$, the disappearance of Procupiu signal can be attributed to the annihilation of transversal domain walls where the signal comes from. Further investigations are necessary to study the correlation of σ_a with the material constants (λ,K) and the residual stress.

APPLICATIONS

Testing of amorphousness. The transversal coercive force where the signal starst to appear depends on the processing parameters via residual stresses and/or structural imperfections produced by partial crystallization (Fig. 7).

Testing of glassy stability. The current through the sample can be used also for heat treatment. To avoid heat losses a current pulse of 2 seconds was used. By transversal induction measurements the relaxation and crystallization process during thermal shock heat

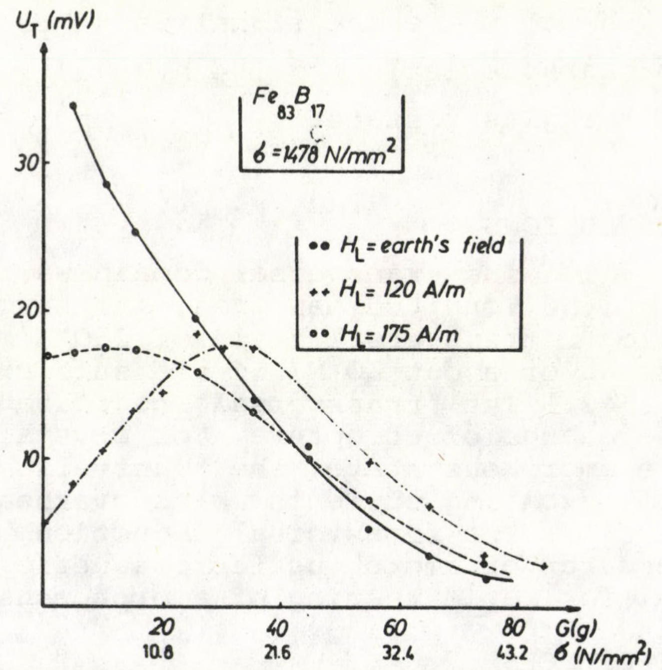

Fig. 7. Transversal induction as a function of the applied tensile stress

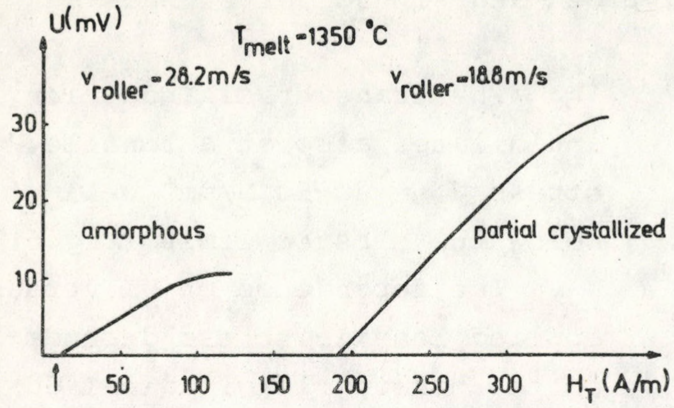

Fig. 8. Influence of the sample preparation parameters on the transversal induction

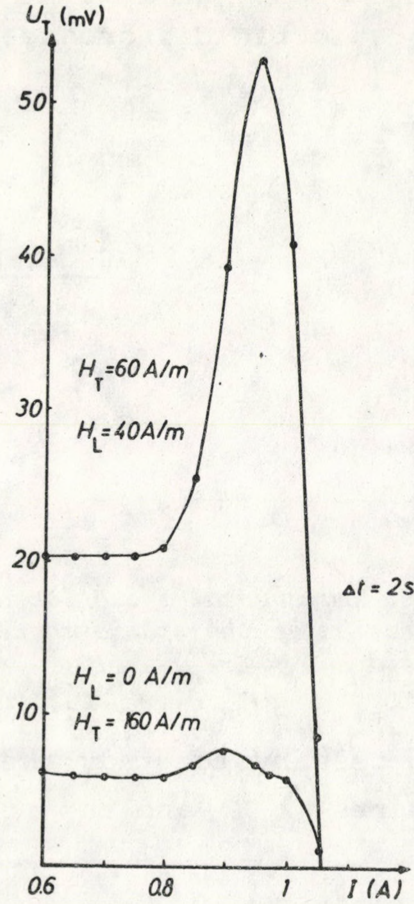

Fig. 9 Influence of the thermal shock heat treatments on the transversal induction

treatments can be monitored (Fig. 8). The enhancement of signal amplitude during the relaxation can be enlarged using a combination of transversal and longitudinal applied fields. At crystallization the signal disappears.

The magnitude of thermal shock ($I^2 \cdot R \cdot \Delta t$) where the signal vanishes is characteristic for the stability of the glassy state.

CONCLUSIONS

1.) The transversal domain walls annihilate more rapidly than the longitudinal ones. In the case of $Fe_{83}B_{17}$ amorphous alloy a transversal field of 250 A/m or a tensile stress of about 50 N/mm^2 are sufficient.

2.) The "transversal" coercive force is very sensitive to the change of structure. For crystallized samples, in contrast to the amorphous state, the transversal induction appears only at high exciting currents which overheat the sample.

3.) The transversal induction method applied first in the research of amorphous ferromagnetic alloys has proved to be useful for rapid testing of amorphousness and glassy stability.

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