PROPERTIES OF CAST AMORPHOUS MICROWIRE

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ABSTRACT

The cast amorphous glass-coated microwires with different magnetostriction constant were investigated. Microwires were produced of these alloys by the Ulitovsky - Taylor method. We explain the experimental data in the area of study natural ferromagnetic resonance, giant magneto-impedance and domain structures.

Keywords: Amorphous glass covered microwires, domain structure and magnetic properties.

INTRODUCTION

Interest in glass-covered cast amorphous magnetic microwire has greatly increased in the last few years [1-12]. The diameter of the core lies in the range 1-20 µm, glass thickness is 1-30µm. The filament of 1-50 µm in diameter has a tensile strength of 10 GPa. Specific anisotropies, mechanical stresses, and the presence of boundary layer metal-glass make some properties of cast amorphous magnetic microwire quite different compared with those in other materials. The interface between the “metglass” and the glass is considered to play an important role in the enhanced magnetostriction. Ferromagnetic amorphous microwire is known to exhibit good magnetic properties [1 – 4]. Our measurements of $H_c$ in the cast amorphous magnetic microwire gave values in the range of 0,1 to 10 Oe. Amorphous Fe-based microwires covered with glass with positive magnetostriction characterized by large Barkhausen jump down to sample length equal to some mm in as-cast state are provided.

PRODUCTION AND PROPERTIES OF AMORPHOUS MICROWIRE

The formation procedure includes melting of 1 g of a metal composition under glass flux, making of a metal capillary and attaching of it to a fast rotating coil [1-6]. The cooling velocity actual to an amorphous glass coated microwire formation is about $10^5$-$10^6$ grad/sec.

All presently known metallic glasses are alloys of the metal-metalloid type. The technology makes it possible to expand the range of amorphous material of traditional alloys based on Fe, Co and Ni with additions of B, Si, C, P. This is confirmed by direct X-RAY diffraction using the Debye-Sherrer method. The structure of thin wire was examined by transmission electron microscope and differential thermal analysis.

The microwires possess metal core diameter 0,5 to 20 µm, thickness of glass cover from 0,5 to 20 µm. FeBSi, FeBSiC, FeBSiCMn, FeCoBSi, FeCoNiBSi microwires are studied with different magnetostriction constant $\lambda$ (positive ~5•$10^{-5}$, nearly zero, negative~ -$10^{-6}$). Our measurements of $H_c$ in the amorphous wires gave values in the range of 0,01 to 10 Oe. Amorphous Fe-based microwires covered with glass with positive magnetostriction characterized by large Barkhausen jump down to sample length equal to some mm in as-cast state are provided.

NATURAL FERROMAGNETIC RESONANCE AND FERROMAGNETIC RESONANCE

One of the most interesting phenomenon observed in these microwires is natural ferromagnetic resonance (NFMR) in the frequency range of 1 – 10 GHz [2-9]. The microwires are of great importance for use as radioabsorbing materials.
Relaxation parameters, gyro magnetic ratio, and other properties related to the structure and short-range order of amorphous alloys are studied by the ferromagnetic resonance method.

We have studied the residual stresses in cast amorphous microwire with positive magnetostriction constant by method of ferromagnetic resonance (FMR). The microwires with positive magnetostriction constant ($\lambda \sim 10^{-6}$) have metal cores of $2r \sim 10 - 15$ $\mu$m, and diameters (with glass insulator) of $2R \sim 15 - 30$ $\mu$m.

The characteristic parameter is the skin width:

$$\delta = (4\pi \mu_0 \mu \sigma \omega)^{-1/2}$$

$\mu_0$ is the magnetic permeability, $\omega$ is the electromagnetic field frequency, $\sigma$ is the microwire conductivity.

The resonance permeability $\mu$ is $\mu \sim 102$, and skin width decreases three times when frequency increases from 1 GHz to 10 GHz. The dependence of frequency ferromagnetic resonance on the external magnetic field $H_b$ was defined and interpreted as the dependence of the internal fields of anisotropy on depth of skin width.

The universal dependence $H_a/H_{\text{max}}$ was an increasing function of frequency. Calculation of $H_a$ was taken from the equation:

$$(\omega/\gamma)^2 = (H_a + H_b + 4\pi M)(H_a + H_b).$$

In the production of amorphous glass-covered cast microwire, the residual stresses increase from the center and attain maximum values on its surface.

**RADIO-ABSORBING MATERIAL**

This is due to the discovery of microwire properties such as natural ferromagnetic resonance. In the case of microwire, natural ferromagnetic resonance becomes apparent by abnormal absorption of electromagnetic wave energy.

The phenomenon of electromagnetic radiation absorption has been investigated in a wide range of frequencies, up to 10 GHz. Propagation of electromagnetic wave through an absorbing screen with microwire-based absorption elements can be characterized by propagation factor $|T|$ and reflection factor $|R|$

$$|T|^2 \cong \frac{(\alpha^2 + \beta^2)}{((1 + \alpha^2) + \beta^2)}, \quad |R|^2 \cong 1/((1 + \alpha^2) + \beta^2)$$

where: $\alpha = (2 \cdot R)/Z_0$, $\beta = (2 \cdot X)/Z_0$ (a)

$R$ is the real part of a complex of linear resistance impedance, $X$ is an imaginary part of a complex of linear resistance impedance, $Z_0 = 120\pi$ is wave resistance of free space.

The results of tests of grids made of materials based on magnetic microwires with $R = 10k$ $\Omega$ and those based on non-magnetic resistive microwires show significant (up to 20dB) propagation factor difference. It is impossible to explain this difference only by an increase of linear resistance due to the skin-effect. Increase of resistance and $\alpha$ due to the skin-effect is proportional to a square root of effective magnetic permeability of microwire-based material.

The discrepancy of expression (a) by the experimental data could be eliminated by introduction of the absorption factor $\gamma^2$, which describes frequency and magneto-dependent parameters of a microwire-based material.

**THE RESIDUAL STRESSES**

We study the residual stress in metallic nucleus cast glass-covered amorphous microwire. Magnetoelastic anisotropies in amorphous microwires are originated by the residual stresses introduced during the fabrication process. The direction of these local anisotropies determines the magnetic structure. A model of stresses (due to the difference between the thermal expansion coefficient of the metal and glass) induced during the cooling from the solidification of the composite
temperature to room temperature has a magnitude of \( \sim 10^9 \) Pa. In a model of elastic-plastic cylinder we have:

\[
\sigma_r(r) \approx K \ln \frac{r}{a} + \sigma_r(t^0);
\sigma_\phi(r) \approx K (l + \ln \frac{r}{a}) + \sigma_\phi(t^0);
\sigma_z(r) \approx \nu [\sigma_\phi(r) + \sigma_r(r)];
\]

where \( a \) is plastic deformation radius, \( K \) is fluidity factor, \( \nu \) is Poisson’s coefficient (in elastic-plastic displacements case \( \nu \sim 0.5 \)), \( \sigma(t^0) \) are the thermal residual stresses operating during the cooling of the cylinder should decrease on the surface (X-ray research of microwires with a crystalline core structure allows us to evaluate thermal stresses as \( \sim 10^7 \) Pa). The theoretical models of thermal stresses in elastic-plastic cylinder is evaluated as \( \sim 10^8-10^9 \) Pa. For the explanation of obtained outcomes we should assume that on the boundary of metal and glass there is a thin shell, where stresses increase.

GIANT MAGNETO-IMPEDANCE EFFECT (GMI)

Discovery of the phenomenon of giant magneto-impedance effect (GMI) in amorphous microwire aroused the interest of theoreticians, experimental scientists and developers of magnetic sensors. Investigation of the GMI phenomenon in cast amorphous microwire carried out by us has led to the discovery of the tenso-GMI effect [10,11].

Coefficient of sensitivity of magnetic response is about \( 100\% / \) Oe\(^{-1} \), and it should be noted that the coefficient of piezo sensitivity \( S = (\delta \zeta / \delta \ell)/(\delta \zeta / \delta l) \) reaches 200. This microwire is a very interesting material for creating different types of sensors. When the microwire was heated to a temperature of 100-200\(^\circ\) C, GMI resonance broadens dramatically, in contrast to FMR resonance, which only broadens at temperatures close to the Curie temperature (about 400 \(^\circ\) C). If heat treatment was carried out (30 min at 300\(^\circ\) C), then after they cooled the resonance curve was not significantly broadened. A theory of ferromagnetic resonance in a transverse magnetic structure with flux-closure domains on the surface of a metal was suggested.

We will use the formula for the resonance frequency of a flux-closure domain

\[
\omega_0/\gamma \equiv H_c + NM + K/M
\]

where \( N \) is the difference between the transverse and longitudinal demagnetizing factors of a flux-closure domain, \( K \) is anisotropy factor.

We will consider the case when the anisotropy energy is greater than the energy of the difference in demagnetizing factors. For practical application of a microwire, the longitudinal magnetic permeability is an important characteristic. In our case, it is determined as

\[
\mu \equiv 4\pi M/H_c
\]

This formula enables us to evaluate the variance of longitudinal magnetic permeability from the quantities measured in GMI resonance.

PERMEABILITY AND MAGNETIC PROPERTIES OF AMORPHOUS MICROWIRES

We are interested in magnetic properties of amorphous microwires with close to zero negative magnetic magnetostriction constant [12]. At a high value of negative magnetostriction, the shape of the reversal magnetization presents the flat non-hysteresis loop or non-hysteresis loops with the coercive force, \( H_c \), less than 0.1 Oe. We discovered the appearance of the low temperature domain renormalization. As a result of this, the hysteresis loop drastically changes. The rectangular loop arises with the abnormally large \( H_c \) (up to 10 Oe). As the value of \( H_c \) decreases and becomes equal to 1-5 Oe for the loop with positive magnetostriction, the temperature decreases.

We have investigated microwire of \((Co_{100-x}Mn_x)_{75}B_{15}Si_{10}\), where \( x \) lies in the range 4 to 8. The diameter of the core lies in the range 6 - 12 \( \mu m \), glass thickness is 2 - 4 \( \mu m \). We have measured static hysteresis loop, and real and imaginary parts of permeability at different frequencies in the range 0.5 - 30 MHz. Permeability at high frequency was measured by the resonance method - \( \mu \sim 10^5 \). For permeability in the case of the easy plane solution it is possible to obtain:
\[ \mu \approx \left( \frac{3\lambda \sigma}{M^2} - N_\lambda \right)^{-1} \]

If \( 3\lambda \sigma/M^2 - N_\lambda = 0 \) the influence of magnetostatic and magnetoelastic anisotropies are equal one to another. In this condition the maximum of \( \mu \) values will be observed.

Experimentally we obtained the large values of the magnetic permeability in the amorphous magnetic microwire, which remain up to the high frequencies.

REFERENCES