The influence of adsorption of water molecules on magnetic susceptibility of amorphous ferromagnets

ARTICLE *in* SENSORS AND ACTUATORS A PHYSICAL · JUNE 2001

Impact Factor: 1.9 · DOI: 10.1016/S0924-4247(01)00494-0

4 AUTHORS, INCLUDING:

A. D. Kudakov
Lomonosov Moscow State University
24 PUBLICATIONS **41** CITATIONS

ELSEVIER

Sensors and Actuators A 91 (2001) 214–217

SENSORS AND ACTUATORS A PHYSICAL

www.elsevier.nl/locate/sna

The influence of adsorption of water molecules on magnetic susceptibility of amorphous ferromagnets

V.E. Zubov, A.D. Kudakov*, N.L. Levshin, T.S. Fedulova

Department of Physics, M.V. Lomonosov State University, Moscow 119899, Russia

Abstract

The reversible influence of weakly adsorbed water molecules on the magnetic susceptibility of amorphous ferromagnets of composition $Fe_{76.5}Cu_1Nb_3Si_{13.5}B_6$ is observed by a magneto-optical method at room temperature. The decrease of an amplitude of the domain wall (DW) oscillations is observed when the pressure of water vapour decreases from 400 to 1300 Pa. This effect is explained by appearance of surface perpendicular magnetic anisotropy, which is caused by the sample surface contraction. The surface contraction arises in consequence of the pressure on the walls of the micropores located on the surface of ferromagnets. The pressure is induced by H-bond adsorbed clusters of water molecules. The various magnetic charges emerge on the surfaces of domains through the presence of the surface perpendicular magnetic anisotropy. The field of magnetic charges causes an increase in the restoring force affecting the DW under its displacement from equilibrium position.

Keywords: Domain wall; Magnetic susceptibility; Amorphous magnets; Adsorption; Magneto-optics

1. Introduction

Defects caused by adsorption of molecules present in the air can impact essentially the domain wall (DW) properties in the near-surface region of magnetic materials. During the studies of the oscillations of DW in iron whiskers, which have a perfect bulk and surface crystal structure, high surface deceleration of the DW relative to the bulk was found in [1]. The differences between the DW dynamics on the surface and in the bulk disappear when the air pressure in the vacuum cell, where the sample under study was placed, decreases from 100 to 1 kPa [2]. In the present work, we have investigated the influence of reversible adsorption of water, oxygen, nitrogen and argon molecules on the DW oscillations in the near-surface region of soft amorphous ferromagnets by a magneto-optical method at room temperature in the external magnetic field in the frequency range of 20–200 Hz.

2. Experimental procedure and samples

The investigated amorphous ferromagnetic samples of composition $Fe_{76.5}Cu_1Nb_3Si_{13.5}B_6$ were obtained by the spinning technique. Before amorphization, the melt was subject to a special time–temperature treatment to obtain a uniform distribution of doping elements and, as a result, an improvement of the soft magnetic properties of the alloy [3]. The samples were 25–30 μm thick, 0.55 mm wide and 15–20 mm long. The used coordinate system and the magnetic structure of the sample are shown schematically in Fig. 1.

The effective width of the DW at the surface and the coercive force of the DW were determined by magneto-optical method and proved to be equal to 7 μm and 1 A/m. The surface properties of the DW were investigated with the help of the magneto-optical micromagnetometer described in [4]. The equatorial Kerr effect (EKE) was measured, which was caused by the change in magnetization of illuminated part of the surface of the sample through the DW motion in ac magnetic field with an amplitude of 80 A/m in the frequency range of 20–200 Hz directed along the *y*-axis. The micromagnetometer was supplemented with a vacuum cell, where the sample was placed, and with the control system of gas flooding. The pressure of the gas (p) in the cell can be changed from the atmospheric pressure to 1 Pa.

The measurements were realized on the real surface of the sample which was not exposed to preliminary purifying from adsorbed gases. The real surface means the sample surface, which is covered with thin oxide layer. The hydrate cover presenting on the sample surface consists of OH groups, and H_2O molecules adsorbed by coordination and

* Corresponding author.
E-mail address: kudakov@magn.phys.msu.su (A.D. Kudakov).

0924-4247/01/$ – see front matter
PII: S0924-4247(01)00494-0

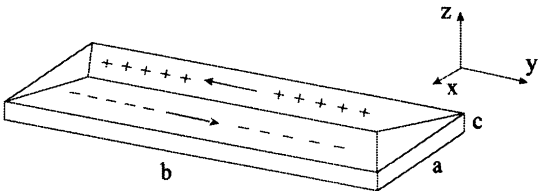

Fig. 1. Magnetic structure of the amorphous ribbon. Different magnetic charges, which were caused by perpendicular magnetic anisotropy produced by the water molecules adsorption are located on the surface.

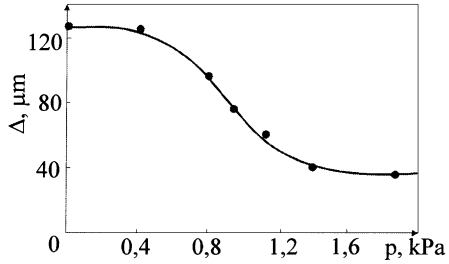

Fig. 3. Dependence of the domain wall oscillation amplitude on the water vapour pressure.

H-bond mechanisms. The OH groups and the coordination-bond H_2O molecules are localized on the iron atoms which are present in the oxide structure [5].

3. Results and discussion

Fig. 2 presents the dependencies of the equatorial Kerr effect (δ) versus x, caused by the M_y magnetization component on the sample surface emerging with the DW oscillations at different values of water vapour pressure. The oscillation amplitude of DW (Δ) is determined as the width of EKE curves at its base minus the width of the DW. The magnitude of Δ was equal to 125 μm at the pressure of water vapour 1 Pa and magnetic field with the amplitude 80 A/m and it did not change when the pressure of water vapour increased up to 0.4 kPa. Magnitude of Δ decreased from 125 to 40 μm when the pressure was changed from 0.4 to 1.3 kPa. Further increasing of the water vapour pressure up to 1.8 kPa (the value near the saturated vapour pressure at room temperature) did not lead to the change of the magnitude of Δ. The dependence of the DW oscillation amplitude on the water vapour pressure is demonstrated in Fig. 3.

The observed effect is completely reversible — DW oscillation amplitude increases to the former value when the pressure of water vapour decreases down to 1 Pa. The shape of the curves does not change with the increase of the magnetic field frequency from 20 up to 200 Hz. The reversibility of the effect at the room temperature indicates that the adsorption and desorption processes of weakly adsorbed water molecules which are adsorbed by the H-bond mechanism on the coordination-bond H_2O molecules on the real surface of the iron-based amorphous alloy take place in our experiments (see for example [5]).

The flooding of oxygen, nitrogen and argon into the vacuum cell with the near-atmospheric pressure values did not change the DW oscillation amplitude. This fact can be explained by the small value of adsorption energy of the O_2, N_2 and Ar molecules on the real surface of magnets and these molecules are connected with the sample surface by weak van der Waals bonds.

The amorphous ferromagnetic samples possess a complicated surface which is characterized by the micropores in particular. The water molecules are connected with the coordination-bond H_2O molecules by the H-bond mechanism in the strongest way. At relatively small quantities of adsorbed water molecules (parts of monolayer), they can form chains which connect and constrict the coordination-bond molecules among them. At a pressure of 0.4–1.3 kPa the quantity of the adsorbed water molecules is about 1–3 monolayers [5]. In this case, the micropores are filled with adsorbed water molecules and hydrostatic pressure caused by the adsorbed water molecules acts on the micropores walls. The resulting microstrains due to the magneto-elastic interaction generate magnetic microdefects. Characteristic sizes of micropores involved in generating the magnetic microdefects are determined by the merging together of clusters of water molecules. These clusters adsorb on the micropores walls composing ~6 layers of water molecules.

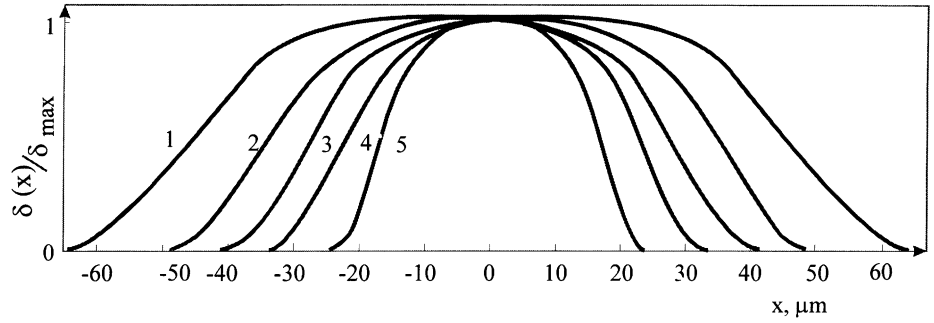

Fig. 2. Distributions of the EKE, $\delta(x)/\delta_{max}$, caused by the oscillations of a 180° domain wall at different pressures of water vapour. Curves 1–5: p = 1–400 Pa, p = 800 Pa, p = 1 kPa, p = 1.2 kPa, p = 1.9 kPa, respectively.

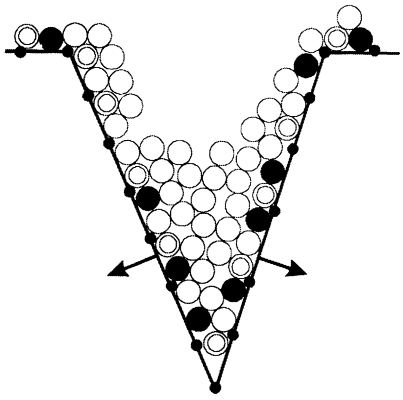

Fig. 4. The model of the adsorption magnetic defect formation on the rough surface of amorphous ribbon. Defects are caused by the hydrostatic pressure of adsorbed molecules on the walls of the micropores when the density of adsorbed molecules is high. (●), Fe atom; (⬤), OH groups; (◎), coordination-bond molecules of water; (◯), water molecules adsorbed by the H-bond mechanism.

The proposed model of formation of magnetic adsorption microdefects on the surface is shown schematically in Fig. 4.

As the DW oscillation amplitude stays invariable and the volume DW stays plane in the frequency range of 20–200 Hz in samples with thickness of ∼30 μm, the extrapolation of the dependence $\Delta(f)$ to $f = 0$ leads to the conclusion that the adsorption of water molecules brings the change of initial static magnetic susceptibility of the samples.

The decrease of initial static magnetic susceptibility of the samples can be explained by the arising of the surface perpendicular magnetic anisotropy under the influence of water molecules adsorption. Actually, different magnetic charges must appear on the surfaces of the two domains if the perpendicular anisotropy exists (see Fig. 1). Thus, an effective restoring force, which acts on the DW, increases when DW is displaced from its equilibrium position. The increase of this restoring force decreases the initial susceptibility of the sample.

The model which explains the appearance of surface perpendicular magnetic anisotropy for high density of adsorbed molecules is demonstrated in Fig. 5. Under the influence of adsorbed water hydrostatic pressure on the walls of micropores the surface of the sample tends to expand, but the volume prevents expansion. This leads to compression of the thin surface layer of the sample. The contraction of the surface leads to the appearance of perpendicular magnetic anisotropy if the constant of surface magnetostriction is negative. The effect is intensified due to the fact that the magnetoelastic energy constants for the surface atoms are higher than for atoms in the bulk volume due to lower surrounding symmetry of the surface atoms.

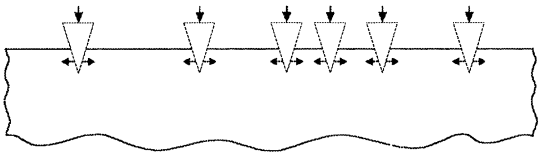

Fig. 5. The model of the contraction of rough surface due to the adsorption of water molecules.

4. Conclusion

In this work, the influence of reversible adsorption of water molecules, which are adsorbed on the surface of amorphous magnets by the H-bond mechanism, on the DW oscillation amplitude at the low frequency of ac magnetic field (20–200 Hz) was detected. Due to extrapolation of the dependence $\Delta(f)$ to zero frequency we could reach a conclusion that an adsorption of water molecules changes the initial static magnetic susceptibility of the whole sample. The main change of the DW oscillation amplitude realizes at the pressure of water vapour in the range of 0.4–1.3 kPa. In this case, the cover of adsorbed water is formed by the 1–3 monolayers. The observed effect was explained by the hydrostatic pressure of adsorbed water on the sides of surface micropores, which leads to surface compression. As a result, the appearance of the surface perpendicular magnetic anisotropy takes place. The magnetic charges arising on the surfaces of the magnetic domains increase the effective restoring force acting on the DW when it is displaced from the equilibrium position.

An influence of adsorption of O_2, N_2 and Ar molecules is insignificant because these molecules are connected with the real surface of magnets by van der Waals bonds. In this case, adsorption does not deform the surface of sample significantly.

Acknowledgements

We are grateful to V.S. Tsepelev for supplying us with the amorphous magnetic samples. This work was supported by the Russian Foundation for Basic Research (grant no. 99-0216595) and a grant from the Ministry of Education of the Russian Federation (The St. Petersburg Competition Center).

References

[1] V.E. Zubov, G.S. Krinchik, A.D. Kudakov. Influence of the structure of a domain wall on its dynamics in an iron single crystal, Fiz. Met. Metalloved. (USSR) 67 (2) (1989) 405–407 (Phys. Met. Metallogr. (UK)).

[2] V.E. Zubov, A.D. Kudakov, N.L. Levshin, V.V. Pilipenko, Influence of adsorption–desorption processes on dynamics of 180-degree domain wall in iron, J. Magn. Magn. Mater. 140-144 (1995) 1890–1895.

[3] U.N. Starodubtsev, L.D. Son, V.S. Tsepelev et al., The influence of the reheat temperature of melt on the mechanical and magnetic properties of the amorphous ribbon, Rasplavy 4 (1992) 76–79 (in Russian).

[4] V.E. Zubov, G.S. Krinchik, A.D. Kudakov, Radio-frequency magneto-optic micromagnetometer, Instrum. Exp. Tech. (USA) 31 (3) (1988) 766–767 (Prib. Tekh. Eksp. (USSR) 31 (3) (1988) 206–207).
[5] V.F. Kiselev, O.V. Krylov, Adsorption Processes on Semiconductor and Dielectric Surfaces, Springer Series in Chemical Physics, Vol. 32, Springer, Berlin, 1985.

Biographies

V.E. Zubov obtained his Doctor of Sciences (Physics and Mathematics) in 1994 from the Physics Department of M.V. Lomonosov Moscow State University. He is the chief researcher from 2000 till date at the Physics Department. His fields of scientific interests are low dimension magnetic structures, surface magnetism, domain walls, Bloch lines and Bloch points in particular, thin magnetic films, magnetochemistry and influence of adsorption on properties of low-dimension magnetic structures in particular.

A.D. Kudakov obtained his PhD in 1988 from the Physics Department M.V. Lomonosov Moscow State University. He has been a senior researcher from 1995 till date at the Physics Department. His fields of scientific interests include low dimension magnetic structures, surface magnetism, domain walls, Bloch lines and Bloch points in particular, thin magnetic films, magnetochemistry and the influence of adsorption on properties of low dimension magnetic structures in particular.

N.L. Levshin obtained his PhD in 1982 from the Physics Department M.V. Lomonosov Moscow State University. He has served as an assistant professor from 1993 till date at the Physics Department. His fields of scientific interests include surface phenomena, adsorption and solid state phase transitions in particular.

T.S. Fedulova is a student of Physics Department at M.V. Lomonosov Moscow State University. His fields of scientific interests are low dimension magnetic structures, thin magnetic films and the influence of adsorption on properties of low dimension magnetic structures.