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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

MAGNETIC AND MAGNETOOPTIC PROPERTIES OF AMORPHOUS MAGNETS CoFe AND $(CoFe)_{75}Si_{10}B_{15}$

Speciality:	2211.01 - Solid state physics
Field of science:	Physics
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The work was performed at the Scientific Research Laboratory "Physics of Metals and Alloys" under the department of Physics and chemistry of the Azerbaijan University of Architecture and Construction.

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GENERAL CHARACTERISTICS OF WORK

Relevance and currency of the research topic. Although amorphous materials were discovered more than 60 years ago, interest in studying their structure and magnetic properties has not diminished. This is possible primarily by explaining the wide spread use of amorphous materials in modern microelectronics at a small cost of production. The most popular amorphous soft magnetic materials are alloys containing 70-80% iron or Co atoms.

The successful development of metal physics in the field of studying the properties of materials made with the addition of metal alloys has led to the implementation of "STELS" technology in recent years. The study of the effect of Si and B additives on the physical properties of ferromagnetic metals and alloys is one of the promising directions in solid state physics. In terms of basic research and practical applications, ribbon - shaped amorphous materials deserve special attention. The field of application of these ribbons is wide in terms of the production of sensor elements. The study of magneto-optical properties of such materials allows to solve a number of topical issues in order to discover their new properties and expand their field of application. Another aspect of the dissertation's relevance is the study of the magnetic properties of samples obtained on the basis of the technology of industrial production of thin layers of ferromagnetic alloys such as Co-Fe and Ni-Fe and their practical application in thermoelectronics. The creation and development of modern technology is based on fundamental research. The study of magneto - optical properties is more relevant in this regard. In modern times, the use of materials with certain physical and chemical properties in industry is important in all areas of technology. The development of high-efficiency technologies for the processing of materials, their use for the manufacture of industrial products is no less important. One of the main directions in this direction is the development of solid state physics, especially the technology of metal physics.

Amorphous soft magnetic materials have unique properties that are in some respects superior to those of soft magnetic crystalline alloys. The distinguishing features are the low temperature dependence of the electrical resistance of amorphous materials, high initial and maximum magnetic permeability, low cost of coercive force and magnetic anisotropy constant, and close to zero magnetostriction.

Saturation magnetization of amorphous alloys, coercive force, rectangularity of the hysteresis loop, magnetic permeability are valued in a wide range. Saturation magnetization of amorphous alloys, coercive force, rectangularity of the hysteresis loop, magnetic permeability are valued in a wide range. Even after the voltages are fully removed, the cost of such losses depends on the magnetostriction. In this case, the condition of the spins in the lower zones must be taken into account. Taking this into account, as a result, allows the calculation of various physical parameters and effects. The magnetic and magnetooptic properties of these alloys are related to their structure and chemical composition. External influences such as thermomagnetic (fixed and variable magnetic fields) processing are of great importance in the formation of their practically important properties. As a result of such an effect, the nature of the anisotropy changes, the shape of the hysteresis loop changes, and so on. Therefore, the study of these events has not only scientific but also practical significance, ie it is relevant.

Research objects and subjects. $(CoFe)_{75}Si_{10}B_{15}$ and CoFe ribbon samples were taken as the object of research. The characteristics of the magnetic and magneto-optical properties of amorphous ribbon samples studied depending on different thermal processing conditions were studied.

The purpose and objectives of the study.

The aim of the thesis is to determine the mechanisms of magnetic and magnetooptic properties of $(CoFe)_{75}Si_{10}B_{15}$ and CoFe magnetics subjected in both stable and variable magnetic fields, and investigate their practical applications

The following issues have been resolved to achieve this goal.

1. Obtaining samples of the studied $(CoFe)_{75}Si_{10}B_{15}$ and CoFe amorphous ribbons.
2. Investigate magnetic properties of $(CoFe)_{75}Si_{10}B_{15}$ and CoFe magnetics after various thermal and thermomagnetic processing in the air, in the vacuum, in the water.
3. Determination of the dependence of magnetic losses and magnetized anisotropy on the amount of Boron in Co-Fe ribbon samples.
4. Investigation of the effect of diffusion processes occurring in various heat treatment processes on the maximum magnetic permeability of the $(CoFe)_{75}Si_{10}B_{15}$ ribbon.
5. Investigation of the effect of thickness on magnetic and magneto-optical properties in $(CoFe)_{75}Si_{10}B_{15}$ amorphous samples.
6. Obtaining a new sample of magnetic thermocouples based on CoFe and NiFe ribbons and investigating its application..

Research methods. After crushing, the materials studied in the dissertation were melted in an argon medium by means of an induction furnace UPI-60-2. Sampling was carried out in an electric furnace SUOL-0,15,1,1./12MP-H3. Teslameter Ф 4354/1 was used to measure magnetic induction. The following methods were used to obtain information about the microstructure of the studied ribbon.

- X-ray structure study Dron-3 diffractometer,
- Atomic force microscope (AFM),
- Scanning electron microscope (SEM)

As a method of studying the magneto-optical properties in the dissertation, the Bitti method and Transversal MOKE magnetization are based on a magneto-optical device.

Basic provisions for defense

1. The role of $(CoFe)_{75}Si_{10}B_{15}$ amorphous soft magnetic ribbon sample in the process of significantly reducing the magnetic losses of water quenching in the magnetic field;
2. Determination of the dependence of magnetic losses and the applied magnetic anisotropy on the amount of pipe in the samples of Co-Fe amorphous soft magnetic ribbon;

3. Assessment of the possibility of using magnetic thermocouples made of CoFe - NiFe permalloy ribbon in the laboratory and in industry;
4. The role of diffusion processes occurring at different thermal processing temperatures, cooling speed and heat treatment times for maximum magnetic permeability of $(CoFe)_{75}Si_{10}B_{15}$ ribbon;
5. Investigation of the effect of the annealing time of $(CoFe)_{75}Si_{10}B_{15}$ sample on the value of the Transversal MOKE;
6. The effect of annealing time in magnetic field on the formation of the structure in the near-surface layer of the $(CoFe)_{75}Si_{10}B_{15}$ amorphous ribbon sample;
7. Determination of the dependence of the studied $(CoFe)_{75}Si_{10}B_{15}$ amorphous ribbon sample on the effect of magnetic impedance on different thermal processing temperature and processing time;

Scientific innovation of the research:

1. The optimum heat treatment temperature for Co-Fe alloys to obtain maximum magnetic permeability has been determined to be between 400-420^{0}C.
2. The study of magnetic and magneto-optical properties shows that the reduction of saturation magnetization is linear, depending on the alloying elements such as Si-B.
3. It was shown that the transverse magnetic anisotropy obtained by thermomagnetic treatment of $(CoFe)_{75}Si_{10}B_{15}$ at the beginning of crystallization creates a rectangular hysteresis loop with a stable magnetic permeability in the tape samples in the region of 2-10 Oe of the external magnetic field.
4. $(CoFe)_{75}Si_{10}B_{15}$ amorphous soft magnetic alloy. ribbon after thermal treatment in air, depending on the cooling speed of the formation of amorphous or amorphous crystalline layer is observed.
5. It was found that in the field dependences of the Transversal MOKE effect, the magnetic and magneto-optical properties of the $(CoFe)_{75}Si_{10}B_{15}$ amorphous sample change depending on the thickness. It was determined from the field dependences of the Transversal MOKE that, with increasing time, the amorphous ribbons in the surface layer become more magnetic solid.

6. It has been shown that thin magnetic ribbons based on Co-Fe and Ni-Fe can be used as materials for the production of thermoelectric sensors that minimize errors in temperature measurements in a changing magnetic field due to heat dissipated by induction currents.
7. A significant increase in the Transversal magneto-optic Kerr effect is observed near the percolation threshold, and a gradual decrease in the Transversal MOKE is observed with a further increase in the concentration of the ferromagnetic component.

Theoretical and practical significance of the research. In the dissertation it was determined that CoFe-based amorphous ribbons can be used in solid state electronics, in the development of transformers, in the manufacture of thermocouples.

Thermocouples from CoFe and NiFe amorphous ribbons were prepared in the experiments on the dissertation.

Approbation and application. The results of the scientific work in the dissertation work were discussed and published at the International and Republican conferences.

“Fizikanın müasir problemləri” VI Respublika konfransının materialları “Opto, nanoelektronika, kondensə olunmuş mühit və yüksək enerjilər fizikası” 14-15 dekabr 2012, Bakı;

Magistrantların və gənc tədqiqatçıların “Fizika və Astronomiya Problemləri” Respublika Elmi Konfransının Materialları, 19 may 2012, Bakı;

Doktorantların və gənc tədqiqatçıların XVIII respublika elmi konfransının materialları, 19-20 dekabr 2013, Bakı;

Metallar fizikasının müasir problemləri V Beynəlxalq Elmi-Praktik konfransının materialları, 10-11 iyun 2016, Bakı;

Doktorantların və gənc tədqiqatçıların XX Respublika Elmi konfransının materialları, 24-25 may 2016; Bakı;

Магнитные фазовые переходы Сборник трудов XII международного семинара, Институт физики ДНЦ РАН, 60 лет, 7 сентября 2017 г. Махачкала;

Doktorantların və gənc tədqiqatçıların XXI Respublika Elmi konfransının materialları I bölmə, 24-25 oktyabr 2017,

Bakı; Energetika ixtisasları üzrə kadr hazırlığının aktul məsələləri Respublika Elmi konfaransının materialları 30-31 may 2019, Sumqayıt.

Name of the organization where the dissertation work is performed:

It was conducted in the Scientific Research Laboratory "Physics of Metals and Alloys" of the Physics and chemistry Department of the Azerbaijan University of Architecture and Construction.

Published scientific works: The materials of the dissertation were published in local and foreign journals, including 12 articles and 8 theses. Two of the articles were published abroad in journals, including the Web of Science, and two were co-authored.

The total volume of the dissertation with a sign, indicating the volume of the structural units of the dissertation separately The dissertation consists of 175 pages in the volume of computer text, tables, pictures, bibliography, except for conventional signs 208504 signs, Introduction 14306 signs, Chapter I 75799 signs, Chapter II 34872 signs, Chapter III 59225 signs, Chapter IV 22114 signs, 7 table, 43 pictures and list of used literature by 164 names are included.

MAIN CONTENT OF THE STUDY

The introduction substantiates the relevance of the topic of the dissertation, the purpose of the work, scientific novelty, practical significance and the main defense of the work. It also provides a brief summary of existing theoretical and practical work.

In chapter I Based on the literature review, amorphous metal alloys, prospects of their application, structure of amorphous soft magnetic alloys, magnetic properties, anyzotropy and domain structure of amorphous alloys, thermal, thermomagnetic processing and effect of additional stresses on amorphous material and optical and magneto-optical properties of nanocomposites were studied.

In chapter II Optical characteristics of metals and alloys, magneto-optical phenomena in ferromagnets, methods of measuring magnetic and magneto-optical properties of CoFe-based alloys, design, structure and working principle of the device are provided. Physical methods were used to analyze the composition and structure of the amorphous ribbon obtained in the dissertation. The magnetic properties of the obtained amorphous (residual magnetization, coercive force, etc.) are determined from the hysteresis loop.

In the Scientific Research Laboratory "Physics of Metals and Alloys" of the Azerbaijan University of Architecture and Construction, the polyarimetric Bitti method and transversal magnetization was based on a device for simultaneous determination of optical and magneto-optical parameters of the sample. The block diagram of the device is given in Figure 1.

S - light source, EMM-modulator; MDR-12 monochromator; EMM- electromechanical modulator; P-polarizer; N-sample; L-focusing lens; A-analyzer; IB-management block; IG -impulse amplifier; K-impulse generator; FQ-photo receiver; OC-optocouple; QB-1-energy block; B7-22 digital voltmeter; B9-2-phase detector; U2-8 selective amplifier; IK -primary amplifier; BB-section block;
SCK-DC amplifier; QB-2 power supply; OYM is a self-typing machine[1, p.26-28].

The light from the light source passes through the modulator and the transmitted signal is modulated. EMM is a device that changes the parameters of the carrier signal in accordance with the changes in the signal collected and transmitted at the base of the DC motor. This process is called modulation and the transmitted signal is modulated. EMM keeps the modulation frequency constant. The modulated light passes through a monochromator, a spectral optical device. The MDR-12 monochromator allows the measurement of the optical properties of the samples studied over a wide spectral range from 0.2 μm to 16 μm using a variable diffraction grating. The wavelength is selected through a monochramator and separated into the optical spectrum.

The light from the monochromator passes through the polarizer and is focused on the surface of the ferromagnetic sample examined by the lens. The light reflected from the ferromagnetic sample passes through the analyzer and is focused on the photodetector by means of a lens. Glan-Thomson prisms with 10^{-4} polarization degrees are used for polarization of light, which allows to determine the polarization angle with 1 degree of accuracy. Photo resistance is used in the visible region of the optical spectrum, and photodiode in the infrared region. The light signal is recorded on a microvoltmeter U2-8 and transmitted to a digital voltmeter B7-22. The light flux is amplified by an IG with high input resistance before being fed to the U2-8 microvoltmeter. Assembled on the basis of IG-high input resistance operational amplifier.The IG increases the current in the photodetector to a certain extent and coordinates other amplifier units based on the resistance of the photodetector. After the light signal exits the IG, it is sent to the appropriate sections, depending on the determination of the magneto-optical and optical parameters of the sample.

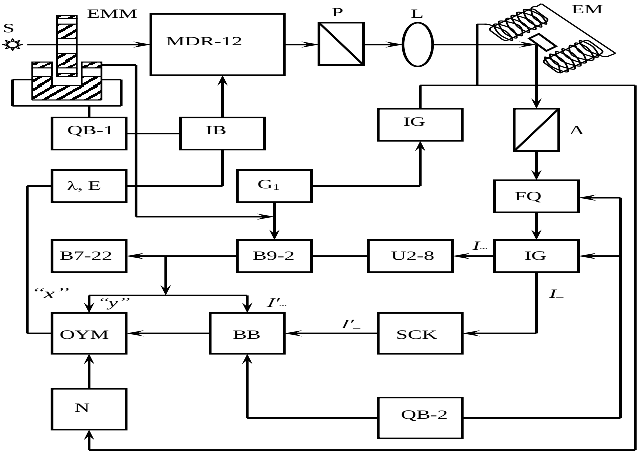

Figure 1. Block diagram of the magnetooptic universal device

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[1] Аззам Р., Башара Н. Элипсометрия и поляризованный свет / М. Изд.Мир, – 1981, –с.441.

To determine the optical parameters of the sample, a light signal is sent to the input of the microvoltmeter U2-8 after the output of the IG. To determine the useful light signal received, the signal from the U2-8 microvoltmeter is fed to the B9-2 phase detector. A signal with a fixed amplitude of modulated frequency passing through an optron pair located on the top of the modulator is fed to the input of the phase detector .The signal is transmitted to the digital voltmeter B7-22 after the defect. The signal from the digital voltmeter is determined by a two-coordinate self-recording machine [1, p. 26-28]. In order to conduct research on these materials, the technology of their acquisition has been developed.

Although there are many ways to obtain metallic glass in an amorphous structure, the most convenient of these is the liquid quenching method. In all liquid quenching metod, the liquid flows over the surface of the rotating metal cooling disc, cools rapidly (10^5-10^7 C^0/sec) and hardens quickly. When the composition of the alloy remains constant, the cooling speed depends on the volume of liquid alloy poured into the cooling disc and the characteristics of the refrigerant. When obtaining an amorphous ribbon, it is important that the cooling speed is 10^6 ^{0}C/s to avoid crystalline structure [4, p.79-83]. Amorphous ribbons containing CoFeSiB were considered in this study. The results of X-ray studies showed that the ribbons were amorphous. The magnetostriction constant of the ribbon is $\lambda \sim 10^{-6}$ [4, p. 79-83].

Materials used in the research. FeSi, Fe, Co and B were used as primary raw materials in the processing of alloys. An electric arc furnace is used to obtain the FeSi alloy. The elements Fe, Co, B used in the research were obtained from the German company Sigma Aldrich. Substances containing Co, Fe, Si and B are broken down into small particles of 0.3 mm. After crushing, УПИ-60-2 was melted in an argon medium through an induction furnace. CoFe-based amorphous ribbon was obtained by flowing over a rotating cooling disc. CoFe-based amorphous ribbon was obtained by flowing over a rotating high-speed cooling disc. The sample of the studied samples was taken in the electric furnace СУОЛ -0.15.1.1. / 12MP-

H3, which can be heated up to T = 1200^0C.

In chapter III Co-based amorphous soft magnetic alloys, magnetic structure of $(CoFe)_{75}Si_{10}B_{15}$ amorphous alloy, magnetic losses, dependence of magnetic losses on heat treatment mode and structure, effect of magnetic resistance in amorphous ferromagnetic alloys, magnetic and impedance of FeCoCrSiB amorphous magnetic alloys effects have been studied [2, p.113-115]. X-ray structure of amorphous $(CoFe)_{75}Si_{10}B_{15}$ ribbon was drawn.

The structural properties of soft magnetic materials significantly affect the magnetic properties of these materials. In turn, their structural properties also change sharply as a result of a number of external influences: thermal, thermomagnetic (in fixed and variable magnetic fields) processing. Thus, as a result of the application of external influences, an important issue arises, such as the coordination of changes in the magnetic properties of these systems due to their structural properties. The analysis of these issues is also considered in the study. Total and hysteresis electromagnetic losses of five components with a pipe size of 8, 9, 10, 11 and 12% at a frequency of 80 kHz, in the initial state of induction amplitude B_m = 0.3 Tl and in a vacuum at a temperature of 300 ^{0}C in a longitudinal magnetic field, transverse magnetic field, also measured after exposure to a temperature of 420 ^{0}C. A comparison of total and hysteresis losses shows that hysteresis losses account for several percent of total losses. For alloys with 8.1 and 9.1 at.% B, the magnetic field resistance creates a noticeable reduced anisotropy, and the level of losses differs sharply from the losses of samples exposed to longitudinal and transverse magnetic fields. The hysteresis component of losses changes weakly during longitudinal magnetic field resistance, while total losses almost double. This means that the losses associated with eddy currents have more than doubled ($P_t = P_h + P_b$). This can be attributed to the increase in the width of domains [3, p. 48-51].

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[2] Herzer. G Modern soft magnets: Amorphous and nanocrystalline materials/ /Acta Materialia –2013. V.61, – p.718–734

Complete losses are reduced after annealing the transverse magnetic field. Thus, as the domain structure formed during the formation of transverse magnetic texture is reduced, the losses to vortex currents are reduced. Resistance without a magnetic field in alloys with 9.1 at.% B leads to a significant (approximately 8 times) increase in total and hysteresis losses. However, this resistance eliminates internal stresses and the stresses that arise when the ribbon is wrapped around the toroid. The greatest reduction in losses is observed after annealing in water at a temperature of 420 ^{0}C. Due to the high tensile temperature in alloys with more than 10 at.% B, the post-exposure value of losses is less than the indicated value of losses.

For alloys with a small amount of B, the elimination of locally induced anisotropy and destabilization of the domain structure during resistance is significant. Thus, research shows that the magnetic resistance for alloys with $x<10$ has a significant effect on the volume of magnetic losses [3, p.10-12].

The effect of heat treatment, the thickness of the layer of amorphous crystals, the time and temperature of annealing, and the effect of annealing environment on the magnetic properties of a tape made of amorphous magnetic alloy has been investigated. The study of soft amorphous magnetic alloys of various structures makes it possible to reveal the main physical reasons for the formation of magnetic losses. It was found that the formation of an amorphous crystalline surface layer of optimal thickness is necessary to achieve high magnetic properties by heat treatment.

One of the most efficient sensors for measuring and recording temperature is the thermocouple. Thermocouples can withstand experimental temperatures and work reliably in a variety of environments, despite vibrations and even ionizing radiation. Thermocouples are often exposed to external, usually undesirable and uncontrolled magnetic fields in the laboratory or in industry. In this case, the parameters of thermocouple sensors made of traditional metal are distorted by the influence of the magnetic field. In this study, thermocouples made of permalloy ribbon were investigated.

Here, we report the thermoelectric performance of thermocouples made of thin narrow amorphous Co-Fe and Ni-Fe films. Magnetically soft Co-Fe and Ni-Fe films were prepared on a two-high casting installation. A metallic alloy was melted in a cruible and then fell into a gap between two cooling rolls in the form of a ribbon. The rolls were cooled by a liquid nitrogen flow. The ribbon was cooled to a temperature of 300-400^{0}C in a mixture of nitrogen and inert gases. The thickness of the film varied between 100 and 200 μm, and its width was equal to 3cm. Co-Fe and Ni-Fe films were cut into1.5 mm-wide strips 20-25 cm in length. The ends of the Co-Fe strip were welded to the ends of Ni-Fe strips by electric-arc welding in distilled water.

In particular, it is possible to produce magnetic thermocouples based on CoFe from ferromagnetic materials that can come into direct contact. Images of the surface of the Co-Fe tape (50% Co and 50% Fe) taken with an atomic force microscope are shown (Figure 2). As you can see in the picture, the structure of the ribbon is homogeneous and its surface is fairly smooth. CoFe and NiFe films were analyzed for X-ray structure. The boundary between CoFe-NiFe alloys was drawn by scanning electron microscopy Figure 3. After annealing in air at 900^{0}C, the surface roughness greatly decreases. It was that the film gains in weight by oxidation.

The gain no uniformity is likely to be associated with a slight liquation of Co and the presence of a weak Fe gradient in the area being analyzed. Straight lines and distict hexagonal segments indicate that the Co-Fe alloy crystallizes at the contact. One junction of a differential thermocouple was kept at 0^{0}C and the other was placed in a thermostat where the temperature can be varied from -196 to 500^{0}C. The thermopower was measured by the compensation method. It should be noted that the ribbons of Co-Fe and Ni-Fe alloys high coercivity.

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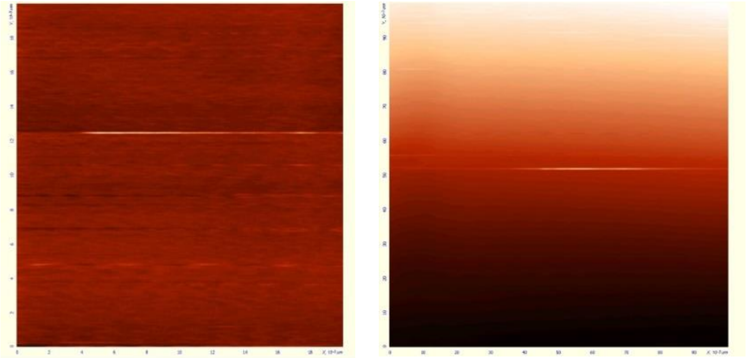
[3] Gregor, G. G, Samo, B. Thermometers in low magneticfields // Int. J. Thermophys – 2010. v.311, – p. 622–632.

[4] Farhad, S. Effect of Magnetic Field Dynamics on the Copper-Constantan Thermocouple Performance / S.Farhad, M.Catherine, H.Lawrence [et all.] // Journal Instrumentation Science & Technology –2005. v. 33, – p. 661-671.

The temperature dependence of differential α(T) thermopower (α), for Co-Fe and Ni-Fe thermocouples is shown in Figure 5. At the contact of the alloys, Co-Fe alloy has a positive potential.



a) b)

Figure 2. Surface images of Co-Fe (50% - Co and 50% - Fe) taken with an AFM: a) before quenching b) after quenching

Figure 3. The boundary between CoFe-Ni Fe alloys taken by scanning electron microscopy

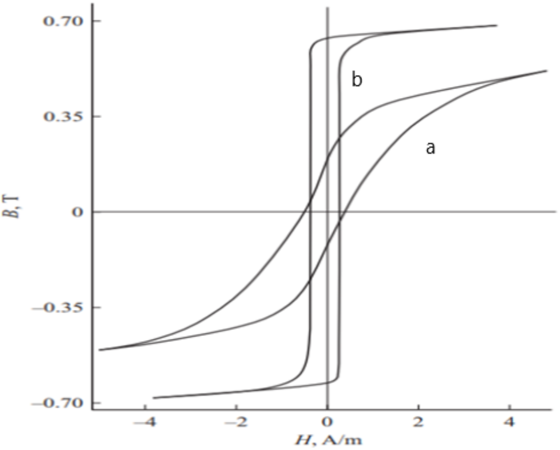


Figure 4. Hysteresis curve of CoFe permaloy tape after water resistance at 410^{0}C: a) permanent; b) variable magnetic field

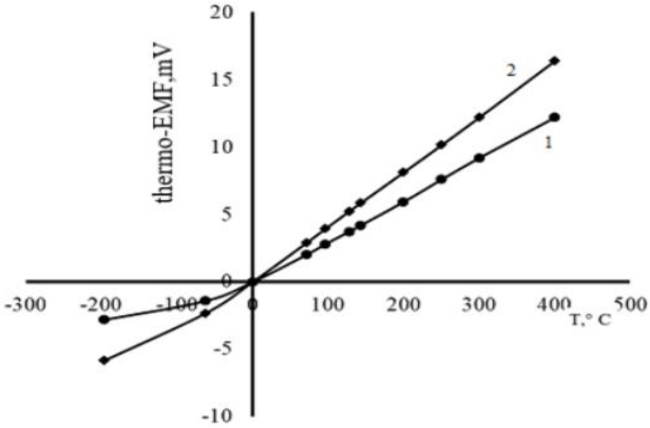


Figure 5. Temperature dependence of Thermo-EMF of the Permaloy thermocouple (curve 1) and Chromel - Alumel thermocouple (curve 2)

According to the Pauling scale, the electronegativity of iron, cobalt and nickel is respectively, 1.83, 1.88 and 1.91. Consequently, the contact potential difference at the interface is due to diffusion flux of electrons from Co-Fe to Ni-Fe. The run of the α (T) curve for the permalloy thermocouple (curve 1) is identical to that fot chromel –alumel type K thermocouple (curve 2) [15, p. 990].

The sensitivity of permalloy thermocouples is slightly inferior to that of chromel-alumel ones.

However the former offer a number of advantages. Film thermocouples were magnetized in magnetic field H=4.8A/m.

Hysteresis loops taken in a variable and permanent magnetic field from a Co-Fe permalloy film heated to 410^0S and quenched in water are shown in Figure 4. The hysteresis loops suggest that the magnetization of the film is high enough and can provide good sticking of magnetically soft flexible Co-Fe and Ni-Fe thermocouples to paramagnetics and ferromagets (Figure 4). Specifically, the magnetization of permalloy thermocouples allows for their direct contact with a paramagnetic or ferromagnetic object owing to magnetic interaction. [15, p. 990].

The effect of isothermal storage temperature and cooling rate on thermal processing on the maximum magnetic penetration in amorphous ribbon of magnetically soft $(CoFe)_{75}Si_{10}B_{15}$ alloys was studied. The results of the study show that the dependence of maximum magnetic penetration on the isothermal storage temperature is determined by the diffusion processes that occur during thermal processing at certain isothermal storage temperatures. The increase of cooling speed has an unambiguous impact on the magnetic properties. The increase in cooling speed causes magnetic properties to be approached after thermal treatment of the surface when the surface is amorphous and at a certain optical thickness during formation of the amorphous-crystalline layer.

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[5] Скулкина, Н.А., Иванов, О.А. Магнитомягкие материалы. Физические воздействия и магнитные свойства // Lambert Academic Publishing, –2010, – с.404

The investigated samples were in the form of the 100 x 10 x 0.022 mm dimension board. Thermal treatment of amorphous $(CoFe)_{75}Si_{10}B_{15}$ alloy was carried out in the air at a temperature of 360-430 ^{0}C and cooled to about 20 and 40 K / min. In figure 6 shows the dependence of the maximum magnetic permeability of amorphous magnetic alloy $(CoFe)_{75}Si_{10}B_{15}$ sample on the heat treatment temperature at a cooling rate of 20 and 40 K / min, when the isothermal storage $\tau = 5$ minutes time in air.

An increase in the temperature of isothermal storage leads to an increase in the maximum magnetic permeability. An increase in the cooling speed limits the increase of diffusion processes at this stage. Consequently, the internal stresses arising during heat treatment after annealing at 360 °C at a speed of 40 K/min are less relaxed, and as a result, the relative volume of orthogonal magnetized domains is higher. In this case, the situation can be associated with the fact that the flow of diffusion processes in the cooling phase is limited to maintain a higher concentration of atoms falling on the surface relative to the ribbon axis. However, depending on the isothermal storage temperature μ_{max}, the shoulder is observed in the temperature range 380–400 °C when cooled at both 20 and 40 K/min.

The dependence of the maximum magnetic permeability on the temperature of isothermal storage, which is determined primarily by diffusion processes occurring in the ribbon during heat treatment in air at a certain isothermal storage temperature, correlates with the corresponding change in magnetization in the tape. At isothermal storage temperatures above 400^{0}C, the activity of diffusion processes is quite high.

It is optimal to have an isothermal storage time of 5 minutes at 420 ^{0}C, which corresponds to the formation of an optimal thickness of the surface amorphous - crystalline layer. The increase in maximum magnetic permeability after heat treatment at a cooling speed of 20 K/min in air in the temperature range 400-420^{0}C is practically due to the interaction of water vapor in the air with the surface of the ribbon and the induction of planar tensile stresses as a result of surface crystallization [13].

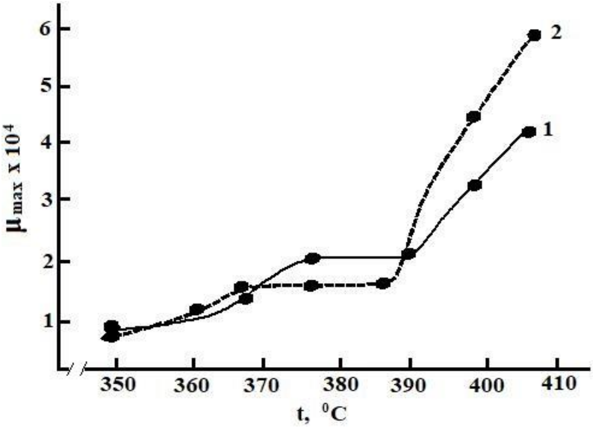

Figure 6. When the maximum magnetic penetration of the amorphous magetically soft $(CoFe)_{75}Si_{10}B_{15}$ alloy specimens is τ = 5 min. its dependence on the thermal treatment temperature with cooling point of 20 and 40 K/min. (Curves 1 and 2 respectively).

Thus, during heat treatment of amorphous magnetic alloy sample studied in this temperature range, the maximum magnetic permeability is practically independent of the isothermal storage temperature, and after heat treatment in air, the surface is mostly amorphous or an amorphous crystalline layer is formed.

A sample of the amorphous magnet alloy $Fe_{72}Co_3Si_{12}B_{13}$ was compared with the curves of the temperature dependence of heat transfer for cooling speed of 15 and 40 K/min (curves 1 and 2, respectively), when the magnetic permeability of the sample is equal to the isothermal retention time in air τ = 7.min and is practically the result is close to the CoFe ribbon sample [5, p.21-24] .

In chapter IV. Phenomenological description of magneto-optical phenomena in ferromagnets is given, magneto-optical Kerr effects are studied. The experimental results obtained using the investigated transversal MOKE on the magnetic and magneto-optical properties of the $(CoFe)_{75}Si_{10}B_{15}$ alloy are studied. The field dependencies of the transversal MOKE were determined in the magnetic field parallel to the surface of the amorphous ribbon and in a direction perpendicular to the axis of the ribbon.

In practice, the value of the transversal magneto-optic Kerr effect is determined by the following expression:

$$\delta = \sqrt{2}\,U_{-}/U_{\sim} = \sqrt{2}\left(I - I_0\right)/I_0$$

I is the intensity of light reflected from the magnetized surface, I_0 is the intensity of light reflected from the non-magnetized surface.

The field dependencies of the transversal MOKE are determined in the magnetic field parallel to the surface of the amorphous ribbon and perpendicular to the axis of the ribbon.

$$\frac{M}{M_s} = \frac{\delta(H)}{\delta(H_s)}$$

formula $\delta(H)$ and $\delta(H_S)$ transversal magneto-optic Kerr effects in magnetic fields, respectively, H and H_S for untreated and heat-treated samples. The value of the magnetic field in the direction of the surface of the heat-untreated amorphous ribbon in the field-dependent energy of 2 eV was 10 Oe. In the direction perpendicular to the axis of the surface, saturation occurs in the direction of the magnetic field 300 Oe. As a result of studying the magnetic properties of heat-treated samples, it was determined that the amorphous ribbon is softer and more magnetically parallel to the surface of the ribbon as the time spent on heat treatment increases.

Experimental studies of magneto-optical properties were performed for unprocessed $(CoFe)_{75}Si_{10}B_{15}$ sample, as well as for samples obtained in air and vacuum. After obtaining the alloys, they were subjected to heat treatment in air and vacuum at a temperature of 420^0C (below the crystallization temperature) in a weak magnetic field.

The amorphous ribbon were 25 µm thick, 10 mm long and 5 mm wide. At field values 2 Oe and 3 Oe, the shape of the spectra and the value of the transversal MOKE for array samples annealed to air change as the annealing time increases as follows.

For untreated and annealing 20-minute ribbons and samples, the value of transversal magneto-optic Kerr effect increases in the energy field of the falling light in the range of 1.5-2.5 eV. Starting at 3 eV, it gradually acquires a frequency-independent appearance. The obtained results were compared with known spectral transversal MOKE dependencies of Co-based amorphous alloys characterized by a wide maximum in the 3 eV region.

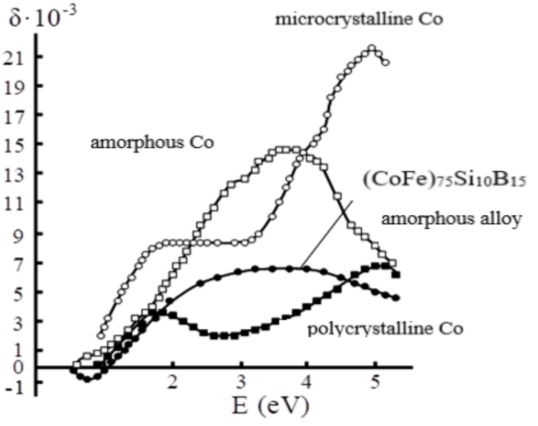

Figure 7. Sample transversal MOKE spectra for Co based amorphous alloys

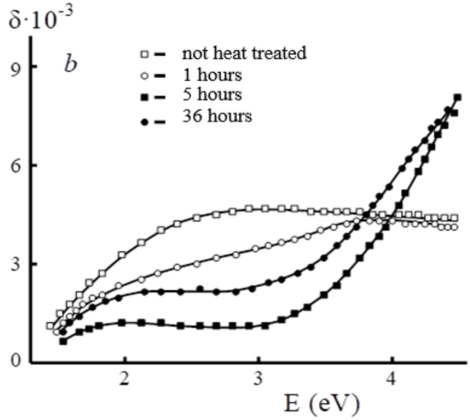

Figure 8. Transversal MOKE spectra of amorphous ribbons annealing to air at different times in the 2Oe field

It is clear that the comparable curves have a similar shape and have the same value of the magneto-optical effect. As the annealing time increases, the transversal MOKE spectra of amorphous ribbons become more accurate, as evidenced by the anomaly that occurs at a value of hν ~ 4.5eV of incident light. A comparison with similar spectral dependencies for CoFe alloys (Figure 7) suggests that the transversal MOKE in amorphous ribbons annealed to air gradually falls to the form characteristic of microcrystalline CoFe alloys. For samples with a annealing time of 5 hours or more, the EKE curves take the final shape formed, which is characteristic of crystalline Co alloys. In the transversal MOKE spectra of such samples, changes in the amplitude of the transversal MOKE were found with increasing value of the magnetic field in the resistance. In this case, the shape of the curves was almost unchanged (Figure 8). The transversal MOKE spectral dependence of such ribbons has similar properties in the range hν ~ 1.8eV and hν ~ 4.5eV, which are characteristic of microcrystalline Co alloys. However, changes in the shape and spectral values of the transversal MOKE prove a change in the microstructure of the samples. That is, as a result of studies of the magneto-optical properties of the given amorphous ribbons, it was determined that a microcrystalline layer is formed and develops in a sequence near the surfaces of the samples during heat treatment [14, p. 716-719].

It should be noted that only the process of flattening in the air causes the formation of a crystalline layer around the surface. No change was observed in the transversal MOKE spectral dependencies of the samples subjected to vacuum. The study of the magnetic properties detected on the surface of amorphous microcrystalline ribbons was carried out using field dependencies and magnetostatic measurements of the transversal MOKE at different wavelengths of incident light.

Depending on the field dependence of the heat-treated amorphous ribbon, saturation occurs at a value of 10 Oe of the magnetic field in the parallel orientation at 2 eV, and at 300 Oe in the perpendicular orientation. As a result of studying the magnetic properties of heat-treated samples, it was found that the direction along the axis of the amorphous ribbon is much softer with respect to the perpendicular direction as the heat treatment time increases. However, as the heat treatment time increases, it is necessary to increase the value of the magnetic field in order to achieve saturation of both the width and length of the sample. At a field dependence of heat-treated amorphous ribbons at a magnetic field value of 2Oe for 5 hours, saturation is observed at 200 Oe during parallel orientation and at 400 Oe during perpendicular orientation [4, p. 79-83]. The fact that the transversal MOKE behaves in this way depending on the field shows that the magnetic structure of the surface layer is not homogeneous in thickness, and the layer closest to the surface is more magnetic. This suggests that magnetic anisotropy occurs in an amorphous sample under such conditions. The value of such a difference in the magnetic properties of amorphous ribbon increases even more in a small magnetic field after heat treatment in air. The alloy under study has a magnetostriction close to zero, and its magnetic anisotropy can be explained by the internal stresses generated during the preparation of the amorphous alloy or the effect of its deformation [13].

To eliminate the effect of the form of anisotropy on the magnetic properties of amorphous ribbon, the field dependencies of the transversal magneto-optic Kerr effect were studied in 2 × 2 mm sample. That the results of measurements in both directions overlap for square-shaped heat-treated amorphous ribbons and are observed at a saturation dependence of the field intensity at 150 Oe. The main factor influencing the anisotropy of the magnetic properties of untreated amorphous tape is the change in the shape of the internal anisotropy. At the same time, it should be noted that the magnetic anisotropy remains unchanged in the square-shaped samples annealed in the air in the 2 Oe magnetic field for 5 hours. More precisely, the behavior of the transversal MOKE designed for thermally processed specimens, depends not only on its shape, but also on the properties of small crystals and crystallites formed in the surface layer.

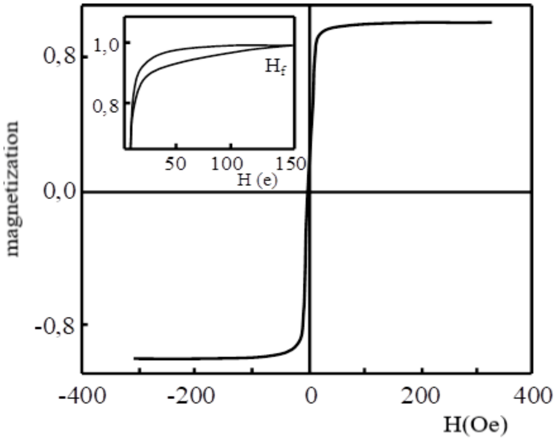

Figure 9. Hysteresis loops for untreated amorphous ribbon

A hysteresis loop was constructed with the help of a magnetometer vibrating in a magnetic field of up to 8 kOe at room temperature of the amorphous bands heat-treated in air and vacuum (Figure 9).Additional hysteresis was observed in a magnetic field of 30-300 Oe for heat-treated samples in air, which is an indication of the formation of a highly coercive phase. It is known that measurements on a vibrating magnitometr give an average result over the entire volume of the sample. During such measurements, the change in magnetization in the surface layer is 5% [8, p. 191-195].

Figure 10 shows the spectra of the transversal magneto-optic Kerr effects measured when the field is applied along the axis of the tape, as well as in the perpendicular direction. The shape of the spectra measured perpendicular to the tape axis changes more attractively. The transversal magneto-optic Kerr effect curves show that anisotropy occurs in samples annealed to a magnetic field for more than 2 hours. When the annealing time is more than 8 hours, the anisotropy disappears. It was found that the amplitude of the magneto-optical property in a sample annealed in an area of 100 mOe for 8 hours remained practically unchanged at various temperature changes [9, p. 43-46]. The giant magnetic impedance of the sample in the profile is symmetrical, a very strong asymmetric dependence of the magnetic impedance on the field is observed in a very strong 5Oe magnetic field for annealing 8 hours [11, p. 86].

For such amorphous ribbons, the amplitude of the transversal MOKE decreases when first heated. Subsequent studies show that this change in magneto-optical properties is irreversible in the range under consideratio. Thus, the transversal magneto-optic Kerr effect of amorphous tape remains virtually unchanged when reheated to 420 K and cooled to room temperature [7, p.48-51]. Crystallization of amorphous alloys depends on the heat treatment process, the annealing temperature and its duration. Amorphous tapes are slowly formed in the non-uniform thickness of the microcrystalline phase during weathering in the near-surface layer. After obtaining the annealing, heat treatment takes place in the subsequent arrangement of the structure of amorphous alloys, the microcrystalline layer is distributed along its width [9, p.43-46].

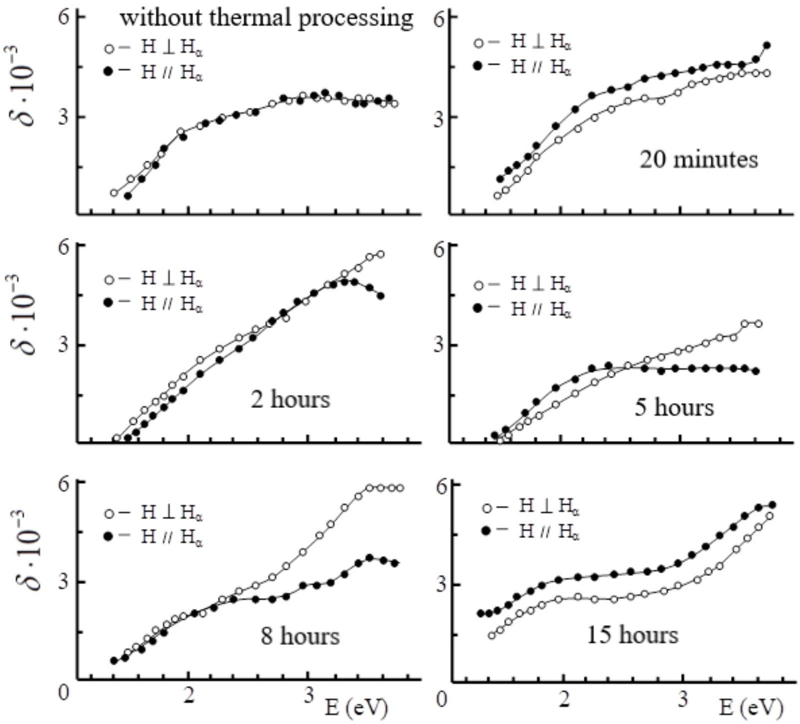

Figure 10. Transversal MOKE spectra for $(CoFe)_{75}Si_{10}B_{15}$ amorphous ribbons annealed to 3Oe magnetic field at different time periods.

In transversal MOKE measurements, variable magnetic fields were applied along the axis (H_{par}) as well as in a direction perpendicular to the field (H_{per}).

The results of the measurement of the field dependencies of the transversal MOKE show that the difference in magnetic properties, measured in two directions, disappears in the 300-400 Oe field. In addition, anisotropy of the values of the transversal MOKE in strong fields has been observed for samples annealing to air in the 3Oe constant magnetic field at different time periods.

MAIN RESULTS

1. It was found that $(CoFe)_{75}Si_{10}B_{15}$ amorphous soft magnetic ribbon sample showed a significant reduction in magnetic losses, the smallest coercive force (0.4 A/m), high magnetic permeability ($\mu = 1,250,000$), high rectangularity ($B_r / B_m = 0$). , 94) hysteresis occurs due to exposure to water in a changing magnetic field. Due to the formation of quenching stresses during quenching, a small local magnetoelastic anisotropy occurs, which leads to the fragmentation of the domain structure.
2. It has been shown that, in contrast to thermal treatment in vacuum and water, additional hysteresis occurs in a magnetic field of 30-300 Oe due to the formation of a highly coercive phase in thermally treated samples in air.
3. It has been shown that thin magnetic tapes based on Co-Fe and Ni-Fe can be used as materials suitable for the production of thermoelectric sensors, which allows to minimize errors in temperature measurements in a changing magnetic field due to heat released due to induction currents.
4. It was found that the effect of isothermal storage temperature and cooling speed on the amorphous maximum magnetic permeability of $(CoFe)_{75}Si_{10}B_{15}$ soft magnetic alloys is determined by diffusion processes occurring during heat treatment. Since the isothermal storage time in the temperature range of 400-420 ^{0}C is 5 minutes and the heat treatment with cooling rate of 40K / min in air increases the maximum magnetic permeability, it can be considered as a practically optimal heat treatment mode.
5. It was found that anisotropy arises perpendicular to a magnetic field of 2 kOe as a result of the formation of crystals and crystallites in the near-surface layer of amorphous tapes in the magneto-optical spectra of the transversal MOKE of the $(CoFe)_{75}Si_{10}B_{15}$ sample annealed in 3 Oe magnetic field.
6. When the CoFe amorphous ribbon is annealing air in a weak magnetic field, it is shown that as a result of the heterogeneity of

anisotropy in the nanocrystalline surface layer, the GMI effect in the 2 Oe - 10 Oe field is enhanced and asymmetric.

7. Based on the spectral dependence of the transversal MOKE, when $(CoFe)_{75}Si_{10}B_{15}$ amorphous ribbon 3 Oe was annealing to a magnetic field for 2-8 hours, anisotropy of the magnetic field was observed as a result of incomplete formation of the crystalline layer in this tape. When the temperature of the $(CoFe)_{75}Si_{10}B_{15}$ amorphous ribbon changed from 350 K to 370 K, two time decrease in the magnetic impedance was found as a result of changes in the microcrystalline state in the near-surface layer of the tape.

The main results of the dissertation are reflected in the following published scientific works of the author.

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