MAGNETIC MICROWIRES FOR GMI-BASED MAGNETIC SENSORS IN AVIATION

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This article is dedicated to the study of magnetic properties of glass-coated ferromagnetic microwires and especially to giant magneto-impedance (GMI) effect. Magnetic sensors based on the GMI effect are suitable candidates for use in many sensor devices. Those devices can be find in aviation industry, on airports and in aircrafts. Some of applications are presented in third chapter. The main part of the article is result of experiment, which examines GMI effect in amorphous Co-Fe microwire. This experiment was carried out at two different frequencies (1 MHz and 1,6 MHz).

K e y w o r d s: glass-coated magnetic microwires, GMI effect, sensors.

1 INTRODUCTION

Air transport, as an important part of the economic activity, places great emphasis on development of new technologies. These technologies are to ensure continuous improvement of accuracy and integrity of the information on which it is dependent on the functioning of the air transport. Current efforts to modernise and miniaturization of technical equipment leads to the development of new advanced technologies, which make it possible to produce smaller devices, but with similar or even with improved properties compared with the previously used.

As a new family of very promising magnetic materials were discovered glass-coated magnetic microwires (Fig.1).

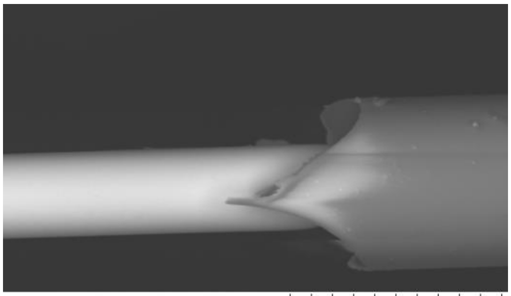

Figure 1: Glass-coated microwire.

They are the object of international research within the last few years. The microwires composed of tiny metallic nucleus (with diameter from 1-30 μm) surrounded by an insulating Pyrex glass coating (thickness of 2-20 μm) [1]. The physical properties of these microwires are related to a great extent to the geometry, microstructure, and chemical composition of the metallic nucleus. Low weight, small geometric dimensions, excellent magnetic characteristics, ability to work in a variety of physical environments in which there are other materials inappropriate, high sensitivity, and last but not least a negligible cost of production, are just a few advantages of products of amorphous glass-coated magnetic microwires with a core from ferromagnetic alloys. For these reasons the use of ferromagnetic microwires are expected in several areas and their applications in the technical bodies for aerospace and aviation technologies.

The magnetic material suitable for applications in sensor technology must have the appropriate properties such as magnetic bistability, magnetic softness. A large group of applications used giant magneto-impedance effect. These properties are determined by the shape of hysteresis loop and magnetoelastic anisotropies [2].

2 THEORY OF GMI EFFECT

Glass-coated amorphous ferromagnetic microwires have been extensively explored due to their high-performance sensing applications based on the giant magneto-impedance effect. The study of the GMI effect became a topic of intensive research in the field of applied magnetism during the last few years. GMI effect is consists in the change of the electric impedance of a metallic magnetic conductor when the material is submitted to an external magnetic field. This effect is the most significant in amorphous magnetic microwires with negative and nearly zero magnetostriction. The main interest of GMI effect is related to the high sensitivity of the total impedance to an applied magnetic field. The magnetoimpedance ratio $\Delta Z/Z$ is defined as

$$\frac{\Delta Z}{Z}(\%)=\frac{Z(H)-Z(H_{max})}{Z(H_{max})}\times 100\% \, , \tag{1}$$

where $Z(H)$ and $Z(H_{max})$ are the impedance magnitudes of the microwire in the measured external magnetic field and maximum magnetic field to saturate the wire [3]. The origin of GMI is associated with the classical skin effect, which relate to the fact that an applied ac current of high frequency concentrates mainly at the surface of the magnetic material with a depth of penetration (δ). Penetration depth is inversely proportional to the frequency of a driving ac current, the electrical resistivity of the material and the circumferential permeability. GMI can be understood as a consequence of the increase in the penetration depth (δ) until it reaches the radius of the wire (a), through the decrease of the circumferential permeability (μ_Φ) under an applied dc magnetic field (H) (see Fig. 2, 3).

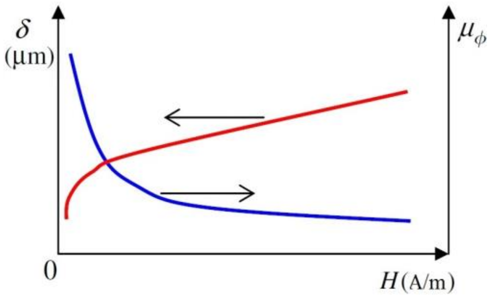

Figure 2: dc applied magnetic field (H) dependences of skin depth δ and circumferential permeability μ_Φ [3].

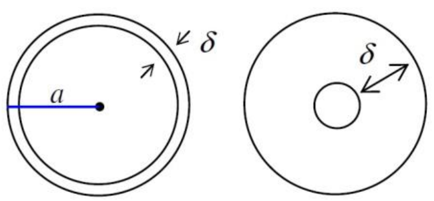

Figure 3: Schematic view of the change of δ with H [3].

A large GMI effect should be especially achieved in ferromagnetic magnetically soft wires (with amorphous and nanocrystalline structure) with large circumferential permeability, small skin depth and electrical resistance [4], [7].

Based on the frequency of the driving ac, the giant magnetoimpedance can generally be classified into the following frequency regimes:

- Low-frequency regime - with frequency up to a few kHz,
- Intermediate frequency regime – there is frequency ranging 100 kHz and a few MHz,
- High-frequency regime - where measuring frequency is several MHz up to GHz [3].

The frequency regimes are changing according to the material, and generally, thus the frequency is higher, the GMI effect is more pronounced. GMI actually depends not only on frequency but also on a number of additional parameters, which include current flowing through the microwire, alloy composition, the actual magnetic domain structure and thermal treatments relaxing the amorphous microstructure or inducing anisotropies. Based on the alloy composition of the core of microwires are known groups of microwires:

- with positive magnetostriction – Fe-rich alloy, axial magnetic anisotropy,
- with negative magnetostriction – Co-rich alloy, circumferential anisotropy,
- with nearly zero magnetostriction constant – Co- and Fe-rich alloy, very weak circumferential anisotropy.

For GMI effect is important very weak circumferential anisotropy, which is typical for amorphous magnetic microwires with nearly zero magnetostriction [5].

A thorough knowledge of the measuring temperature dependence of GMI is important and necessary. In general, with increasing measuring temperature the GMI effect first increases and reaches a maximum value near the Curie temperature of the material, then at higher temperatures finally decreases. For amorphous magnetic microwires: the temperature dependence of GMI has been related to that of the circular permeability. Because the magnetic permeability is sensitive to temperature, the GMI changes rapidly as a function of temperature [3].

Generally, the circular (or transverse) magnetisation process is caused by ac magnetic field. The impedance change is directly depended on this process of magnetization. The higher the amplitude of the ac current the larger impedance is obtained.

The amorphous glass-coated magnetic microwires are considered to be attractive candidates for making miniature GMI-based magnetic sensors. There are four various types of sensors based on the GMI effect (so-called GMI sensors): magnetic field sensors, passive wireless magnetic field sensors, current and stress sensors. These sensors can be used to precisely measure magnetic fields in space, to detect the presence or passage of moving objects, to traffic controls, to detect magnetic anomaly and localised weak magnetic fields. GMI sensors can be used in technologies such as car traffic monitoring, antitheft systems, computer disk heads, rotary encoders, pin-hole detectors, displacement detection sensors, direction sensors for navigation (electronic compass), field sensors, biomedical sensors, quality control of steels, vibrational detection of earthquakes [3].

3 APPLICATION OF GMI-BASED MAGNETIC SENSORS IN AVIATION

GMI sensors are able to sensitively measure any change in the magnetic field and respond to different magnetic field of ferromagnetic objects. Due to this ability they can be used for automatic operation of aircraft or mobile vehicle on the runway, taxiway or apron. This can be achieved by sensor for an automatic driving system, which is located on the landing gear or on the axle of mobile vehicle. Mentioned sensor follows marker magnets on the taxiways, runways or aprons [6].

Safety in aviation is given close attention. The main task is to prevent the introduction of prohibited articles into restricted areas airport security as well as on board an aircraft. To ensure security at the entrance in to the security restricted area, is generally used device frame metal detector. GMI sensor can be used to detect the presence or passage of moving metal objects. These sensors are part of the magnetic security gate. It uses high sensitivity sensors (30 V/G) with frequency band restricted to 0,3–5 Hz. Sensors resistant to interference from steady magnetic field such as geomagnetism and are able to detect magnetic fields generated by movable objects with high sensitivity [6]. Mentioned sensors are able to detect metal objects such as knifes at security gates without any false readings. Another advantages are small dimensions and lower energy consumption.

4 EXPERIMENT

As mentioned, the GMI effect is most significant for microwires with nearly zero magnetostriction. This condition is reached by the chemical composition of microwires based on cobalt and iron. In our case, it was measured microwires with nominal composition of $Co_{70,5}Fe_{4,5}Si_{15}B_{10}$. Mentioned microwire was made in Instituto de Ciencia de Materiales in Madrid. Using above specified microwire we made samples according to requirements of our experiment. During production and transportation of microwire mechanical damage could occur. To prevent using damaged or improper sample we checked sample visually by microscope with 80x zoom.

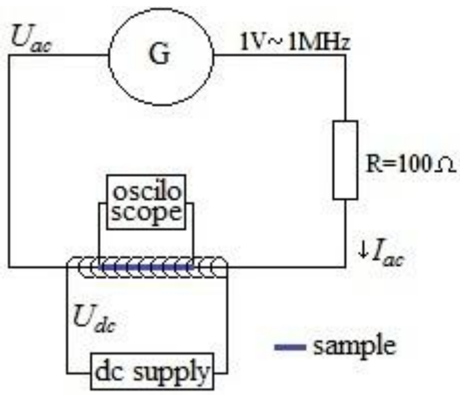

Figure 4: Schematic diagram of the equipments for measuring of the GMI effect.

Main purpose of experiment was to prove and check relation between microwire impedance change and adjusted magnetic field produced by coil. Coil was supplied by direct current from regulated voltage supply. Intensity of external magnetic field of coil is regulated by dc voltage level. Generally we used electric circuit as shown in Fig. 4 and sample was placed inside a coil.

Microwire impedance can be then calculated according to equation $Z = U_{ac}/I_{ac}$, where I_{ac} is alternating current and U_{ac} is ac voltage supplied by generator G. Change of dc voltage is causing variable external magnetic field of coil which affects impedance of microwire. To prove impedance frequency dependence we execute two experiments. First for 1 MHz and second for 1,6 MHz frequency of U_{ac}. Results of both experiments are shown in Fig. 5.

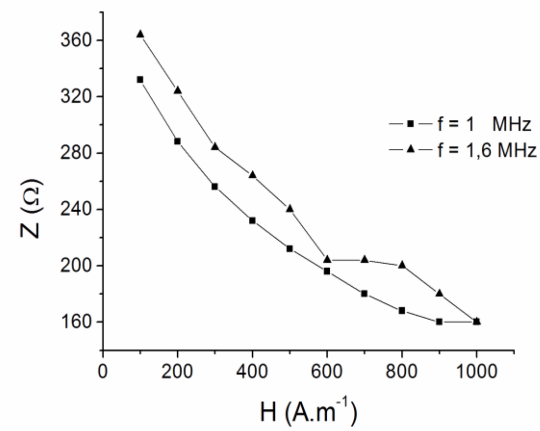

Figure 5: The impedance *Z* as a function of external magnetic field *H* at two different frequencies *f*.

4 RESULTS AND CONCLUSIONS

The GMI effect is most significant at the frequency of 1,6 MHz. This frequency is preferable for using microwires with that composition in the devices based on the GMI. The result is consistent with the theoretical assumption that the GMI effect at high frequencies depends on the skin effect, the penetration depth is inversely proportional to the frequency of the applied alternating current.

GMI-based magnetic sensors exhibit excellent properties compared to conventional magnetic circuit and sensor devices. They do so mainly thanks to those superior sensing performance: extremely high sensitivity, fast response and excellent temperature stability.

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