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Prospects and Applications of Thin-Film Magnetostrictive Membranes for Mems Transducers

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Abstract: The study gives an overview of the use of magnetostrictive films in physical quantities transducers and demonstrates methodsof increasing their sensitive properties due to the implementation of magnetostrictive materials in combination with corrugated membranes, manufactured using MEMS-technology process. This research will provide results regarding magnetostrictive properties of FeNiCo 10 and 20-nm thin films formed on the surface of silicon substrates.

Key words: Magnetostriction, thin film, MEMS transducer, thin membrane, India

INTRODUCTION

Abasis of the functioning of various modern sensors and physical quantities transducers is the relative change in position between several constructive elements of the device. The measuring of relative movements which make utterly small values in the construction of some of the transducers appears to be a challenge without appropriate electronic processing. Controlled small movements usually determine a parameter known as sensitivity. The combination of various effects and properties can be used to increase the sensitivity of physical quantities transducers. The efficiency of such combination depends on a number of factors but the primary focus should be on the technological compatibility throughout the manufacturing process of the device.

The effect of magnetostriction had earlier only some specific applications and was used in highly specialized areas. It is bound to its relatively small observed dimension (length) change $\Delta\lambda/\lambda$ in magnetic field.

MATERIALS AND METHODS

Magnetostrictive transducers of physical quantities: The working principle of Electronic Article Surveillance (EAS) systems is based on magnetostriction. Special tags which represent two (or more) strips on a paper label are placed on product. One of the strips is made of a material with high magnetostriction. The theft is detected in variable magnetic field where the tag works as a non-linear element by sensing harmonics which correspond to operating frequencies. Latest technology development has led to the growing importance of RFID tags (Rmk Shop, 2012).

High-speed non-contact level sensors have found their use in the measurement of liquid level. One part of the magnetostrictive vertically integrated waveguide is installed on top of the outer surface of a reservoir and its lower end rests on the bottom. The sensor circuitry emits ultrasonic pulse. Permanent-magnet floating ring, placed on the waveguide, mechanically deforms the waveguide due to the effect of magnetostriction. The float position and liquid level are defined by measuring how long it takes the pulse to come back after reflection from the bottom part of the waveguide. The measurement accuracy of 12 mm long waveguide is estimated to be about 1 mm (Egorov *et al*., 2016).

Ultrasonic and hypersonic sound waves generators may also be constructed using magnetostrictive materials being almost the only possible solution for the generation of hypersound with the frequency of 1 GHz.

The latest MEMS technologies are capable of producing various micromechanical elementsand can be integrated with other thin-film technologies not only to fabricate physical quantities transducers but also optical switches by silicon micromachining techniques. The research (Lee *et al*. (2007) presents a micro mirror, designed as cantilevershape size of 5×800×50 μm with deposited magnetostrictive TbDyFe film of 0.5 μm thickness. Optical beam from a light source wasreflected from a smooth metal surface and was directed towardsfirst output waveguide. If the magnetic field was applied to the

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mirror in the longitudinal direction it induced strain in the cantilever and bent it so that reflected light reached second output. Thus, it was possible to manufacture magnetostrictive MEMS optical switch by the combination of two technologies.

RESULTS AND DISCUSSION

MEMS transducers of physical quantities using magnetostrictive films on thin membranes: The further development of a joint use of technologies is the fabrication of the membrane-type physical quantities transducers and microdrives. Membrane MEMS are widely used for pressure sensing applications (Amelichev and Ilkov, 2012). The thickness of membrane largely defines sensitivity of a pressure sensor. If the membrane is relatively thin no>1 μm, a strong influence on sensitivity is exerted by internal mechanical stresses. Their minimization presents another task and can be dealt with differently depending on the sensor's construction (Lee *et al*., 2007; Amelichev and Ilkov, 2012). Local corrugation of the surface of a membrane for example, reduces and considerably localizes internal stresses in the central part increasing mechanical sensitivity of the membrane. Figure 1 depicts the view of thin membranes, fabricated in SMC "Technological Centre" (Amelichev *et al*., 2015). It is evident from the photos that "bookletting," resulting from tensile stresses in the structure of element without corrugations is distributed over the entire surface (Fig. 1a) while corrugations release tensions in the central part of the membrane (Fig. 1b). Consequently the results obtained from the corrugated membrane with metal coating are more accurate and structure-sensible properties are higher (Yegorov *et al*., 2015).

Thin membrane can register both acoustic pressure and magnetic field in case of magnetostrictive sensitive element in its central part. The efficiency of magnetostrictive transducers is also determined by magnetostriction coefficient, λ which value depends both on material properties and geometry features (Wang *et al*., 2005). To determine λ, experimental studies were conducted on thin FeNiCo alloys deposited on silicon substrates of 470 μm thickness. Metallic 100 and 200 Å alloys of composition 15% Fe, 65% Ni and 20% Co were coated with electron beam physical vapor deposition. Magnetic parameters of obtained alloys were investigated with the help of MESA-200 magnetic measurement with magnetostriction detection unit. The measurements were based on inverse magnetostriction effect or villary effect.

Predefined mechanical stress, caused by variable mass G of 2-4 kg was applied to the samples with FeNiCo

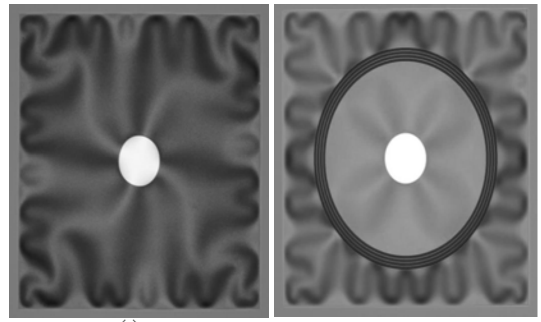

Fig. 1: Photos of dielectric membranes with thin metal layer in the central zone: a) without corrugations and b) with local circular corrugations

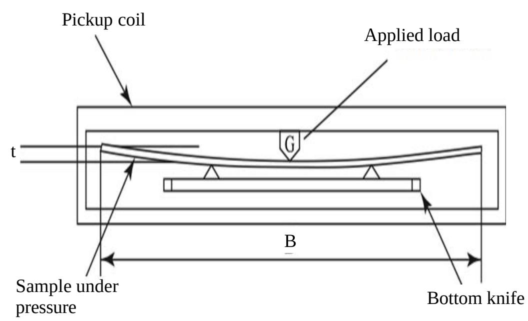

Fig. 2: Schematic diagram of MESA-200 magnetostriction detection unit (B-substrate diameter, t-value of bending of substrate)

alloys (Fig. 2). This load led to bending of substrates by t, measured in the middle between supports B. The values of t (3.3 mm) and substrate diameter B (100 mm) were used to calculate the radius of curvature of the substrate C:

$$C = \frac{B^2 + 4t^2}{8t} \quad (1)$$

The determined geometric parameter C, magnetic saturation and mechanical characteristics were then used to calculate the value of λ (Wang *et al*., 2005):

$$\lambda_S = \frac{2CM_S\Delta H_S(1-v^2)}{3d_S E_f} \quad (2)$$

Where:

E_f = Young's modulus of a thin magnetostrictive film
v = Poisson's ratio of a substrate
M_s = Saturation magnetization along the hard axis
Δh_s = Magnetic anisotropy field induced by stress
d_s = Thickness of substrate

Table 1: The values of mechanical and measured parameters of samples

Structures	Film thickness-Å	E_f (GPa)	V_{si} (μm)	d_s (μm)	t (mm)	C (mm)	ΔH_s,Oe (HMA)	M_s (emu/cm^3, HMA)
FeNiCo	100	159	0.27	470	3.3	380	-17.69	4703
	200	-	-	-	-	-	-18.7	1160

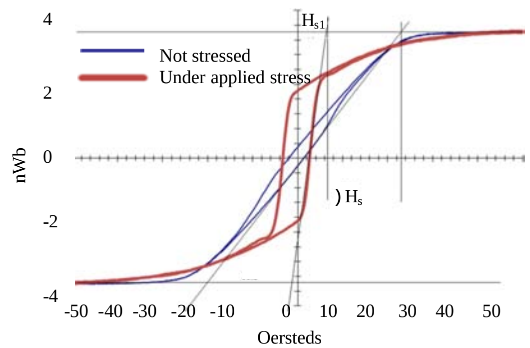

Fig. 3: Alterations of magnetic anisotropy field H_s of FeNiCo alloys, determined along axis of Heavy Magnetization (HMA) before and after applied stress

The value of ΔH_s was obtained from the MESA-200 detection unit. Figure 3 shows the dependence of magnetic flux on the magnetic field of measured sample in stress-free state and under applied load. It is clear that mechanical stress causes alterations of magnetic properties of the active material; in particular the magnetic anisotropy field H_s. Being in stress-free state, domain structures are magnetized along Easy Magnetic Axis (EMA) while stress in the FeNiCo flips the domain's direction of magnetization and orientates them along axis of Heavy Magnetization (HMA) changing the dimensions of the films.

Table 1 represents the structural parameters of samples and values of magnetic anisotropy field ΔH_s with saturation magnetization M_s which are measured and calculated automatically by MESA-200. The calculations of λ using Eq. 2 show that its values for 100 and 200-Å FeNiCo filmsare -2.25 and -6.657×10^{-6}, respectively. Therefore, double increase of thealloy thickness leads to triple increase of λ.

CONCLUSION

The analysis of the application of magnetostrictive materials has revealed that MEMS-based magnetostrictive transducers are promising future direction for research. In contrast to the piezoelectric effect which requires the supply of electric signal these sensors operate by magnetic field and can measure the mechanical impact on microconsoles or thin membranes. A joint use of MEMS and thin-film technologies may be applied in the fabrication of physical quantities transducers and microdrives. The measurements of 100 and 200 Å FeNiCo films on silicon substrates helped to estimate the value of magnetostrictive constant λ which reached its peak of -6.657×10^{-6} on the thicker film. The search for optimal physical and technological parameters of the magnetostrictive films for various sensors and devices requires an extensivestructural and technological study and will be covered in detail separately. These transducers can be widely used in medical devices for cardiovascular and *in vitro* diagnostics.

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REFERENCES

Amelichev, V.V. and A.V. Ilkov, 2012. Technological Basis for Fabrication of Electroacoustic Transducers. TechnoSphere, Inc., Moscow, Russia, Pages: 104.

Amelichev, V.V., S.S. Generalov, S.V. Nikiforov, G.P. Solovyova and M.I. Smekhova *et al*., 2015. The study of membranes with low level of mechanical stress. Intl. J. Appl. Eng. Res., 10: 42767-42769.

Egorov, F.A., V.T. Potapov, M.A. Melkumov, V.V. Amelichev and S.S. Generalov *et al*., 2016. A fiber-optic frequency transducer of variable pressure in gaseous and liquid media. Tech. Phys. Lett., 42: 501-504.

Lee, H.S., C. Cho and M.W. Cho, 2007. Magnetostrictive micro mirrors for an optical switch matrix. Sensors, 7: 2174-2182.

Rmk Shop, 2012. Types and technologies of anti-theft systems. Rmk Shop, Pasay, Philippines. http://www.rmk-shop.ru/technologii-protivorkazhnyh-system.html.

Wang, D., C. Nordman, Z. Qian, J. Daughton and M. John, 2005. Magnetostriction effect of amorphous CoFeB thin ?lms and application in spin-dependent tunnel junctions. J. Appl. Phys., Vol. 97,

Yegorov, F.?., V.V. Amelichev, S.S. Generalov, S.V. Nikiforov and S.V. Shamanayev, 2015. Fibre-optic hydrophone with distant self-calibration. Intl. J. Appl. Eng. Res., 10: 42750-42752.