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High frequency and magnetoelectrical properties of magnetoresistive memory element based on FeCoNi/TiN/FeCoNi film

G.V. KURLYANDSKAYA, J.M. BARANDIARÁN, H. GARCÍA-MIQUEL[*,1], M. VÁZQUEZ[2], V.O. VAS'KOVSKIY[3], A.V. SVALOV[3]
Dpto. Electricidad y Electrónica, Un. País Vasco UPV-EHU, Apdo.644, 48080 Bilbao, Spain,
[1]Dpto. Ingeniería Electrónica, Un. Politécnica de Valencia, Camino de Vera, s/n, 46022 Valencia, Spain;
[2]Instituto de Magnetismo Aplicado,UCM-RENFE, and Instituto de Ciencia de Materiales,CSIC, 28230 Las Rozas (Madrid), Spain;
[3]Institute of Physics & Applied Mathematics, Ural State University, Lenin Ave. 51, 620083 Ekaterinburg, Russia

A miniaturised memory device for information recording and readout processes have been designed on the basis of anisotropic magnetoresistive effect in Fe15Co20Ni65(160Å)/ TiN(50Å)/Fe15Co20Ni65(160Å) three-layered film done by rf diode sputtering. Stable recording and readout processes were available for 32 rectangular element column, where each element had μm dimensions convenient to fabricate memory chip with 10^6 bits capacity. Rectangles of different sizes with removed corners were used in order to define the geometry of most of all stable recording and readout processes. Magnetoresistance and magnetoimpedance effects of a magnetic memory device have been comparatively analysed. We suggest that the decrease of the absolute value of the magnetoimpedance of the memory device comes from the reduction of the real part via the magnetoresistance.

Keywords: Thin film, magnetic memory, magnetoresistance, magnetoimpedance.

Propiedades magnetoeléctricas de una memoria magnetorresistiva basada en películas de FeCoNi/TiN/FeCoNi

Se ha diseñado un dispositivo de memoria para la grabación y lectura de información basado en el efecto de la anisotropía magnetorresistiva de una multicapa fabricada por sputtering mediante diodo de rf. El elemento de memoria se compone de tres películas delgadas, de composición Fe15Co20Ni65(160Å)/ TiN(50Å)/Fe15Co20Ni65(160Å). El dispositivo permite procesos de grabación y lectura estables, y se compone de 32 elementos de memoria rectangulares por columna, donde cada elemento tiene dimensiones de μm lo que permite la fabricación de memorias integradas con capacidades del orden de 10^6 bits. Se han ensayado elementos de memoria rectangulares de diferentes tamaños, con las esquinas redondeadas con objeto de conseguir procesos de lectura-escritura lo más estable posible. Se han analizado comparativamente los efectos de magnetorresistencia y magnetoimpedancia de los elementos de memoria de diferentes dimensiones. Sugerimos que la disminución del valor absoluto de la magnetoimpedancia del elemento de memoria es consecuencia de la reducción de la parte real, de origen magnetorresistivo.

Palabras Clave: Película delgada, memoria magnética, magnetorresistencia, magnetoimpedancia.

1. INTRODUCTION

Magnetotransport phenomena as magnetoresistance, MR, (1,2) and magnetoimpedance, MI, (3,4) become a subject of an active present research due to their technological applications. Application of a magnetic field can lead to resistivity changes of a magnetic conductor if a dc current flows through it (MR) or to a change of the total impedance, both real and imaginary components $Z=R(w,H)+jX(w,H)$, when ac current flows along it (MI).

Magnetic recording together with non-destructive magnetoresistive readout based on anisotropic magnetoresistive effect is one of the advanced principles of the memory device operating. Generally, two types of the MR film memory devices are known: one layer film based device with stable domain structure or domain wall features and two layered film based device with quasi-closed magnetic flux (5,6). The elements of the memory devices of the second type have a finite size showing the tendency to improve the flux closing when the width of the element decreases. It is very important to choose both a correct geometry and optimal size of the rectangular film-element in order to ensure maximum guarantee of the readout process stability and high density of the information for making memory chip (6).

MI materials used in applications show typically negligible MR. But a simple model of the MR contribution to the total MI has been recently presented showing that the MR contribution can play an important role to the total change of impedance in some circumstances (7). Therefore, the comparison between MR and MI effects is then an interesting subject of research. Here we present the analysis of the MR and MI behaviour of a miniaturised magnetic memory device containing rectangular Fe15Co20Ni65(160Å)/ TiN(50Å)/ Fe15Co20Ni65(160Å) film elements with quasi-closed magnetic flux.

2. MAGNETORESISTANCE MEMORY ELEMENTS AND CHIP DESIGN

The memory elements were prepared by photolithography contact method starting from the Fe15Co20Ni65(160Å)/ TiN(50Å)/Fe15Co20Ni65(160Å) non-magnetostrictive three-layered film done by rf diode sputtering. The tree-layers consists in two magnetic layers and a non-magnetic but conducting TiN layer in between with electrical resistivity of about ten times higher than the resistivity of FeCoNi layers (Fig.1). The three-layered structure reduces the demagnetizing field in the transverse direction. Recording and readout processes can be organized for single layered FeCoNi film element but presence of two layers divided by non-magnetic layer ensures stable working parameters.

Our magnetic memory device consists of a number of independent columns of elements, each one being the total contribution of 32 identical individual memory elements aligned with the long rectangular side (Fig. 2). As usual, the number of elements in each column is an even number in order to ensure the recording in binary code. Separate elements are joined together by Cu conductive leads bringing up the flowing dc current to all layers.

The memory device contains two types of columns differing by the size of the rectangular memory elements: type 1 — 15 μm x 3 μm and type 2 — 7 μm x 1.5 μm. The corners of the elements were removed (Fig.2) to ensure a better magnetic flux closure.

Applied magnetic field and flow of dc current I_{line} are parallel to the long side of the element and column of the elements. The easy magnetisation axis of each element is perpendicular to the current direction and parallel to a short side of the rectangle. The pulsed current I_{imp} flowing through the additional conductive lead and having no electrical contact with the magnetic layers is parallel to a short side of the element (Fig.1). The position of easy magnetisation axis and magnetostatic interaction between the magnetic layers leads to the appearance of the quasi-closed magnetic flux structure of the elements.

Each memory element leads to store either "0" or "1" information unit (the clockwise or counter-clockwise magnetic flow circulation stable configuration) depending on the parameters of the pulse current I_{imp} and current I_{line} flowing along the column. The direction of the pulse current was parallel to the magnetization vector and short side of the memory element. Readout process at a fixed value of the flowing current I_{line} consists in measurements of the bridge scheme misbalance versus the applied magnetic field, if the column of the elements joined with one of the bridge arms. Time to read and to write information is 0.2 and 3 ms respectively.

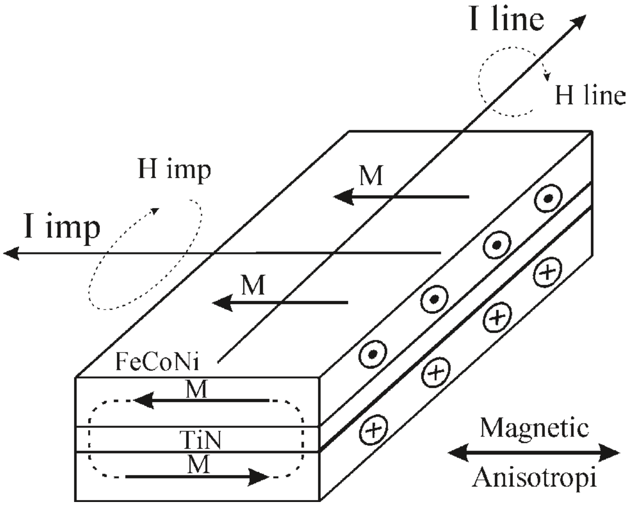

Figure 1. Scheme of the Fe15Co20Ni65(160Å) / TiN(50Å) / Fe15Co20Ni65 (160Å) three-layered film of the single memory element: H - external dc field, I_{line} — dc current flowing through the magnetic layers, I_{imp} – pulse current passing through the additional conductive lead M - magnetization of the magnetic layers.

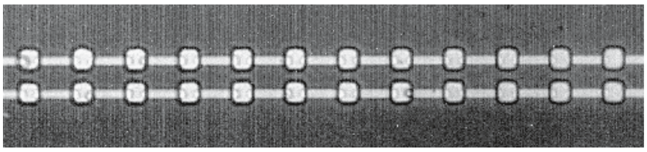

Figure 2. Memory elements connected by Cu-lead; column of the 32 memory elements, view of chip by microscopy.

MR measurements were carried out by two-probe method using a conventional bridge scheme for 1.5 or 0.05 mA dc current. The MI was measured in a frequency range of 0.1-1.25 MHz using HP3589A analyser with alternating sinusoidal driving current of 1.5 mA both in increasing and decreasing external field. The MI ratio is defined as $\Delta Z/Z_{||}(H)=[Z(H)-Z(H_{max})]x100/Z(H_{max})$ and parallel MR ratio as $(\Delta R/R)_{||}=[R(H)-R(H_{max})]\ x100/R(H_{max})$ for $H_{max} = \pm 10$ kA/m. Chip design and geometry of the memory elements observation were done using optical microscopy observation (Figure 2).

3. MAGNETOIMPEDANCE AND MAGNETORESISTANCE STUDY

Figure 3 shows typical MR loop and MI responses for 32 memory elements columns of types 1 and 2. Usual hysteretic behaviour and maximum MR value of about 2.1% were observed. The shape of the MR loop and the maximum value of the MR effect are similar with the parameters of the bulk FeCoNi alloy, i.e. MR loop parameters of macroscopic size this composition three-layers (about 2.3%). The MR loop of type 2 column is very similar with the loop presented in Figure 3.

Elements of two types show similar shape of the MI curve (Fig. 3) with MI hysteretic behaviour, but they differ in details as for example in the MI maximum value. The absolute value of the MI ratio is higher for the bigger size column (15 μm x 3 μm). They depend on the frequency: the higher the frequency the smaller the absolute value of the MI ratio (see Figure 4). Difference in MI behaviour for the columns of type 1 and type 2 can be explained taking into account the particular distribution of the magnetization vectors and therefore the particular magnetisation processes in the small elements (8), where the borders importance is increased. Non-uniformity of the magnetization vector distribution in type 2 elements can make the demagnetisating field become important especially for the high frequency case. The transverse magnetisation processes play a very important role in a MI behaviour and can be different in the elements of various sizes due to the difference of the initial magnetization distribution. That can lead to differences in MI behaviour for type 1 and type 2 columns, especially at a high frequency.

A minimum of the MR is observed near the field corresponding to the minima of MI curves both in the type 1 and type 2 columns (for example, H≈300 A/m for the type 1 column of the elements). We propose that the MI value decrease comes mainly from the reduction of the real part of the impedance $Z(H)=R(\omega,H)+iX(\omega,H)$ due to the magnetoresistance phenomenon. On the other hand, it seems confirmed (see Fig.4) that the rise of the total impedance in Fe15Co20Ni65(160Å)/

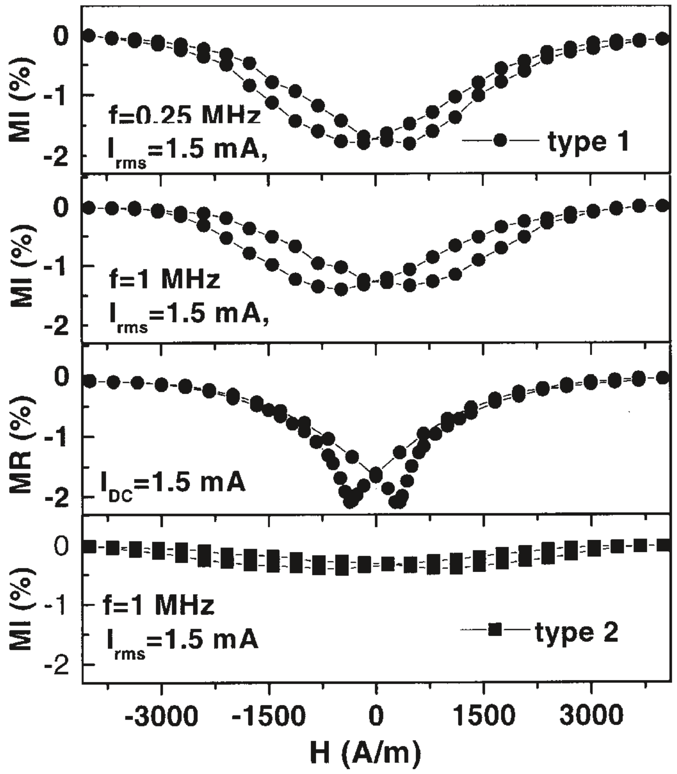

Figure 3.- Longitudinal MR loop, MI responses for the type 1 column at frequencies of 0.25 and 1 MHz and MI response of the type 2 column at frequency of 1 MHz.

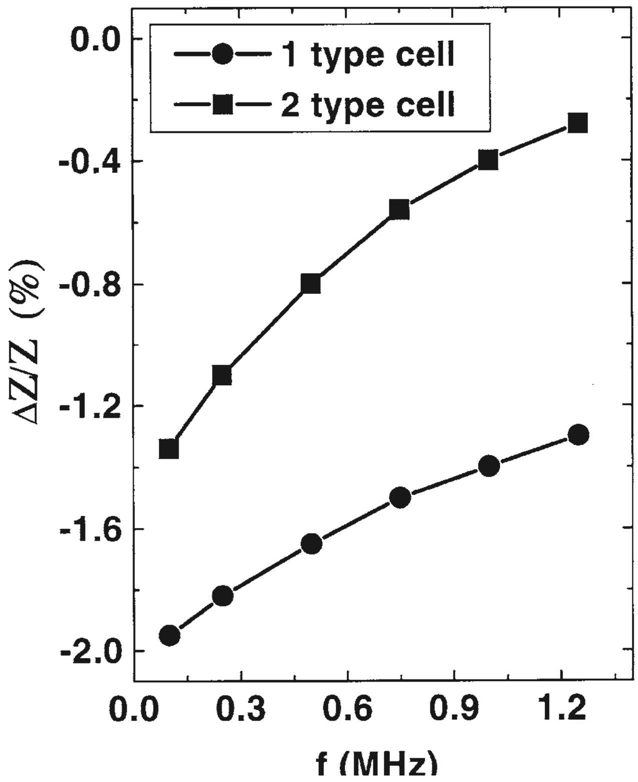

Figure 4. Frequency dependence of the MI ratio maximum for the columns of the memory device based on Fe15Co20Ni65(160Å) / TiN(50Å)/ Fe15Co20Ni65(160Å) three-layered film (the rectangular memory element sizes used: type 1 — 15 μm x 3 μm and type 2 — 7 μm x 1.5 μm).

TiN(50Å)/Fe15Co20Ni65(160Å) three-layered film is restricted by the dc electrical resistance reduction owing to magnetoresistive effect. A similar situation was previously studied for FeNi single layered films (9).

4. CONCLUSION

The MR and MI effects of a minituarized memory device, based on Fe15Co20Ni65(160Å) /TiN(50Å)/Fe15Co20Ni65 (160Å) three-layered film, has been studied. The recording and readout processes has been modelled for the columns of the rectangular elements of two different sizes 15 μm x 3 μm and 7 μm x 1.5 μm. Decrease of the elements size leads to deterioration of the reading process and decrease of the absolute MI ratio value, perhaps due to the difficulties of the magnetisation reversal owing to the borders imperfection. We suggest that the decrease of the magnetoimpedance of memory element arises from the reduction of the real part of the impedance via the MR phenomenon.

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REFERENCES

1. T.R. McGuire, R.I. Potter, "Anisotropic magnetoresistance in ferromagnetic 3d alloys", IEEE Trans.Magn., MAG-11, pp. 1018-1038 (1975).
2. M.A.M. Gijs, G.E.W. Bauer, and Europhysics Journal: Advances in Physics, "Perpendicular giant magnetoresistance of magnetic multilaYers" **46**, pp. 285-445 (1997).
3. L.V. Panina, K. Mohri, T. Ushiyama, K. Bushida, M.Noda, "Giant magnetoimpedance in Co-rich amorphous wires and films", IEEE Trans.Magn., **31**, pp. 1249-1251 (1995).
4. R.S. Beach, C.L.Platt, F. Jeffers, A.E. Bercowitz, " Magneto-impedance effect in NiFe plated wire" Appl. Phys. Lett. **68** (19), pp. 2753-2755 (1996).
5. A.V. Pohm, J.M. Juang, J.M. Daughton, D.R.Krahn, V.Mehra, "The design of a one megabit non-volative M-R memory chip using 1,5x5 μm cells", IEEE Trans. Magn., **24**, pp. 3117-3119 (1988).
6. V.O. Vas'kovskiy, V.G. Muhametov, P.A. Savin, V.V. Strelok, "Magnetoresistive memory elements" Microelectronica, **22**, pp. 64-71 (1993).
7. J.M. Barandiarán, G.V. Kurlyandskaya, M. Vázquez, J. Gutiérrez, D. García, J.L. Muñoz, "A simple model of the magnetoresistance contribution to the magneto-impedance effect in thin films", Phys. Stat. Sol. (a) **171**, pp. R3 (1999).
8. A.V. Pohm, C.S.Comstock, "The reversed word field switching threshold for M-R memory elements", IEEE Trans. Magn. **26**, N 5, pp. 25-29 (1990).
9. G.V. Kurlyandskaya, J.M. Barandiarán, J.Gutiérrez, V.O. Vas'kovskiy, V.N. Lepalovskij, M. Vázquez, D. García, "The magnetoresistance contribution to the magnetoimpedance effect in permalloy thin films" Phys. D: Applied Physics, submitted.

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