Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Sensors and Actuators A 129 (2006) 107–111
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

New 2D fluxgate devices based on the phase modulation of magnetization rotation in AMR films

J. Petrou [a], P.D. Dimitropoulos [b,1], E. Hristoforou [a,*], M. Neagu [c]

[a] *Laboratory of Physical Metallurgy, National Technical University of Athens, Zografou Campus, Athens 15780, Greece*
[b] *THEON Sensors-7, Stratigi Str., 15451 Athens, Greece*
[c] *Al.I. Cuza University of Iasi, Romania*

Received 4 July 2004; received in revised form 6 October 2005; accepted 22 November 2005
Available online 20 January 2006

Abstract

The AMR effect of single-domain film-resistors is being widely used for magnetic field and linear/angular displacement sensing. However, several constrains attributed to the repeatability of magnetization orientation limit the accuracy of such devices. There is a trade-off between device sensitivity and measurement repeatability; the anisotropy field H_K affects both parameters in an inverse manner. To overcome such problems we propose the employment of AMR film-resistors as fluxgate devices. Using a rotating magnetic field vector as excitation, the anisotropic magnetoresistance material is kept continuously in saturation and a pseudo-super-paramagnetic behaviour is observed. Thus, the signal noise coming from Barkhausen jumps can be narrowed down to zero.

Keywords: Magnetic sensor; AMR; Fluxgate; Barkhausen jump; MRAM

1. Introduction

In magnetic field sensing, the main problem that limits the sensitivity capabilities of a sensing device is the magnetic noise [1]. This is mainly originated from the Barkhausen jumps that take place in anisotropic materials, the intensity of which depends on the energy that is consumed for a magnetic dipole to be turned from one crystallographic or magnetic easy axis to another. But even in amorphous materials this is not eliminated, because the shape anisotropy is significant and Barkhausen jumps still exist due to domain wall defects, thus limiting the accuracy of measurements [2].

The AMR effect of single-domain film-resistors is widely used in field sensing. But, the lack of repeatability of magnetization orientation limits the accuracy of such devices [3]. The anisotropy field H_K affects sensitivity and repeatability in an inverse manner, defining this way an ultimate lower limit of sensing capabilities of these devices [4,5]. This happens because the lower the H_K, the greater sensitivity is gained. But the lower the H_K is, the greater the remanence magnetization, thus decreasing the repeatability [6]. If the anisotropic behaviour of a single-domain AMR film could be overcome, the sensitivity would increase significantly [7–9].

In fact, this is the motivation of this paper, namely the development of a technique to increase the sensitivity by eliminating the Barkhausen noise.

2. The theoretical principle

A way to eliminate the Barkhausen noise is to keep the material in deep saturation state. This can be achieved by using a rotating magnetic field vector on the surface of the AMR film as excitation field with an angular speed ω. Rotating magnetic field vector can be obtained by transmitting two vertical fields of $H_x(t) = H_O \sin \omega t$ and $H_y(t) = H_O \cos \omega t$, respectively. The amplitude of the magnetic vector must be significantly larger than the anisotropy field H_K of the material ($H_O \gg H_K$) in order to keep it in far in the saturation state which in fact is the reversible rotation process of magnetic domains. The film magnetization M rotates

* Corresponding author. Tel.: +30 2107722178; fax: +30 21077119.
E-mail addresses: pdimi@pdimi.gr (P.D. Dimitropoulos), eh@metal.ntua.gr (E. Hristoforou).
1 Tel.: +30 2106728610.

0924-4247/$ – see front matter
doi:10.1016/j.sna.2005.11.032

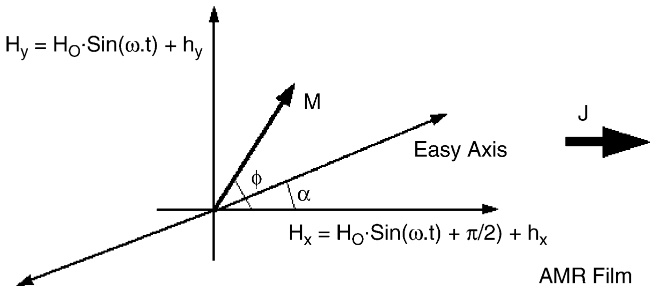

Fig. 1. Analysis of the rotating excitation field.

under the influence of the harmonic excitation field, as shown in Fig. 1. Angle φ is modulated by the axial components h_x and h_y of the ambient magnetic field and, thus, film resistance becomes a phase modulated waveform, ideally a sinusoidal function with angular speed ω and the AMR film behaves as a pseudo-isotropic super-paramagnetic material.

If a DC magnetic field is applied parallel to the surface of the AMR film, the sinusoidal output voltage is formed according to the analysis of the applied vector on the two axes of the material, the one being the axis the resistance under measurement and the other one the vertical to it. The output voltages are then modulated by multiplying them by $\sin(\omega t)$ or $\cos(\omega t)$ with respect to the x- and y-axes, respectively. Therefore, the output at a given axis is a DC voltage offset originated from the applied field that is to be measured.

If the amplitude H_{O} of the rotating excitation field vector is much larger that the anisotropic field H_{K} of the material ($H_{\mathrm{O}} \gg H_{\mathrm{K}}$), the AMR film acts as a pseudo-isotropic and pseudo-super-paramagnetic material and the Barkhausen jumps are eliminated. So, the magnetic noise is narrowed down to theoretically zero and the measurement noise and sensitivity limitation are only due to circuit electronics.

Consequently, the parametric control of the set-up (film geometry, stoichiometry, material structure and micro-structure) can lead to the minimization of the anisotropic field H_{K} and the magnetic noise and increase the sensitivity of the measurement. The magnetization of the material is continuously rotating and on each 360° turn any offset that would be produced because of remanent magnetization by the external field is zeroed.

For amplitudes H_{O} of the rotating excitation field significantly larger than the anisotropic field H_{K}, the magnetization of the material follows adequately the rotating external field and the output is a sinusoidal function. When the excitation field is reduced in amplitude and its value approaches H_{K}, some harmonic functions are added in the previously mentioned sinusoidal function, as shown in Fig. 2(a), due to the difficulty of the magnetic domain rotation.

The series of these harmonics are related to the difficulty of the magnetization vector of a mono-magnetic or quasi-mono-magnetic area to turn from one easy axis to another. The number of the Barkhausen jumps in a given period of the external field is equal to the number of the easy axes that the material has on the surface of the rotating field.

Every term of the series is periodical with the same period but phase difference, which is an unambiguous function of the

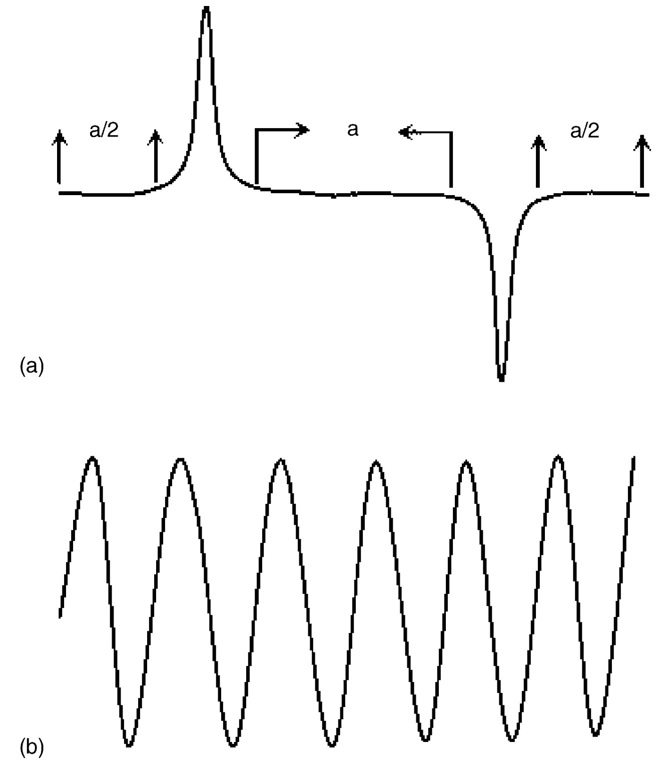

Fig. 2. (a) "Dead" time between the Barkhausen jumps of the material magnetization from one easy axis to another. (b) Elimination of the "dead" time by synchronization of the angular speed of the external field to the magnetization rotation.

orientation of each grain or magnetic domain. The parametric control of the angular speed of the rotating external magnetic field can zero the "dead" time between the Barkhausen jumps in the output voltage, as shown in Fig. 2(b), under the assumption that there are no pinning points in magnetic domain wall motion. Thus, changing the angular speed ω, one can obtain a sinusoidal output signal of the same angular speed.

For a film of cubic bcc or fcc symmetry and with the proper selection of the angular speed of the excitation field, so that the output signal be a sinusoidal function, the frequency of the harmonic addition or noise of each magnetic grain will be 2ω for in plane anisotropy and 3ω for out of plane anisotropy. Thus, all the waveforms that are added to the signal as sinusoidal signals of the same frequency and different phase are obliged not to be random signals, but addition of sinusoidal functions with 2ω or 3ω angular speed. Thus, by placing in the set-up digital band pass filters that eliminate the signals with angular speed of 2ω and 3ω, magnetic noise could be removed.

3. Experimental

For a first validation of the above principle, an AMR magnetic sensor obtained from Honeywell was used (HMC1512). The device consists of two pairs of perpendicular film-resistors connected in Wheatstone bridge configuration. The AMR elements had a saturation field of 6.4 kA/m, which is rather high for high sensitivity field sensors. Acceptable response in such