DYNAMICAL MAGNETOACOUSTIC BEHAVIOR OF NANOSTRUCTURED MAGNETOSTRICTIVE FILMS: MEMS ACTUATION, DESIGN AND TECHNOLOGY

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Abstract

Nanostructured multilayered active films, made of an association of several TbCo/FeCo bilayers, are considered for MEMS actuation. Owing to a second-order instability of Spin Reorientation Transition (SRT) type artificially induced in the films, the sensitivity to the driving field is increased by a factor 100. Application to an example of microvalve is considered.

Introduction

Developing MEMS with mechanical functions -in particular actuation - is a common subject among the international scientific community last years. A first technological solution was focused on electrostatic interactions, but the provided torques and forces were not high enough for many applications. More recently, other technologies, based on shape memory alloys, piezoelectric or magnetostrictive materials, have been prospected. The latter represents a really interesting solution in MEMS, because it can provide strain and stress among the highest available, with possibilities of high frequency actuation. This article presents the characteristics of nanostructured (TbCo/FeCo) magnetostrictive thin films near the Spin Reorientation Transition (SRT) and its possibilities for MEMS actuation. We present two possible designs of microvalves based on such films and the successive technological steps elaborated for its fabrication : the silicon microstructures which will be actuated by the magnetostrictive film, the microcoils which will provide an integrated driving field source, and the solutions for input/ouput microchannels and packaging.

Nanostructured magnetostrictive thin films

The nanostructured magnetostrictive thin films presented in this paper are made of several stacked $Tb_{34}Co_{66}$ and $Fe_{65}Co_{35}$ layers (from 2 to 40 bilayers), with respective thickness of 6.2 nm and 5.8 nm. These layers are deposited by sputtering under a static magnetic field (about 500 Oe). This method allows to induce an easy anisotropy axis in the film (cf. Figure 1) [1]. An external static magnetic field H_s, with a value close to the anisotropy field and direction perpendicular to the easy axis, creates a second-ordered instability of Spin Reorientation Transition type (SRT) [2]. The film can be actuated by applying a dynamic magnetic field h, along the easy axis (cf. Figure 2). Near the SRT, the sensitivity of such films is increased by a factor higher than 100 (cf. Figure 3). Thus, it significantly reduces the driving field, which value is now around 10 Oe.

This phenomenon allows us to use microcoils for the generation of the dynamic driving field, but requires the film's polarisation near the SRT. Such a static field can be generated either by a thin permanent magnet film either by the presence of a bias exchange layer.

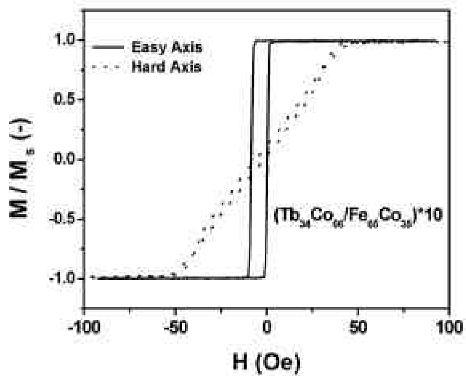

Figure 1: Magnetic characteristic of (TbCo/FeCo)*10 film measured by a Vibrating Sample Magnetometer (VSM).

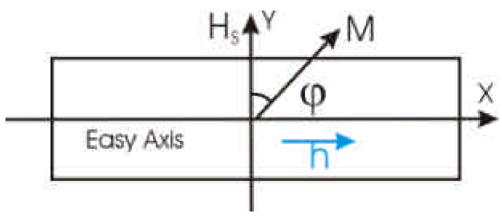

Figure 2: Scheme of a macroscopic test sample (24 mm * 4 mm * 150 µm) (upper view): relative orientations of the easy axis, static field Hs and dynamic excitation h.

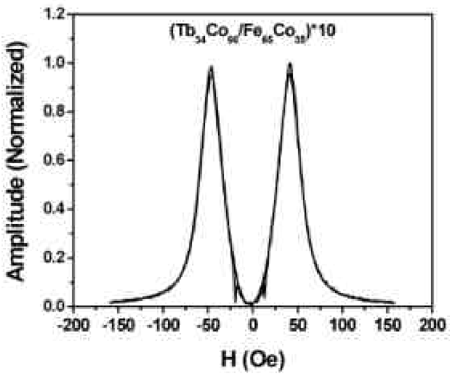

Figure 3: Amplitude of the dynamic oscillations versus static magnetic field H_s (constant dynamic magnetic field) for sample of Figure 2. The amplitude is increased by a factor higher than 100 near the TRS (H # 50 Oe).

Microvalve fabrication

As an example of application of such magnetostrictive films, we present a possible technological strategy for the fabrication of a microvalve : the design, the fabrication of microstructures, the elaboration of microcoils for integrated control, and possible solutions for input/output channels and packaging.

Design

Two designs of microvalves are considered. The first one is based on the oscillations of a cantilever, actuated by a magnetostrictive thin film. A microbeam deflects an incoming constant air flow towards two outputs, so that two outgoing oscillating flows can be obtained (cf. Figure 4-a).

Such a design can also be used by reversing input and output: injection of two air flows on both side of the cantilever can maintain it in a stable equilibrum state without excitation. Then, forced oscillations may generate a flow variation in the central channel at twice the excitation frequency (cf. Figure 4-b).

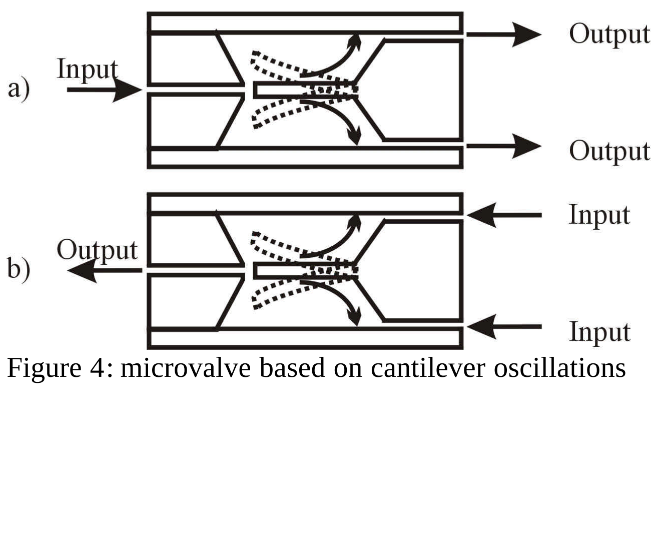

Figure 4: microvalve based on cantilever oscillations

The second design is based on micromembrane vibrations. The oscillations modify the size of the cavity and create alternative modulation of the outgoing pressure. Thus, a pulsed air flow with null mean value can be obtained. An additionnal input constant air flow may change the mean value (cf. Figure 5).

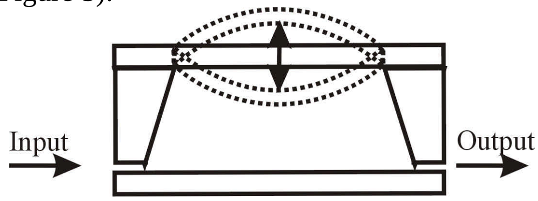

Figure 5: Microvalve based on membrane oscillations

Microstructure fabrication

Microcantilevers and micromembranes are made with two similar processes, in 1,5 micron-thick SOI (Silicon On Insulator) wafers. The membrane is fabricated by a TMAH (Tetramethyl Ammonium Hydroxide ($(CH_3)_4NOH$) wet etching of the lower face of the SOI substrate. The beams are defined by Reactive Ionic Etching (RIE) (dry plasma etching) and then released after TMAH wet etching (cf. Figure 6) [3].

The chosen cantilevers' dimensions are several hundreds of microns with a thickness of 1.5 µm, in order to obtain the resonance frequency around 5 kHz (cf. Figure 7).

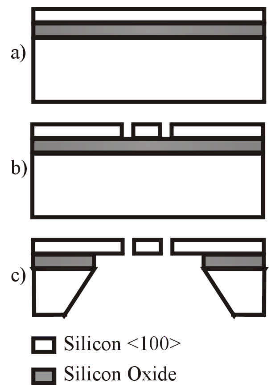

Figure 6: Technological steps for microcantilever fabrication

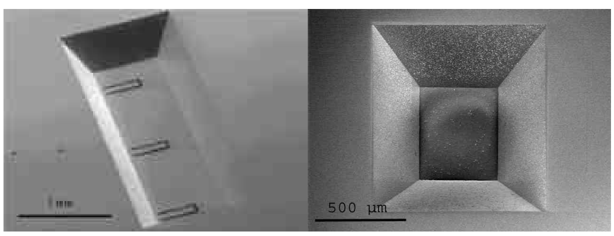

Figure 7: Scanning Electron Microscope (SEM) visualization of microcantilevers and micromembranes elaborated by process of Figure 6.

Magnetostrictive actuation of the microstructures

A 2-bilayer film of (TbCo/FeCo) has been deposited on one of the previous microcantilevers. Actuation at this step has been made by a conventional macroscopic magnetic field source. As for macroscopic scale, it was observed on these microscopic structures that the oscillations' amplitude is greatly increased near SRT (cf. Figure 8).

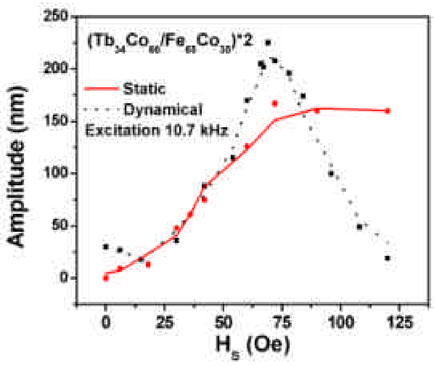

Figure 8: Static and dynamical magnetostriction of a microcantilever (400 µm * 100 µm * 1.5 µm). Magnetostrictive film: (TbCo/FeCo)*2

Microcoils for actuation

For MEMS integration, it is necessary to use microscopic means for the generation of the driving dynamic field. Since this field needs only low amplitude near SRT (about $h_0 = 10$ Oe), it can be generated by integrated plane microcoils. According to simulations, 4 windings of a copper wire (10 µm thick, 20 µm wide) can produce a magnetic field above 15 Oe, which is enough for our applications. These microcoils are fabricated by copper electroplating in AZ 4562 molds [4] (cf. Figure 9 and Figure 10). This technology is compatible with the fabrication of the microstructures and can be included in the process.

Input and output channels/Packaging

Input and output channels are supposed to be fabricated by photolithography of 150 µm-thick SU-8 photoresist. Microcapillaries can be used for the connection to external devices (cf. Figure 11). These technologies are presently being checked on macroscopic devices.

First of all, we will intend to fabricate two microcanals with half the final thickness on two different substrates. Then we will make the microstructures on one of these substrates, and the microcoils on the other. Finally a SU-8 resist layer will bond the two parts with regards of the alignement of both the half-channels. This process will assure the compatibility of the different technologies described in this paper.

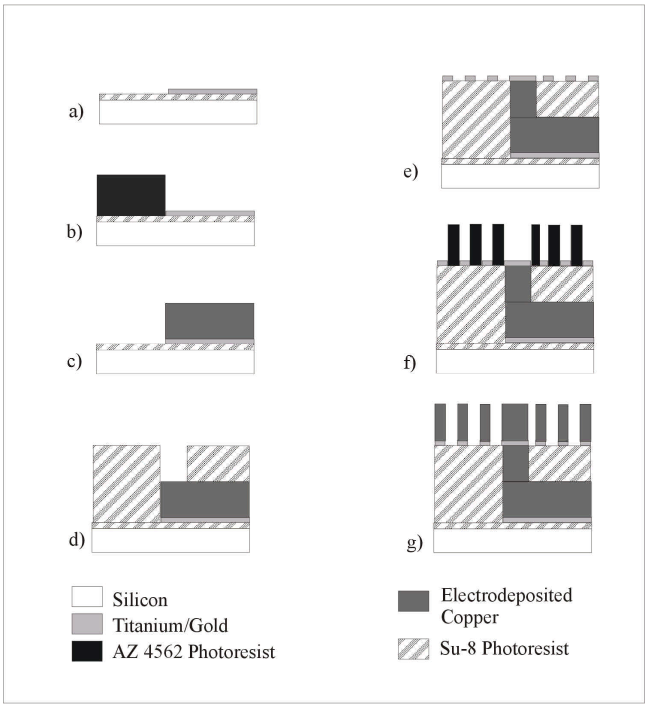

Figure 9: technological steps for microcoils fabrication

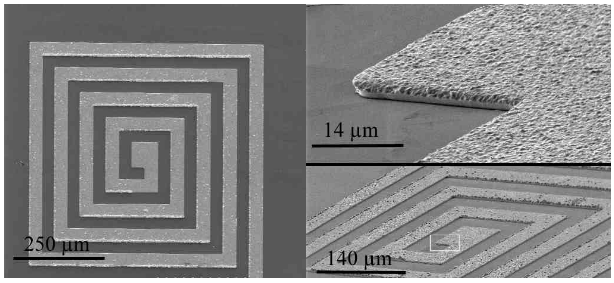

Figure 10: SEM visualization of the fabricated microcoils

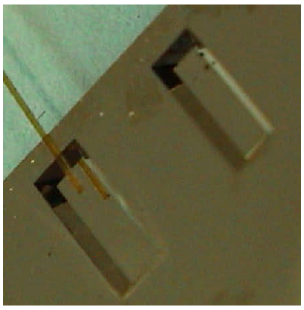

Figure 11: Example of a micromembrane and a microcapillary

Conclusion

In this paper, the concept of a microvalve based on nanostructured active films with giant magnetostriction used near Spin Reorientation Transition type (SRT) has been presented. Because SRT significantly increases the film's sensitivity (x100), the driving field can be lowered, and integrated elements of control, such as microcoils, can then be considered. The technological solutions for the different elements presented in this paper provide fabrication of a microvalve for application in microfluidics.

Acknowledgement

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