

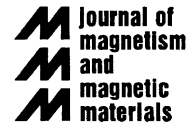


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# Exchange spring recording media for areal densities up to 10 Tbit/in<sup>2</sup>

D. Suess\*, T. Schrefl, R. Dittrich, M. Kirschner, F. Dorfbauer, G. Hrkac, J. Fidler

*Institute for Solid State Physics, Vienna University of Technology, Wiedner Hauptstrasse 8-10, 1040 Wien, Austria*

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## Abstract

In order to achieve an areal density of 10 Tbit/in<sup>2</sup> in perpendicular recording, grains with diameters of about 3 nm are required. However, for such grain sizes, common hard disk materials are magnetically too soft to be thermally stable. Extremely hard magnetic materials such as FePt have a too large coercive field and cannot be reversed with conventional head fields. The proposed FePt (2 nm)/Fe<sub>3</sub>Pt (14 nm)/FePt (2 nm) trilayer reduces the coercive field by a factor of 8 compared to a single-phase FePt layer of the same thickness. At the same time the energy barrier is only decreased by 40%. A high signal to noise ratio can be expected for the multilayer structure since the switching field distribution is insensitive on the angle  $\alpha$  between the easy axis of the hard layers and the external field. A change from  $\alpha = 0.1^\circ$  to  $1^\circ$  changes the coercive field by less than 2.5% (10% for conventional perpendicular media). Thus, small distribution of the anisotropy axes angles have less effect than in conventional perpendicular media.

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*Keywords:* Exchange spring; Perpendicular recording; Capping layer; Thermal stability

## 1. Introduction

In order to achieve an adequate signal-to-noise ratio (SNR) from current thin film magnetic media where grain diameters are about 8 nm, bits comprising of 100–200 grains are typically required. The areal density can be increased by scaling all parameters of the recording system to smaller dimensions. However, as the volumes become too small the magnetization within the grains become unstable due to thermal fluctuations. That effect is known as the super paramagnetic limit and has become increasingly important in recent years as the hard disc drives are getting closer to this limit [1]. The super paramagnetic limit can be shifted to smaller

volumes using high-anisotropy materials. Promising candidates for high-anisotropy media are CoPt, Co<sub>5</sub>Sm or FePt. For example, the anisotropy of FePt is about 10 times larger than that of currently used materials like CoCrPt. The problem of using highly coercive materials is that the strength of the field produced by the write head is limited to about 1.4 T which in turn imposes a limit on the media coercivity [2]. One possibility to overcome the writing problem is to employ thermally assisted recording (TAR). Additionally, the coercive field can be lowered by introducing an exchange coupled antiferromagnetic FeRh layer as proposed by Thiele et al. [3].

In this paper, we propose a media design for perpendicular recording that shows very appealing properties by the use of exchange-coupled hard-soft-hard nanocomposite magnets. Recently, it has been shown that FePt/Fe<sub>3</sub>Pt nanocomposite magnets can be

\*Corresponding author. Tel.: +43 1 58801 137 29; fax: +43 1 58801 138 99.

*E-mail address:* [dieter.suess@tuwien.ac.at](mailto:dieter.suess@tuwien.ac.at) (D. Suess).

fabricated using nanoparticle self-assembly [4]. By proper chosen volume fraction of the composite system the grains of the media are thermally stable but have, at the same time, a sufficient small coercivity that they can be written with conventional write heads.

## 2. Micromagnetic modelling

For the numerical calculation of the magnetic properties such as the coercive field, the switching time and the energy barrier, a finite element approach is applied. The Landau–Lifshitz equation is solved in order to obtain the time evolution of the magnetization and the hysteresis loop. Thermal activations are not taken into account for the simulation of the hysteresis properties. However, we use the intrinsic material parameters at room temperature.

The proposed media design consists of three magnetic layers. A magnetically soft layer  $\text{Fe}_3\text{Pt}$  ( $A = 2.5 \times 10^{-11} \text{ J/m}$ ,  $J_s = 2.15 \text{ T}$ ) is embedded between two magnetically hard  $\text{FePt}$  layers ( $A = 1 \times 10^{-11} \text{ J/m}$ ,  $K_1 = 6.6 \times 10^6 \text{ J/m}^3$ ,  $J_s = 1.43 \text{ T}$ ). The easy axes in the hard layers are parallel to the long axis of the grain. For areal densities of  $10 \text{ Tbit/in}^2$  the grain diameter of the media has to be about  $3 \text{ nm}$ . Therefore, we investigated the magnetic properties for various film thicknesses for a grain with that diameter.

The coercive field of a  $18 \text{ nm}$  thick  $\text{FePt}$  grain with a grain diameter of  $3 \text{ nm}$  is  $\mu_0 H_c = 9.4 \text{ T}$ . The reversal occurs by nucleation. A reduction of the film thickness to  $8 \text{ nm}$  changes the coercive field to  $\mu_0 H_c = 9.2 \text{ T}$ . The coercivity is too high that a conventional write head can reverse the grain. The coercive field can be drastically reduced by introducing a soft layer in between the two hard magnetic layers. The  $\text{FePt} (2 \text{ nm})/\text{Fe}_3\text{Pt} (14 \text{ nm}) / \text{FePt} (2 \text{ nm})$  trilayer has a coercive field of  $\mu_0 H_c = 1.1 \text{ T}$ . A nucleation is formed in the center of the soft magnetic layer. Initiated by the reversal of the soft layer, the two hard magnetic ends can be switched at low external field.

The coercive field as a function of the soft magnetic layer thickness is plotted in Fig. 1 (dotted line). The dependence of the coercive field with layer thickness is in agreement with micromagnetic calculations from Leineweber and Kronmüller [5]. For a softmagnetic layer with thickness larger than the hard magnetic domain wall width  $\delta_h$  ( $3.9 \text{ nm}$  for  $\text{FePt}$ ) and smaller than eight times  $\delta_h$  ( $31 \text{ nm}$ ), they predicted a rapid decrease of the nucleation field. For  $8\delta_h$ , the nucleation field is  $0.1$  times the ideal nucleation field of the hard magnetic layer  $H_a$ . For soft layers thinner than  $\delta_h$ , the nucleation field is determined by  $H_a$  and independent of the layer thickness. For the calculation of the thermal stability the energy barrier between the initial state (magnetization pointing up) and the final state (magnetization

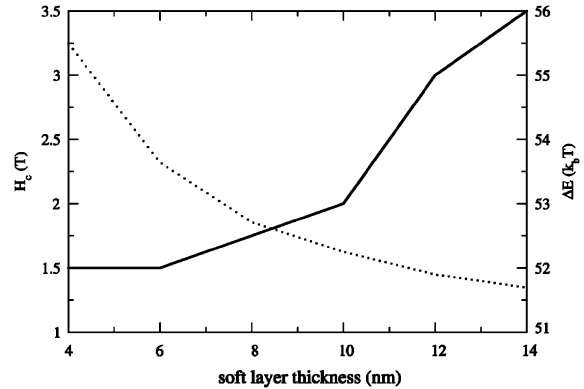


Fig. 1. (Dotted line) Coercive field as a function of the thickness of the soft magnetic  $\text{Fe}_3\text{Pt}$  layer. (Solid line) Energy barrier increases with film thickness.

pointing down) is calculated using the nudged elastic band method [6]. For single-domain particles the energy barrier can be easily derived from the coercive field,  $\Delta E = H_c J_s V/2$ . Therefore, a reduction of the coercive field also leads to a reduction of the energy barrier. A linear dependence of the coercive field and the energy barrier was also found for the hard magnetic  $\text{FePt}$  film. The reason for that dependence is that the thermal-induced switching mode is similar to the reversal process induced by the application of the switching field. In both processes a nucleation is formed at the particle end in a single-phase hard magnetic material. For the thermal activated switching process the state that corresponds to the saddle point is shown by the upper picture in Fig. 2. After nucleation of a reversed domain at one end, a domain wall is formed in the center of the grain which is well localized. For the given material parameters the domain wall energy is  $\Delta E = 72 k_B T$ . The calculated energy barrier for a thickness of  $18 \text{ nm}$  is slightly larger ( $\Delta E = 79 k_B T$ ) due to the increase of the stray field energy as the magnetization of the grain is split up into a two-domain state. The energy barrier decreases linearly to  $\Delta E = 76 k_B T$  as the thickness is changed to  $8 \text{ nm}$ .

The simulations of thermally induced switching by the elastic band method shows that the multilayer structure will reverse one end first, leading to a domain wall in the center. The state corresponding to the saddle point (Fig. 2 bottom) for the multilayer contains a domain wall in the soft magnetic layer. The energy barrier ( $\Delta E = 47 k_B T$ ) is dominated by the domain wall energy. The two hard magnetic ends of the film point in almost opposite directions. Between the hard magnetic ends the magnetization in the soft layer rotates by about  $180^\circ$ . That reversal process which is induced by thermal activation is significantly different as the reversal mode induced by the application of an external field. These different modes give us the ability to optimize the magnetic properties for magnetic recording. Whereas

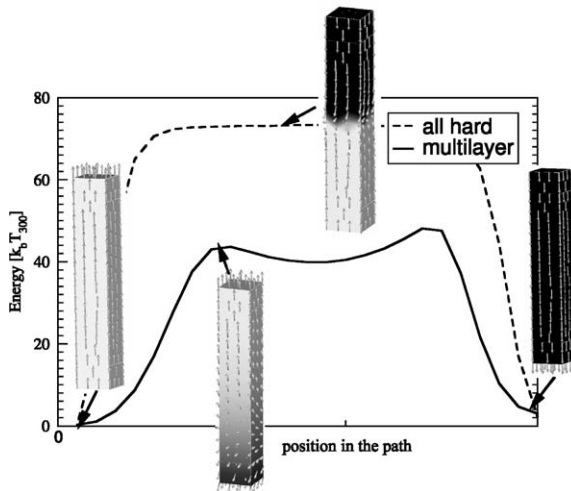


Fig. 2. Energy along the minimum energy path for the FePt grain and the multilayer. The left and the right state correspond to the initial and the reversed state. The states at the top and the bottom correspond to the saddle point states for the the FePt film and the multilayer, respectively.

the coercive field decreases with increasing soft magnetic layer thickness (dashed line in Fig. 1), the energy barrier increases with layer thickness as shown by the solid line in Fig. 1. The origin for the enhanced thermal stability for the thicker soft layer can be found in magnetic charges at surfaces perpendicular to the film plane. These charges are created by the domain wall in the soft layer and increase with film thickness.

A major concern in perpendicular recording is the high sensitivity of the SNR on the switching field distribution (SFD). The Stoner–Wohlfarth model (SW) predicts different switching fields for different angles  $\alpha$  between the easy axis and the external field. As an example, a change from  $\alpha = 0.1^\circ$  to  $1^\circ$  drops the switching field by almost 10% for single-phase and single-domain particles. Although for the hard magnetic FePt film reversal occurs by nucleation the switching fields for various angles  $\alpha$  are only slightly different (max 4%) as the predicted values from the SW model. The angular dependence of the switching field for the multilayer system is shown in Fig. 3. In contrast to the SW-model, which at best only approximates perpendicular media, a change from  $\alpha = 0.1^\circ$  to  $1^\circ$  changes the coercive field by less than 2.5%. Compared to the single-phase film a much better tolerance of the switching field on the easy axis distribution and consequently a better SNR ratio can be achieved.

Finally, we investigated the switching time of the multilayer system as a function of the field strength for different angles  $\alpha$ . The external field is applied instantaneously. A damping constant of 0.02 is used. Fig. 4 shows that for  $\alpha = 0.1^\circ$  and  $10^\circ$  and small external fields

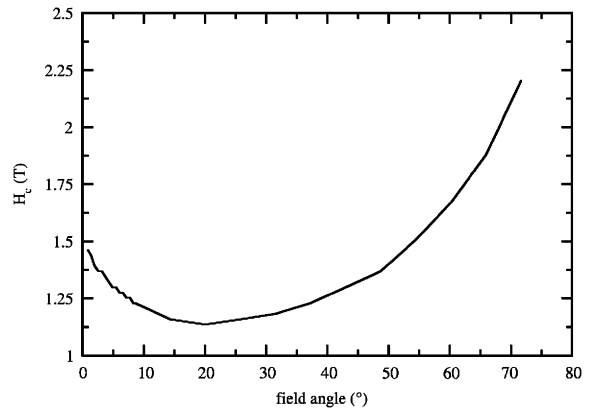


Fig. 3. Coercive field as a function of the angle between the external field and the easy axis of the grain. The soft layer thickness is 12 nm.

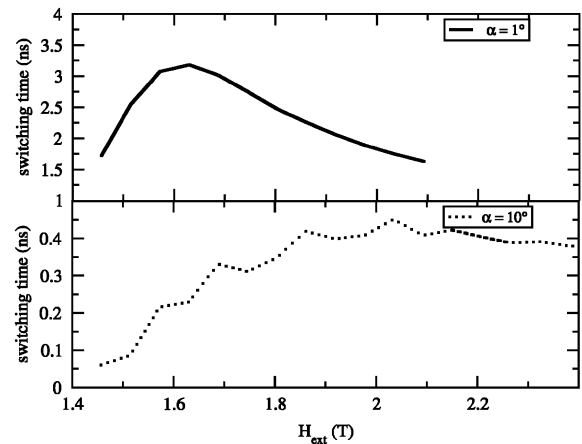


Fig. 4. Switching time as a function of the field strength for two different angles between the external field and the easy axis of the hard layer.

the switching time increases with larger switching field. A similar dependence was found for single-domain particles [7,8]. Switching becomes faster by almost a factor 10 when the external field is applied  $10^\circ$  off the easy axis.

In order to optimize the coercivity and the thermal stability the thickness of the soft magnetic layer should be maximized. The layer thickness is only restricted by the single-pole head geometry. For a 14 nm thick soft layer the energy barrier decreases by less than 40% compared to the FePt film, whereas the coercive field is decreased by more than a factor 8.

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