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HAMR Media Based on Exchange Bias

K. Elphick,[1] G. Vallejo-Fernandez,[1] T. J. Klemmer,[2] J-U. Thiele,[2] and K. O'Grady[1]

[1]*Department of Physics, University of York,York, YO10 5DD ,UK*
[2]*Seagate Media Research Center, Fremont, CA, 94538, USA.*

In this work we describe an alternative strategy for the development of heat assisted magnetic recording (HAMR) media. In our approach the need for a storage material with a temperature dependent anisotropy and to provide a read out signal is separated so that each function can be optimised independently. This is achieved by the use of an exchange bias structure where a conventional CoCrPt-SiO_2 recording layer is exchange biased to an underlayer of IrMn such that heating and cooling in the exchange field from the recording layer results in a shifted loop. This strategy requires the reorientation of the IrMn layer to allow coupling to the recording layer. This has been achieved by the use of an ultrathin (0.8nm) layer of Co deposited beneath the IrMn layer. In this system the information is in effect stored in the antiferromagnetic (AF) layer and hence there is no demagnetising field generated by the stored bits. A loop shift of 688 Oe has been achieved where both values of coercivity lie to one side of the origin and the information cannot be erased by a magnetic field.

The next format of magnetic storage technology will be a heat assisted process (HAMR).[1] This technology should be in the market place within the next year. The principle of HAMR is that a laser delivers heat pulses via near field optics to the surface of a conventional disc with grains oriented in the perpendicular direction. The anisotropy of the material is thereby reduced enabling a conventional write head to switch the grains with a field pulse. Once the grains have cooled the anisotropy rises allowing a higher data density.[1] The material of choice for the recording layer is the alloy FePt. FePt has a high magnetocrystalline anisotropy of 5 x 10^7 ergs/cc with a strong temperature dependence. It has a high magnetic moment of 1150 emu/cc, comparable to CoCrPt-based alloys currently used.[2]

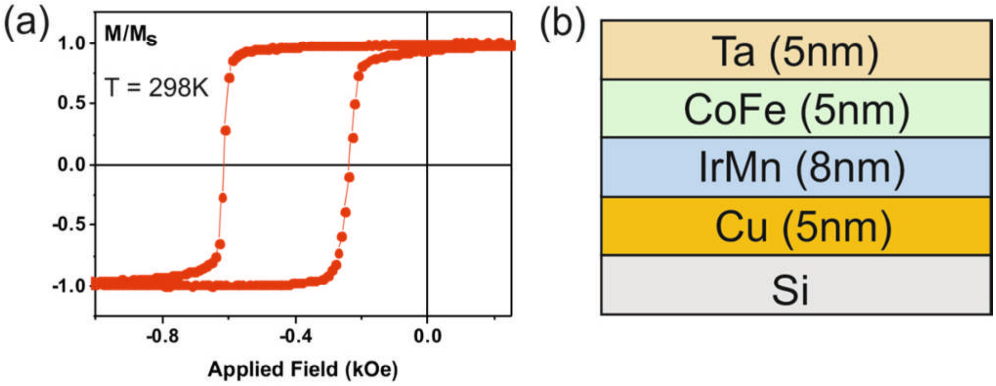

Figure 1. (a) Typical hysteresis loop for an exchange biased system and (b) Schematic of the sample structure for the loop shown in (a).

We have used the phenomenon of exchange bias where a ferromagnetic (F) layer is grown in intimate contact with an antiferromagnetic (AF) layer such that the two layers are exchange coupled. This system, when heated in the presence of a field which saturates the F layer, results in a unidirectional anisotropy being induced in the F layer.[3] The hysteresis loop is then shifted so that both coercivities can lie in negative fields. A typical loop for an in-plane oriented IrMn/CoFe structure is shown in Figure 1(a) together with a schematic of the sample structure in Figure 1(b). For this system the application of a large negative field cannot demagnetise the system. A schematic representation of the writing process is shown in Figure 2. Note that following thermally induced reversal the loop is shifted completely to a positive field.

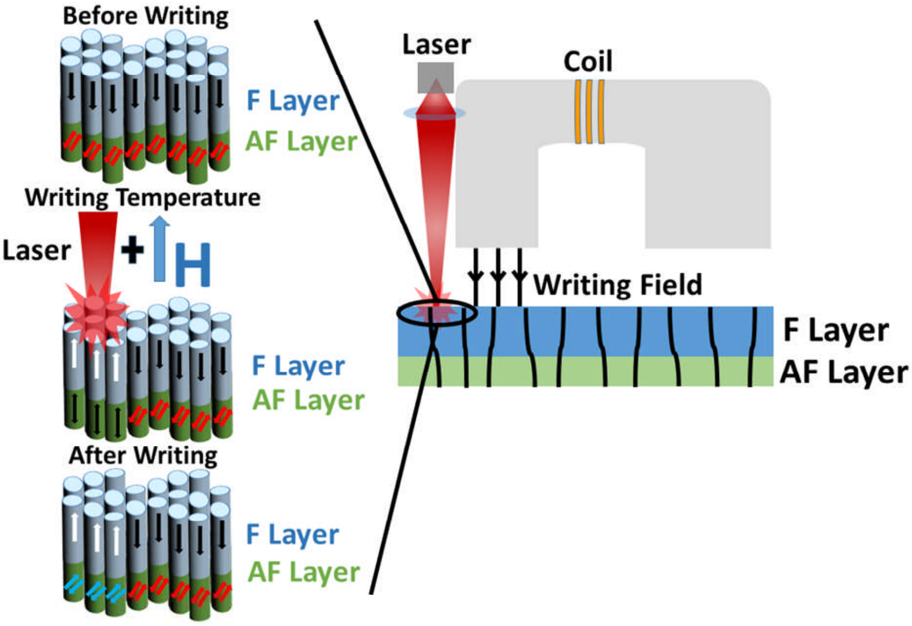

Figure 2. Schematic representation of the writing process for the proposed HAMR media.

To achieve a proof of principle of a perpendicular medium with exchange bias, it is necessary to achieve several goals. The first is to show that it is possible to induce exchange coupling between the normal AF alloy used in exchange bias systems IrMn, to a CoCrPt-SiO_2 recording medium.[4] The second requirement is that the texture of the IrMn be oriented in the perpendicular direction or in a direction where a significant exchange bias can be induced in CoCrPt. Note that in this system the Curie point of the ferromagnet must be higher than the temperature required to switch the antiferromagnet. The effective anisotropy constant (K_{AF}) of IrMn is determined by the degree of texture of the (111) planes.[5] For an in-plane system it is possible to achieve a value of K_{AF} of 2.9 x 10^7 ergs/cc, comparable to that of FePt.[5] In previous work we have shown that the value of the attempt frequency f_0 for IrMn is of the order of 10^{12} s^{-1},[6] which is faster than a ferromagnet indicating that an acceptable write speed would be achievable.

For this proof of principle exercise we have chosen to use a conventional CoCrPt-SiO_2 ferromagnetic layer because the growth process is well established. However in principle any ferromagnetic layer could be used. It may also be possible to have such a system with in-plane anisotropy but the write field is limited in the longitudinal mode. Hence we have followed a conventional perpendicular structure at this time.

In all state of the art discs for hard drive applications the exchange coupling between the CoPtCr grains is mediated by co-depositing SiO_2 with the Co-alloy.[7] The segregation of the SiO_2 is achieved by depositing a first layer of Ru 8nm thick at a sputtering pressure of 8mbar. A second layer of Ru is deposited at a pressure of around 30mbar. A voided structure results and the Co alloy grows with the SiO_2 deposited above the voids achieving spatial and electrical isolation of the F grains thereby eliminating the intergranular RKKY type coupling.[7] For the case of a HAMR medium based on exchange bias, exchange coupling between the Co alloy grains would result in bit spread so that adjacent grains in the AF layer could also be switched giving a requirement for a segregated layer.

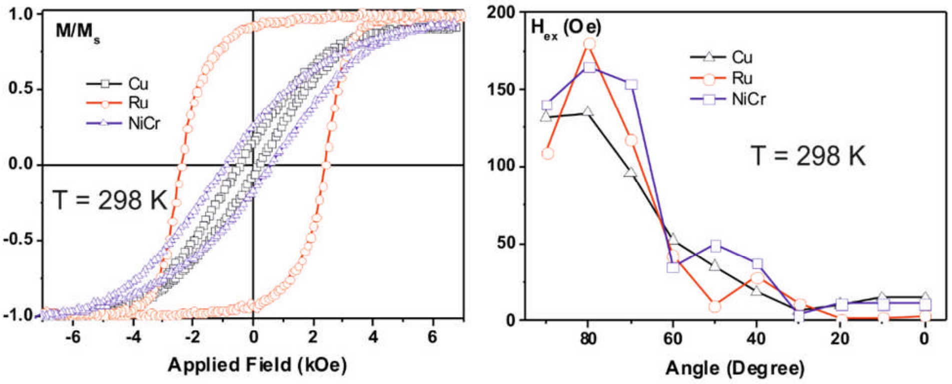

Figure 3. Hysteresis loops measured at 90° and angular dependence measurements for samples with double Cu, Ru and NiCr seed layers (lines are a guide to the eye). N.B. 0° corresponds to a measurement in the plane of the film.

We have studied the exchange bias induced in $CoPtCr-SiO_2$ by the presence of an IrMn layer grown on dual Cu, Ru and NiCr seed layers. We have then measured the value of the loop shift H_{ex} as a function of the setting angle. For (111) planes of IrMn oriented in-plane there should be another set of (111) planes oriented at 70.2^o. The data from this study is shown in Figure 3 together with the loops measured at 90^o. As can be seen from the figure there is indeed a significant value of the loop shift at 70^o (H_{ex} = ~160 Oe) for all the samples but unfortunately this tends to fall away for the perpendicular case. This result is of significance because it demonstrates that coupling between CoPtCr and IrMn can be achieved.

There have been a number of attempts to achieve perpendicular orientation of IrMn in small elements for application in MRAM technology, e.g. Ref. 8. This has never been attempted for a disc medium. It has been shown that perpendicular exchange bias can be induced in a system consisting of IrMn/CoFe if the system is grown on a Pt seed layer and is top biased so that the IrMn is above the F layer. In the work reported by Chen et al.,[9] loop shifts of up to 900 Oe were achieved although the CoFe layer was extremely thin at 0.8nm. We reproduced the work of Chen et al.,[9] using a 0.8nm Co layer and achieved an exchange bias in excess of 1.5kOe. The sample structure and the resulting loop at 298K are shown in Figure 4. The large exchange bias indicates that the antiferromagnetic ordering in IrMn is oriented mainly perpendicular to the plane.

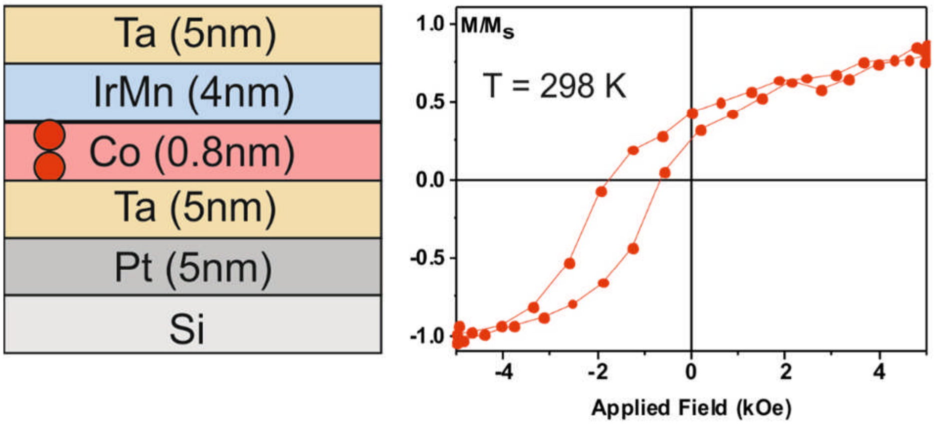

Figure 4. Schematic of the sample structure and hysteresis loop reproducing the work of Chen et al.[9]

A series of experiments have been undertaken to establish if the reorientated IrMn spins would then couple to a CoCrPt layer thereby inducing a perpendicular exchange bias. Following Chen et al.,[9] a 5nm Pt layer was deposited on 5nm of Ta followed by 0.8nm of pure Co. 4 nm of IrMn was used beneath the CoCrPt-SiO_2 layer. This structure induces a perpendicular exchange bias in the cobalt alloy. The hysteresis loops as a function of the thickness of the CoCrPt layer measured at 100K are shown in Figure 5(a). The non-crystalline Co layer is 2-3 atoms thick and induces a 2-ion anisotropy with atoms stacked in a column.[10] This anisotropy then causes a rotation of the spins in the IrMn which couple to the Co-alloy layer. Significant loop shifts were only observed at low temperatures (T=100K) due to the low thickness of the IrMn layer and its poor texture.[5] Also both values of H_c only lie in negative fields for thicknesses of the CoCrPt layer (t_F) of less than 5nm.

It was necessary to optimise the thickness of the F and AF layers for such a unique system. Figure 5(b) shows the variation of the loop shift at 100K as a function of the thickness of the F layer. The variation follows a $1/t_F$ form as expected.[3] To achieve a significant exchange bias a CoPtCr thickness in the range 2-4nm should be used.

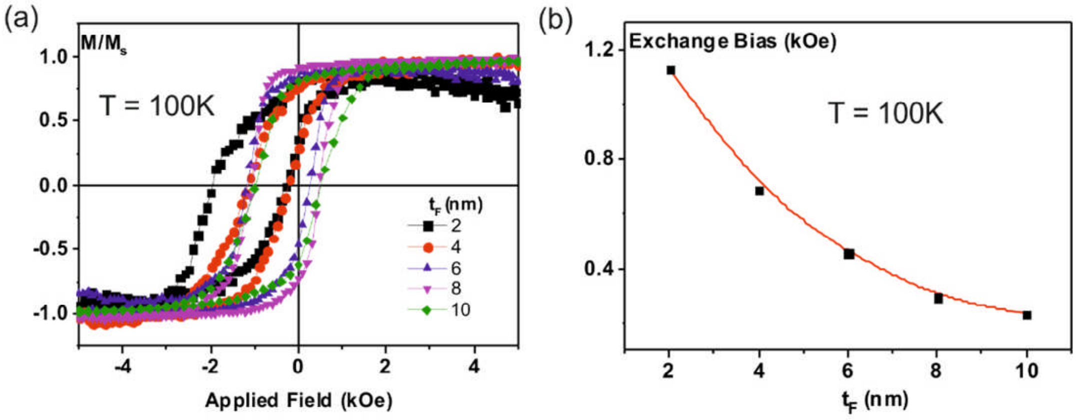

Figure 5. (a) Hysteresis loops measured at 100K for IrMn (4nm)/CoCrPt(t_F) system and (b) Variation of H_{ex} with t_F at that temperature.

Similarly we have optimised the thickness of the IrMn layer as shown in Figure 6. From the data an IrMn thickness of 6 nm appears optimum. For thinner layers a significant fraction of the AF grains would be thermally unstable and for thicker layers an excessive temperature would be required to set the AF.[3] We have confirmed that a 6nm IrMn layer is completely set after field cooling at 225°C. This would be a suitable temperature for the setting of the AF and would be readily achievable in a HAMR medium.

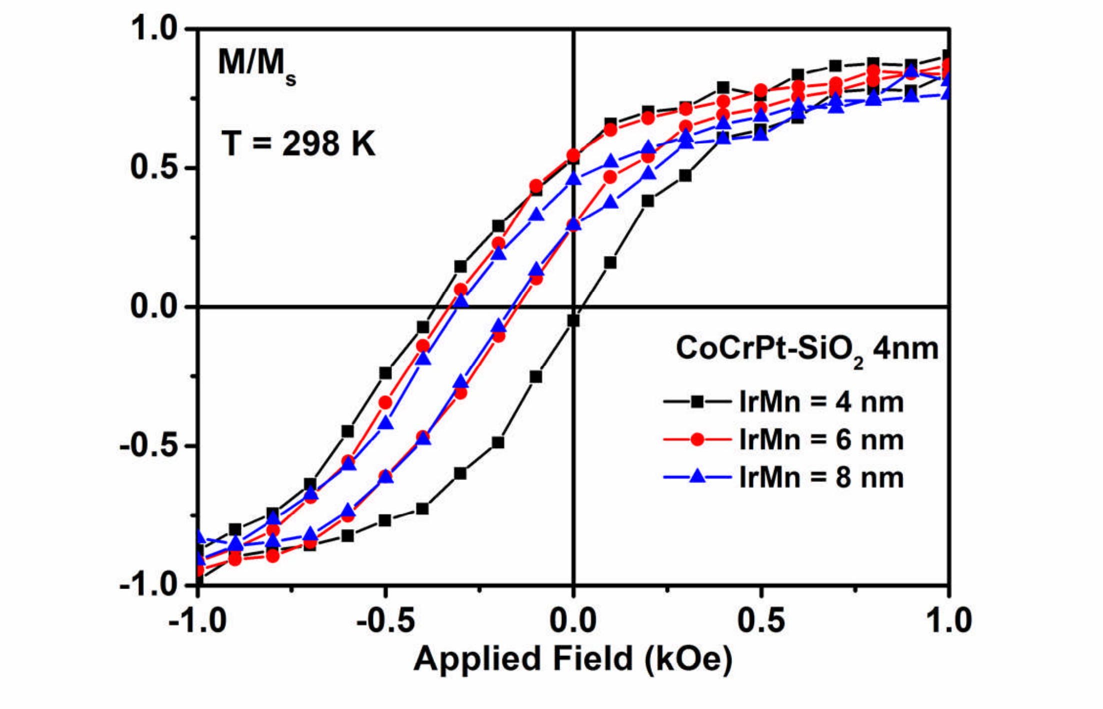

Figure 6. Hysteresis loops for different thicknesses of the AF layer.

Following this optimisation exercise a sample was grown with the structure shown in Figure 7(a). This sample had the conventional 5nm Pt seed layer followed by a 0.8nm Co layer with 6nm of IrMn followed by 4nm of CoCrPt-SiO_2 with a Ta capping layer. The resulting hysteresis loop for this sample is shown in Figure 7(b). This result is of great significance for the potential to create a heat assisted magnetic recording medium using exchange bias. The sample now has both coercivities lying in a negative field following setting of the AF layer at 500K in a positive field of 20 kOe. Hence this material cannot be demagnetised by a magnetic field. The loop shift at 450 Oe is modest but this parameter is not of great significance because the sample cannot be demagnetised other than by the application of heat. This result constitutes a proof of principle that an exchange bias system can be created using a conventional Co-alloy recording medium and IrMn as an AF layer. Both values of the remanence are not the same, and cycling round the hysteresis loop has achieved a partial reversal of the Co-alloy layer but nonetheless a positive value of remanence remains which could be read by a head.

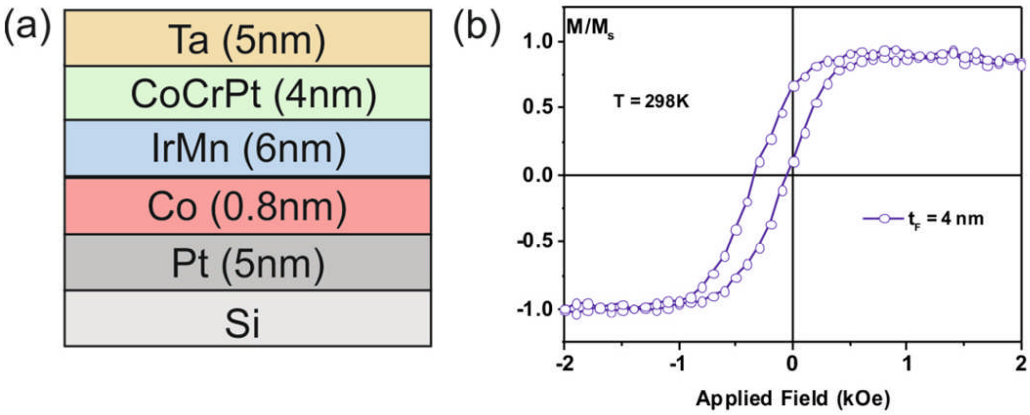

Figure 7. (a) Sample structure and (b) room temperature hysteresis loop for such system.

We have also confirmed the thermal stability of this result by applying a negative field in excess of 2kOe so that the F layer was reversed at room temperature. The exchange field from the F layer now acts as a potential to reverse the AF grains. The field was maintained for 30 minutes, and the loop re-measured. No variation in the loop shift was observed. This indicates that at room temperature such a system would be stable against thermal demagnetisation.

The systems presented here have not been optimised to act as a disc medium. We were seeking to investigate the principle of using exchange bias to create a heat assisted system for disc recording. In this instance it may be that a 4nm thick F layer would be too thin to give a viable signal to be read by a head. We have attempted to grow the Pt seed layer in a segregated form similar to that achieved with Ru by having a double layer grown at different pressures. No seed layer grain segregation was achieved and the Co-alloy layer will not consist of exchange decoupled grains. This may lead to large transition widths in a recording signal as the coupling between the Co-alloy grains will produce a larger region of reversed F layer which in turn will reverse a larger region in the AF layer beneath. The AF grains of IrMn do not exhibit any significant RKKY type intergranular exchange coupling as the grains themselves do not have a net moment to polarise a conduction electron.

If such a structure were converted into a storage medium the information would actually be stored in the AF layer with the Co-alloy layer acting as part of the function of the write head during the setting process and then as part of the read head providing a read back of the degree of order induced in the AF layer.

In conclusion therefore we have reported on an investigation of the potential to use the exchange bias phenomenon to create a perpendicular recording disc medium based on the exchange bias of a conventional Co-alloy. We have demonstrated a proof of principle for such a system. This system may offer an alternative strategy to the use of FePt that can be produced without annealing or the use of heated substrates.

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