Measurement the Magnetic Properties of Double Layered Perpendicular Magnetic Recording Media Using an Anomalous Hall Effect Magnetometer

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***Abstract*--** **The anomalous Hall effect (AHE) has been recognized as a useful tool for measuring the magnetic hysteresis M(H) loops of perpendicular magnetic recording media (PMRM), and has shown particular utility for characterizing double-layered PMRM since the loops for both the recording layer (RL) and soft under layer (SUL) may be measured simultaneously, a task not easily accomplished using conventional magnetometers because of the difficulty associated with extracting the properties of the RL and SUL individually..**

***Index Terms*—Anomalous Hall Effect, Perpendicular recording media, Magnetometers, Materials testing.**

I. Introduction

Conventional magnetometry methodologies (e.g., VSM) are unsuited to the task of characterizing the magnetic properties of double layer perpendicular magnetic recording media (PMRM). In a conventional magnetometer the signal response is dominated by the soft underlayer, rendering it virtually impossible to isolate the magnetic properties of the recording layer. The anomalous Hall effect (AHE) has been recognized as a useful tool for measuring the magnetic hysteresis M(H) loops of PMRM[1,2], and provides for independent measurement of the magnetic properties of both the soft underlayer and recording layer. The Hall voltage contains three terms. The first is proportional to the perpendicular component of the magnetization and is called the anomalous Hall effect (AHE). The second is proportional to the square of the component of magnetization in the plane of the film, and perpendicular to the current, and is called the planar Hall effect (PHE). The third is proportional to the perpendicular component of the B field and is called the ordinary Hall effect (OHE). Measurements of the hall voltage with different current directions allows the in plane and perpendicular magnetization components to be separated. We have measured the AHE and PHE in double-layered PMRM and compared the results with measurements using a VSM. To achieve maximum sensitivity from high conductivity samples, an AC current methodology was used [3]. This technique also eliminates errors due to thermal EMF voltages. To eliminate residual resistance voltages from the Hall measurements, geometry averaging techniques commonly employed in conventional Hall effect measurements on semiconductors were used. For full M(H) loop measurements however, a modified form of field reversal must be used where the Hall voltage from positive fields on the descending curve is averaged with the Hall voltage at negative fields on the ascending curve. We demonstrate that the anomalous and planar Hall effects provide a simple and fast method to characterize the magnetic properties of the hard recording layer in double-layered PMRM.

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II. Method

In a Hall effect measurement there are three Hall voltage (V_H) components,

$$V_H = (R_H I/t)B\cos(\alpha) + (\mu_o R_s I/t)M\cos(\theta) + (kI/t)M^2\sin^2(\theta)\sin(2\phi) \quad (1)$$

where t = film thickness, and the angles α, θ and ϕ are defined in figure 1. The first term in equation (1) is the ordinary Hall effect (OHE) and arises from the Lorentz force acting on conduction electrons. The OHE depends on the z-component of the B field, and produces an electric field perpendicular to B_z and the current density. The second term is the anomalous Hall effect (AHE) and arises due to spin dependent scattering mechanisms. The AHE depends on the perpendicular component of M, and produces an electric field perpendicular to M_z and the current density. The last term in (1) is the planar Hall effect (PHE), or anisotropic magneto-resistance. The PHE is proportional to the square of the planar component of M, and produces an electric field parallel and perpendicular to the current. The third term in (1) is the component that is perpendicular to the current. . Note that all three terms in (1) are inversely proportional to the film thickness t. In a conventional magnetometer (e.g., VSM) the signal magnitude is directly proportional to t, hence as the film thickness decreases it becomes more difficult to extract the signal of interest. Just the opposite effect occurs in an AHE magnetometer rendering it ideal for measuring ultra thin magnetic films.

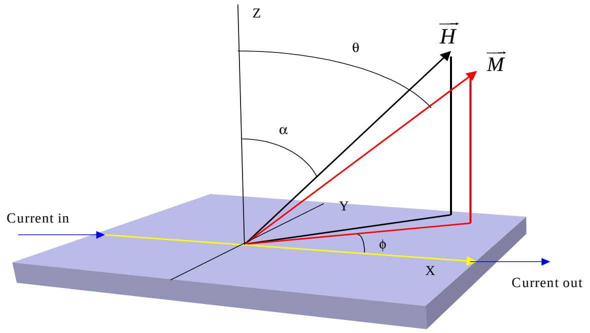

Figure 1. Geometry of the AHE measurement. α is the angle between the applied field and the normal to the sample, θ is the angle between the magnetization and the normal, and ϕ is the angle between the current and the in plane component of the magnetization.

Figure 2 illustrates the problems associated with using conventional magnetometry methods (e.g., VSM) to characterize double-layered PMRM. Note that the VSM M(H) loop is dominated by the magnetically soft underlayer, rendering it virtually impossible to extract the properties of the magnetically hard recording layer (e.g., coercivity of the recording layer). In contrast, note that the AHE results clearly show the recording layer properties, and as such demonstrate the power of this technique for measuring magnetization processes in double-layered PMRM.

Van der Pauw sample geometry was used to measure the AHE effect of perpendicular recording media. In this method, the sample is rectangular with electrical contacts on the corners of the sample. The current source is connected to two of the contacts on a diagonal and the voltmeter is connected to the two contacts on the other diagonal. If the voltage contacts are not on the same equi-potential line, there will be a voltage proportional to the resistance of the material as well as the Hall resistance [4]. Interchanging the current source and voltmeter and averaging the voltage from the two readings removes the resistance offset [4]. Figure 3 shows the raw data for a measurement on a PMRM sample. The linear background is the ordinary Hall effect, which may be removed by fitting a straight line to the high field data and subtracting this linear background [5]. Figure 4 shows the corrected data for one configuration. The resultant magneto-resistance and anomalous Hall voltage signals are clearly observable. Figure 5 shows the averaged hall voltage after removal of the linear background, showing the expected hysteresis loop corresponding to the hard recording layer.

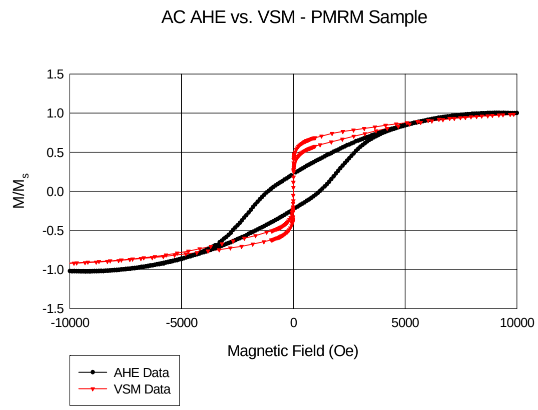

Figure 2. Measurement of double-layered PMRM sample with VSM (showing effect of SUL) and AHE showing only the hard magnetic material in the recording layer. This sample was measured with α = 35°, using AC current.

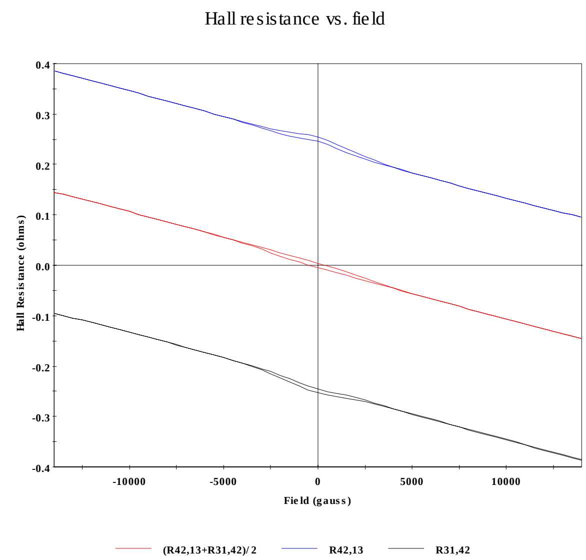

Figure 3. Raw data of a perpendicular recording media. This shows the two different configurations of the current source and voltmeter (R42,13 and R31,42). The first two indices refer to the sample contact numbers of the current source, and the second two indices refer to the sample contact numbers of the voltmeter.

III. Discussion

Anomalous Hall effect magnetometry can be used to study magnetization processes in thin film materials. The AHE technique shows particular promise for those magnetic metrology applications where conventional magnetometry methodologies may be unsuited or limited in their application utility (e.g., double-layered PMRM). Further, since the AHE signal is inversely proportional to the film thickness the technique could prove particularly useful for investigating the magnetic properties of ultra thin magnetic films where conventional magnetometry methodologies lack sufficient sensitivity. For example, the AHE technique has proved useful

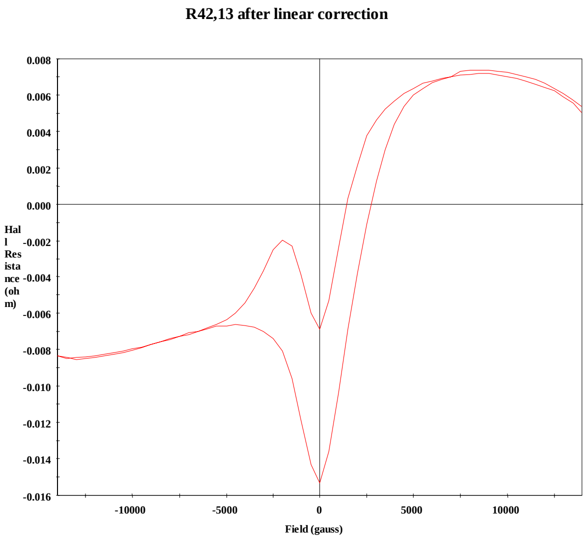

Figure 4. One geometry configuration after removal of the linear background (due to the ordinary Hall effect). Both the AHE and MR signals are observed.

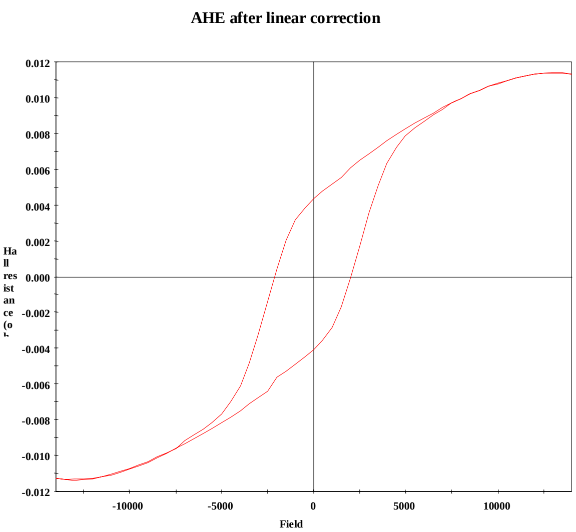

Figure 5. The geometry averaged AHE signal after removal of the linear ordinary Hall effect.

for studying the magneto-transport properties of ferromagnetic/semiconductor heterostructures and diluted-magnetic-semiconductors (DMS) that constitute the basis for spintronics devices. Since the magnetization is small in a DMS thin film, magnetization measurements using the AHE technique are better in terms of measurement sensitivity than conventional magnetic measurement techniques [6].

AHE magnetometry can also be used to study magnetic processes using measurements other than hysteresis loops, and the results correlate well with those obtained using conventional magnetometry methodologies (i.e., VSM) [3]. Further development of this technique is warranted as it may prove to be an instrumental metrology tool for characterizing the magnetic properties of future generation recording materials and spintronics devices.

References

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