Magnetic Media
Measurements with a VSM

B. C. Dodrill
Lake Shore Cryotronics, Inc.
575 McCorkle Blvd
Westerville, Ohio 43082

The last 50 years have seen the development of methods for the digital storage of information. The current method for the storage of digital information is predominantly through the use of magnetic media. Increasing media storage density continues to be a very active area of research. Magnetic media may be divided into particulate and continuous media. Particulate media are comprised of small magnetic particles bonded on a plastic tape or disk, the thickness of the magnetic overcoat is typically on the order of 10,000 Å. Since these are single domain particles, the information is stored by inverting the magnetization of some of the particles. Continuous media are metallic thin films, typically a few hundred angstroms in thickness. Particulate media are advantageous in that they are relatively simple to prepare and are chemically stable, however their recording density is relatively low. Continuous media on the other hand have higher storage densities and the shapes of their hysteresis loops (and hence recording characteristics) may be varied in a controlled way.

Magnetic materials are classified into two broad categories, soft or hard. Soft magnetic materials are characterized by large permeabilities and very small coercivities, typically less than 1 Oe. Hard magnetic materials are most often used in permanent magnet applications, and are characterized by large saturation magnetizations, large coercivities, typically greater than 10 kOe, and also by large energy products (i.e., BH_{max}). Intermediate magnetic materials are generally characterized by coercivities on the order of 1 kOe, and these materials are usually used in magnetic media. Intermediate magnetic materials include; γ-Fe_2O_3, $Co_{80}Cr_{20}$, $Co_{77}Ni_{10}O_{13}$, and thin films. The characteristics of any magnetic material, whether it is hard, soft, or intermediate, are best described in terms of their hysteresis loop. The most common measurement method employed for hysteresis loop determinations at ambient temperature is the Vibrating Sample Magnetometer (VSM). This paper will discuss the utility of the VSM in the characterization of magnetic media materials. We will limit our discussion to longitudinal recording media, i.e., where the magnetization is parallel to the plane defined by the substrate/film. Perpendicular media, where the magnetization is perpendicular to the plane defined by the substrate/film, and magneto-optical materials are currently enjoying considerable research effort because of their potential for increasing areal storage densities.

Vibrating Sample Magnetometer (VSM) systems are used to measure the magnetic properties of materials as a function of magnetic field, temperature, and time. They are ideally suited for research and development, production testing, quality and process control. Powders, solids, liquids, single crystals, and thin films are all readily accommodated in a VSM. Contemporary commercial VSM's feature virtually automated operation via data acquisition/control and analysis software that runs on a personal computer, thus making the VSM accessible to the non-specialist. This has dramatically increased the utility of this measurement technique in a broad range of measurement applications.

Theory of Operation

If a material is placed within a uniform magnetic field H, a magnetic moment m will be induced in the sample. In a VSM, a sample is placed within suitably placed sensing coils, and is made to undergo sinusoidal motion, i.e., mechanically vibrated. The resulting magnetic flux changes induce a voltage in the sensing coils that is proportional to the magnetic moment of the sample. The magnetic field may be generated by an electromagnet, or a superconducting magnet. Variable temperatures may be achieved using either cryostats or furnace assemblies. In the context of the current discussion, we will consider electromagnet based systems only, as magnetic media are usually characterized at ambient temperature, and for only moderate field strengths. Tape and thin film samples to 1 inch in diameter may be characterized in the Lake Shore VSM.

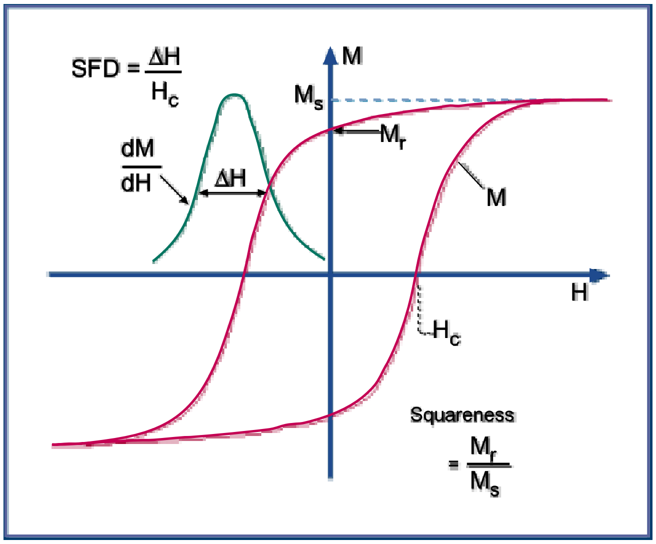

Figure 1

The Hysteresis Loop

In the case of a typical recording medium the hysteresis loop gives the relation between the magnetization M and the applied field H. A hysteresis loop of a magnetic recording medium is illustrated schematically in Figure 1. The parameters extracted from the hysteresis loop that are most often used to characterize the magnetic properties of magnetic media include; the saturation magnetization M_s, the remanence M_r, the coercivity H_c, the squareness ratio SQR, S* which is related to the slope at H_c , and the switching field distribution SFD. The loop illustrated in Figure 1 shows the behavior for the easy axis of magnetization (i.e., in the anisotropy direction). The loop has a rectangular shape and exhibits irreversible changes of the magnetization. The hard axis loop, where the hard axis is at right angles to the easy axis, is more or less linear and generally hysteresis free, i.e., the magnetization is reversible. Magnetic materials that show a preferential direction for the alignment of magnetization are said to be magnetically anisotropic. When a material has a single easy and hard axis, the material is said to be uniaxially anisotropic.

The intrinsic saturation is approached at high H, and at zero-field the remanence is reached. The squareness ratio is given by the ratio of (M_r/M_s) and is essentially a measure of how square the hysteresis loop is. In general large SQR values are desired for recording medium. The formal definition of the coercivity H_c is the field required to reduce the magnetization to zero after saturation. The physical meaning of H_c is dependent on the magnetization process, and may be the nucleation field, domain wall coercive field, or anisotropy field. H_c is a very complicated parameter for magnetic films and is related to the reversal mechanism and the magnetic microstructure, i.e., shape and dimensions of the crystallites, nature of the boundaries, and also the surface and initial layer properties, etc.

S* and SFD are of particular importance in characterizing the magnetic properties of magnetic media. S* is related to the slope of the hysteresis loop at H_c, i.e., $dM/dH|_{Hc} = M_r/(H_c(1 - S^*))$. This is known as the Williams-Comstock construction. For longitudinal recording media there are two important parameters associated with the recording process that are intimately related to S*. Namely, the maximum output signal depends on M_r, H_c, and S*, and the optimal bias current also depends on S*. The SFD = $\Delta H/H_c$ where ΔH is the full width at half maximum of the differentiated curve dM/dH (as illustrated in Figure 1) can be thought of as a distribution function of the number of units reversing at a certain field. For a particulate medium without collective behavior, the SFD has a close relation to particle size distribution because differently sized and shaped particles will reverse at different field strengths. For longitudinal media the SFD is related to recording parameters such as noise, optimal bias current, and time dependent behavior. Media with high H_c and small SFD are desirable for high density recording.

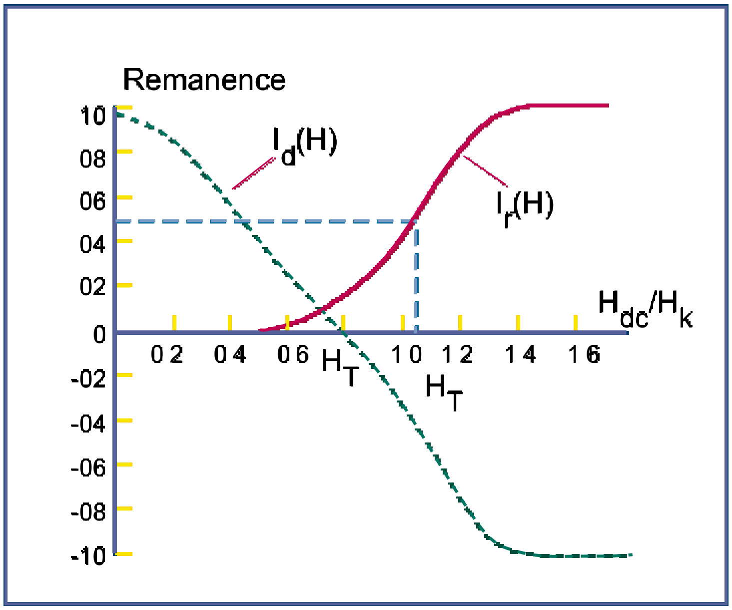

Figure 2

In addition to the full hysteresis loop properties of magnetic media, there has been increased interest in the measurement of remanence curves. Measurement of remanence determines only the irreversible component of magnetization and thus enables the phenomena of switching to be deconvoluted from the hysteresis measurement, which generally includes a reversible component. There are two principle remanence curves; the isothermal remanence (IRM) and the DC demagnetization curve (DCD). The IRM is measured after the application and removal of a field with the sample initially demagnetized. The DCD is measured from the saturated state by application of increasing demagnetizing fields. Both are illustrated schematically in Figure 2. These remanence curves are of importance because they yield the true SFD for the material. The VSM may also be used to measure the IRM and DCD remanence curves.

The remainder of this paper will present magnetic data for thin film magnetic media, thus demonstrating the utility of the Lake Shore VSM for measuring media magnetic properties.

Magnetic Measurements Using the VSM

The Lake Shore VSM features variable-gap electromagnets providing field strengths to over 2 tesla. Experimental flexibility, both in terms of achievable field strengths, and in terms of allowable sample sizes are provided since the gap spacing may be adjusted to maximize either. Auto-rotation and Vector options facilitate investigations of anisotropy in magnetic media. With the auto-rotation option the sample may be rotated such that the applied field is oriented parallel to either the easy or hard axis of magnetization, or at any angle in between. The Vector option, which includes 2-axis or 3-axis coil sets placed at right angles to one another, permits simultaneous measurement of both easy and hard axis magnetization for fields oriented parallel to either axis. This option also permits the derivation of torque since torque is equal to the cross product of the field and magnetization vectors (i.e., $\tau = M \times H$). Data collection is fully automated with Windows based data acquisition/control and analysis software. Broad application versatility is maintained since measurement parameters may be easily defined and controlled. The software automatically extracts any of a number of parameters, e.g., M_s, M_r, H_c, SQR, S*, SFD, etc., directly from the measured hysteresis loop. And, extensive data analysis capabilities are also provided, e.g., derivative (SFD) curves, substrate and paramagnetic background corrections, etc.

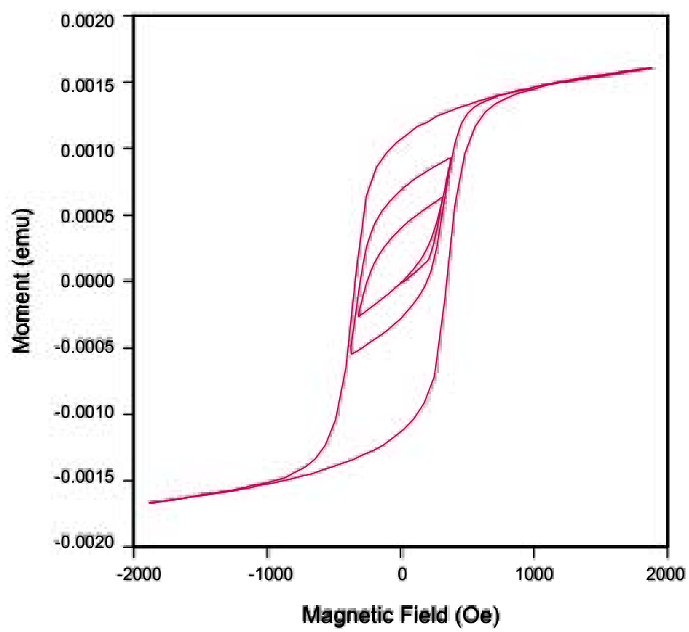

Figure 3

Measurement Results

Figure 3 shows the initial, minor, and major hysteresis loop for a thin film disk material. In the context of the present discussion, the minor loops of magnetic media are sometimes of interest as they relate to modeling of the write process. Taken together with the major loop, the minimum head field strength required to ensure saturation and hence maximum remanence are determined.

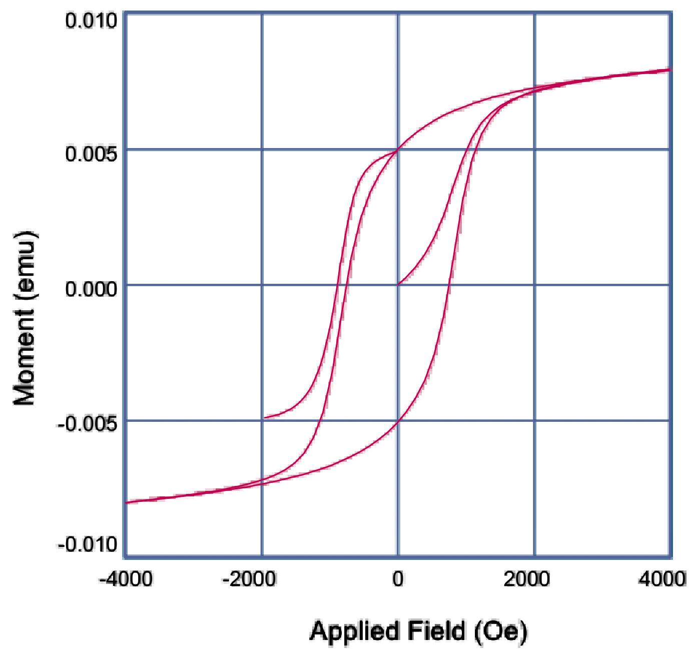

Figure 4

Figure 4 shows the initial magnetization curve, major hysteresis loop, and also the DCD demagnetization or remanence curve for a flexible magnetic media material.

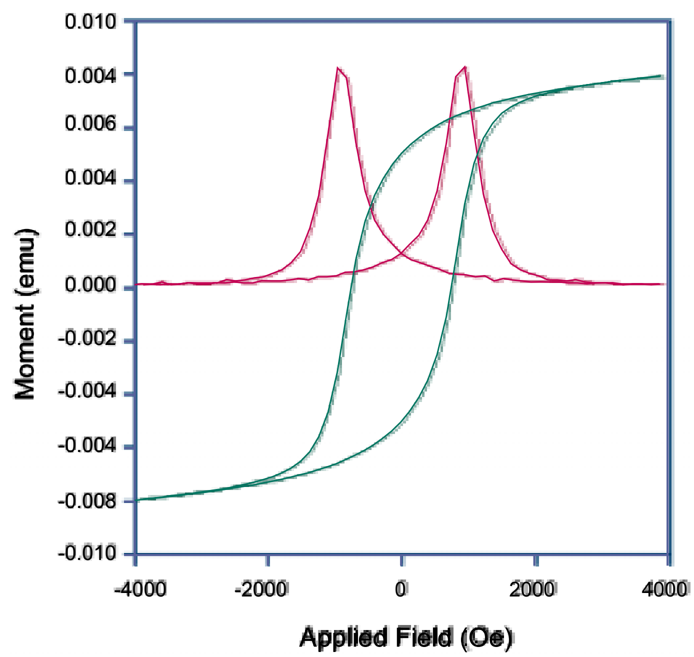

Figure 5

Figure 5 shows the major hysteresis loop for a flexible media material, and the derivative curves are also illustrated. These derivative curves are directly related to S* and the SFD. Since small SFD's are desirable, the sharpness and width of these derivative curves are of interest. A narrow and stable switching transition produces a small SFD, and hence the derivative curves yield useful information concerning the magnetic structure of the media, which in turn is related to the microstructure and chemical inhomogeneities in the layer. These parameters are principally related to the deposition process itself.

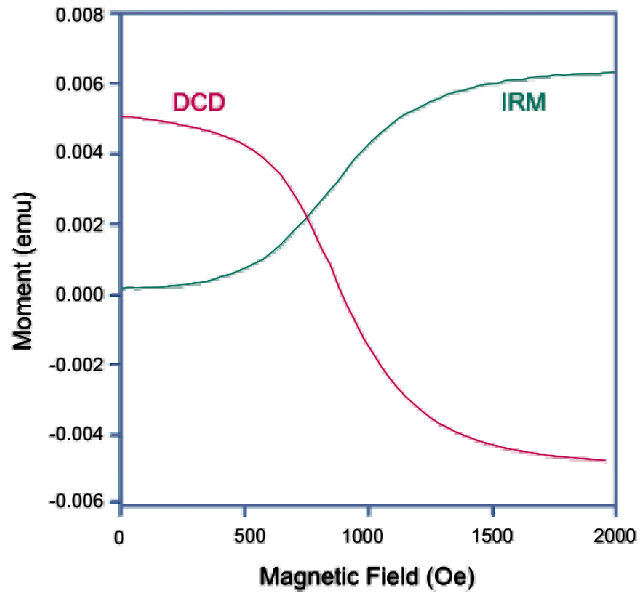

Figure 6

Figure 6 shows the isothermal remanence (IRM) and DC demagnetization (DCD) remanence curves for a flexible media material. Interaction effects may be investigated by analyzing these curves. If the particulate media is characterized by non-interacting particles then a Henkel plot, i.e. IRM(H) vs. DCD(H), will be linear, and the forward and reverse SFD's will be identical. Deviations from linearity are attributable to the effects of interactions in the system. Figure 7 shows the Henkel plot corresponding to Figure 6 and Figure 8 illustrates the forward and reverse SFD's obtained from differentiation of the IRM and DCD curves. Clearly the SFDs are not identical. The extent to which interactions exist in the system are revealed by these types of ΔM vs H curves. A larger interaction yields a larger ΔM peak. The use of this type of analysis is becoming increasingly common in the investigation of interaction effects in particulate and thin film media. A strong correlation exists between the form of these interaction effects, and the degree of dispersion of the particles.

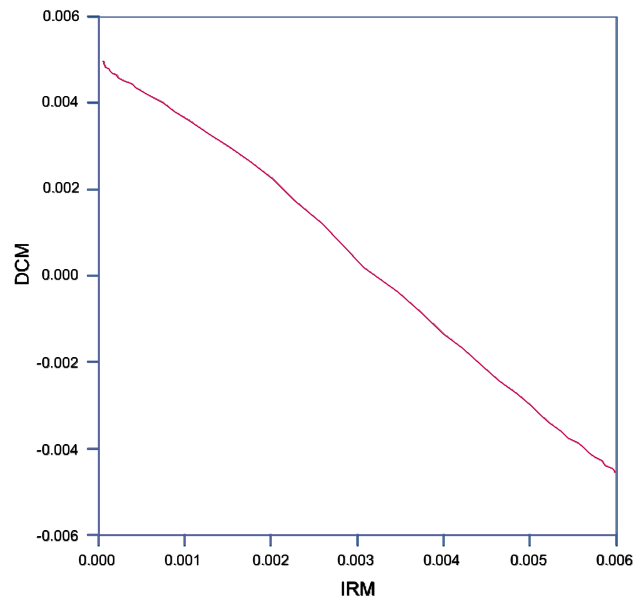

Figure 7

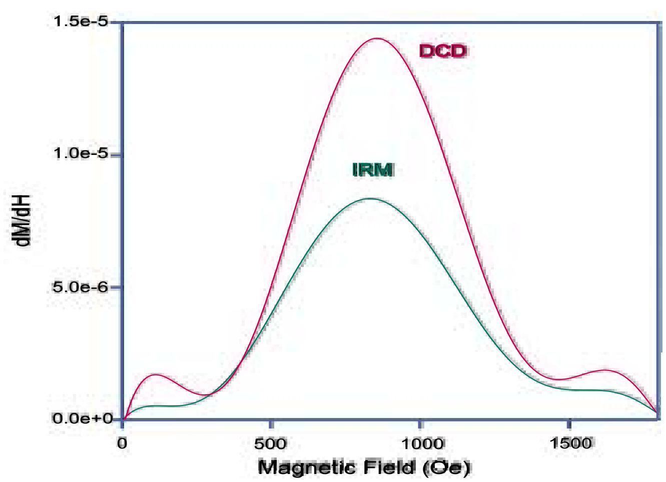

Figure 8

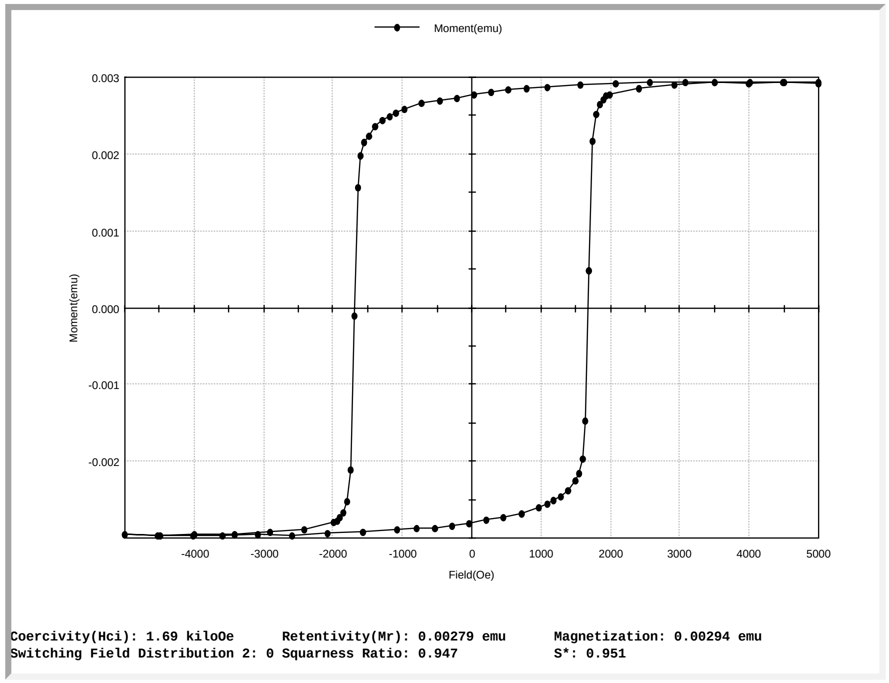

Figure 9

Figure 9 shows a hysteresis loop for hard disk CoPt magnetic film deposited on a rigid disk substrate. Critical M(H) loop parameters are indicated in the figure.

Figures 10 and 11 show the hysteresis loop and derivative curve, respectively, for a hard disk film sample.

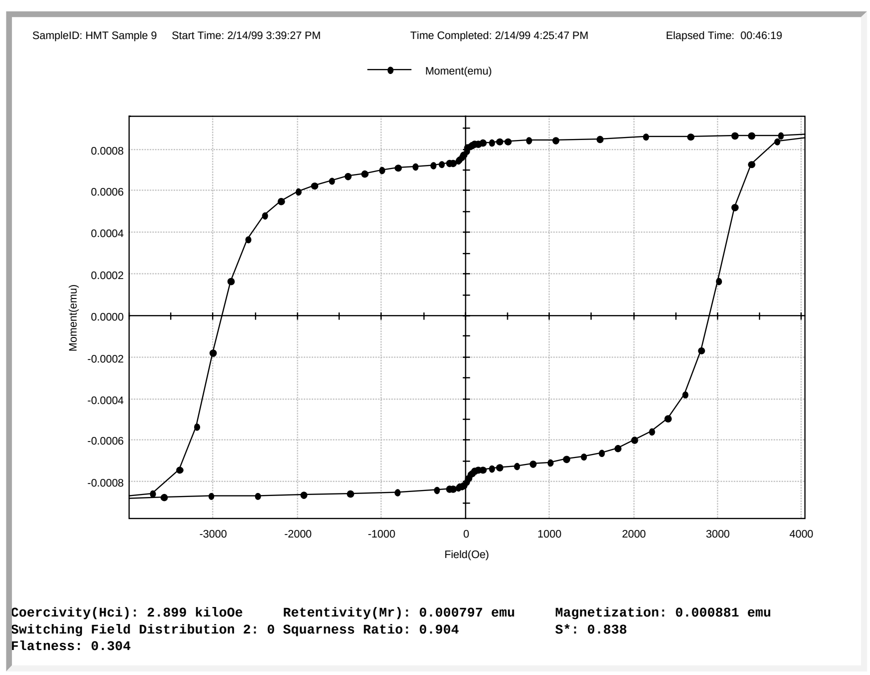

Figure 10

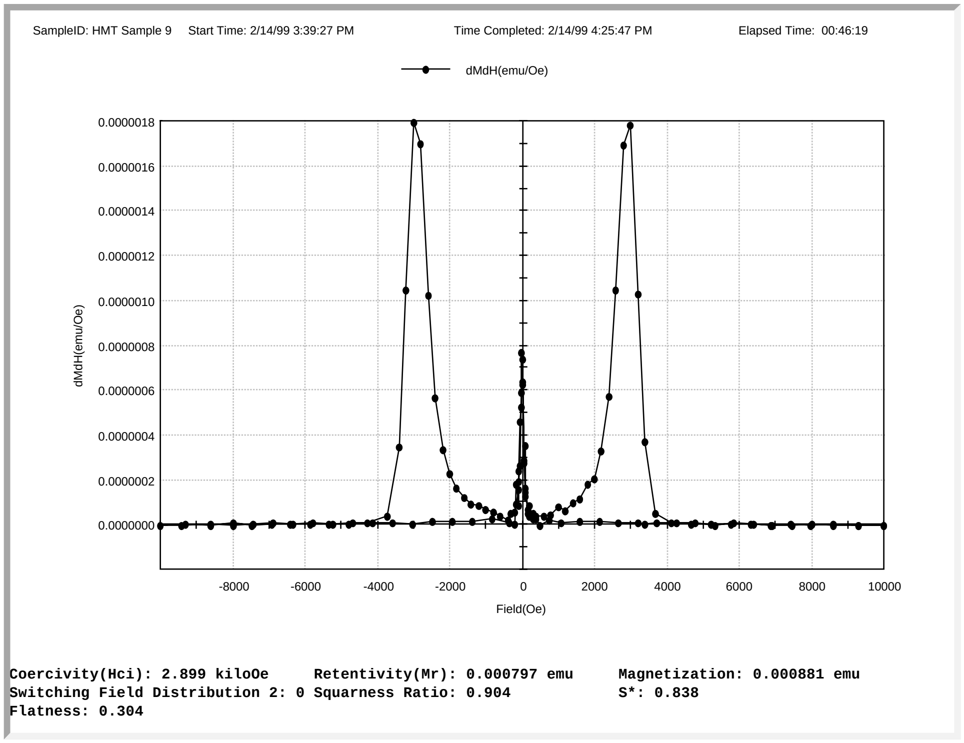

Figure 11

Summary

Selecting a VSM and Future Requirements

There are a number of considerations that come into play when selecting an appropriate VSM. These include; the types of materials that are to be measured, i.e., both intrinsic magnetic characteristics and physical properties and dimensions are important, required magnetic field strength, accessible temperature range, available measurement options, ease-of-use which is largely dictated by the software interface, etc.

Current research trends in magnetic media include the development of perpendicular recording media, magneto-optical materials, the development of pseudo-contact recording techniques, the use of magnetoresistive (i.e., GMR and CMR) multi-layer films for read heads, the use of alternative substrate materials (e.g., glass), and patterned media. Additionally, the superparamagnetic limit is being approached as magnetic film thicknesses are decreased. This trend will force VSM manufacturers to enhance the sensitivity characteristics of their VSM's.

This paper has discussed some of the more important magnetic properties of magnetic media, their relation to the recording process, and their determination utilizing a Vibrating Sample Magnetometer measurement methodology. The wide spread use of magnetic media materials for audio, video, and data storage systems results in a continual research effort to increase storage densities, and decrease access time. Advances made possible by materials science, combined with the development of commercially available computer automated characterization tools, such as the VSM will certainly result in significant advances in this area.

References

High Density Digital Recording, edited by K. H. J. Buschow, G. J. Long, and F. Grandjean, NATO ASI Series E, Vol. 29, Kluwer Academic Publishers, Boston, 1993, and references cited therein.

Introduction to Magnetism and Magnetic Materials, David Jiles, Chapman and Hall, New York, 1991, and references cited therein.

Magnetic Ceramics, Raul Valenzuela, Chemistry of Solid State Materials, Cambridge University Press, 1994, and references cited therein.

The Foundations of Magnetic Recording, J. C. Mallinson, Academic Press, New York, 1993, and references cited therein.

The Physics of Magnetic Recording, C.D. Mee, North Holland, New York, 1986, and references cited therein.

Theory of Magnetic Recording, H. Neal Bertram, Cambridge University Press, 1994.