Measurement of the magnetic anisotropy energy constants for magneto-optical recording media

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ABSTRACT

Measurement of the magneto-optical polar Kerr effect is performed on rare earth-transition metal (RE-TM) amorphous films using in-plane fields. From this measurement and the measurement of the saturation magnetization using a vibrating sample magnetometer (VSM), the magnetic anisotropy constants are determined. In this paper, we present the temperature dependence of the magnetic anisotropy in the range of $-175^\circ C$ to $175^\circ C$. The results show a dip in the anisotropy near magnetic compensation. This anomaly is explained based on the finite exchange coupling between the rare earth and transition metal subnetworks.

1. INTRODUCTION

Understanding the temperature dependence of magnetic anisotropy in the media of magneto-optical (MO) data storage is important for their applications. Measurements of the magneto-optical polar Kerr effect using in-plane external magnetic fields have been reported in several publications[1-3]. We have also reported recently, that the extraordinary Hall effect can be used to determine the magnetic anisotropy[4]. Due to the spin-orbit coupling, the perpendicular component of the magnetization of the transition metal subnetwork is proportional to the polar Kerr and Hall signals. Therefore, by proper normalization, the direction of magnetization θ with respect to the film normal can be obtained as function of the magnitude and direction α of the applied field H. Knowing θ, α, H and the saturation magnetization of the film M_s which is determined separately using a VSM, the uniaxial anisotropy energy $E_{anis}(\theta)$ can be calculated. We determine the anisotropy energy constants by matching $E_{anis}(\theta)$ with an expression of the form[5] $K_1\sin^2(\theta) + K_2\sin^4(\theta) + ...$. In this paper, we will present the temperature dependent anisotropy of TbFeCo films using the polar Kerr effect with perpendicular and in-plane applied magnetic fields. The films are of different terbium content ranging from 22.5% to 28%. The films were sputtered onto quartz substrates and consist of a quadrilayer structure of AlCr with MO layer sandwiched between two dielectric SiN layers. The magnetic anisotropy shows a dip near the magnetic compensation. We will discuss this anomaly based on the finite exchange coupling between rare earth (RE) and transition metal (TM) subnetworks.

2. TEMPERATURE DEPENDENT MAGNETIC PROPERTIES

Figure 1(a) displays the temperature dependence of M_s for the six films studied. Figure 1(b) displays the compensation temperature (T_{comp}) and the room temperature M_s versus terbium atomic percent $(T_{comp} \approx 25^\circ C$ when the terbium content is near 25%). Figure 2(a) displays the coercivity H_c as a function of temperature for these samples. H_c is obtained from the hysteresis loops measured using the polar Kerr effect. As expected, the coercivity diverges at T_{comp} which is a characteristic of ferrimagnetic materials. The room temperature H_c is shown in Fig. 2(b) as a function of the terbium content.

Figure 3(a) shows the magnetic anisotropy constant K_1 for these films as a function of temperature. The experimental set-up which uses the polar Kerr effect to determine K_1 and K_2 has been described in reference [2]. Since the maximum θ in the measurement was usually less than 15°, there was a large spread of about 50% in the fitted K_2 values. Figure 3(a) shows a dip in K_1 near the T_{comp} for the samples measured. This dip is clearly shown in the plot of Fig. 3(b) for K_1 and $K_1 + K_2$ at room temperature versus terbium atomic percent. The sample with 25% terbium could not be measured at room temperature since it requires infinite fields to tilt the magnetization. This point is represented by a question mark in Fig. 3(b). It is important to note that direct measurements of the anisotropy constants using a torque magnetometer show a similar rapid drop
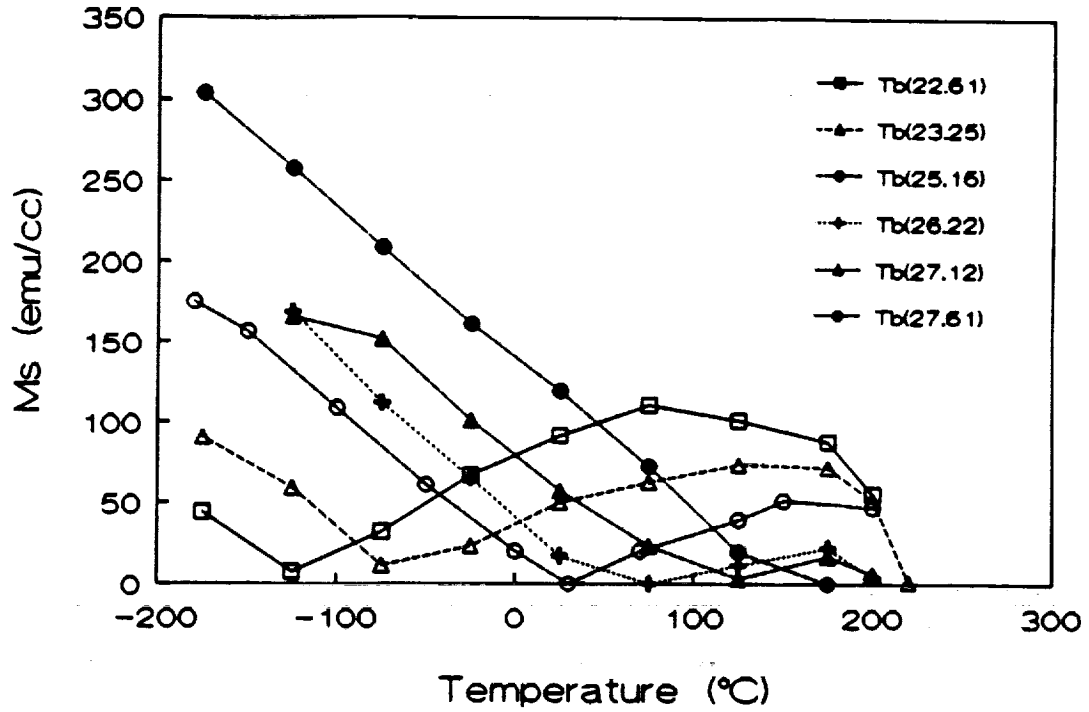
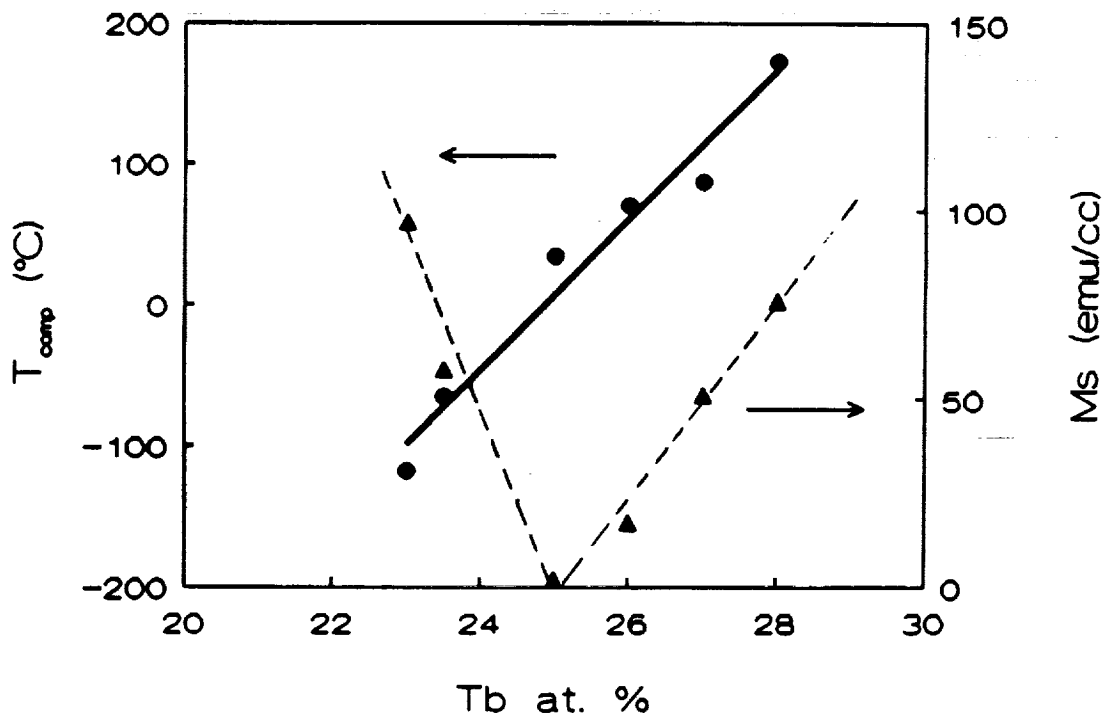**Fig. 1(a)** Saturation magnetization M_s versus temperature for six TbFeCo samples.

Fig. 1(b) Saturation magnetization M_s and compensation temperature T_{comp} at room temperature plotted as a function of terbium atomic percent.
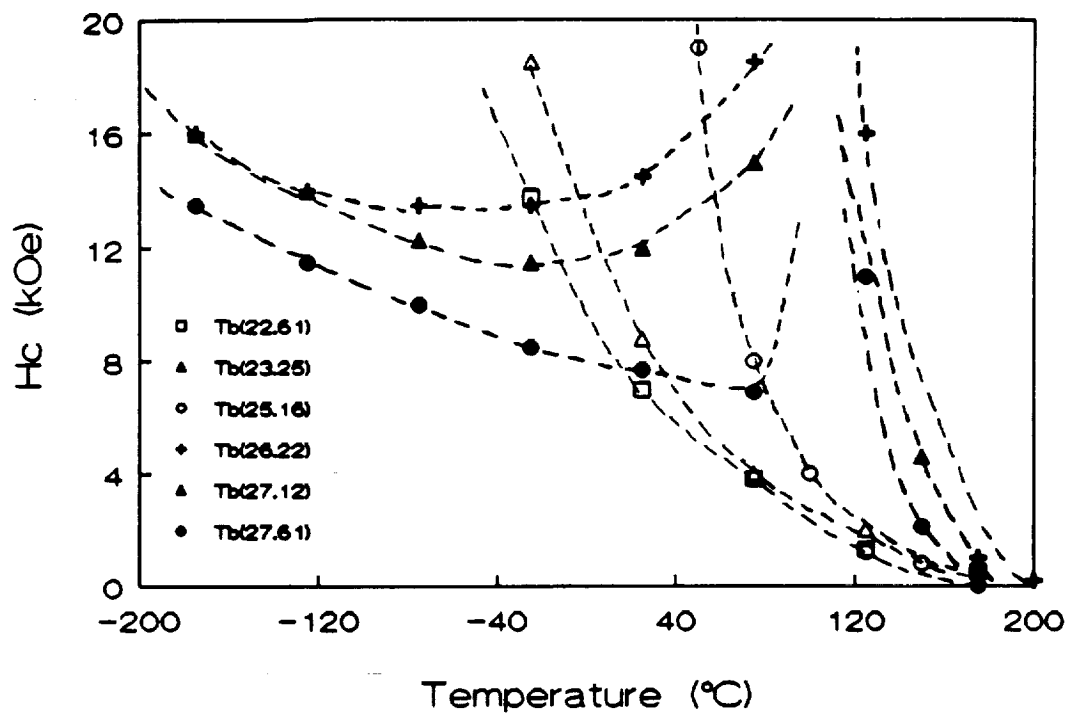
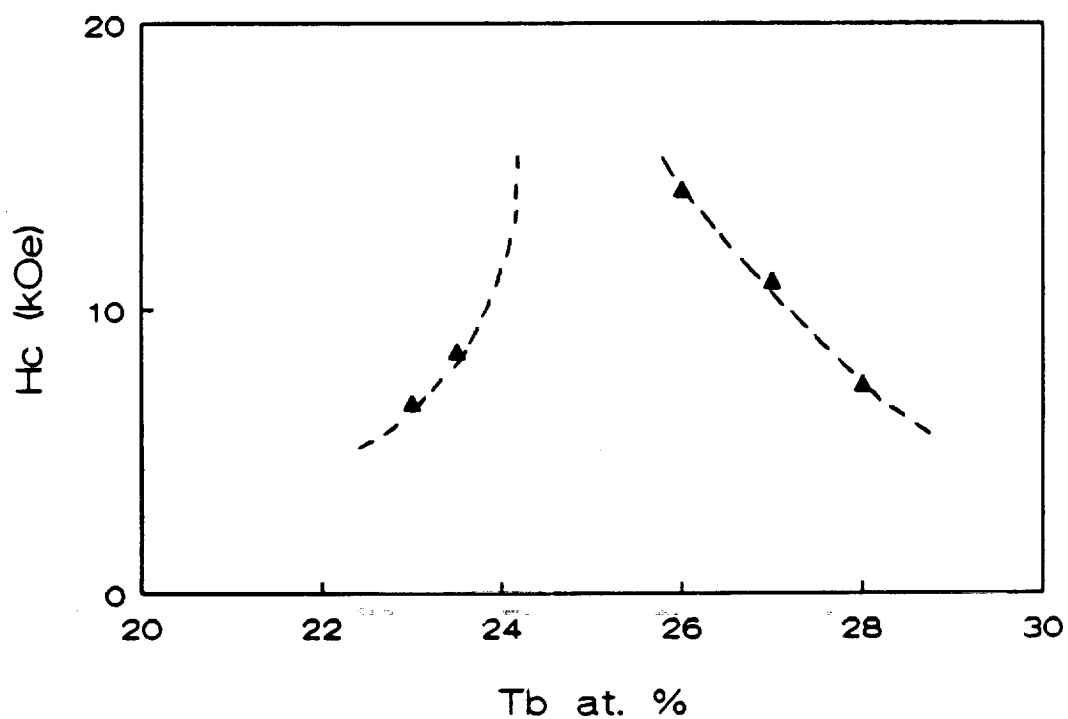**Fig. 2(a)** Coercivity H_c versus temperature for six TbFeCo samples.

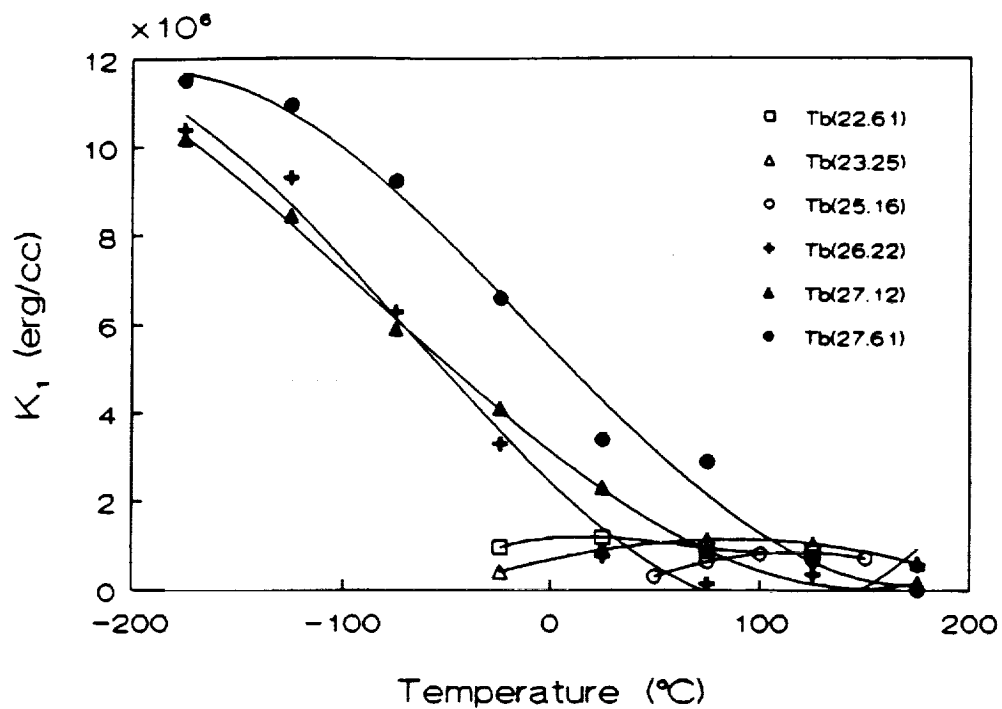**Fig. 2(b)** Coercivity H_c at room temperature plotted as a function of terbium atomic percent.

Fig. 3(a) Magnetic anisotropy constant K_1 versus temperature for six TbFeCo samples.
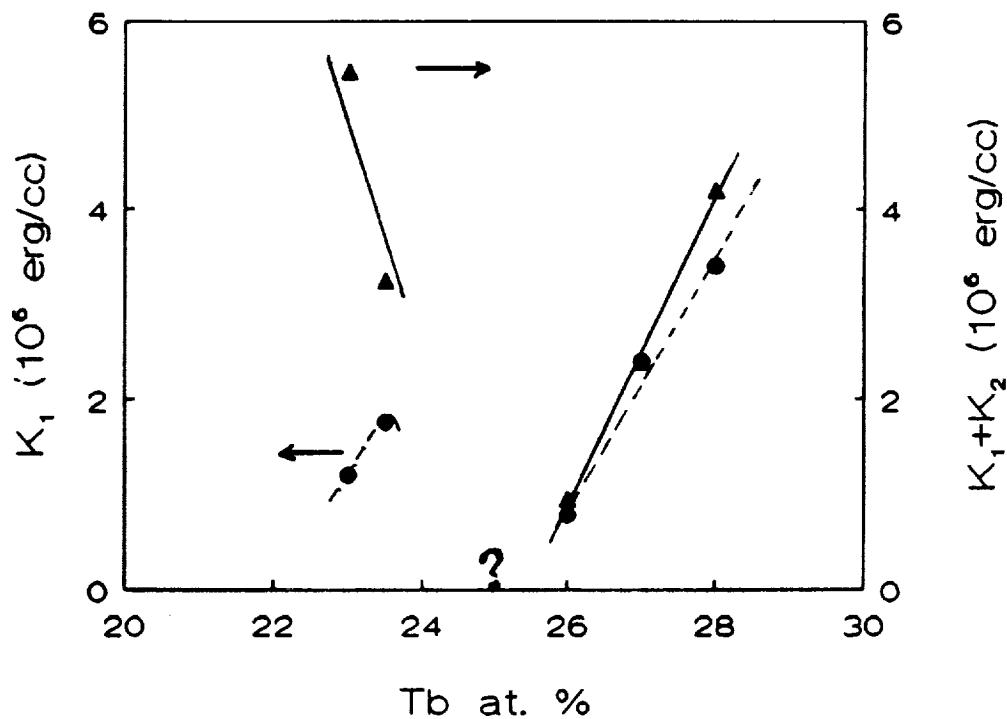

Fig. 3(b) Magnetic anisotropy constants K_1 and K_1+K_2 at room temperature plotted as a function of terbium atomic percent.

near T_{comp} as well. This anomaly is independent of the preparation or measurement technique and has been previously observed in similar samples[6-9]. The drop of anisotropy constant near compensation is quite unexpected, because compensation is simply a cancellation of the two subnetwork magnetizations and should have no effect on the anisotropy. Next, we discuss a mechanism that may explain this anomaly.

2.3 The Canting Model for the Anomaly

Sarkis and Callen[10] pointed out that the exchange coupling between RE and TM subnetworks in RE-TM ferrimagnets is not so large as to hold the RE and TM moments rigidly antiparallel. The external field used in measuring anisotropy can cause canting between the two sublattices. The amount of the canting is usually very small. For example, it is on the order of 1° when a 20kOe field is applied to a typical TbFe thin film. However, neglecting this small canting by assuming infinite exchange between the two subnetworks in the total magnetic energy of the system and using this model to match the measured data, the K_1 found could be much smaller than the physical anistropy constant near compensation and would be zero at the exact compensation. Only in regimes far away from the compenstion, the fitted anisotropy approaches the physical anisotropy constant of the measured material. This problem has also been studied recently by Hellman[11].

In torque measurement, the reason why a small canting can cause a large discrepancy in the anisotropy constant can be easily understood in the following example. Consider the direction of the net magnetization M_s of the two sublattices of a RE-TM thin film under the influence of an in-plane applied field (Fig. 4). Usually, the tilted angle θ_N of the net magnetization from the normal direction is directly related to the anisotropy constant: small θ_N implies large K_1 and large θ_N indicates small K_1. However, when there is a canting between the sublattice magnetizations near compensation, θ_N can be very large even if the two sublattice magnetization are slightly tilted from the normal direction, see Fig. 4(a). Obviously, this large θ_N is not a result of small K_1 (and K_2), but a result of canting near the compensation. Far away from the compensation, the net magnetization will not tilt too much away from the major sublattice magnetization if the canting is small, see Fig. 4(b).

However, in the case of Kerr effect measurement, we only monitor the TM subnetwork magnetization direction θ_{TM}. The effect of the canting on the measured anisotropy constant becomes complicated. In fact, the fitted anisotropy based on infinite exchange can be smaller or larger than the physical anisotropy constant of the material, depending on the applied field direction α, which is 90° in our case. Without going into a detailed theoretical treatment[12], it can be shown that if we assume a physical anisotropy constant of 5×10^6 erg/cc which is independent of M_s and take into account a finite exchange interaction between the RE and TM subnetworks[11], we can reproduce the measured θ_{TM}. Now, if we use the θ_{TM} found by the canting model and calculate K_1 with the assumption that the RE and TM moments are infinitely coupled to each other, we obtain the plot of Fig.5 showing a dip in K_1 (for the case of $M_{TM} > M_{RE}$). This finding suggests that the dip in the fitted anisotropy constants might be caused by an incomplete model that neglects the finite exchange between the sublattices. We will present in [12] a series of different measurements of K_1 and K_2 performed on a set of TbFeCo samples and discuss their differences based on the canting model.

3. ACKNOWLEDGMENTS
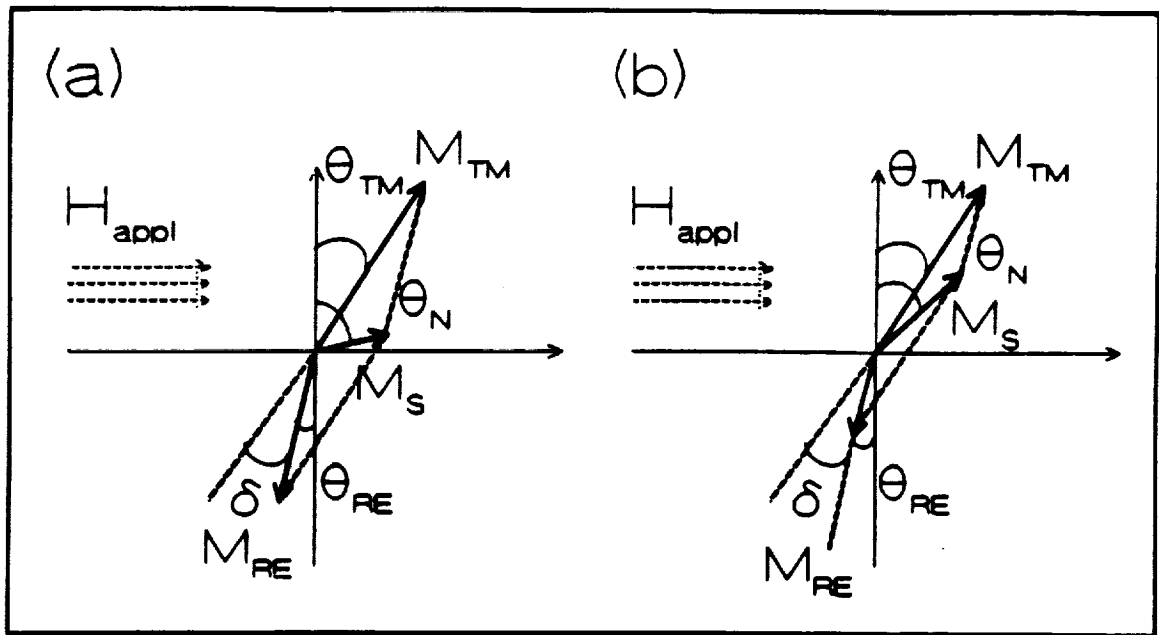
Fig. 4 The sublattice magnetization directions θ_{TM} and θ_{RE} and the net magnetization direction θ_N near (a) and far (b) from compensation. δ is the canting between the two sublattice magnetizations. In the case of (a) and when the canting is not zero, θ_N can be very large even when θ_{TM} and θ_{RE} are small. In the case of (b), the canting does not make θ_N and θ_{TM} too much different.
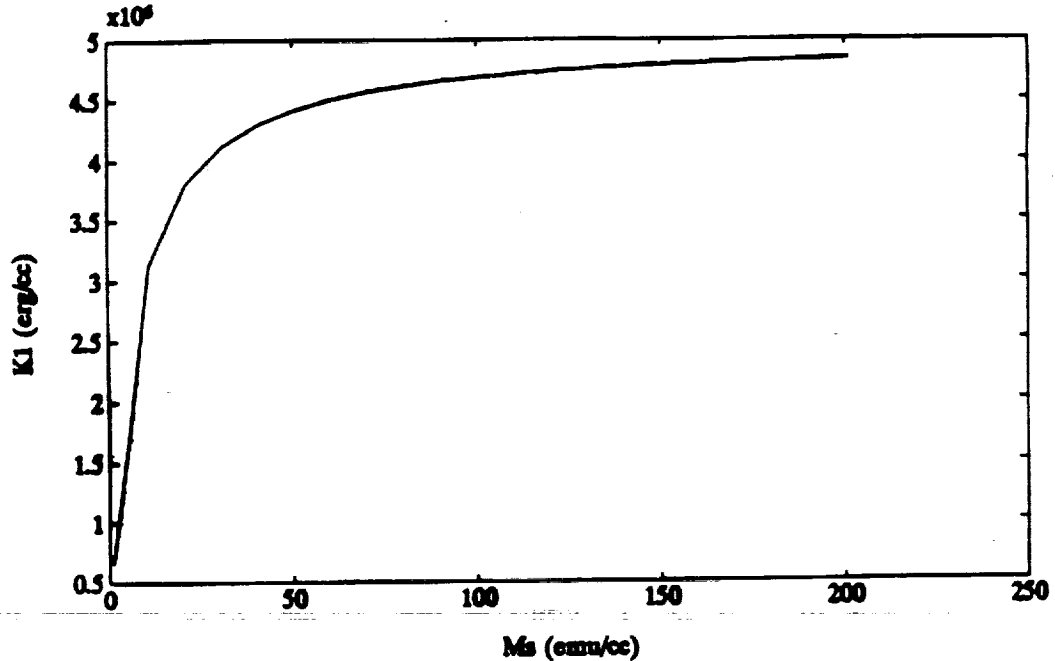

Fig. 5 Calculation of K_1 versus saturation magnetization M_s for a sample with a physical anisotropy constant of 5×10^6 erg/cc. The dip observed near magnetic compensation is a consequence of neglecting the finite exchange interaction between the two subnetworks.

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APPENDIX E

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