# Magnetic Characterization of Nano-Scale Granular Materials

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Progress in the Nano-Sciences during the past decade opened up new pathways for developing materials with enhanced electronic or other properties. Their potential applications are wide-spread, such as semiconductor electronics, spintronics, photonic devices, sensors for molecular recognition in chemistry and biology to name a few. Despite the tremendous progress in recent years, however, substantial challenges remain to be resolved before many of these nanotechnologies can reach their anticipated potential. Hereby, one needs to recognize that further advancement inevitably relies on the availability of characterization methodologies that allow for optimization of materials design and processing as well as for gaining a fundamental understanding of underlying scientific phenomena and concepts.

As an example of such materials characterization challenges, we have studied issues related to nano-scale granular materials, such as the ones used for the purpose of information storage in hard disk drives (HDD). To achieve today's product level technology, magnetic grains of only 6-10 nanometer diameter have to be utilized with further technical progress requiring even smaller functional particles. In turn, the already achieved technology requires methodologies that allow for a sufficiently accurate and time-efficient magnetic characterization of the about 100 trillions magnetic grains in a typical last-generation laptop computer HDD [1].

In recent years, numerous attempts have been made to develop a reliable and efficient characterization methodology capable of extracting all relevant information about the recently introduced perpendicular magnetic recording (PMR) media [2, 3]. Specifically, the magnetization switching field distribution was found to be a crucial material property and the so-called ΔH-method (Fig. 1) has been the most reliable technique for its determination so far [2, 3]. However, as all other available methods today, also the ΔH-method has its limits of applicability, and an all-around satisfactory technique is yet to be developed. Correspondingly, the main goal of the present work is to estimate the range of applicability of the ΔH-method. For our computational analysis, we used a previously devised realistic model [4, 5], in which PMR media are viewed as a planar assembly of magnetic single domain nano-grains. Magnetization reversal of each grain is described by a rectangular hysteresis loop with a randomly chosen switching field in accordance with an overall representative switching field distribution. Every grain interacts with its nearest neighbors via ferromagnetic exchange interactions of strength $J_{ex}$ and with all other grains on the lattice via the distance-dependent dipolar interaction of strength $J_{dp}$. Correspondingly, the interaction constants $J_{ex}$ and $J_{dp}$ as well as the switching field distribution determine the hysteresis loop behavior.

We observe, using this computational model of nano-scale granular PMR-media, that the simultaneous presence of exchange and dipolar interactions between individual grains generally allows for a precise determination of the intrinsic switching field distribution (Fig. 2). The method's reliability is due to the fact that the two types of interactions have opposite signs, which partially suppresses the correlation of the magnetic reversal in neighboring particles. Otherwise, the particle interaction would wash out the individual character of the magnetic grains and make the characterization in terms of single grain properties impossible. However, due to the existence of this compensation effect it appears impossible to separate the different interaction contributions from each other by means of the ΔH-method, and this fact seems to even hold for ΔH-dataset analysis schemes that go beyond the presently used mean-field approximation.

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**References:**

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**Figures:**

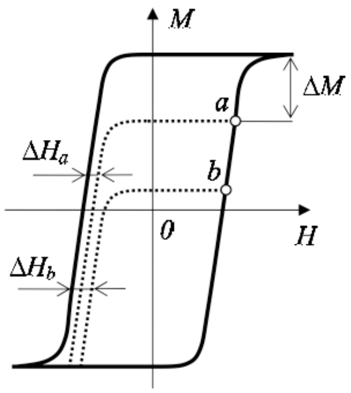


Fig. 1: Major hysteresis loop (solid line) and two recoil loops (dotted lines). $\Delta H$ is the field difference between the major and a given recoil loop for the same magnetization M value. $\Delta H(M, \Delta M)$ data are then compared with the analytical solutions of the mean-field model to determine the intrinsic switching field distribution [2, 3].

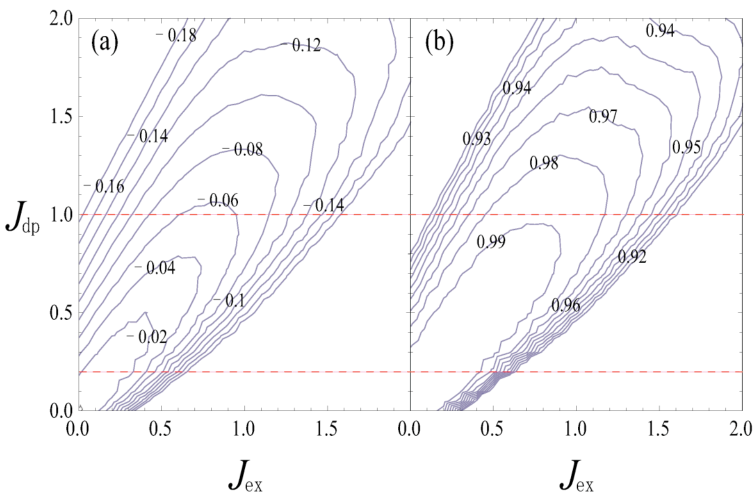


Fig. 2: Contour plots of the data analysis quality and accuracy of the $\Delta H$–method as a function of $J_{ex}$ and $J_{dp}$. (a) difference between the recovered value and the input parameter for the variance of the switching field distribution. (b) Multiple correlation coefficient $R^2$ of the least-squares fit to the mean-field model. The dotted horizontal lines indicate the range $0.2 < J_{dp} < 1.0$ applicable to real recording materials.