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Spin frustration in nanostructured gadolinium iron garnets

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Abstract – We have studied the magnetic properties of bulk and nanostructured gadolinium garnets (Gd3Fe5O12) using DC, AC and RF susceptibility experiments. The intrinsic geometric spin frustration in garnet systems presents and interesting situation with competing effects due to blocking, surface spin disorder and other particle size effects contributing to the glass dynamics in nanoscale garnets. The magnetic entropy as probed through magnetocaloric effect (MCE) experiments also reveal the role of spin frustration in the bulk and nanostructured phases of garnets.

Gadolinium iron garnets ($Gd_3Fe_5O_{12}$) are technologically important materials for applications such as magnetic refrigeration, lasers, phosphorescent sources, microwave and electrochemical devices. They are also model systems for the investigation of physics of magnetic frustration. In garnets, the intrinsic geometric frustration in the lattice structure leads to complex magnetization dynamics due to competing interactions between rare-earth (Gd) and transition-metal (Fe) ion sublattices. When the garnets are synthesized in the nanostructured form, the magnetic interactions tend to become even more complicated due to superparamagnetism and blocking effects associated with reduced particle size [1]. We present a systematic study of the cooperative magnetic phenomena that arise from the interplay of these competing effects in nanostructured gadolinium iron garnets using DC, AC and RF transverse susceptibility.

A sensitive tunnel-diode oscillator (TDO) operating at 12 MHz was used to measure the transverse susceptibility (TS) of nanocrystalline $Gd_3Fe_5O_{12}$ particles prepared by ball milling and with average grain size varying from 50 nm to 30 nm. The main advantage of TS over conventional methods is that it uses a resonant singular point detection method to directly provide information about the most important parameters in magnetic materials such as the switching and anisotropy fields. The RF TS method has been validated over the years by us as being very effective for studying anisotropy field distribution, inter-particle interactions and superparamagnetic relaxation that are inherent in nanoparticle aggregates [2-4]. TS has also been used to study exchange bias in nanoparticles with enhanced surface spin disorder [5].

In this study on nanostructured $Gd_3Fe_5O_{12}$, we show how the low temperature spin glass phase due to the geometric frustration in bulk garnets is suppressed in nanostructured garnets. As the particle size is reduced, conventional blocking mechanism is observed. However, careful analysis of the AC and RF susceptibility reveal the presence of intrinsic glass-like features persisting within the blocked state. For the smallest average particle size (~30nm), surface spin disorder tends to dominate the low temperature magnetization. Overall, the results obtained from TS are fully consistent with the DC and AC data showing that bulk $Gd_3Fe_5O_{12}$ undergoes two different glassy states at temperatures below its compensation temperature with the low temperature glass properties strongly influenced by Gd ordering and the glassy nature is largely suppressed in nanocrystalline $Gd_3Fe_5O_{12}$ particles in which the blocking phenomenon competes with the spin frustration effect. Magnetocaloric effect (MCE) measurements were also done on the garnet systems to probe the enhanced magnetic entropy due to the competing effects of blocking and intrinsic spin frustration in nanostructured garnets [1]. In summary, our studies provide new insights into the competition between spin frustration and conventional blocking mechanisms in nanostructured garnet materials. We also demonstrate, for the first time, the ability of transverse susceptibility to probe glass dynamics which opens up a new powerful tool for studying systems with competing magnetic interactions.

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