OBSERVED SUPER-SPIN GLASS BEHAVIOR IN $Ni_{0.5}Zn_{0.5}Fe_2O_4$ NANOPARTICLES

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by

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Abstract

OBSERVED SUPER-SPIN GLASS BEHAVIOR IN $Ni_{.5}Zn_{.5}Fe_2O_4$ NANOPARTICLES

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In this investigation we seek to identify the magnetic behavior of $Ni_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles though AC-susceptibility and DC-magnetization measurements. Powder x-ray diffraction was performed to determine the purity and average diameter (<D> ˜ 9nm) of the particles. Aditionally, structure was confirmed by comparison through the International Centre for Diffraction Data's Powder Diffraction File [52] (PDF # 08-0234).

Zero-field cooled and field cooled DC magnetization measurements (bifurcation and blocking temperature), as well as M(H) hysteresis (below and above the blocking temperature) lead us to initially suggest that the material may in fact be superparamagnetic. However, further investigation of the real AC susceptibility through typical magnetic models (Néel- Arrhenius, Vogel Fulcher), suggest an influence from interparticle interactions on the overall magnetic behavior of the system. In addition, the relative variation of the blocking temperature per frequency decade was 0.032 within the range commonly associated with spin glass behavior (0.007 - .05) [75,76].

Further investigation leads us to conclude that the in-phase component of the AC susceptibility is well described by the critical dynamics of the power law, commonly associated with spin-glass behavior. Our parameters were well within observed spin-glass range, showing a critical dynamic exponent zv=10 (range 8-10) and attempt frequency 10^{11}Hz (range 10^{11} -

10^{13}Hz) [77]. The transition temperatures DC field dependence was found to follow the AT line (commonly associated with glassy behavior) and showed a zero field freezing temperature consistent with that found from the power law fit, further evidencing super-spin-glass behavior [79]. Additionally, the out-of-phase component of the AC susceptibility was probed for dynamic scaling behavior (associated with spin-glass like systems). The data produced parameters (β=1.0) in perfect agreement with already established values for spin-glass systems [80]. Furthermore thermo-remnant magnetization (TMR) measurements lead to a peak at the wait temperature, this peak has been used previously to differentiate between super-spin glasses and superparamagnets. Throughout our investigation, all magnetization experiments seem to point to the likelihood of super spin-glass behavior in the $Ni_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticle system.

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Chapter 1: Introduction

Currently, nickel zinc ferrites are used for their magnetic properties in the modern electronics industry, due to their high electrical resistivity. These high electrical resistivities imply very low eddy current losses, only significant at higher electromagnetic field frequencies. In addition nickel zinc ferrites exhibit many other properties that make them valuable to the electronic industry including, high mechanical strength, high values of saturation magnetization/magnetic permeability, excellent chemical stability, and low coercivities/dielectric losses [1].

The electronics industry is turning to nanosized nickel zinc ferrite to reduce the energy losses commonly associated with bulk powders. Furthermore nickel zinc ferrite nanoparticles are prime candidates for the changing face of electronics, as more and more electronic applications require materials be pressed into larger shapes with near theoretical density (difficult to obtain if the particles have a wide size distribution) [2].

Evidently there are a large number of potential applications of nickel zinc ferrite nanoparticles, as well as magnetic nanoparticles in general, including the electronic/computer industry and biomedical sciences. Applications aside, the study and classification of magnetic nanoparticles, spinel ferrites in particular, is of great importance to our understanding of material magnetization in general. It will only be through numerous studies of all types of spinel ferrites that we will be able to use these materials to the fullest.

In this study we present our investigation of the magnetic behavior of nanosized spinel ferrite $Ni_{0.5}Zn_{0.5}Fe_2O_4$, though means of dc and ac magnetic susceptibility as well as powder X-ray diffraction (XRD) measurements. In addition to the geometric structure of the sample, our study produces a wide array of evidence that shows superspin-glass behavior in this material.

1.1 Why Magnetic Nanoparticles?

Magnetic nanoparticles have been found to exhibit may interesting properties, most notably, properties that appear to be size induced. Consequently, many unique and unexpected magnetic behaviors arise in magnetic nanoparticles. Perhaps most notably is the well known below some critical size.

Over the last few decades the dynamics of how magnetic nanoparticles interact has been a subject of extensive research [3-5]. While numerous work has been done on magnetic nanoparticle systems simply to increase our basic understanding of magnetism, the recent surge in magnetic nanoparticle research has primarily been motivated by two main industries, the electrical industry/computer sciences [6-8], and the biosciences [9,10]. In addition due to recent breakthroughs involved in synthesis, as well as the United States government's strong recognition of nanoparticle importance, magnetic nanoparticles make an optimal candidate for university research.

In the biosciences, a wide variety of applications of magnetic nanoparticles has been envisaged, including magnetic hyperthermia (cancer treatment) [11], and magnetic immunoassay [12] (using magnetic beads for diagnosis). The great potential of using magnetic nanoparticles in the biosciences stems from the presumed ability to control key magnetic properties, chemical binding properties, reliable retrieval or dispersion mechanisms which magnetic particles provide, as well as the ability to locate said particles in a unobtrusive fashion (magnetic imaging techniques).

In the electronics industry and computer sciences, the main driving force is that of producing higher density magnetic storage media [13]. The magnetic data storage industries are constantly seeking to improve their technologies, making faster and smaller data storage

materials. Because there are some presumed limitations (mutual dipolar interactions, superparamagnetic limit) to making data storage devices in the current manner, much interest has been generated by the claims that there are ways to produce materials around said “limits”, (ex. arrays of single-domain magnetic nanoparticles may lead to ultrahigh density magnetic recording media [14]).

Magnetic nanoparticles are practical to work with as there has been great advances in their synthesis, allowing for easier and more economical production. Accordingly, there have been extensive chemical procedures developed (*rf* sputtering [15], chemical synthesis [14]) to precisely tailor magnetic nanoparticles for specific composition and size. In addition, nanoparticles research in the United States is generally cast in a favorable light due in part to programs such as The National Nanotechnology Initiative, which provides generous public funding for nanoparticle research [16].

Ultimately it will be our understanding of the different types of magnetic behavior present in magnetic nanoparticles (transitions, relaxations, reversal dynamics [3]) and how these behaviors arise from the chemical composition that lead us to manipulate such systems for our benefit. Therefore, numerous theories and studies have been developed, dedicated to explain, classify and hypothesize the complex inner workings of magnetic nanoparticles. It is only through work such as this (our own work included) that progress is made towards the ultimate goal of the field, a completely developed coherent model explaining the behavior of magnetic nanoparticles.

1.2 Why Zinc Doped Nickel Ferrite?

For the past few decades, much research has been dedicated to the study of magnetic nanoparticles, especially regarding the direct influence of size effects on the behavior of the