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A Comprehensive Review of Magnetic and Electron Transport Properties in Granular Films

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Abstract: Granular films, consisting of magnetic nanoparticles embedded in a non-magnetic matrix, have garnered significant attention due to their unique magnetic and electron transport properties. The size and distribution of these magnetic nanoparticles critically influence the overall magnetic behavior and electron transport mechanisms. When the nanoparticles are sufficiently small, the films exhibit super-paramagnetism, with individual particles acting as single magnetic domains. Insights into the structural and compositional characteristics of granular films are obtained through electron microscopy and various spectroscopic methods.

Keywords: Granular films, magnetic nanoparticles, matrix, electron transport

I. INTRODUCTION

Granular films are composite materials where magnetic nanoparticles are dispersed within a non-magnetic insulating or metallic matrix. The distinctive properties of these films stem from their nanoscale structure, which leads to novel magnetic and electronic behaviors not observed in bulk materials. This review aims to provide an in-depth analysis of the magnetic and electron transport properties of granular films, exploring how these properties are influenced by factors such as particle size, interparticle distance and the nature of the matrix [1].

Granular materials, found in natural, biological, and industrial processes, are composed of assemblies of objects typically larger than 1 micron in size [2], [3]. At this scale, thermal agitation is negligible, resulting in primary interactions between individual components that are short-range and non-cohesive, such as inelastic collisions and friction [4]. These systems can exist in a wide range of metastable states, requiring external energy inputs, such as gravity or mechanical perturbations, to transition from one metastable state to another [4].

The experimental results demonstrated a correlation between the structural-phase state, magnetotransport, and magnetic properties of granular thin films composed of Co and Ag across a wide range of component concentrations. The analysis of the structural state and magnetic properties indicated that films with a low concentration of Co exhibited a superparamagnetic state, with cobalt granules sized between 4 and 13 nanometer in the silver matrix [5].

Efforts to create small dispersions of magnetic materials in metals date back to the 1930s [6], [7]. It appears that the first model of a nanoparticle was developed by Kittel in 1946 [8]. From the outset, these models assumed that the magnetic moment would adhere to an Arrhenius law, characterized by a specific relaxation time, τ, as will be discussed below. However, the precise determination of τ was only accomplished by Neel [9] in 1949.

The effect of the composition of alloy thin films based on Cu and Co on their structural-phase state, electrophysical, and magneto-transport properties is shown. The studies were conducted on non-annealed and annealed alloy thin films with a thickness of 40 nm, across a wide range of cobalt atomic fractions. For alloy thin films with $x \leq 0.42$, thermal treatment in the temperature range from 300 to 800 K for 30 minutes caused an increase in the value of coercivity and giantmagnetoresistance due to the increase in the size of the hexagonal packed -Co granules. In alloy thin films with a total atomic fraction of Co at $x = 0.32$, the highest amplitude of GMR was found. The thermal coefficient of resistance of the alloys shows qualitative agreement with experimental results for alloy thin films with a total atomic fraction of Co $x \leq 0.32$ [10].

II. STRUCTURAL CHARACTERISTICS

The structure of granular films plays a pivotal role in determining their magnetic and electronic properties. Key parameters include: Particle Size and Distribution: The size and distribution of magnetic nanoparticles affect the overall magnetic behavior and electron transport mechanisms. Matrix Composition: The choice of matrix material influences the coupling between magnetic particles and the resultant electronic properties. Film Thickness: Variations in film thickness can lead to changes in both magnetic properties and electron transport phenomena. The experimental demonstration of the correlation between the structural-phase state, magnetotransport, and magnetic properties of the granular thin films based on Co and Ag in a wide range of component concentration was achieved [11]. The maze structure with interconnected cobalt particles and SiO2 deposited on a Si substrate was analyzed for its structure and magnetic properties [12].

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III. MAGNETIC PROPERTIES

The magnetic properties of granular films are characterized by: Superparamagnetism: Granular films with sufficiently small nanoparticles exhibit superparamagnetism, where individual particles act as single magnetic domains. Exchange Coupling: The nature and strength of exchange coupling between nanoparticles can significantly influence the magnetic properties of granular films. Weak coupling leads to independent magnetic behavior of particles, whereas strong coupling can induce collective magnetic states. Magnetic Anisotropy: Magnetic anisotropy in granular films arises from both shape anisotropy and crystalline anisotropy of the nanoparticles. The interplay between these anisotropies dictates the magnetization reversal processes and overall magnetic stability of the films.

IV. ELECTRON TRANSPORT PROPERTIES

The electron transport properties of granular films are intricately linked to their magnetic structure. Key mechanisms include: Tunneling Magnetoresistance (TMR): Electron tunneling between magnetic nanoparticles leads to TMR, which is sensitive to the relative orientation of their magnetizations. Giant Magnetoresistance [13] (GMR): In metallic granular films, spin-dependent scattering at interfaces can give rise to GMR [14]. Coulomb Blockade and Single-Electron Tunneling: At very small particle sizes and low temperatures, electron transport can be dominated by Coulomb blockade effects.

V. ELECTRON TRANSPORT PROPERTIES

Characterizing the magnetic and electron transport properties of granular films requires a range of experimental techniques: Magnetometry: Used to measure magnetic properties such as hysteresis loops and temperature-dependent magnetization. Transport Measurements: Techniques like four-point probe measurements and tunneling spectroscopy are employed to study electron transport phenomena. Microscopy and Spectroscopy: Electron microscopy and various spectroscopic methods provide insights into the structural and compositional characteristics of granular films.

VI. APPLICATIONS AND FUTURE DIRECTIONS

Granular films hold promise for various applications: Data Storage: The high density and stability of magnetic nanoparticles make granular films suitable for high-density magnetic storage media. Spintronics: The spin-dependent transport properties of granular films are critical for the development of spintronic devices such as magnetic sensors and memory elements. Sensors: The sensitivity of granular films to external magnetic fields can be leveraged in magnetic field sensing applications.

Future research in granular films is likely to focus on: Nanoengineering: Precise control over nanoparticle size, distribution, and matrix composition to tailor magnetic and electronic properties. Hybrid Materials: Combining granular films with other nanostructured materials to enhance performance and functionality. Advanced Characterization: Developing new techniques to probe the properties of granular films at the atomic scale.

VII. CONCLUSION

This review has provided a comprehensive analysis of the magnetic and electron transport properties of granular films, highlighting the significant influence of particle size, interparticle distance, and matrix composition. Granular films, characterized by magnetic nanoparticles dispersed within a non-magnetic matrix, exhibit unique magnetic and electronic behaviors due to their nanoscale structure. Granular films exhibit superparamagnetism when nanoparticles are sufficiently small, with magnetic properties significantly influenced by exchange coupling and magnetic anisotropy, while the electron transport in these films is governed by mechanisms such as Tunneling Magnetoresistance (TMR) and Giant Magnetoresistance (GMR), which are also influenced by the magnetic structure.

VIII. REFERENCES

[1] Garcia, N., & Muñoz, M. (2000). Magnetoresistance in granular films. Journal of Magnetism and Magnetic Materials, 203(1-3), 155-159.

[2] Papadopoulos L, Porter MA, Daniels KE, et al. Network analysis of particles and grains. J Complex Networks. 2018;6:485.

[3] Jaeger HM, Nagel SR, Behringer RP. The physics of granular materials. Phys Today. 1996;49:32.

[4] De Gennes PG. Granular matter: a tentative view. Rev. Mod. Phys. 1999;71:S374.

[5] Shpetnyi, I. O., Vorobiov, S. I., Kondrakhova, D. M., Shevchenko, M. S., Duplik, L. V., Panina, L. V., Luciński, T. (2020). Correlation between the structural state and magnetoresistive properties of granular Co Ag100-alloy thin films. Vacuum, 109329.

[6] W.Shih, *Phys. Rev.* 38, 2051 (1931).

[7] C.Elmore, *Phys. Rev.* 54, 309 (1938).

[8] C.Kittel, *Phys. Rev.* 70, 965 (1946).

[9] L. Neel, *C. R. Acad. Sci., Paris* 228, 664 (1949); L.Neel, *Ann. Geophys.* 5, 99 (1949).

[10] Shpetnyi, I. O., Protsenko, I. Y., Vorobiov, S. I., Grebinaha, V. I., Satrapinskyy, L., & Luciński, T. (2021). Influence of composition on the structural-phase state, electrophysical andmagnetotransport properties of alloy thin films based on Co and Cu.

[11] Shpetnyi, I. O., Vorobiov, S. I., Kondrakhova, D. M., Shevchenko, M. S., Duplik, L. V., Panina, L. V., Lucinski, T. (2020). Correlation between the structural state and magnetoresistive properties of granular Co Ag100-alloy.

[12] Natalia A. Grigoryeva,Victor Ukleev, Alexey A. Vorobiev, Alexander I. Stognij, Nikolay N. Novitskii,Leonid V. Lutsev and Sergey V. Grigoriev, Mesostructure and Magnetic Properties of SiO2-Co Granular Film on Silicon Substrate, Magnetochemistry 2022, 8(12), 167.

[13] Kulkarni, M., & Sahu, P. (2015). Tunneling magnetoresistance in granular films. Applied Physics Letters, 107(14), 142405.

[14] Ferton, J., & Dieny, B. (2003). Magnetic properties and GMR of granular films. Physical Review B, 67(9), 094433.

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