Correlation between Magnetoresistive Behavior, Dynamic Magnetic Properties, and Structural State of Granular Co-Ag Alloy Thin Films

Motivation

Granular magnetic thin films are of considerable interest for spintronic and nanoelectronic applications due to their distinctive magnetic and magnetotransport properties. Among these materials, Co–Ag alloys represent a model system in which ferromagnetic Co nanograins are distributed within a nonmagnetic Ag matrix. Their giant magnetoresistance (GMR) originates from spin-dependent scattering of conduction electrons at the interfaces between ferromagnetic granules and the nonmagnetic matrix, as well as within the granules themselves [1]. The magnetic state of such systems depends strongly on the size, spatial distribution, and interactions of Co granules. Ferromagnetic resonance (FMR) provides information on magnetic anisotropy, effective magnetic fields, and magnetization dynamics. Nevertheless, the relationship between the evolution of the granular structure, FMR characteristics, and temperature-dependent GMR in Co–Ag thin films remains insufficiently investigated.

Experiment

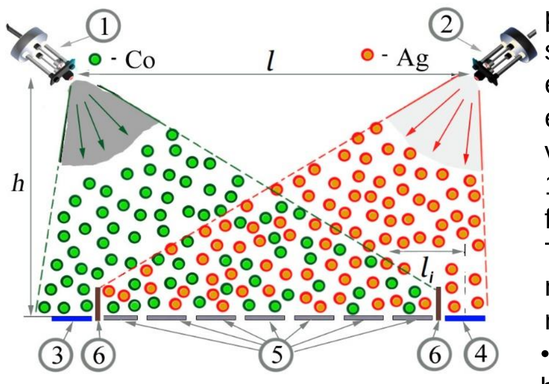


Fig. 1. Scheme for obtaining alloy thin films [2]

• Magnetoresistance was measured by the four-point probe method (I = 1mA) at 140, 290, 380, and 440 K in fields up to ±1.6 kOe.

Co_xAg_{100-x} alloy thin films (15 at.% ≤ x ≤ 75 at.%) were deposited at RT on polished sitall (glass-ceramic) substrates by simultaneous evaporation from two independent electron-beam sources in a high-vacuum chamber (base pressure ~ 10^{-4} Pa) (Fig. 1). All samples were fabricated in a single deposition cycle. They had the same thickness (d = 85 nm) but different Co-Ag concentration ratios.

• The film composition was determined by SEM (Tescan Lyra III) equipped with a Bruker EDX analyzer.

• The nanostructure and phase state were investigated using TEM-125K (125kV) and JEOL ARM 200F HRTEM.

• FMR measurements were performed using a Bruker Elexsys E500 spectrometer at 9.86 GHz.

Results and Discussion

• The maximum GMR was observed near x = 32 at.% Co at 290–440 K, shifting toward x = 26 at.% Co at 140 K.

• The maximum low-field GMR reached 1.26 % at 140 K (x = 26 at.% Co), while high-field measurements revealed ≈33% GMR at 5 K and 90 kOe.

• FMR measurements showed nearly isotropic resonance fields at x ≤ 26 at.% Co, followed by pronounced magnetic anisotropy with increasing Co concentration.

• The perpendicular FMR resonance field increased to ≈15 kOe at x = 75 at.% Co.

• The effective magnetization (M_{eff}), calculated using g = 2.15, increased from ≈10 to 933 emu/cm³ over x = 32–75 at.% Co.

• Combined TEM, FMR, and GMR results indicate increasing intergranular connectivity and magnetic interactions with Co concentration, accompanied by a reduction in GMR above its maximum.

TEM investigation of the structural-phase state of alloy thin films

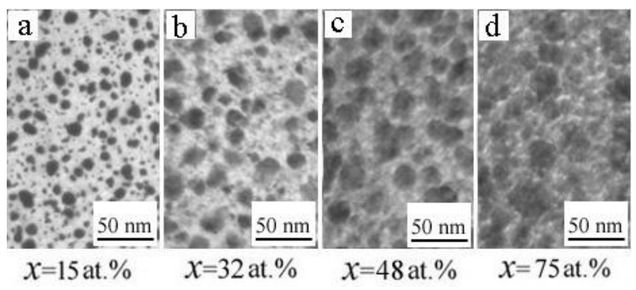


Fig. 2. TEM micrographs of as-deposited Co_xAg_{100-x} alloy thin films with various Co concentrations (x, at.%).

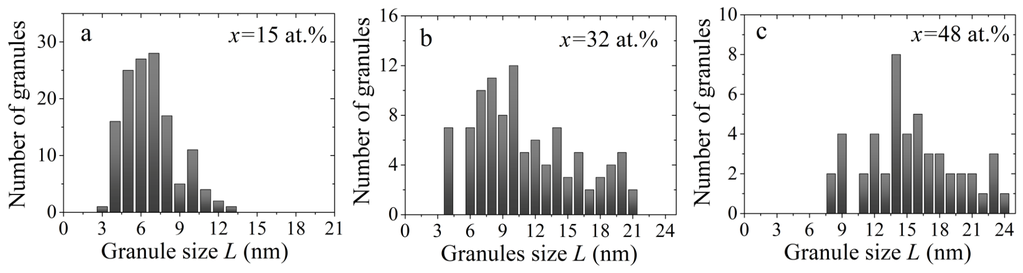


Fig. 3. Co-granule size distributions in as-deposited Co_xAg_{100-x} alloy thin films with Co concentrations of 15 (a), 32(b), and 48 at.% (c), determined from the TEM micrographs shown in Fig. 2.

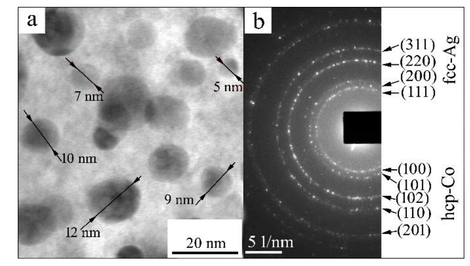


Fig. 4. TEM image (a) and selected-area electron diffraction (SAED) pattern (b) of a Co_xAg_{100-x} alloy thin film with a cobalt concentration of x = 32 at.%.

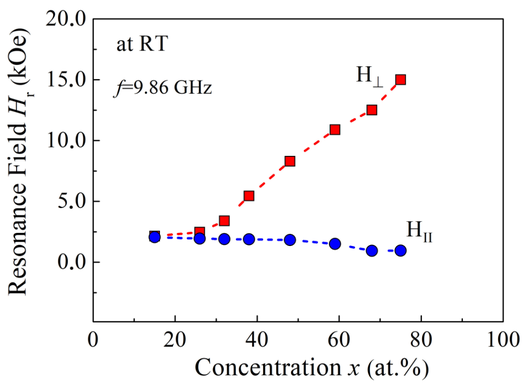


Fig. 5. Compositional dependence of the resonance fields for the parallel (blue circles) and perpendicular (red squares) orientation of the Co_xAg_{100-x} alloy thin films in the external magnetic field. The dashed lines are a guide to the eye.

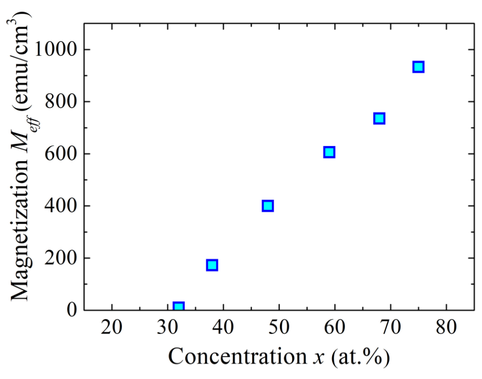


Fig. 6. Effective magnetization M_{eff} as a function of Co concentration x (at.%) in Co_xAg_{100-x} alloy thin films measured with the external magnetic field applied perpendicular to the film plane.

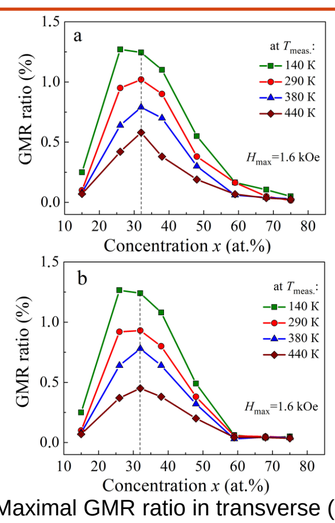


Fig. 7. Maximal GMR ratio in transverse (a) and longitudinal (b) geometries of granular Co_xAg_{100-x} alloy thin films as a function of Co concentration (x, at.%).

Acknowledgments

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References

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[2] I. Shpetnyy, S. Vorobiov, V. Komanicky, I. Iatsunskyi, V. Grebinaha, Yu.I. Gorobets, V. Tkachenko , P. Skokowski, T. Luciński, S. Jurga, *J. Magn. Magn. Mater.* **527,** 167762 (2021).

Conclusions

1. The GMR of Co_xAg_{100-x} granular films strongly depends on Co concentration and temperature. The GMR maximum occurs at x = 32 at.% Co (290–440 K) and shifts to x = 26 at.% Co at 140 K, reaching ≈ 1.26% at 1.6 kOe. Further increasing the Co concentration reduces GMR due to the development of a percolating Co network.
2. High-field measurements (H ≤ 90 kOe) for x = 26 at.% Co revealed GMR ≈ 33% at 5 K. The absence of MR saturation at 290 and 380 K is consistent with predominantly superparamagnetic behavior.
3. FMR measurements revealed nearly isotropic resonance behavior at x ≤ 26 at.% Co, indicating weak intergranular interactions. At x ≥ 32 at.% Co, increasing FMR anisotropy reflects stronger magnetic coupling and the formation of ferromagnetic clusters.
4. TEM/SAED confirmed a two-phase granular structure consisting of hcp-Co embedded in an fcc-Ag matrix. Increasing Co concentration promotes grain growth and coalescence.
5. Combined TEM, FMR, and magnetotransport results establish a correlation between structural evolution, magnetic interactions, and GMR, revealing a gradual transition from weakly interacting Co granules to magnetically coupled clusters and a percolating Co network.

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