FeCo-based nano-granular films with ultra-high resistivity for sub-GHz magnetics-on-silicon

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Nanogranular soft magnetic thin films with high resistivity are crucial for next-generation power and RF applications, where minimizing losses is more critical than achieving high permeability. In this work, we demonstrate a sputtered FeCoX (X: B and/or N) nano-granular thin-film core with isotropic in-plane properties, achieving a permeability of ~5 and a high resistivity exceeding 3000 μΩ·cm—more than 30× higher than conventional CoZrTa films. This combination enables significant reduction in eddy current losses, making the films ideal for sub-GHz-range integrated power inductors, GHz-range electromagnetic interference (EMI) suppressors, and for CMOS-compatible magnetic-core RF inductors. The combination of high ferromagnetic resonance (FMR) frequency, ultra-high electrical resistivity, and high saturation flux density of this FeCo-based nanogranular films highlight its potential in achieving efficient, miniaturized, and monolithic magnetics solutions for various RF and power electronic applications.

Keywords: Nano-granular thin film; integrated inductors; High resistivity; GHz magnetics-on-silicon.

1. Introduction

Integrated inductors, essential for sub-GHz-range power conversion, RF circuits, and electromagnetic interference (EMI) suppression, require materials with low core loss, high resistivity, and controlled permeability to ensure efficiency and scalability. However, conventional magnetic thin films, such as CoZrTa and permalloy, suffer from high eddy current losses due to their relatively low resistivity (<100 μΩ·cm), limiting their effectiveness at 100s of MHz and at GHz frequencies.

To overcome these limitations, researchers have explored nanogranular magnetic films to achieve high resistivity while achieving sufficiently high permeability. For instance, FeCo-based nanogranular films with oxide or nitride additions have demonstrated resistivity enhancements up to several thousand μΩ·cm, reducing losses at high frequencies. Similarly, CoFe-dielectric [2, 3] composites have been developed to suppress eddy currents in GHz frequency applications – establishing the importance of high-resistivity films.

In this work, we developed sputtered FeCoX (X: B and/or N) thin films exhibiting permeability of ~5 and an ultra-high resistivity of ~3000 μΩ·cm, making them ideal for integrated inductor in 100s of MHz and for EMI shielding in GHz frequencies. By precisely tuning sputtering pressure and power, we controled the nanostructure, and thus electrical resistivity while maintaining sufficient soft magnetic properties.

2. Results and discussion

By optimizing sputtering pressure, we achieved a significant enhancement in electrical resistivity. Increasing the pressure from 5 mTorr to 10 mTorr led to a resistivity rise from 1850 μΩ·cm to 3000 μΩ·cm (see Fig. 1). This parameter adjustment was guided by our previous findings on sputtering power, where a reduction in power transformed the film from an amorphous, uniaxial state to a nanogranular, isotropic structure—reducing permeability from hundreds to 5 and drastically increasing the electrical resistivity. Then COMSOL sheet resistivity modeling was used to study the most influential physical parameters on resistance.

The films exhibit isotropic behavior across the range of sputter pressures, with permeability decreasing from 8 to 4.5 as pressure increases from 5 mTorr to 10 mTorr (see Figure 2). Higher sputter pressure reduces the energy of deposited atoms, leading to less dense films with increased structural defects, which hinder domain formation and suppress permeability. To further investigate this behavior, LLG simulations were performed, revealing that the reduced permeability is primarily driven by increased magnetization dispersion induced by the nanogranular structure. Additionally, as sputter pressure increases, the ferromagnetic resonance (FMR) frequency approaches 1 GHz, but the FMR peak broadens, suggesting enhanced damping and magnetic relaxation due to increased defect density and grain boundary effects. This trade-off, with reduced permeability and increased resistivity, makes the films better suited for high-frequency applications where minimizing eddy current losses is more critical, such as in GHz-range integrated inductors, RF circuits, and EMI suppression.

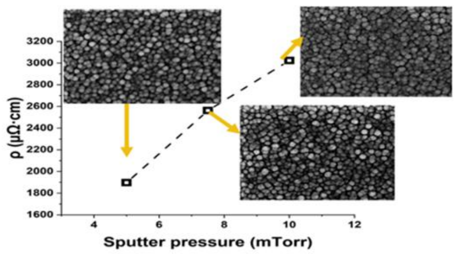

Figure 1: Sheet resistivity of samples deposited at different sputter pressure. The inserts are the SEM top view of the samples.

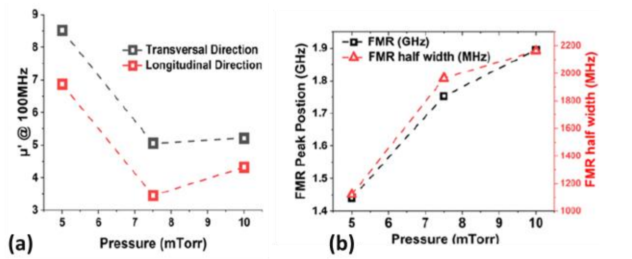

Figure 2: a) the permeability of the thin films along two in-plane orthogonal directions. b) the FMR peak position over sputter pressure.

References

[1] Y. Wang et al., *J. Alloys Compd.*, Vol. 667, pp. 229, 2016.
[2] G. Lu et al., *Chinese Phys. Lett.* Vol. **27**, pp. 097501, 2010.
[3] B. Zhang et al., *App. Phys. A*, Vol. 97, pp. 657, 2009.

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