Substrate and Thickness Effects on $Fe_{70}Ga_{30}$ Thin Films for SAW-Based Applications

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$Fe_{70}Ga_{30}$ thin films were deposited on Si/SiO_2, $LiNbO_3$, and PMN-Pt substrates to investigate the influence of substrate-induced strain and thickness (50–200 nm) on structural, morphological, and magnetic properties. Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) were performed to study surface properties, while Alternating Gradient Force Magnetometry (AGFM) was performed to examine the volumetric magnetic properties. Domain structures were evaluated with Magnetic Force Microscopy (MFM) and Magneto-Optical Kerr Effect (MOKE) measurements. The results showed that piezoelectric substrates induce strain-mediated interactions despite improvements in thickness to roughness and coercivity. The results illustrate how substrate engineering could be used to tune magnetoelectric coupling for Surface Acoustic Wave (SAW)-based sensor applications.

Keywords: Magnetoelectric coupling (ME); Morphology; Thickness; Piezoelectric substrates; SAW devices

1. Introduction

The magnetostrictive materials have been highly appealing in recent decades for developing next-generation low-power biomedical and electronic devices for their coupling of mechanical strain with magnetization and magnetoelastic effects [1]. The Fe-Ga alloy family (Galfenol) is found as a rare-earth-free alternative magnetostrictive material with magnetostriction (up to 350 ppm) and good mechanical properties [2]. The integration of $Fe_{70}Ga_{30}$ thin films with piezoelectric substrates allows the study of magnetoelectric coupling (ME) and magnetoelastic coupling (MEL) in hybrid devices. The controlling of ME and MEL couplings, along with piezoelectric interactions, will establish new opportunities for developing reconfigurable hybrid sensors and multifunctional devices that could benefit spintronics technology and sensor applications [3]. However, precise control of $Fe_{70}Ga_{30}$ thin film properties by deposition parameters, thickness, substrate effects, and morphology is required to achieve high-performance devices. This work explores a comparative study of the $Fe_{70}Ga_{30}$ thin film deposited on different substrates such as Si/SiO_2, $LiNbO_3$, and PMN-Pt, and investigates the influence on morphological, structural, and magnetic properties. Research outcomes will lead to finding superior configurations for Surface Acoustic Wave (SAW)-based sensor applications with high sensitivity.

2. Results and discussion

$Fe_{70}Ga_{30}$ thin films were deposited on Si/SiO_2, $LiNbO_3$, and PMN-PT substrates by RF sputtering with thicknesses ranging from 50 nm to 200 nm. The samples were characterised with SEM, AFM, AGFM, MFM, and MOKE.

To improve sputtering conditions and examine property variations with thickness, Si/SiO_2 was initially employed as a substrate. This served as a reference for subsequent samples deposited on piezoelectric substrates.

Surface morphology and grain analysis were performed using SEM and AFM. SEM analysis revealed that film roughness and columnar development increased with thickness, and AFM investigation confirmed that surface roughness increased.

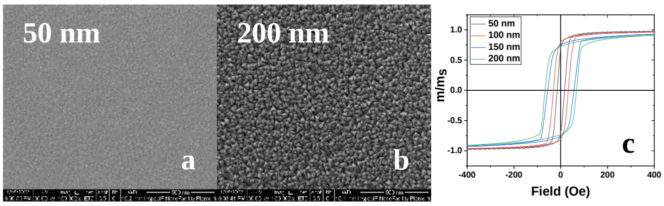

Figure 1. SEM images of $Fe_{70}Ga_{30}$ on Si/SiO_2 substrate with the thickness (a) 50 nm and (b) 200 nm, (c) Hysteresis loops at room temperature

Magnetic properties at room temperature were studied with AGFM, MFM, and MOKE measurements, and the results have shown the relationship between magnetic behaviours and thickness. AGFM results revealed coercivity increases with thickness which can be attributed to the pinning effect, raised due to more voids, defects, and grain boundaries in a thicker film. MOKE and MFM measurements were further investigated to analyse the domain structure of $Fe_{70}Ga_{30}$.

The systematic comparison of different substrates Si/SiO_2, $LiNbO_3$, and PMN-Pt, where the effect of strain and electromechanical coupling on $Fe_{70}Ga_{30}$ was evaluated. The substrate-induced strain leads to substantial modifications in $Fe_{70}Ga_{30}$ film characteristics, including microstructure, domain patterns, and magnetic properties, and directly impacts magnetoelectric coupling. This strain engineering in $Fe_{70}Ga_{30}$ opens new opportunities for SAW-based sensors and reconfigurable magnetoelectric devices for low-power sensing applications.

References

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