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# Structural, magneto-static and magneto-dynamic properties of Fe substituted Ni-Mn-In films

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**Abstract**

Off-stoichiometric Ni-Mn-In films of 500 nm thickness were deposited on Si (100) substrate by dc magnetron sputtering at ambient temperature. As-deposited films were annealed *ex situ* at 550 °C and 700 °C for 1 h under high vacuum. As-deposited Ni-Mn-In films which were amorphous, exhibited orthorhombic martensite structure upon annealing. The amorphous film was found to be paramagnetic whereas the annealed (martensite) film exhibited weak ferromagnetic behavior. Fe substituted Ni-Mn-In films of the same thickness annealed at 550 °C exhibited orthorhombic martensite structure, whereas films annealed at 700 °C exhibited dual phase (cubic $L2_1$ austenite and orthorhombic martensite) structure. Martensite Ni-Mn-Fe-In films showed large magnetic moment as compared to the ternary alloy film. Interestingly, films with dual phase structure yielded much higher magnetic moment. Ni-Mn-Fe-In films with higher thicknesses annealed at 700 °C showed enhanced magnetic moment due to higher $L2_1$ phase content in them. Analysis of polar angle variation of resonance field and linewidth of the dual phase Ni-Mn-Fe-In films revealed very low effective perpendicular magnetic anisotropy ($3.0 \times 10^3$ J/m$^3$) and low Gilbert damping constant (0.009 ± 0.001) for the first time. The new results obtained are interpreted in terms of the crystalline nature of the films.

*Key words:* Heusler alloy films, Martensite and austenite structures, Magnetic anisotropy, Ferromagnetic resonance, Gilbert damping constant.

## 1. INTRODUCTION

During the last few decades, the ferromagnetic full Heusler $Ni_2MnZ$ (where Z = Ga, Sn, In, Sb) alloys have drawn significant attention because of their potential applications in spintronics, magnetic refrigeration systems, and magneto-mechanical devices such as actuators and transducers for future technological developments [1–4]. Among these, Ni–Mn–In alloys stand out owing to their multifunctional properties such as giant magneto-caloric effect [5], magneto-resistance [5,6], magnetic field induced strain [7] and magnetic shape memory effect [8]. Though, bulk Ni-Mn-In alloys have been well studied, the physics of these magnetic materials in the nanoscale has been an active subject of research in recent years. Recent studies on Ni-Mn-In thin films has been revealed the presence of martensitic phase transitions in these alloy, making them suitable for fabricating magnetic cooling devices [9–12]. There are also some reports on substitution of a fourth element such as Si, Co, and Cr in the ternary Ni–Mn–In alloy films.

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