Chemical ordering, anisotropy, and (non)linear spin waves in epitaxial Co_2MnSi Heusler waveguides – Perspectives for robust half-metal magnonics at the nanoscale

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We present a perspective for versatile nanoscale half-metal magnonics based on epitaxial Co_2MnSi. Combining 100% spin polarisation with record-low Gilbert damping [1], this half-metallic Heusler compound exhibits a unique set of material properties for hybrid magnonic-spintronic applications. We demonstrate nanoscale robustness and nonlinear functionality in a comprehensive study [2] spanning from thin film growth to magnetisation dynamics in patterned magnonic devices.

Epitaxial, $L2_1$-ordered Co_2MnSi thin films of $20\,\mathrm{nm}$ thickness are grown by molecular beam epitaxy. The critical impact of nanofabrication [3] is assessed by transmission electron microscopy, confirming structural integrity and robust chemical ordering in the nanostructures (Fig1.a). The associated key parameters are quantified by magnetometry and ferromagnetic resonance spectroscopy. We identify an intrinsic cubic magnetocrystalline anisotropy with first- and second-order energy contributions. This anisotropy stabilises an alignment along the crystal $\langle 110 \rangle$ directions (Fig1.b), enabling high group velocities and propagation lengths associated with the large magnetisation $M_s \approx 1000\,^{\mathrm{kA}}/_{\mathrm{m}}$ and low Gilbert damping $\alpha \leq 10^{-3}$ even towards vanishing bias fields. We investigate the anisotropy impact on the spin wave dynamics by microfocused Brillouin light scattering spectroscopy (µBLS) on the patterned Co_2MnSi waveguides (Fig1.c). In the nonlinear regime, an anisotropy-induced first-order instability suppression range extending over several GHz is confirmed (Fig1.d). The µBLS investigations further reveal various nonlinear features, including a significant nonlinear frequency shift and the generation of higher harmonics, appearing at low threshold powers $P \leq 0.1\mathrm{mW}$ linked to the low Gilbert damping in the half-metallic Heusler compound. Our results establish epitaxial Co_2MnSi as a robust and scalable platform for half-metal magnonics, opening perspectives particularly towards hybrid nonlinear computing applications with reconfigurable interconnectivity.

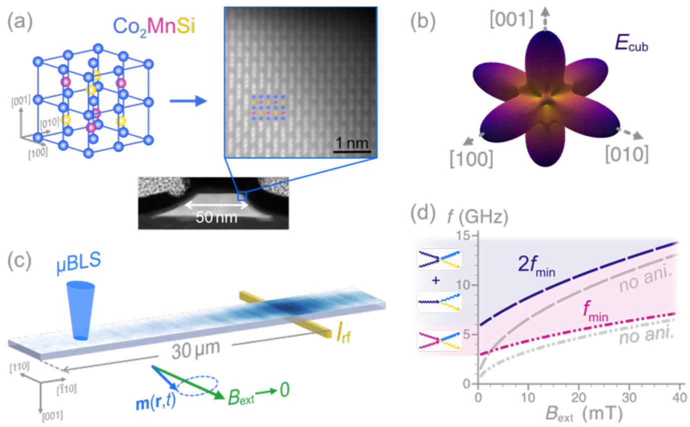

Fig. 1. (a) The $L2_1$-ordered Heusler crystal structure evidenced in the nanofabricated waveguides by scanning transmission electron microscopy.
(b) The intrinsic cubic magnetocrystalline energy favours an alignment along $\langle 110 \rangle$.
(c) Schematic of the µBLS experiments on patterned Co_2MnSi waveguides detecting propagation over tens of microns even towards zero bias field.
(d) Anisotropy-induced upshift of the dispersion minimum f_{min} yields an instability suppression range over several GHz.

[1] C. Guillemard, et al., *Ultralow magnetic damping in Co_2Mn-based Heusler compounds: Promising materials for spintronics*, Physical Review Applied **11**, 064009 (2019).
[2] A.M. Friedel, *Heusler compounds for magnonic and spintronic applications*. PhD thesis. RPTU Kaiserslautern-Landau, Kaiserslautern, Germany, and Université de Lorraine, Nancy, France. DOI: 10.26204/KLUEDO/9537 (2026).
[3] S. Mantion and N. Biziere, *Influence of Ga+ milling on the spin waves modes in a Co_2MnSi Heusler magnonic crystal*, Journal of Applied Physics **131**, 113905 (2022).