# Switching of Magnetization in Strained Noncollinear Antiferromagnet $Mn_3Sn$

B. Pruckner*, W. Goes‡, S. Selberherr†, and V. Sverdlov*†
* Christian Doppler Laboratory for Nonvolatile Magnetoresistive Memory and Logic, at the
† Institute for Microelectronics, TU Wien, Gußhausstraße 27-29, A-1040 Wien, Austria
‡ Silvaco Europe Ltd., Compass Point, St Ives, PE27 5JL, Cambridge, United Kingdom
e-mail: pruckner@iue.tuwien.ac.at

Noncollinear antiferromagnets (nc-AFM) have been studied for their potential use as spin-polarizing layer in Spin-Orbit Torque Magnetoresistive Random Access Memory (SOT-MRAM) devices [1]. Experimentally shown SOT-induced magnetization switching of the nc-AFM $Mn_3Sn$ between two distinct magnetic states, proves the potential of these materials to be also utilized as free magnetic layer in MRAM devices [2,3]. We study the magnetic behavior of the nc-AFM $Mn_3Sn$. Fig. 1a shows the structure of the Mn and Sn atoms, arrange in a two-dimensional Kagome lattice [2,3,4], with the Mn atoms carrying the magnetic moments $\mathbf{m_A}$, $\mathbf{m_B}$ and $\mathbf{m_C}$. The energy of the system is comprised of the interlayer and intralayer antiferromagnetic exchange energies acting between the Mn nearest neighbors, with $J_1 = 23.15$ meV and $J_2 = 17.53$ meV, the single-atom anisotropy $K = 0.19$ meV acting along $\mathbf{e_A}$, $\mathbf{e_B}$, $\mathbf{e_C}$, and the Dzyaloshinskii–Moriya-interaction $D = 0.833$ meV acting along $\mathbf{e_D} = \mathbf{e_y}$ [2]. When introducing epitaxial tensile strain, as shown in Fig. 1b, additional energy contributions arise: the modulated exchange energies $J_1 * (1 - \delta)$ and $J_2 * (1 - \delta)$, with the parameter $\delta$ accounting for the change in distance between two nearest neighbor Mn atoms, and a global uniaxial strain-induced anisotropy $K_{strain}$, caused by the displacement of Sn atoms neighboring the Mn atoms. The crystal symmetry of the unstrained Kagome lattice is broken, introducing a small net magnetic moment $\mathbf{m_{net}}$, as depicted in Fig. 1c. Fig. 2 shows the energy of the system over the polar angle of $\mathbf{m_{net}}$ from the z-axis and various strain strengths indicated with the $\delta$ parameter. With increasing strain we observe a six-, four-, and twofold energy of the system. At high strain only the two distinct stable states remain, with $\mathbf{m_{net}}$ pointing along positive or negative z-direction Fig. 1c shows the stable 'up' state with high strain.

Applying an external magnetic field along x-direction shifts the energy barriers, through the contribution of $\mathbf{m_{net}}$ to the energy, as depicted in Fig. 3. We show that the shifted energy barriers facilitate deterministic switching making the nc-AFM $Mn_3Sn$ a potential candidate for the use as magnetic memory. We reduce the 6-spin model to an effective 3-spin model without neglecting interlayer nearest neighbor effects. We apply SOT-induced current generated in an adjacent Pt heavy metal layer and solve the coupled Landau-Lifshitz-Gilbert (LLG) equations for our system. We calculate the octupolmoment $\mathbf{m_{oct}} = \frac{1}{3}\left[\mathbf{M_{xy}}\mathbf{m_A} + \mathbf{R}\left(\frac{-2\pi}{3}\right)\mathbf{m_B} + \mathbf{R}\left(\frac{2\pi}{3}\right)\mathbf{m_C}\right]$ used as order parameter in nc-AFM materials [3].

Fig. 4 shows $\mathbf{m_{oct}}$, $\mathbf{m_{net}}$, and the energy, when an SOT-current in x-direction is applied. Fig. 4a shows the system without applied external field, Fig. 4b and Fig. 4c for an external field of $H_{ext,x} = 0.05$ T and $H_{ext,x} = 0.1$ T, respectively. A variation of the absolute value of $\mathbf{m_{net}}$ proportional to the energy is shown. The description of the system by an effective 1-Spin-LLG using the octupolmoment has been suggested [4]. However, as $\mathbf{m_{net}}$ is neglected, dynamic processes cannot be captured to a full extent, therefor a careful consideration of the energy of $\mathbf{m_{net}}$ and $\mathbf{m_{oct}}$ is necessary.

## References

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[3] J.-Y. Yoon et al. Nat.Mat. 22, 1106, 2023
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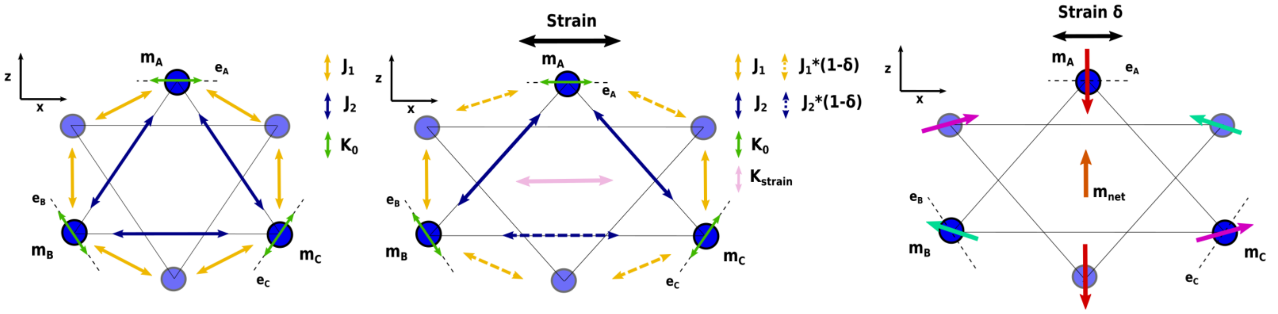


Fig. 1. Kagome lattice of the nc-AFM $Mn_3Sn$ without (left) and with (center) tensile strain applied to the crystal lattice. (Right) The magnetic moments of the sublattices. In a strained state, a small nonzero net-magnetization $\mathbf{m_{net}}$ emerges.

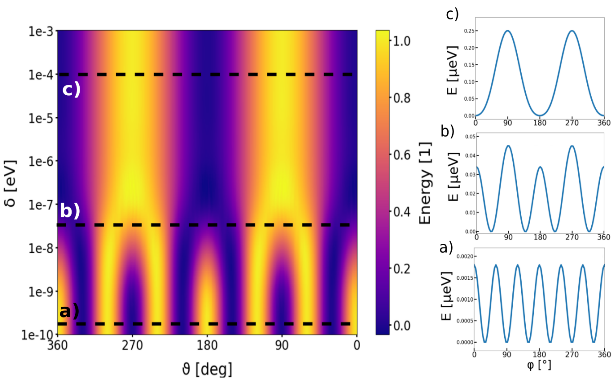


Fig. 2. The normalized energy for various applied strain values. For no and very small strains a sixfold energy profile can be observed (a). Increasing the strain leads to a fourfold (b) and twofold (c) energy profile.

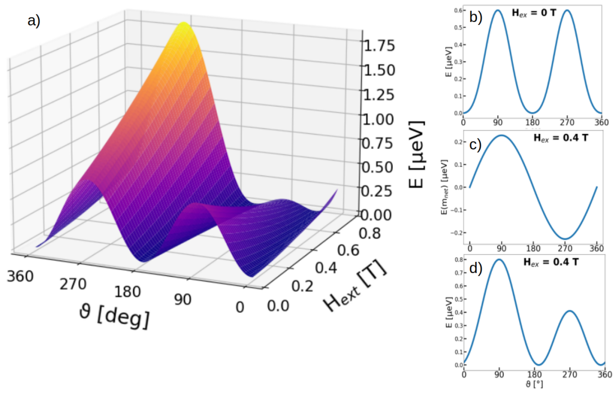


Fig. 4. a) The energy of the system over the polar angle of $\mathbf{m_{net}}$ with an external field applied along x-direction. (Right) The energy for b) no applied field, the energy of $\mathbf{m_{net}}$ in a field of $H_{ext,x} = 0.4T$, and the total energy for $H_{ext,x} = 0.4T$.

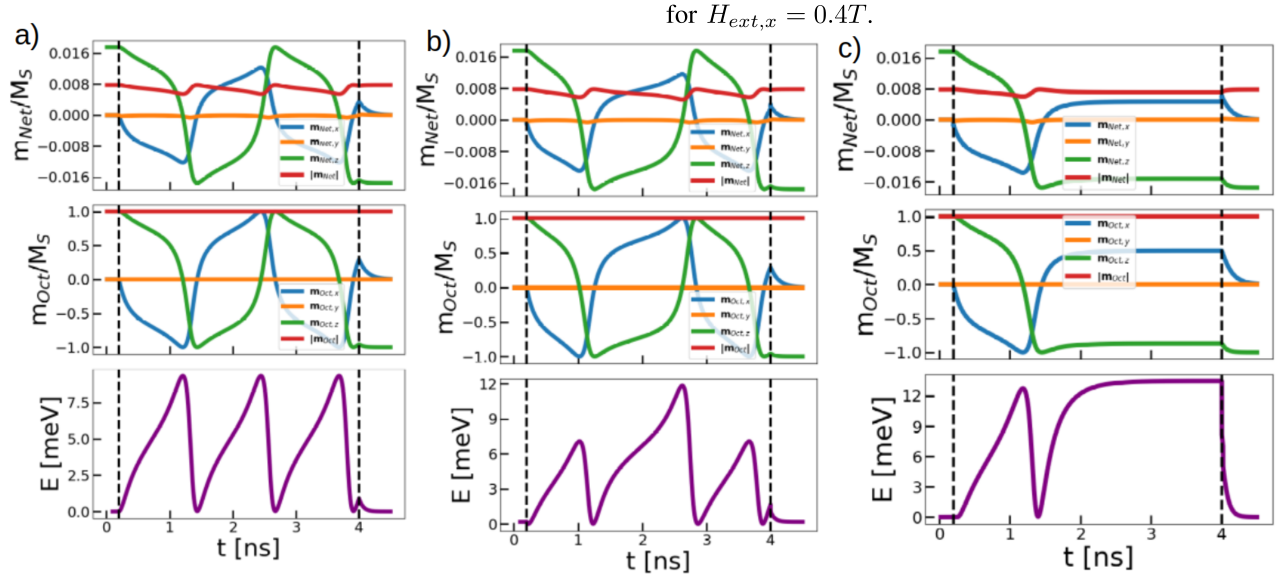


Fig. 3. $\mathbf{m_{net}}$, $\mathbf{m_{oct}}$, and the energy of the system displayed for an applied SOT-current of $9 * 10^{11}$ A/m² in x-direction. a) $H_{ext,x} = 0$ T, b) $H_{ext,x} = 0.05$ T, c) $H_{ext,x} = 0.1$ T. $M_S$ is calculated to $1.5 * 10^6$ A/m by using the crystal parameters in [1].