

Supplementary information

Figure S1 shows the surface morphology of the 34 nm Mn_3SnN (110) film, indicating that the whole film is continuous and smooth. The average surface roughness Ra is 0.199 nm.

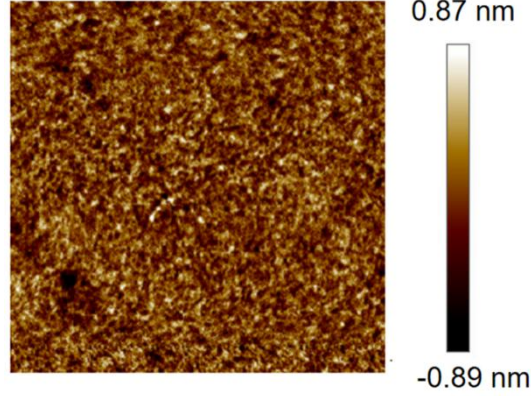


Fig. S1 Surface morphology of the film with an area of $2\ \mu\text{m} \times 2\ \mu\text{m}$.

Figure S2 shows the magnetic property of the 34 nm Mn_3SnN film after subtracting the diamagnetic background of the MgO substrate at 300 K. The film shows a small magnetization of $\sim 16000\ \text{A/m}$, which is also discovered in other noncollinear AFM films^{S1-S5}.

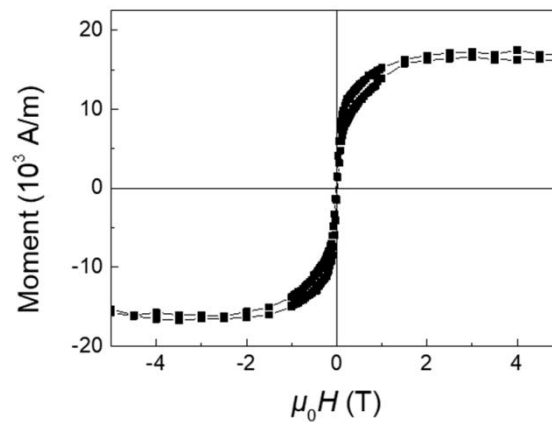


Fig. S2 Magnetization hysteresis loops of 34 nm Mn_3SnN (110) film deposited on MgO (110) substrate without diamagnetic background from the substrate. Out-of-plane magnetic field was applied at 300 K.

Figure S3 shows the ST-FMR measurement of (001)-oriented Mn_3SnN (16 nm)/Py(12 nm) sample at room temperature, where the magnetic mirror plane is represented by the dashed black line. When the current I is applied along the [100] or [010] directions (shown in Figs. S3a and S3d, respectively), which has parallel component to the cluster magnetic octupole moment, we can observe apparent ST-FMR signals from σ_z in Figs. S3b, S3c, S3e and S3f. For the case in Fig. S3a, the antidamping and field-like spin torque ratios of σ_z , $\theta_{\text{AD},z}$ and $\theta_{\text{FL},z}$ are 0.017 ± 0.001 and 0.090 ± 0.003 , respectively. For the case in Fig. S3d, the antidamping and field-like spin torque ratios of σ_z , $\theta_{\text{AD},z}$ and $\theta_{\text{FL},z}$ are 0.019 ± 0.002 and 0.123 ± 0.006 , respectively, comparable to the values of the case in Fig. S3a. Note that the values of the extracted torque induced by σ_z is also close to that of (001)-orientated Mn_3GaN , where $\theta_{\text{AD},z}$ and $\theta_{\text{FL},z}$ are 0.019 and 0.15, respectively^{S6}.

Differently, for the case in Fig. S3g, where the current is applied perpendicular to the cluster magnetic octupole moment, the antidamping and field-like spin torque ratios of σ_z , $\theta_{\text{AD},z}$ and $\theta_{\text{FL},z}$ are 0.001 ± 0.001 and 0.016 ± 0.004 , respectively, much smaller than that of Figs. S3a and S3d. A quite weak σ_z still exists, which may be caused by the slight misalignment of the device or/and the imperfect growth of the film. In a word, the ST-FMR results of (001)-oriented Mn_3SnN also support our conclusions in the main text.

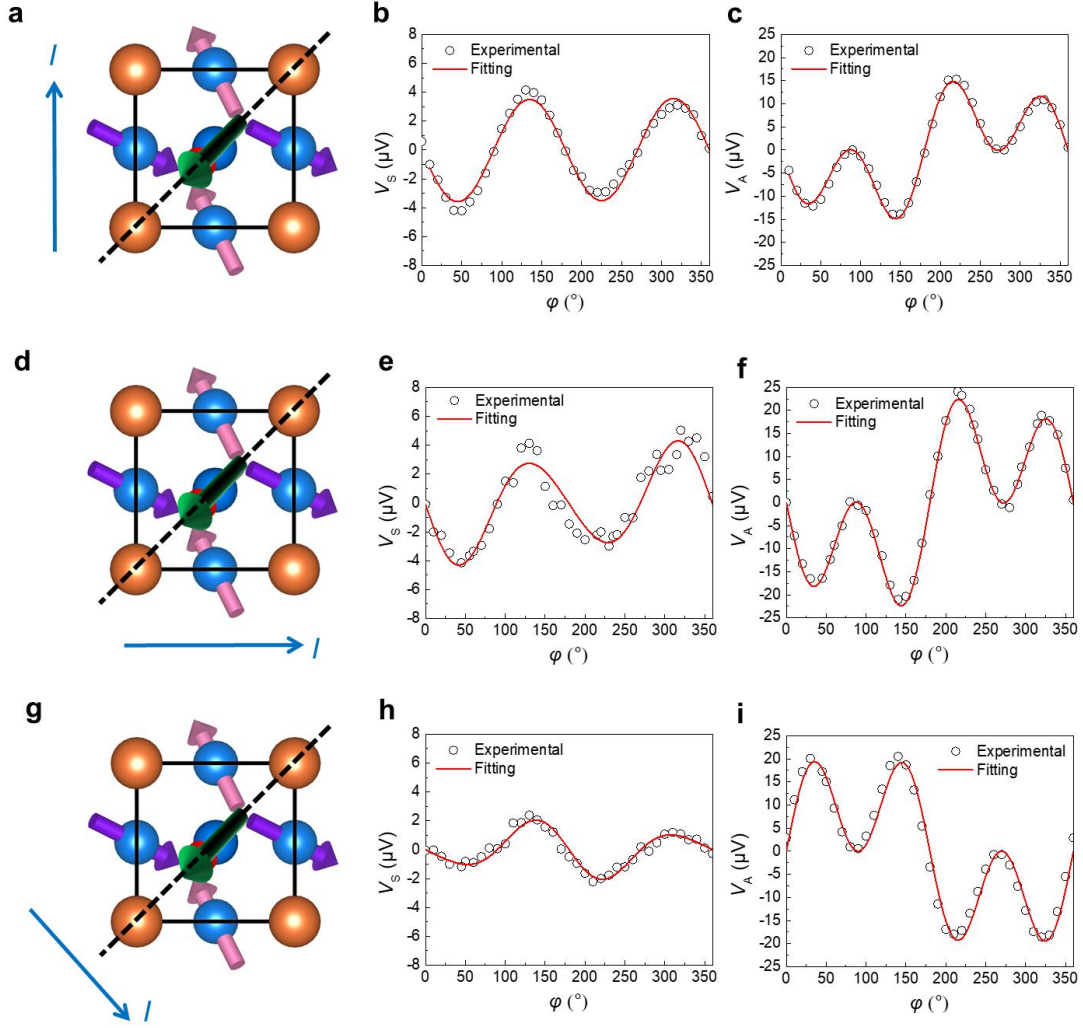


Fig. S3 ST-FMR measurement of (001)-oriented $\text{Mn}_3\text{SnN}/\text{Py}$ sample at room temperature. **a** Schematic diagram of magnetic structure and current direction, where the magnetic mirror plane is represented by the dashed black line. The current is applied along the $[100]$ -direction. Angular dependence of line shape amplitude of ST-FMR signals for **b** symmetric and **c** antisymmetric signal in $\text{Mn}_3\text{SnN}/\text{Py}$ structure. **d** Schematic diagram for the case when the current is applied along the $[010]$ direction. Angular dependence of line shape amplitude of ST-FMR signals for **e** symmetric and **f** antisymmetric signal in the same sample. **g** Schematic diagram for the case when the current direction is perpendicular to the cluster magnetic octupole moment. Angular dependence of line shape amplitude of ST-FMR signals for **h** symmetric and **i** antisymmetric signal in the same sample.

Figure S4 displays the ST-FMR measurement of the (110)-oriented $\text{Mn}_3\text{SnN}/\text{Py}$ sample at 380 K (the highest of our equipment). We can see that σ_z still exists since 380 K is lower than the Néel temperature (475 K) of Mn_3SnN . The antidamping and field-like spin torque ratios of σ_z , $\theta_{\text{AD},z}$ and $\theta_{\text{FL},z}$ at 380 K are 0.003 ± 0.001 and 0.018 ± 0.003 , respectively, smaller than the values at room temperature. The existence of σ_z but with smaller spin torque ratios supports σ_z is related to the magnetic configuration (the cluster magnetic octupole).

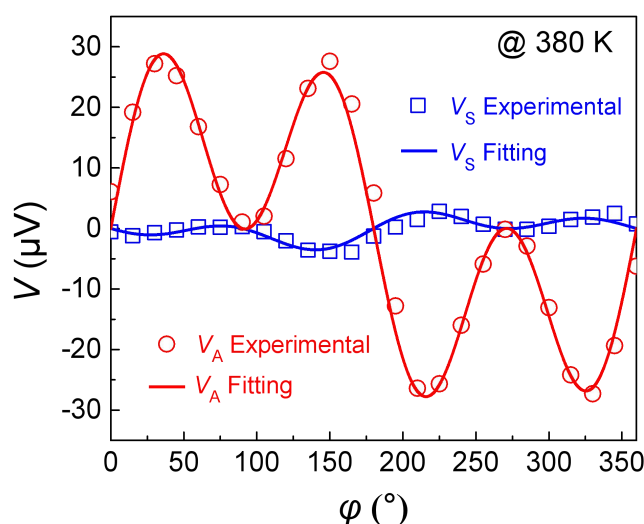


Fig. S4 ST-FMR measurement of the (110)-oriented $\text{Mn}_3\text{SnN}/\text{Py}$ sample at 380 K. The blue or red curve represents the angular dependence of line shape amplitude of ST-FMR signals for symmetric or antisymmetric signal, respectively.

Figure S5 shows the measurement configuration of the resistivity of Mn_3SnN and $\text{Mn}_3\text{SnN}/(\text{Co}/\text{Pd})_3$ samples at room temperature. The resistivity of Mn_3SnN film deposited on the MgO substrate is $913.1 \pm 0.2 \mu\Omega \text{ cm}$ and the resistivity of $(\text{Co}/\text{Pd})_3$

multilayer is $74.8 \pm 0.1 \mu\Omega \text{ cm}$ based on the simple parallel resistance formula. Then the current density to achieve the field-free SOT switching is estimated to be $\sim 9 \times 10^6 \text{ A cm}^{-2}$, taking the film thickness of $\text{Mn}_3\text{SnN}(12 \text{ nm})/(\text{Co}(0.4 \text{ nm})/\text{Pd}(0.8 \text{ nm}))_3$ sample, the channel width of $5 \mu\text{m}$ and the average critical switching current of $\sim 28 \text{ mA}$ into account.

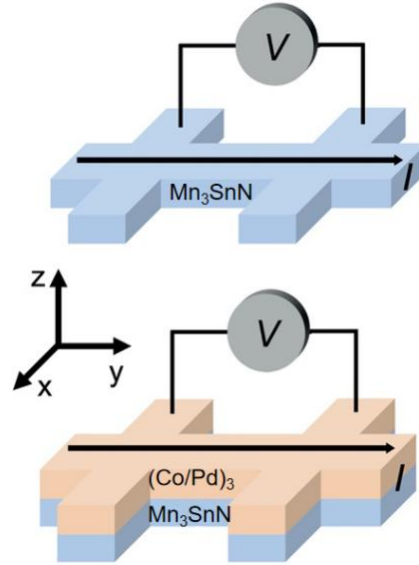


Fig. S5 Measurement configuration of the resistivity of Mn_3SnN and $\text{Mn}_3\text{SnN}/(\text{Co/Pd})_3$ at room temperature.

Figure S6 illustrates typical field-free SOT switching for 10 times. Remarkably, the SOT switching does not decline after 10 cycles, revealing the robustness of our device.

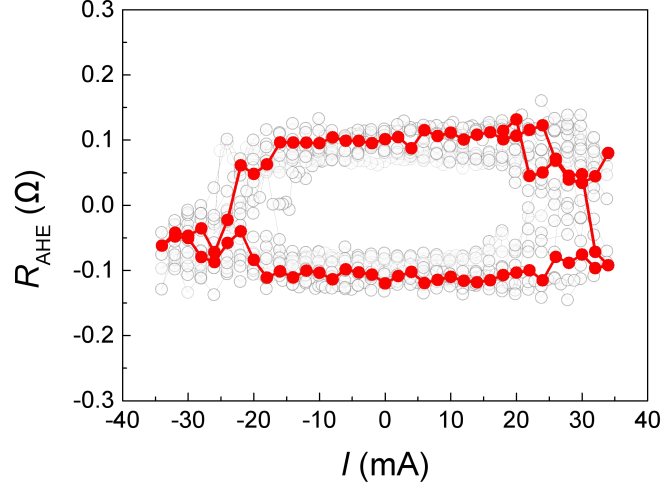


Fig. S6 Field-free SOT switching of 10 cycles. The red one is the same loop in Fig. 4c.

Figure S7 shows the in-plane M - H curve of $\text{Mn}_3\text{SnN}(12 \text{ nm})/(\text{Co}(0.4 \text{ nm})/\text{Pd}(0.8 \text{ nm}))_3$ sample we use to realize the field-free SOT switching. We can see that there is no exchange bias at room temperature, revealing that the field-free switching is irrelevant to the exchange bias.

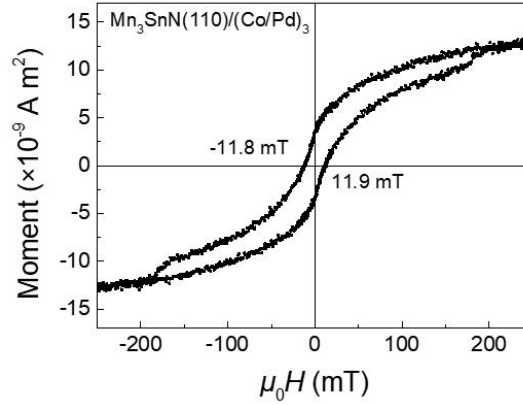


Fig. S7 In-plane hysteresis loop of $\text{Mn}_3\text{SnN}(12 \text{ nm})/(\text{Co}(0.4 \text{ nm})/\text{Pd}(0.8 \text{ nm}))_3$ at room room temperature.

Figure S8 exhibits the R_{AHE} relationship with different pulse current I along the $[001]$ direction under a large magnetic field of 500 mT along the same direction as I

(Fig. S8a), which is larger than the anisotropy field of the Co/Pd multilayer (Fig. S8b). We observe that there is no switching signal under 500 mT, showing that the variation of anomalous Hall resistance is not triggered by the thermal effects caused by the pulse current.

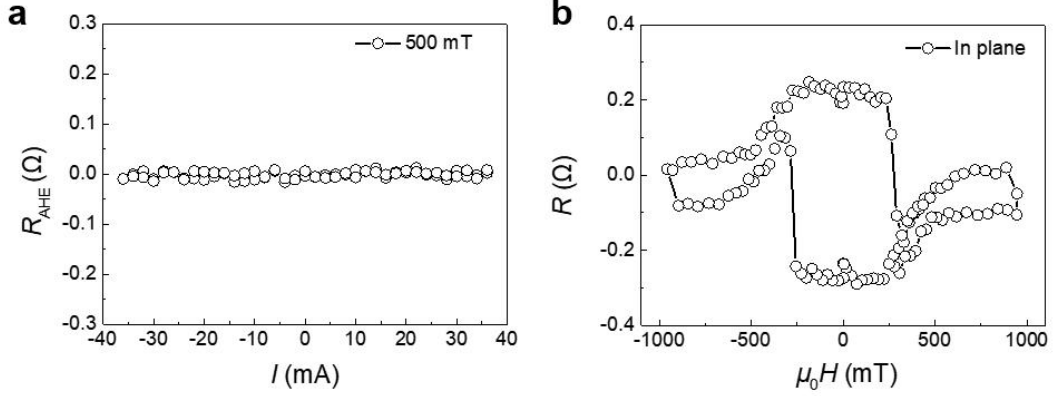


Fig. S8 **a** R_{AHE} relationship with different pulse current I when a large magnetic field of 500 mT is applied along the same direction (the [001] direction) as I . **b** R - H curve recorded with an in-plane magnetic field.

Table S1 makes a comparison of the antidamping and field-like spin torque ratios of σ_z , $\theta_{\text{AD},z}$ and $\theta_{\text{FL},z}$, for the present Mn_3SnN and three typical materials with σ_z , e.g., Mn_3GaN ^{S6}, WTe_2 ^{S7} and MnPd_3 ^{S8}. Although $\theta_{\text{AD},z}$ of Mn_3SnN is smaller than that of other three materials, $\theta_{\text{FL},z}$ of Mn_3SnN is larger than that of WTe_2 and MnPd_3 , reflecting that in $\text{Mn}_3\text{SnN}/\text{Py}$ system, the out-of-plane spin polarization σ_z mainly contributes to the field-like torque. The comparatively large field-like torque is most likely due to the spin accumulation at the $\text{Mn}_3\text{SnN}/\text{Py}$ interface, which interacts with the adjacent Py layer, producing an exchange field^{S9}. The relatively large $\theta_{\text{FL},z}$ affirms the existence of σ_z in our material, which is promising for high-density and low-power spintronics.

Table S1 Comparison of the antidamping and field-like spin torque ratios of σ_z , $\theta_{AD,z}$ and $\theta_{FL,z}$, for Mn₃SnN, Mn₃GaN, WTe₂ and MnPd₃.

Materials	$\theta_{AD,z}$	$\theta_{FL,z}$	Reference
Mn ₃ SnN	0.003	0.053	This work
Mn ₃ GaN	0.019	0.15	S6
WTe ₂	0.013	0.0325	S7
MnPd ₃	0.014	0.046	S8

Table S2 makes a comparison of the magnetization of different noncollinear AFM films. We can see that the magnitude of our Mn₃SnN film is reasonable. The weak uncompensated magnetization may be caused by the imperfect growth or the spin canting of the films. Massive researches have shown that the uncompensated magnetization is not the reason for the large anomalous Hall effect, anomalous Nernst effect or the magneto-optical Kerr effect in noncollinear AFM. In fact, the Berry curvature in momentum space of the special AFM spin texture, that is, the cluster magnetic octupole, gives rise to the above physical phenomena. The direction related σ_z and field-free SOT switching here also illustrates that the weak magnetization of the film does not have obvious influence on the switching measurement.

Table S2 Comparison of the magnetization of different noncollinear AFM films.

Materials	Néel Temperature	Measurement Temperature	Magnetization	Reference
Mn ₃ SnN	475 K	300 K	16 emu/cm ³	This work
Mn ₃ Sn	420 K	300 K	34 emu/cm ³	S1
Mn ₃ Ge	390 K	Room temperature	34 emu/cm ³	S2
Mn ₃ Ga	650 K	Room temperature	48 emu/cm ³	S3
Mn ₃ NiN	260 K	150 K	36 emu/cm ³	S4
Mn ₃ GaN	345 K	300 K	7.2 emu/cm ³	S5

References

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