Electronic Supplementary Material (ESI) for Nanoscale.

Supplemental Material - Control and regulation of skyrmionics' topological charge in a novel synthetic antiferromagnetic nanostructure

Supplementary 1:

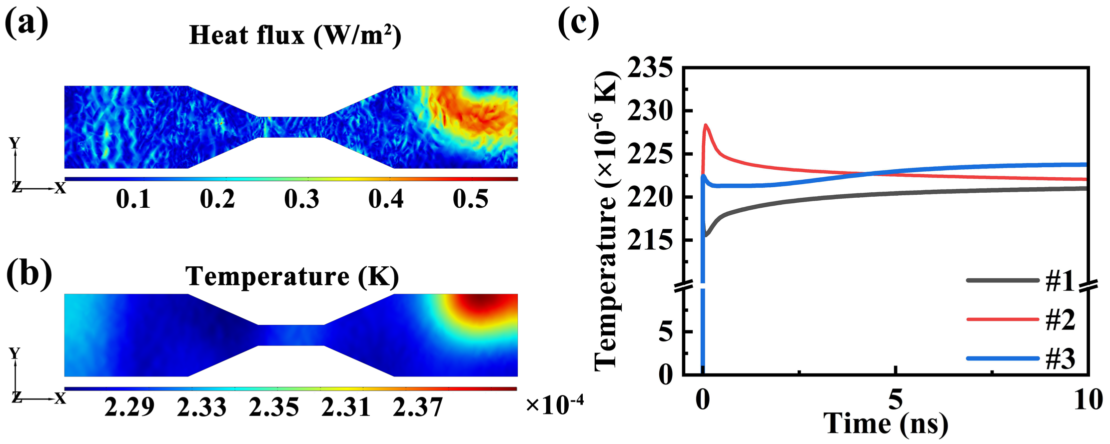

Fig.S1 The field diagram of heat flux (a) and temperature (b) at 10 ns for nanostructure, $J_{CIP} = 1\times10^{13}$A/m^2, (b) The temperature of the three representative points (#1, #2 and #3) at 10 ns.

Fig.S1(a and b) show the field diagram of heat flux and temperature at 10 ns for nanostructure, when $J_{CIP} = 1\times10^{13}$A/m^2. The multi-physics fields were calculated using COMSOL Multiphysics. The material parameters were based on Pt/Co. As shown in Fig.S1 (a and b), there is heat accumulation in the end of the nanostructure due to Joule Heating. But from the temperature of three representative points at 10 ns, the maximum temperature reaches approximately 2.30×10^{-4} K.

Supplementary 2:

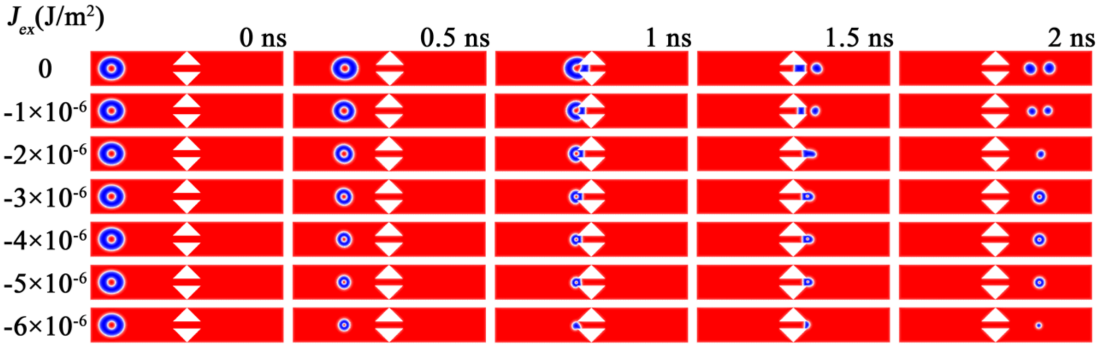

Fig. S2. Phase diagrams of skyrmionium passing the channel with different J_{ex} (40 nm width and 160 nm length). ($D = 3$ mJ/m^2, $K_{up} = 6 \times 10^5$ J/m^3, $K_{low} = 1 \times 10^6$ J/m^3).

When J_{ex} is considered, the large skyrmionium is converted into a small one while increasing J_{ex} (Fig.S2) in synthetic antiferromagnetic (SAF) nanostructure with a narrow channel. When J_{ex} is stronger than -5×10^{-6} J/m^2, the skyrmionium transforms to annihilation. When is weaker than -3×10^{-6} J/m^2, the skyrmionium transforms to skyrmions. The smaller skyrmionium will cross the channel intactly, when $J_{ex} = -3\times10^{-6}$ J/m^2 ~ -5×10^{-6} J/m^2.

Supplementary 3:

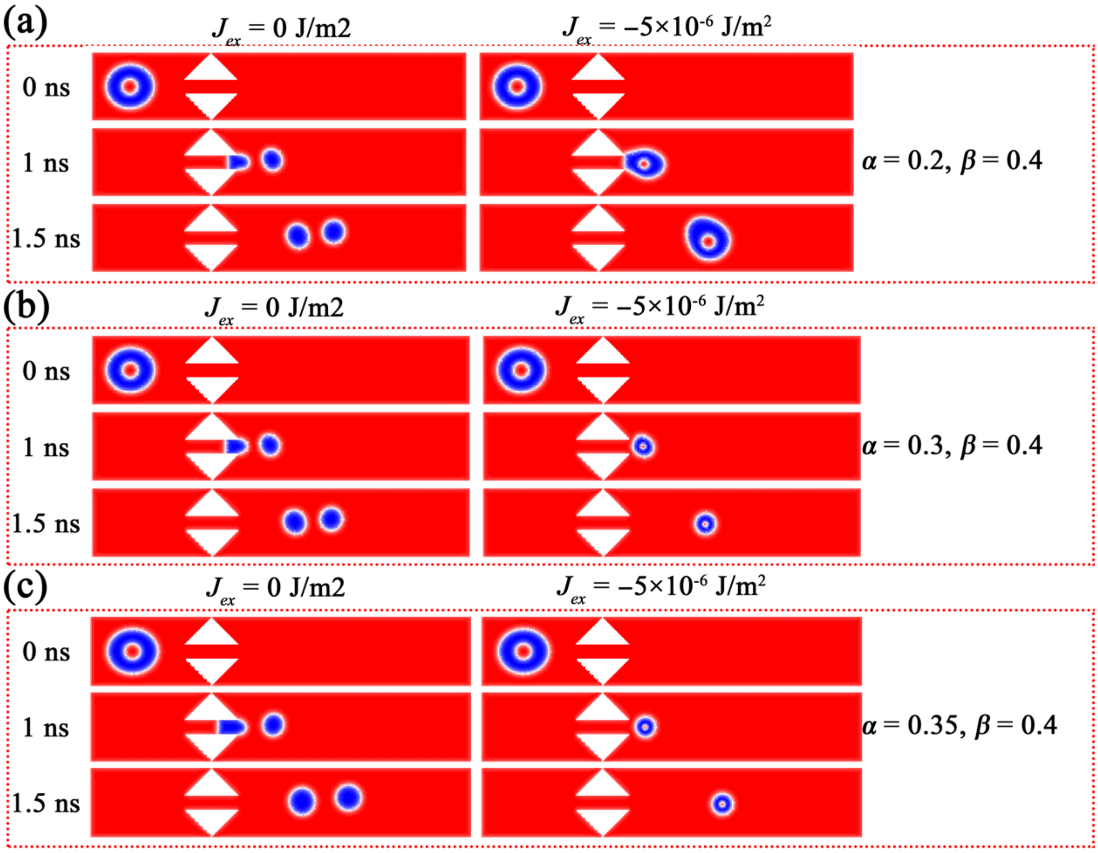

Fig. S3 Phase diagrams of skyrmionium passing the channel when $\alpha \neq \beta$. (a) $\alpha = 0.2$, $\beta = 0.4$; (b) $\alpha = 0.3$, $\beta = 0.4$; (c) $\alpha = 0.35$, $\beta = 0.4$. ($D = 3$ mJ/m^2, $K_{up} = 6\times10^5$ J/m^3, $K_{low} = 1\times10^6$ J/m^3, and $J_{CIP} = 1\times10^{13}$ A/m^2)

For $\alpha \neq \beta$, the skyrmion should move slightly upward or downward due to skyrmion Hall Effect. And the skyrmionium becomes deformed because of the local skyrmion Hall effect for the two skyrmions with opposite Q. The skyrmionium is able to move along the middle line of the nanotrack without distortion under moderate RKKY exchange coupling[1]. Fig.S3 shows the skyrmionium motion in the SAF nanostructure, when $\alpha \neq \beta$. The skyrmionium can become two skyrmions ($Q = \pm2$) under the RKKY AFM exchange coupling or maintain its structure ($Q = 0$) after passing through the channel, which is consistent with the phenomenon of $\alpha = \beta$.

References

1. Z. Yu, B. Gong, C. Wei, R. Wang, L. Xiong, L. You, Y. Zhang, S. Liang, Z. Lu and R. Xiong,

Applied Physics Letters, 2022, **121**, 012403.