Supplementary Information:
Flexible heat-flow sensing sheets based on the longitudinal spin Seebeck effect using one-dimensional spin-current conducting films

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TE experiment in TSSE setup We have performed additional experiments to check whether transverse spin Seebeck effect (TSSE) [1-3] contributes to the TE signal in our devices. The schematics of the experimental setup is shown in Fig S1(a). For the TSSE experiment, we prepared a TE-sheet sample in a similar fashion as described in the main article. In the sample, a 20 × 5-mm² Pt strip with a thickness of 5 nm was formed on an edge of 20 × 20-mm² ferrite-plated film, as shown in Fig. S1(a). To investigate the TSSE, output voltage $V$ along the $y$-direction between two ends of the Pt strip was measured, when a temperature difference $\Delta T$ was applied in the $x$-direction. To magnetize the ferrite-plated film, an external magnetic field $H$ was also applied in the $x$-direction. If the TE-sheet sample exhibits the TSSE, output voltage is expected to occur in the $y$-direction. Figure S1(b) shows the measured $V$ as a function of $H$ when $\Delta T = 1.1K$ was applied to the sample, where no output signal was clearly observed. The result suggests that our TE sheet with a ferrite-plated film having one-dimensional spin-current conducting properties does not exhibit any TE voltage originating from the TSSE, since a transverse spin current is effectively blocked by its columnar crystalline structure.

LSSE-based TE sheets with different metallic films To gain further insights into the TE mechanism, we also prepared and evaluated TE sheets using different metal-film materials instead of Pt. TE measurements were performed in the same experimental configuration as mentioned above. Figure S2(a) represents the TE voltage from a sample composed of a 10-nm-thick Cu film and a 500-nm-thick Ni₈₀Zn₂₀Fe₂₅O₄ film on a polyimide substrate, showing that the output voltage from the
Cu film is negligibly small. This result is consistent with the negligible ISHE in Cu, which has a weak spin-orbit interaction. Figure S2(b) shows the experimental result of a TE sheet in which a W film with a thickness of 5 nm was deposited on the same Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$/polyimide substrate. In this case, the clear TE voltage $V$ was observed and its sign was found to be opposite to that of the Pt/ Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$ sample (compare Fig. S2(b) with Fig. 2(d) in the main article), which is consistent with the fact that the spin-Hall angle of W has a sign opposite to that of Pt [4,5]. Notably, the heat-flow sensitivity of the W/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$ sensor is $V/q = 3.55$ nV/(W/m$^2$), a value 3.5-fold greater than that of the Pt/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$, although the W-film resistance between the ends of the sample ($R_w = 2.04$ k$\Omega$) was an order of magnitude greater than that of the Pt film. This large value suggests that W appears to be a promising material for heat-flow sensing applications.

Reference

Figure S1 | TE experiment in transverse-SSE setup. (a) Experimental set up for checking the transverse SSE. Output voltage $V$ along the $y$-direction between two ends of the Pt strip was measured when temperature difference $\Delta T$ was applied in the $x$-direction. To magnetize the ferrite, an external magnetic field $H$ was also applied in the $x$-direction. (b) Measured voltage $V$ as a function of external magnetic field $H$ when $\Delta T = 1.1\text{K}$ was applied to the sample.

Figure S2 | SSE-based TE sheets with different metallic films. (a) TE voltage $V$ from a Cu/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_{4}$/polyimide sample as a function of an external magnetic field $H$, measured when the heat flux $q$ was applied across the sample. The voltage was negligibly small, due to the small ISHE in Cu. (b) TE voltage $V$ from a W/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_{4}$/polyimide sample obtained with the same measurement setup. The voltage signal has a sign opposite to that of the Pt/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_{4}$ sample.
because the spin-Hall angle of W has the opposite sign to that of Pt. (c) TE voltage from the TE sheet W/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$ compared with that from Pt/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$ as a function of $q$. According to the fitting with the solid line, the heat-flow sensitivity of W/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$ was evaluated to be $V/q = 3.55$ nV/(W/m$^2$), which is more than 3 times larger than that of Pt/Ni$_{0.2}$Zn$_{0.3}$Fe$_{2.5}$O$_4$. 