Supplementary Information for:

Broadband hyperbolic thermal metasurfaces based on plasmonic phase-change material In_3SbTe_2

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Materials and methods

1. Average Emissivity Calculation

With the blackbody radiation law, we calculated the average emissivity of sample with the following formula[1]:

$$e_{\text{average}} = \frac{\int_{\lambda_1}^{\lambda_2} a e(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} a d\lambda} \tag{1}$$

in which $a = 2\pi hc^2\lambda^{-5}\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right]^{-1}$, h is the Planck constant, c is the speed of light in vacuum, k is the Boltzmann constant, $[\lambda_1, \lambda_2]$ is the wavelength range [8 μm, 14 μm], T is the temperature, and $e(\lambda)$ is the emissivity spectrum within 8−14 μm.

2. Sample Fabrication

The PCM (IST, GST, GeTe) films were deposited on 1-mm-thick SiO_2 substrates using stoichiometric targets by direct current magnetron sputtering. The thickness of PCM films were controlled by a stylus profiler (Brucker DektakXT) at 80 nm. The as-deposited PCM films are in the amorphous state, the crystalline state of PCMs shown in Fig. 1 of main text is achieved by heating in a vacuum oven at 300 °C for 10 min (IST, GST) and at 260 °C for 15 min (GeTe), respectively.

3. Laser Printing

We built a customized setup for patterning the IST film by focusing a laser beam through a ×20 objective (NA = 0.4) on the sample surface. A nanosecond laser diode source with a central wavelength of 660 nm provides single pulses with tunable output power (up to 400 mW) and pulse duration (from 1 ns to 10 μs). To crystallize the IST film, laser pulses of 70 mW power and 85 ns duration were used. An *x–y* movable sample stage with maximum range of 50 mm in each direction and minimal step size of 625 nm was used to prepare the structures shown in Figs. 2–4 of main text.

4. Infrared Spectrum Measurement

A Bruker Vertex 80v Fourier transform infrared (FTIR) spectrometer was used to measure the infrared reflection spectrum of the sample with a resolution of 0.88 cm^{-1} from 714 cm^{-1} to 1250 cm^{-1}. Since a sufficiently thick SiO_2 substrate suppresses the transmission of the entire structure to zero in the LWIR band, the absorptance spectrum is obtained from A (absorption) = $1 - R$ (reflection).

5. Numerical Simulation

The simulations were performed using the radio frequency module of the commercial software COMSOL Multiphysics (see schematic in Supplementary Figure S7). Periodic boundary conditions are applied to a cell containing IST grating. The absorptance A is calculated by $1 - R$, while the reflection R is obtained by integrating over the surface area above the sample surface. The relative permittivity of IST was obtained from Heßler et al.[2]

Supplementary Figures

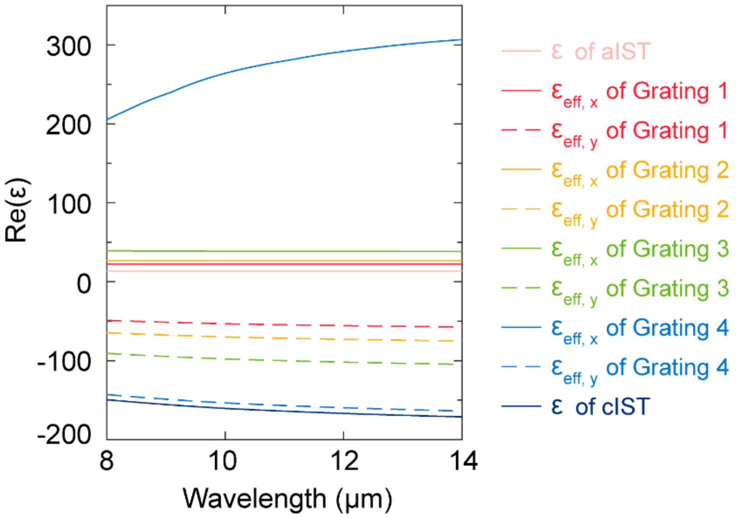

Fig. S1 Calculated effective permittivities (real part) along *x* and *y* directions of gratings with different fill factors *f* (Grating 1: *f* = 38.4%; Grating 2: *f* = 48%; Grating 3: *f* = 64%; Grating 4: *f* = 96%).

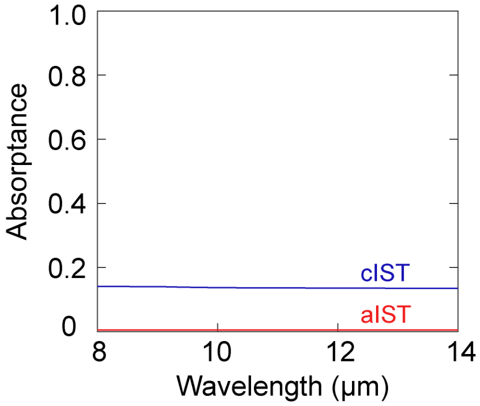

Fig. S2 Calculated LWIR absorptance spectra of 80-nm-thick IST in crystalline and amorphous phases. The permittivity used for the calculations were obtained from Heßler et al.[2]

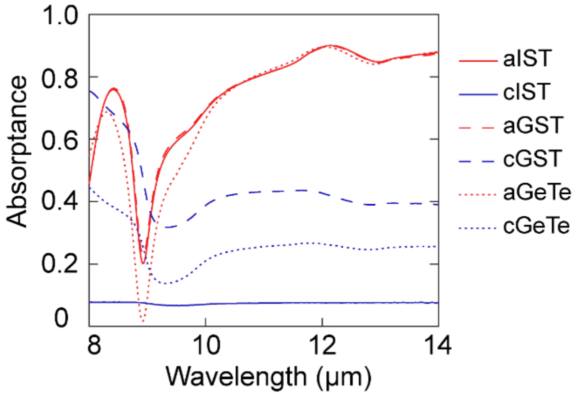

Fig. S3 Measured FTIR spectra of different PCM films (IST, GST and GeTe) of the same thickness (80 nm) on SiO_2 substrates. Solid, dashed and dotted lines correspond to IST, GST and GeTe, red and blue colors represent the amorphous and crystalline phases, respectively.

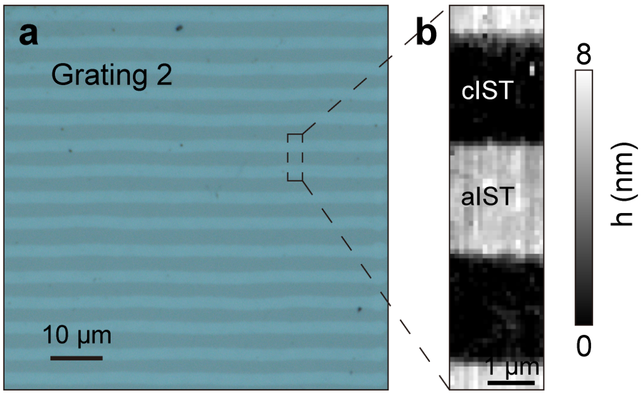

Fig. S4 (a) Original optical microscope image of Grating 2. (b) AFM topographic image of the printed area in Grating 2.

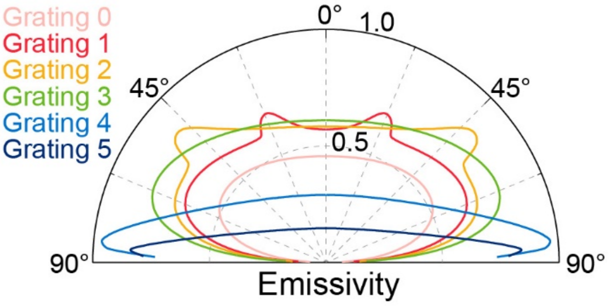

Fig. S5 Simulated polar plot of the emissivity for the gratings depicted in Fig.2d at $\lambda = 9$ μm and for $\theta = 90°$.

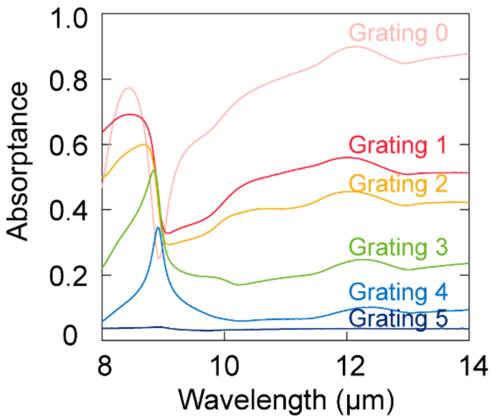

Fig. S6 Measured absorptance spectra of IST gratings of different fill factor (see main text) without polarizer inserted.

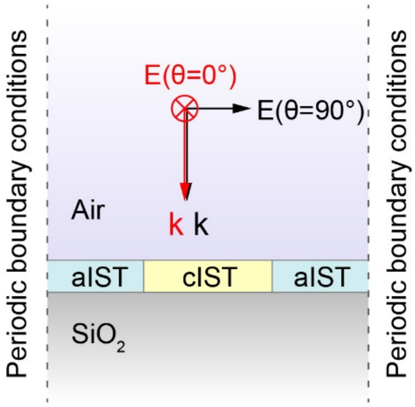

Fig. S7 Schematic of simulations for the gratings' absorption spectra shown in Figure 2 of the main text.

References

1. Granqvist CG, Hjortsberg A. Radiative cooling to low temperatures: General considerations and application to selectively emitting SiO films. *J Appl Phys* **52**, 4205-4220 (1981).

2. Heßler A, Wahl S, Leuteritz T, Antonopoulos A, Stergianou C, *et al*. In_3SbTe_2 as a programmable nanophotonics material platform for the infrared. *Nat Commun* **12**, 924 (2021).