Engineering the Spectral and Spatial Dispersion of Thermal Emission using Phonon Polaritons

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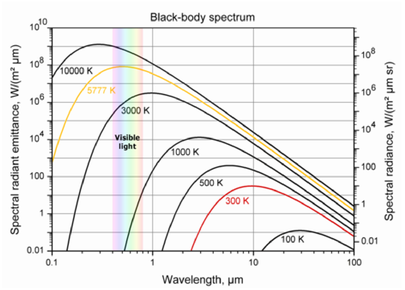
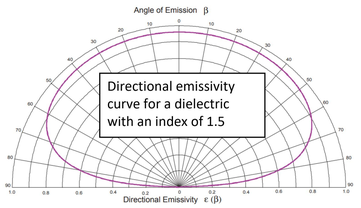
Thermal emission

- Described by Planck's law:

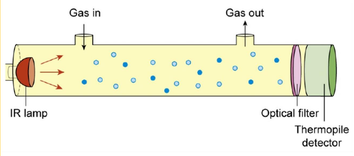
$$L_{BB}(\nu,T)=\frac{c}{4\pi}\frac{8\pi\nu^2}{c^3}\frac{h\nu}{e^{\frac{h\nu}{k_BT}}-1}$$

- Thermal emission from a black body has broadband emitting energy distribution in both the spectra and spatial domains.



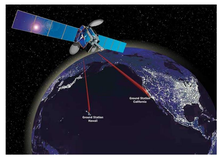


- The broadband nature of the emission becomes less useful for many other long-wave infrared (LWIR) applications.



Non-dispersive IR gas sensors

Infrared beacons



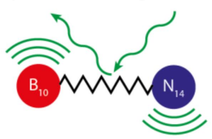
Free-space communications

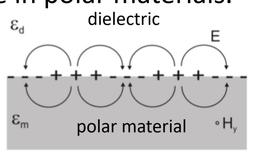
- Recent advances in nanophotonics: it is possible to engineer far-field thermal emitters by engineering the emissivity.

$$L(\nu,T,\theta,p)=\underbrace{\epsilon(\nu,T,\theta,p)}_{\text{Emissivity}}L_{BB}(\nu,T)$$

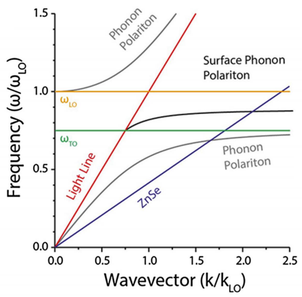
Phonon polaritons

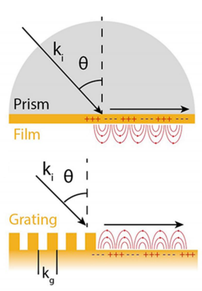
- They are quasiparticles that comprise a photon and a coherently oscillating ionic charge in polar materials.

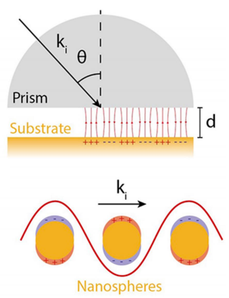




- Momentum mismatch: can't be launched by free-space light.



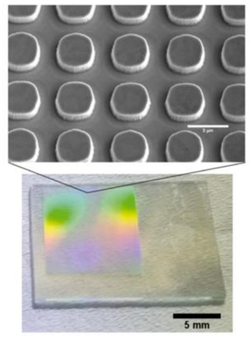


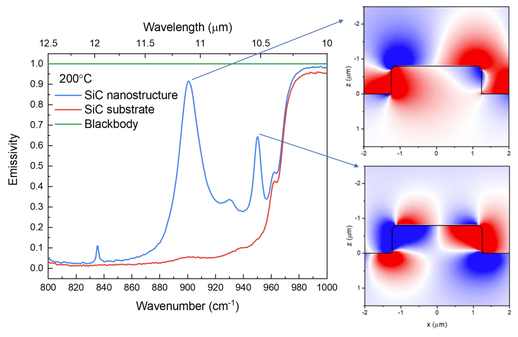


- Lower loss compared to plasmons in the LWIR spectra region.

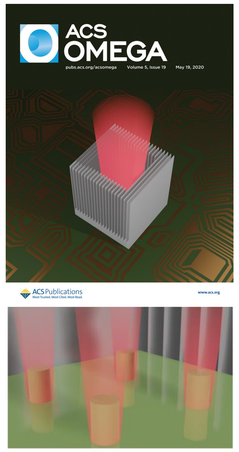
Waste-heat driven narrowband thermal emitter

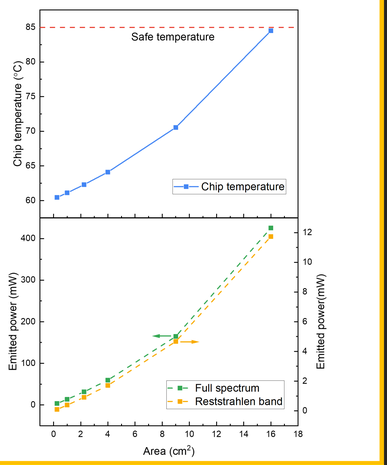
- Low-loss localized surface phonon polaritons (LSPhP) from SiC nanopillar array can give rise to narrowband thermal emission [1].





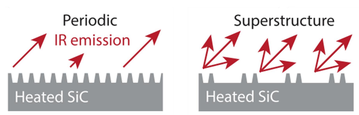
- We demonstrated that the SiC narrowband thermal emitter can be potentially driven by waste heat: over 10 mW output LWIR power.

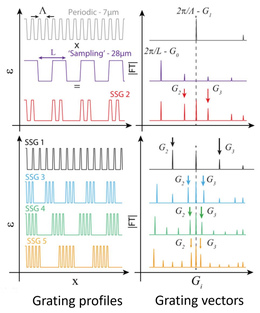




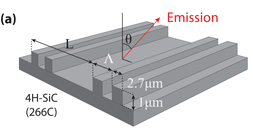
Spatially coherent emission from superstructure gratings

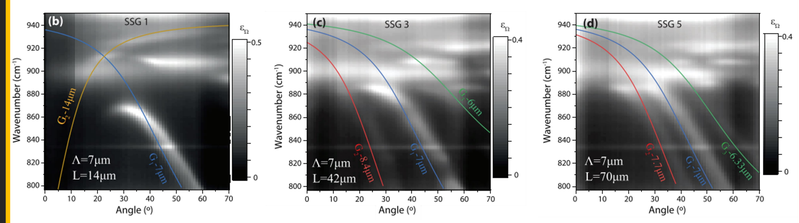
- Superstructure gratings (SSGs) can launch surface phonon polaritons (SPhP) with different wavevectors in a single grating [2].





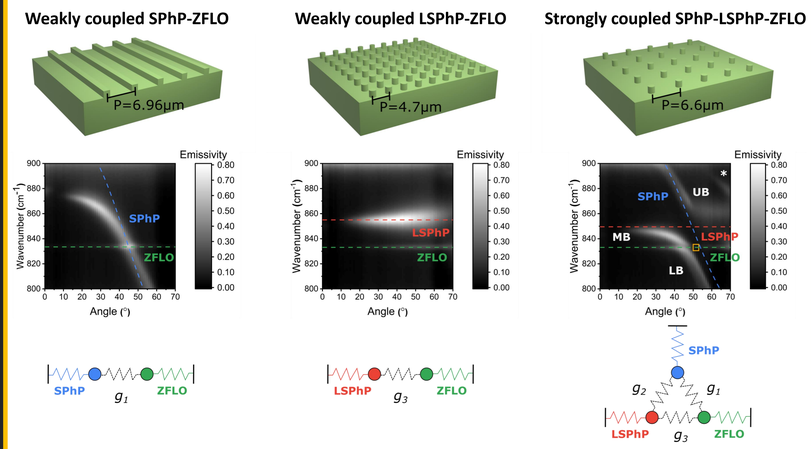
- Multiple spatially coherent emission modes from SSGs fabricated into a 4H–SiC substrate:



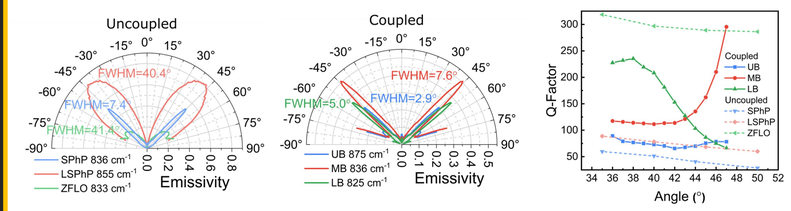


Strongly coupled thermal emitter

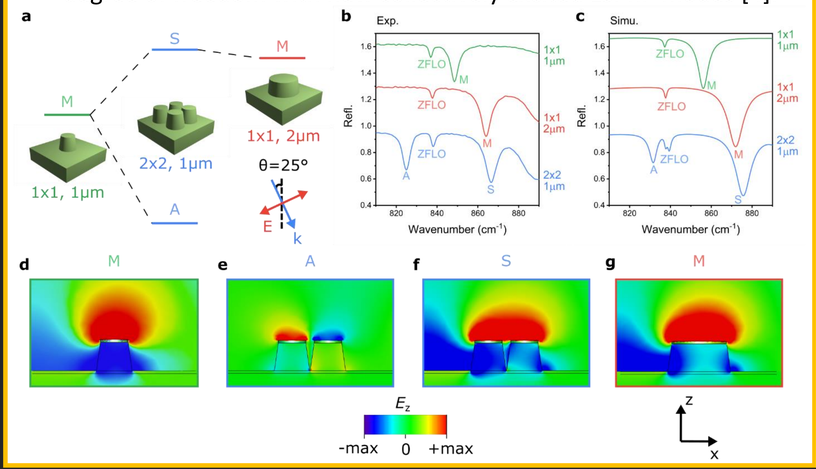
- Strong coupling phenomenon can combine the corresponding virtues of both LSPhP and SPhP into a new, hybrid mode [3].
- Coupling to a third zone-folded longitudinal optic phonons (ZFLO) mode can make the emission electrically driven possible.



- We demonstrated a 5-fold improvement in the spatial coherence and 3-fold enhancement of the quality factor for coupled modes.



- Increasing the complexity of LSPhP unit cell can introduce a new degree of freedom with new collectively excited LSPhP modes [4].



References and Acknowledgements

1. Lu, G., et al., *ACS Omega,* (2020)
2. Lu, G., et al., *Applied Physics Letters* (2021).
3. Lu, G., et al., *Nano Letters* (2021).
4. Lu, G., et al., *ACS Nano* (under review).

Funding: Vanderbilt University, NSF STTR, ONR, DOE user facility