



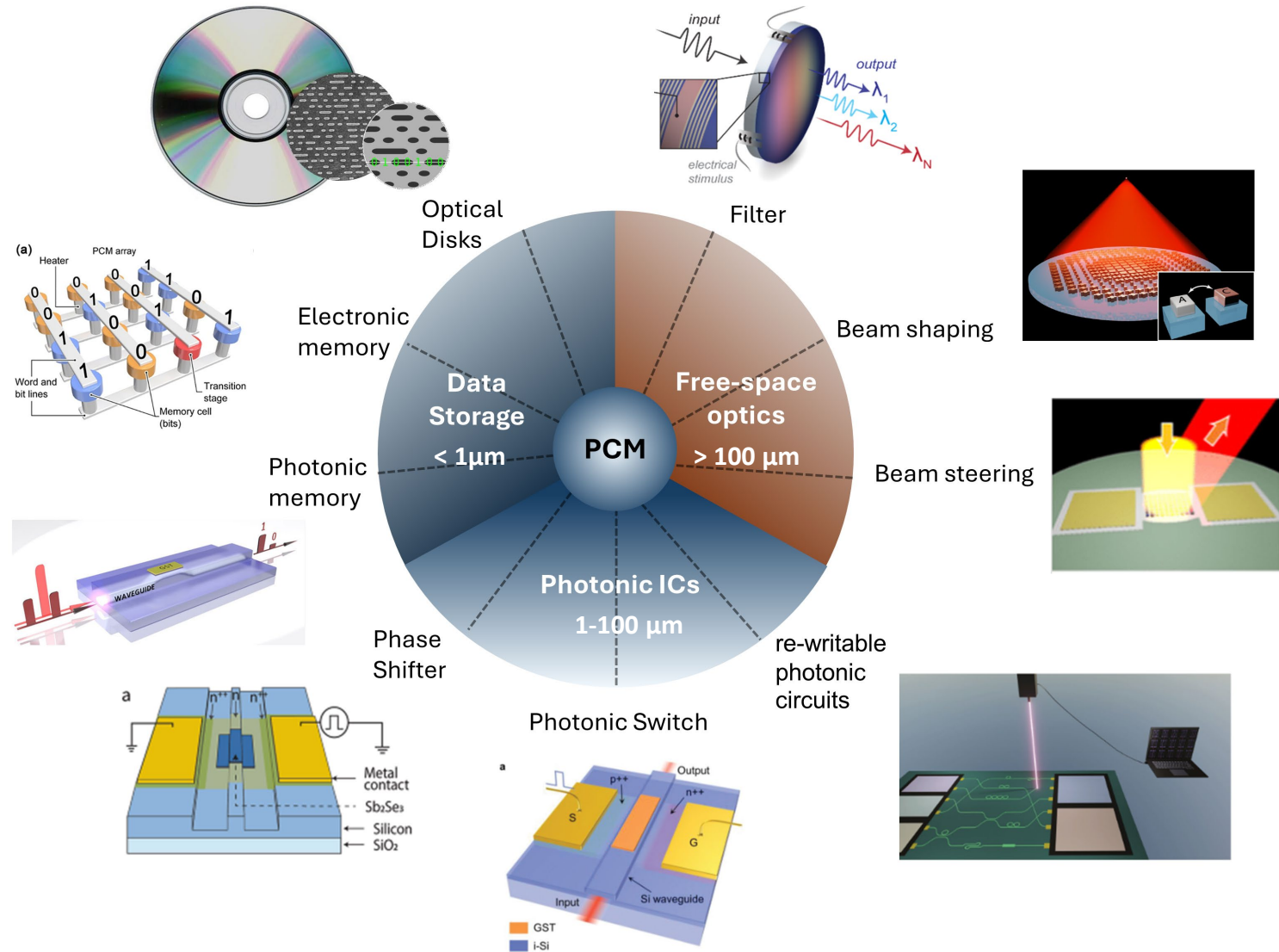
Scaling up PCM-based devices: Expanding dimensions for broader functionalities



Kiumars Aryana

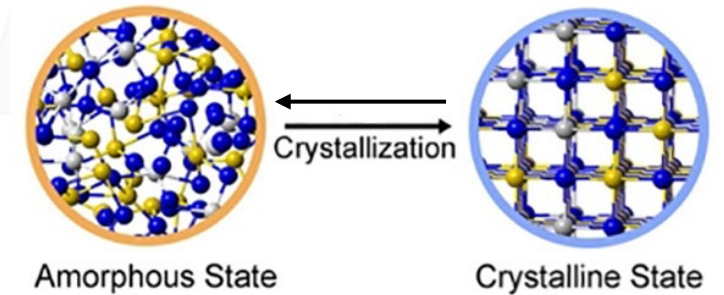
Postdoctoral Fellow,
Advanced Measurements and Data Systems Branch (AMDSB)
NASA Langley Research Center
Advisor: Dr. Hyun Jung Kim

Phase Change Materials for Reconfigurable Optics



Thermo-optic  Electro-optic 
volatile

To achieve reconfigurable properties, we need materials that can **switch** between two different states upon a **trigger**.

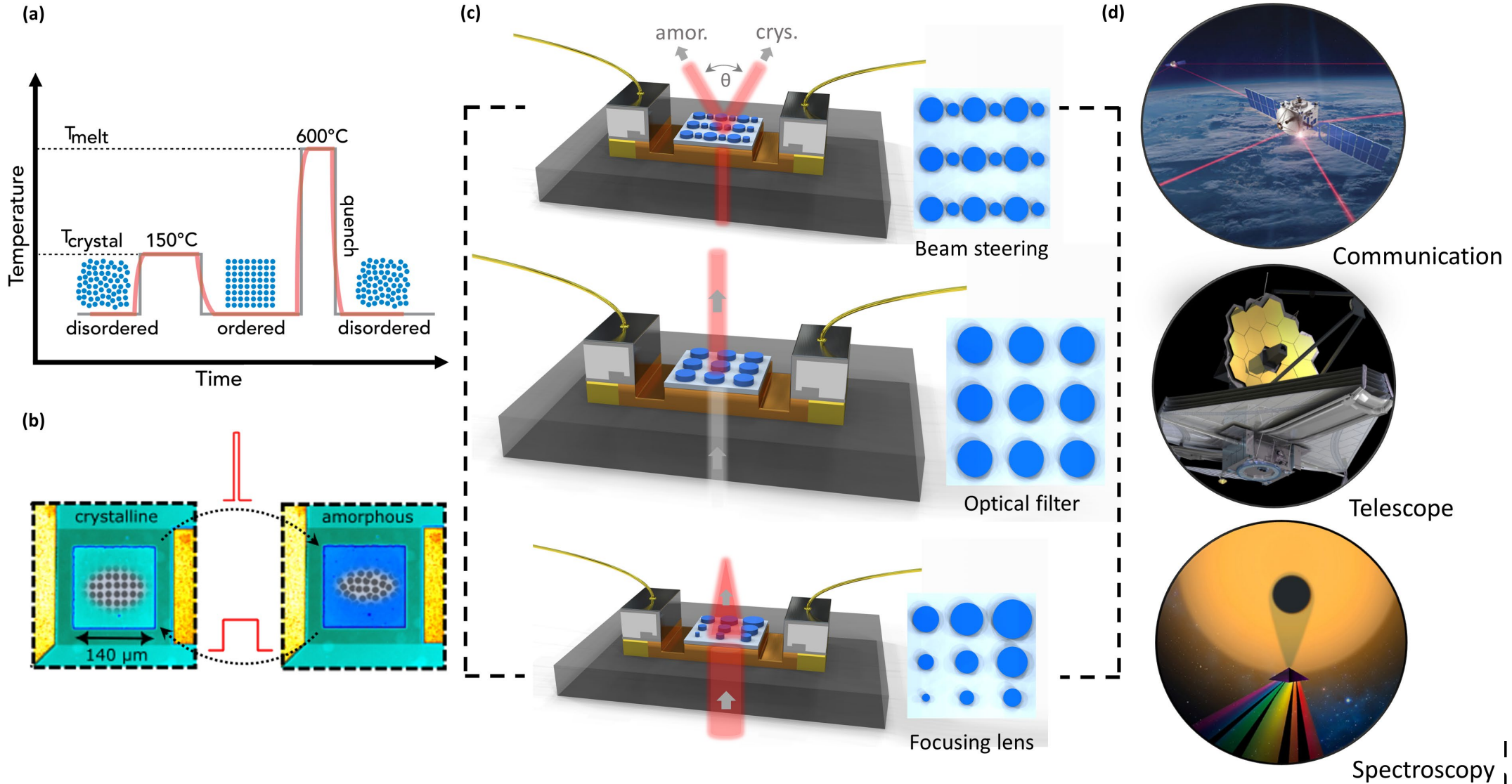


 non-volatile

National Aeronautics and
Space Administration



Applications in Free-space Optics



PCM-Based Actively Tunable Filter

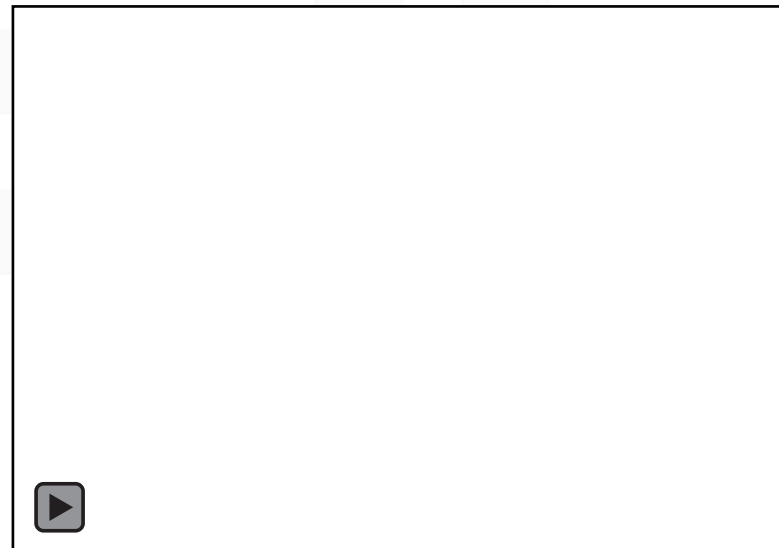
State of the Art:

- ✓ Filter wheels comprised of several static filters physically rotate to switch spectral passband
- ✓ Has moving parts, large mass, slow response time (ms), and provides limited spectral resolution
- ✓ 0.8kg (weight), 725cm³ (volume), 15W to power motor



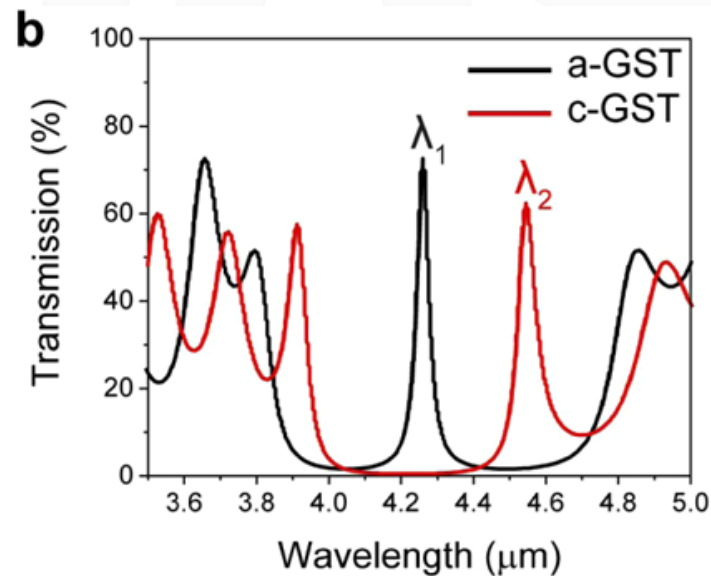
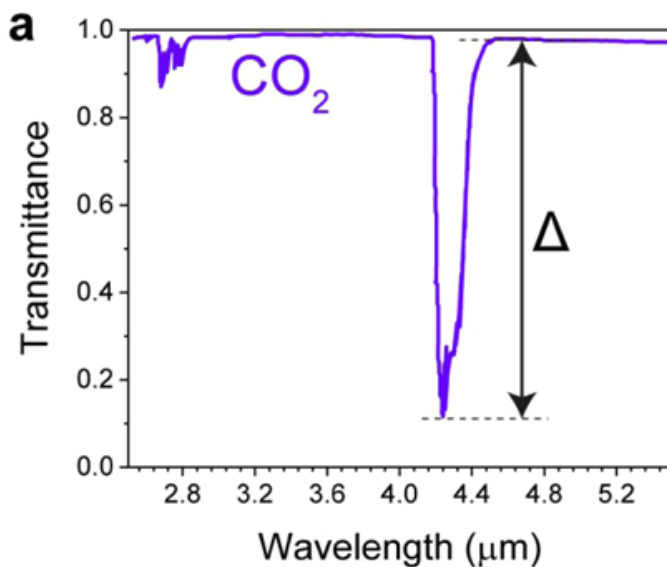
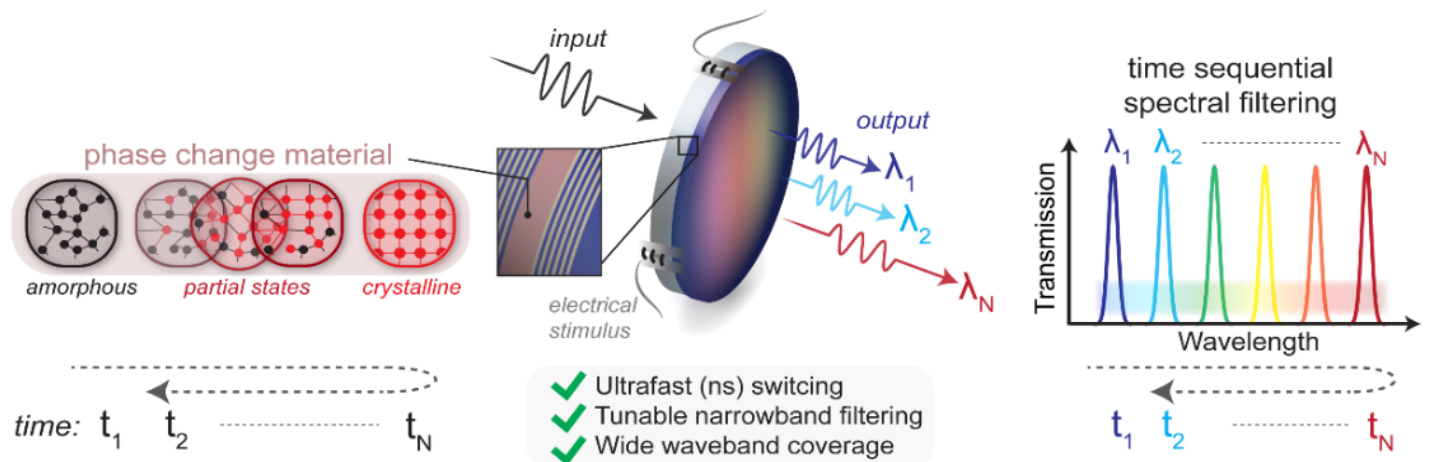
Reconfigurable Filter:

- ✓ Increased spectral and temporal resolutions
 - ✓ GHz (ns) switching speed (10⁶x improvement!)
 - ✓ Continuously-tunable passband
- ✓ Single-component, non-volatile, broad tunability
- ✓ 10g (weight), 0.253cm³ (volume), ~mW average power to tune filter

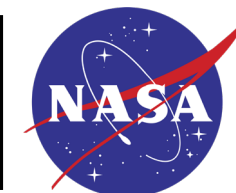


Bandpass Filters – Tunable Fabry-Perot

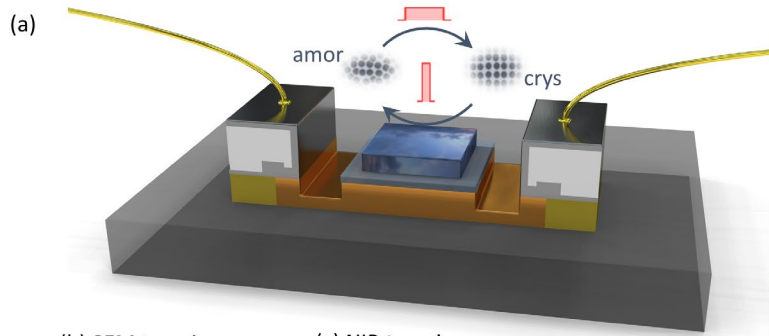
Our technology: Phase-change tunable optical filter



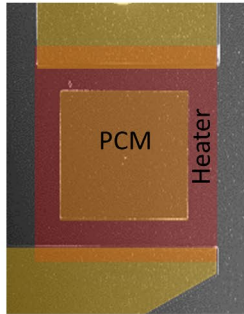
National Aeronautics and
Space Administration



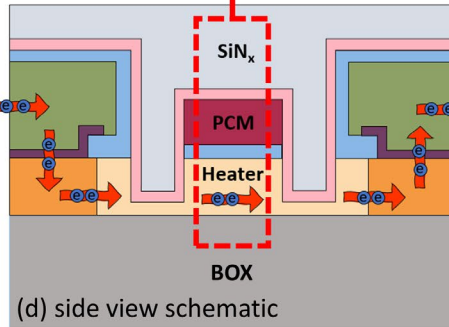
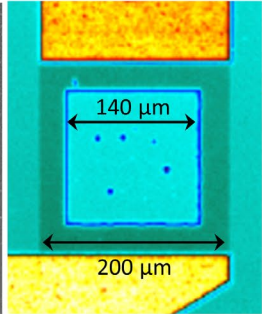
Simulation Domain



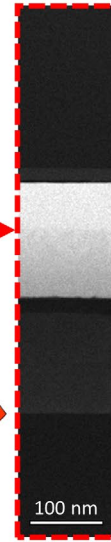
(b) SEM top view



(c) NIR top view



(e) TEM

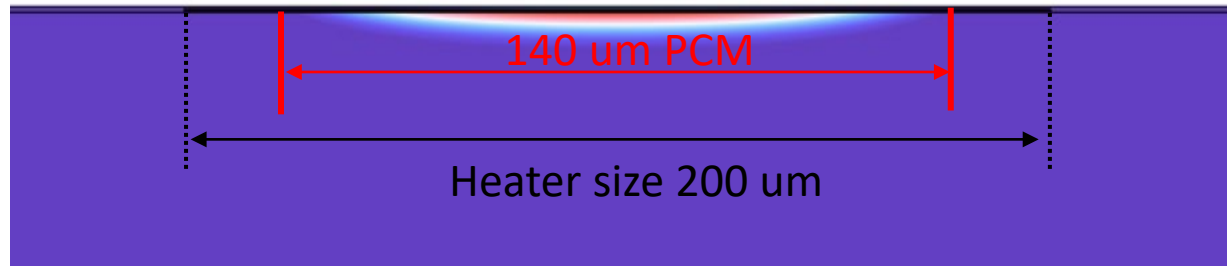
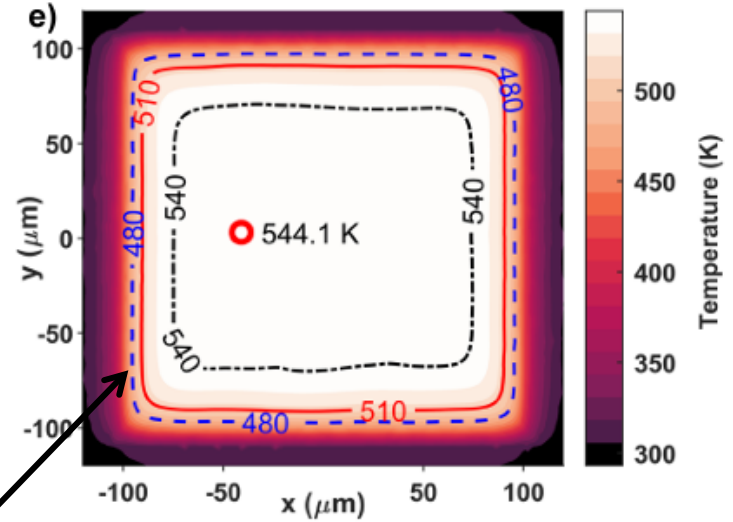
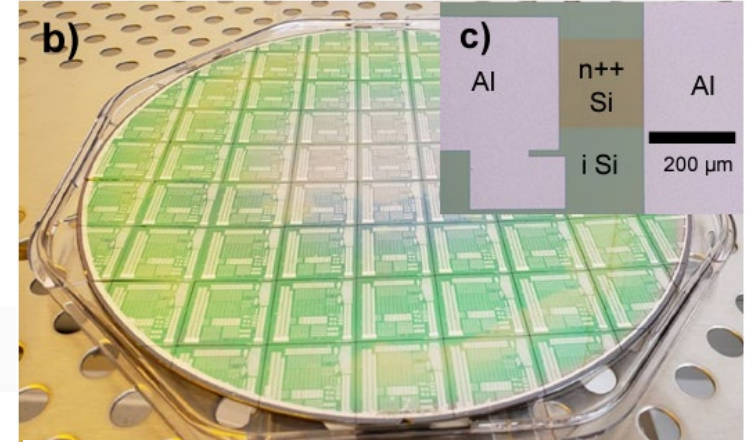


100 nm

(f) sim. section



T(K)



Aryana et al. *Small* **19**(50), (2023)

non-uniform temp. profile

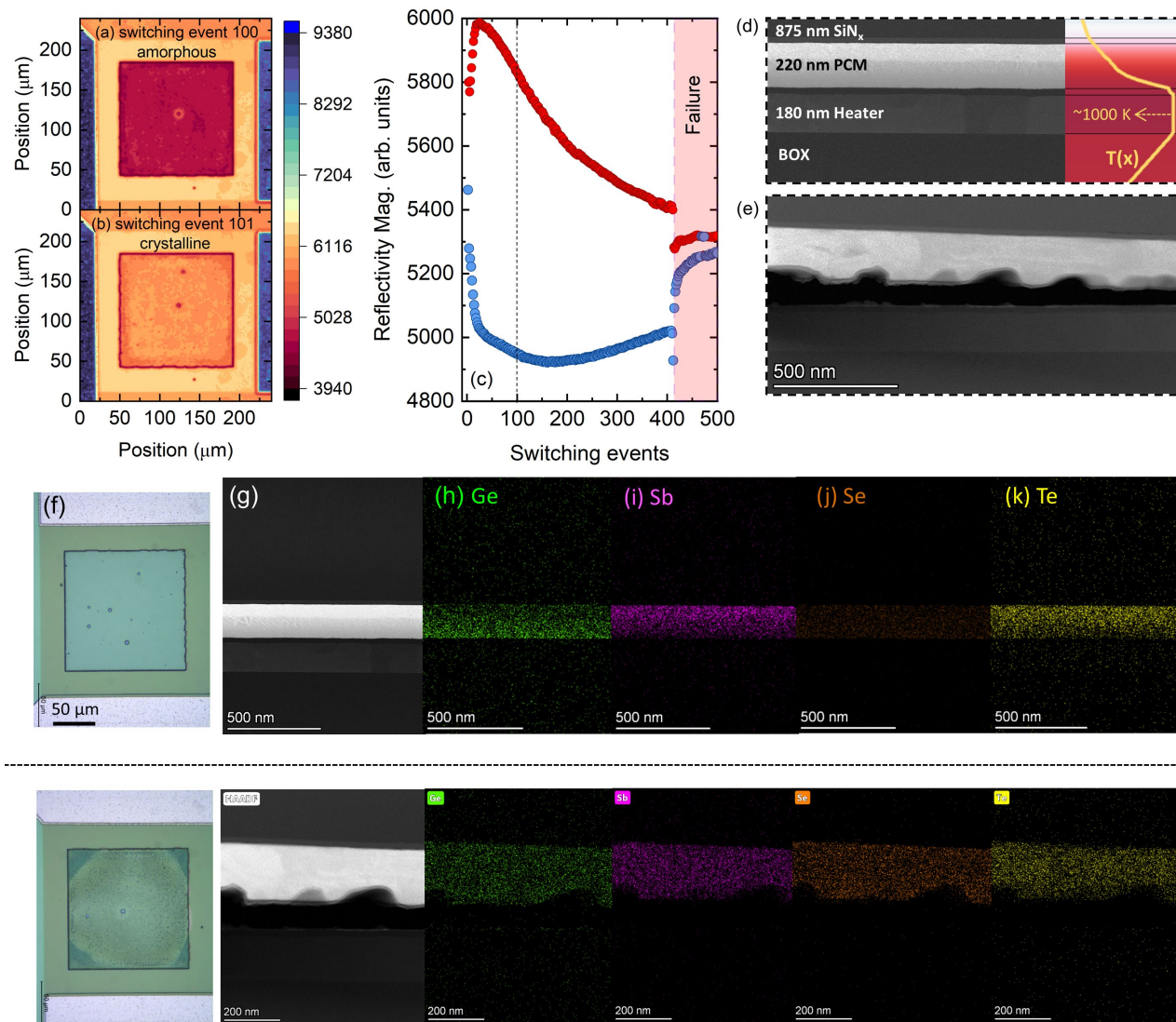
National Aeronautics and
Space Administration



Popescu, et al. *Photonic and Phononic Properties of Engineered Nanostructures XIII* (Vol. 12431, pp. 40-48). SPIE.

Blanket-coated Thin Film GSST

Popescu et al. *arXiv preprint arXiv:2312.10468* (2023).

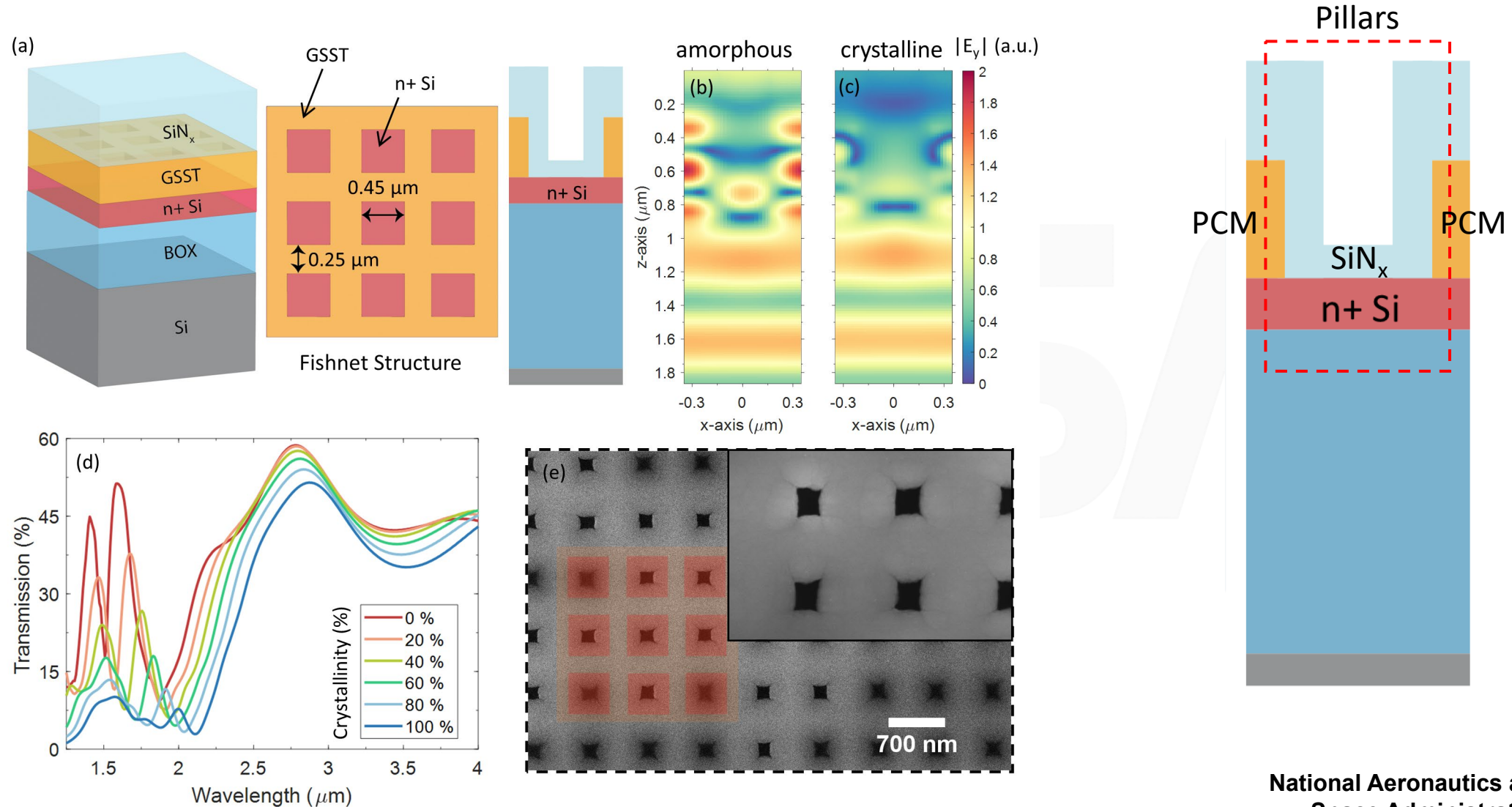


National Aeronautics and
Space Administration



Metasurface Deposition of PCM for Filtering

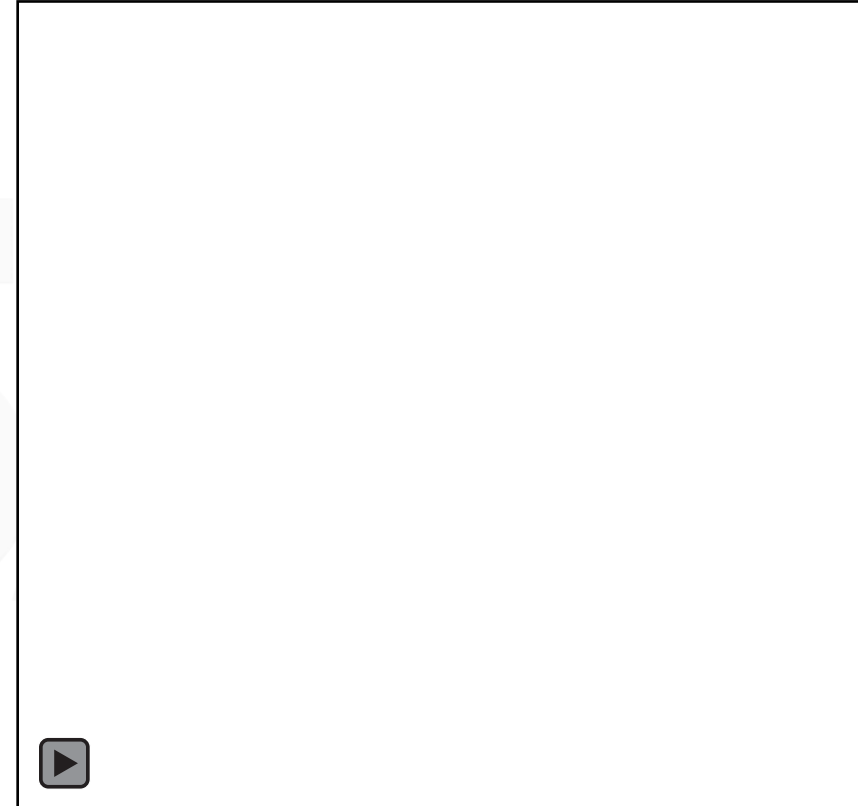
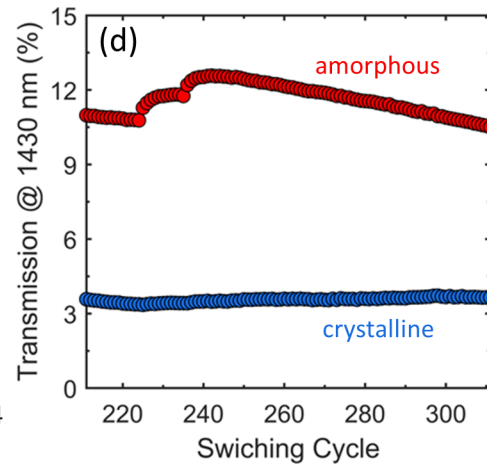
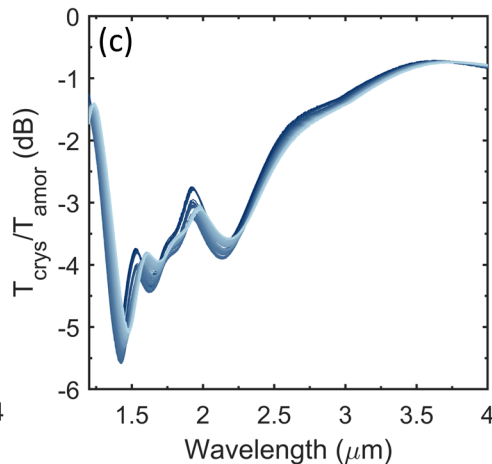
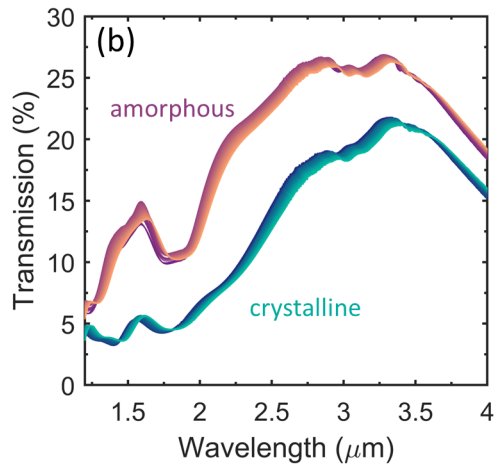
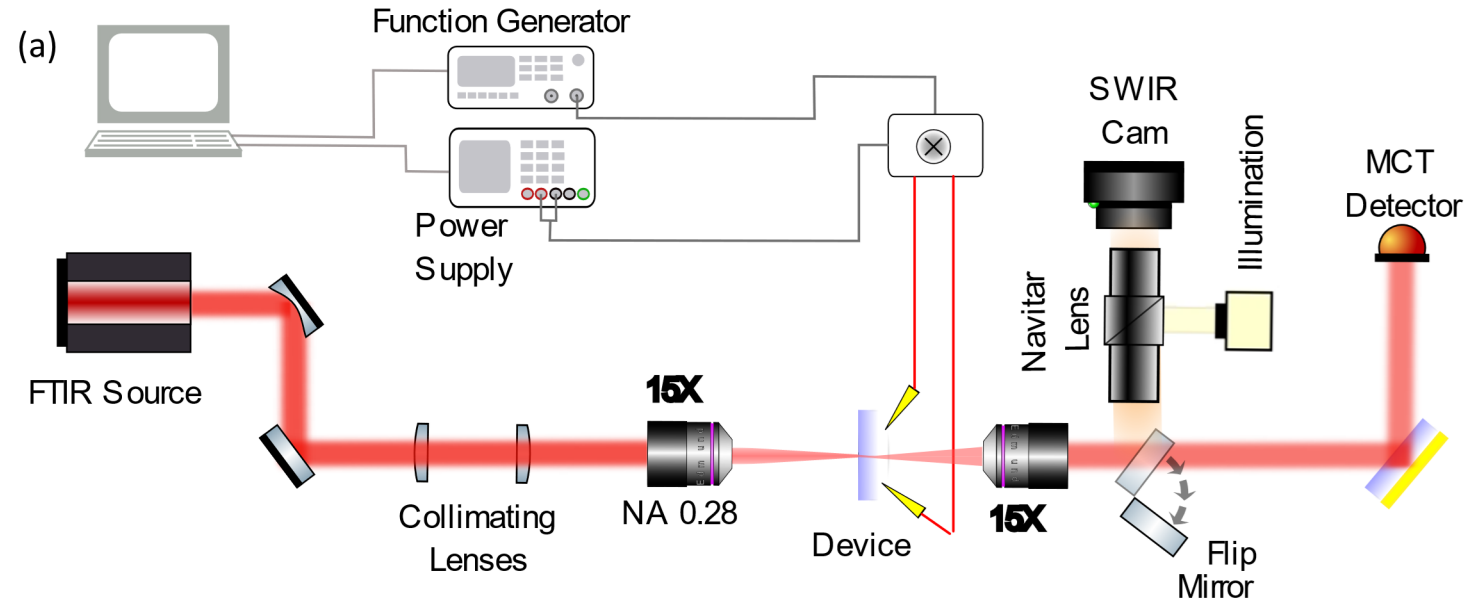
Popescu et al. *arXiv preprint arXiv:2312.10468* (2023).



National Aeronautics and
Space Administration

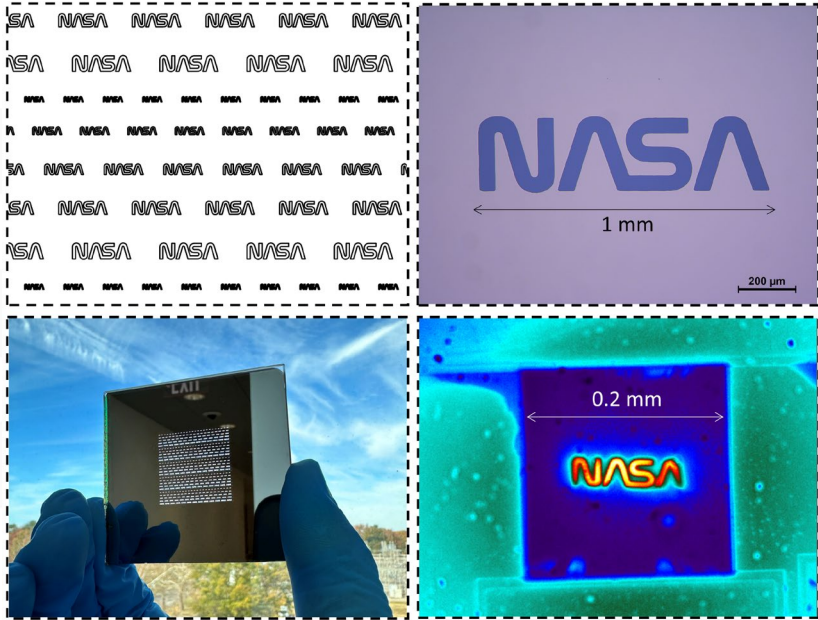
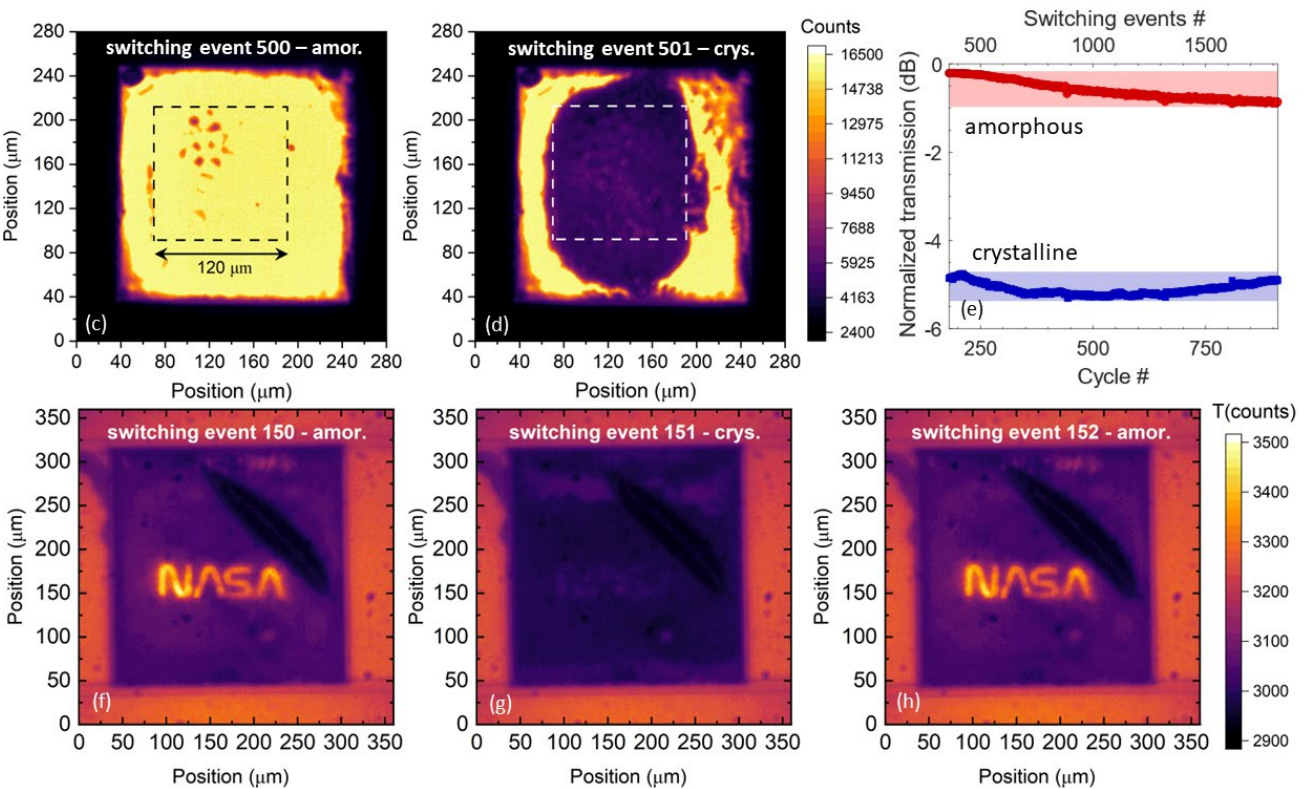
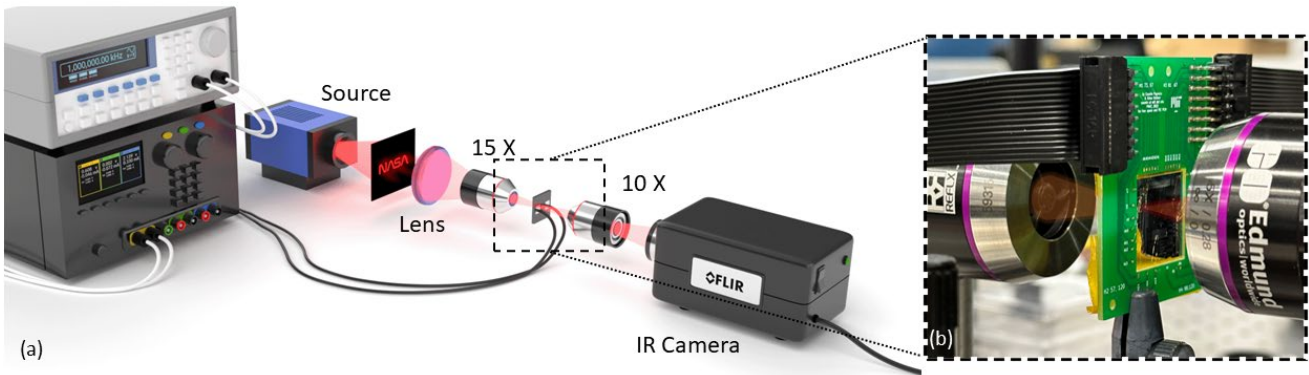


Filtering Performance - FTIR

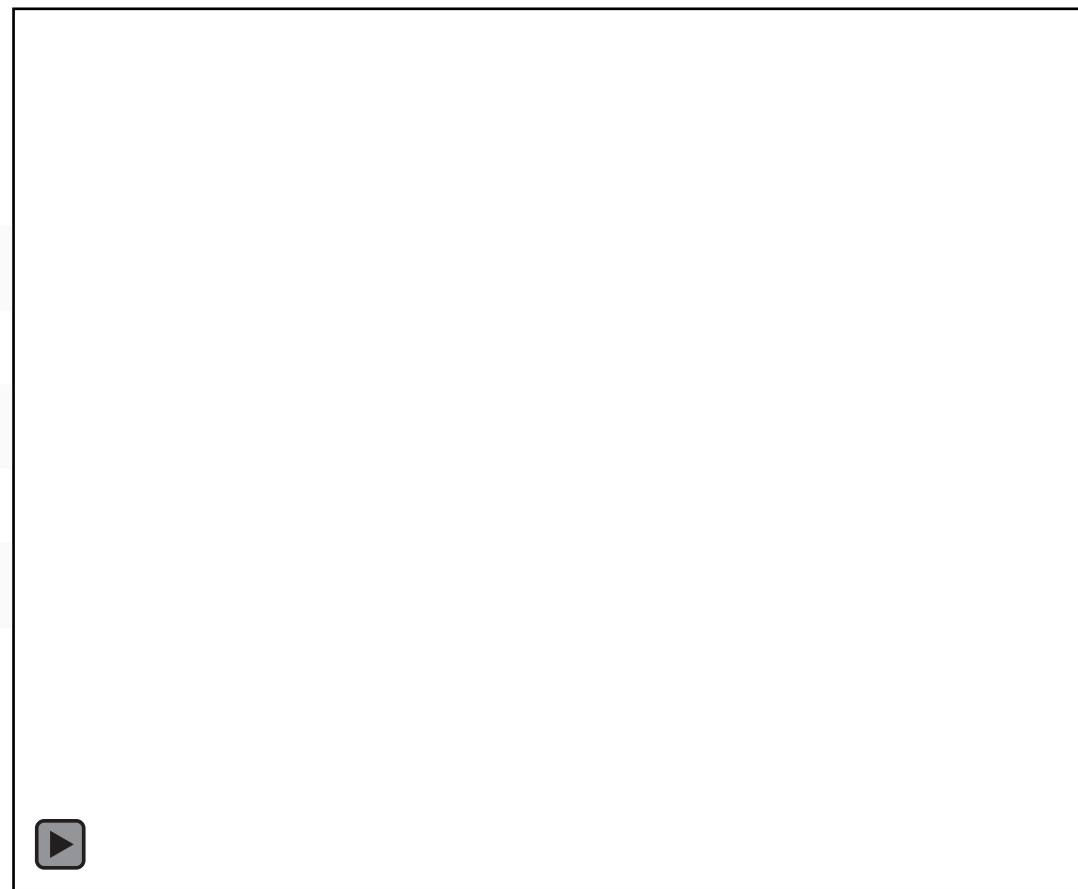
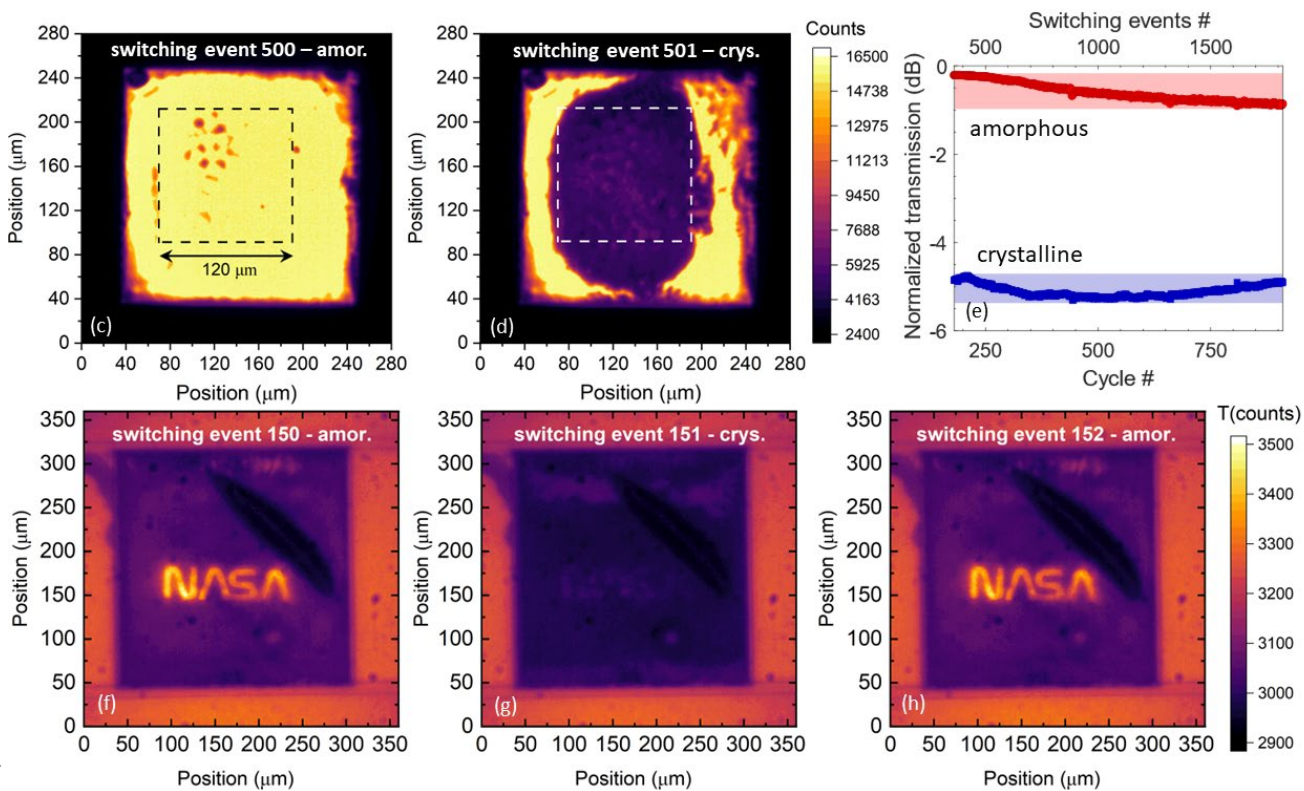
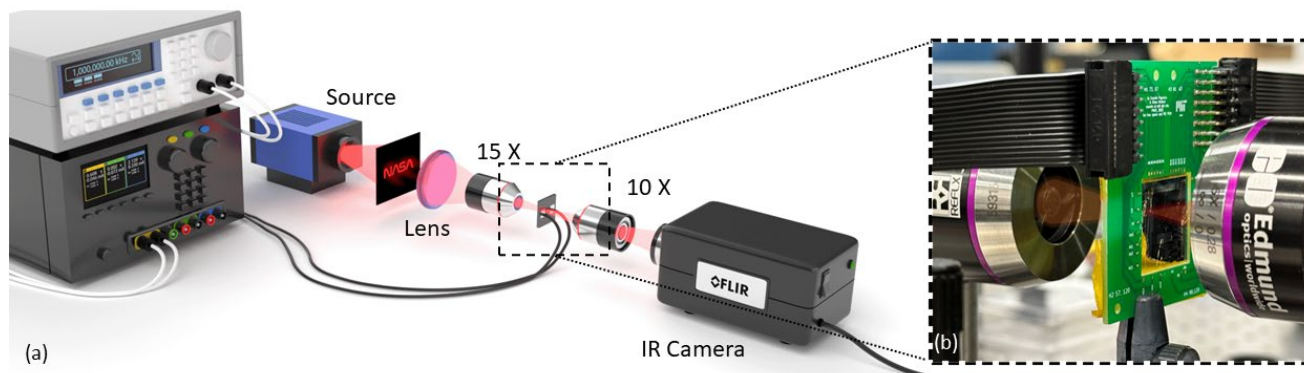


Filtering Demo

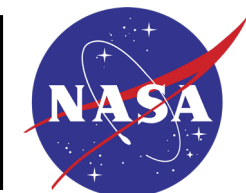
Popescu et al. arXiv preprint arXiv:2312.10468 (2023).



Filtering Demo



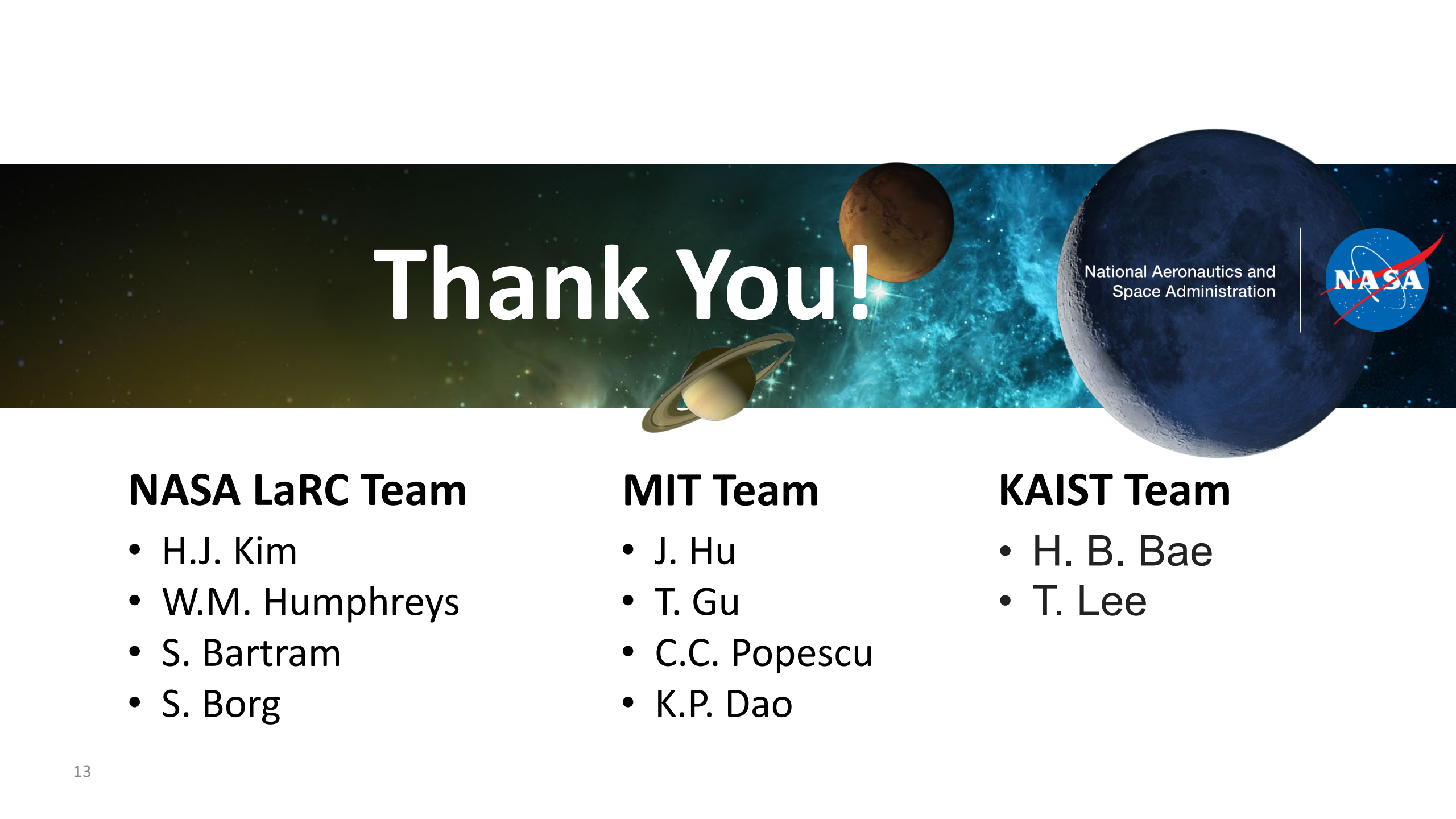
National Aeronautics and
Space Administration



Summary

- Increasing the size of PCM devices poses a challenge to **uniformly switch** the device between amorphous and crystalline.
- Switching **blanket-coated PCM** is prone to failure and shorter lifetime.
- Reconfigurable optical metafilter is demonstrated with switching contrast **>5 dB** and lifetime over **1000 cycles**.
- Metasurface PCM is more stable upon switching due to existence of **pillar type connections** between the capping layer and the heater surface.





Thank You!

National Aeronautics and
Space Administration



NASA LaRC Team

- H.J. Kim
- W.M. Humphreys
- S. Bartram
- S. Borg

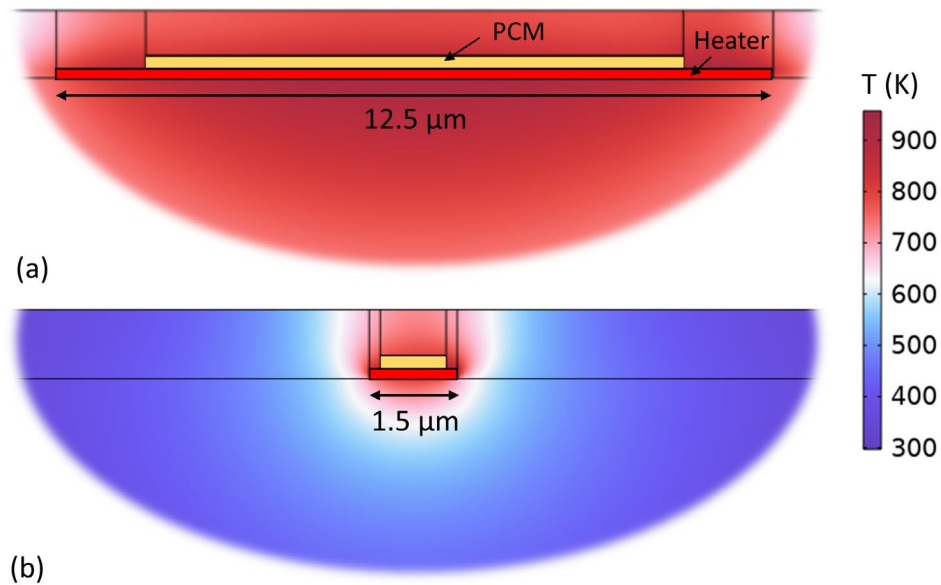
MIT Team

- J. Hu
- T. Gu
- C.C. Popescu
- K.P. Dao

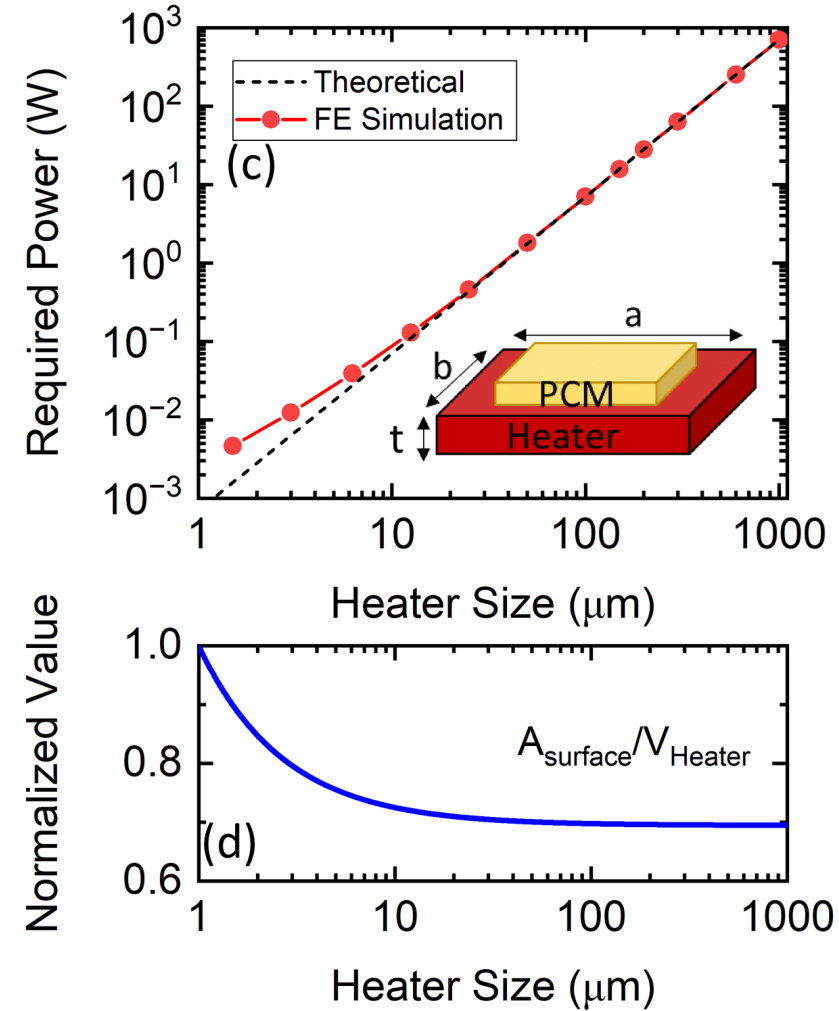
KAIST Team

- H. B. Bae
- T. Lee

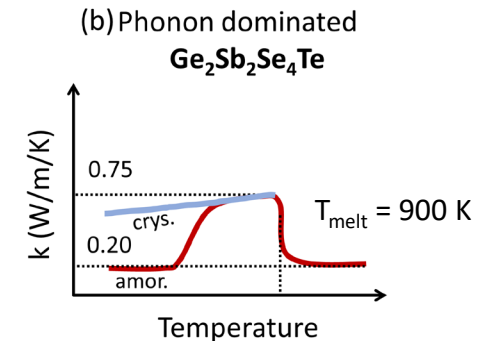
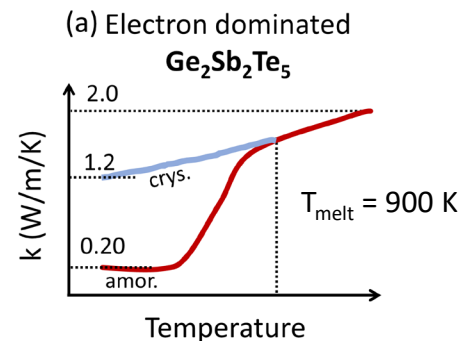
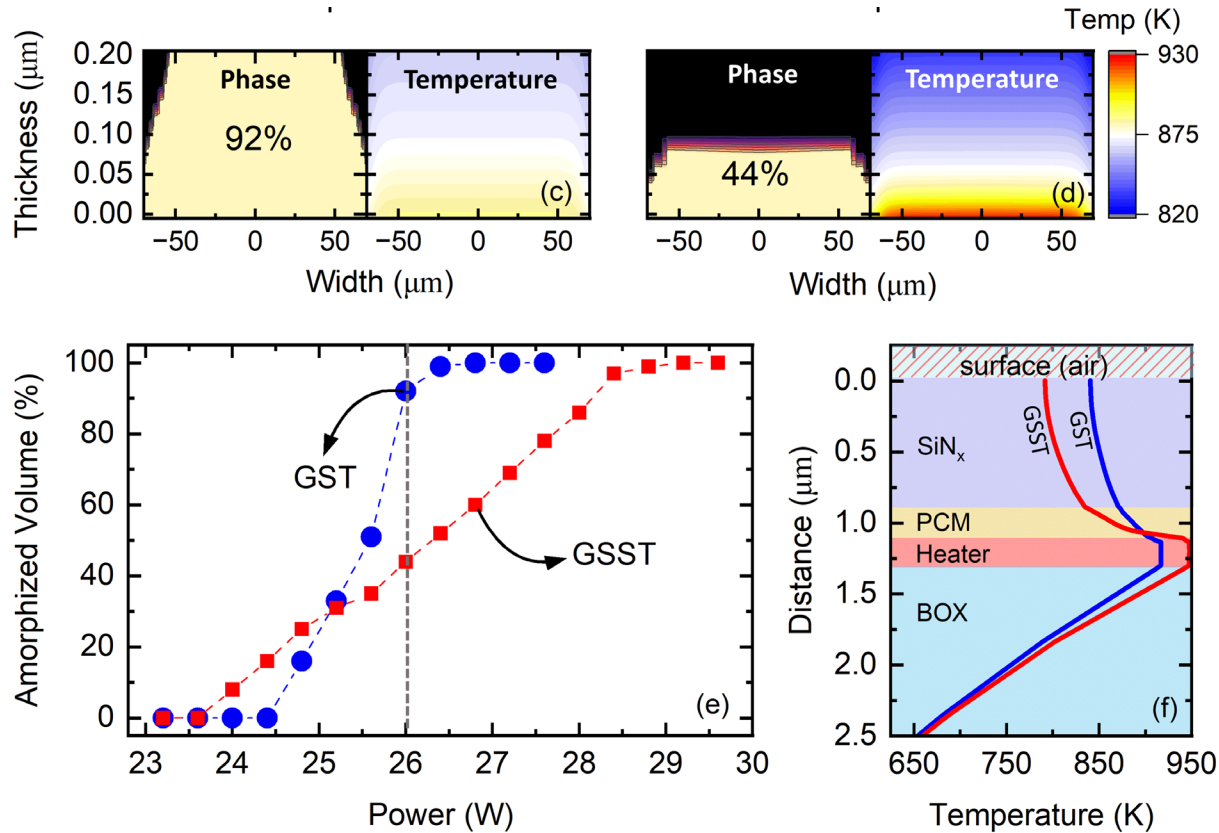
Power Consumption vs. Heater Size



Fourier's law: $Q = -kA(dT/dx)$

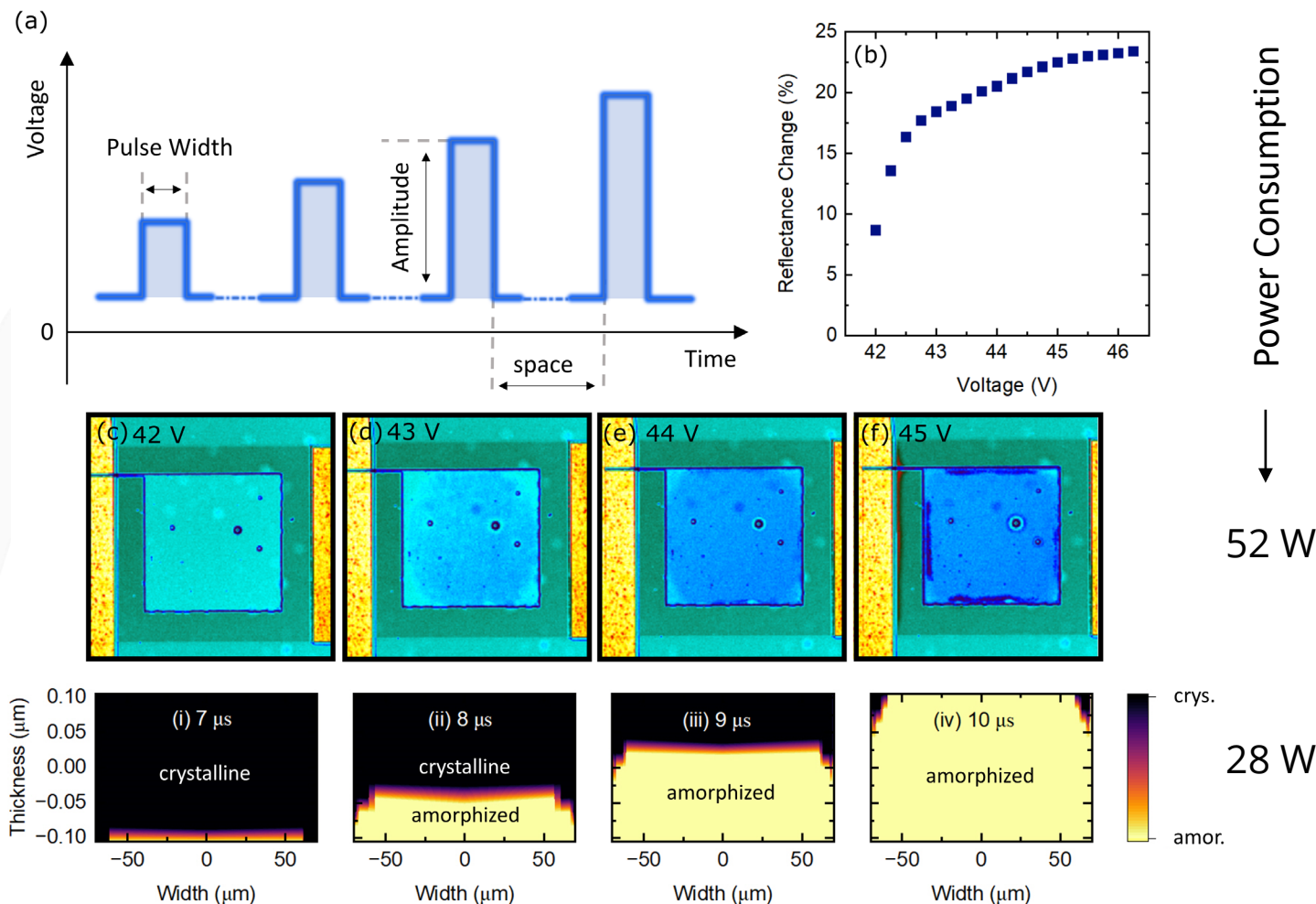
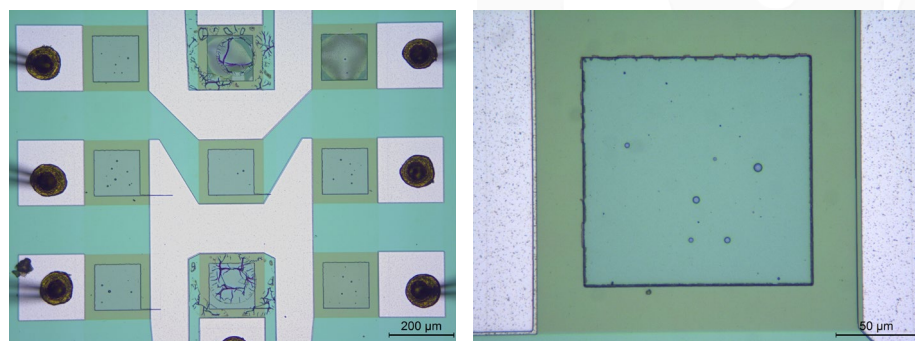
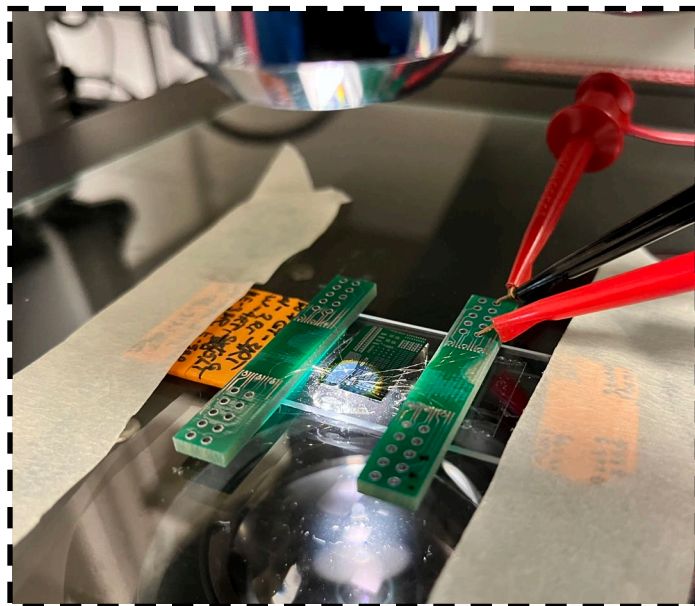


Thermal Conductivity of Liquid PCM



Aryana, et al. Toward accurate thermal modeling of phase change material based photonic devices. *Small* (2023).

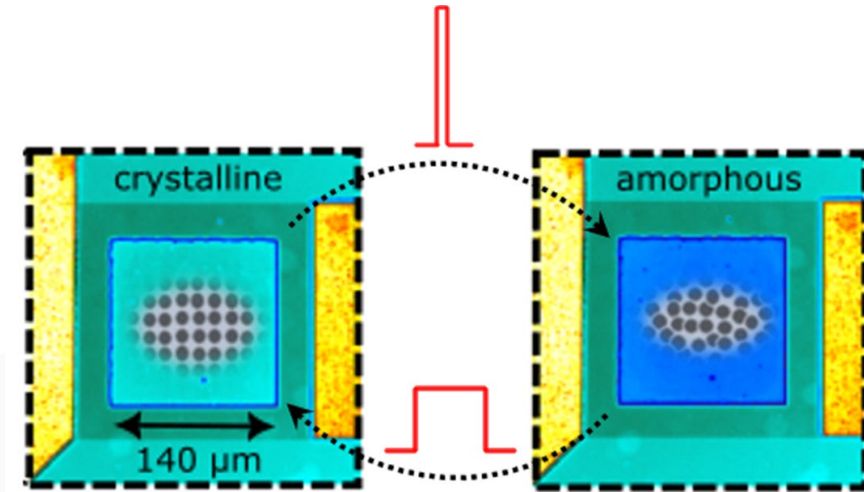
Experimental Results vs. Simulations



Critical Thermodynamic Parameters

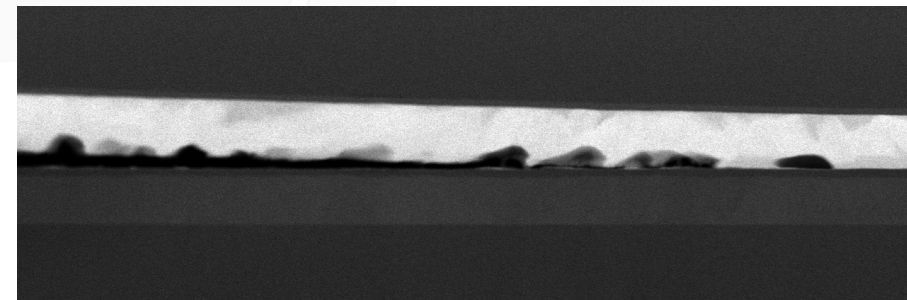
Critical thermodynamic parameters in crystalline-to-amorphous phase transformation:

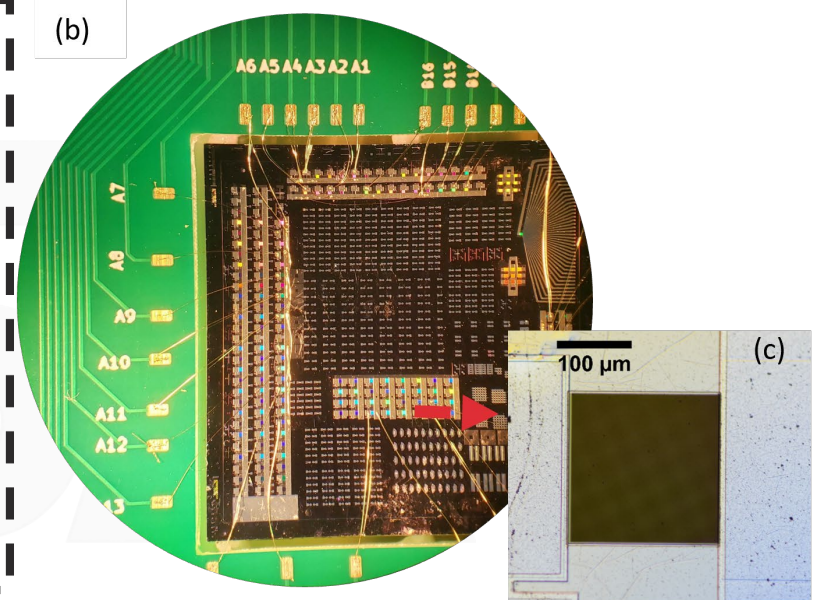
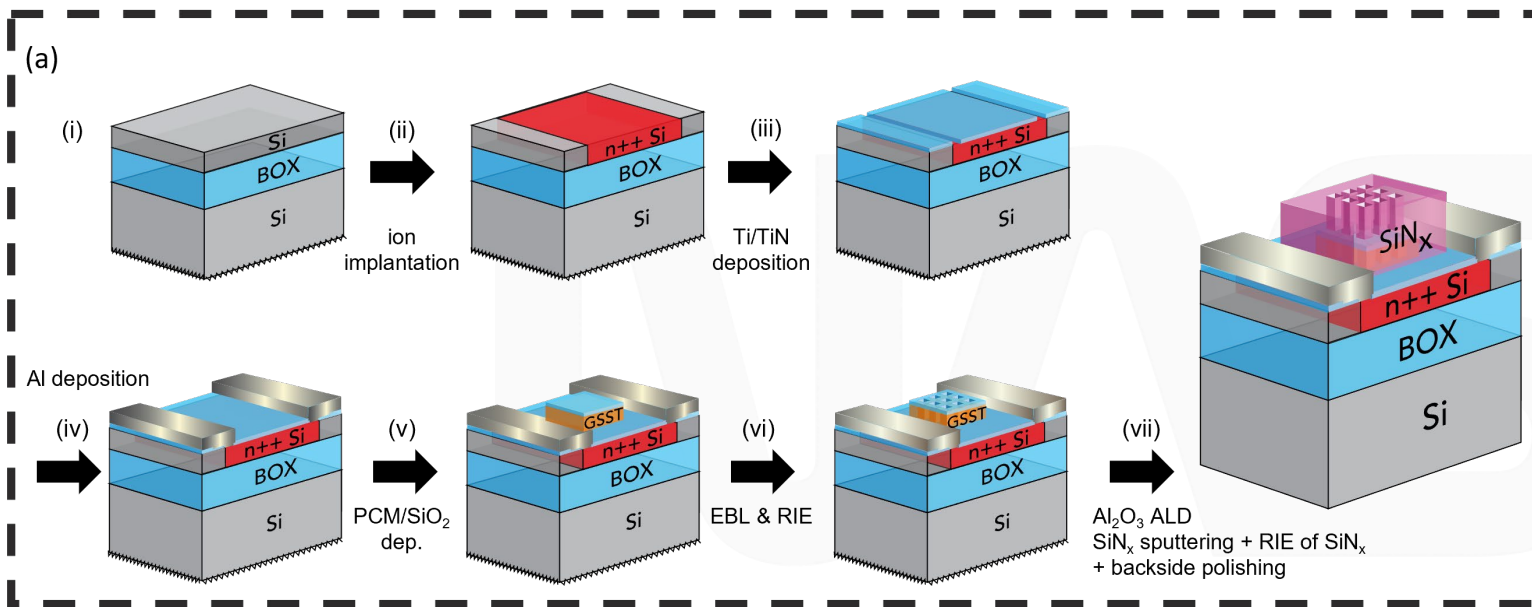
- Effect of heat capacity
- Enthalpy of melting
- Thermal conductivity of liquid phase

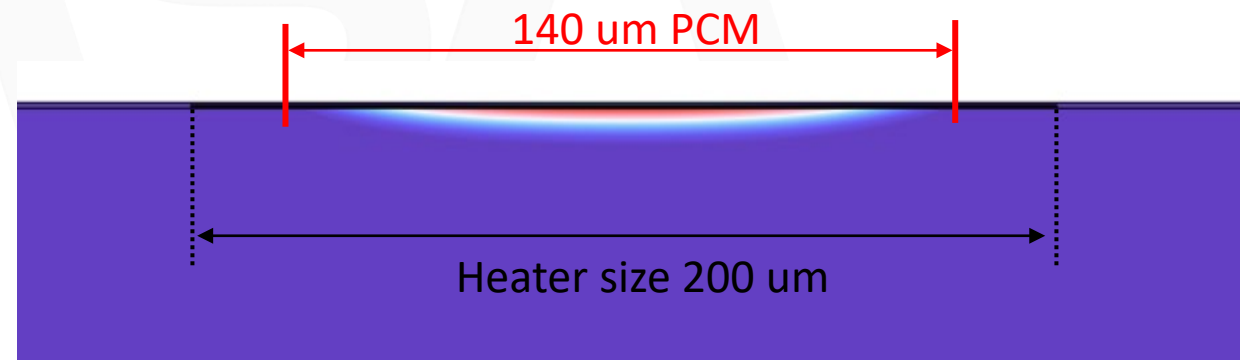
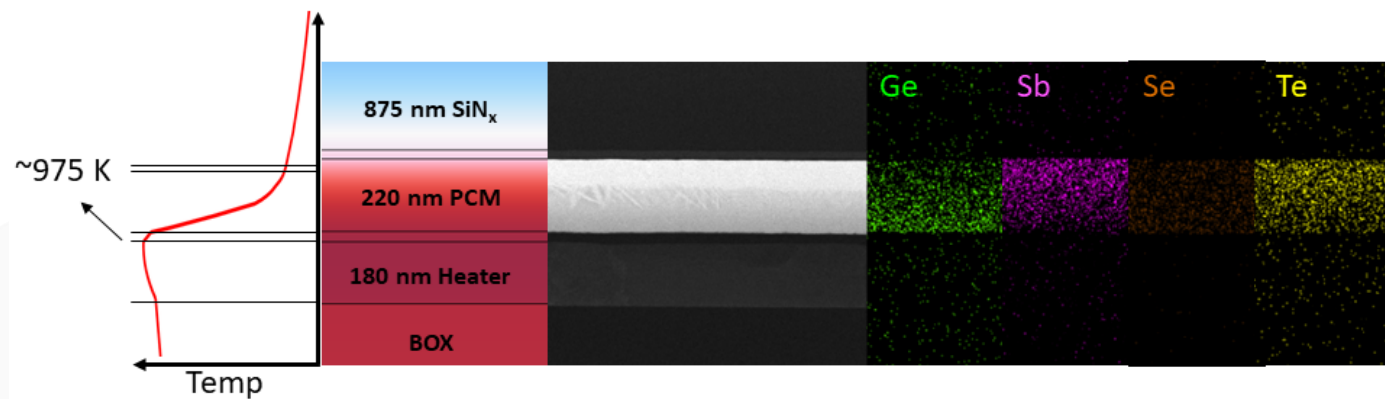
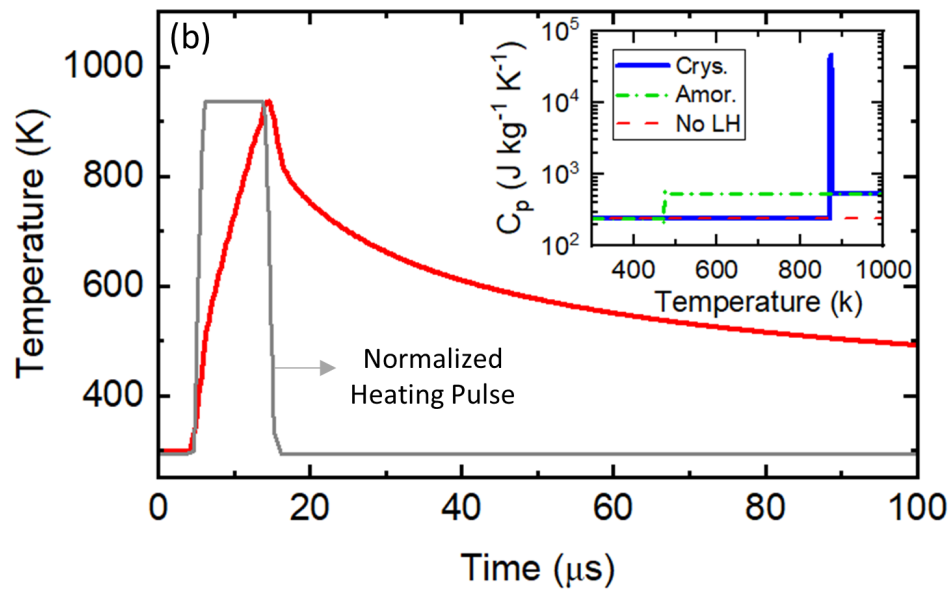
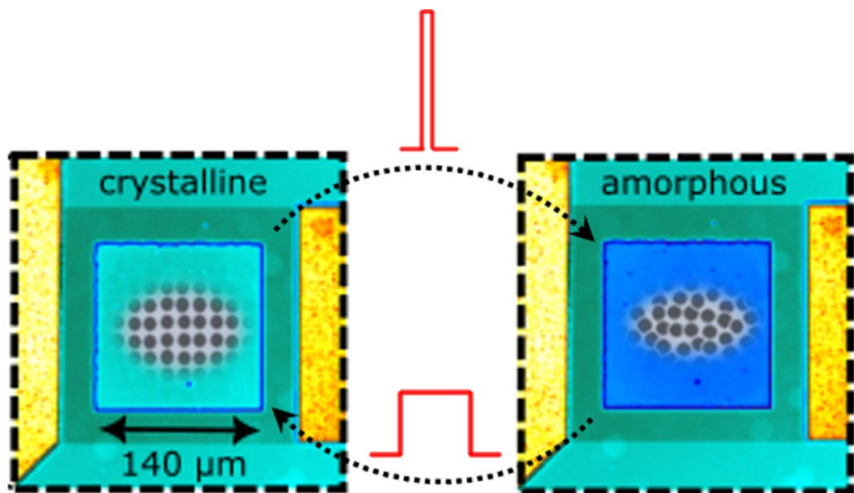


after ~1000 cycles

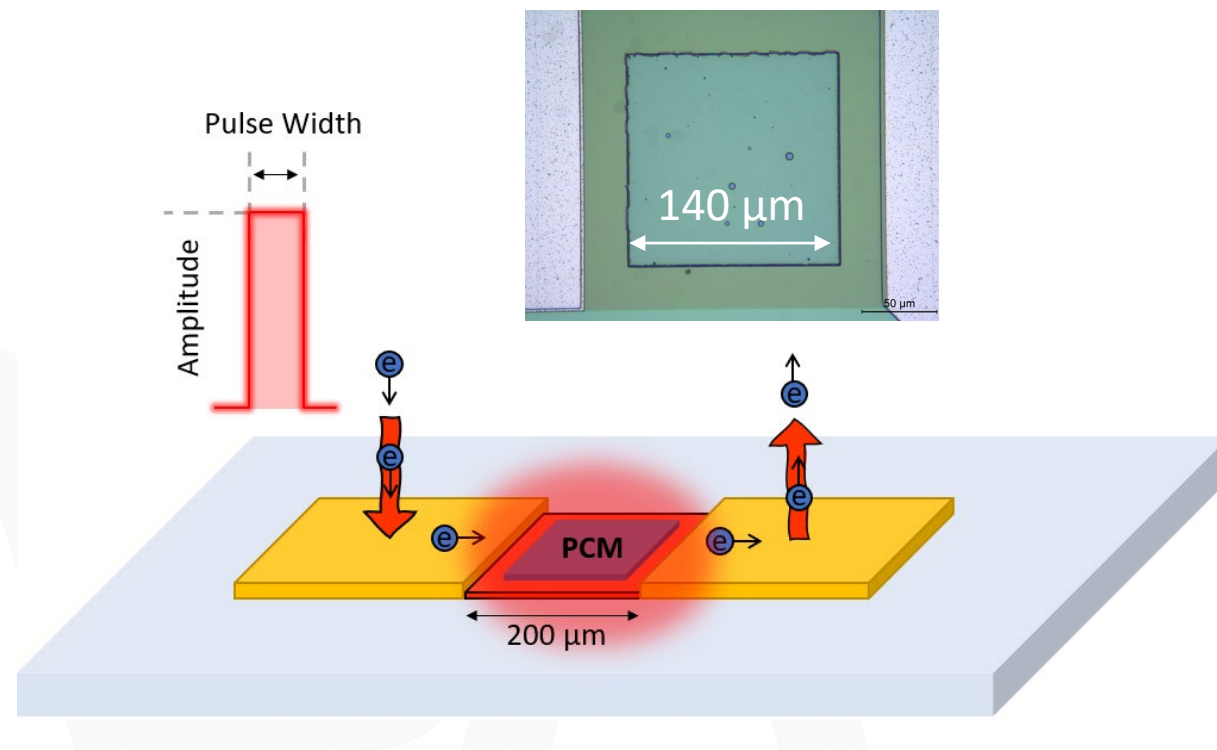
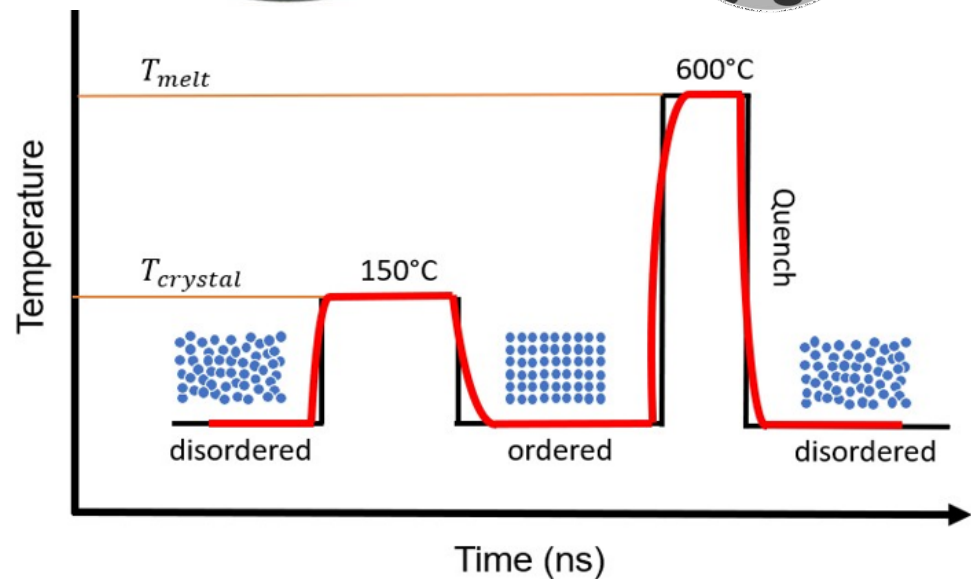
Failure



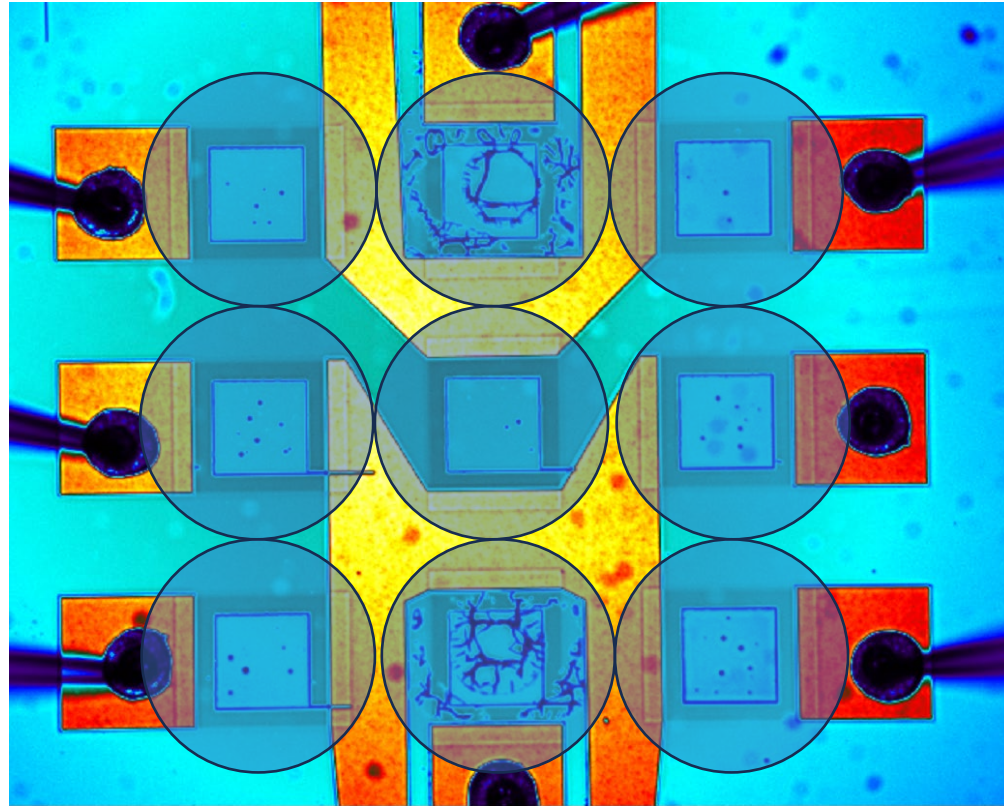




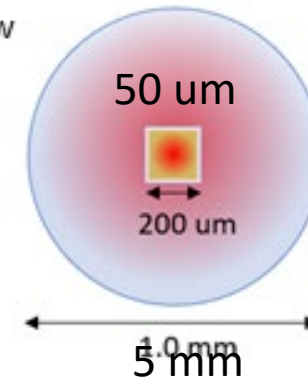
Phase Change Materials



Multi-pixel Array of PCM

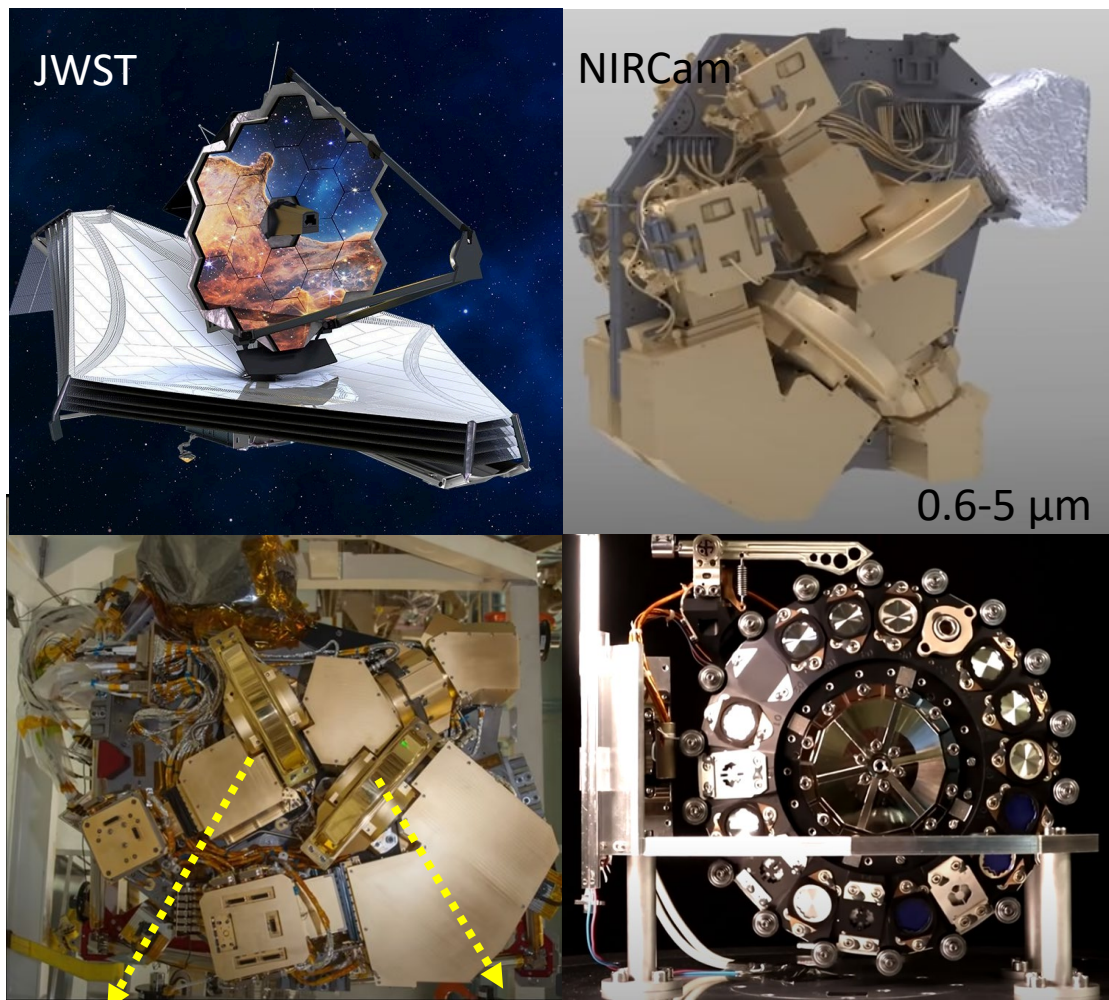


Front view



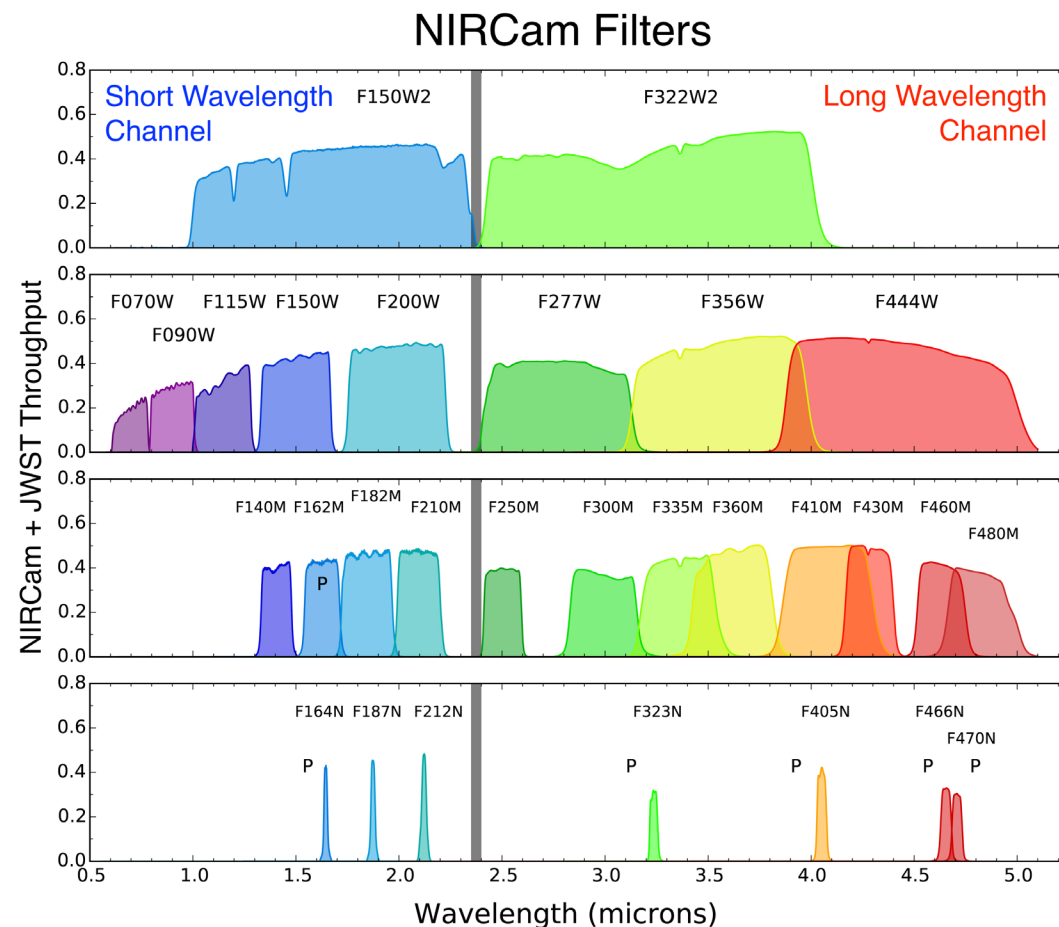
Tunable Optics for Space Explorations

<https://www.youtube.com/watch?v=MzWfUK0yvdy>

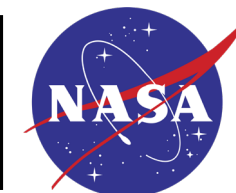


Long Wavelength
Filter Wheel

Short Wavelength
Filter Wheel



National Aeronautics and
Space Administration



Enthalpy of Fusion

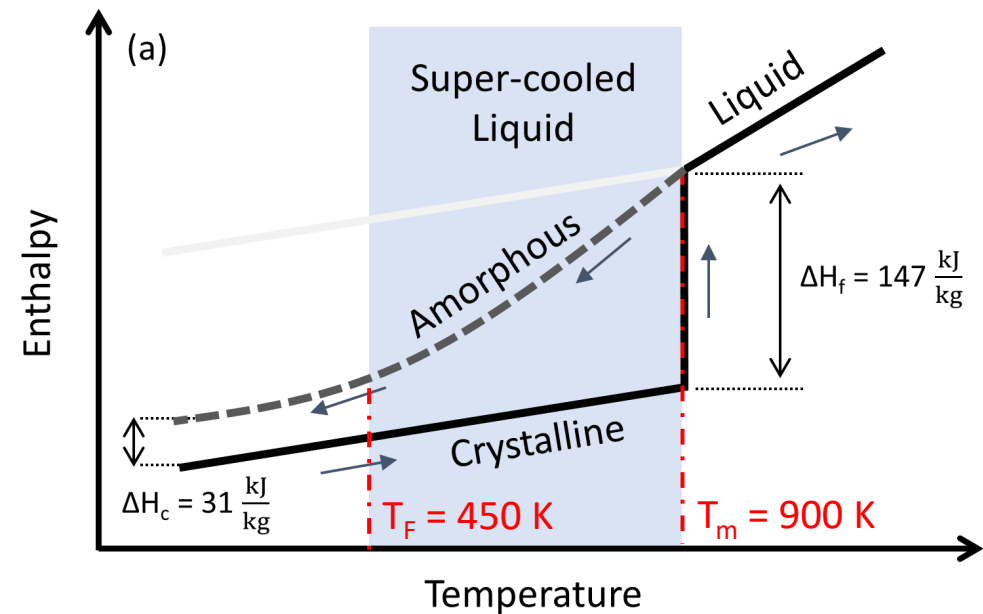


Specific heat capacity of Ice: **2090 J/kg/K**



ΔH : 334,000 kJ/kg

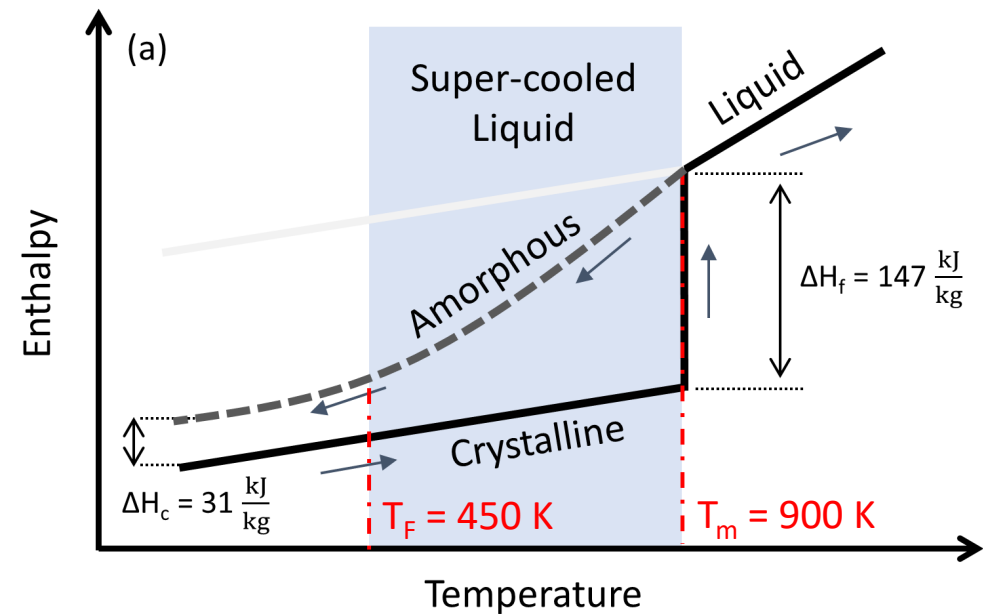
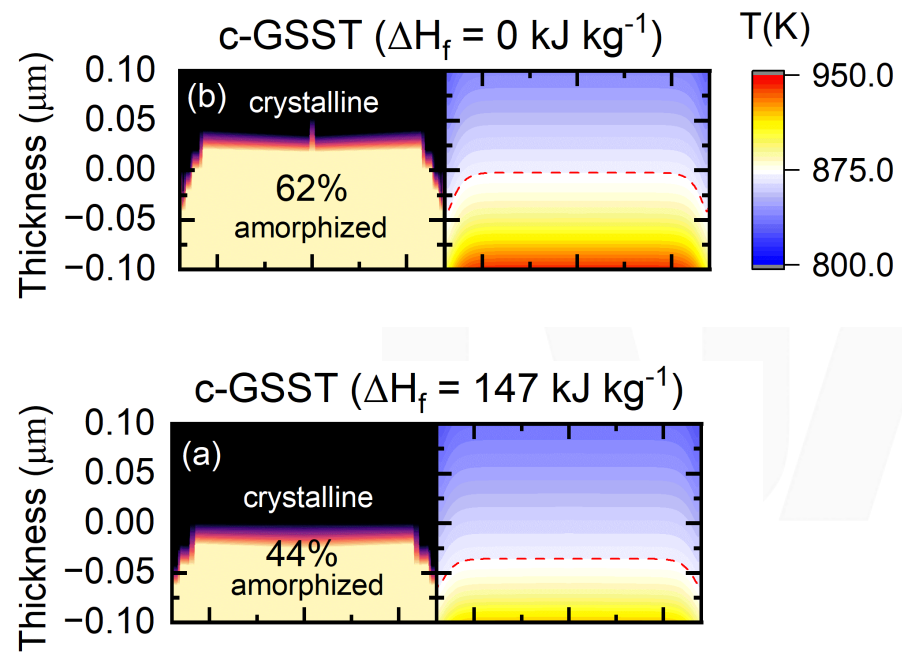
Specific heat capacity of Water: **4181 J/kg/K**



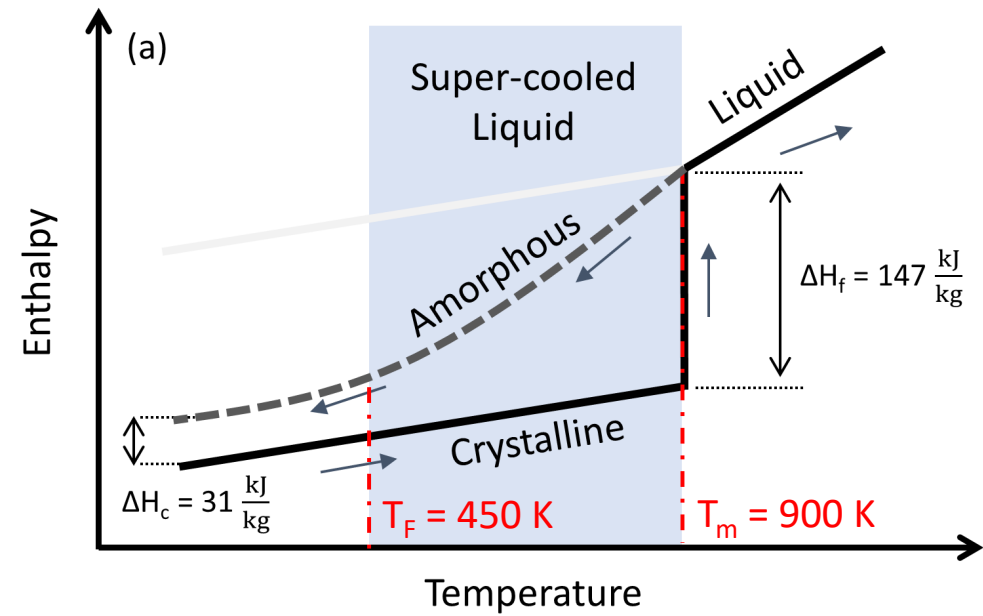
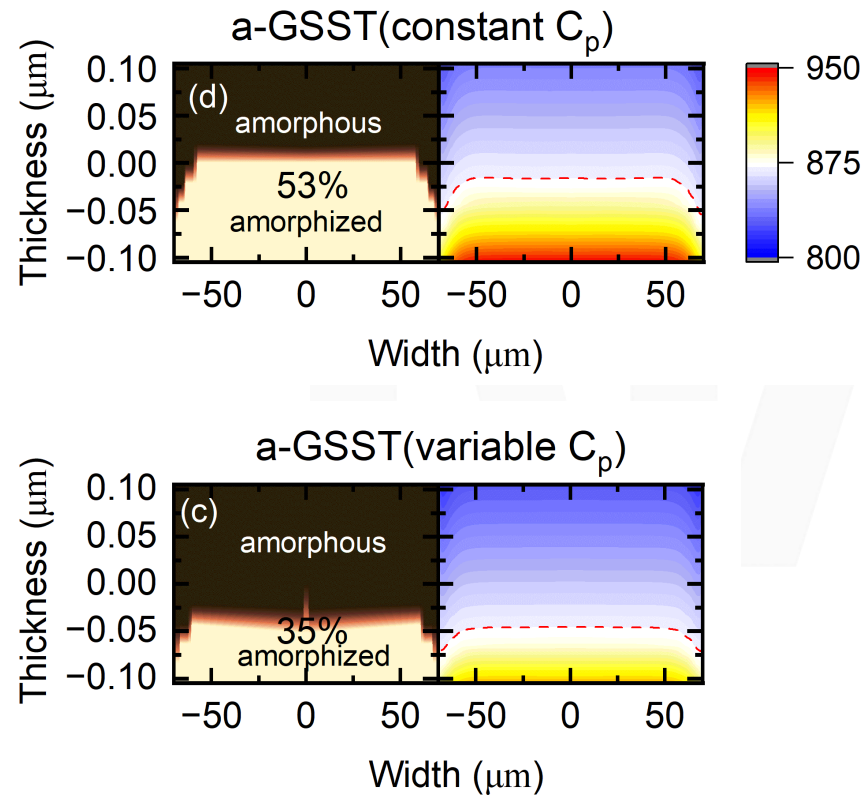
National Aeronautics and
Space Administration



Latent Heat Effects

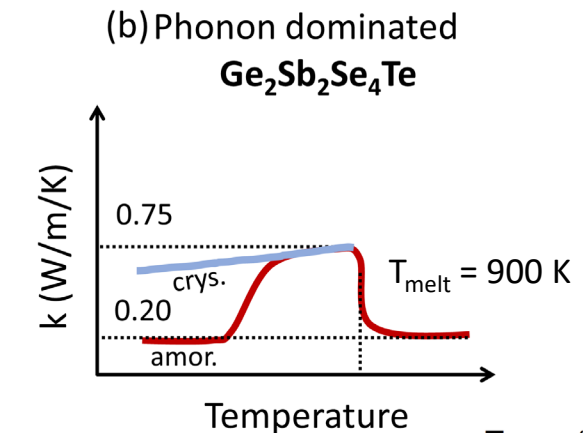
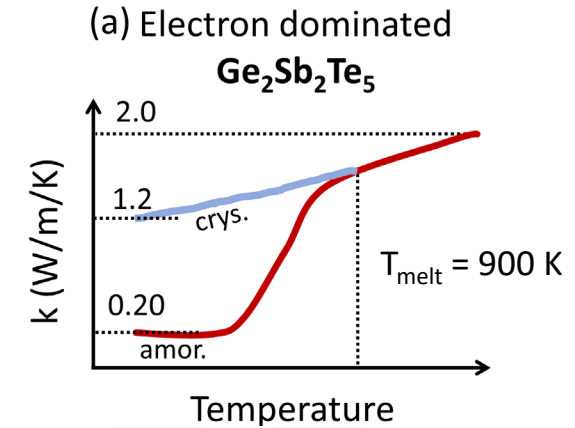
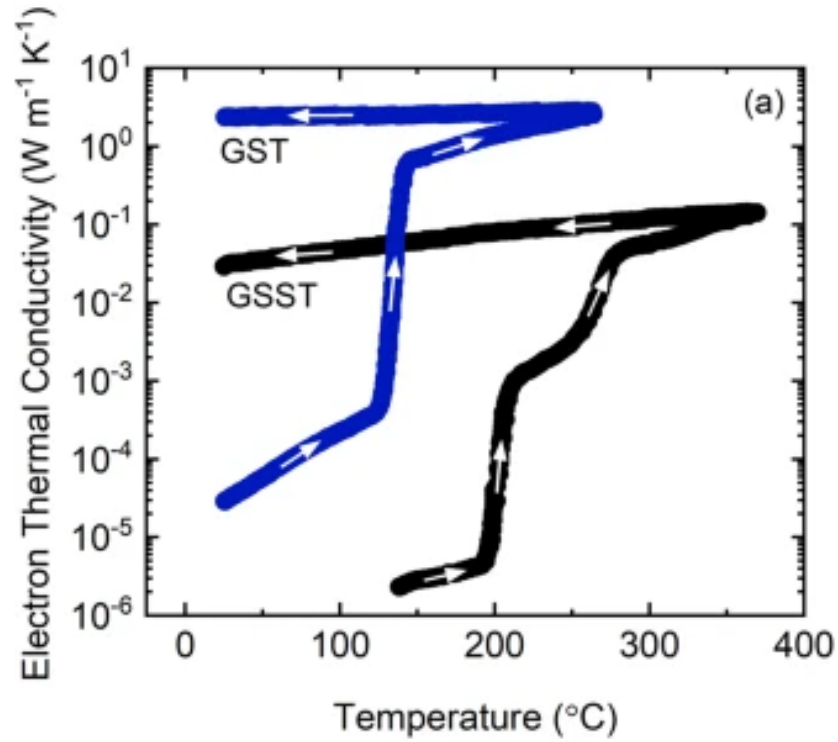


Heat Capacity Effect



Electron vs. Phonon Dominated Thermal Transport

- Thermal conductivity of the liquid phase is largely affected by the carrier's type.



Aryana et al., Suppressed electronic contribution in thermal conductivity of $\text{Ge}_2\text{Sb}_2\text{Se}_4\text{Te}$. *Nature Communications*, 12(1), p.7187.