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Thermal Homeostasis Material

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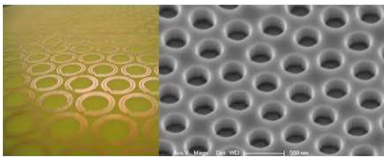
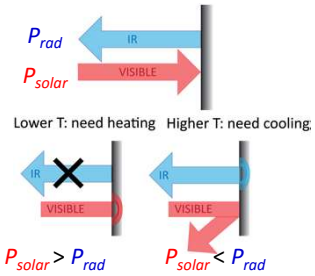
Motivation

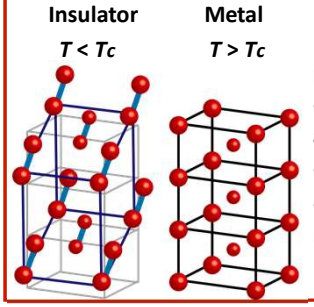
- **Goal:** Material that passively stabilizes its temperature within target range
- **Approach:** Phase-change material + nanostructure



Homeostasis idea in optics



Background: Phase-Change Materials

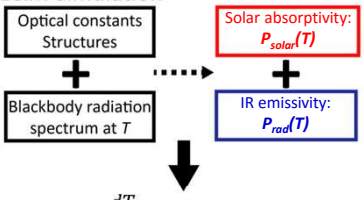


Dramatic change in optical properties due to phase transition[1,2]

- *Tc* can be engineered via doping, annealing, structuring
- Latent heat provides hysteresis
- For VO_2, hysteresis range can be reduced <5K

Thermal-optical Model

E&M Simulation



$$\rho c \frac{dT}{dt} l = P_{solar} - P_{rad}$$

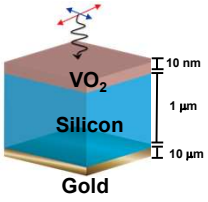
- Calculated *Psolar* and *Prad* for different structures
- Figure of merit

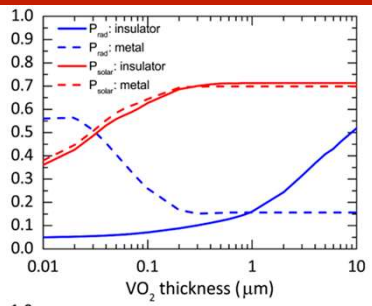
Solar: $$\frac{\int_{0.25\mu m}^{2.5\mu m} AM0(\lambda) \times \alpha(\lambda)\, d\lambda}{\int_{0.25\mu m}^{2.5\mu m} AM0(\lambda) \times 1\, d\lambda}$$

IR: $$\frac{\int_{2.5\mu m}^{30\mu m} I_{BB}(\lambda, T_I \text{ or } T_M) \times \varepsilon(\lambda)\, d\lambda}{\int_{2.5\mu m}^{30\mu m} I_{BB}(\lambda, T_I \text{ or } T_M) \times 1\, d\lambda}$$

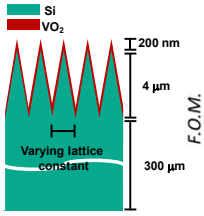
Sample Design: Planar Structure and Micro-Cone

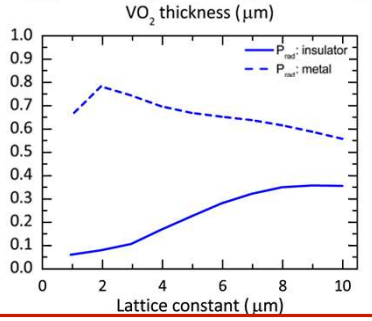
- **Planar Structure**





- **Micro-Cone**





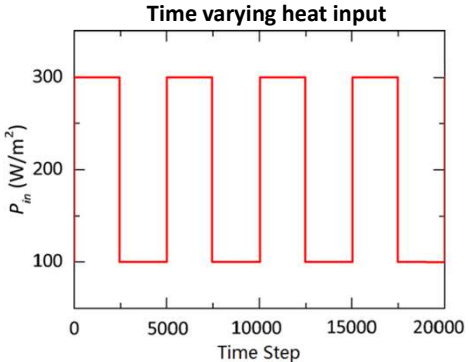
- Difference in P_{solar} is negligible (<0.05)
- Difference in P_{rad} peaks at 10 nm VO_2 and 1 μm Si substrate
- Insulating VO_2: *F.O.M.* (P_{rad})=0.05
  Metallic VO_2: *F.O.M.* (P_{rad})=0.56
  F.O.M. (ΔP_{rad})=0.51
- Higher difference in P_{rad} (> 0.75) between metallic and insulating state
- Difference in P_{rad} peaks at lattice constant = 2 μm
- Less affected by the direction of incidence

Temperature Regulation Using Ideal Nanostructured PCM

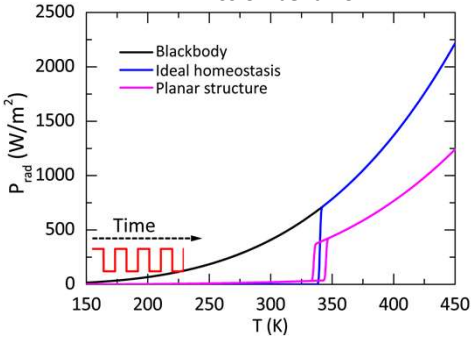
- Equilibrium temperature is determined by phase-transition temperature (T_c = 340K for thin film VO_2) and steepness of the transition curve
- Ideal Homeostasis P_{rad} Model:

$$F.O.M.(P_{rad}) = \begin{cases} 0, & T < T_c \text{ (Insulating State)} \\ 1, & T > T_c \text{ (Metallic State)} \end{cases}$$

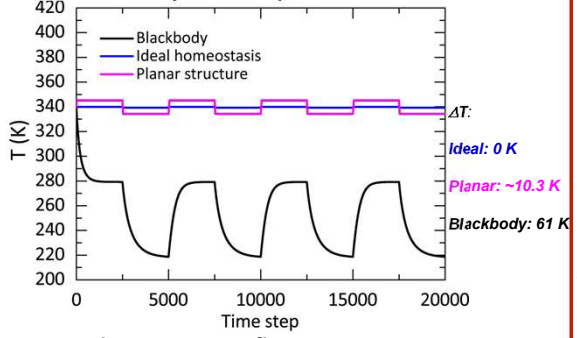
Time varying heat input



Emission behavior



System temperature



- **Size of the hysteresis window controls temperature fluctuations**

Conclusions

- Mapped out general conditions for thermal homeostasis
- Showed that nanostructured VO_2 satisfies required emission characteristics
- Further designs will tailor hysteresis window characteristics

References:
[1] Y. Gao, et. al., *Nano Energy*, **1**: 221 (2011),
[2] G. V. Chandrashekhar, et. al., *Mat. Res. Bull.*, **8**: 369 (1973)
[3] J. B. Kana Kana, et. al., *Opt. Mat.*, **54**: 165 (2016)

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