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**
- $P_{\text{rad}} > P_{\text{sol}}$: Lower $T$: need heating; higher $T$: need cooling
- $P_{\text{sol}} > P_{\text{rad}}$: Insulator
- $P_{\text{sol}} < P_{\text{rad}}$: Metal

**Background: Phase-Change Materials**
- Dramatic change in optical properties due to phase transition\(^\text{1-2}\)
- $T_c$ can be engineered via doping, annealing, structuring
- Latent heat provides hysteresis
- For VO\(_2\), hysteresis range can be reduced <5K

**Thermal-optical Model**
- $\rho c \frac{dT}{dt} \Delta l = P_{\text{sol}} - P_{\text{rad}}$
- Calculated $P_{\text{sol}}$ and $P_{\text{rad}}$ for different structures
- Figure of merit
  - Solar: $\int_{0.25 \mu m}^{2.5 \mu m} \alpha(\lambda) \lambda d\lambda$
  - IR: $\int_{2.5 \mu m}^{10 \mu m} \varepsilon(\lambda) \lambda d\lambda$

**Sample Design: Planar Structure and Micro-Cone**
- **Planar Structure**
  - Solar absorptivity: $P_{\text{sol}}(T)$
  - IR emissivity: $P_{\text{rad}}(T)$
- **Micro-Cone**
  - Solar: $\int_{0.25 \mu m}^{2.5 \mu m} AM0(\lambda) \lambda d\lambda$
  - IR: $\int_{2.5 \mu m}^{10 \mu m} T_{\text{rad}}(\lambda, T_1 \text{ or } T_2) \lambda d\lambda$

**Temperature Regulation Using Ideal Nanostructured PCM**
- Equilibrium temperature is determined by phase-transition temperature ($T_c \approx 340K$ for thin film VO\(_2\)) and steepness of the transition curve
- **Ideal Homeostasis $P_{\text{rad}}$ Model**:
  - $F.O.M. (P_{\text{rad}}) = \begin{cases} 0, & T < T_c \text{ (Insulating State)} \\ 1, & T > T_c \text{ (Metallic State)} \end{cases}$

**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**: