Nano cool, micro cooler: Enhanced infrared reflectance from composites with low bandgap semiconducting microinclusions

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Conventional insulators for applications at low temperatures are primarily designed to prevent conductive heat loss. However, design of efficient thermal insulation for high temperature conditions must also minimize the dominant heat loss through radiative transfer. Increased reflectance from highly scattering microparticle inclusions in an insulating dielectric at low volume fractions thus offers a promising way to reduce radiative thermal losses with a negligible increase in thermal conductivity. Here, we employ Monte Carlo modeling and Mie scattering theory in conjunction with the effective medium theory (EMT) to understand the underlying principles for the design of efficient thermal insulators at high temperatures. We study the influence of the size-dependent Mie scattering efficiency Q_{sca}, absorption efficiency Q_{abs} and anisotropy factor g on the radiative transfer properties of insulating composites to identify the optimal size, volume fraction and material of microinclusions for obtaining maximal infrared reflectance. Results are presented for the infrared spectra of an insulating dielectric with microinclusions of low bandgap semiconducting tellurium and lead-sulfide. Similar to enhanced reflectance from metallic nanoparticles [1], the low bandgap semiconducting microparticles enhance reflectance in the infrared regime due to increased scattering (see figure 1a) from the localized surface plasmon resonances (LSPR). At volume fractions as low as $f = 0.01$ reflectances of 70 - 85 % are obtained (figure 1 b-c). Increased Q_{sca} and decreased g improve reflectance, while a high value of Q_{abs} results in a decrease due to increased absorbance. Our results thus identify the relevant factors that influence the design of thermal insulators for high-temperature applications.

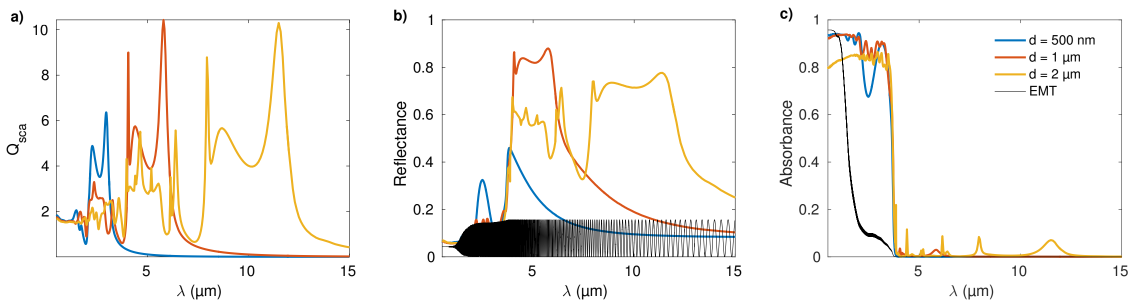

Figure 1: Scattering efficiency Q_{sca} of Te particles of different diameters (a), spectral reflectance and absorbance (b-c) for composites with Te inclusions in a host medium of refractive index $n_m = 1.5$, thickness $l = 200\,\mu m$ and volume fraction of inclusions $f = 0.01$.

[1] J.M. Luther, P.K. Prashant, T. Ewers and A.P. Alivisatos, Nature Materials **10** (2011) 361-366.