Optical properties of films embedded with particles of a known size distribution

Kevin Conley,[1] Vaibhav Thakore,[2] Tapio Ala-Nissilä[1,3]

[1] Department of Applied Physics and QTF Center of Excellence, Aalto University, Finland

[2] Department of Applied Mathematics, Western University, Canada

[3] Interdisciplinary Centre for Mathematical Modelling, Departments of Mathematical Sciences and Physics, Loughborough University, United Kingdom

August 22, 2019

Scattering from mixtures of particles

- Previously, we considered films embedded with uniform particles with radius, r.
- The absorption and scattering coefficients of the films $\rightarrow$ Maxwell-Garnett effective medium:

$$\mu_{\mathrm{sca,abs}} = \frac{3}{2}\frac{f\ Q_{\mathrm{sca,abs}}}{2r},$$

  where Q_{sca} and Q_{abs} are the scattering and absorption coefficients of single particles (for ex. from Mie theory) and f is the volume fraction of the inclusions.
- The results of a few films embedded with mixtures, but these were not considered in a robust manner.

Particle size distribution

- The absorption and scattering coefficients of a distribution of i particle sizes:

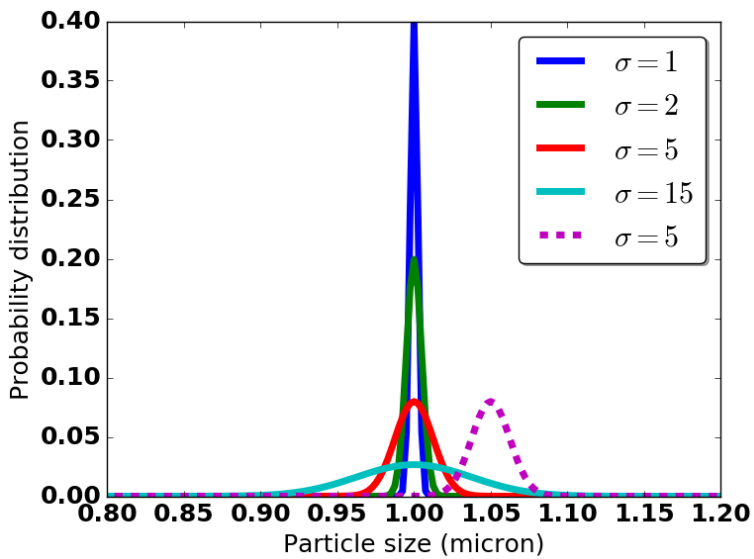
$$\mu^{mix}_{\mathrm{sca,abs}} = \sum_r \frac{3}{2} \frac{f(r)\ \rho(r) Q_{\mathrm{sca,abs}}(r)}{2r},$$

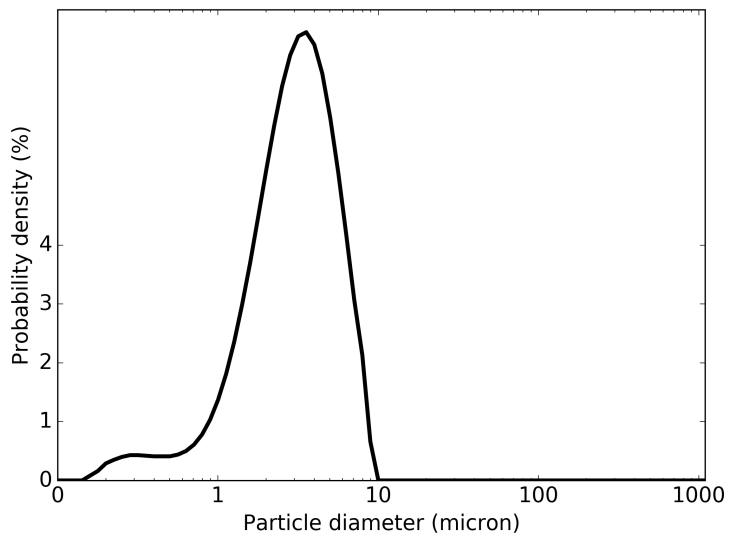
  where $\rho(r)$ is the probability distribution function:

- For example, a normal size distribution with standard deviation, σ, and average, μ

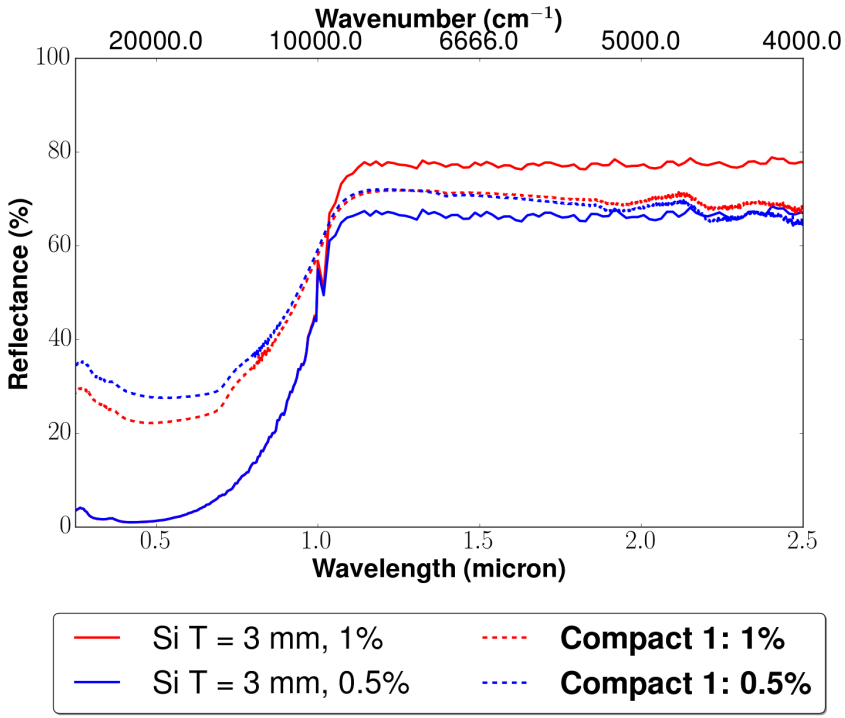
$$\rho(r) = \frac{1}{\sigma\sqrt{2\pi}} \exp[\frac{-(r-\mu)^2}{2\sigma^2}].$$

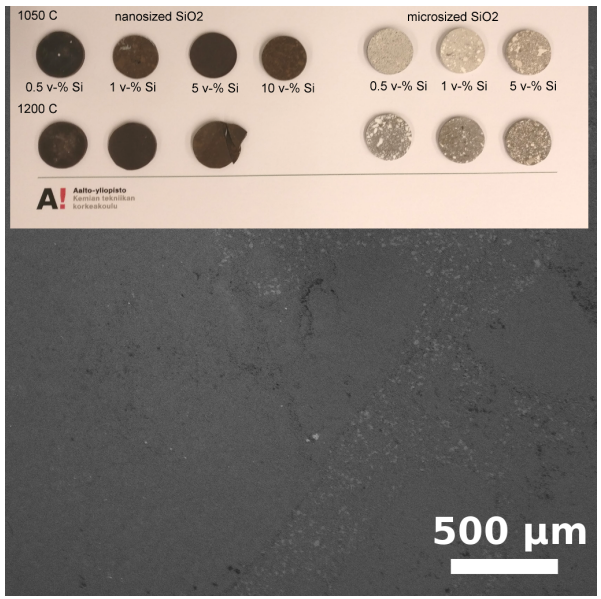
- Or a measured size distribution (Static Light Scattering)





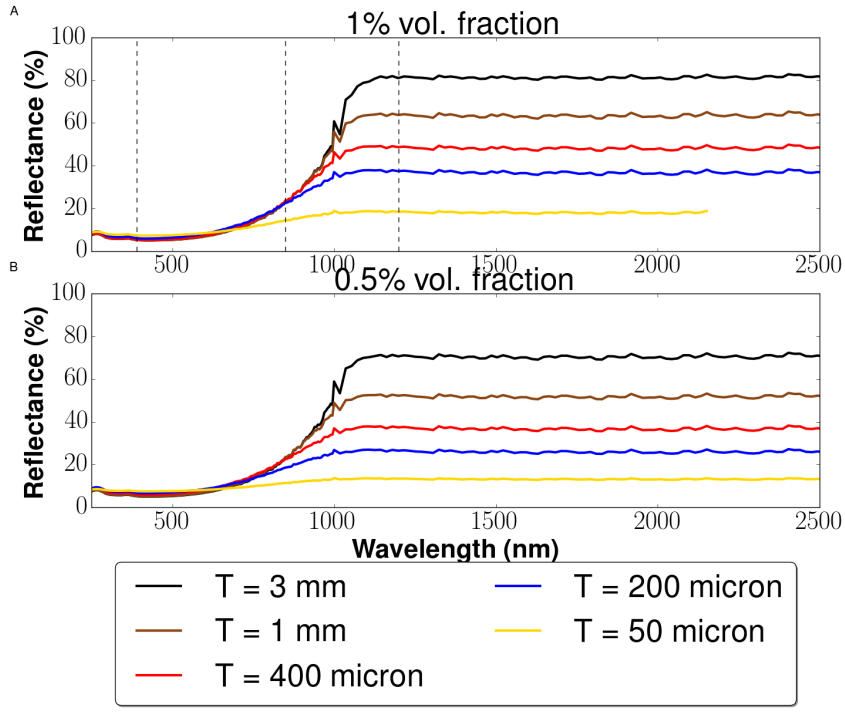
Diffuse reflectance of Si/SiO_2 composites





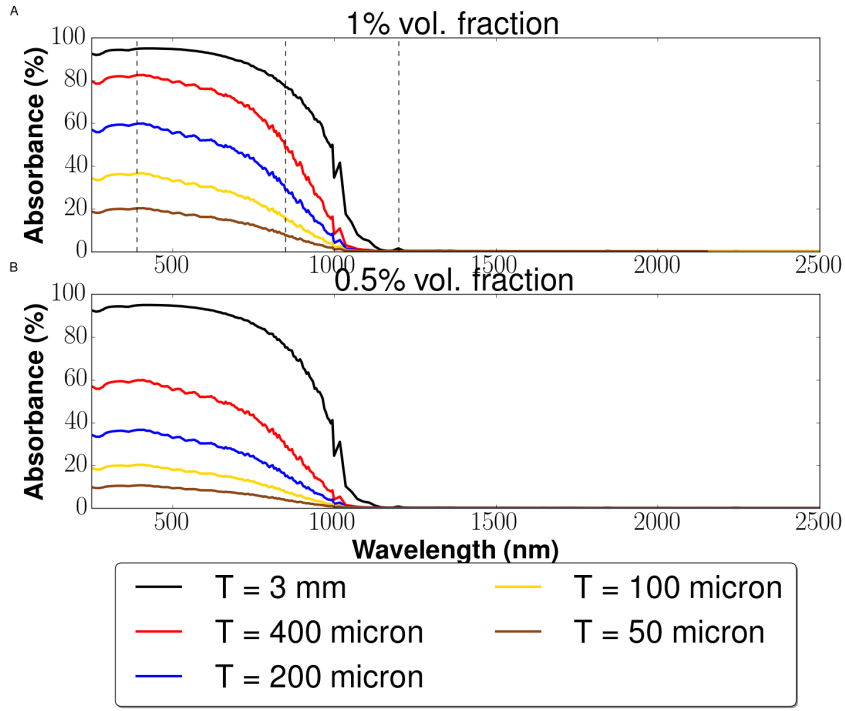
- Reflectance spectra simulated with experimentally obtained size distributions
- Good agreement between theory and experiments - Diffuse Reflectance Spectroscopy.
- **T = 3 mm**
- Si band gap = 1.11 micron

Composites thickness



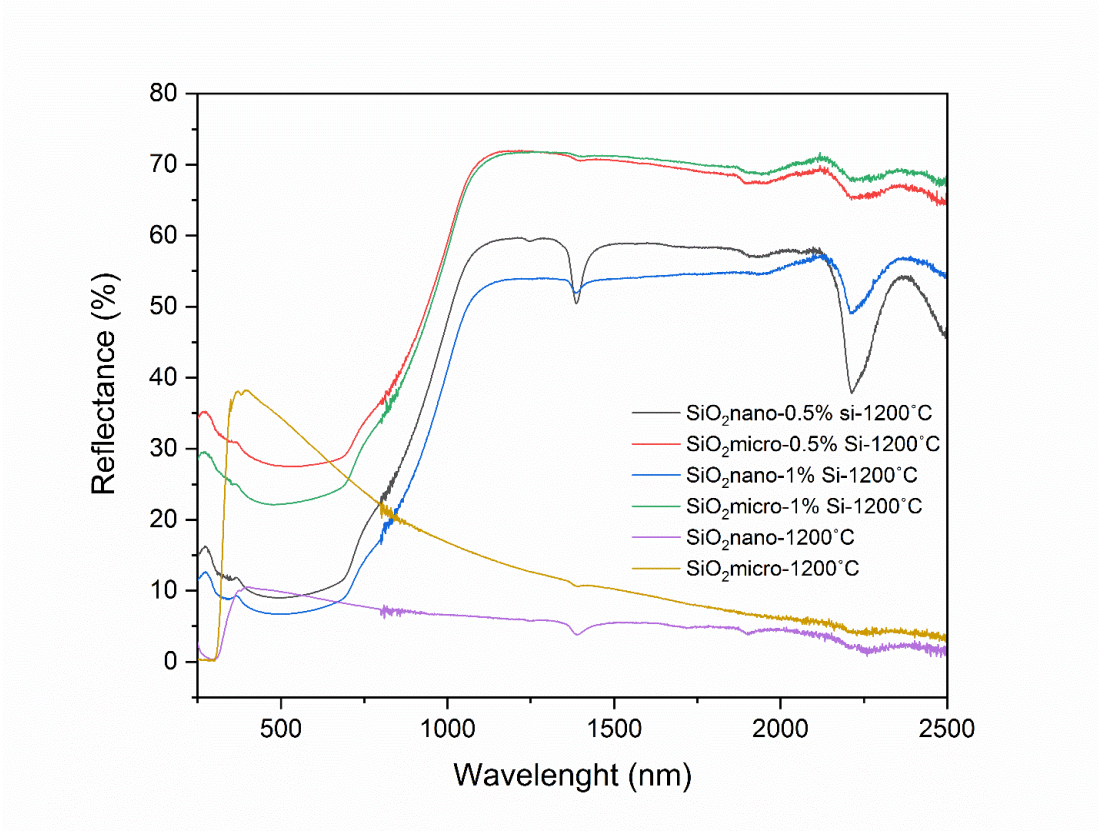
- Plateau reflectance increases with composite thickness
- Reflectance minimum decreases with composite thickness $\rightarrow$ absorption

Absorption of Si/SiO_2 composites



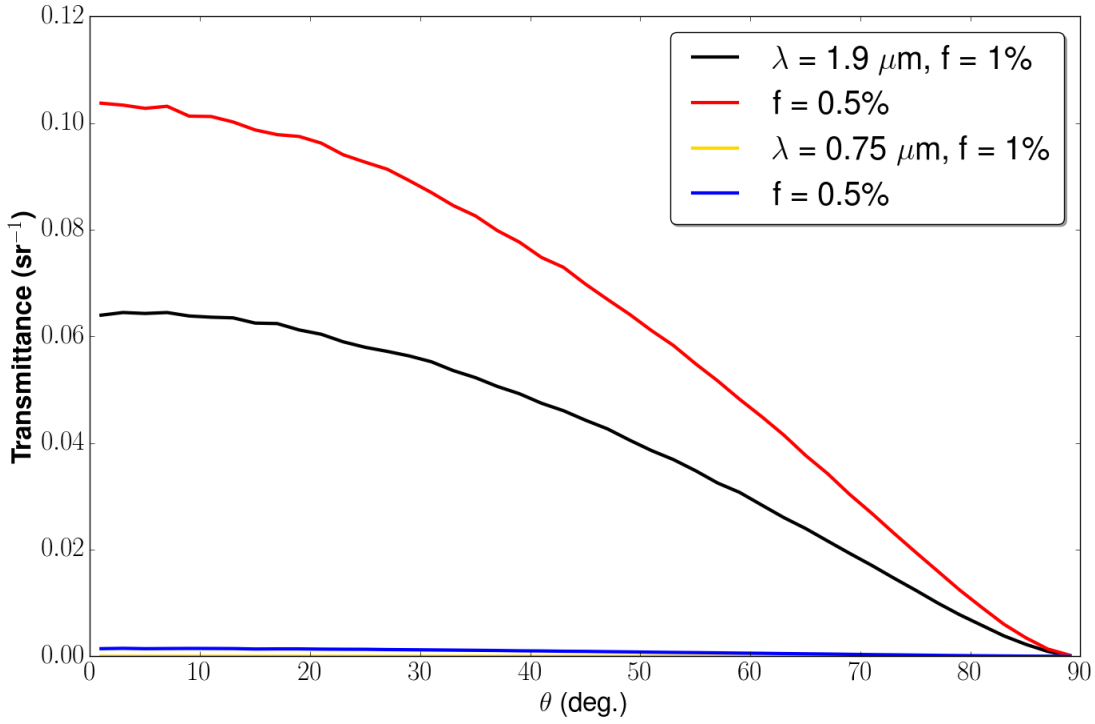
- Three regions: A - High absorption ($\lambda < 0.6$ micron), B- Competing absorption and reflectance (0.6 micron $< \lambda <$1.1 micron), C - high reflectance ($\lambda > 1.1$ micron)

Diffuse reflectance of Si/SiO_2 composites



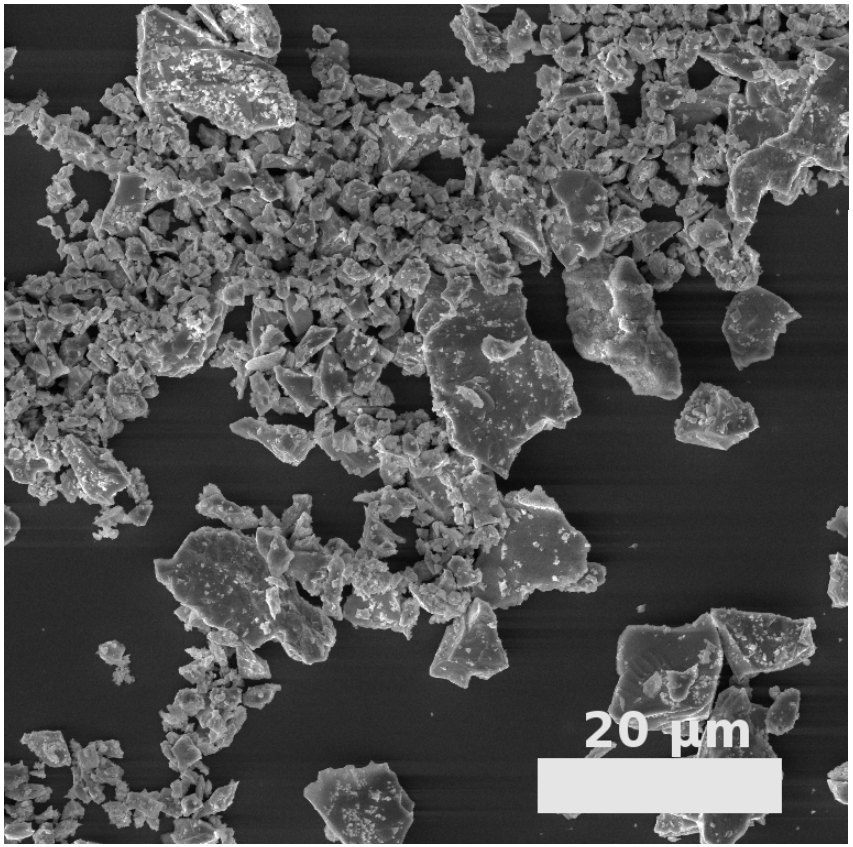
- Medium affecting the spectra $\lambda < 0.6$ micron
- Reflectance lower in nano-SiO_2 due to the grain boundaries (higher absorption)
- Including experimental n,k(λ) might capture these effects
- Several exisiting forms of SiO_2 (fused silica, quartz, etc.)

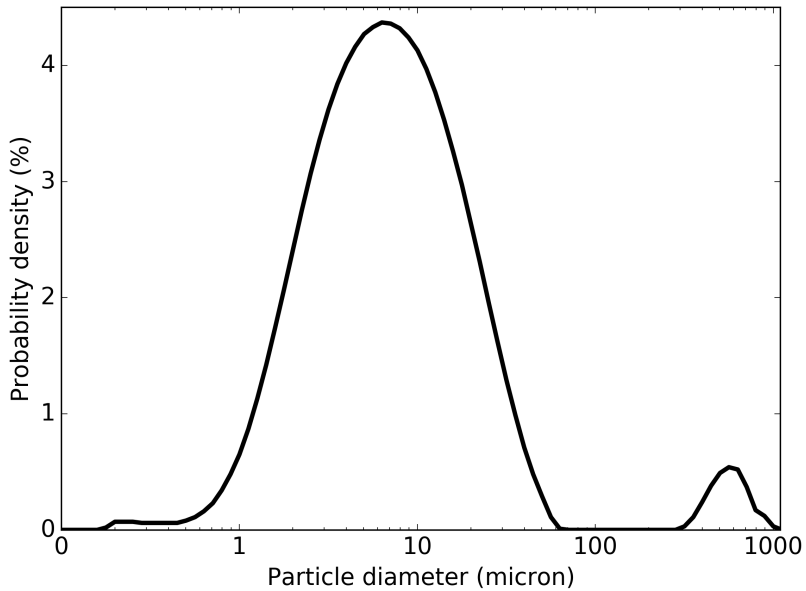
Angular dependent transmittance intensity



- 3 mm thick composite of Si embedded in SiO_2 at 1% and 0.5%

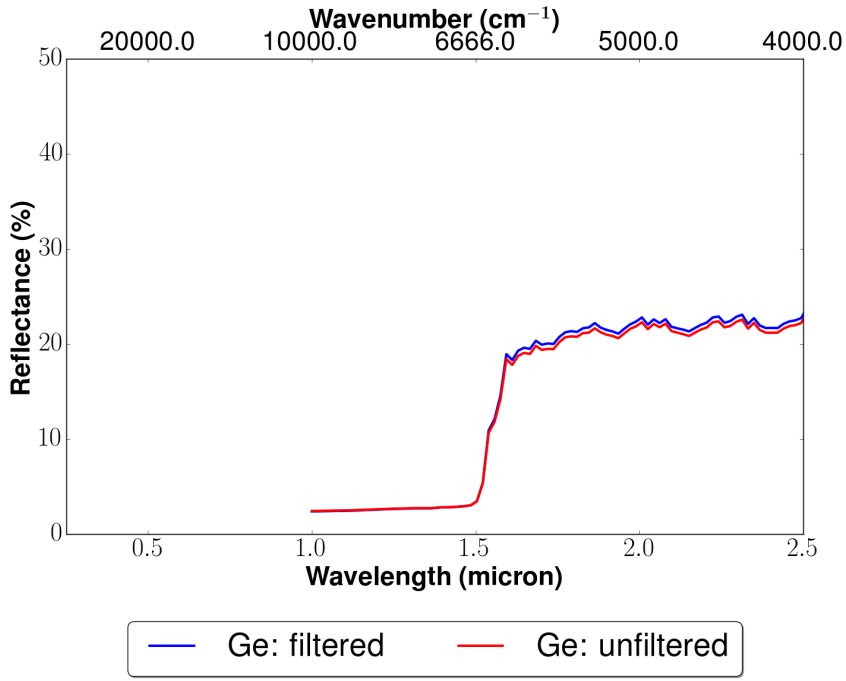
Ge: micro-particle size distribution





- Distribution measured by Static Light Scattering
- Non-spherical particles

Ge: predicted reflectance with experimental size distribution



- Simulate reflectance spectra with experimental particle size distribution: filtered and unfiltered
- Filtering the large particle sizes does not produce reflectance "windows"
- Resonances in large (greater than 100 micron) Ge microparticles are mostly continuous.
- Need better separation of small (less than 5-10 micron) particles