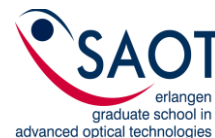


EUROREG-PV 2014

Light Propagation in Phosphor-Filled Matrices for Photovoltaic PL Down-Shifting

Anastasiia Solodovnyk, B. Lipovšek, K. Forberich, E. Stern, M. Topič, and C. J. Brabec

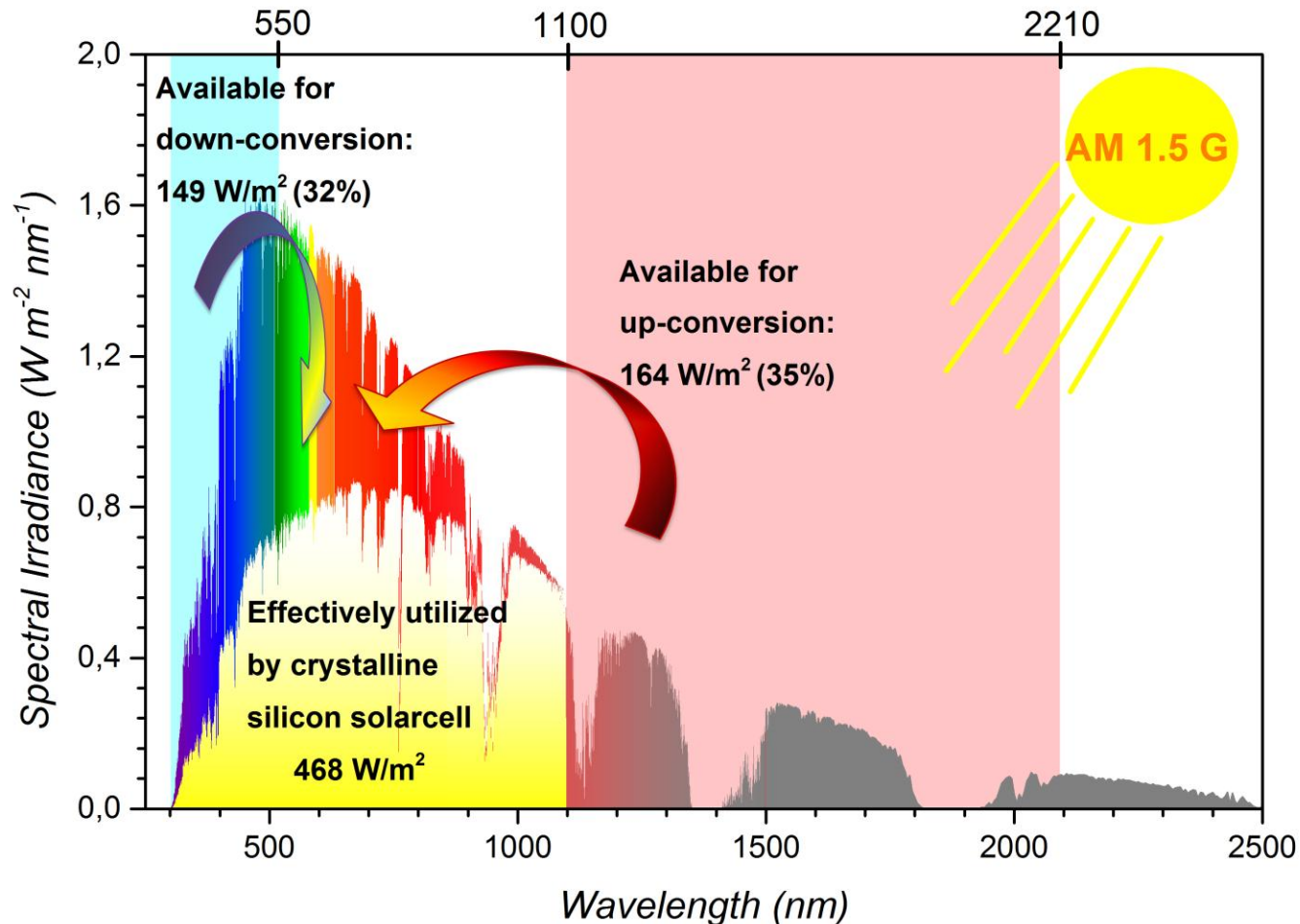


Outline

1. Motivation for LDS
2. Computational Model
3. Properties of Materials
4. Experimental Methods
5. Results
 - Variation of Matrices
 - Variation of Particle Size Distributions AND Matrices
6. Summary and Conclusions

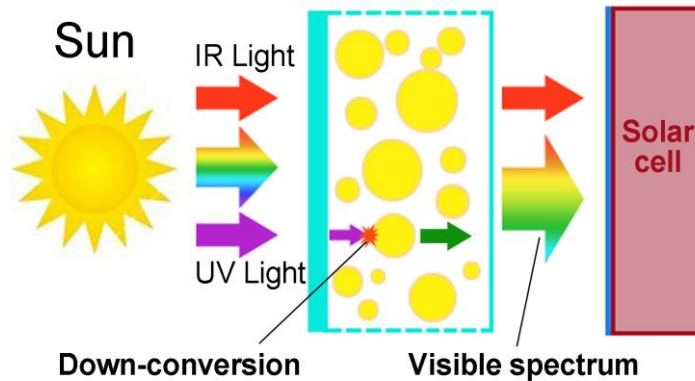
Motivation

Luminescent Down-Shifting (LDS) – conversion of the UV-photons to the visible light wavelengths with the efficiency $\leq 100\%$.



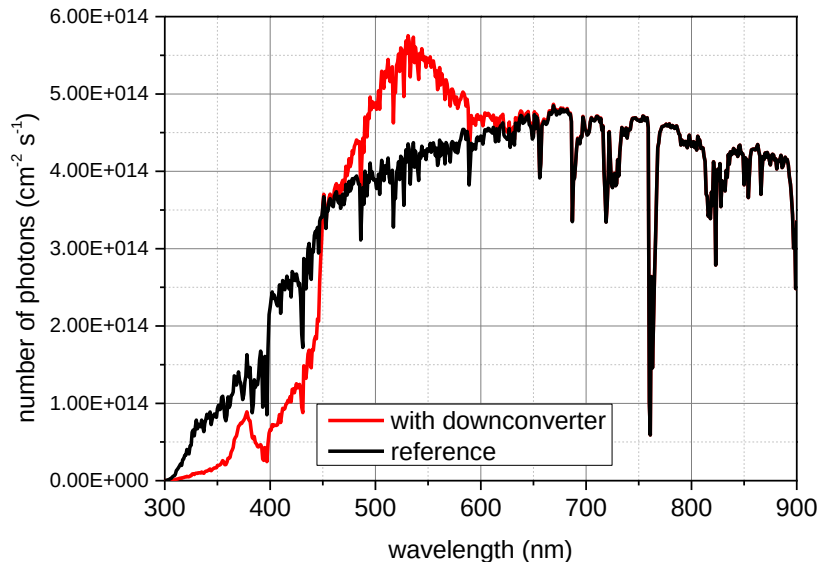
Motivation

Solar Spectrum Modification for Solar Cells

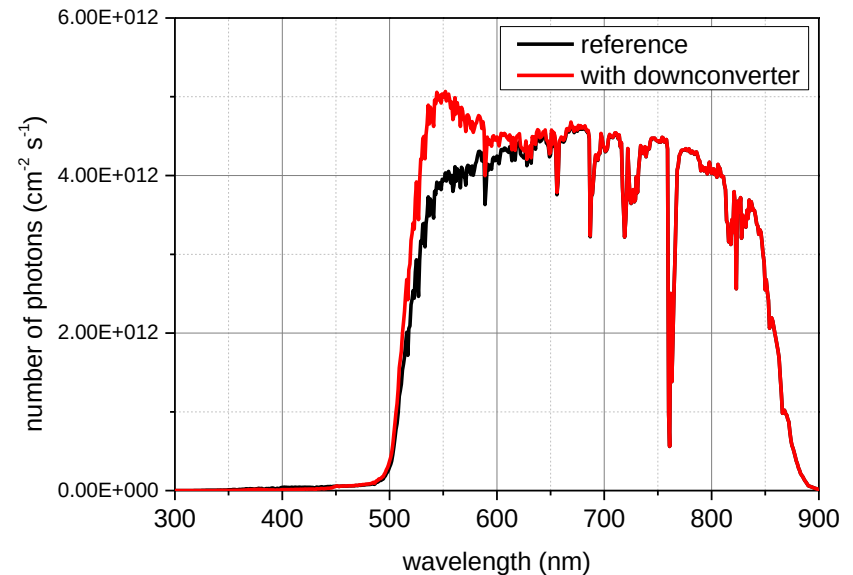


Materials for LDS:

- Fluorescent Dyes
- Quantum Dots
- Phosphors



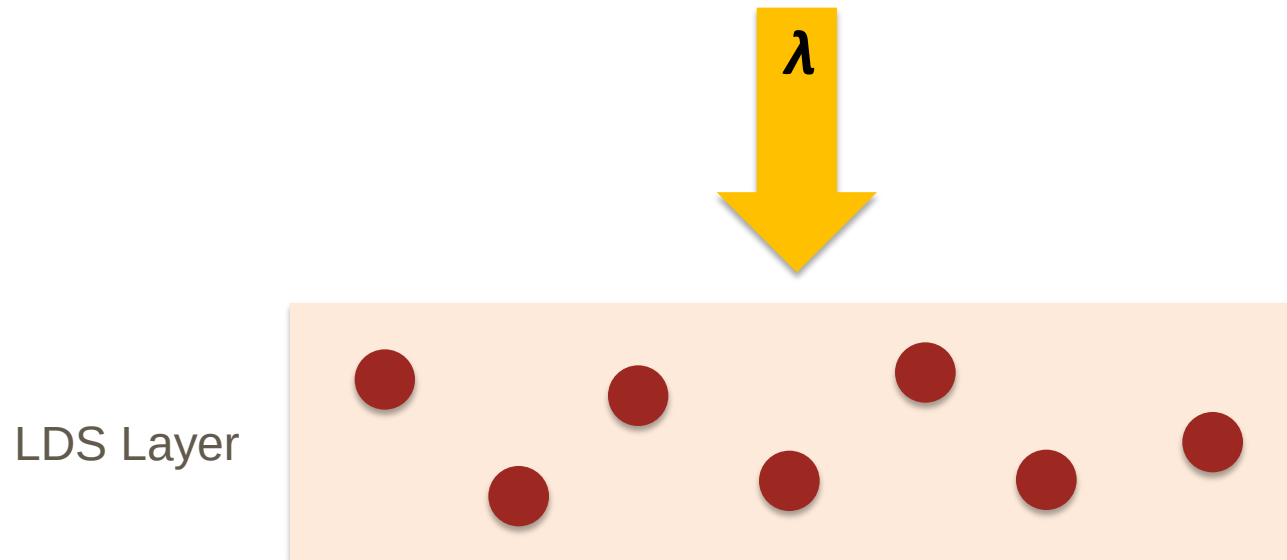
Modified Solar Spectrum



Photons Absorbed by the Solar Cell

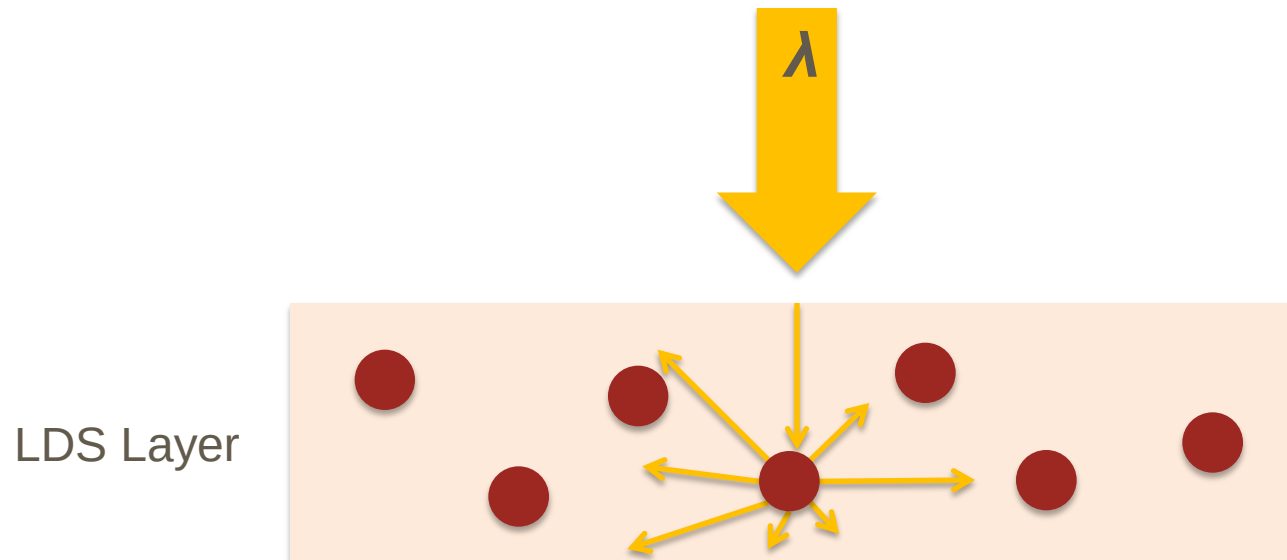
Motivation

Optical Processes in the LDS Layers with Phosphor Particles



Motivation

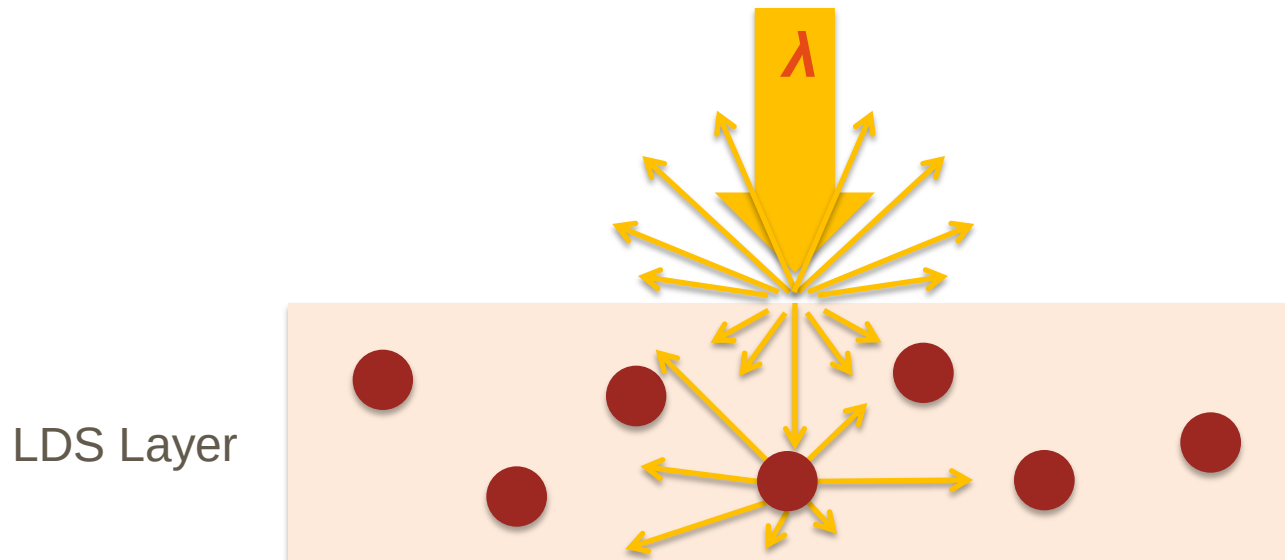
Optical Processes in the LDS Layers with Phosphor Particles



- Volumetric scattering at LDS particles

Motivation

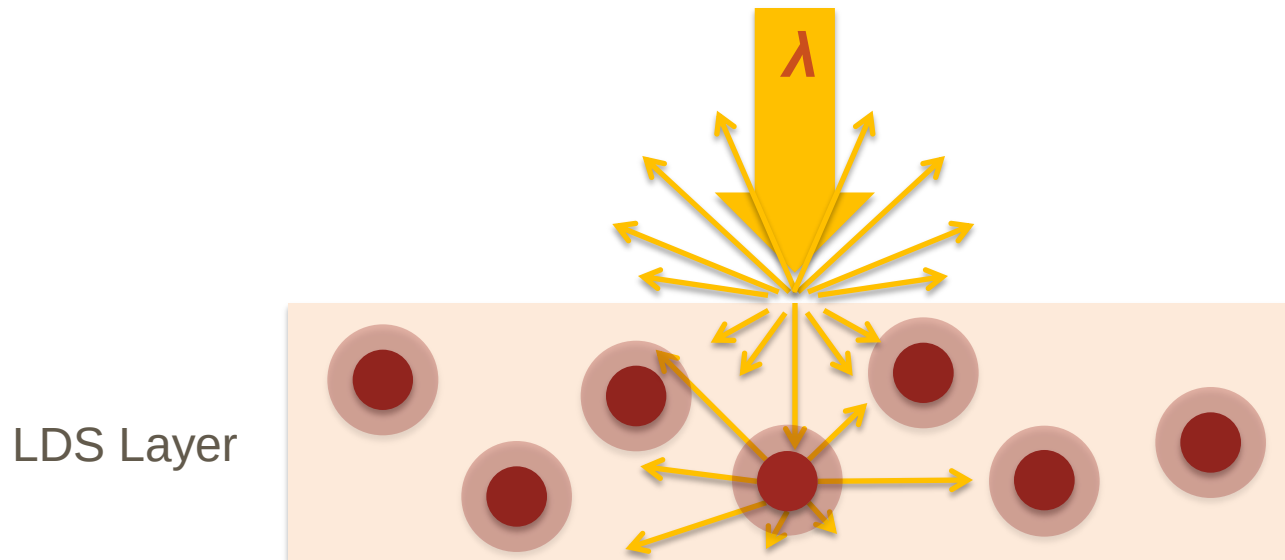
Optical Processes in the LDS Layers with Phosphor Particles



- Volumetric scattering at LDS particles
- Surface scattering at the rough surface

Motivation

Optical Processes in the LDS Layers with Phosphor Particles

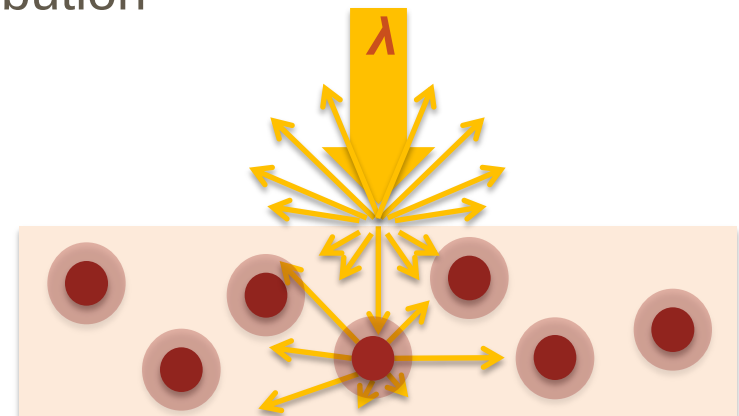


- Volumetric scattering at LDS particles
- Surface scattering at the rough surface
- Photoluminescence of LDS particles

Motivation

Optical Processes in the LDS Layers with Phosphor Particles

- **Volumetric scattering at LDS particles** →
 - Surface scattering at the rough surface
 - Photoluminescence of DC particles
1. Difference in the refractive indices of particles and matrix Δn
 2. Particle size and particle size distribution
 3. Particle volume concentration
 4. Particle surface morphology



Computational Model

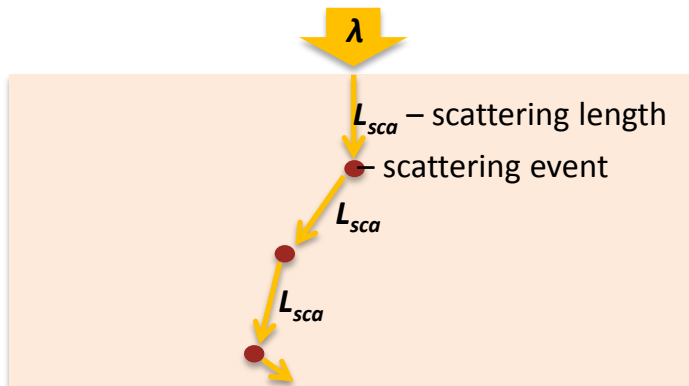
CROWM:

Combined Ray Optics / Wave Optics Model

- Includes volumetric scattering model based on the Mie scattering theory
- Assumptions: spherical particles, uniform distribution in the layer
- Calculates layers' transmittance and reflectance
- Uses such parameters as: layer thickness, the particle volume concentration, and the particle diameter (particle size distribution)

Our Aim:

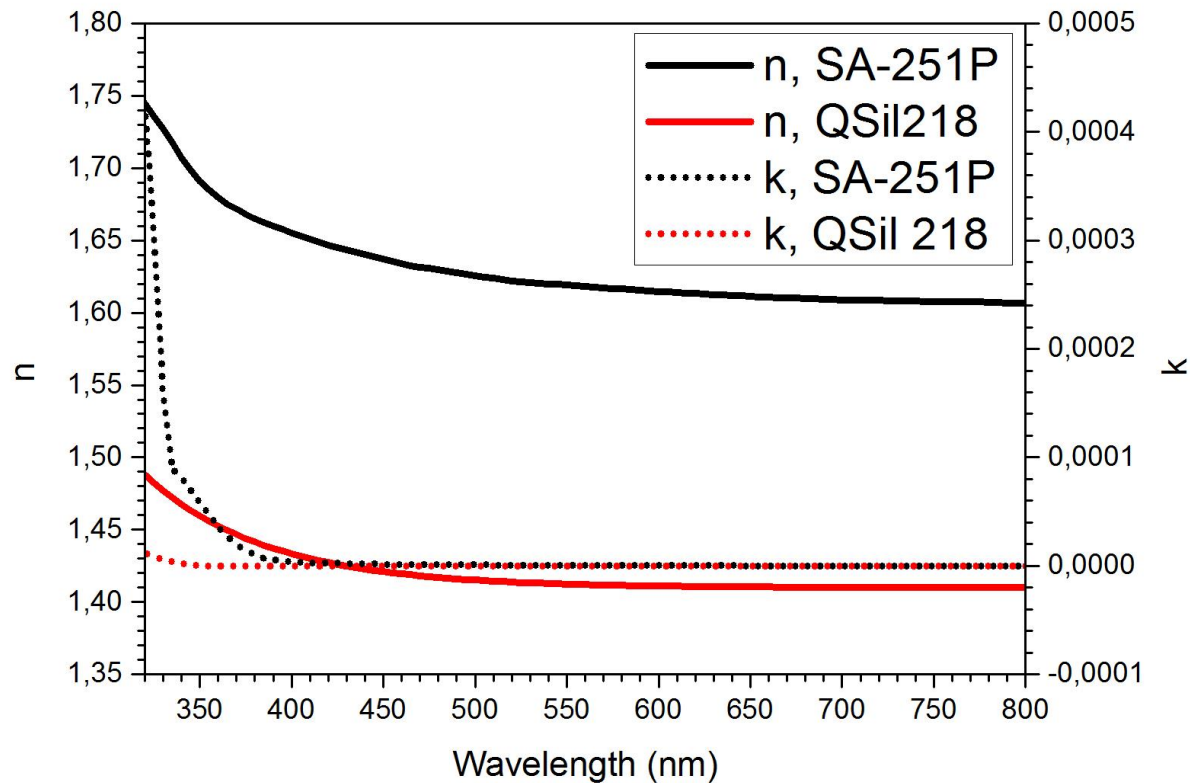
1. Understanding the Light Propagation Processes
2. Being Capable of Calculating the Optimal Layer Parameters



Properties of Materials

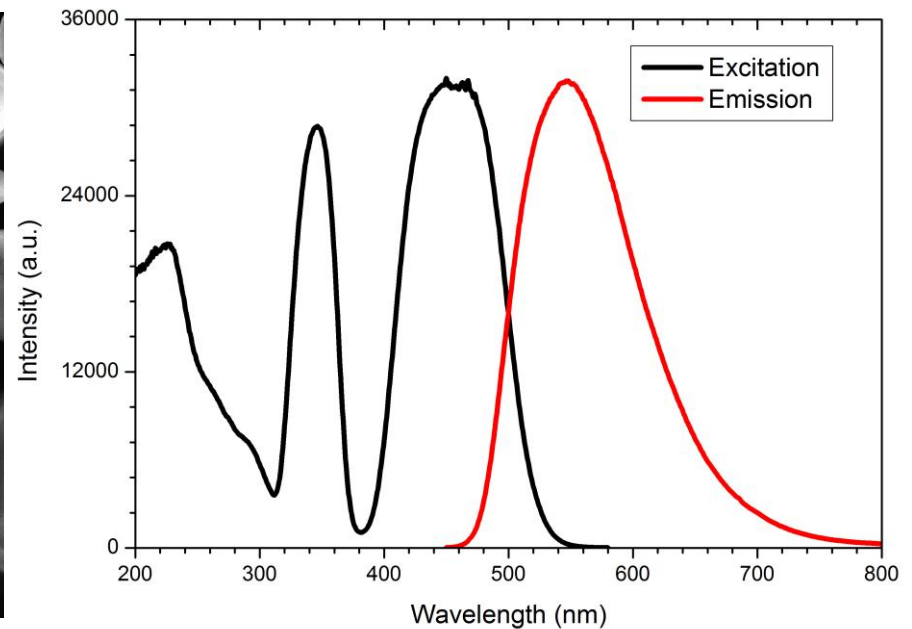
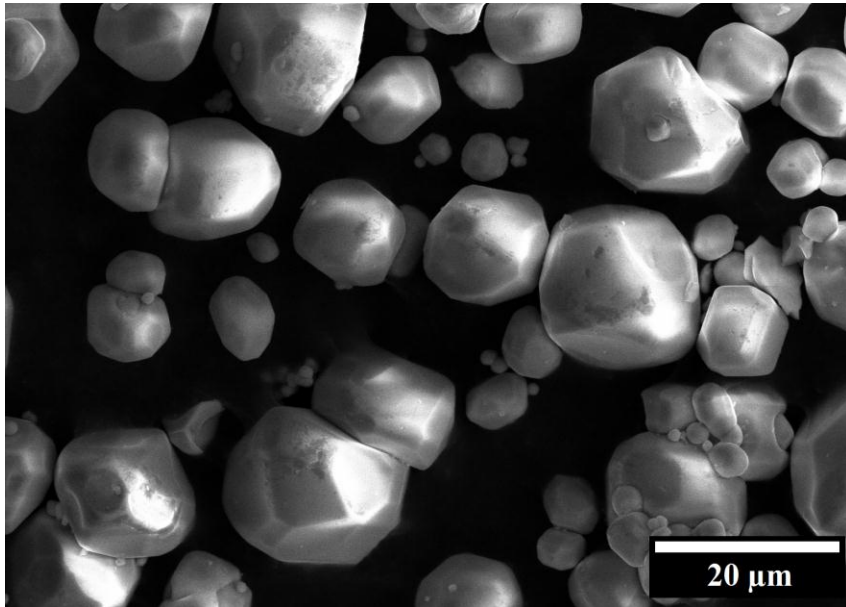
Chosen Matrix Materials:

Matrix	Company	Viscosity, Pa·s
QSil 218 (A+B)	ACC Silicones Ltd., UK	2.2
SA-251P	Nagase ChemteX Corp., Japan	2.1



Properties of Materials

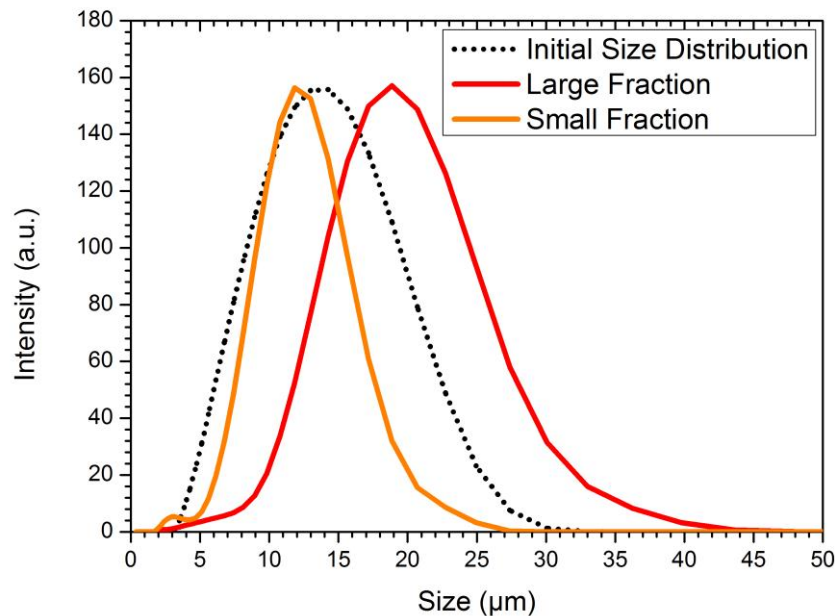
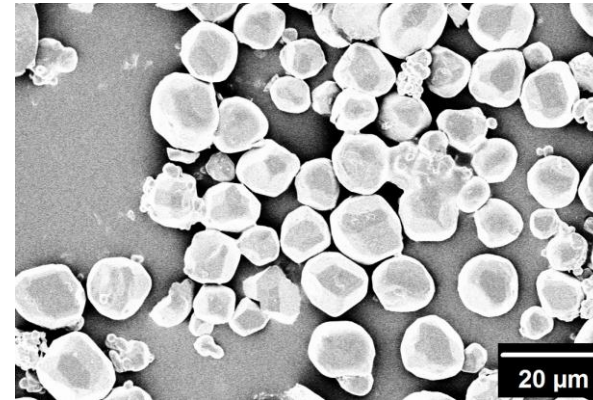
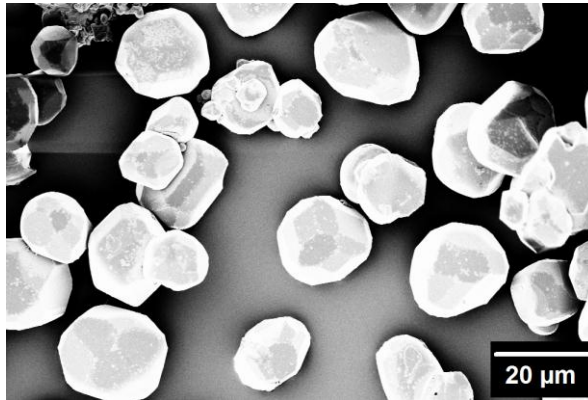
Chosen Phosphor Particles:



- GAL 545L (Intematix Corp., USA) – yellow aluminates.
- Average Size 15 μm .
- $n \sim 1.86 - 1.81$ ($\lambda = 400 - 800$ nm).
- PLQY (GAL545L) ≥ 91 %.

Properties of Materials

Sieving Particles:

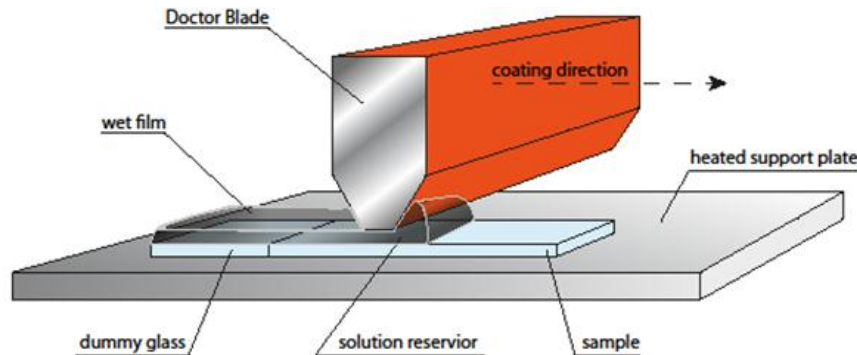


Large Fraction: Mean: 18.8 μm ;
SD: 6.5 μm ; D50: 18.71 μm

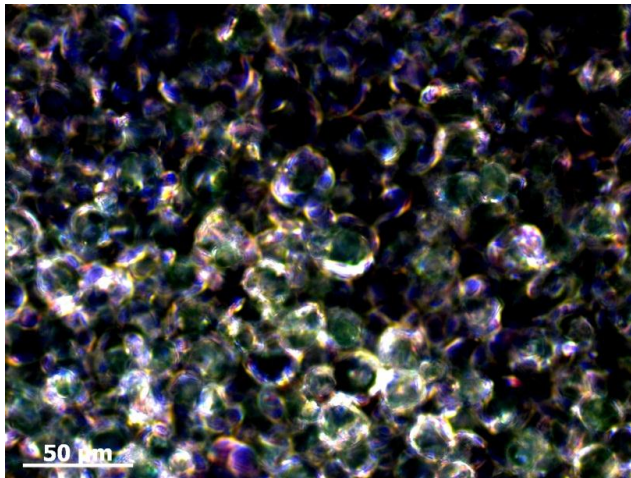
Small Fraction: Mean: 11.34 μm ;
SD: 4.82 μm ; D50: 11.68 μm

Experimental Methods

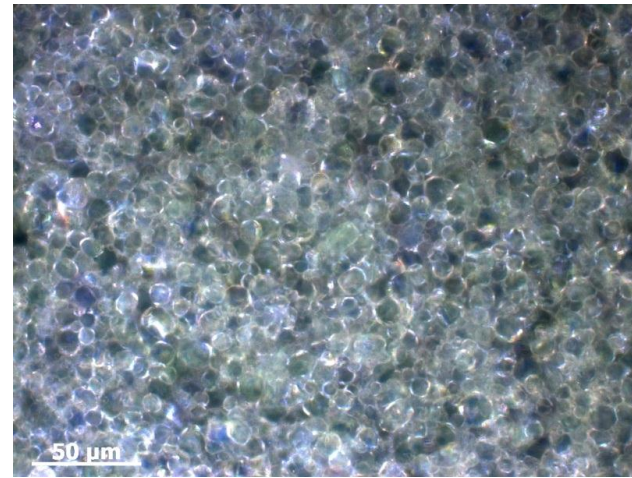
LDS Layer Preparation:



- Coated Area: 25 x 25 mm²
- Layer Thickness: 150-600 µm
- Particle Volume Concentration (PVC): 6, 13, 18 %



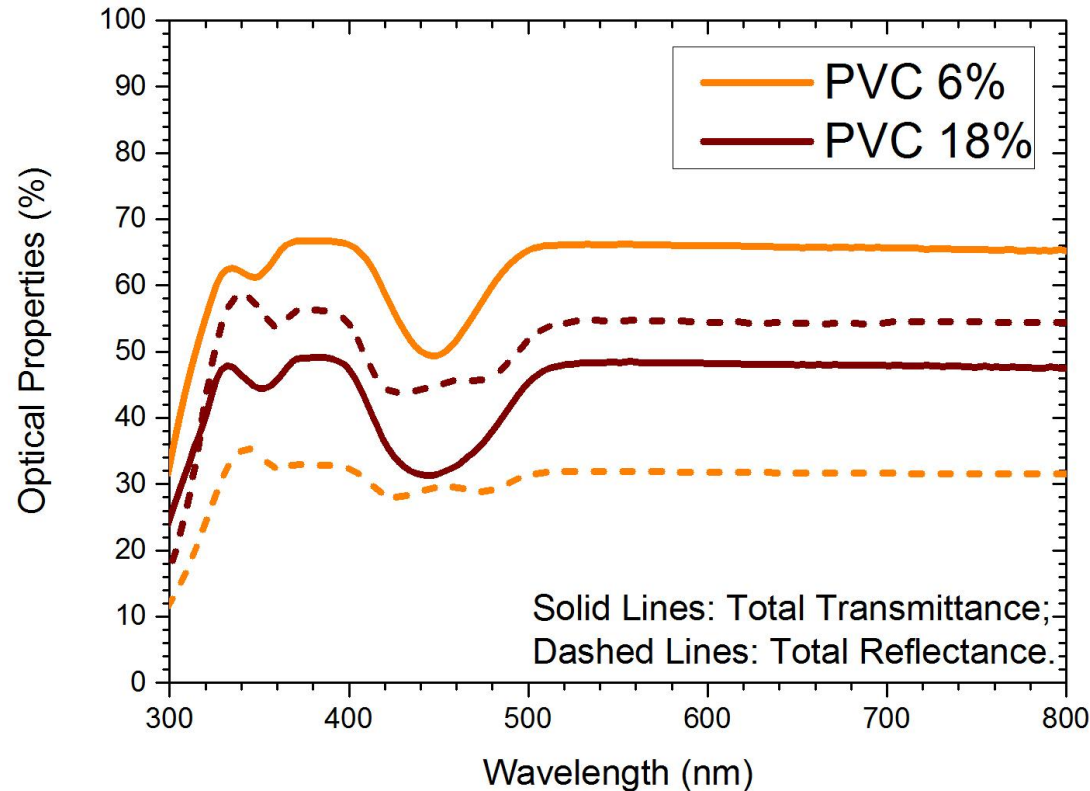
Large Fraction
PVC 6%, Thickness 350-450 µm, Matrix SA-251P



Results

Transmittance and Reflectance Spectra (GAL+QSII218):

thickness 330-350 μm

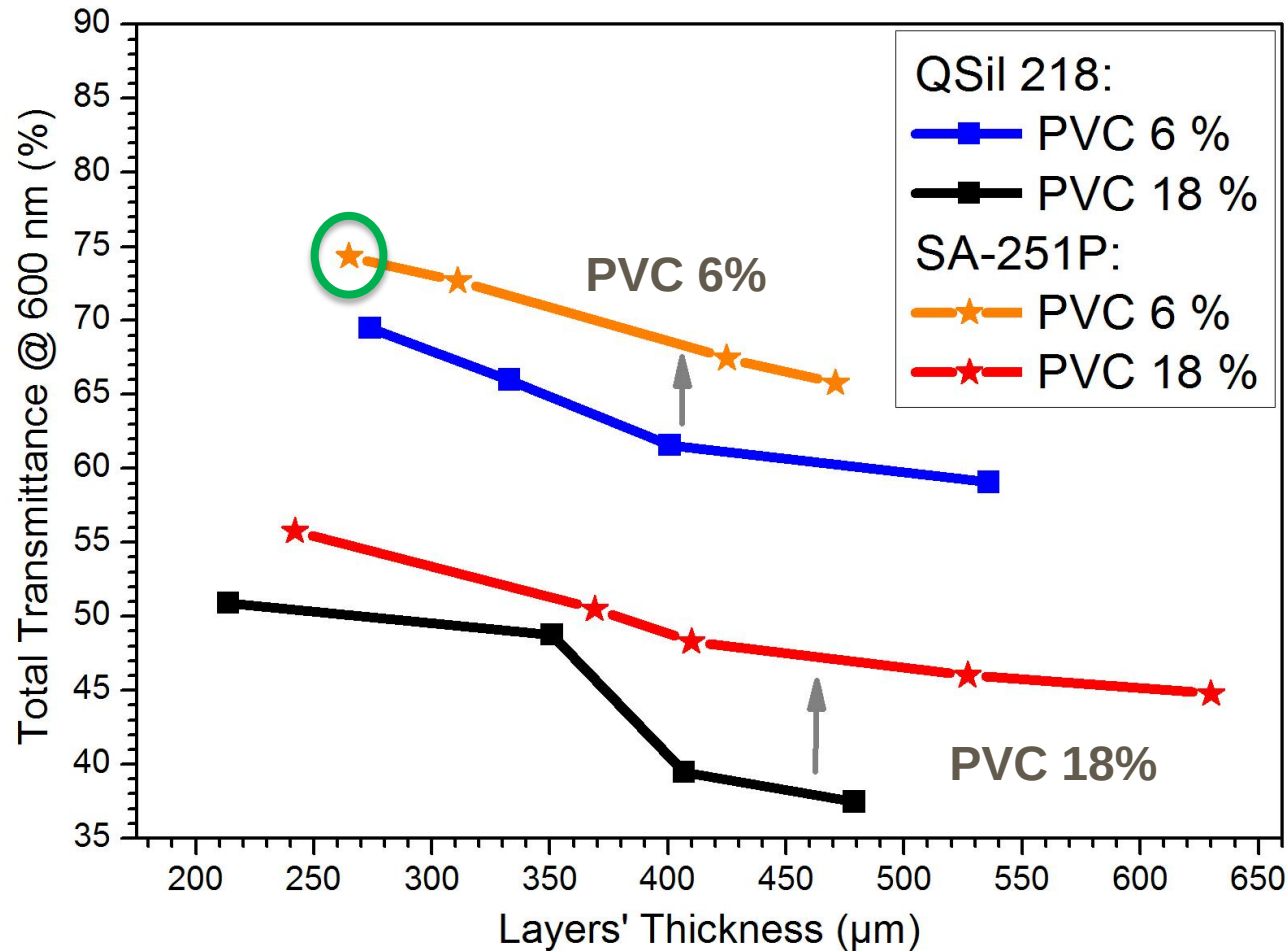


→ increase transmittance and/or suppress reflectance

→ further evaluation @ $\lambda = 600 \text{ nm}$

Results

Transmittance @ 600 nm of Layers with QSil 218 and SA-251P:



QSil 218 $n \sim 1.4$

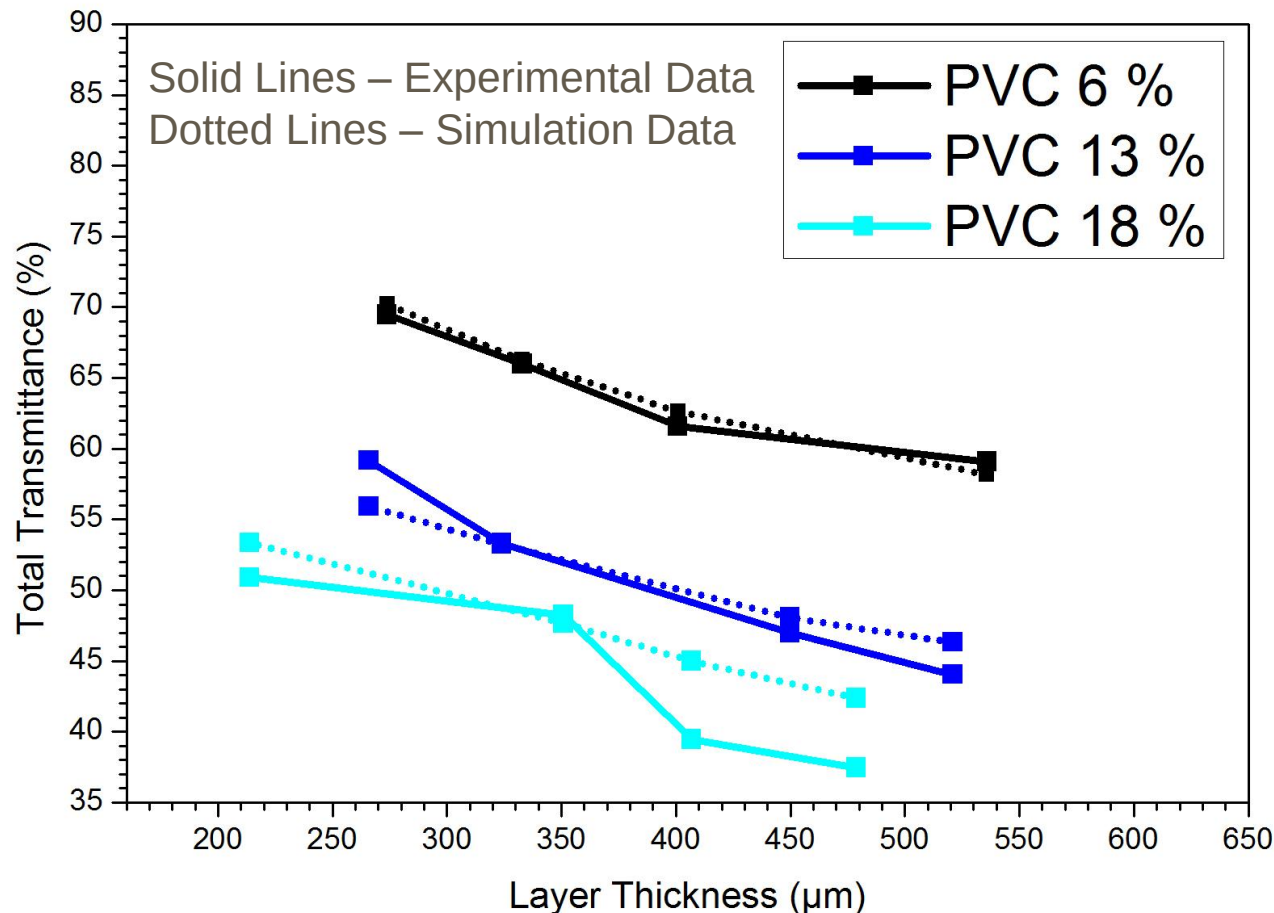
SA-251P $n \sim 1.6$

GAL545L $n \sim 1.81$

→ transmittance is increased by 5-7% via reducing Δn from 0.4 to 0.2

Results

Comparison of Experimental Data with Simulation QSil218 + GAL545L:

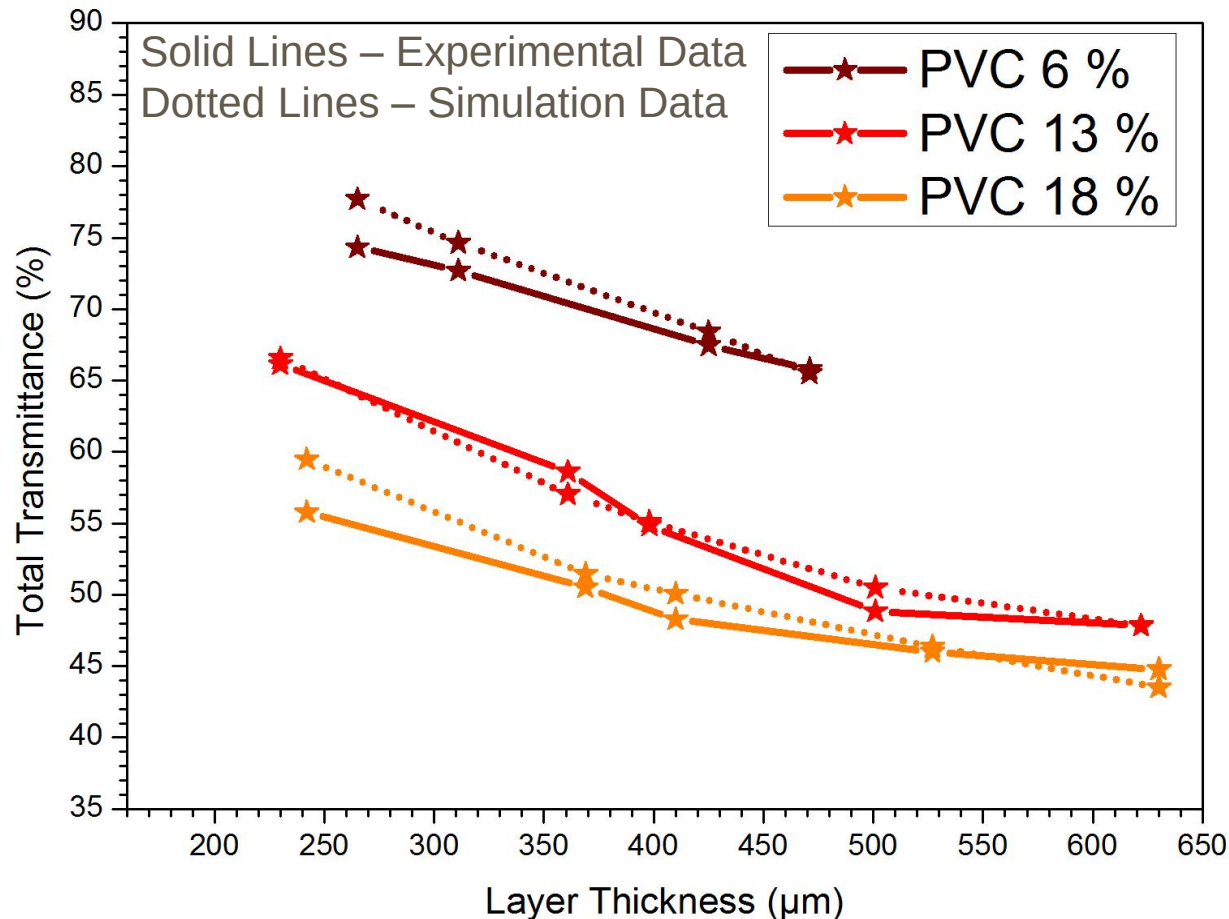


→ curves were obtained with the same fitting parameters

→ good agreement with the experimental data

Results

Comparison of Experimental Data with Simulation SA-251P + GAL545L:

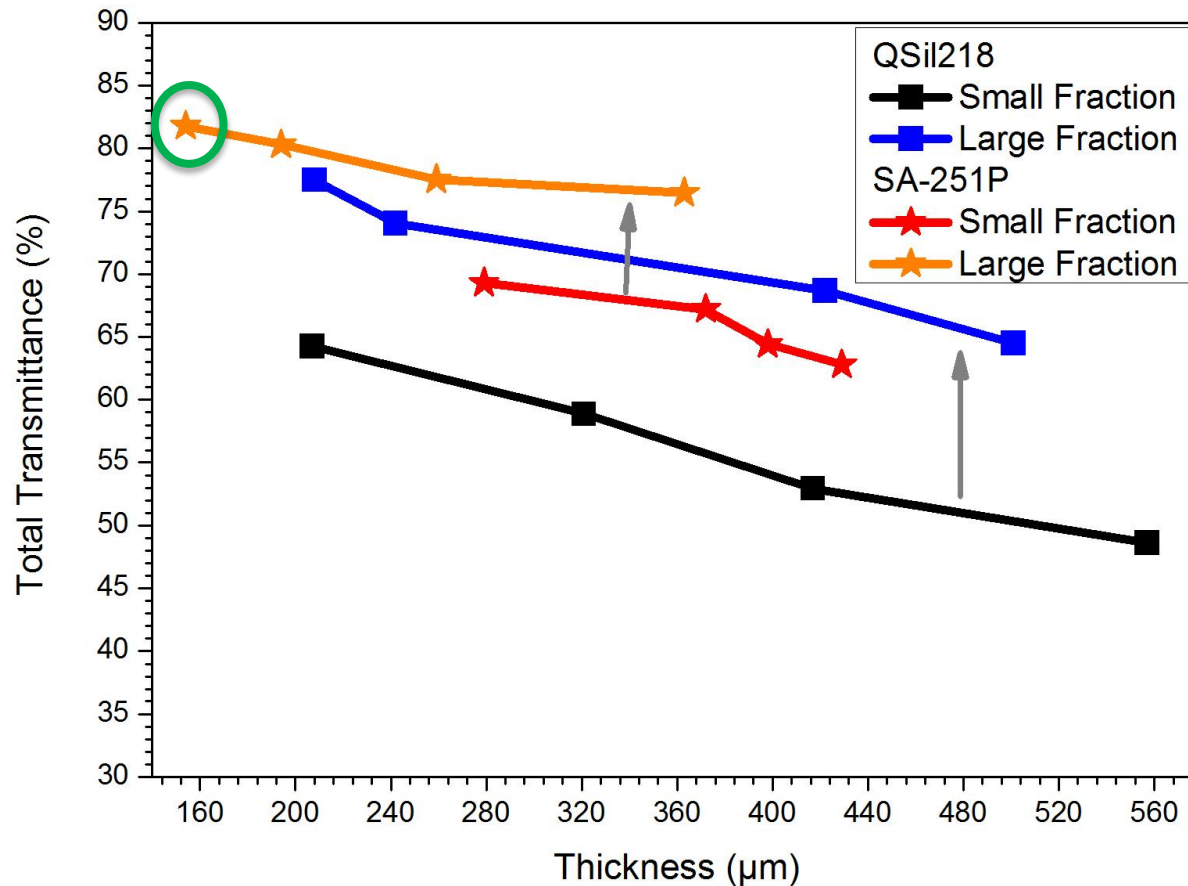


→ curves were obtained with the same fitting parameters

→ good agreement with the experimental data

Results

Transmittance @ 600 nm of Layers with QSil 218 and SA-251P +
Small and Large Particle Fractions:

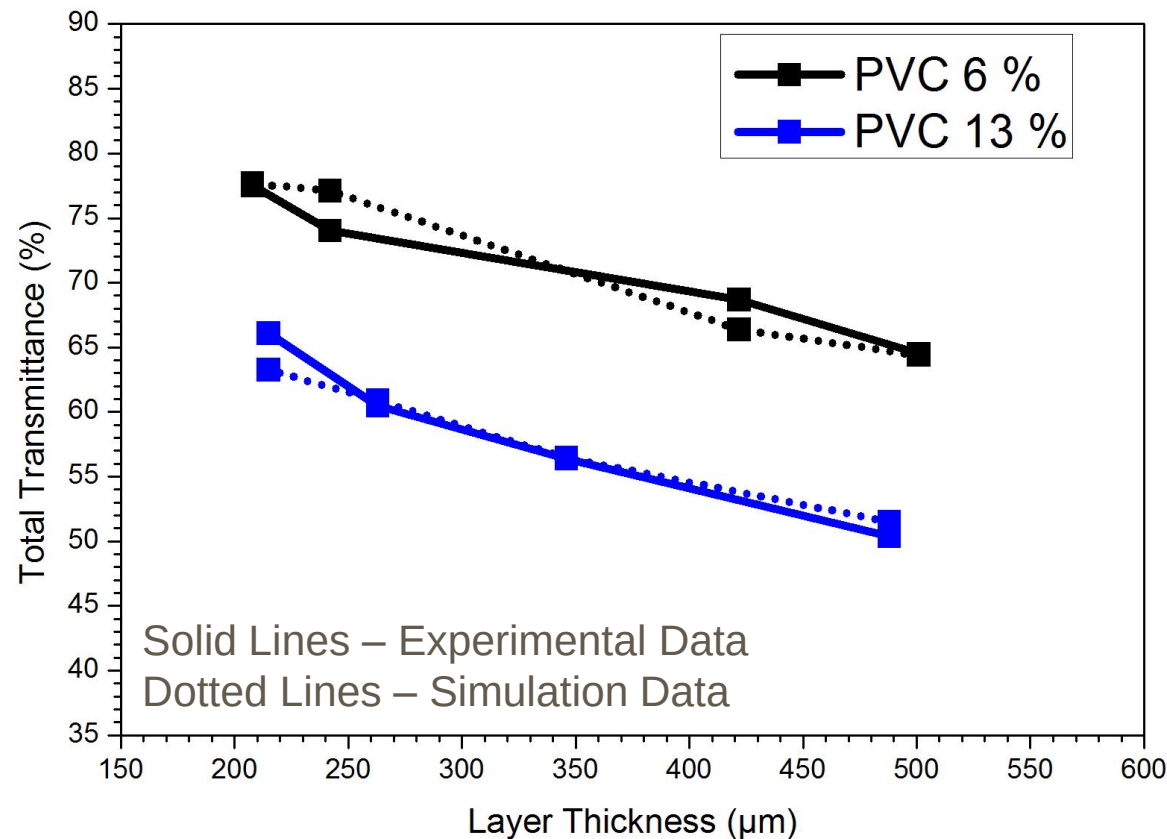


→ transmittance is increased by **9-11%** with larger particles in the layers

Results

Comparison of Experimental Data with Simulation

QSil218 + Large Fraction:



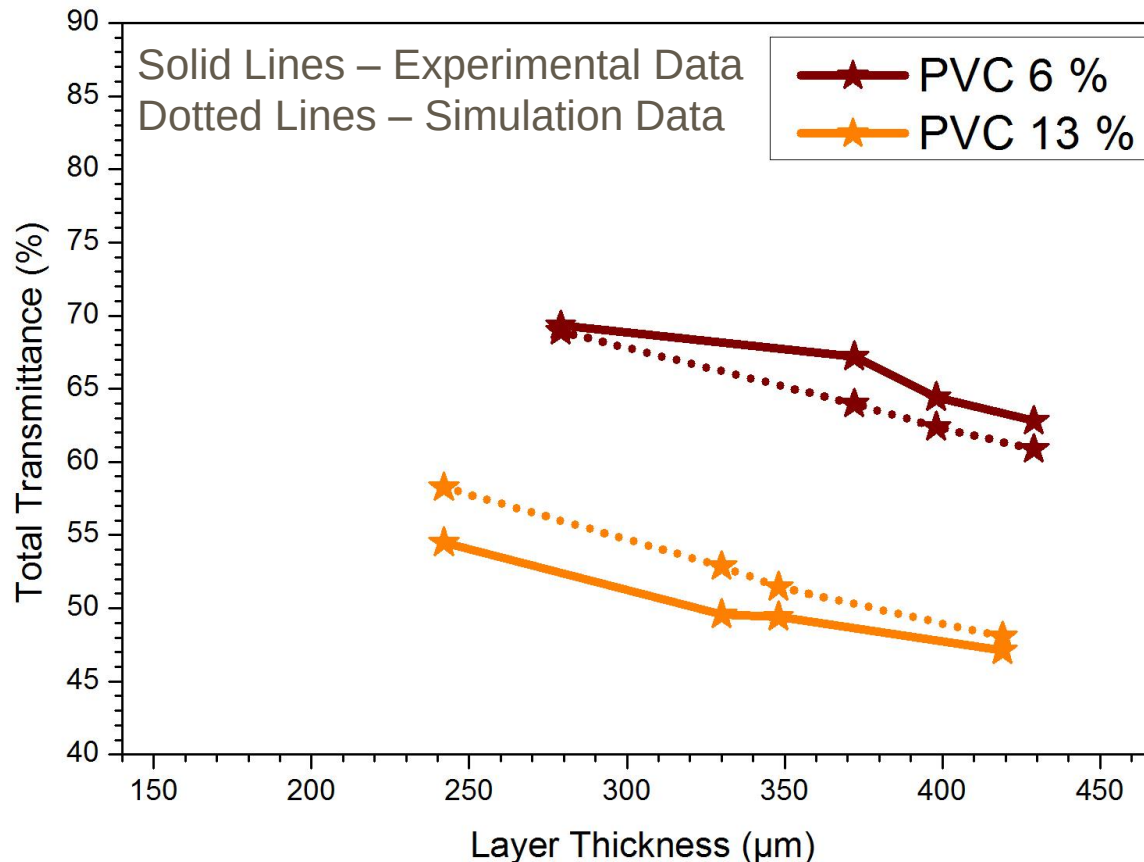
→ curves were obtained with the same fitting parameters

→ good agreement with the experimental data

Results

Comparison of Experimental Data with Simulation

SA-251P + Small Fraction:



→ curves were obtained with the same fitting parameters

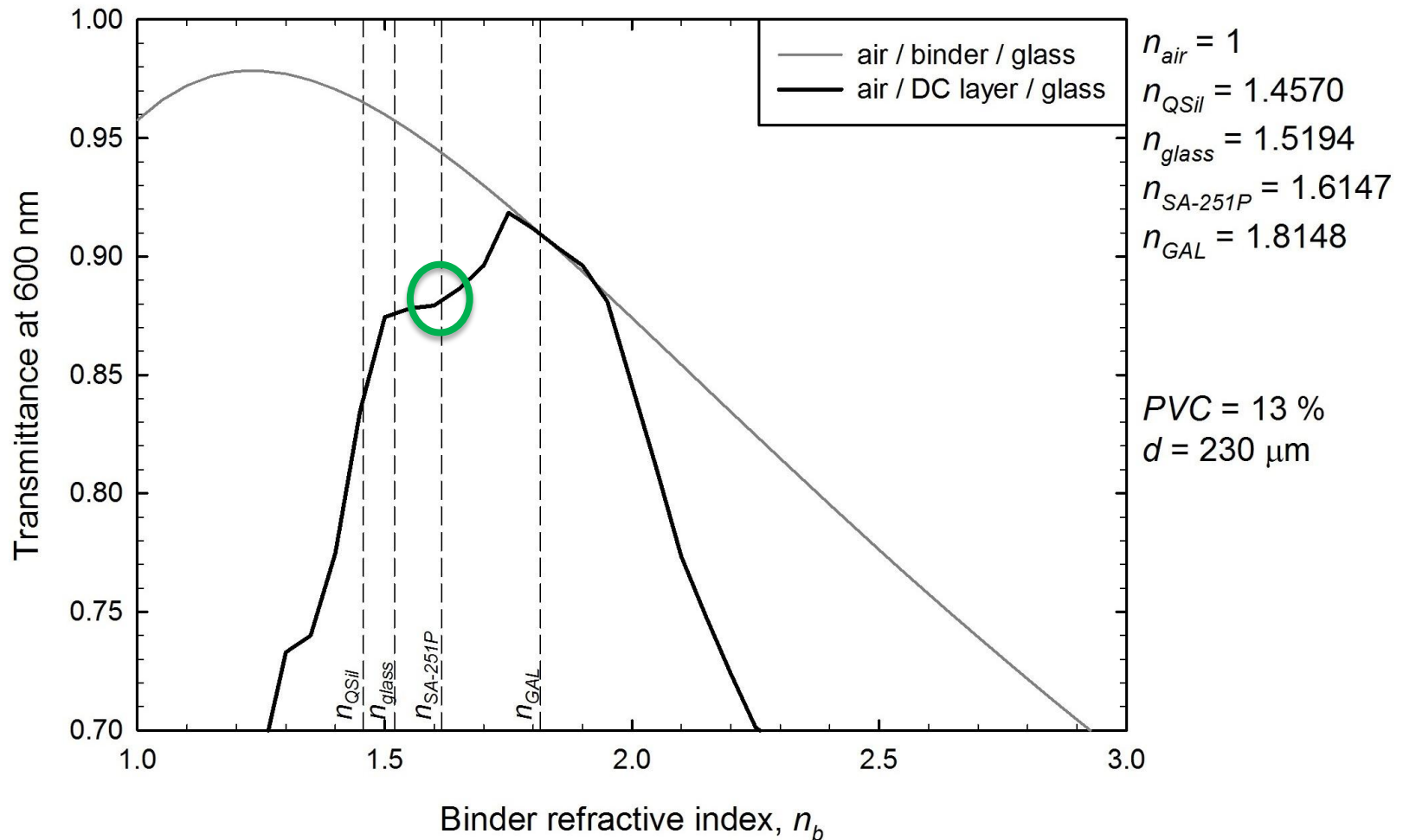
→ good agreement with the experimental data

Summary

1. Reducing the difference in the refractive indices of the binder and the particles results in:
 - higher transmittance,
 - lower reflectance.
2. Increasing the size of the particles also results in the higher transmittance of the layers.
3. CROWM reproduces well the experimental results.
4. Systems with the actual solar cell devices must be considered to understand the entire light propagation process.

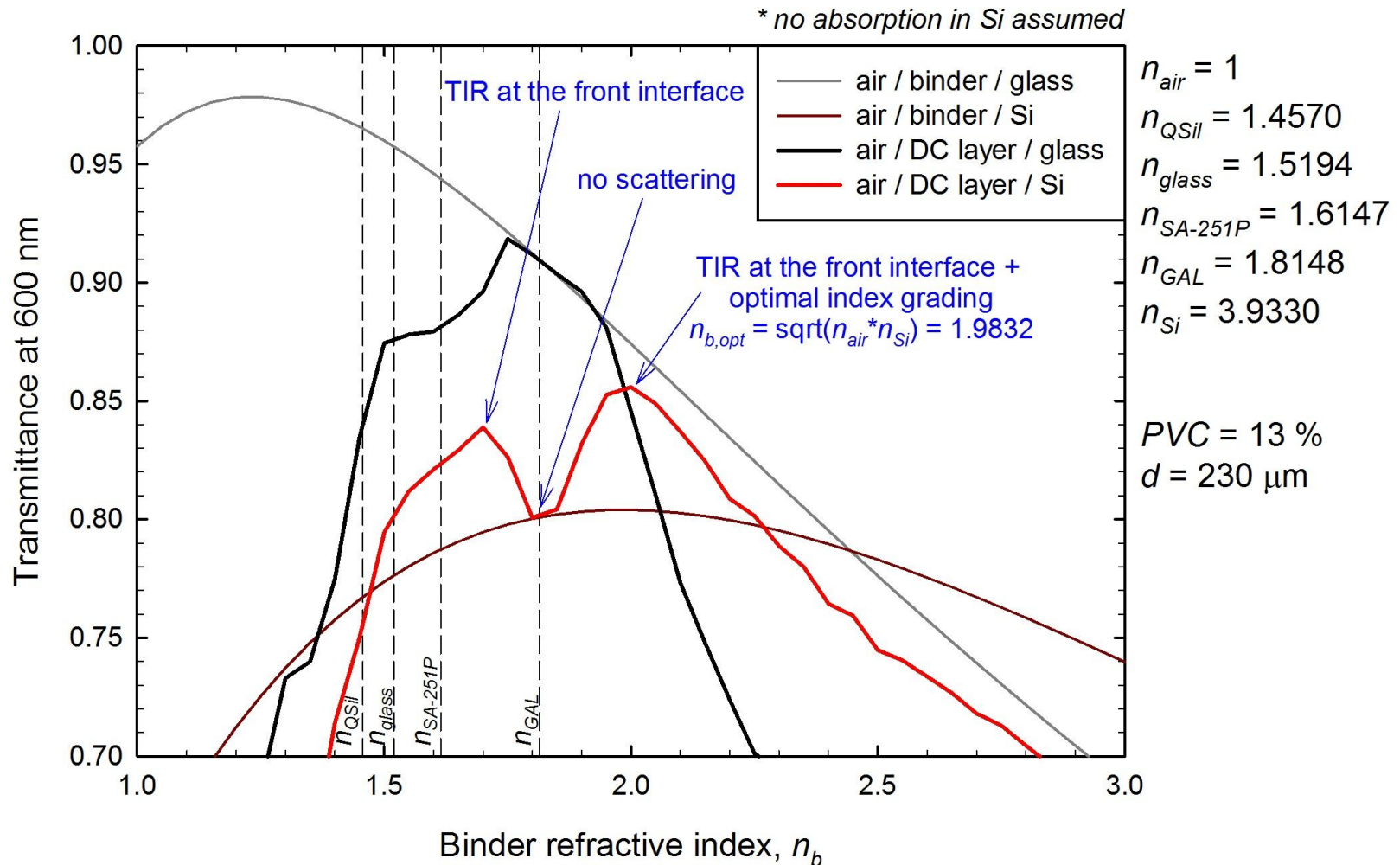
Conclusions

Optimization Outlook



Conclusions

Optimization Outlook



Acknowledgements

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Thank You for Your Attention!

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