### **Incoherent Propagation of Light in Coherent Models**

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# Outline

- Introduction
- Incoherent propagation of light
- Thinning down the incoherent layer
- Model
- Results
- Conclusions



## Example of a-Si thin-film solar cell structure



Incoherent propagation of light
 Thining down of thick glass layer

 mm range to nm range!

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# Incoherent propagation of light

In many optical cases light loses coherence:

- 1. Spatial incoherence
- 2. Spectral incoherence
- 3. Temporal incoherence

Incoherent light does not interfere, we have to eliminate
 constructive and destructive interference in coherent models

#### Constructive interference

#### Destructive interference



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### Incoherent propagation of light

In rigorous simulations interference term of Poynting vector has to be eliminated





## Incoherent propagation of light

Two approaches:

- a) Phase matching method
  - the structure needs to be well defined to find the phase shift of the reflected wave

interference term = 0

$$d' = Re[\frac{\frac{\pi}{2} + m\pi - \varphi}{2k}], \qquad m = 0, \pm 1, \pm 2, ...$$

- a) Phase elimination approach
  - the phase is eliminated by two simulation runs
  - more appropriate for structure that are not well defined

interference term (d) – interference term (d') = 0  $d' = d - Re[\frac{\lambda}{4N(\lambda)}]$ 

\*A. Campa et al., "Two approaches for incoherent propagation of light in rigorous numerical simulations," Progress In Electromagnetics Research, Vol. 137, 187-202, 2013.

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## Thinning down the incoherent layer



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### Model

#### Non-conformal growth model



 $g_{\mu c-Si:H} = 0.3$  $g_{Ag, ZnO} = 0.2$ 

\*M. Sever et. al., Combined model of non-conformal layer growth for accurate optical simulation of thin-film silicon solar cells, Sol. energy mater. sol. cells., Vol. 119, 59-66 (2013)

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### Model

🖌 🚍 Global Definitions	Falameters
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, Interpolation 1 (int1)	v c1*D
a 🚺 Model 1 (mod1)	X. 31 F
Definitions	y: s2*P
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Parametric Surface 8 (ps8)	2. 1300 Hambda/ (+ Intr(lamb
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Convert to Solid 1 (csol1)	
Form Union (fin)	Axis
a 🍀 Materials	▼ Rotation Angle
b source (mat3)	- notation/ngic
Ag (mat4)	Rotation: 0
# TCO_ZnO_u_sputtered (mat5)	
i_a_SiH_Prague (mat6)	Advanced Settings
b site n_a_SiH_Prague (mat2)	
b  p_a_SiCH_Prague (mat7)	- Output properties
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🔩 Interpolation 1 (int1)	
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Electromagnetic Waves (emw)	
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b 🎬 Study 1	
Results	•

<ul> <li>Expressions</li> <li>x: s1*P</li> <li>y: s2*P</li> <li>z: 1500+lambda/(4*int1(lambda))</li> <li>Fosition</li> <li>Axis</li> <li>Rotation Angle</li> <li>Rotation: 0</li> <li>Advanced Settings</li> <li>Output properties</li> <li>Property Var Expression</li> <li>Refractive index, ima ki ; int1(t)</li> <li>Refractive index, ima ki ; int2(t)*10^6/(1000+lambda/(4*int1(lambda))</li> </ul>	Farameters									
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Realistic optical constants (layers)



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## Results – thick glass layer

#### Incident plane wave

Incoherent glass layer 1 mm thick

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### Results thin-film amorphous silicon solar cell





### Results





Cell made and measured at Inst. of Energy Research (IEK-5) – Photovoltaics, FZJ



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### Results

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## Conclusions

- Optical simulations including thick incoherent layer were shown
  - a) using phase matching method
  - b) using phase elimination method
  - c) thinning down thick layer
- Results of simulations compared with realized cells of different institutes



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### Thank you for your attention





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