Prediction of nanotexture transfer and optical gains in ultra-thin textured CIGS solar cells

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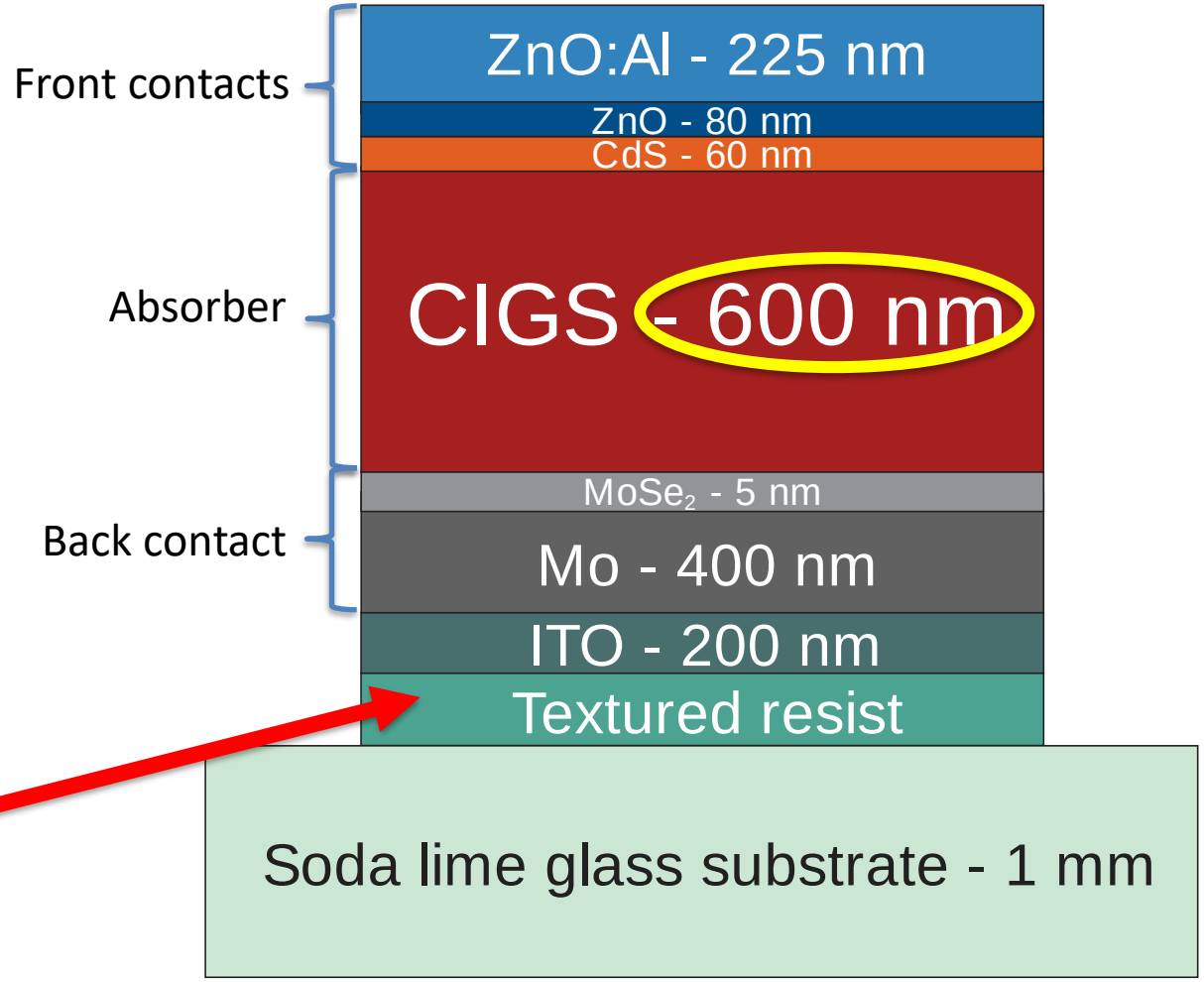
Outline

- Introduction
- Textured substrates & layer by layer texture transfer
- Optical modeling
- Results
- Conclusions

Ultra-thin CIGS solar cell (on textured substrate)

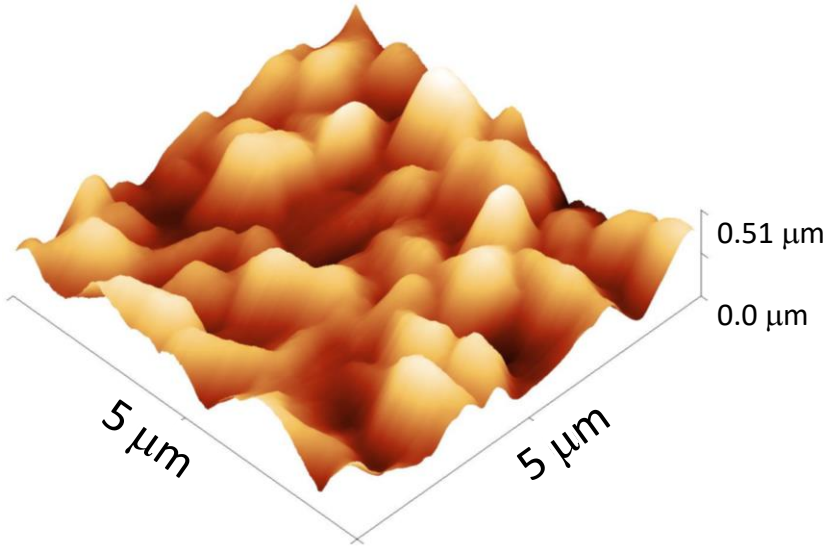
- Thin film CIGS solar cell technology:
  - Record efficiency of 23.35 %
- Usual thickness of CIGS ≥ 1.8 μm
  - Consumption of scarce materials (e.g. In, Ga)
  - Longer deposition times (thick layer)
- **Our aim: usage of ultra-thin (≤ 600 nm) CIGS absorbers** -> J_{sc} reduction
  - **Sol-gel SiO_2 based lacquer with NIL imprinted texture for light management**



AFM measurements of textured substrates

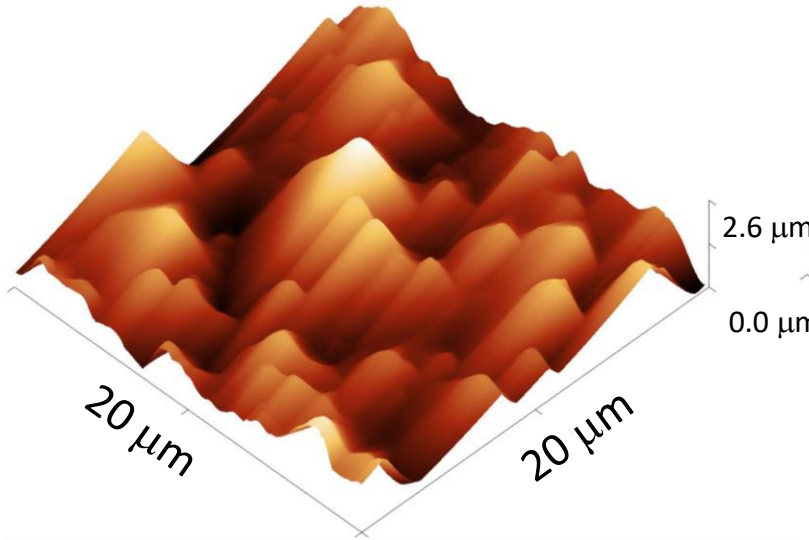
3 types of textured substrates: SLG–textured resist–ITO surface

Texture M –
Random nano pyramids



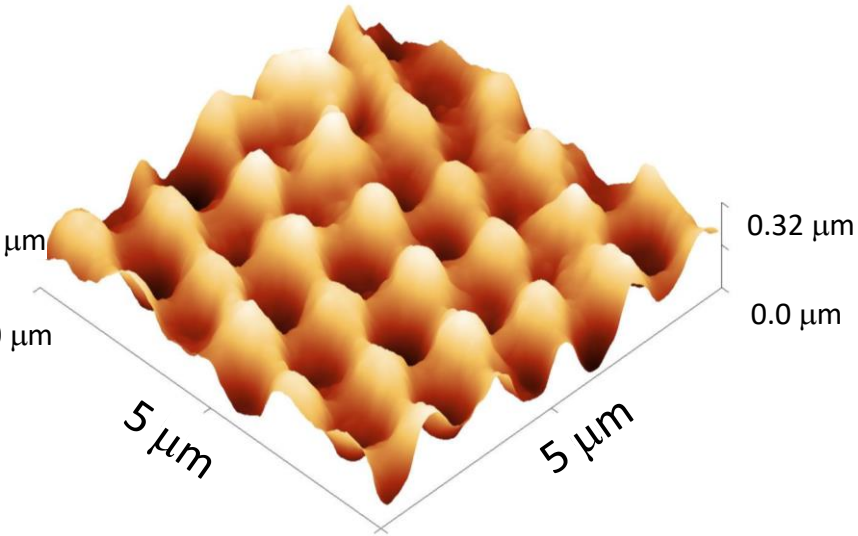
σ_{rms} = ~ 85 nm
$L_{autocorrelation}$ ~ 350 nm

Texture W -
Large random pyramid texture



σ_{rms} = ~ 400 nm
$L_{autocorrelation}$ ~ 1500 nm

Texture H –
Periodic texture

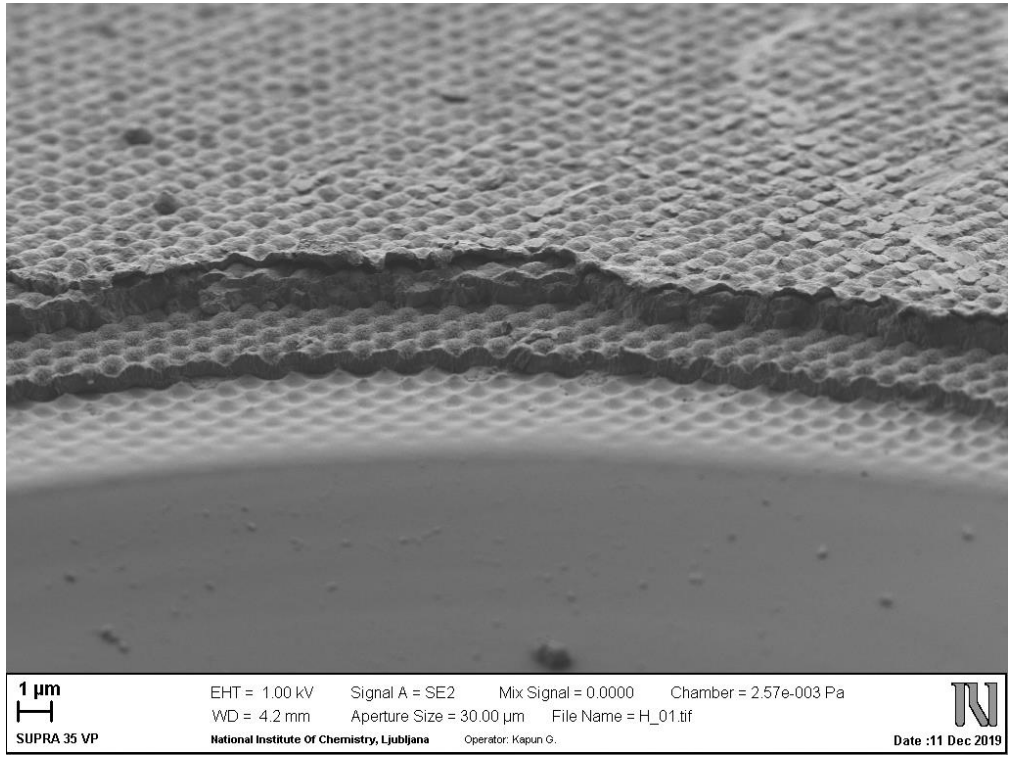


σ_{rms} = ~ 60 nm
Period ~ 1000 nm

Layers growth on textured substrates

Cross sectional SEM images of CIGS cell structures deposited on textured substrates

Texture H –
Periodic texture



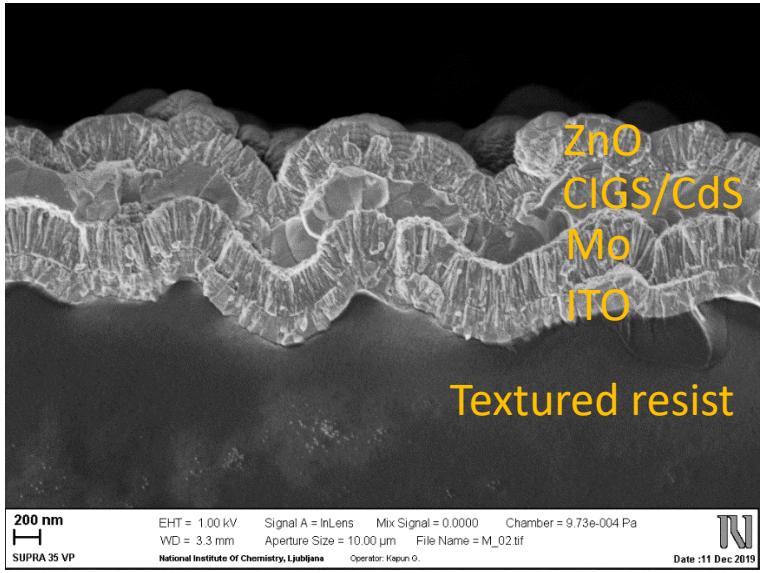
Detailed view on texture transfer

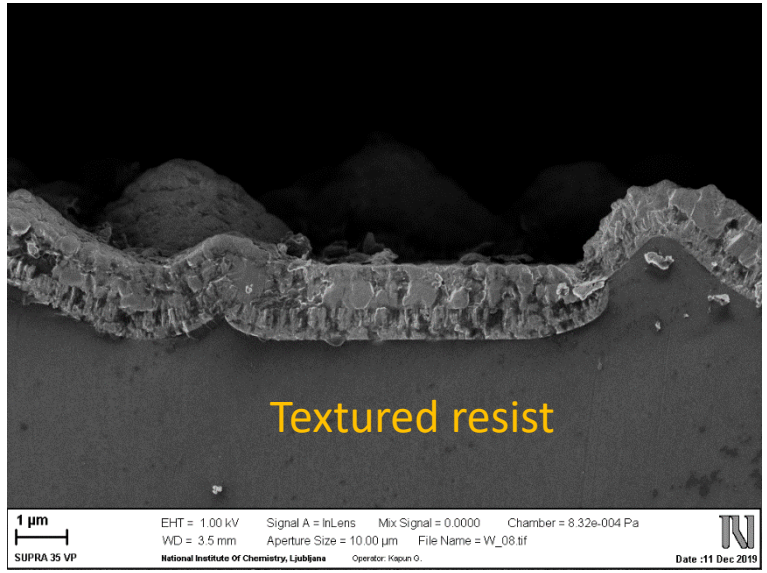
Cross sectional SEM images of CIGS cell structures deposited on textured substrates

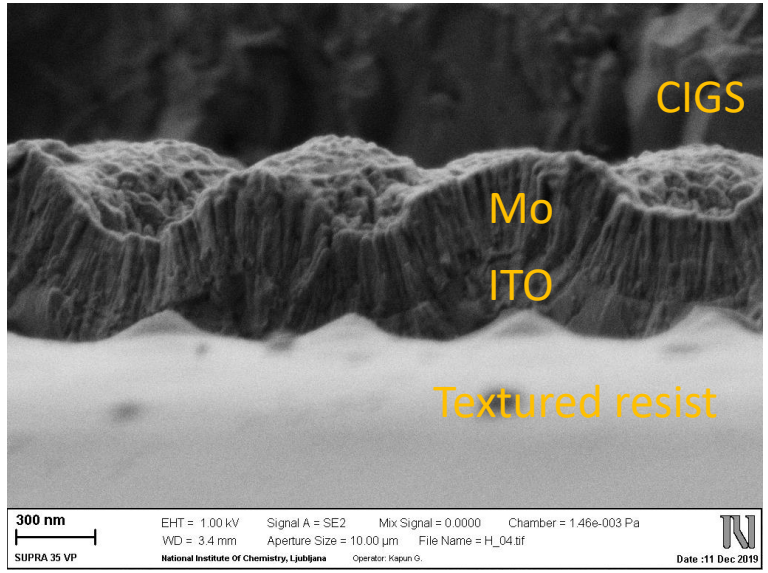
Texture M –
Random nano pyramids

Texture W -
Large random pyramid texture

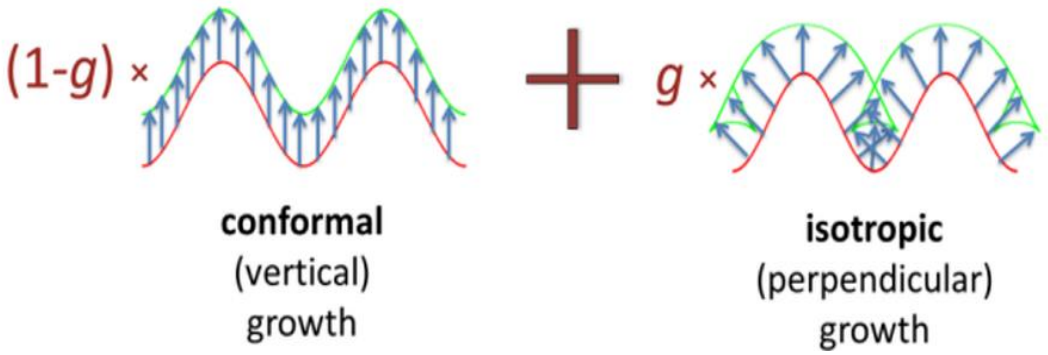
Texture H –
Periodic texture





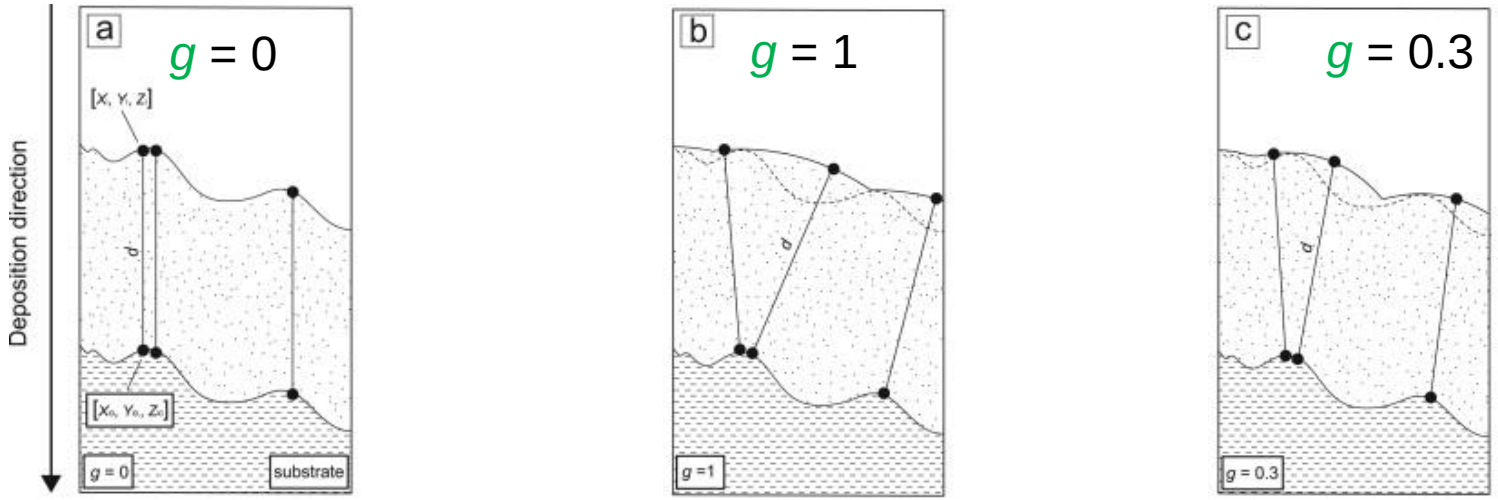


3D model of non-conformal growth - concept



***g* = 0** => fully conformal growth

***g* = 1** => fully isotropic growth



g = 0.3 means more conformal than isotropic growth

M. Sever et al., Sol. energy mater. sol. cells., 119 (2013) 59-66. M. Kovacic et al., Sol. energy mater. sol. cells., 200 (2019) 109933.

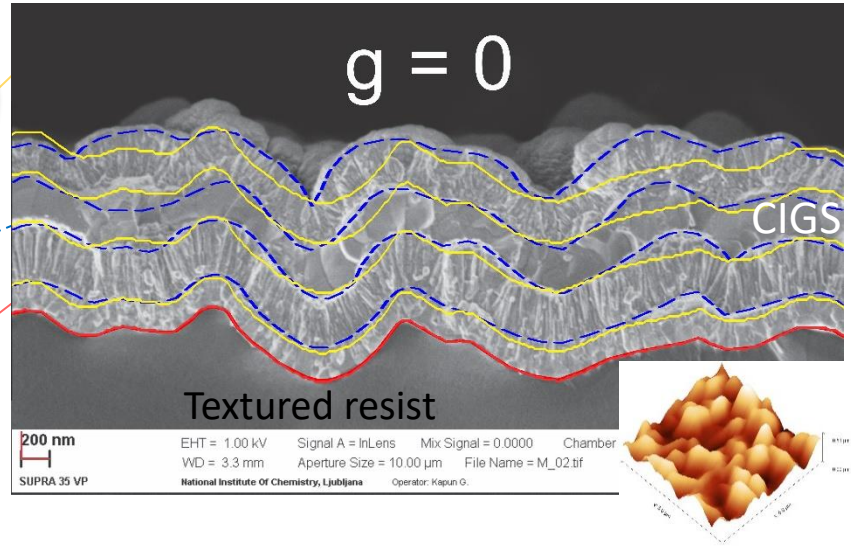
Texture transfer prediction - Random nano pyramids – M

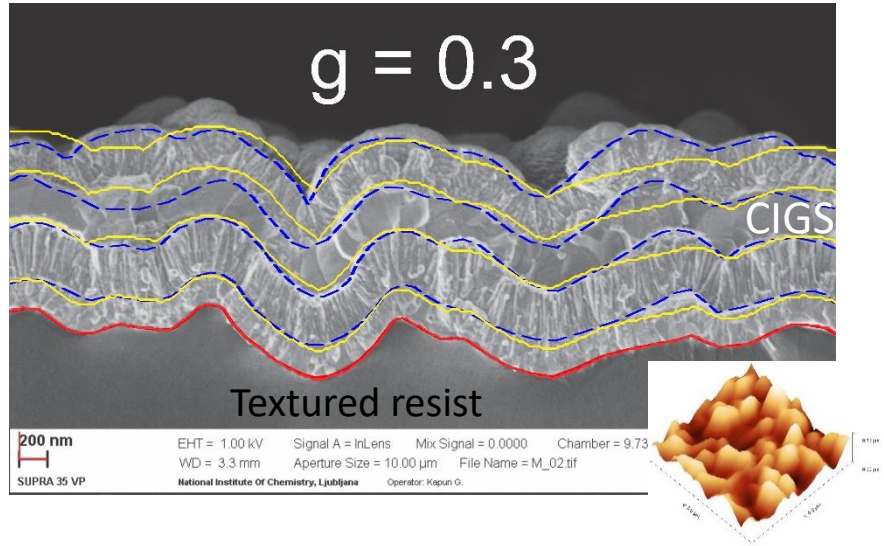
g	Deviation (nm)*
0.0	108
0.1	96
0.2	87
0.3	**83**
0.4	84
0.5	86
1	91

Model Prediction (Yellow)

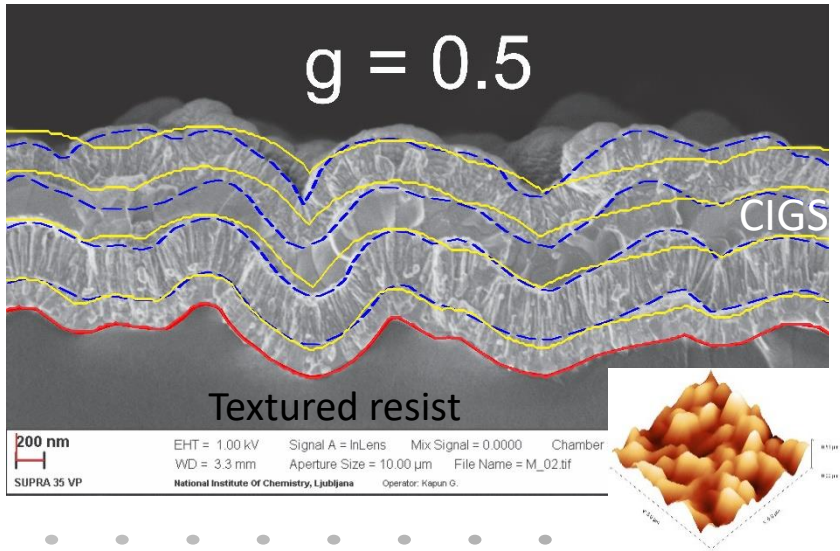
Layer interfaces

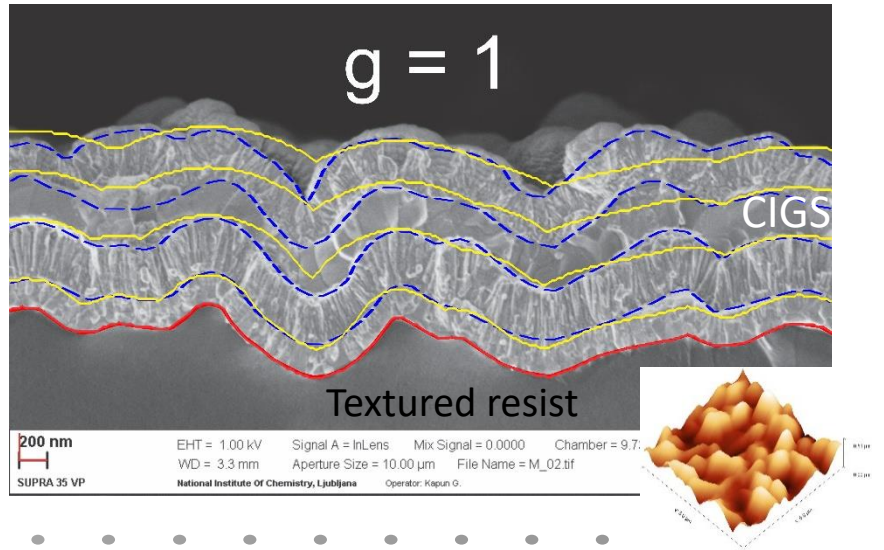
Initial layer





ZnO/ZnOAl
CIGS/CdS
Mo
ITO



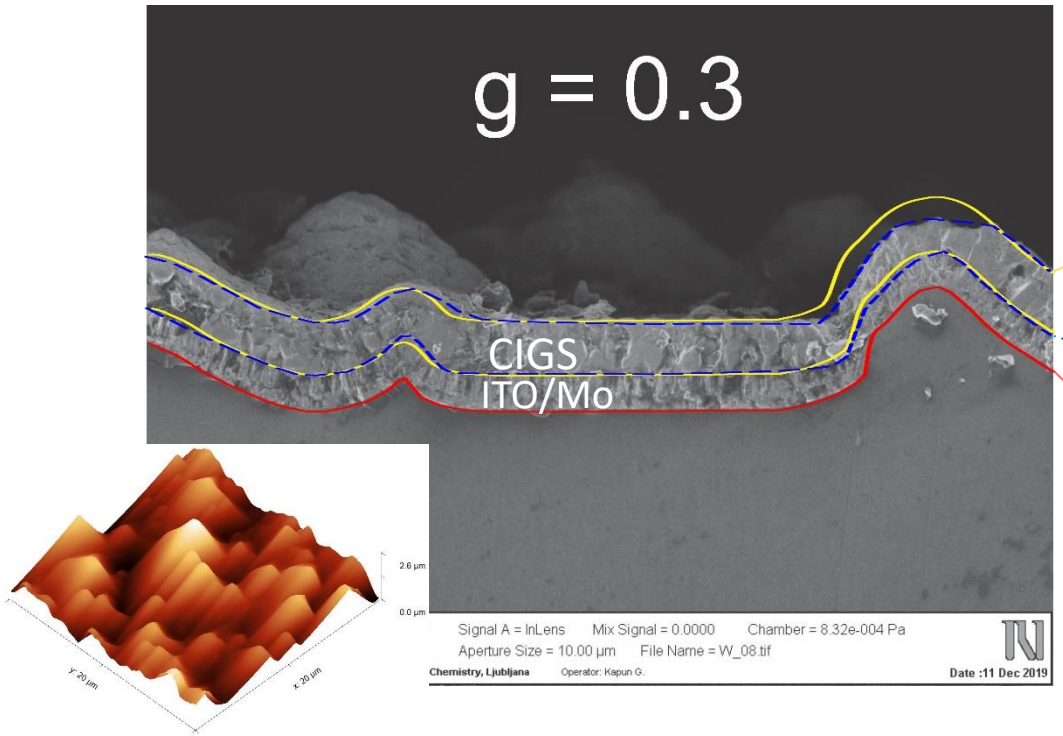


$$^{*}\sqrt{\frac{\sum_{i=1}^{n}\left(y_{model\ prediction}(i)-y_{layer\ interface}(i)\right)^{2}}{n}}$$

Texture transfer prediction

Texture W -
Large random pyramid texture

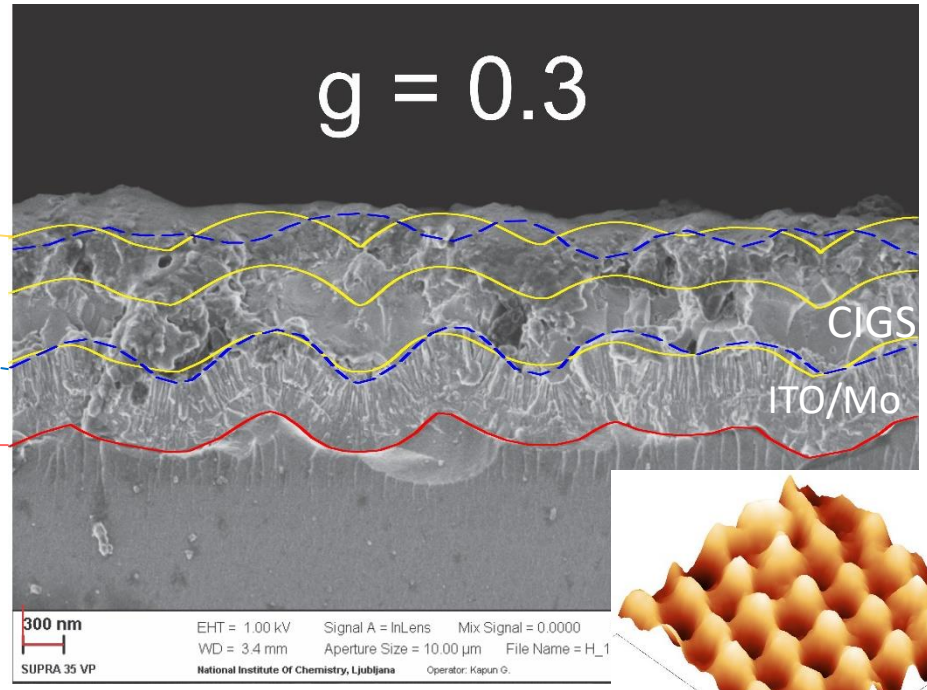
Texture H –
Periodic texture

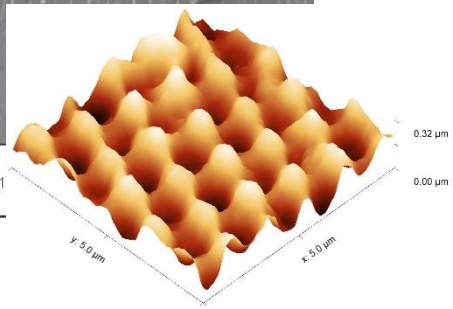


Model prediction

Layer interfaces

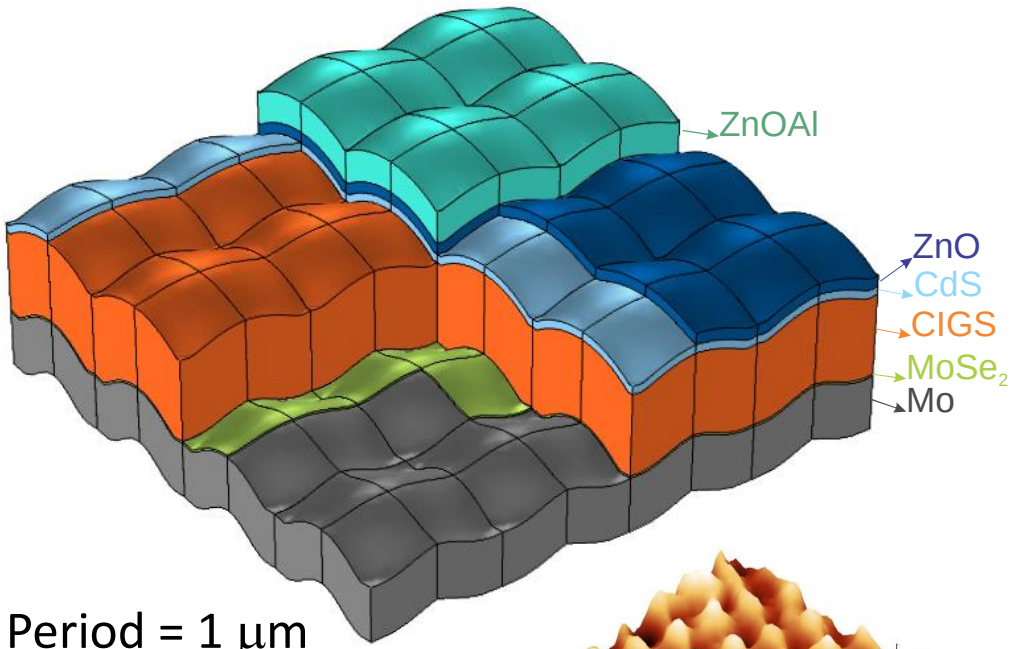
Initial layer





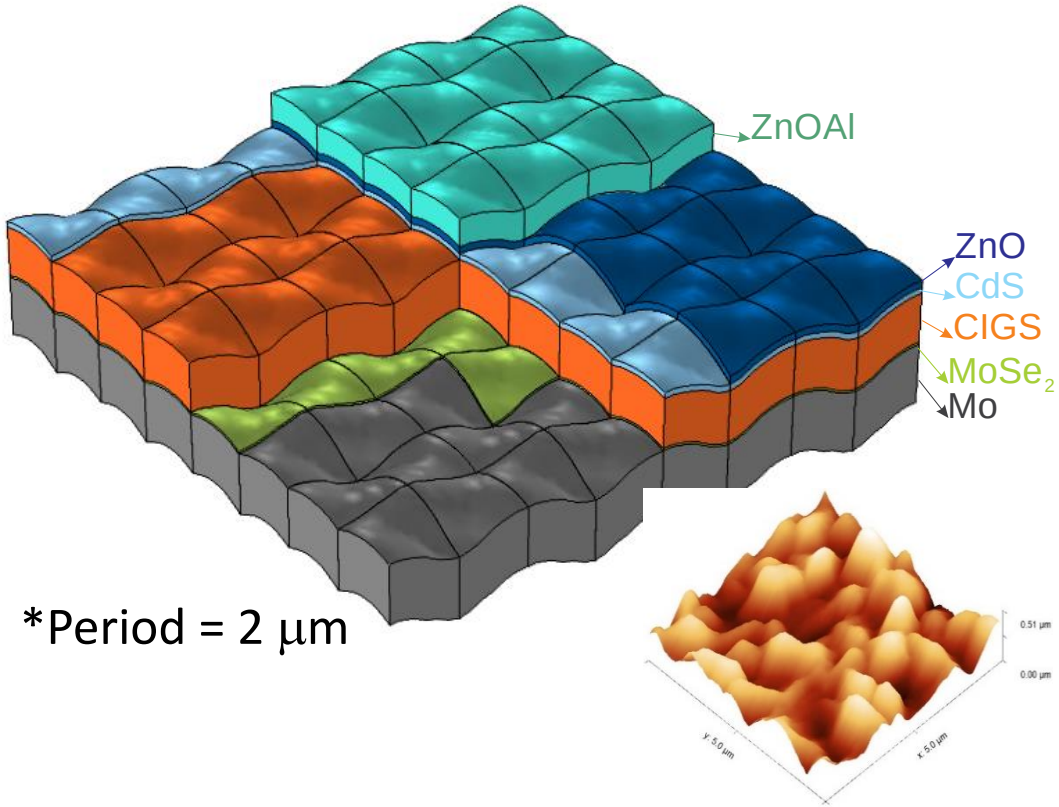
Modelled texture transfer in 3-D used in optical simulations

Periodic nano texture - **H**



Period = 1 µm

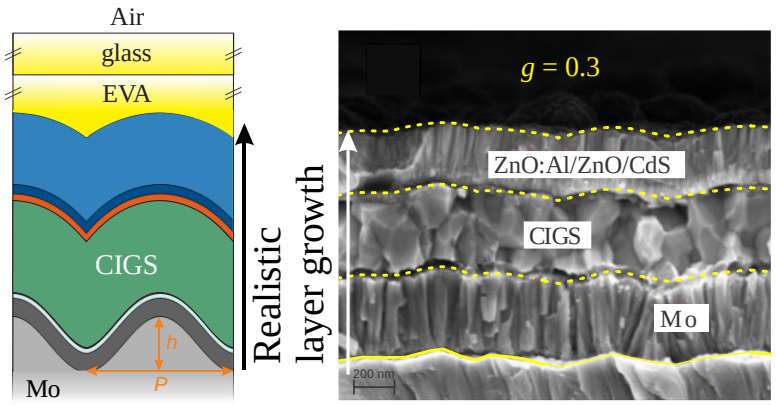
Random nano pyramids – **M**

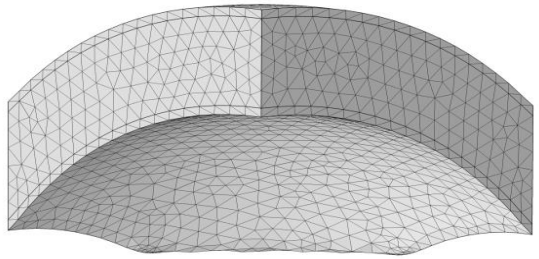


*Period = 2 µm

Optical modelling & simulations

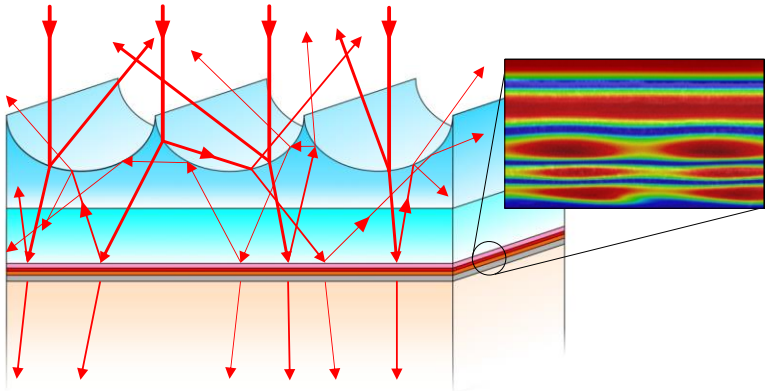
- Nano-sized internal textures:
  - Realistic layer growth
  - 3D Finite Element Method (FEM)
  - COMSOL Multiphysics Simulator





COMSOL MULTIPHYSICS

- Micro-sized textures:
  - 3D Combined Ray Wave Optics
  - *CROWM simulator



Informacije MIDEM, nr. 41 (2011) pp. 264-271

Model of texture transfer

+

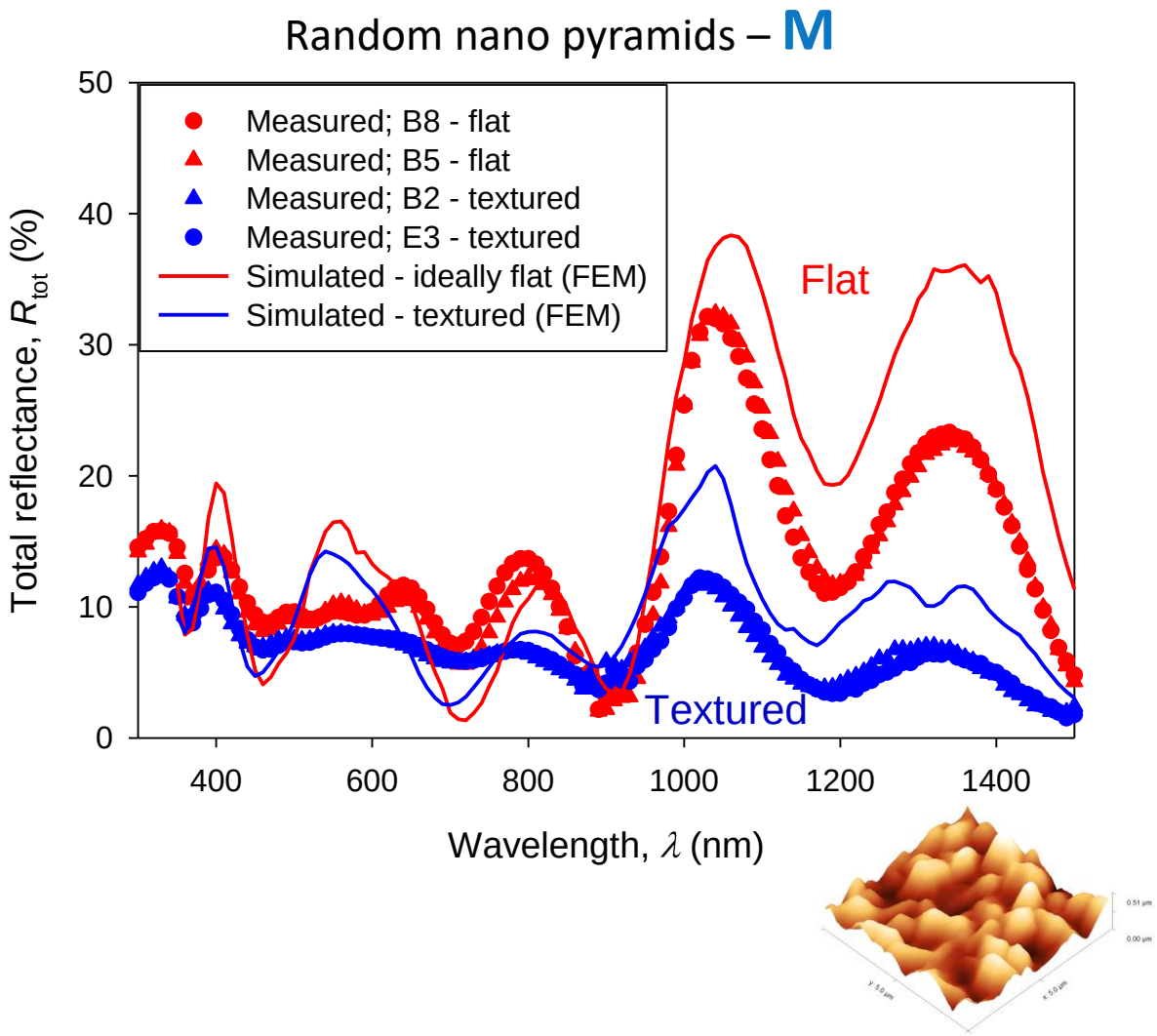
optical data and thicknesses of layers

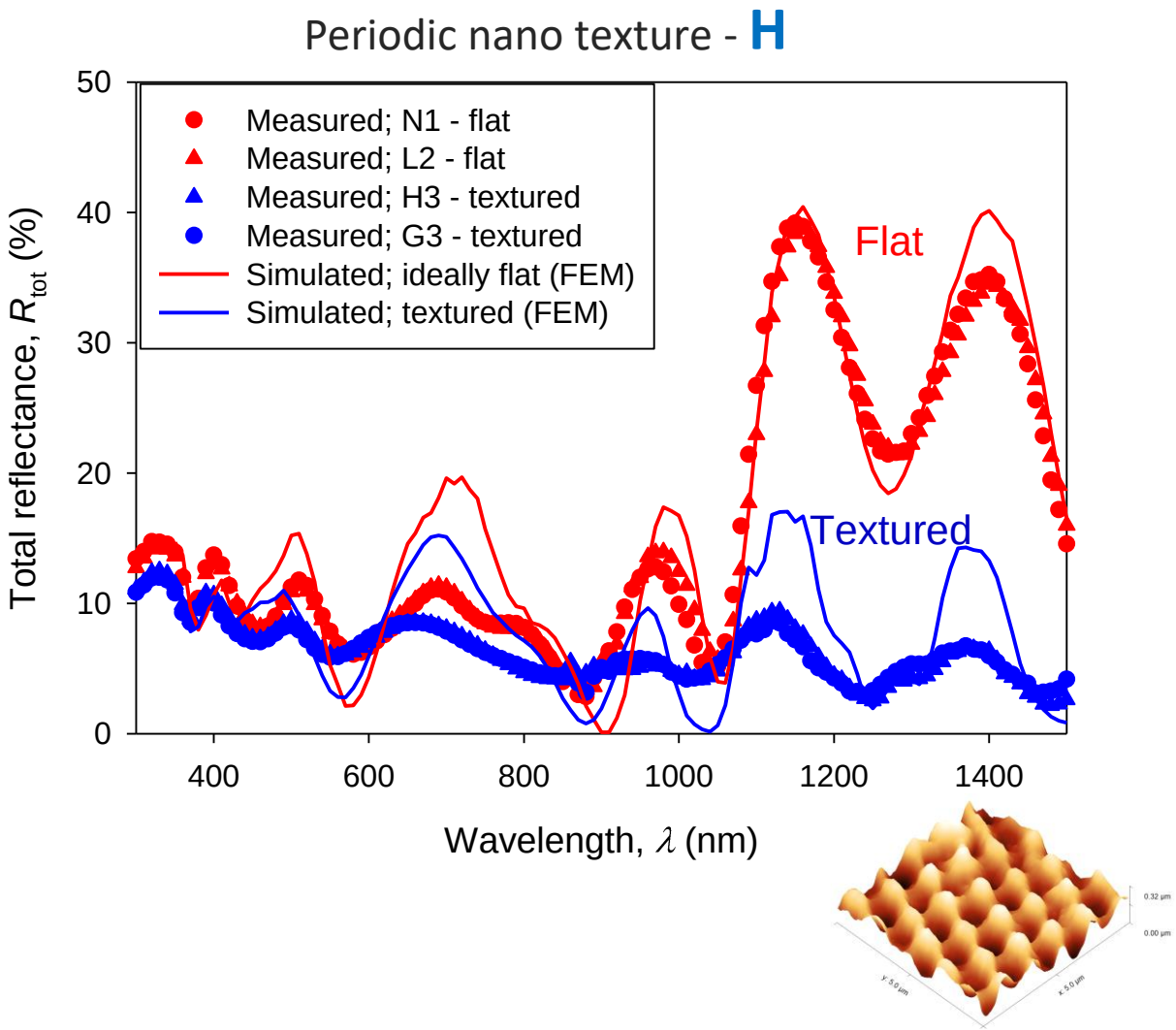
+

optical simulations with FEM or combined wave & ray optics

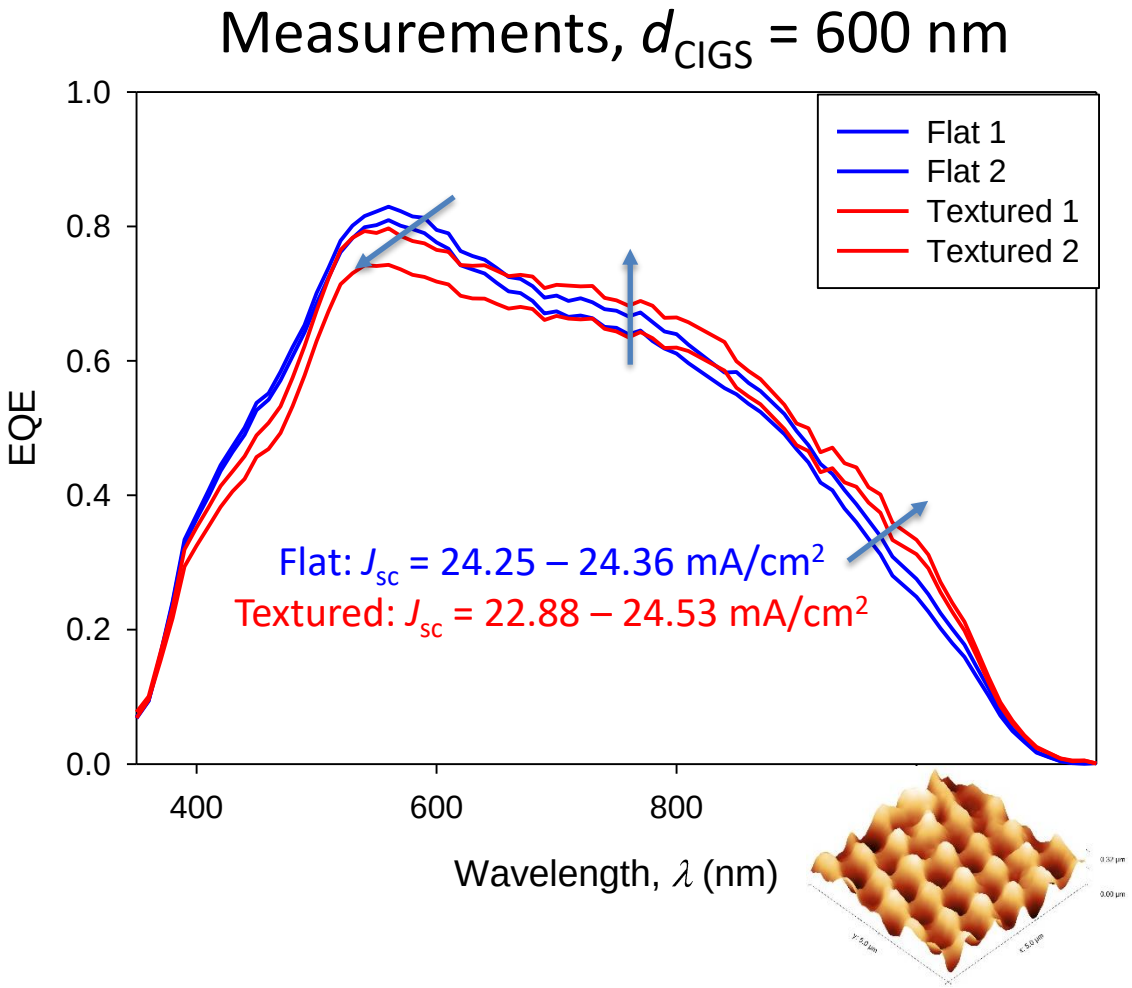
prediction of *EQE* and J_{SC} + analysis&optimization
(assuming certain carrier extraction rate)

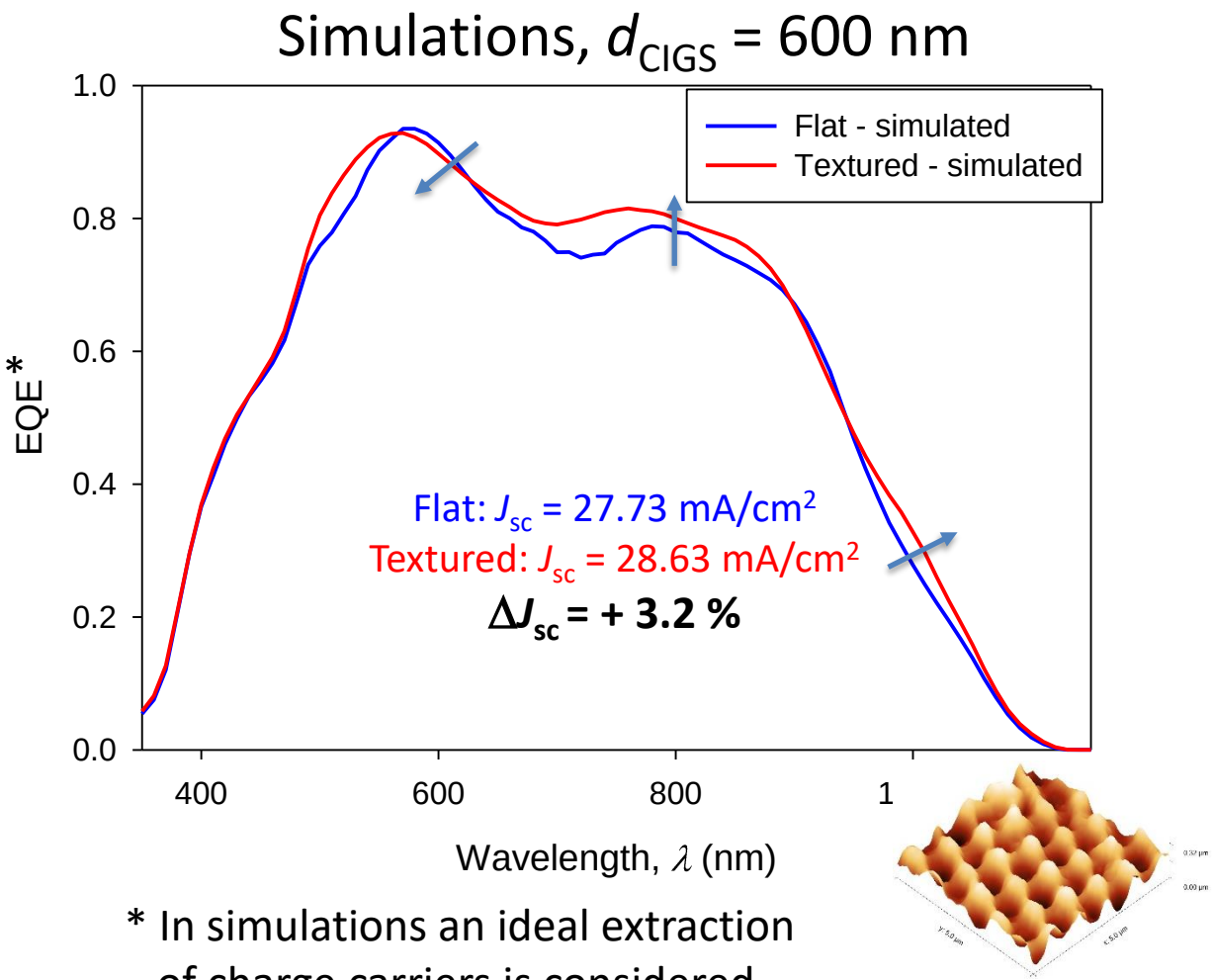
R measurements & simulations





EQE measurements & simulations - Periodic nano texture - H



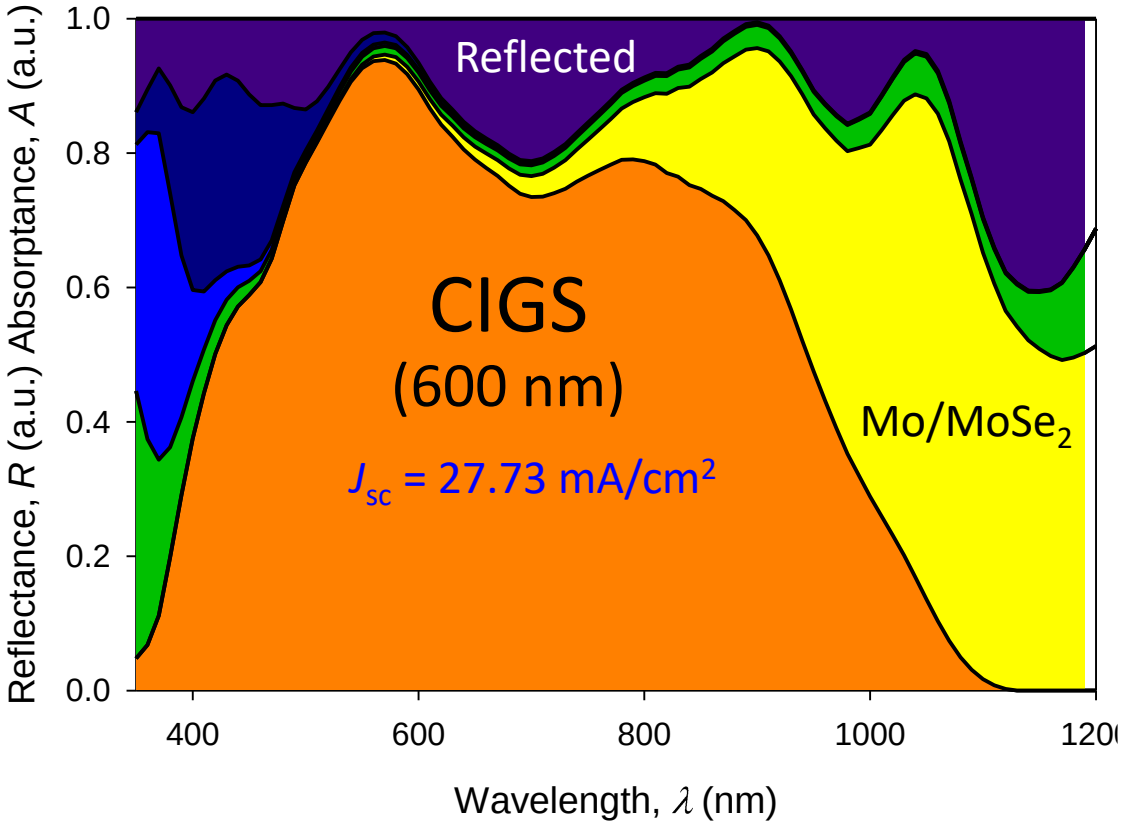


* In simulations an ideal extraction of charge carriers is considered

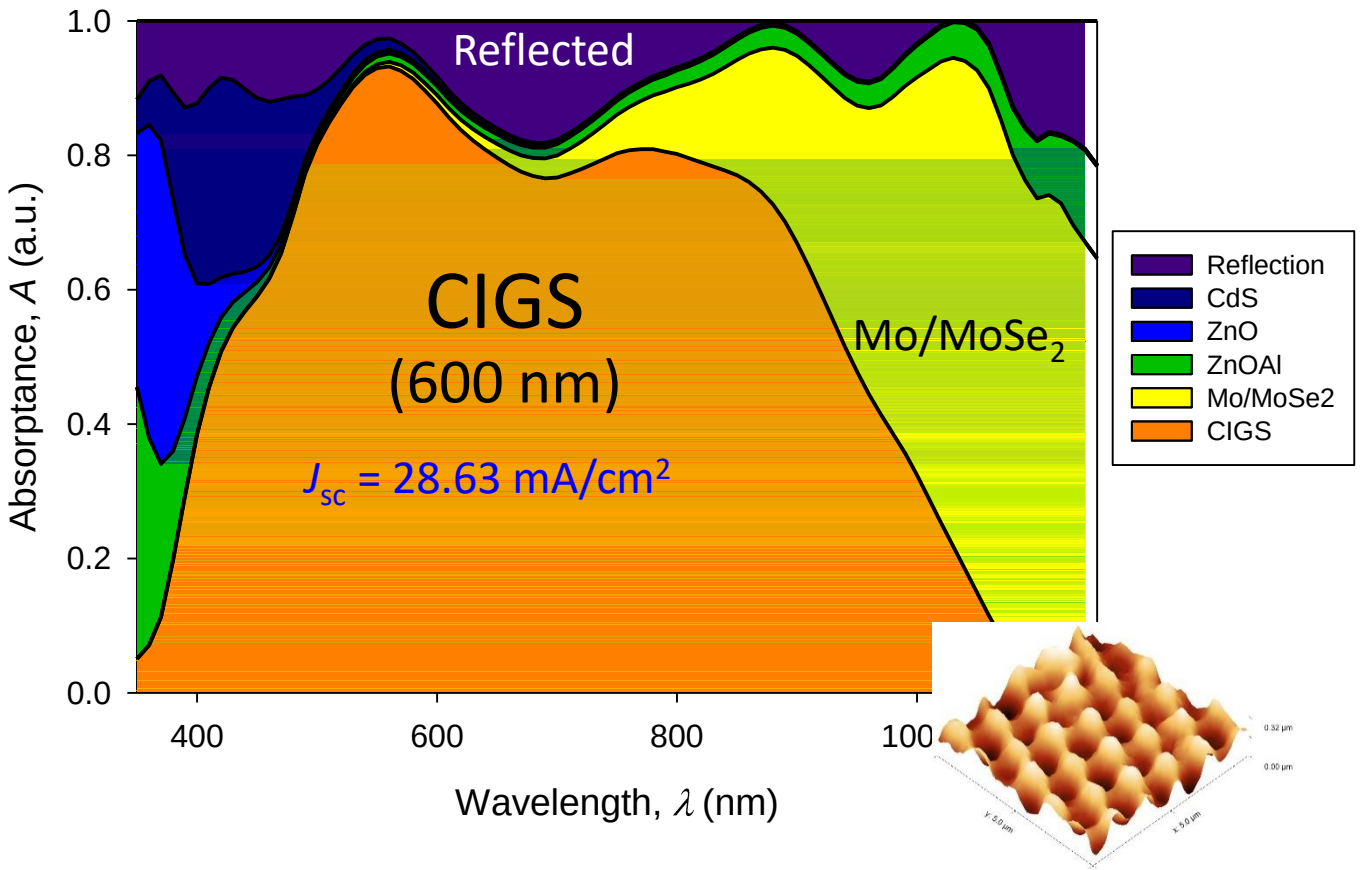
EQE & optical losses in cell – Mo contact

Simulations:

Ideally flat interfaces



Periodic nano texture - **H**



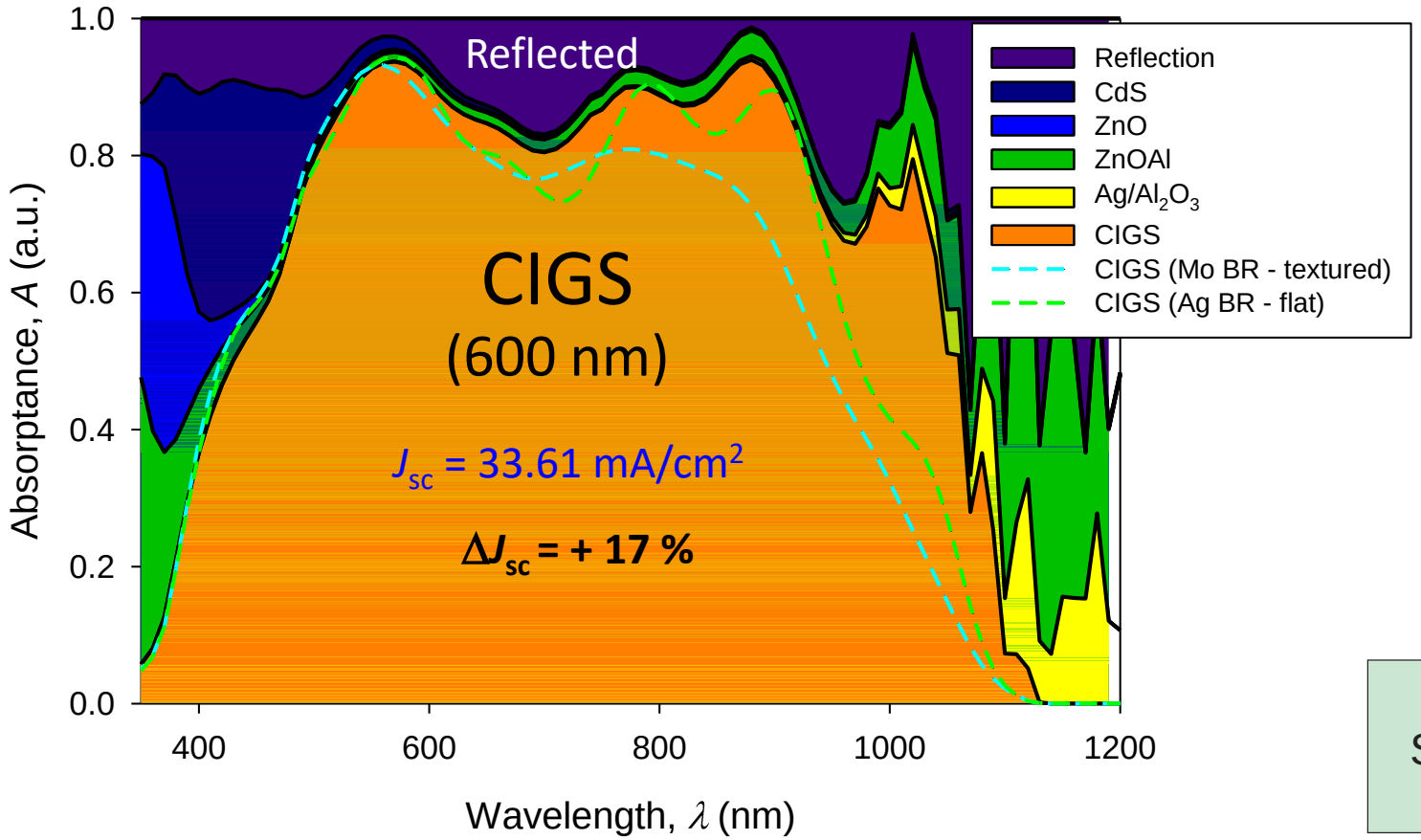
EQE & optical losses in cell – **highly reflective back contact**

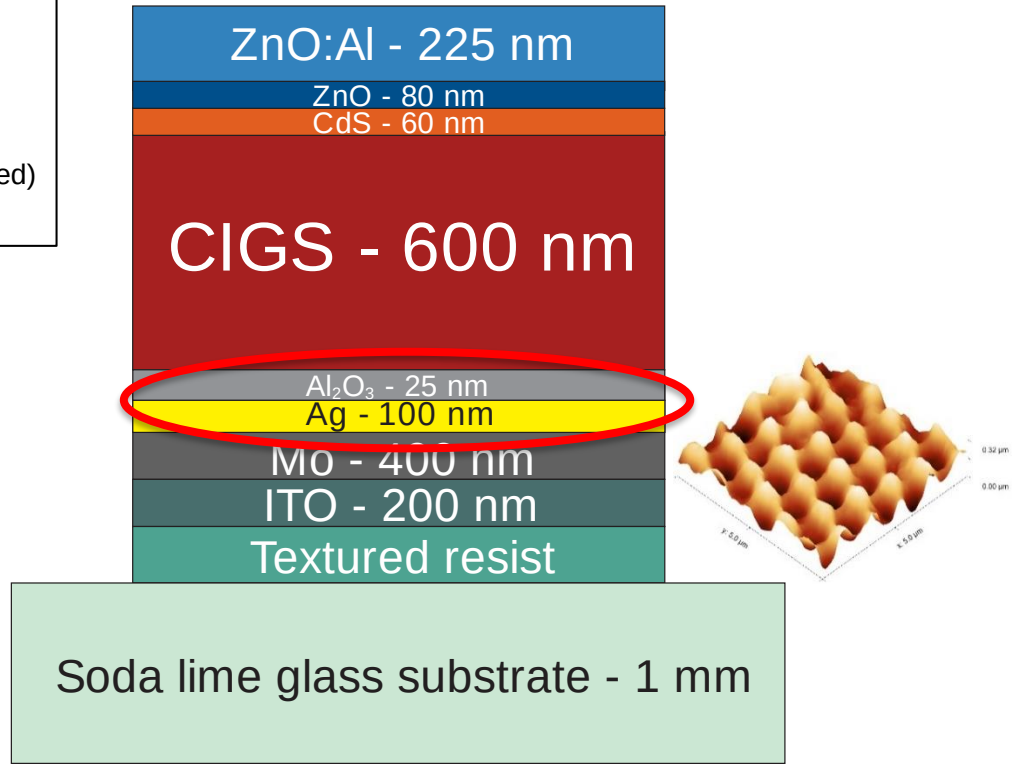
Simulations:

Periodic nano texture - **H**

+

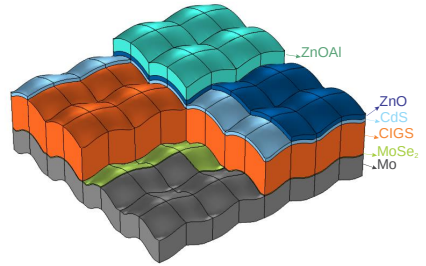
texturization



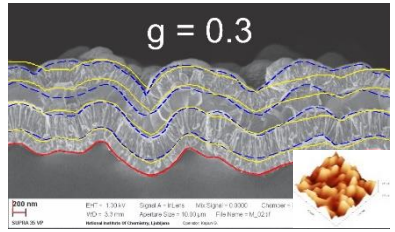


Conclusions

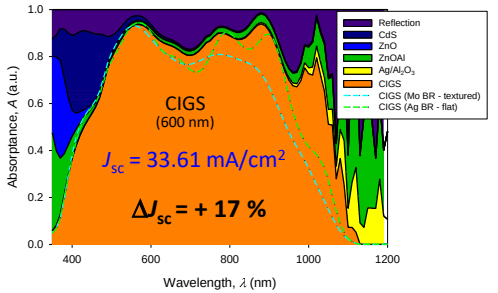
- Using modelling and simulations supported by experimental verification we evaluated optical impact of internal textures (textured substrate) in ultra-thin CIGS solar cells



- Actual texture transfer (conformal + isotropic) of CIGS solar cell layers on top of a textured substrate is modelled and further used in optical simulations



- Main losses of textured and flat devices are evaluated and a solution with an internal nanotexture and highly reflective back contact (e.g. Ag) is proposed for more than 17 % increase in J_{sc} (compared to flat thin CIGS solar cell on Mo back contact)



More on modelling of ultra-thin CIGS:
- M. Kovacic et al., Sol. energy mater. sol. cells., 200 (2019) 109933
- M. Kovacic et al., Inf. Midem., Vol. 49, No. 3(2019), 183 – 190

Acknowledgements

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Thank you for your attention

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