ohm Technische Hochschule Nürnberg

On the theoretical framework to manufacture OPV modules with world record efficiency

18.03.2024

DPG Frühjahrstagung

Fabian Gumpert

Outline

Introduction | Organic Photovoltaic, Module Efficiency, Blade Coating

Simulation | CFD Simulation, Empirical equation

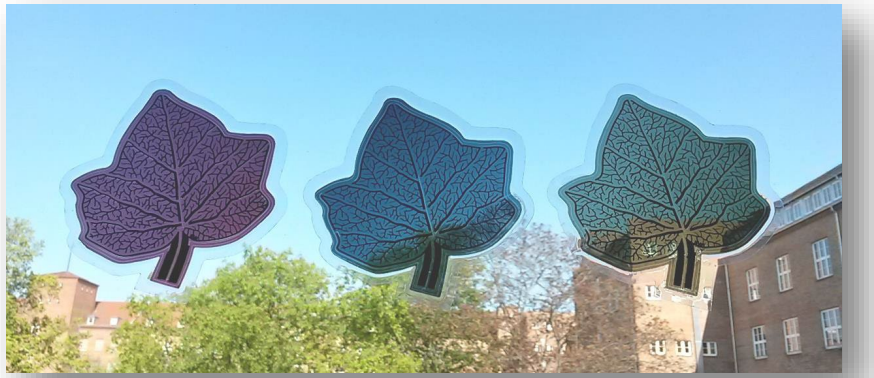
Theory | Derivation of an analytical equation

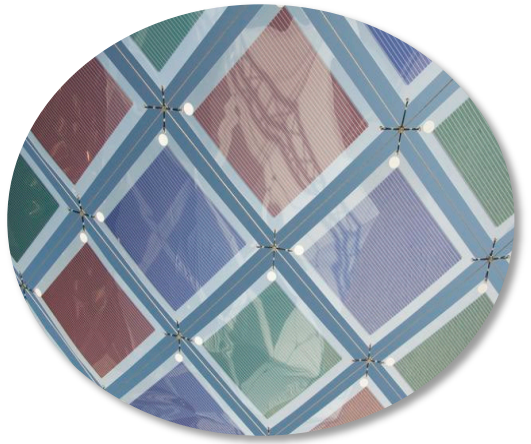
Contribution to world record module | Accelerated blade coating

Summary

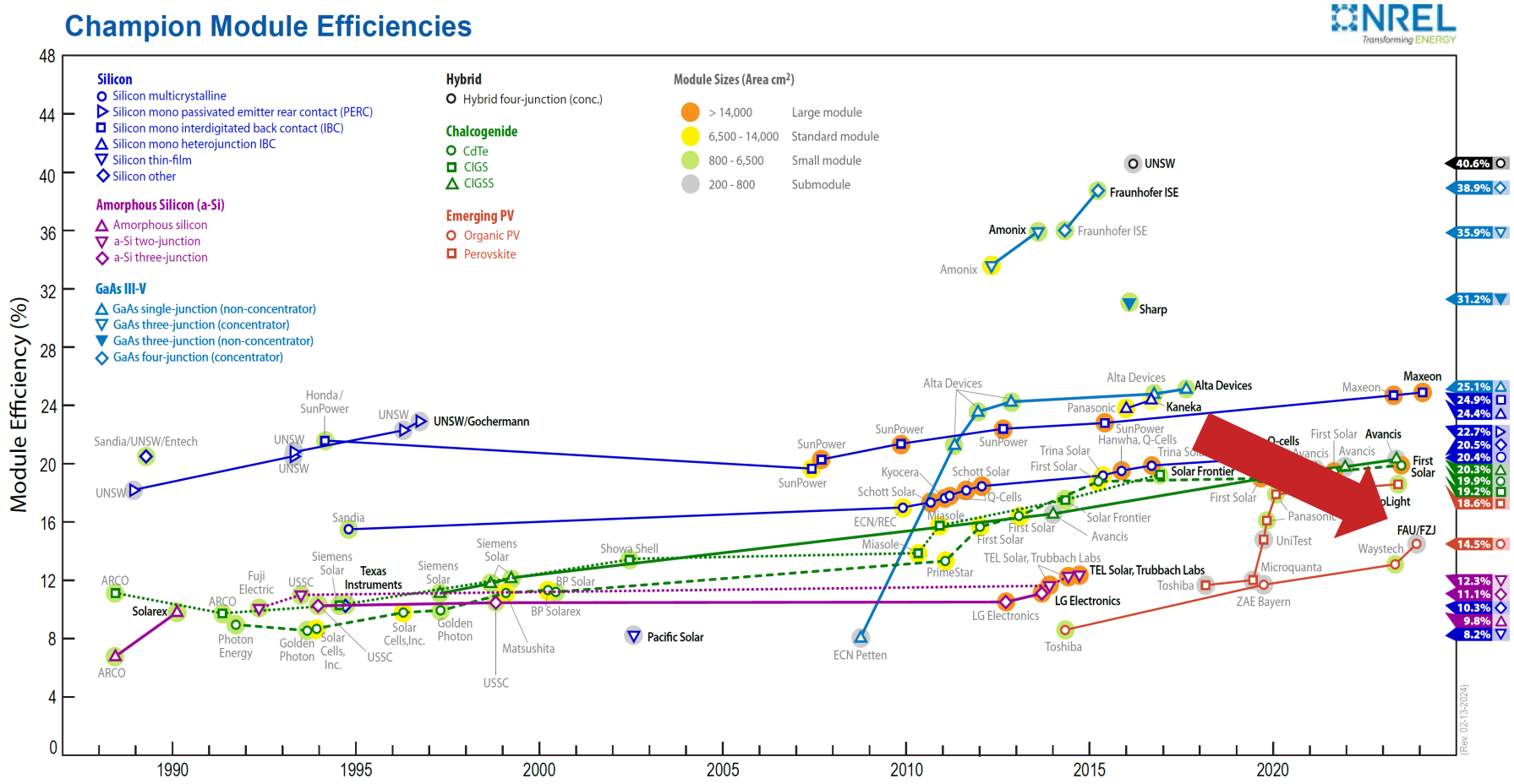
Organic Photovoltaics (OPV)

Organic Photovoltaics (OPV)



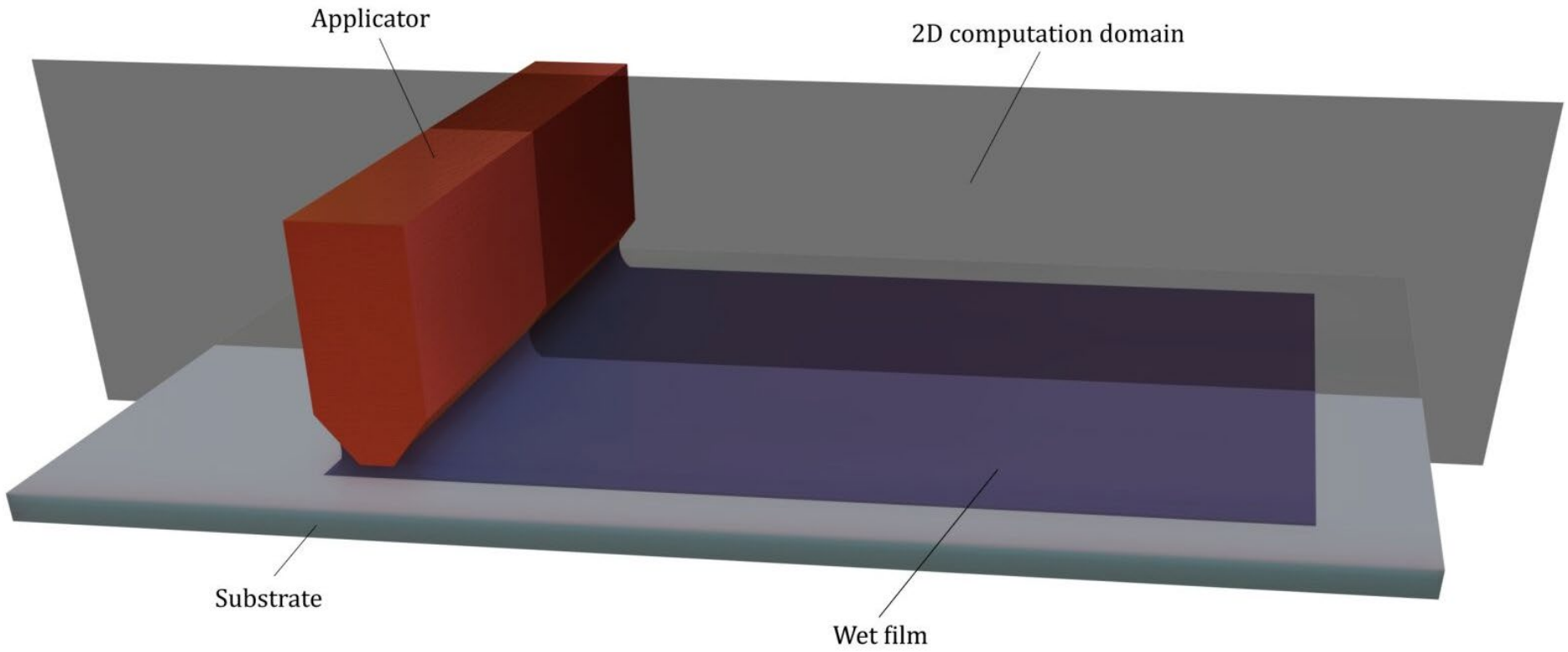


Module Efficiencies



[1] NREL, Champion Photovoltaic Module Efficiency Chart, https://www.nrel.gov/pv/module-efficiency.html (03.03.2024).

Blade coating



Gumpert et al.: “Predicting layer thicknesses by numerical simulation for meniscus-guided coating of organic photovoltaics”, 2023, DOI: 10.1080/19942060.2023.2242455

Outline

Introduction | Organic Photovoltaic, Module Efficiency, Blade Coating

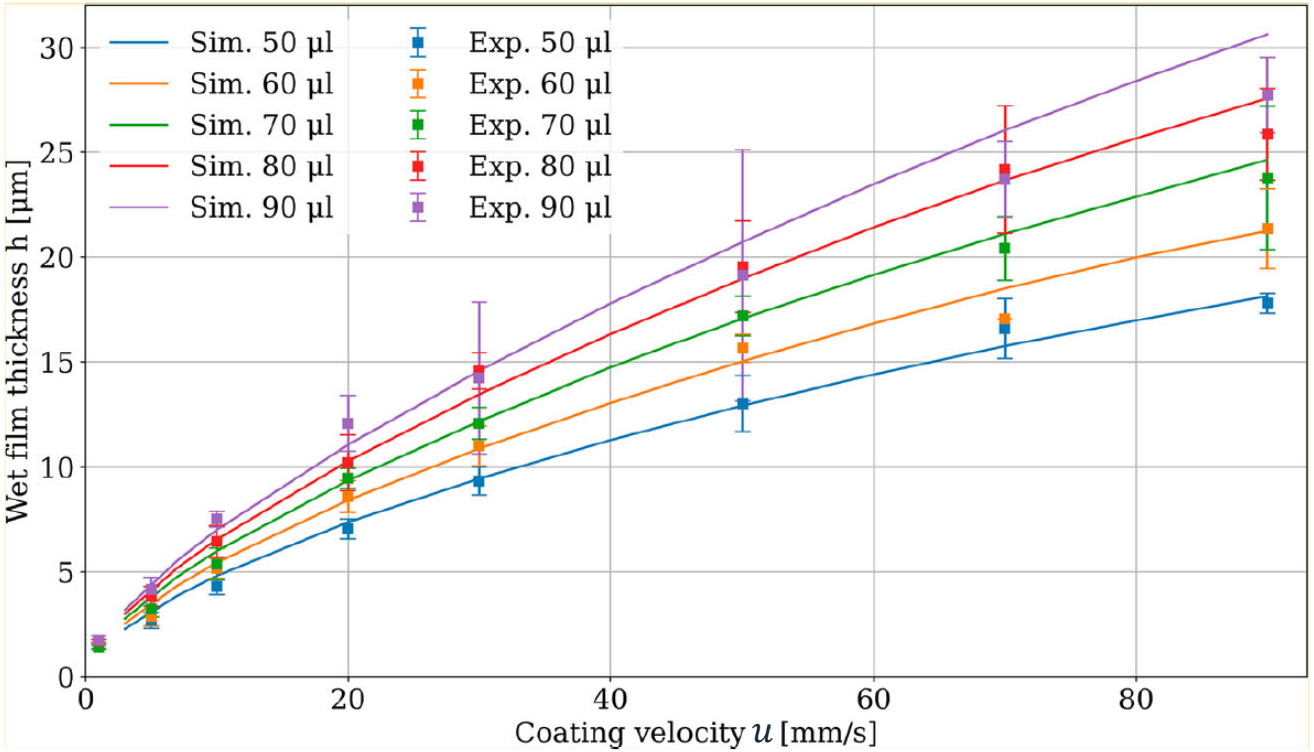
Simulation | CFD Simulation, Empirical equation

Theory | Derivation of an analytical equation

Contribution to world record module | Accelerated blade coating

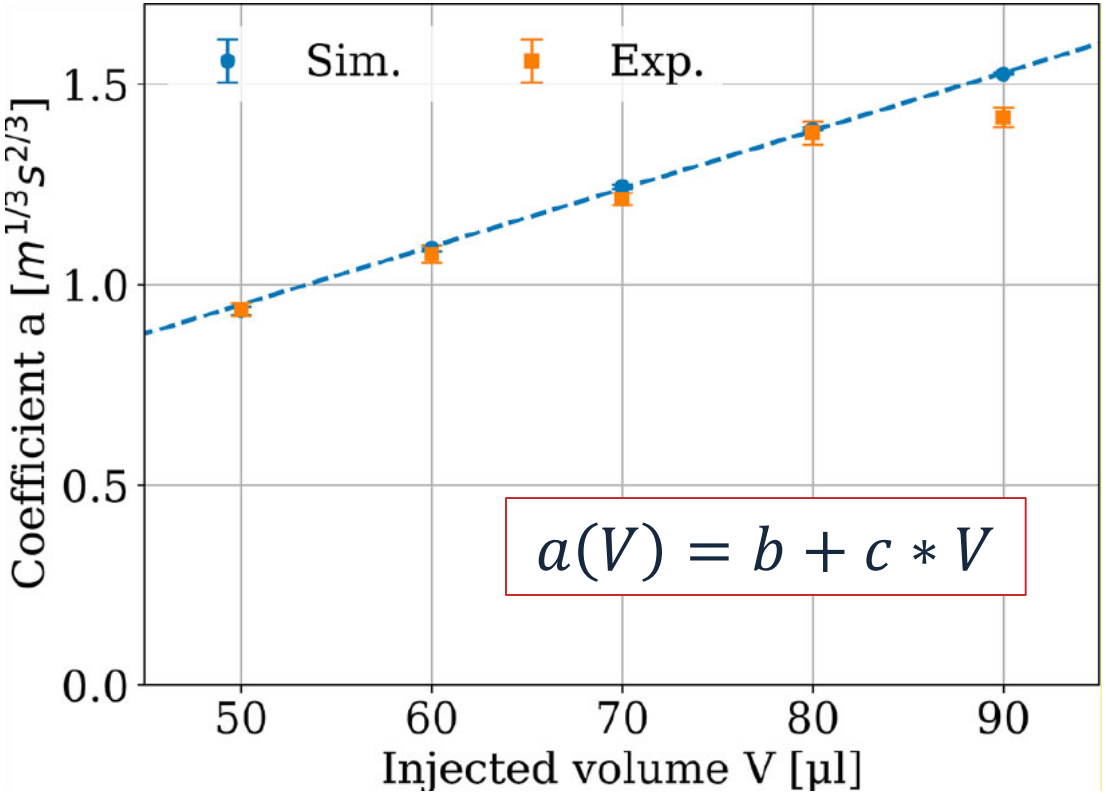
Summary

Derivation of empirical equation

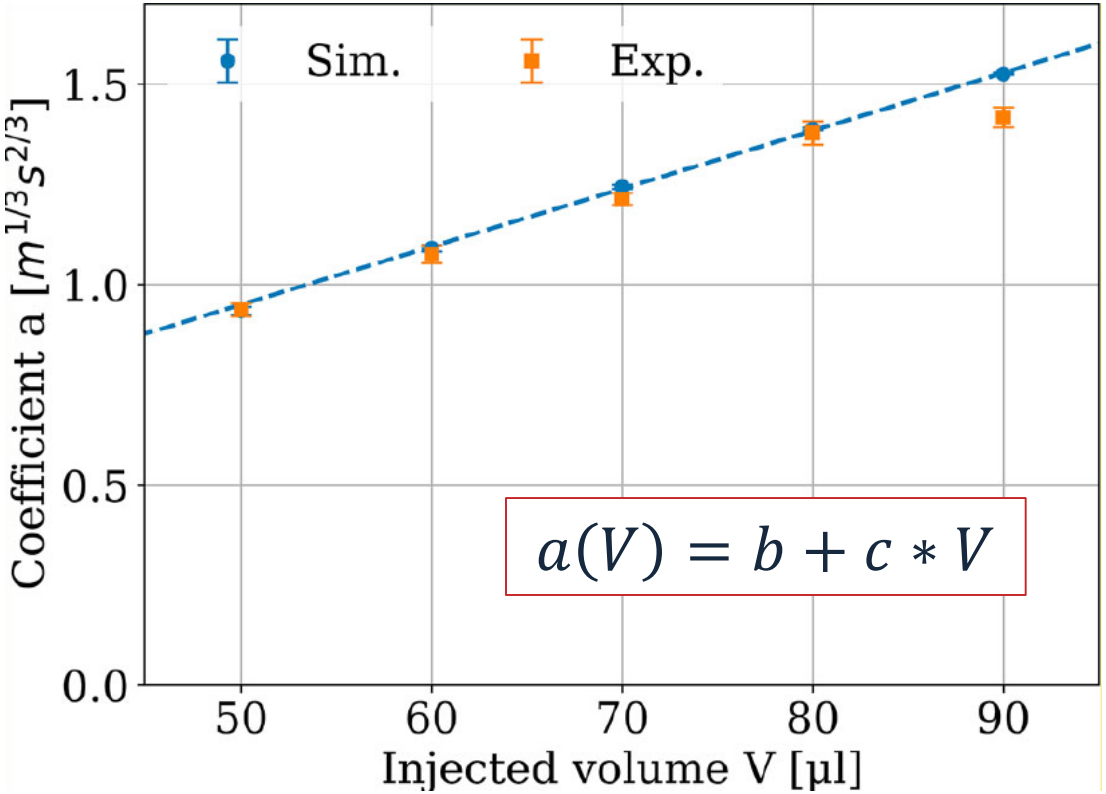


>> Good agreement between simulation and experiments

Derivation of empirical equation



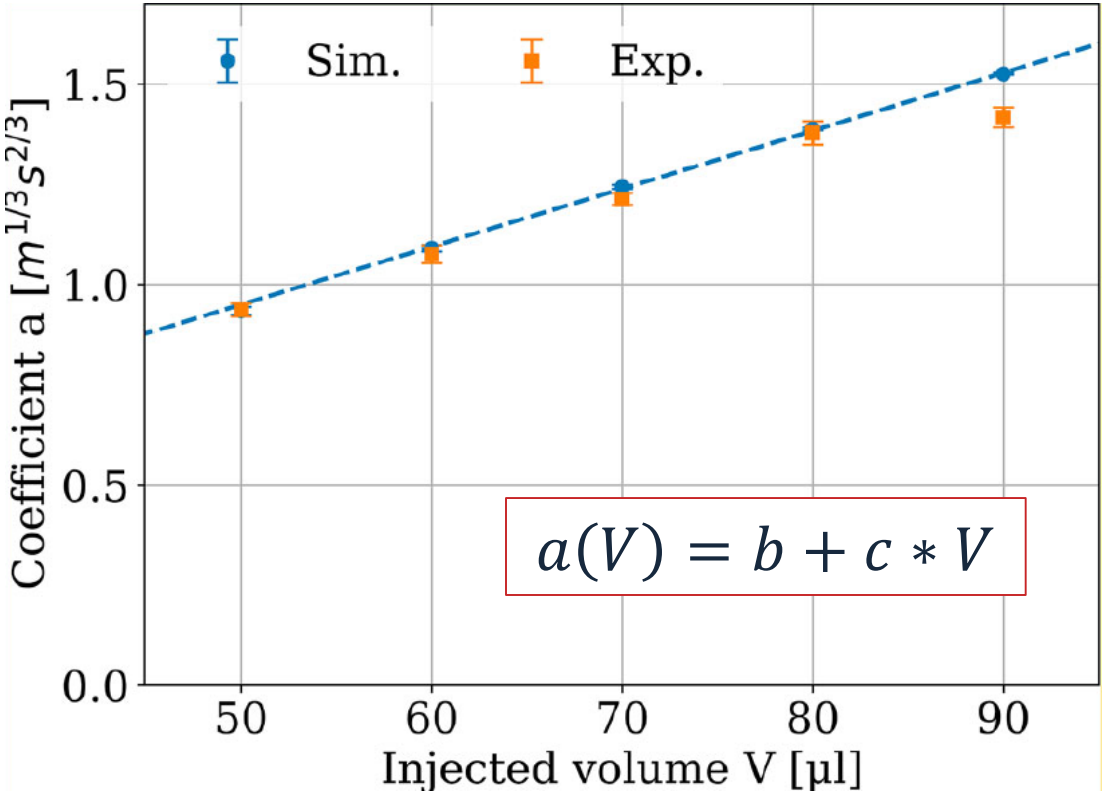
Derivation of empirical equation



Empirical description of the wet film:

$$h_{\text{fit}}(u, V) = (b + c \cdot V)\, u^{2/3}$$

Derivation of empirical equation



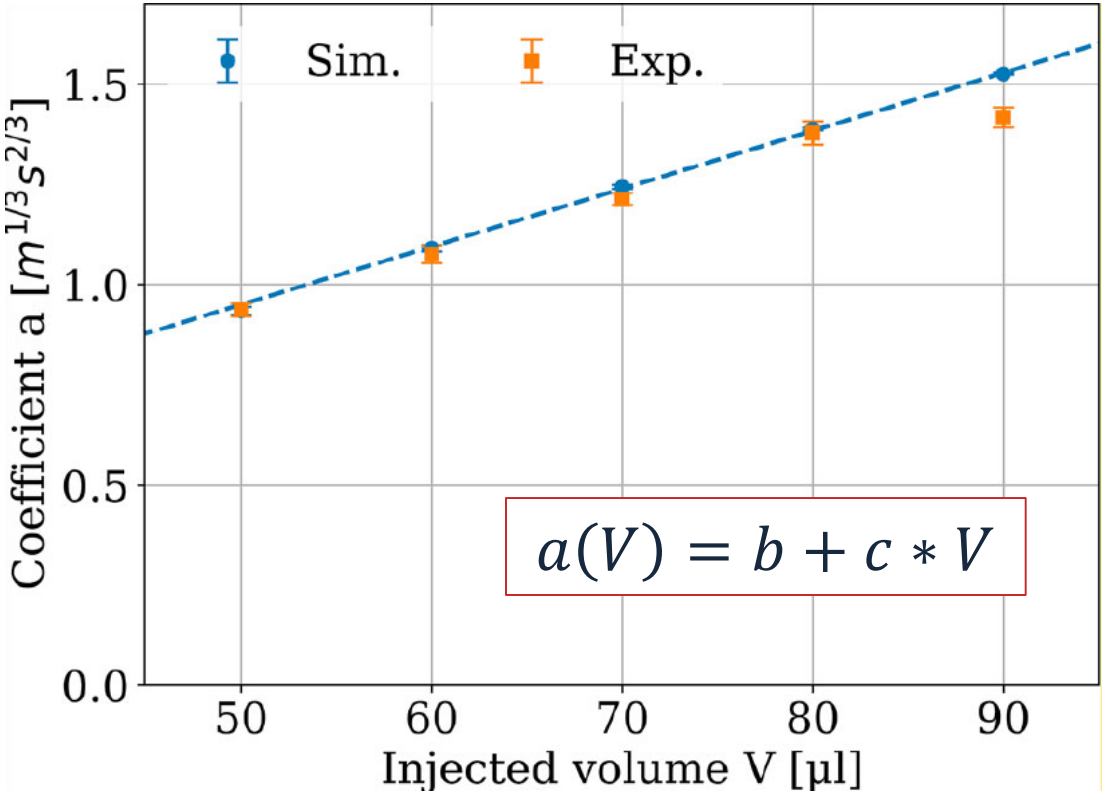
Empirical description of the wet film:

$$h_{\text{fit}}(u, V) = (b + c \cdot V)\, u^{2/3}$$

Velocity profile:

$$u_{fit}(x) = \left[\frac{h_c}{b + \tilde{c}(\frac{V_0}{w} - h_c \cdot x)} \right]^{3/2}$$

Derivation of empirical equation



Empirical description of the wet film:

$$h_{\text{fit}}(u, V) = (b + c \cdot V)\, u^{2/3}$$

Velocity profile:

$$u_{fit}(x) = \left[\frac{h_c}{b + \tilde{c}(\frac{V_0}{w} - h_c \cdot x)} \right]^{3/2}$$

>> Simple formula to predict h and to propose velocity profile for uniform coating

Outline

Introduction | Organic Photovoltaic, Module Efficiency, Blade Coating

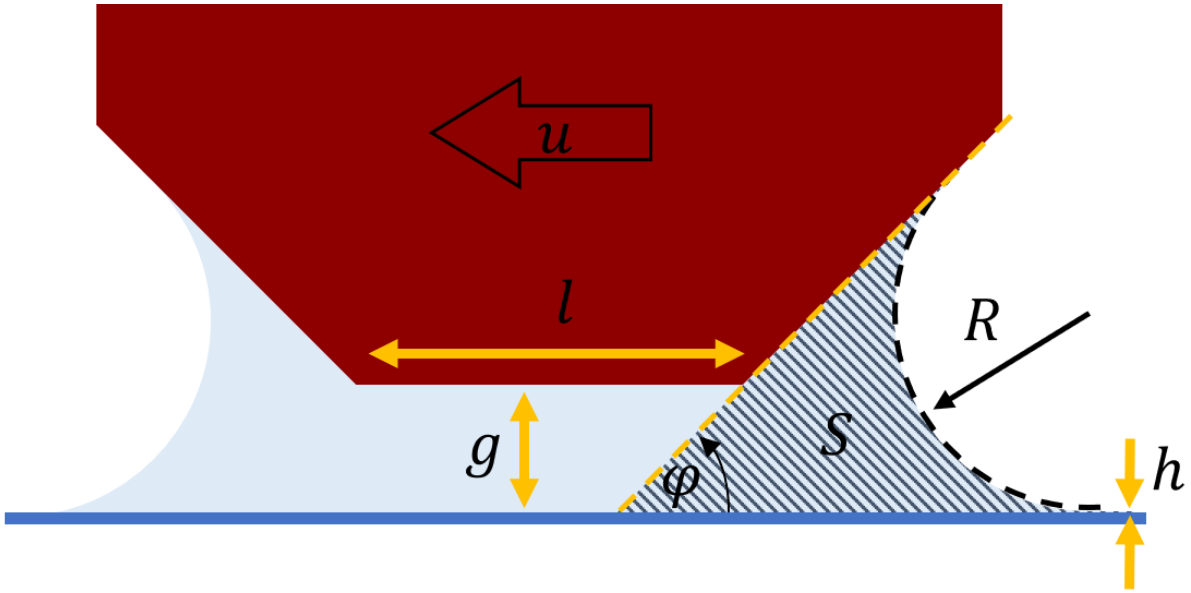
Simulation | CFD Simulation, Empirical equation

Theory | Derivation of an analytical equation

Contribution to world record module | Accelerated blade coating

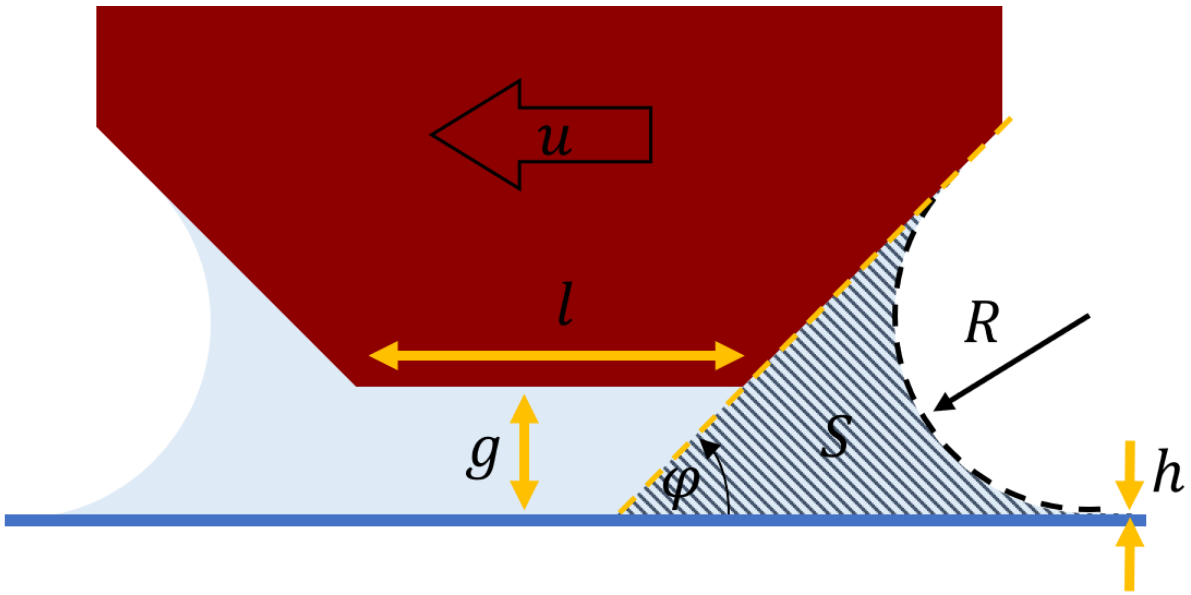
Summary

Derivation of an analytical equation



Gumpert et al.: “On the theoretical framework for meniscus-guided manufacturing of large-area OPV modules”; DOI: https://doi.org/10.48550/arXiv.2401.08439

Derivation of an analytical equation

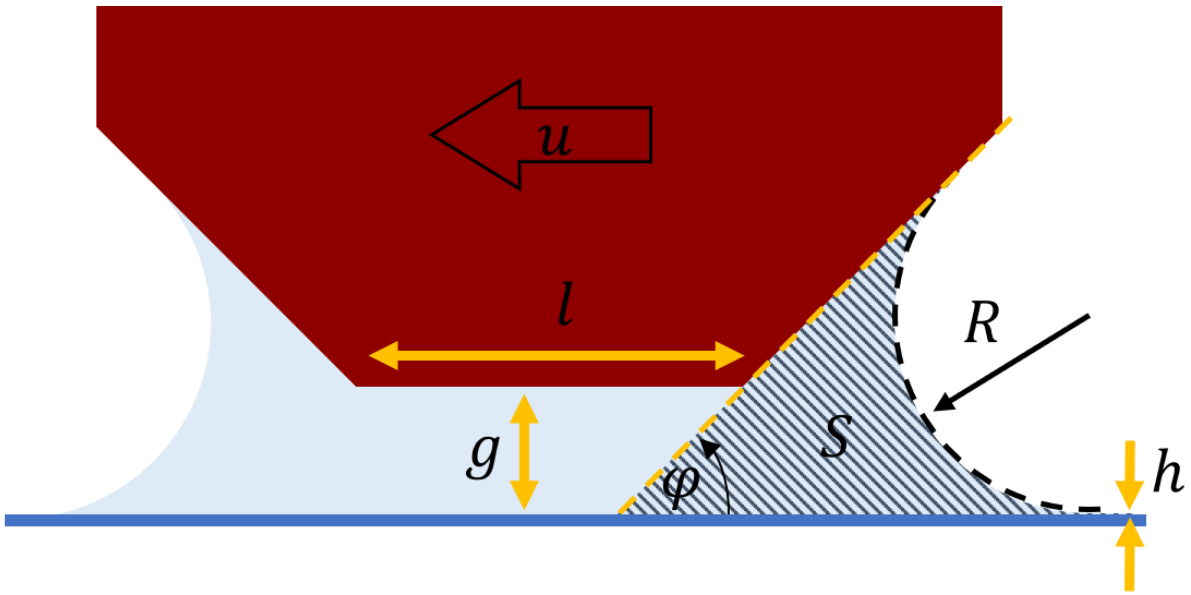


Theoretical description:

$$h = 1.34 \cdot R \cdot Ca^{2/3} \qquad Ca = \frac{\mu \cdot u}{\sigma}$$

Gumpert et al.: “On the theoretical framework for meniscus-guided manufacturing of large-area OPV modules”; DOI: https://doi.org/10.48550/arXiv.2401.08439

Derivation of an analytical equation



Theoretical description:

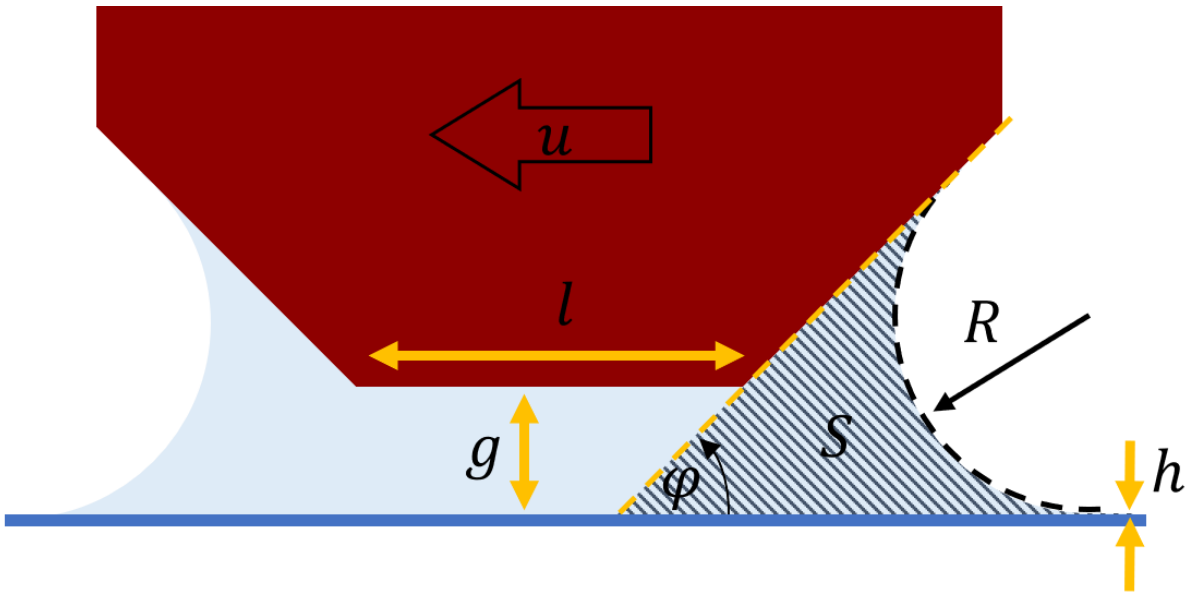
$$h = 1.34 \cdot R \cdot Ca^{2/3} \qquad Ca = \frac{\mu \cdot u}{\sigma}$$

Trapezoidal shaped applicator:

$$h_{\text{theo}}(u, V) = 0.95 \sqrt{\frac{\left[\frac{g^2}{\tan(\varphi)} + \frac{V}{w} - g \cdot l\right]}{\tan\left(\frac{\pi-\varphi}{2}\right) + \frac{\varphi-\pi}{2}}} \left(\frac{\mu \cdot u}{\sigma}\right)^{2/3}$$

Gumpert et al.: “On the theoretical framework for meniscus-guided manufacturing of large-area OPV modules”; DOI: https://doi.org/10.48550/arXiv.2401.08439

Derivation of an analytical equation



Theoretical description:

$$h = 1.34 \cdot R \cdot Ca^{2/3} \qquad Ca = \frac{\mu \cdot u}{\sigma}$$

Trapezoidal shaped applicator:

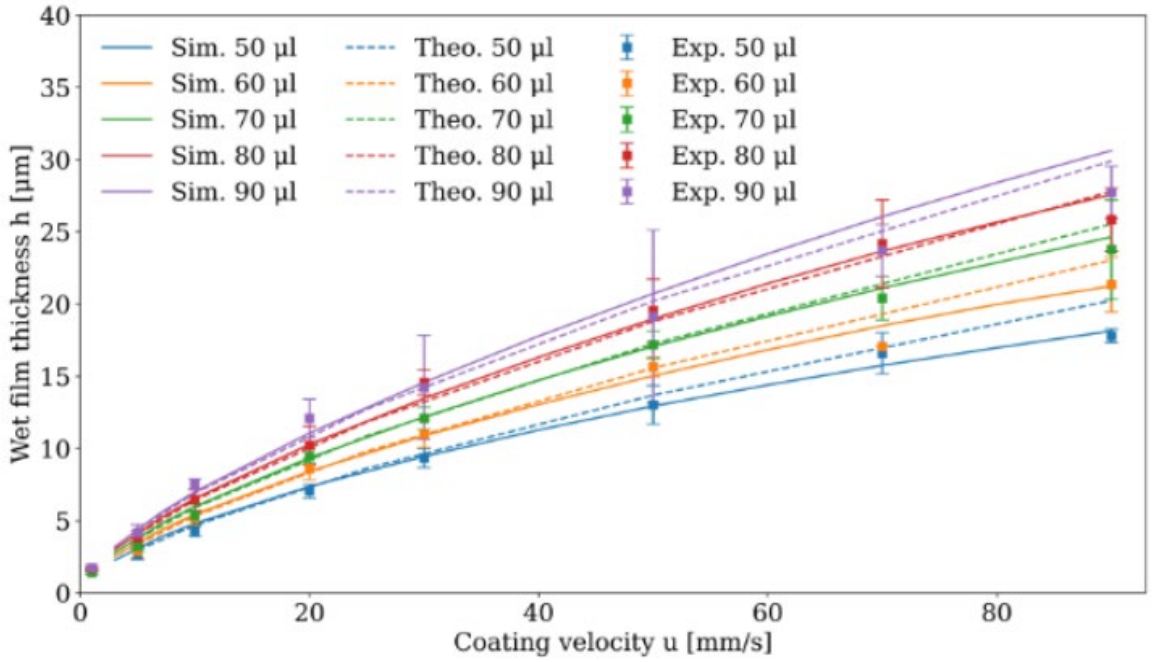
$$h_{\text{theo}}(u, V) = 0.95 \sqrt{\frac{\left[\frac{g^2}{\tan(\varphi)} + \frac{V}{w} - g \cdot l\right]}{\tan\left(\frac{\pi-\varphi}{2}\right) + \frac{\varphi-\pi}{2}}} \left(\frac{\mu \cdot u}{\sigma}\right)^{2/3}$$

Velocity profile:

$$u_{\text{theo}}(x) = 1.08 \frac{\sigma}{\mu} \left\{ h_c \sqrt{\frac{\tan\left(\frac{\pi-\varphi}{2}\right) + \frac{\varphi-\pi}{2}}{\left[\frac{g^2}{\tan(\varphi)} + \frac{V_0}{w} - h_c \cdot x - g \cdot l\right]}} \right\}^{3/2}$$

Gumpert et al.: “On the theoretical framework for meniscus-guided manufacturing of large-area OPV modules”; DOI: https://doi.org/10.48550/arXiv.2401.08439

Derivation of an analytical equation



Theoretical description:

$$h = 1.34 \cdot R \cdot Ca^{2/3} \qquad Ca = \frac{\mu \cdot u}{\sigma}$$

Trapezoidal shaped applicator:

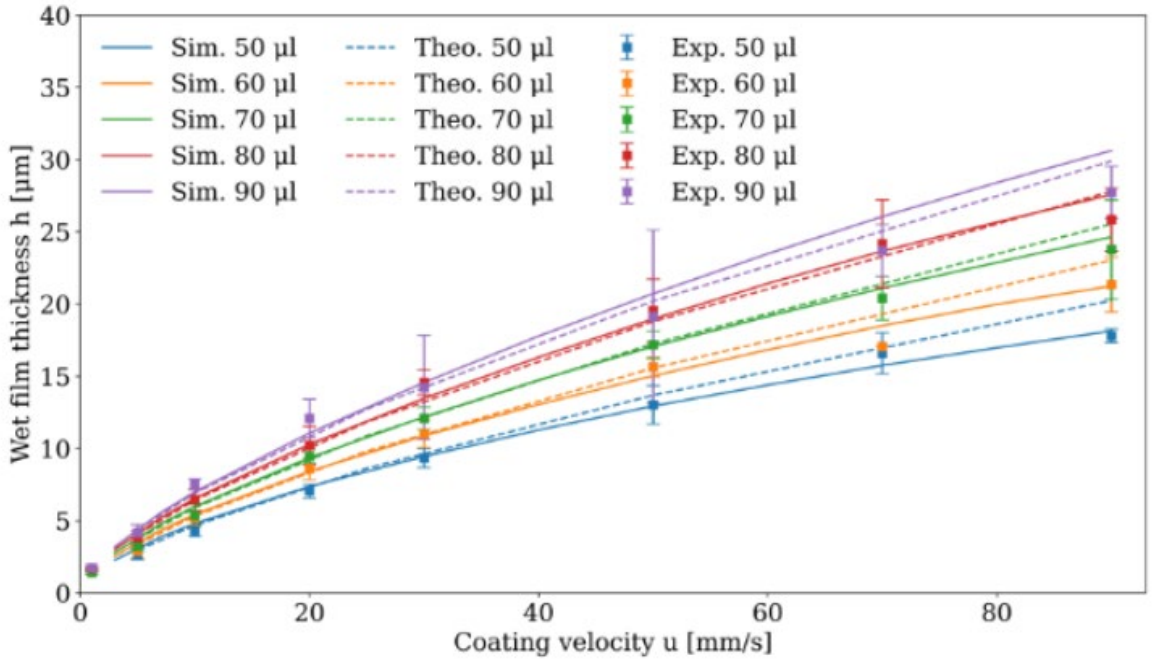
$$h_{\text{theo}}(u, V) = 0.95 \sqrt{\frac{\left[\frac{g^2}{\tan(\varphi)} + \frac{V}{w} - g \cdot l\right]}{\tan\left(\frac{\pi-\varphi}{2}\right) + \frac{\varphi-\pi}{2}}} \left(\frac{\mu \cdot u}{\sigma}\right)^{2/3}$$

Velocity profile:

$$u_{\text{theo}}(x) = 1.08 \frac{\sigma}{\mu} \left\{ h_c \sqrt{\frac{\tan\left(\frac{\pi-\varphi}{2}\right) + \frac{\varphi-\pi}{2}}{\left[\frac{g^2}{\tan(\varphi)} + \frac{V_0}{w} - h_c \cdot x - g \cdot l\right]}} \right\}^{3/2}$$

Gumpert et al.: “On the theoretical framework for meniscus-guided manufacturing of large-area OPV modules”; DOI: https://doi.org/10.48550/arXiv.2401.08439

Derivation of an analytical equation



Theoretical description:

$$h = 1.34 \cdot R \cdot Ca^{2/3} \qquad Ca = \frac{\mu \cdot u}{\sigma}$$

Trapezoidal shaped applicator:

$$h_{\text{theo}}(u, V) = 0.95 \sqrt{\frac{\left[\frac{g^2}{\tan(\varphi)} + \frac{V}{w} - g \cdot l\right]}{\tan\left(\frac{\pi-\varphi}{2}\right) + \frac{\varphi-\pi}{2}}} \left(\frac{\mu \cdot u}{\sigma}\right)^{2/3}$$

Velocity profile:

$$u_{\text{theo}}(x) = 1.08 \frac{\sigma}{\mu} \left\{ h_c \sqrt{\frac{\tan\left(\frac{\pi-\varphi}{2}\right) + \frac{\varphi-\pi}{2}}{\left[\frac{g^2}{\tan(\varphi)} + \frac{V_0}{w} - h_c \cdot x - g \cdot l\right]}} \right\}^{3/2}$$

>> Theoretical formula to predict h and to propose velocity profile for uniform coating

Gumpert et al.: “On the theoretical framework for meniscus-guided manufacturing of large-area OPV modules”; DOI: https://doi.org/10.48550/arXiv.2401.08439

ohm

Outline

Introduction | Organic Photovoltaic, Module Efficiency, Blade Coating

Simulation | CFD Simulation, Empirical equation

Theory | Derivaiton of an analytical equation

Contribution to world record module | Accelerated blade coating

Summary

Accelerated blade coating

Constant velocity

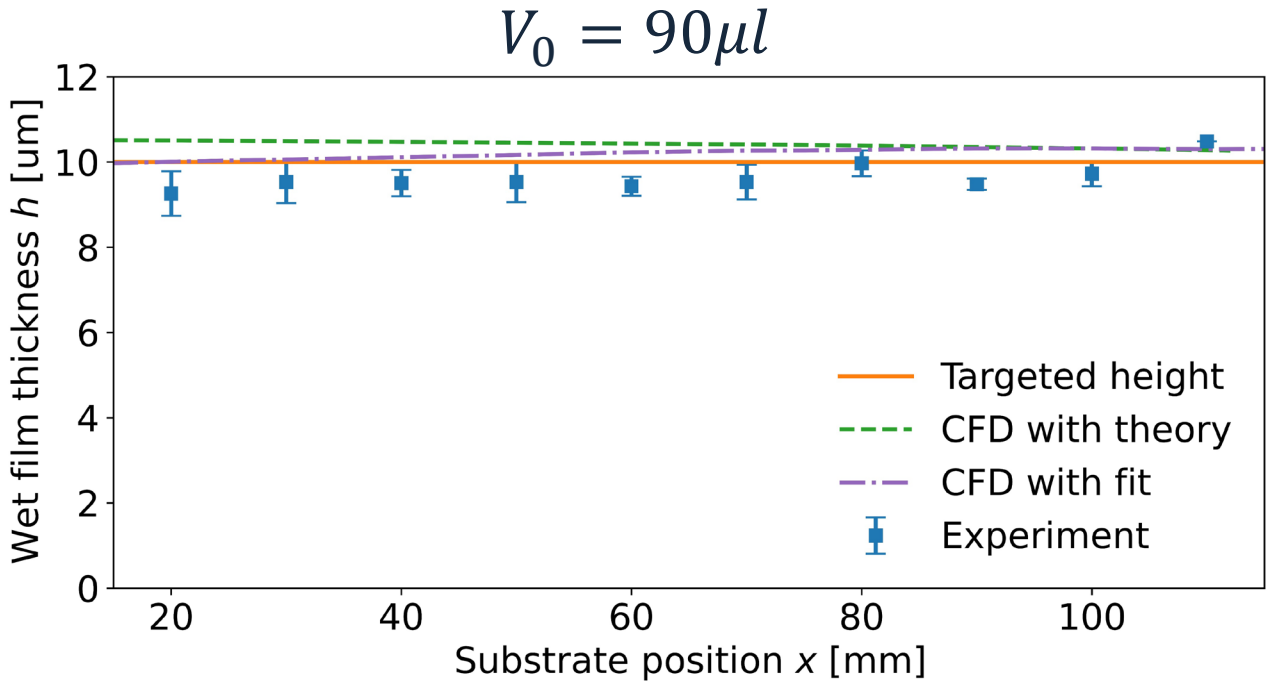
Accelerated coating

Accelerated blade coating

Constant velocity

Accelerated coating

$V_0 = 90\mu l$

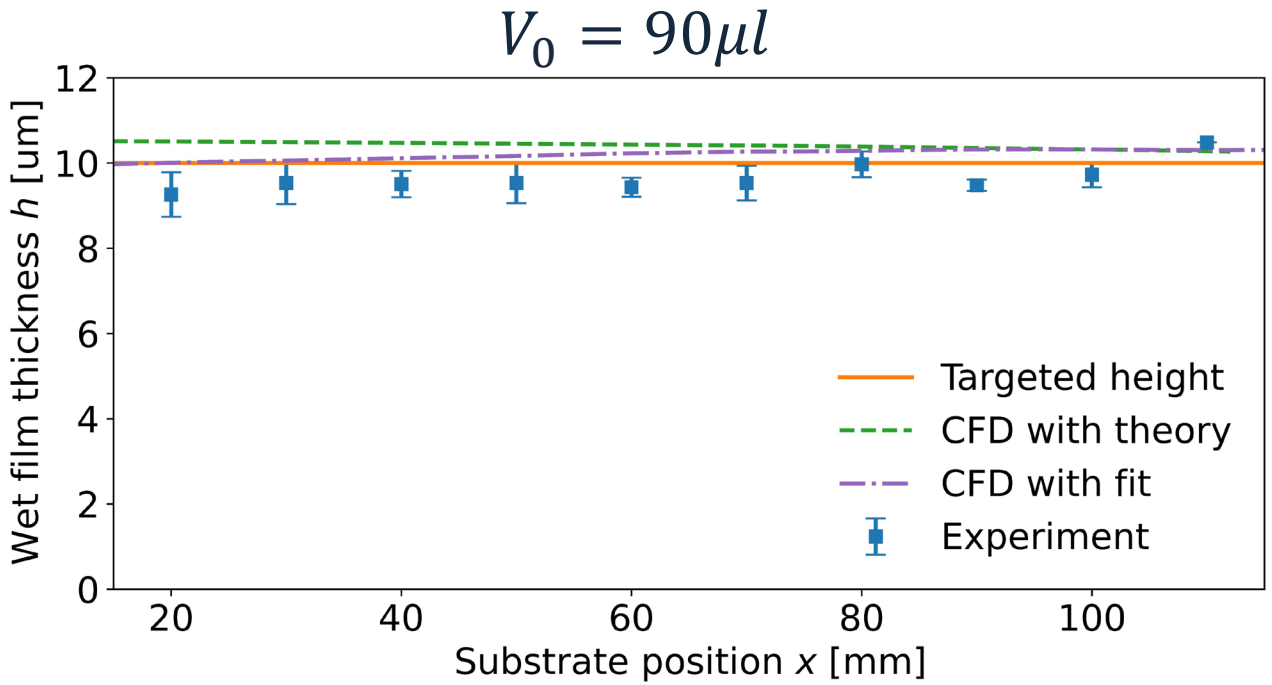


Accelerated blade coating

Constant velocity

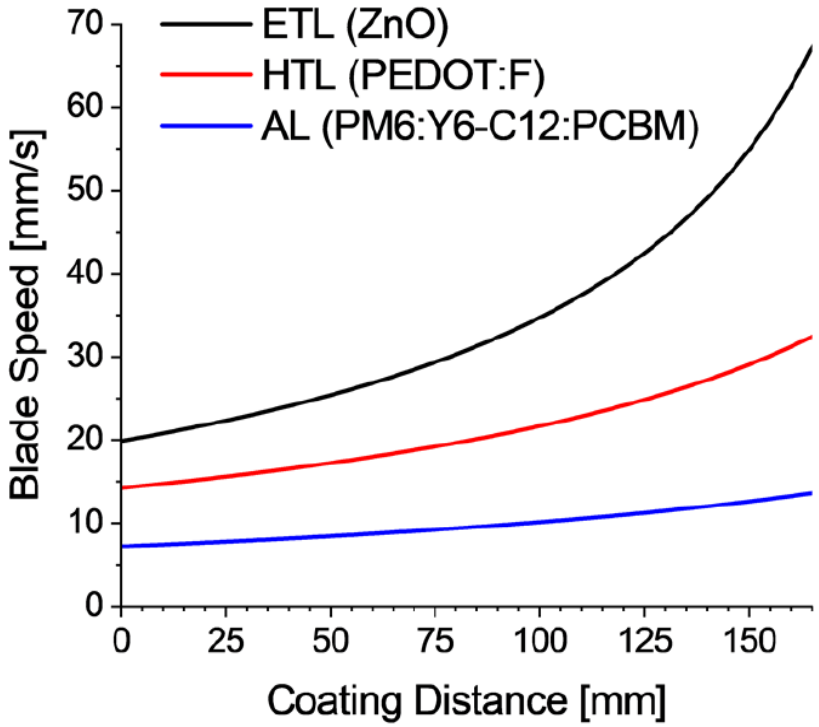
Accelerated coating

$V_0 = 90\mu l$



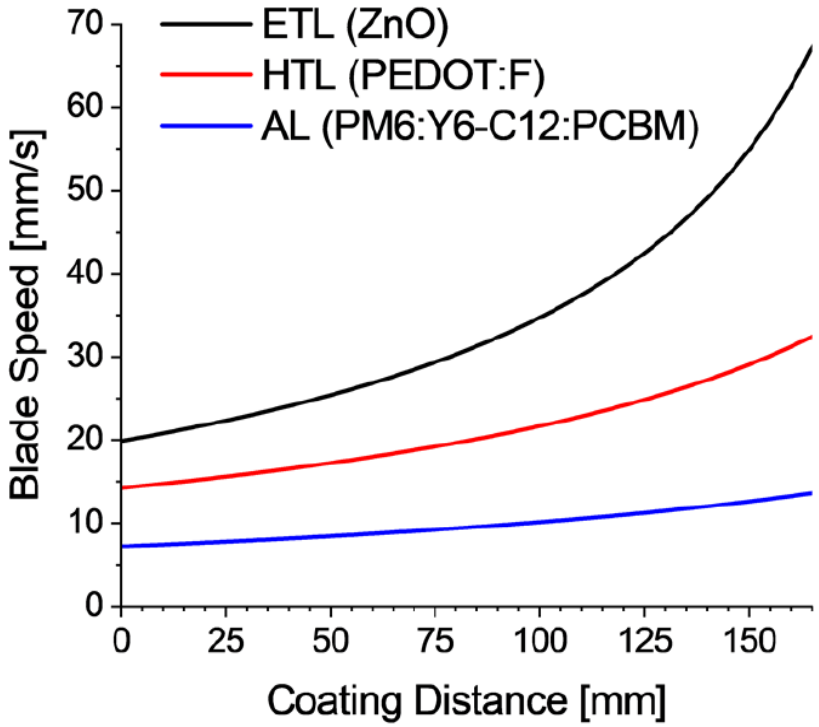
>> Accelerated blade coating can provide uniform layers for large distances

Accelerated blade coating



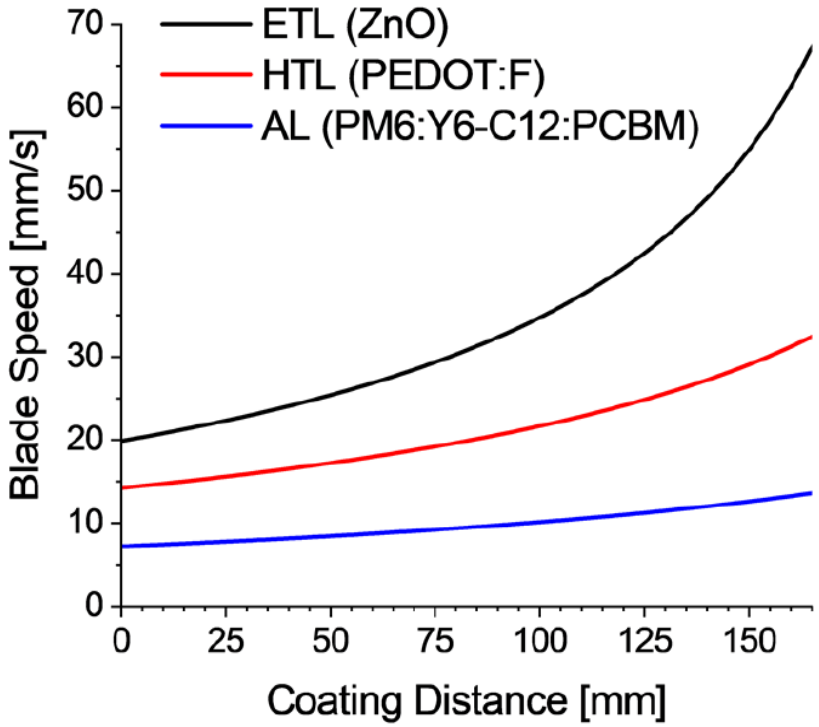
Basu et al.: “Large-area organic photovoltaic modules with 14.5% certified world record efficiency”; DOI: https://doi.org/10.1016/j.joule.2024.02.016

Accelerated blade coating



Basu et al.: “Large-area organic photovoltaic modules with 14.5% certified world record efficiency”; DOI: https://doi.org/10.1016/j.joule.2024.02.016

Accelerated blade coating



>> Material and thickness specific velocity profiles

Basu et al.: “Large-area organic photovoltaic modules with 14.5% certified world record efficiency”; DOI: https://doi.org/10.1016/j.joule.2024.02.016

Outline

Introduction | Organic Photovoltaic, Module Efficiency, Blade Coating

Simulation | CFD Simulation, Empirical equation

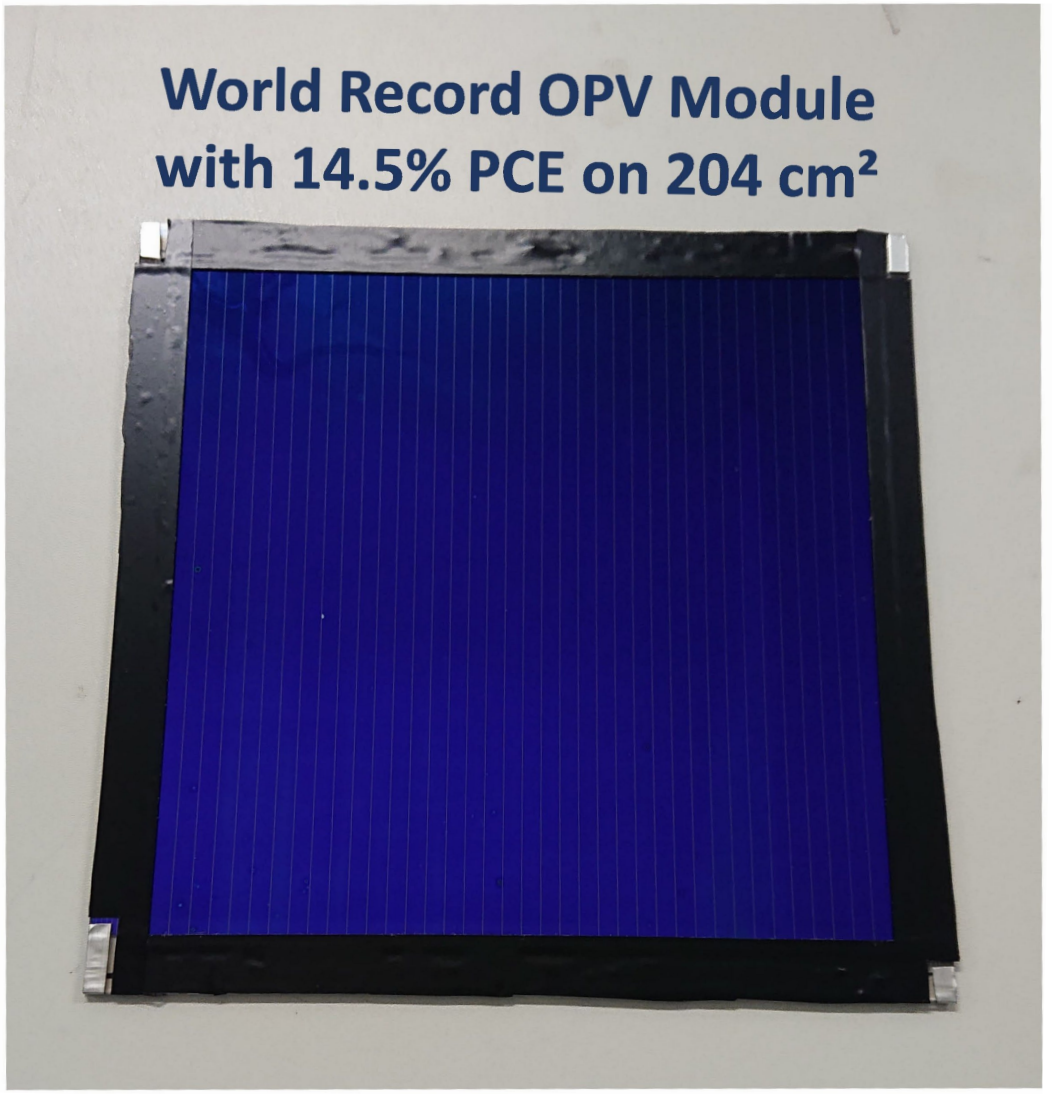
Theory | Derivation of an analytical equation

Contribution to world record module | Accelerated blade coating

Summary

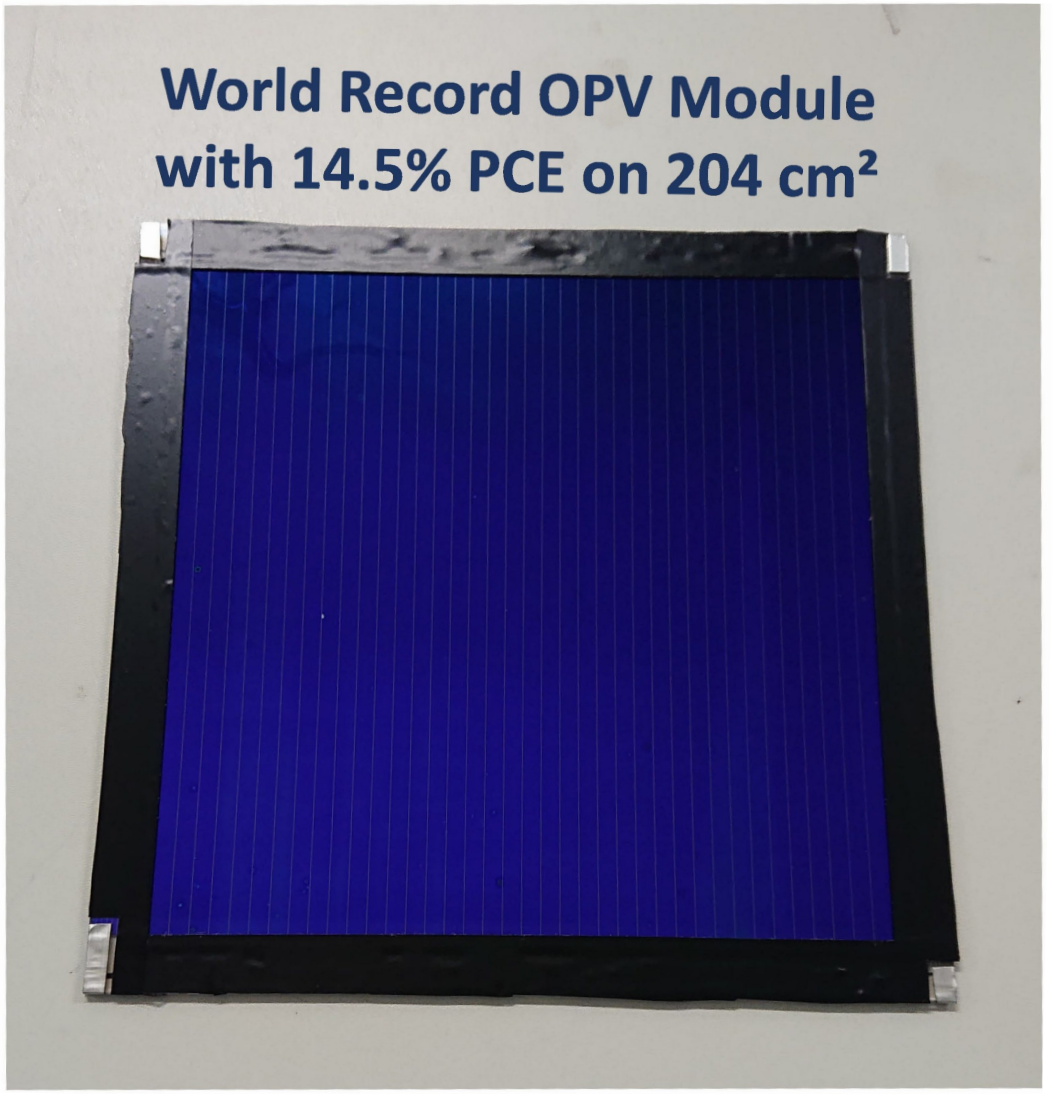
Summary

- New world record efficiency for large-area OPV modules



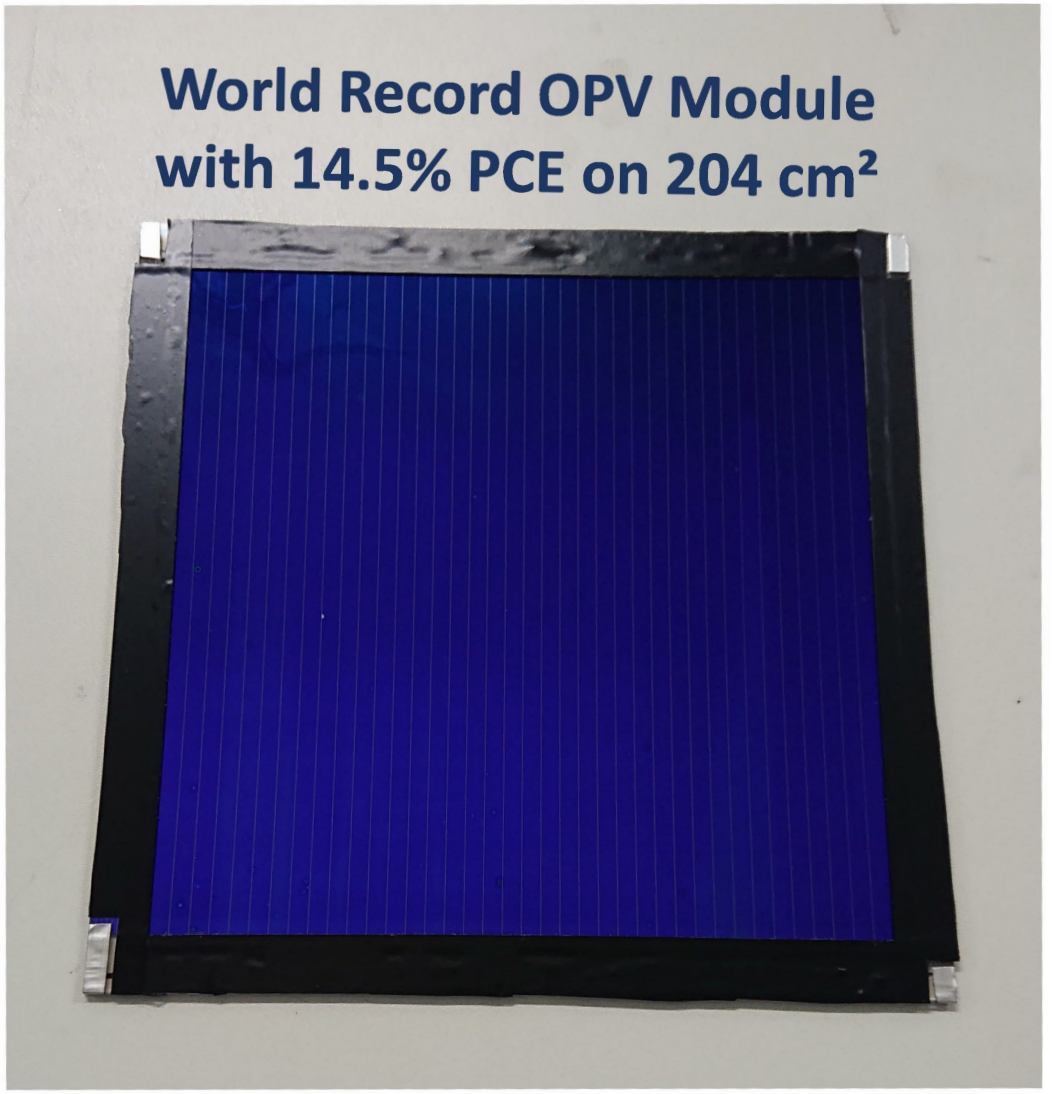
Summary

- New world record efficiency for large-area OPV modules
- Barely any performance loss upon upscaling from lab cells to >200cm^2 modules



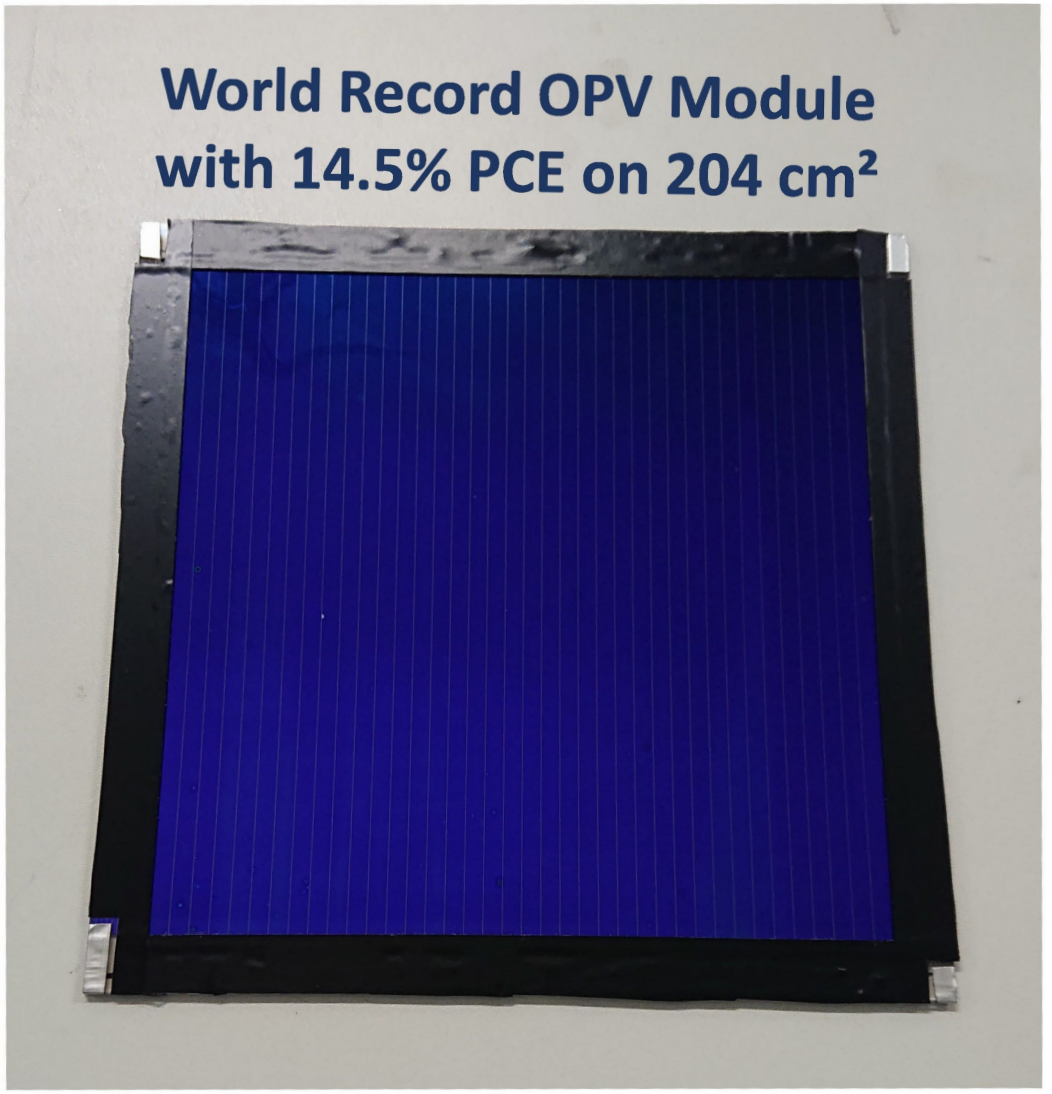
Summary

- New world record efficiency for large-area OPV modules
- Barely any performance loss upon upscaling from lab cells to >200cm^2 modules
- Accelerated blade coating enables homogeneous large-area coatings



Summary

- New world record efficiency for large-area OPV modules
- Barely any performance loss upon upscaling from lab cells to >200cm^2 modules
- Accelerated blade coating enables homogeneous large-area coatings
- Theoretical equations allow time- and resource efficient research with new OPV materials



Thank you very much for your attention

Contact:

Computational Physics For Green Energy:
www.th-nuernberg.de/cp4x/

Fabian Gumpert
fabian.gumpert@th-nuernberg.de
Technische Hochschule Nürnberg Georg-Simon-Ohm
Keßlerplatz 12, 90489 Nürnberg

In cooperation with:

FAU

HI ERN
Helmholtz Institute
Erlangen-Nürnberg

ENERGIE
CAMPUS
NÜRNBERG

OPV module

Top electrode

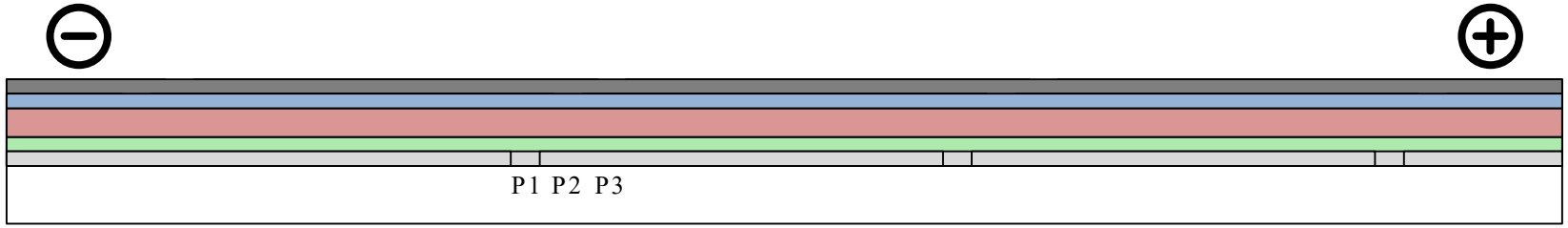
Electron transport layer (ETL)

Active layer (AL)

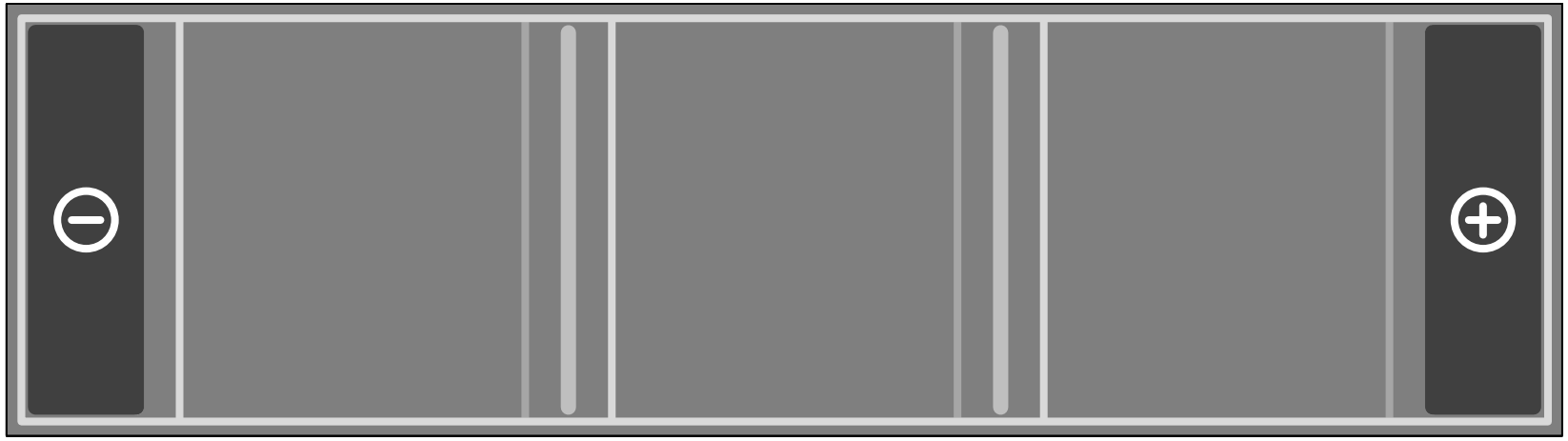
Hole transport layer (HTL)

Bottom electrode

Substrate



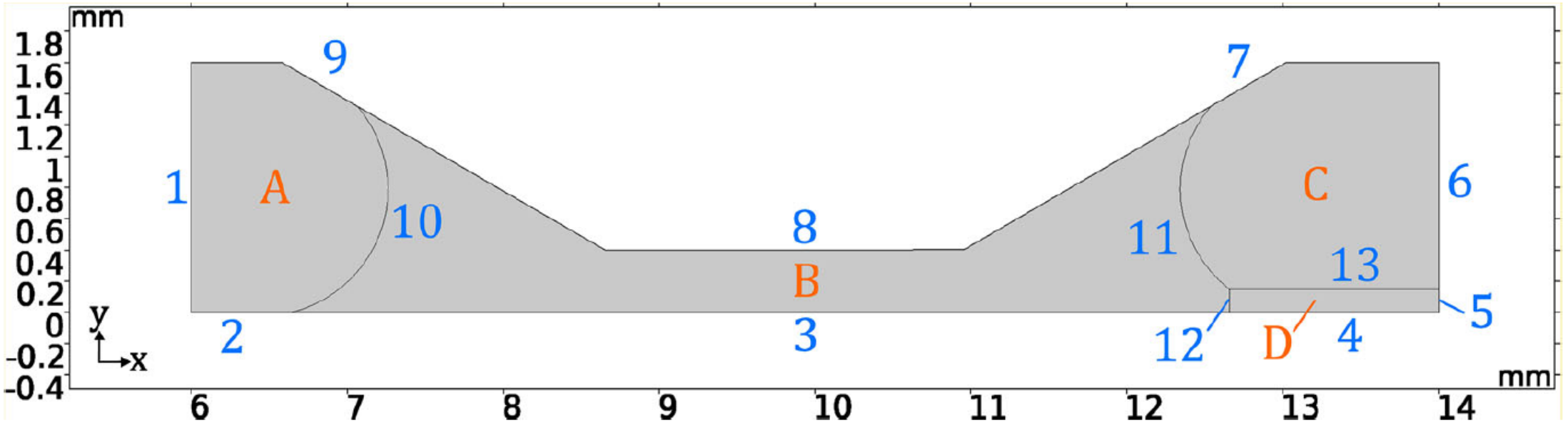
cross section



top view

CFD Model

Modelling Domain:



>> 2D simulation sufficent to model coating process