Optical Simulation of Arbitrary Thin Film Solar Cells with Rough Interfaces

Zurich University
of Applied Sciences

**Thomas Lanz^{a,†}, B. Perucco^{b}, D. Rezzonico^{b}, Felix Müller^{b},
N. A. Reinke^{a}, R. Häusermann^{a}, B. Ruhstaller^{a,b}**

^{a}Zurich University of Applied Sciences, Institute of Computational Physics, Wildbachstrasse 21,
8401 Winterthur, Switzerland, ^{b}Fluxim AG, 8835 Feusisberg, Switzerland, www.fluxim.com

†`lanz@zhaw.ch`

1. Abstract

IN thin-film solar cells optical scattering effects at rough layer interfaces are exploited to enhance the light absorption and make it possible to construct thin cells with inorganic materials such as a-Si or μc-Si [5]. SETFOS [2] is an optical and electrical device simulator, that is widely used in the OLED and OPV community. To perform an optical simulation of an arbitrary combination of inorganic or organic layers of any thickness, it is necessary to be able to treat light propagation both as coherent or incoherent. We have therefore extended the optical model of SETFOS for the treatment of mixed systems of incoherent/coherent layers. We have broadened the scope of the simulator by including scattering effects at rough layer interfaces.

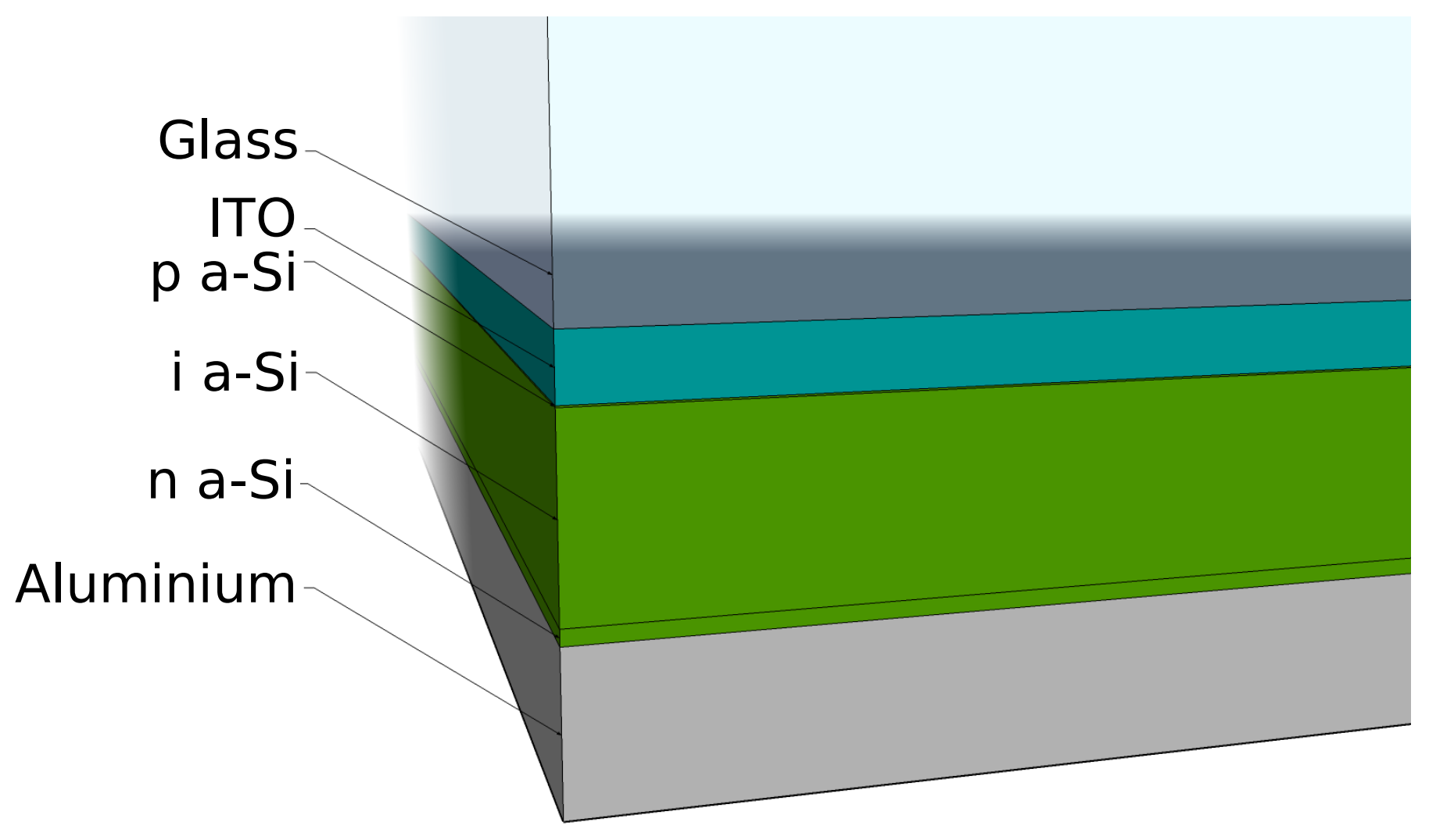

Figure 1: *Amporphous silicon p-i-n solar cell used for the calculations.*

The following layout was used in the simulations, as illustrated in Figure 1: Glass (1 mm), ITO (200 nm), *p* a-Si (5 nm), *i* a-Si (600 nm), *n* a-Si (50 nm), Al (500 nm).

2. Incoherence

THE ability of the incident light to interfere within the structure is expressed using the coherence length. Coherence within the structure can be reduced due to reflections at rough interfaces or in passing through bulk layers.

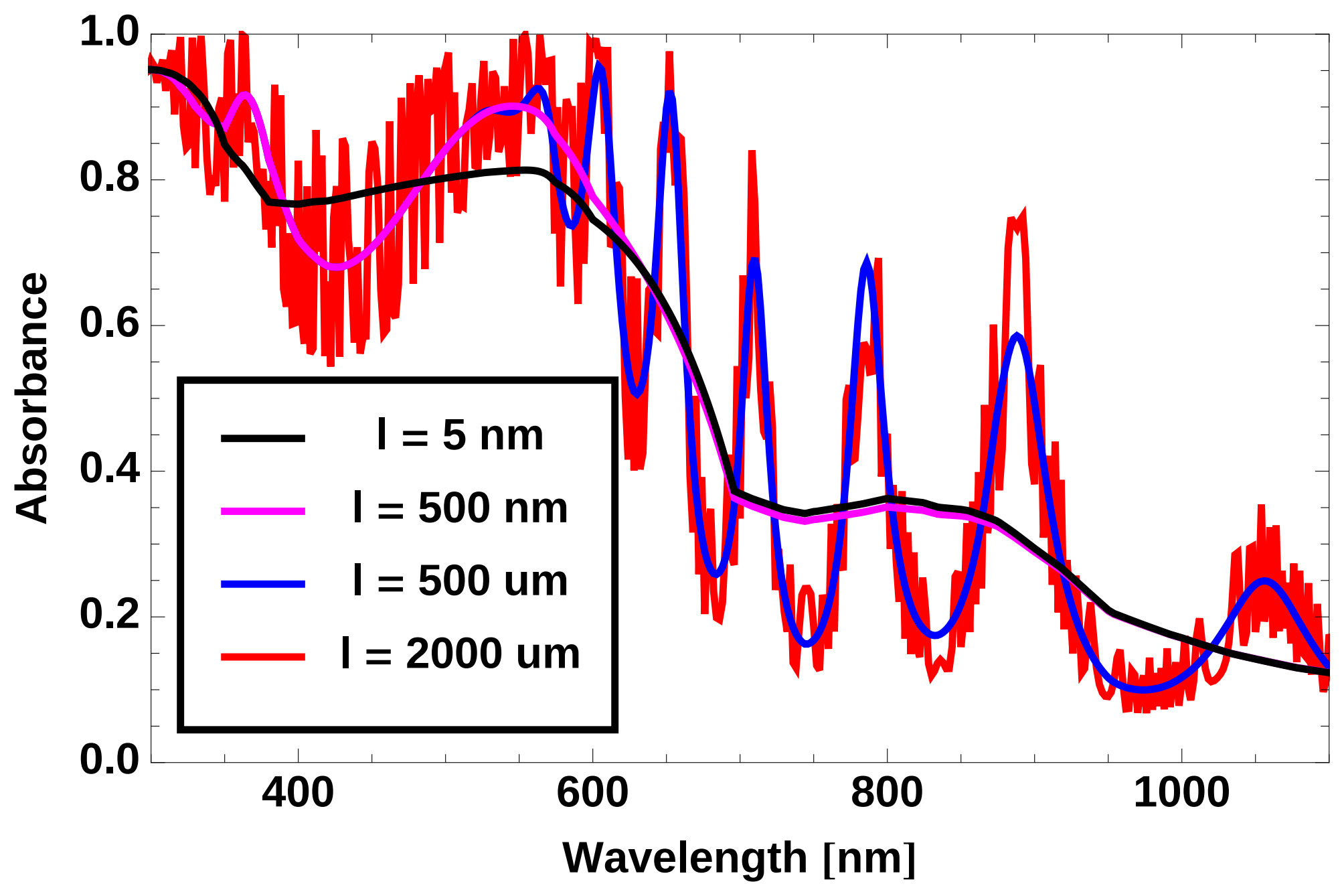

Figure 2: *Calculated absorbance for the a-Si solar cell described in the text. Reducing the coherence length of the incident light reduces the interference fringes. The label gives the coherence length that was used for the calculations.*

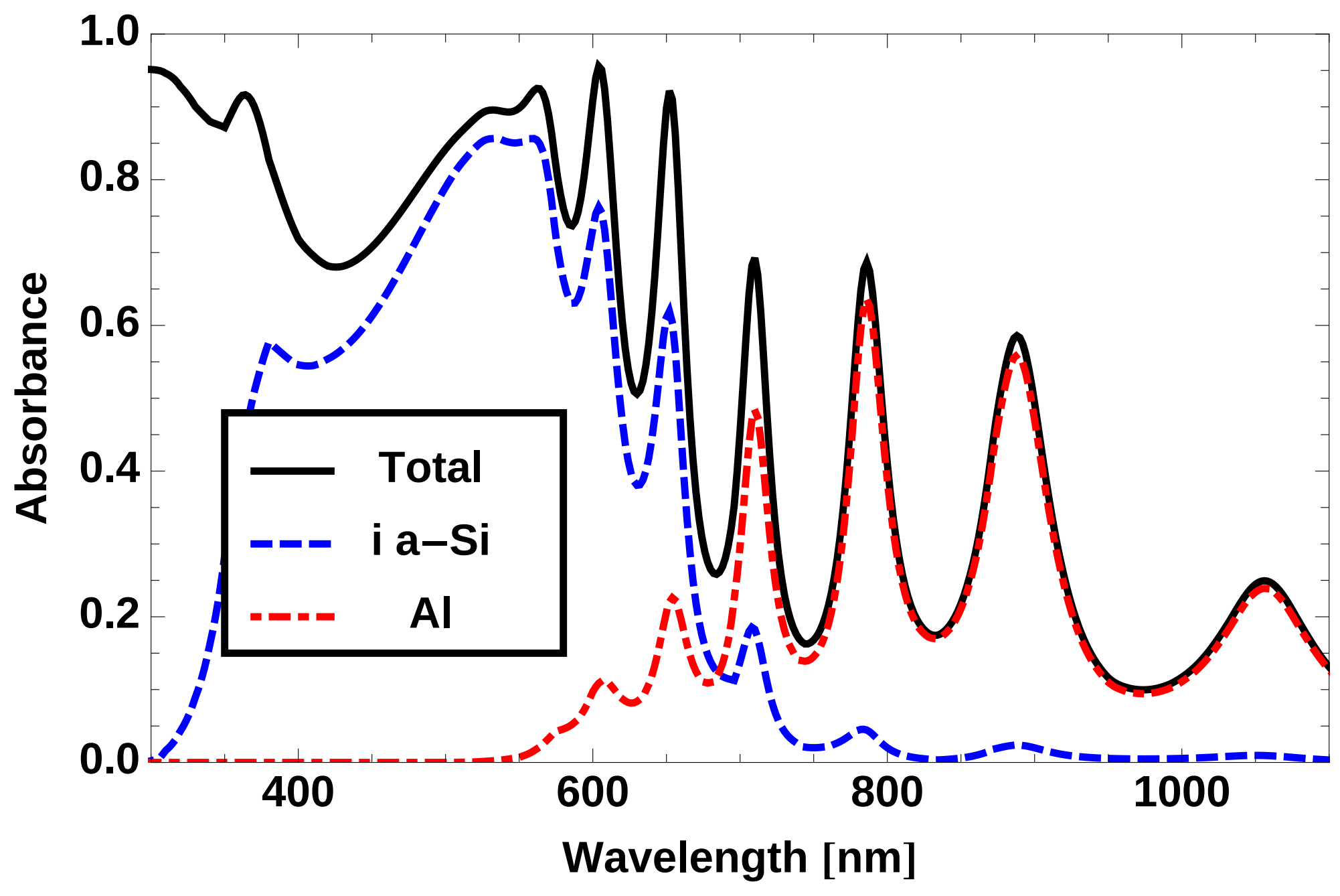

Figure 3: *Calculated normalized layer absorbances for the a-Si solar cell. The glass is treated as incoherent.*

The coherent calculation (Figures 2 and 3) reveals strong interference fringes in the absorption for wavelengths between 500 and 1000 nm. They can be attributed to internal reflections in the a-Si layer.

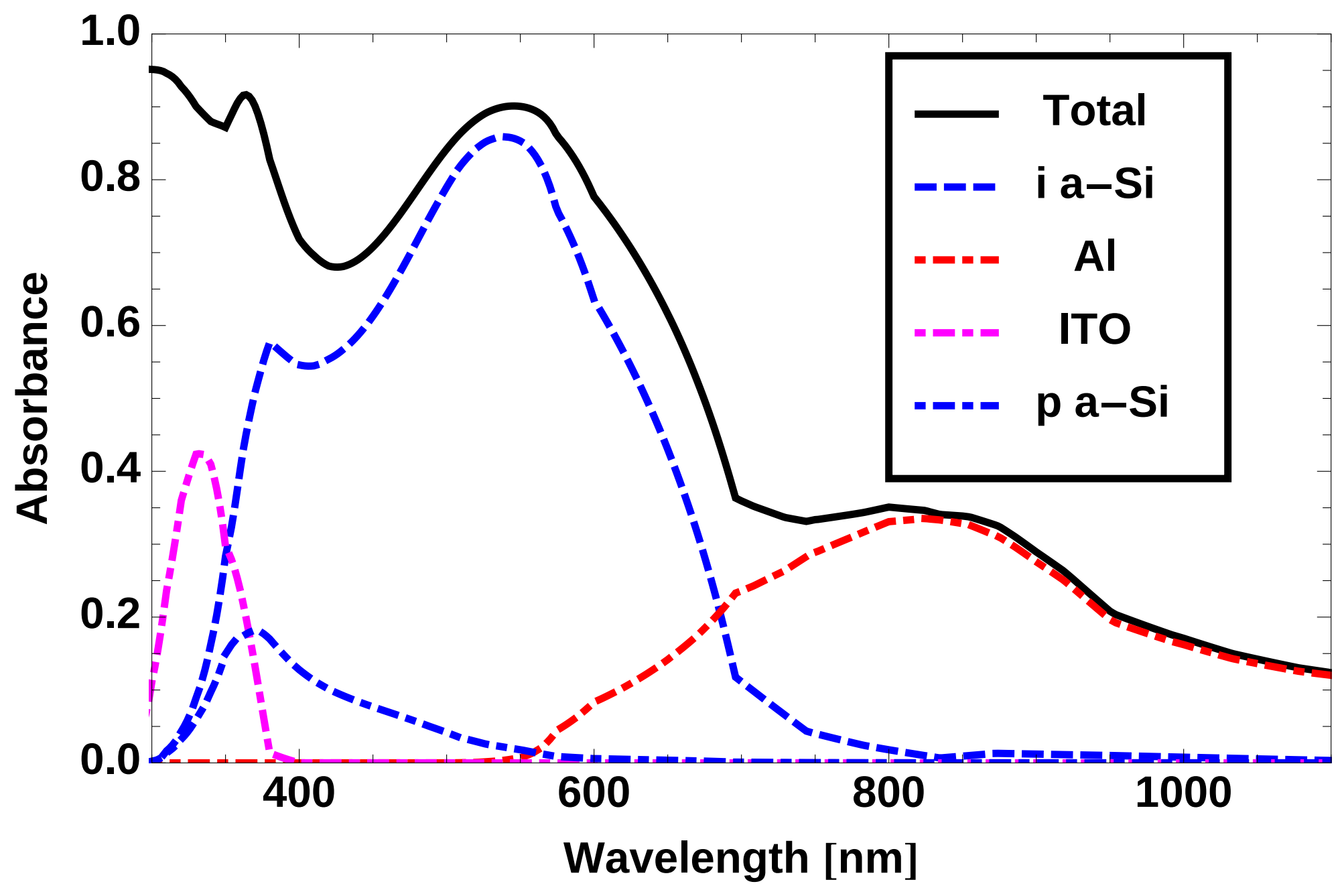

Figure 4: *Calculated normalized layer absorbances for the a-Si solar cell. The glass and the intrinsic a-Si layer are treated as incoherent.*

3. Effective Media Approximation

THE effect of a rough interface can be approximated using a gradient in the effective refractive index. One introduces interlayers between layers with a rough interface which effectively reduces the reflectance of the interface [3].

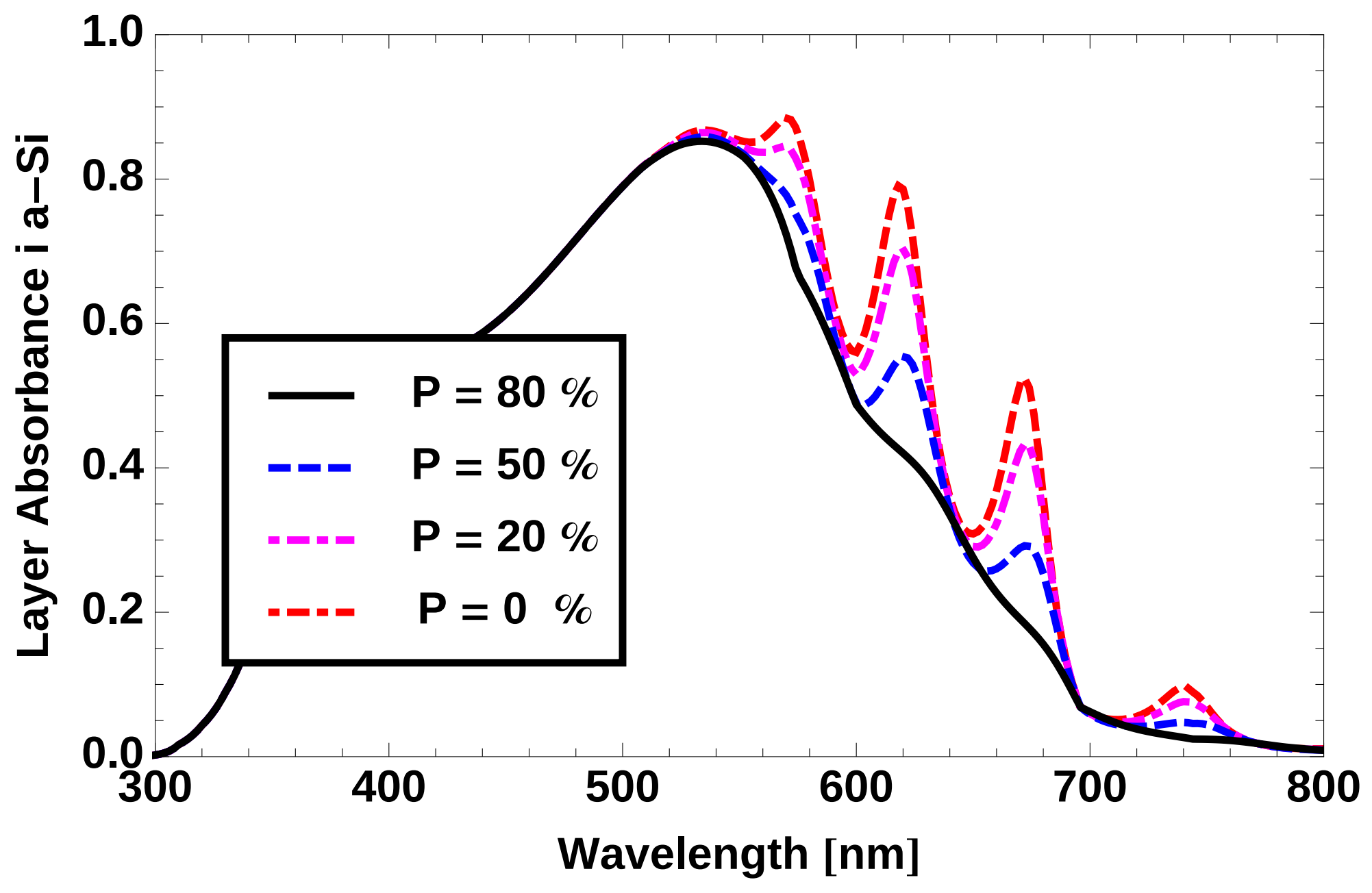

Figure 5: *Calculated layer absorbance for the intrinsic a-Si layer. The label states the volume fraction that determines the effective refractive index of the n a-Si layer. 100 % corresponds to pure a-Si and 0 % to pure Aluminium.*

In Figure 5 the n a-Si layer is used as an EMA layer and its complex refractive index is determined with linear interpolation between the indices of a-Si and Aluminium:

$$\tilde{n}_{EMA} = P \cdot \tilde{n}_{a-Si} + (1-P) \cdot \tilde{n}_{Al}.$$

4. Modified Fresnel Coefficients

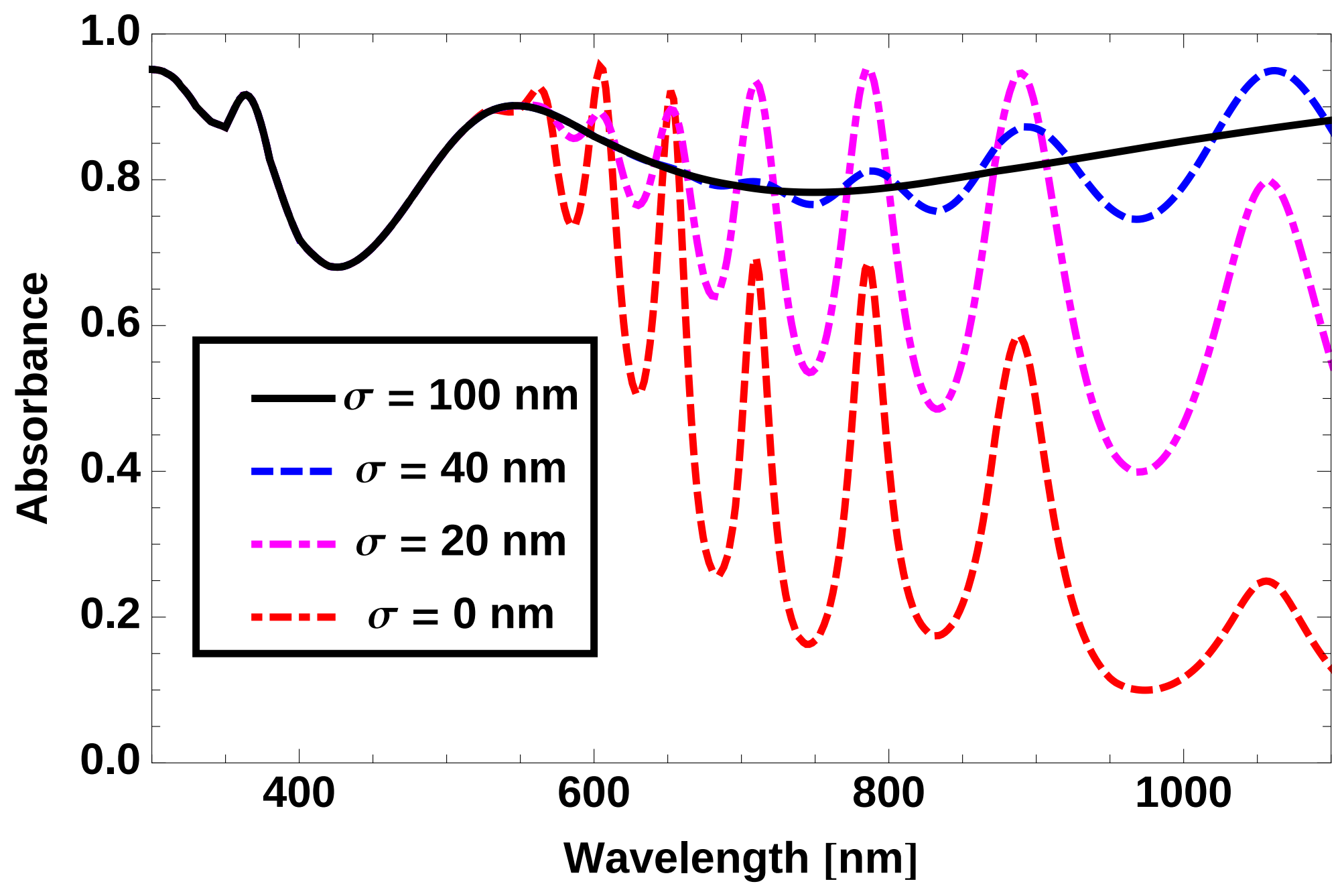

Figure 6: *Calculated total unpolarized absorbance ($A = 1 - R - T$) for the a-Si solar cell for increasing back contact (a-Si / Al interface) roughness.*

TO account for the scattering effects we have extended the transfer-matrix formalism [4] to reproduce partial coherence. This is achieved by modifying the Fresnel coefficients in the transfer-matrix formalism using the root-mean-square roughness σ [1]. Figure 6 illustrates the effect of interface roughness at the a-Si / ITO interface. The interference fringes disappear for increasing interface roughness. For wavelengths shorter than 500 nm the absorption is not affected as they are almost completely absorbed in the Glass, ITO and p a-Si layers, as illustrated in Figure 4. The presented method can so far not track and quantify the scattered light that leads to higher total absorbance in real cells. The three methods are compared in Figure 7, where the calculated localized generation in the ITO, a-Si and Aluminium layer is shown.

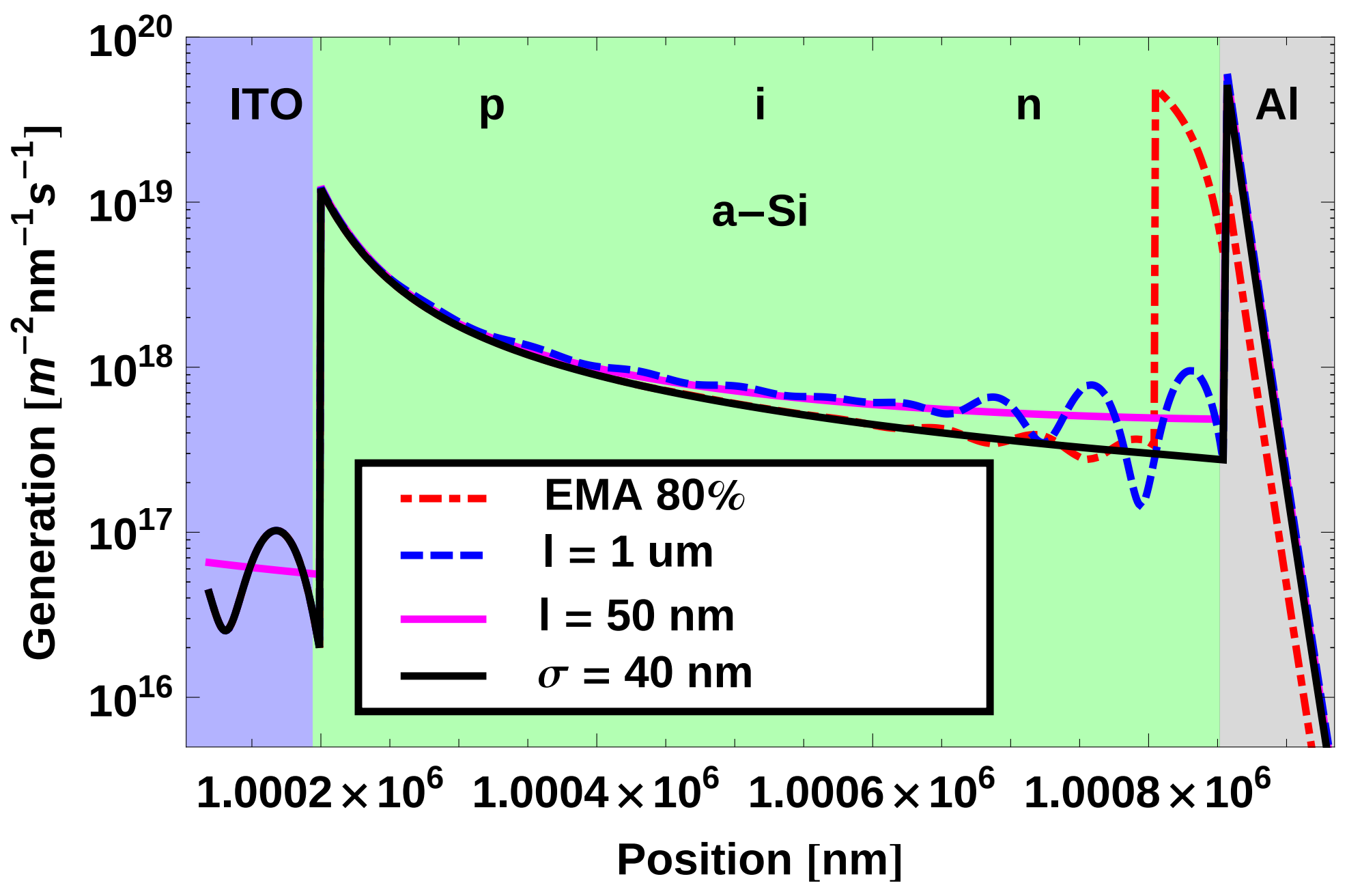

Figure 7: *The computed generation in the ITO, a-Si and Aluminium layer. For both short coherence length ($l = 50$ nm) and surface roughness ($\sigma = 40$ nm) no interference fringes are visible in the a-Si layer.*

To demonstrate the use of incoherence in a tandem structure, we calculate in Figure 8 the localized absorbance in an a-Si based tandem cell, composed of two a-Si subcells (i1 and i2). The glass, ITO and the intrinsic cell i2 (a-Si) are treated as incoherent.

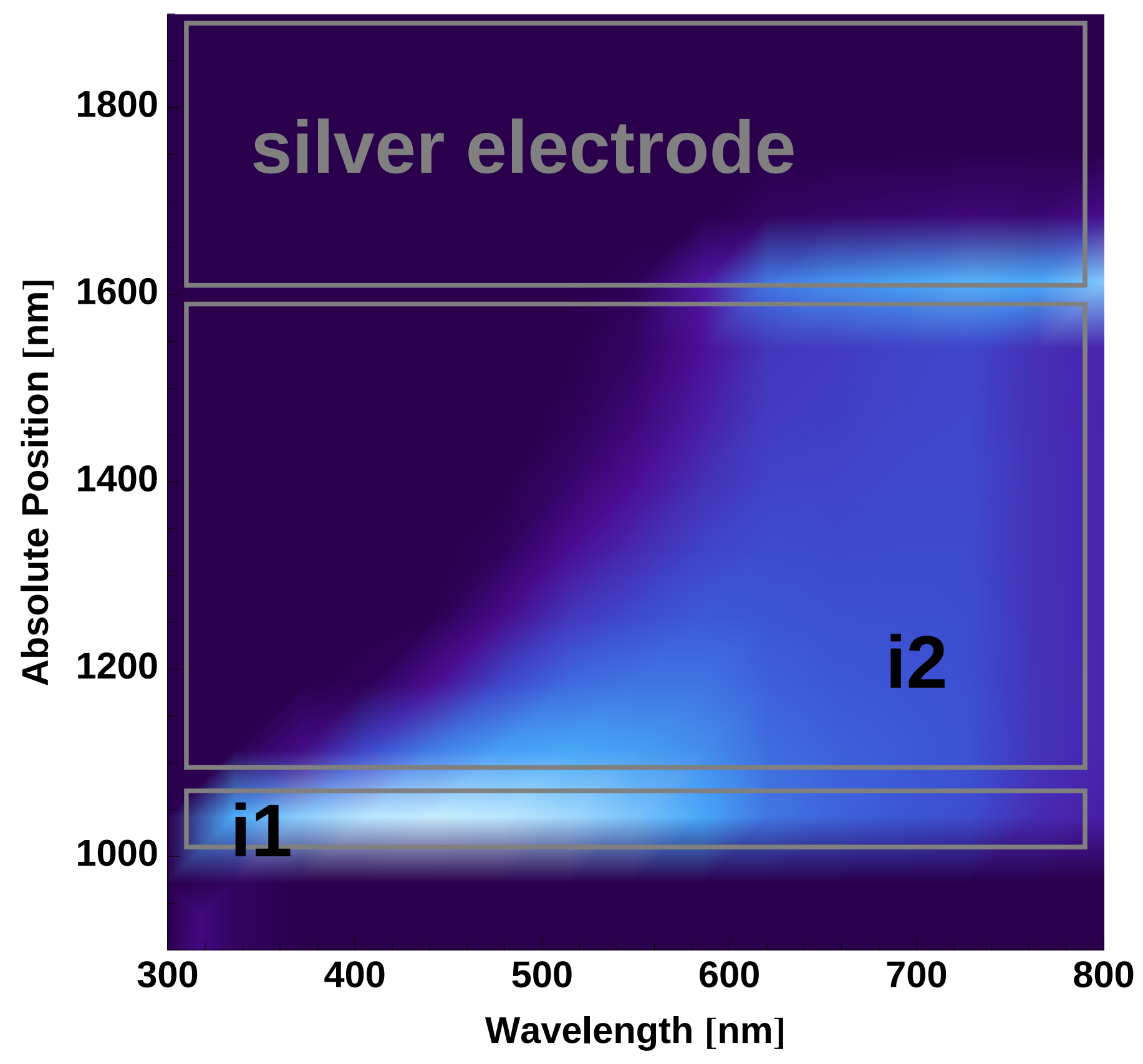

Figure 8: *Localized absorbance (a.u.) in an a-Si based tandem solar cell, layout taken from [5].*

5. Conclusion

THREE distinct simulation approaches are presented to model the optical scattering effects: Effective Media Approximation, incoherence and modified Fresnel coefficients in the Transfer-Matrix-Formalism for partial coherence. We assess and illustrate these methods using single-junction and tandem a-Si-based solar cells by calculating key figures such as the spectral layer absorbance and the localized generation.

References

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