Core Shell Plasmonic Nanoparticles for Absorption Enhancement in Ultra-Thin Chalcopyrite Solar Cells

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Helmholtz-Zentrum Berlin

in cooperation with

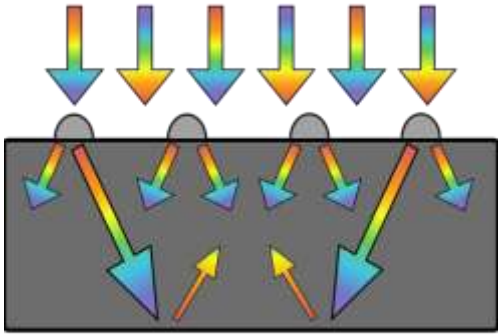
Zuse Institute Berlin

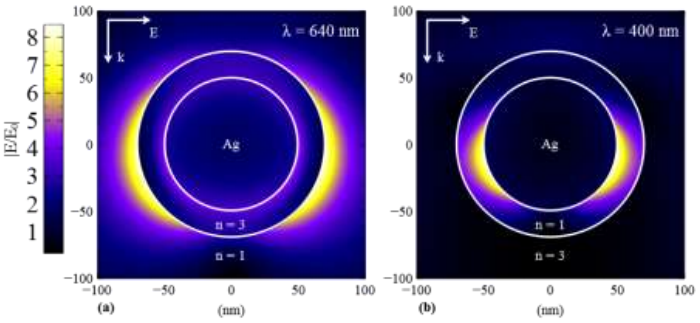
Motivation + Principles

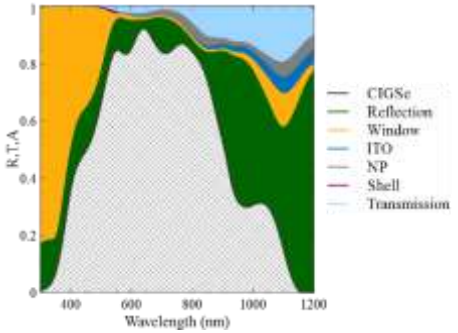
Challenges + Investigations

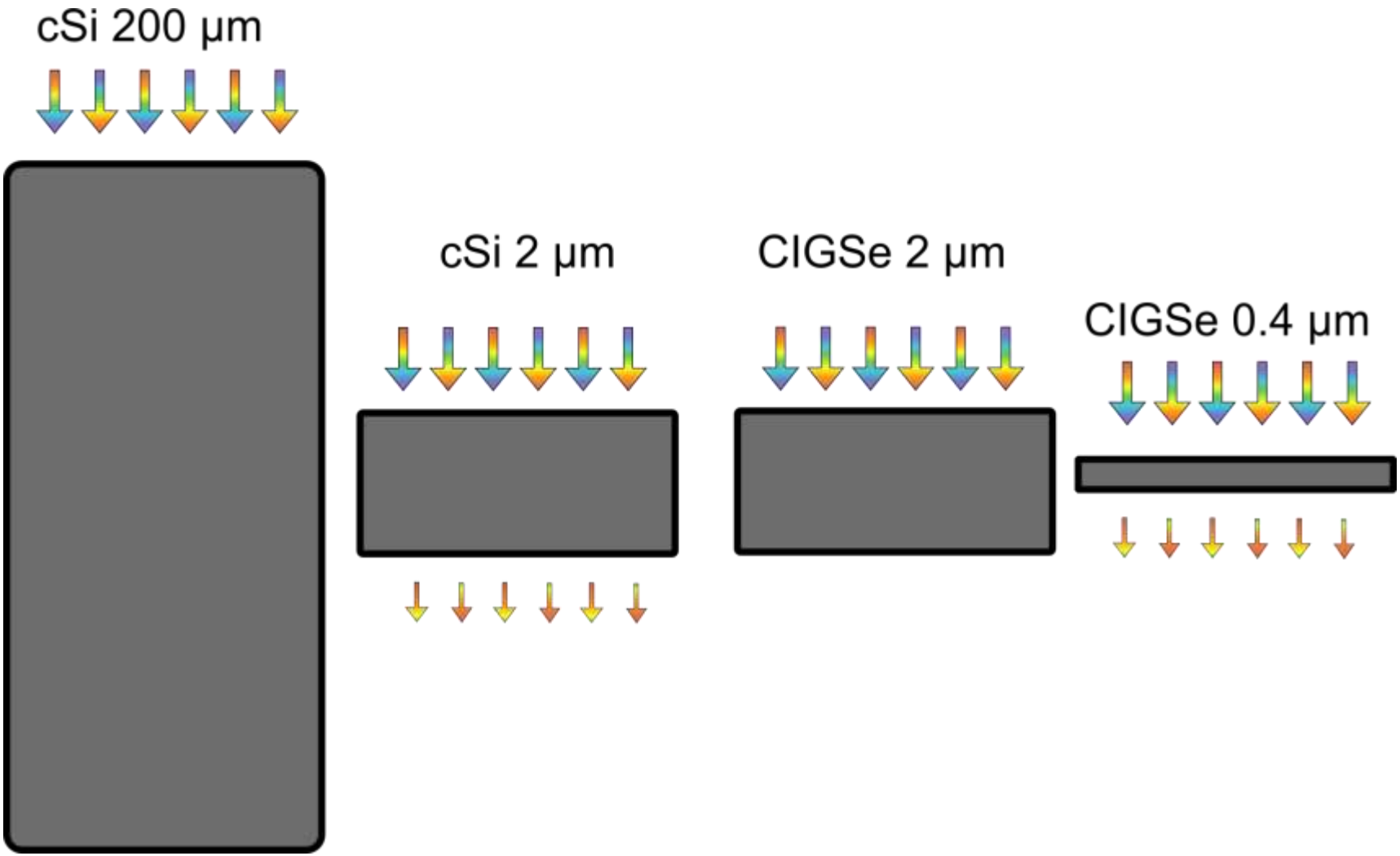
Solutions + Outlook

- Ultra-Thin Solar Cells
- Core-Shell Nanoparticles
- Implementation








cSi 200 µm
cSi 2 µm
CIGSe 2 µm
CIGSe 0.4 µm

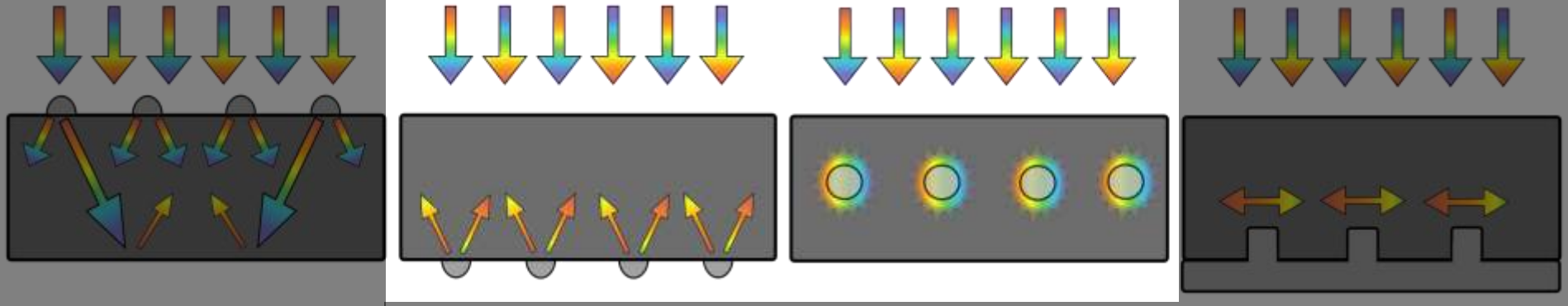
Far Field

Near Field

Waveguide

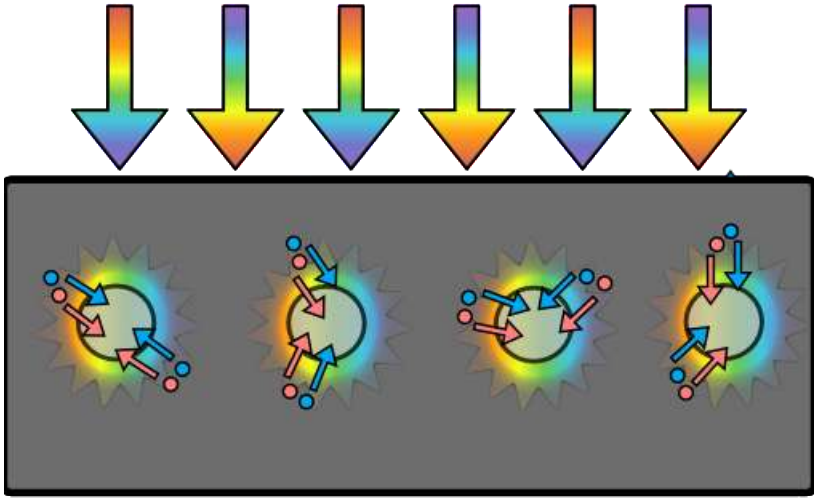
Forward Scattering

Back Scattering

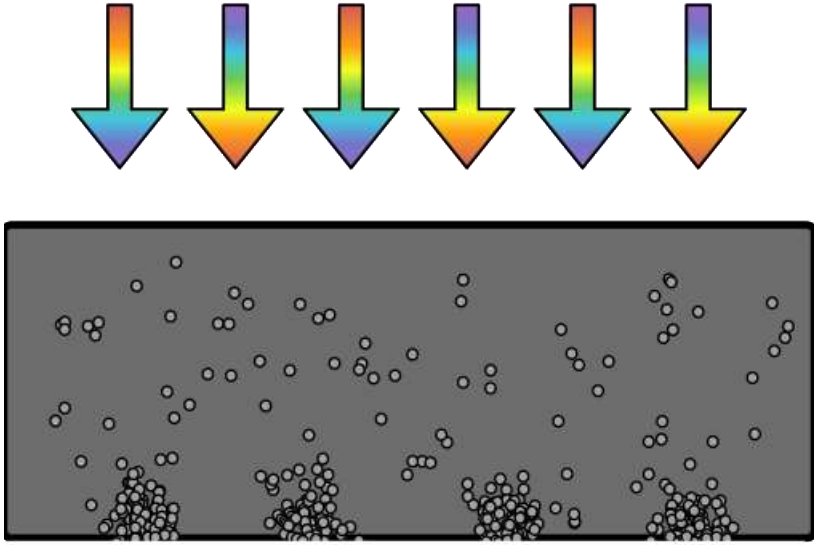


Adapted from: Atwater & Polman, *Nature Materials* (2010)
"Plasmonics for Improved Photovoltaic Devices"

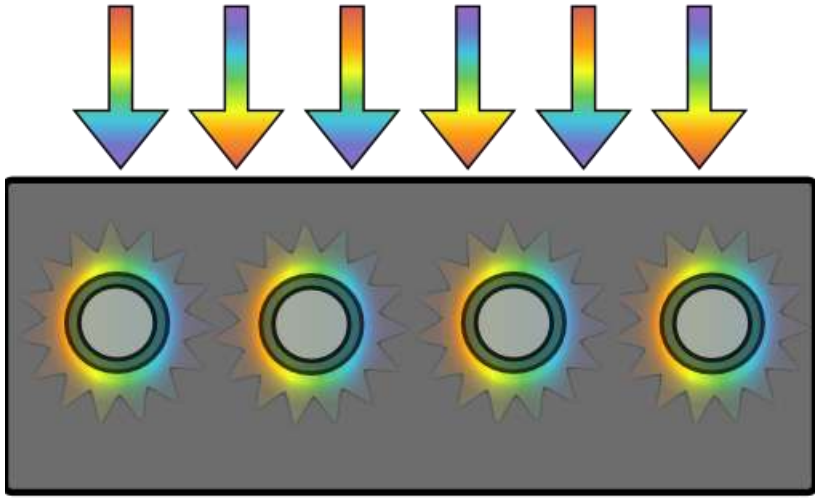
Recombination



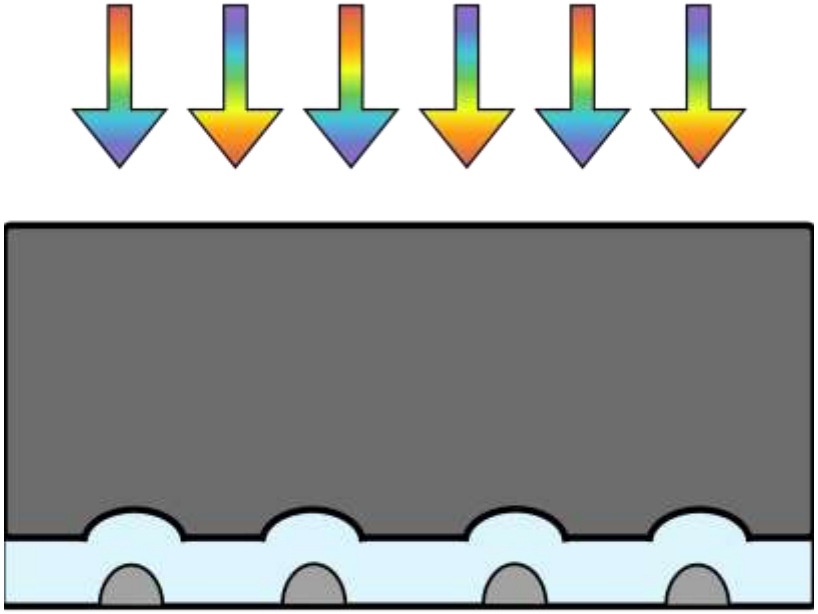
Diffusion



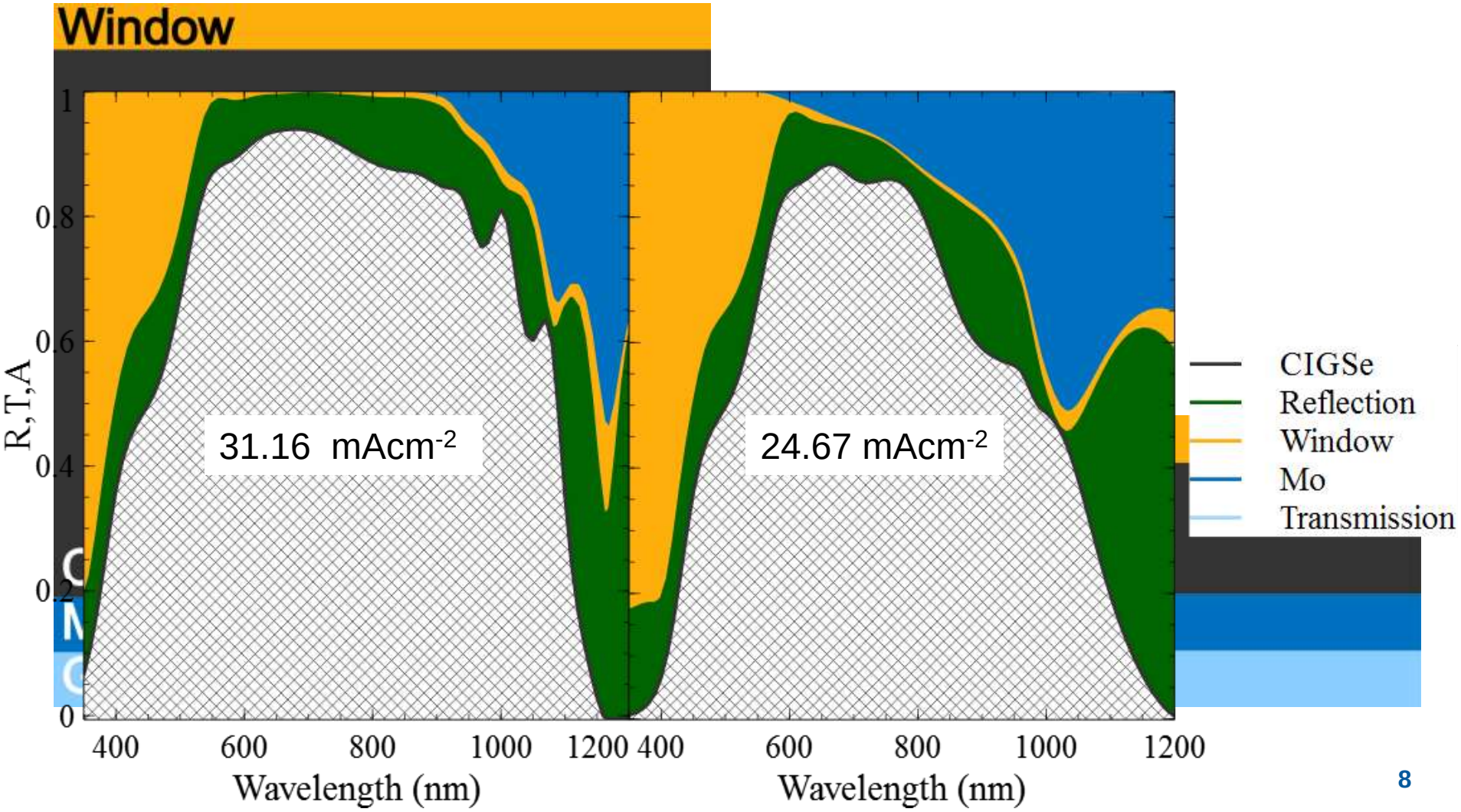
Core - Shell



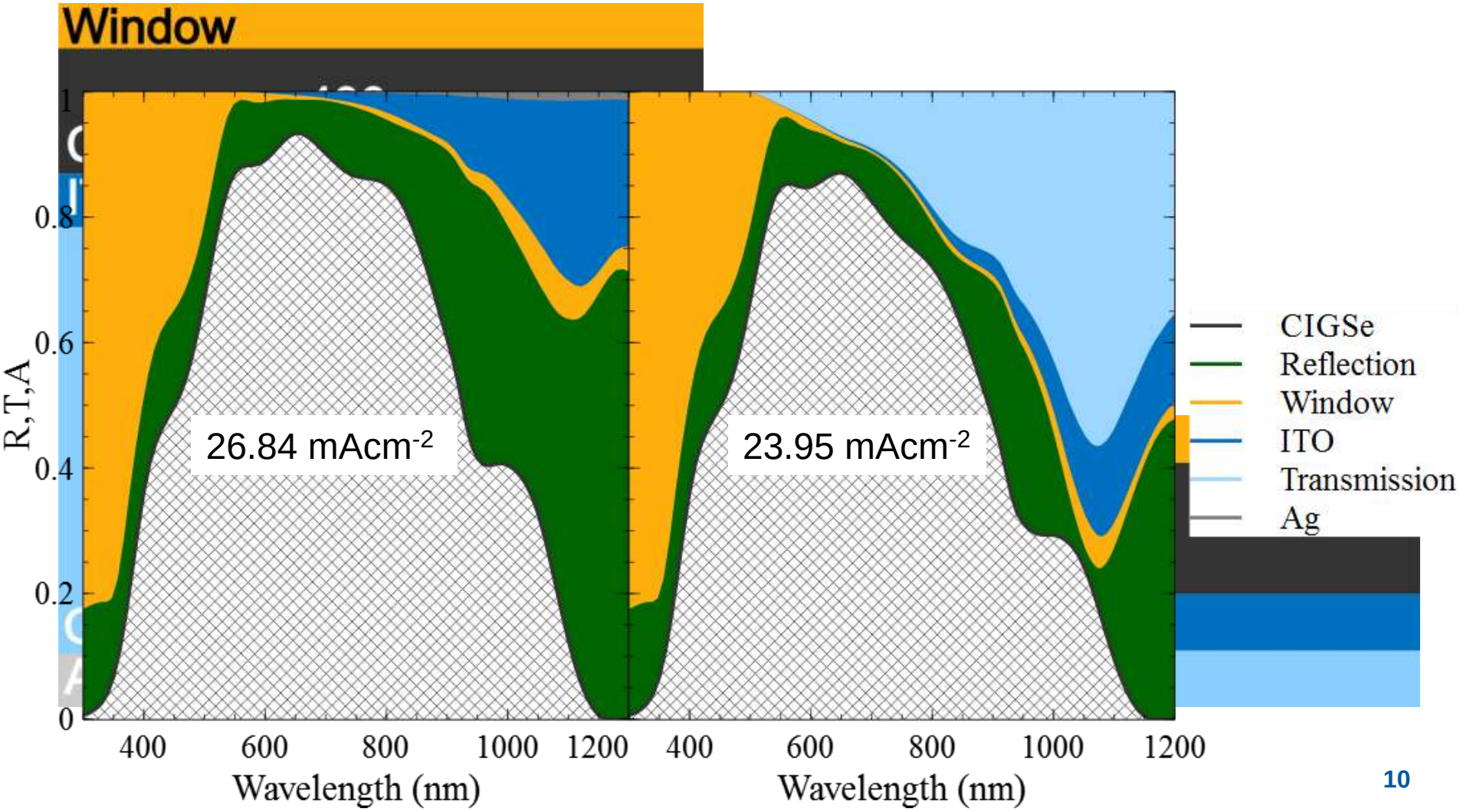
Overcoatings

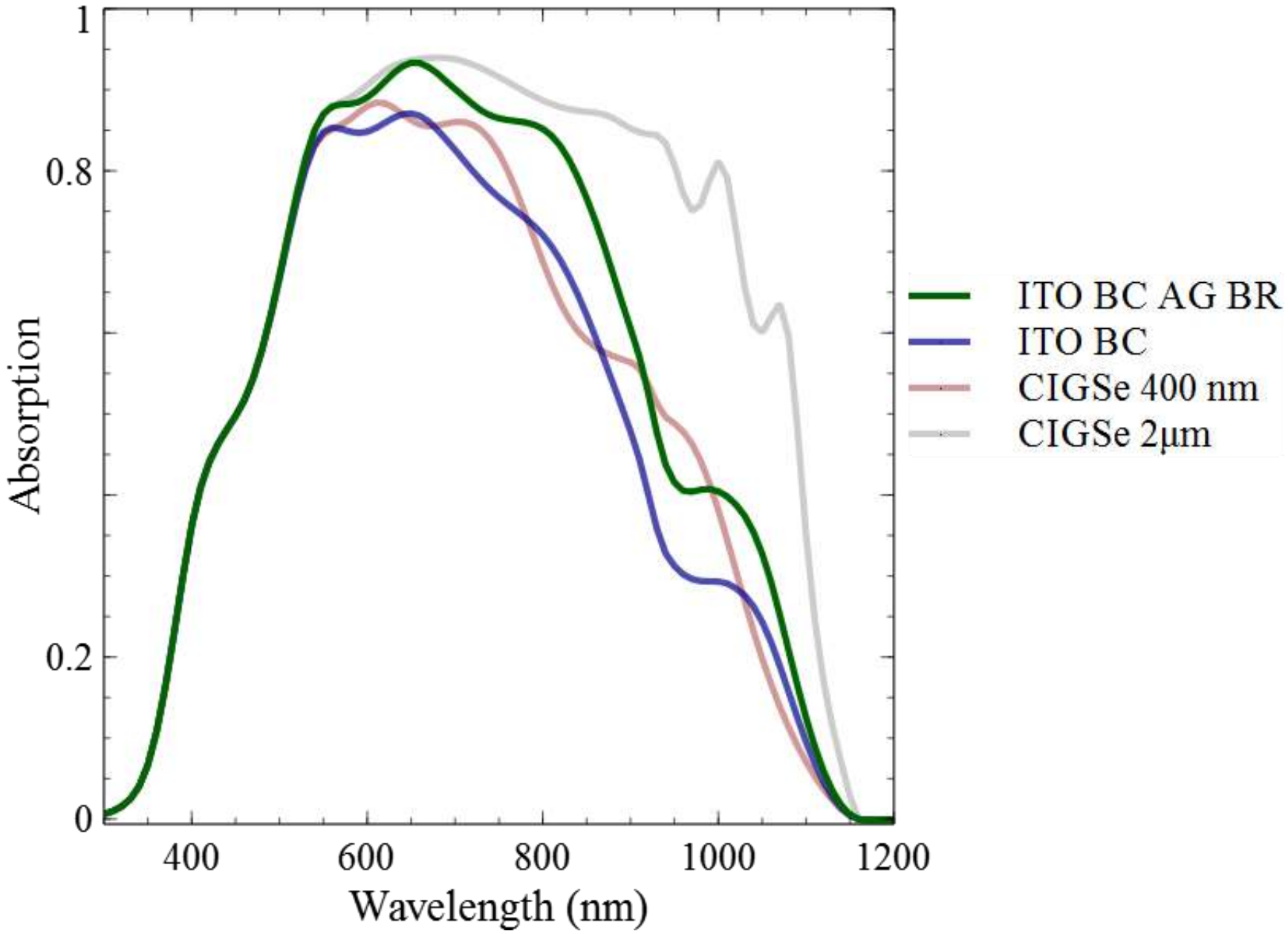


Investigations Part 1 – Ultra-Thin CIGSe Solar Cells

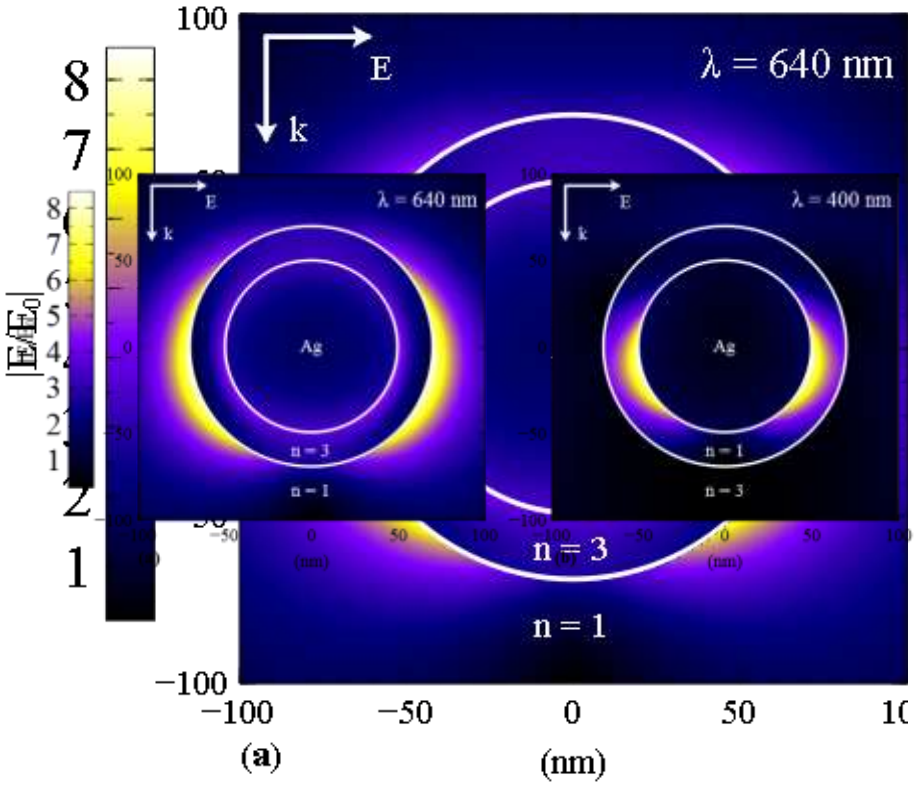

Window
R,T,A
1
0.8
0.6
0.4
0.2
0
400
600
800
1000
1200
Wavelength (nm)
31.16 mAcm-2
24.67 mAcm-2
CIGSe
Reflection
Window
Mo
Transmission

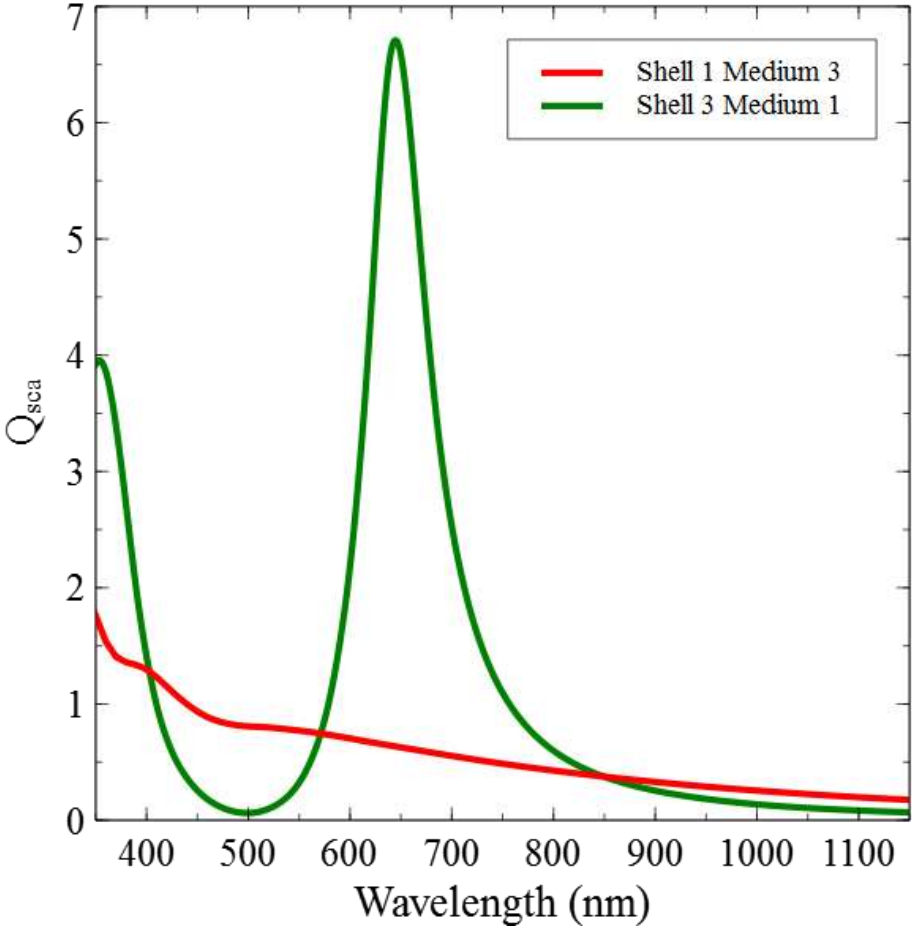
Diffusion


Window
R,T,A
0
0.2
0.4
0.6
0.8
400
600
800
1000
1200
Wavelength (nm)
26.84 mAcm-2
23.95 mAcm-2
CIGSe
Reflection
Window
ITO
Transmission
Ag

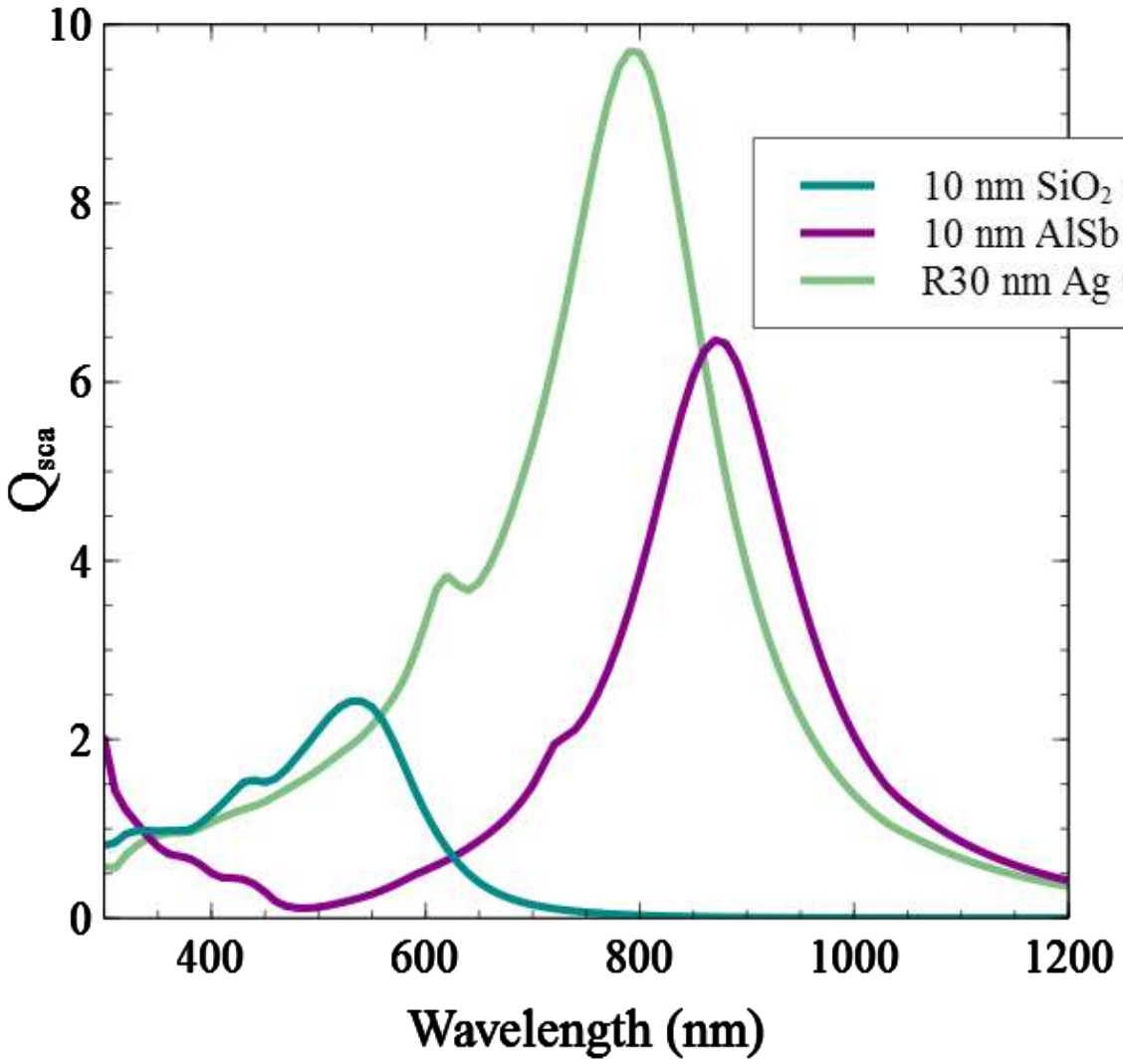

1
0.8
0.2
0
Absorption
400
600
800
1000
1200
Wavelength (nm)
ITO BC AG BR
ITO BC
CIGSe 400 nm
CIGSe 2µm

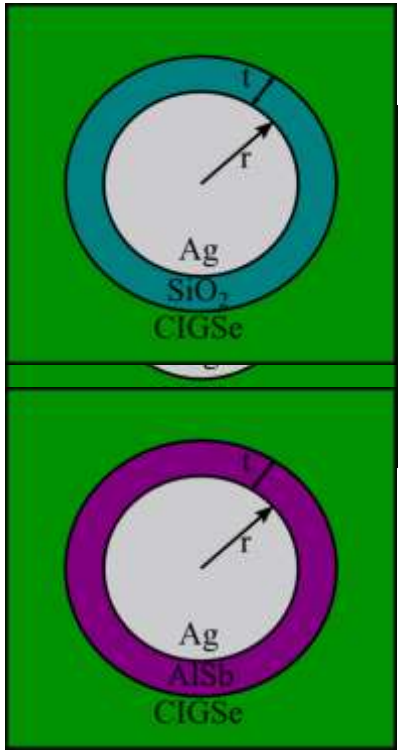
Investigations Part 2 – Properties of Core Shell Nanoparticles





JCMsuite – Finite Element Method





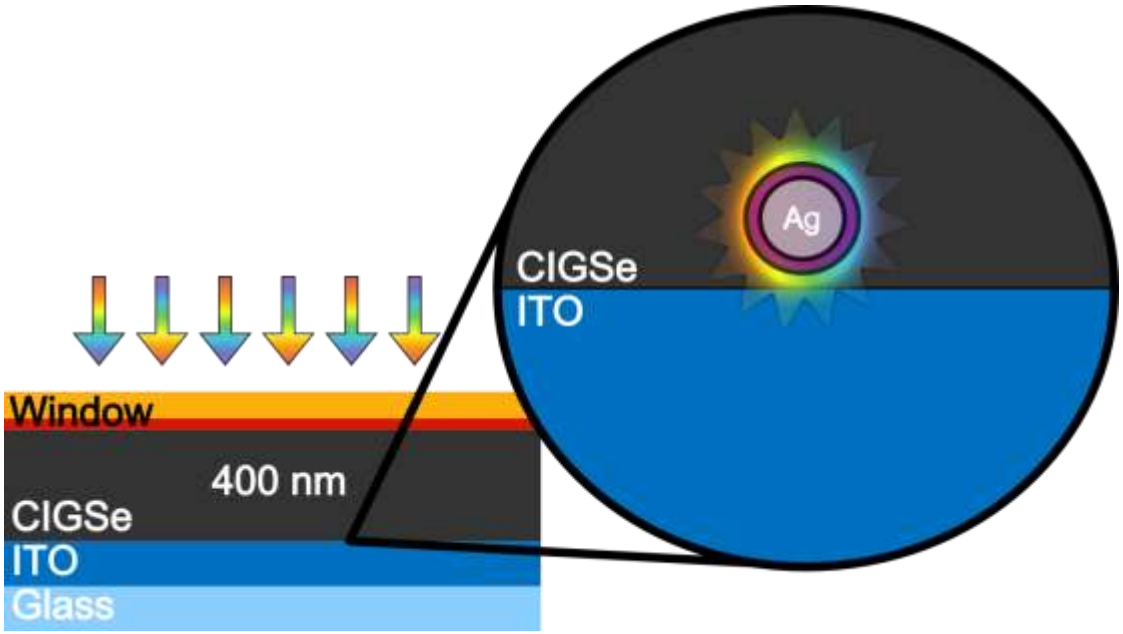
$\lambda = 800$

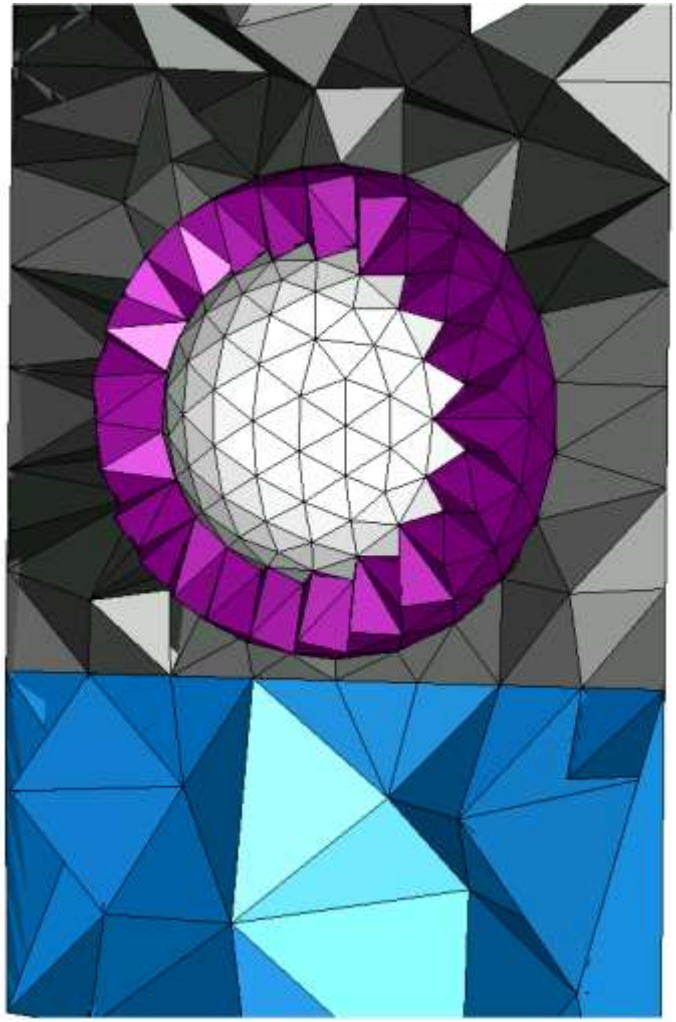
$n_{CIGSe} = 2.9$

$n_{SiO2} = 1.5$

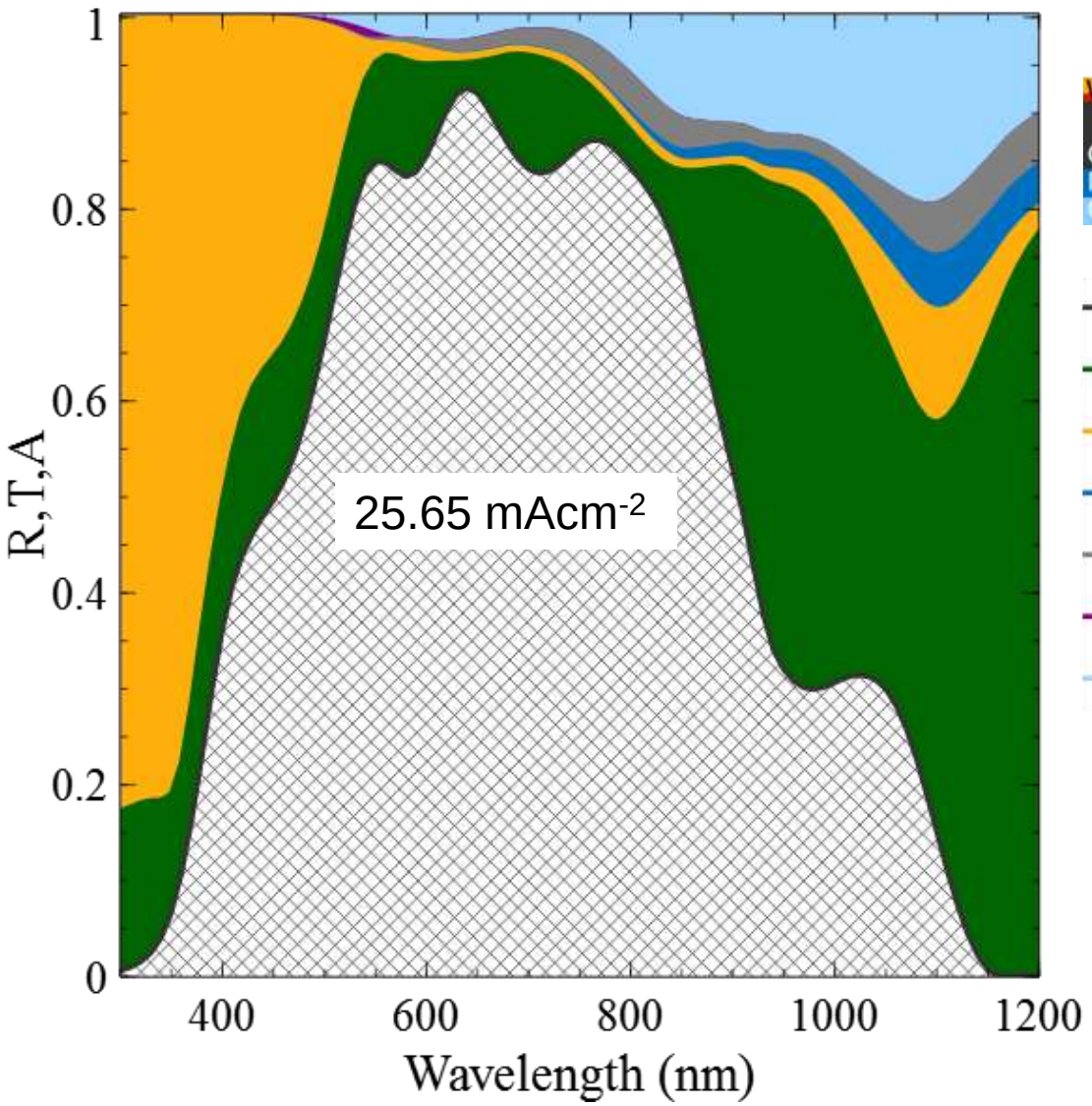
$n_{AlSb} = 3.6$

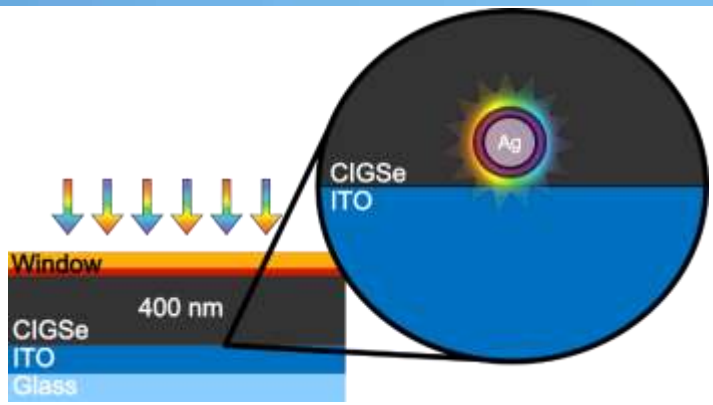
Investigations Part 3 – Core-Shell Nanoparticles in Ultra-Thin CIGSe Solar Cells

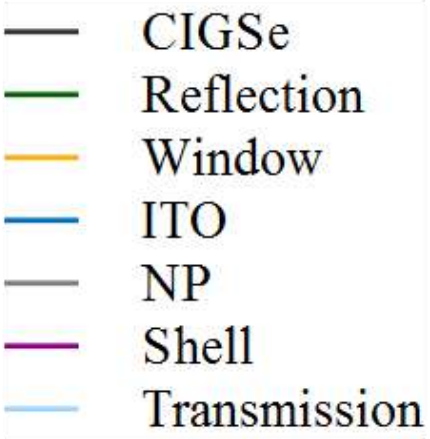


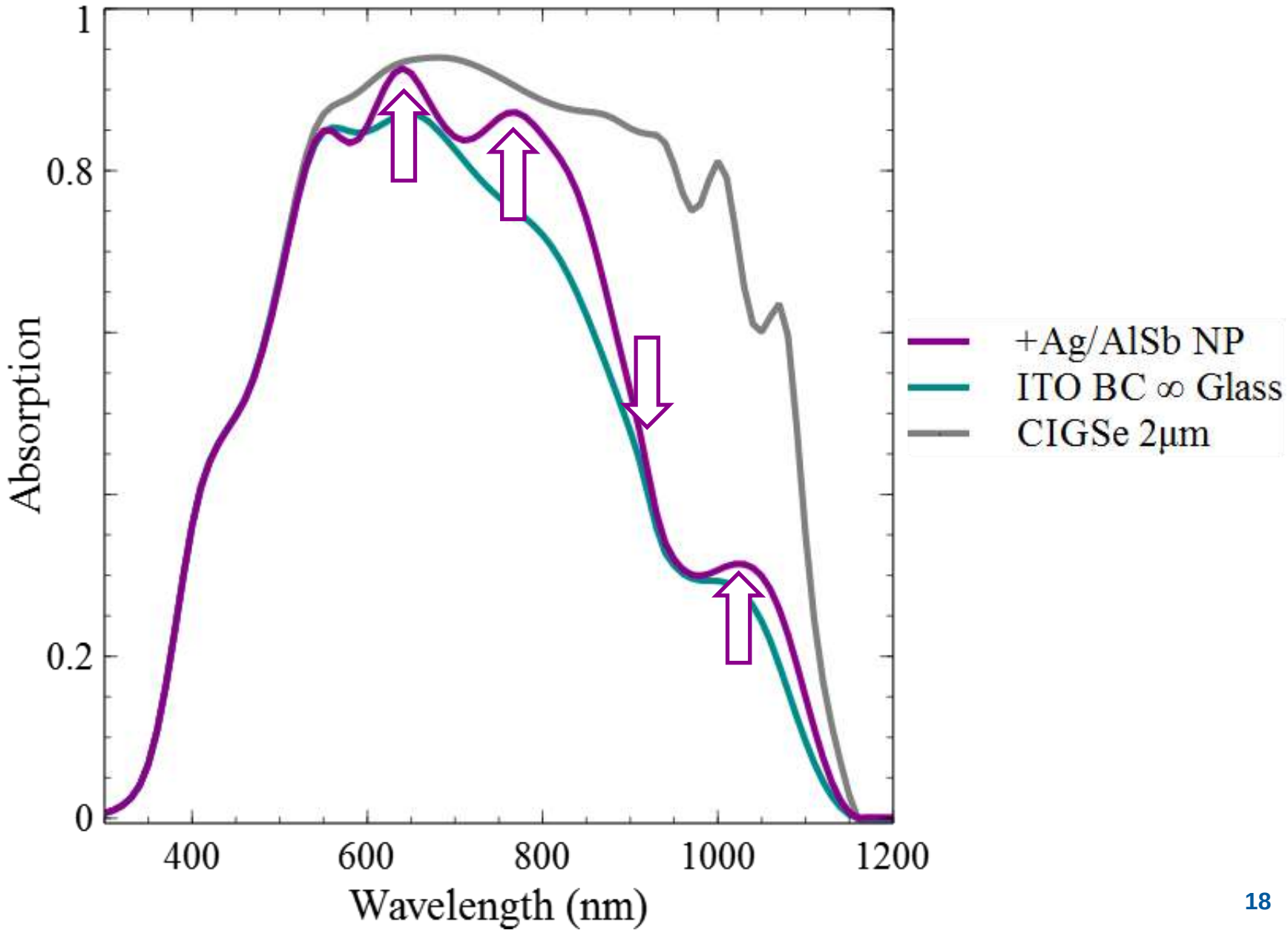


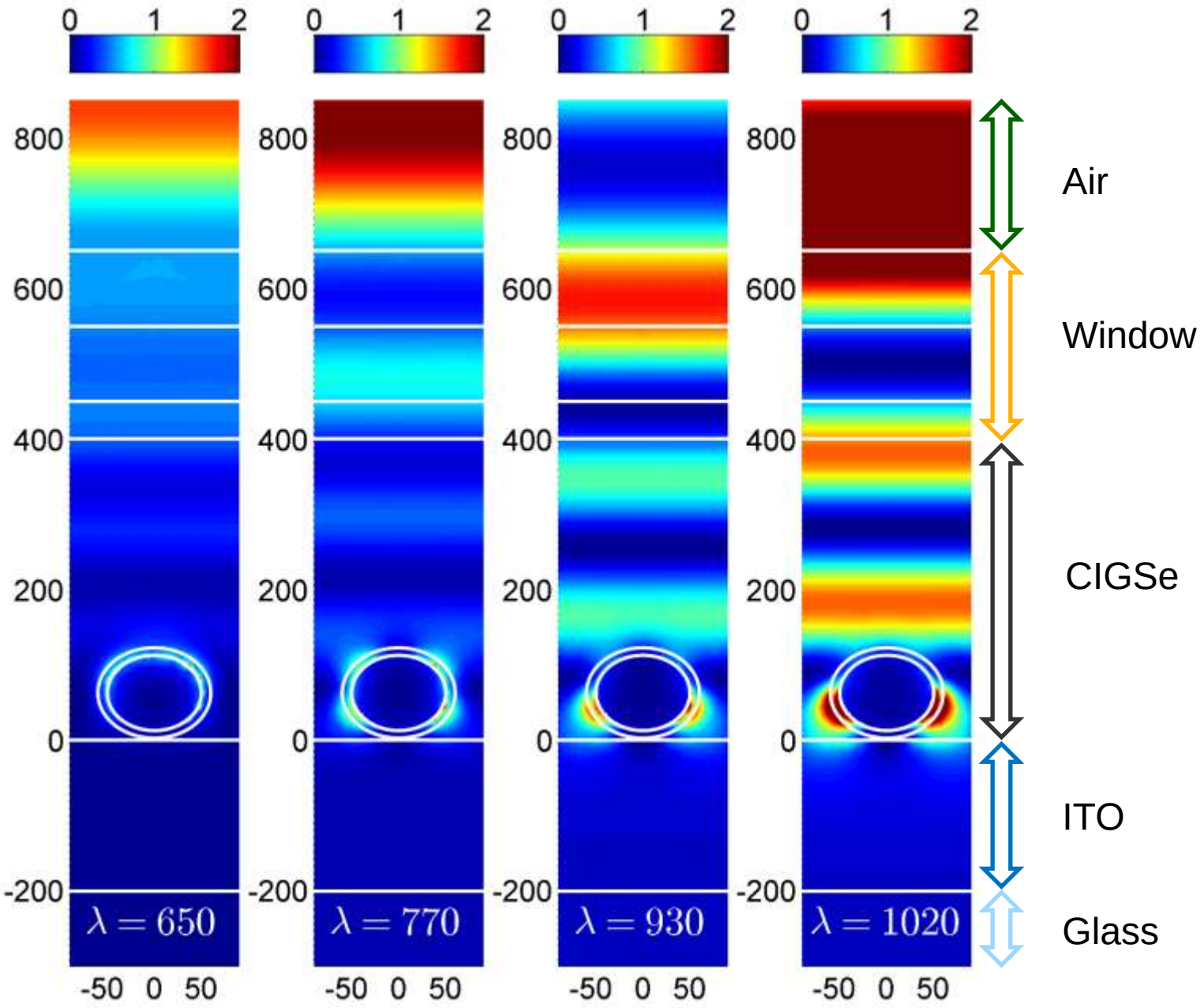
R 50 nm Ag NP with 10 nm thickness AlSb Shell

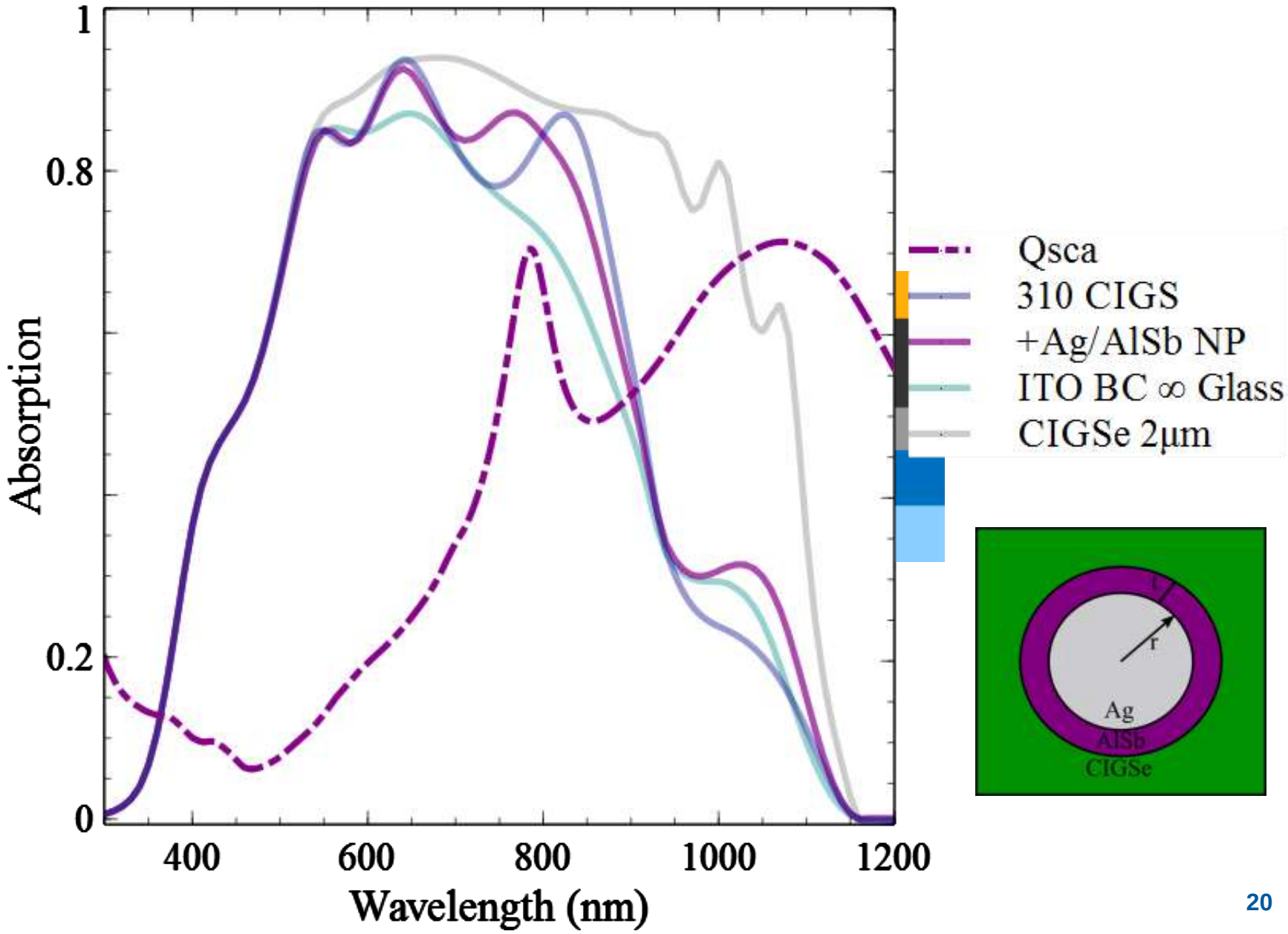

1
0.8
0.6
0.4
0.2
0
R,T,A
400
600
800
1000
1200
Wavelength (nm)
25.65 mAcm-2


Ag
CIGSe
ITO
Window
400 nm
CIGSe
ITO
Glass


CIGSe
Reflection
Window
ITO
NP
Shell
Transmission


1
0.8
0.2
0
Absorption
400
600
800
1000
1200
Wavelength (nm)
+Ag/AlSb NP
ITO BC ∞ Glass
CIGSe 2µm


0 1 2
800
600
400
200
0
-200
-50 0 50
$\lambda = 650$
$\lambda = 770$
$\lambda = 930$
$\lambda = 1020$
Air
Window
CIGSe
ITO
Glass


1
0.8
0.2
0
Absorption
400
600
800
1000
1200
Wavelength (nm)
Qsca
310 CIGS
+Ag/AlSb NP
ITO BC ∞ Glass
CIGSe 2µm
t
r
Ag
AlSb
CIGSe

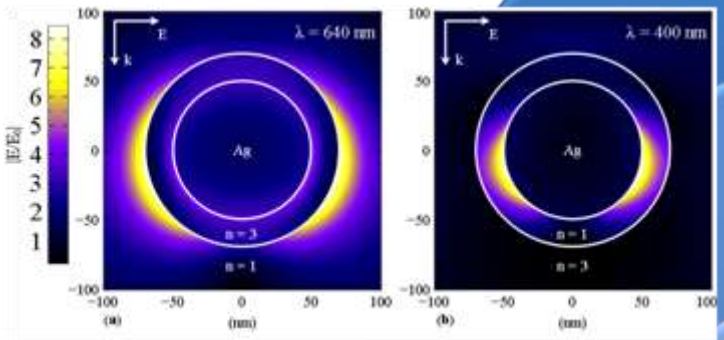
Near-Field and Far-Field

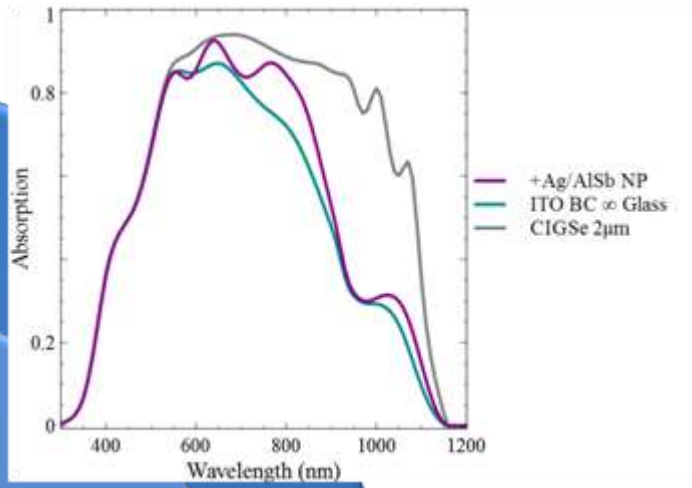
High Index Shell

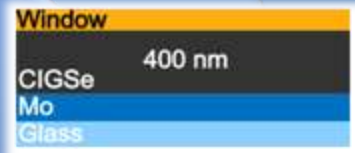
Back Contact Choice

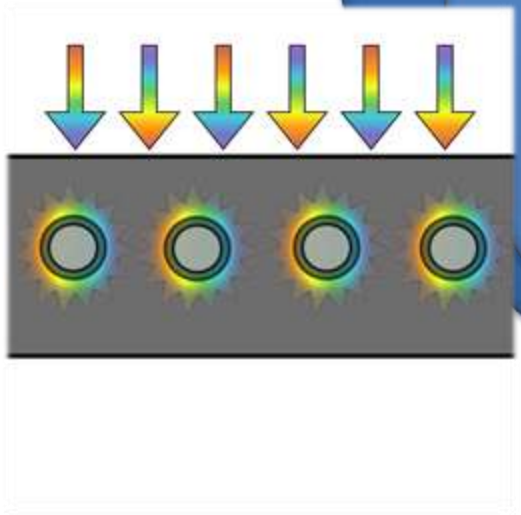
Plasmonic Core

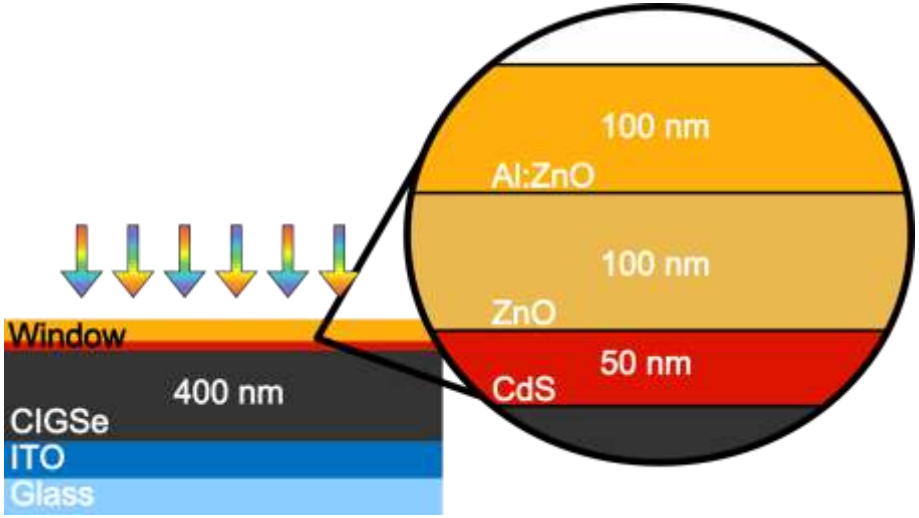
Dielectric Shell



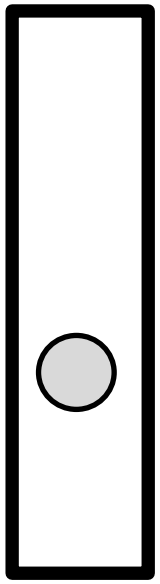






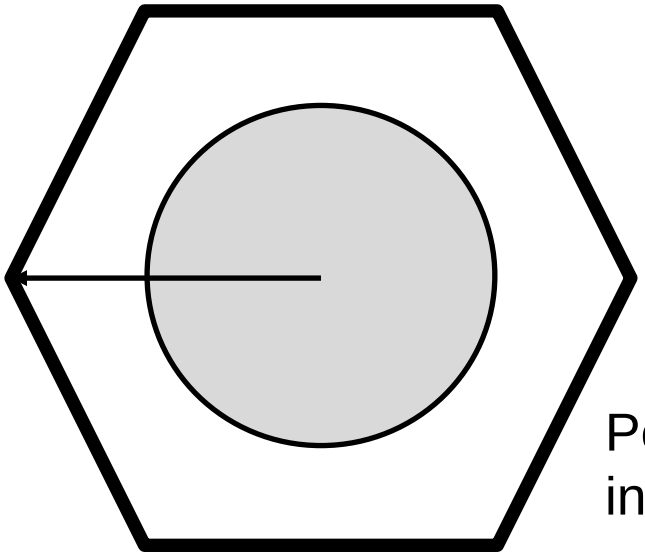


PML above



PML below

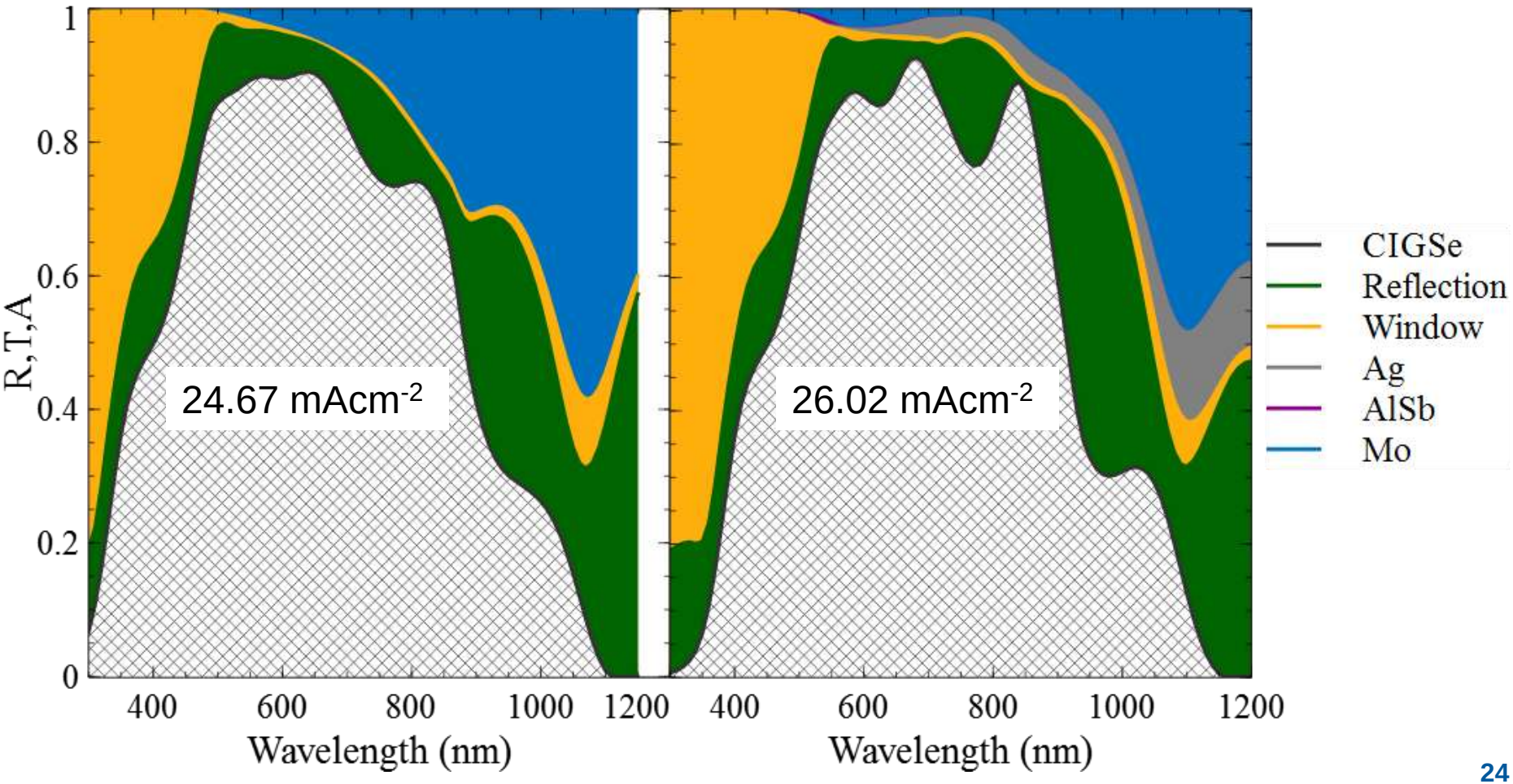
Domain „Radius“
= 90 nm

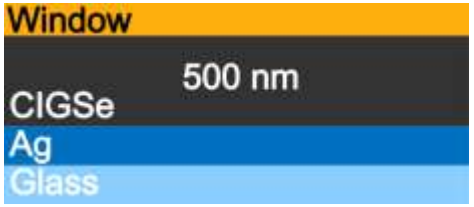


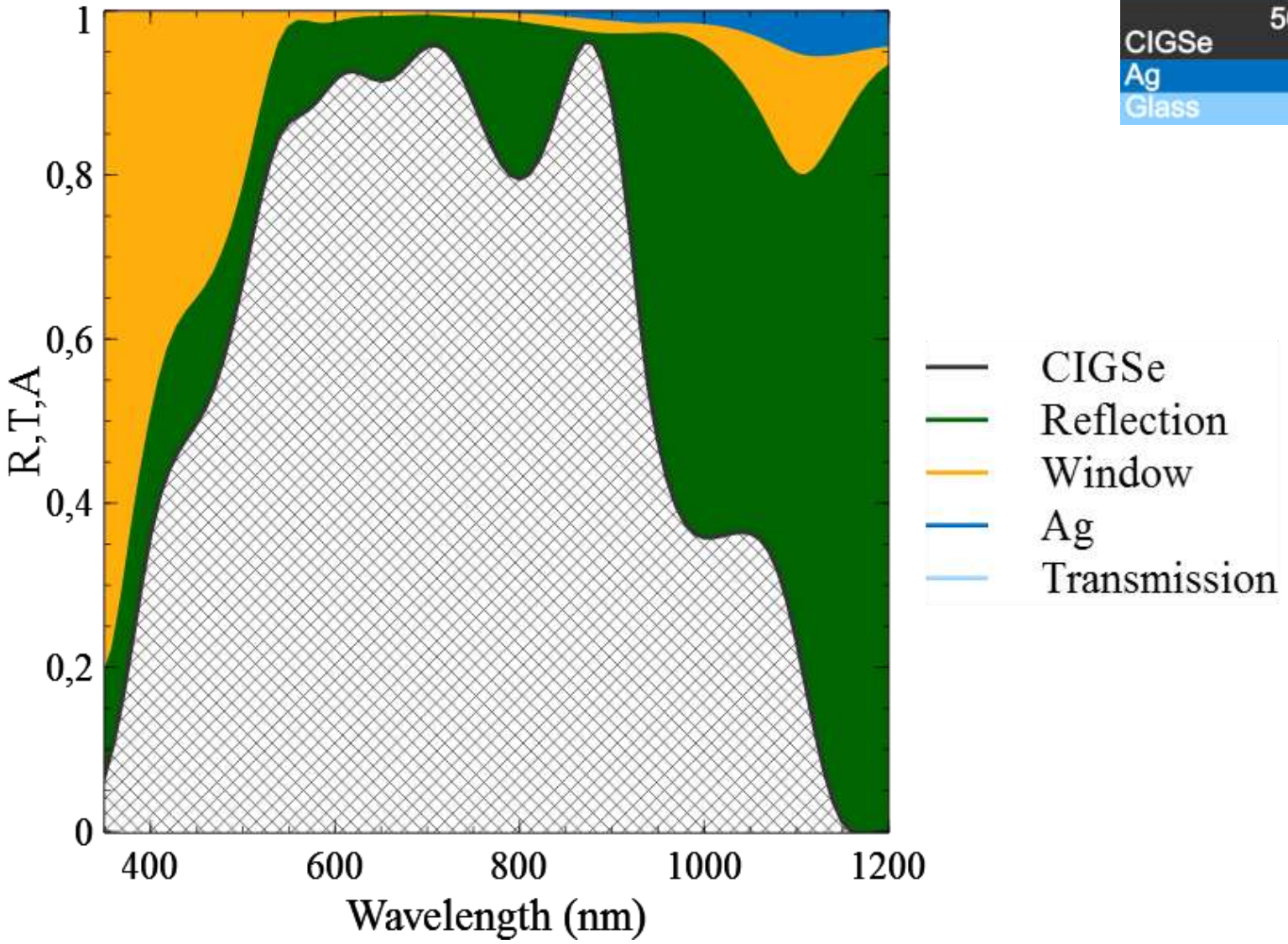
Periodic BC‘s
in x-y plane

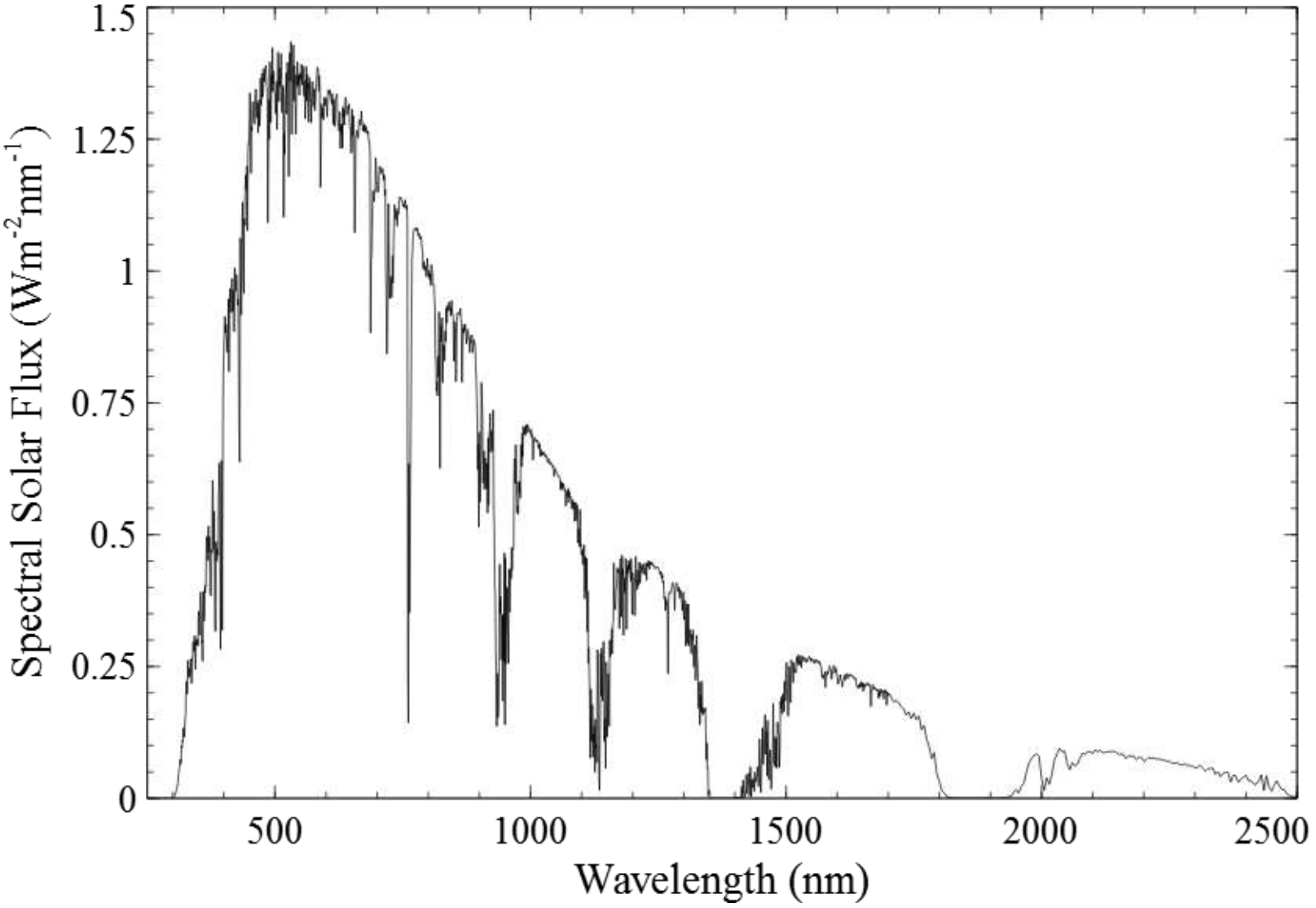
400 nm thick CIGSe layer with 200 nm thick Mo back contact

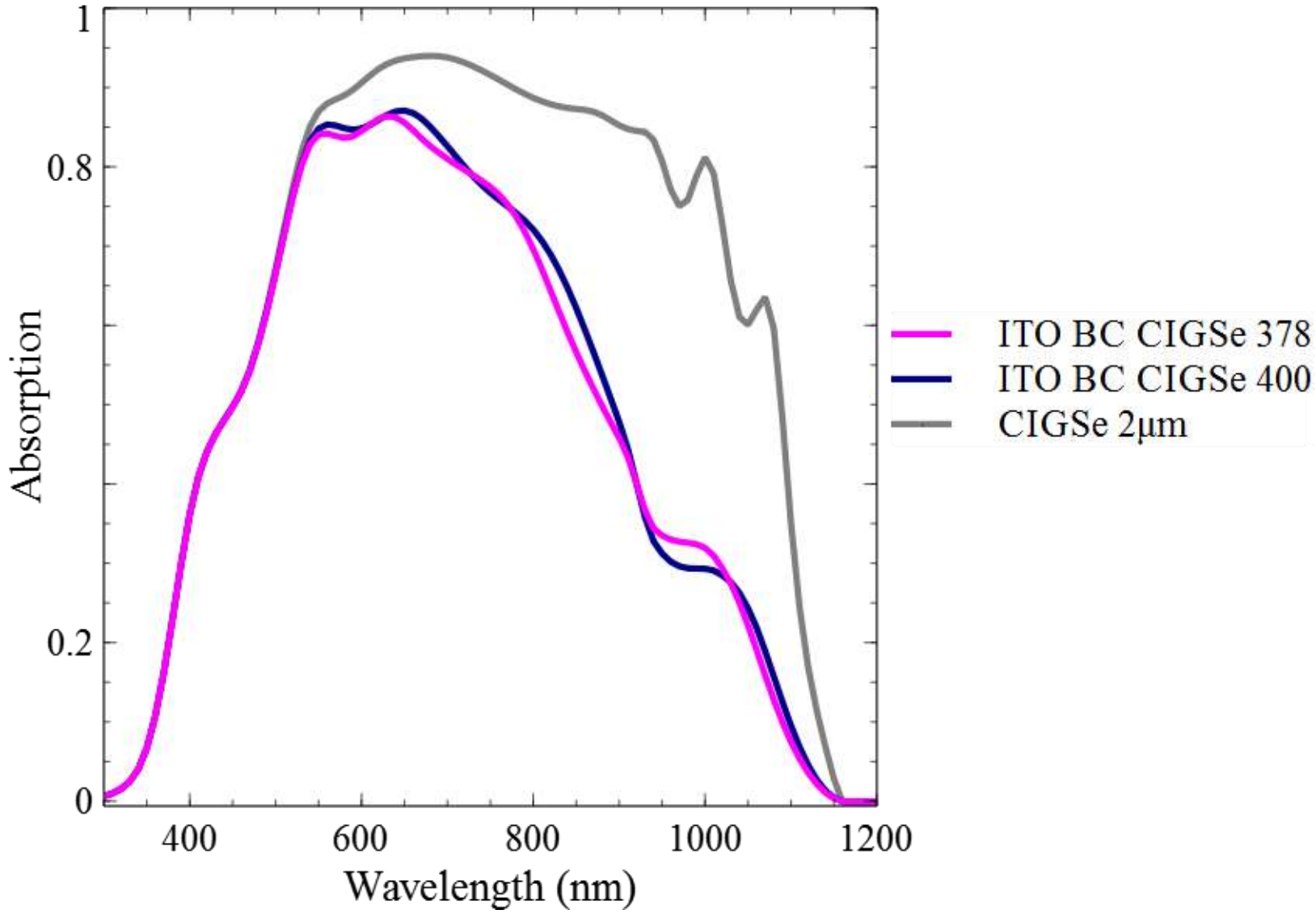
+50 nm diameter Ag particle with 10 nm AlSb Shell

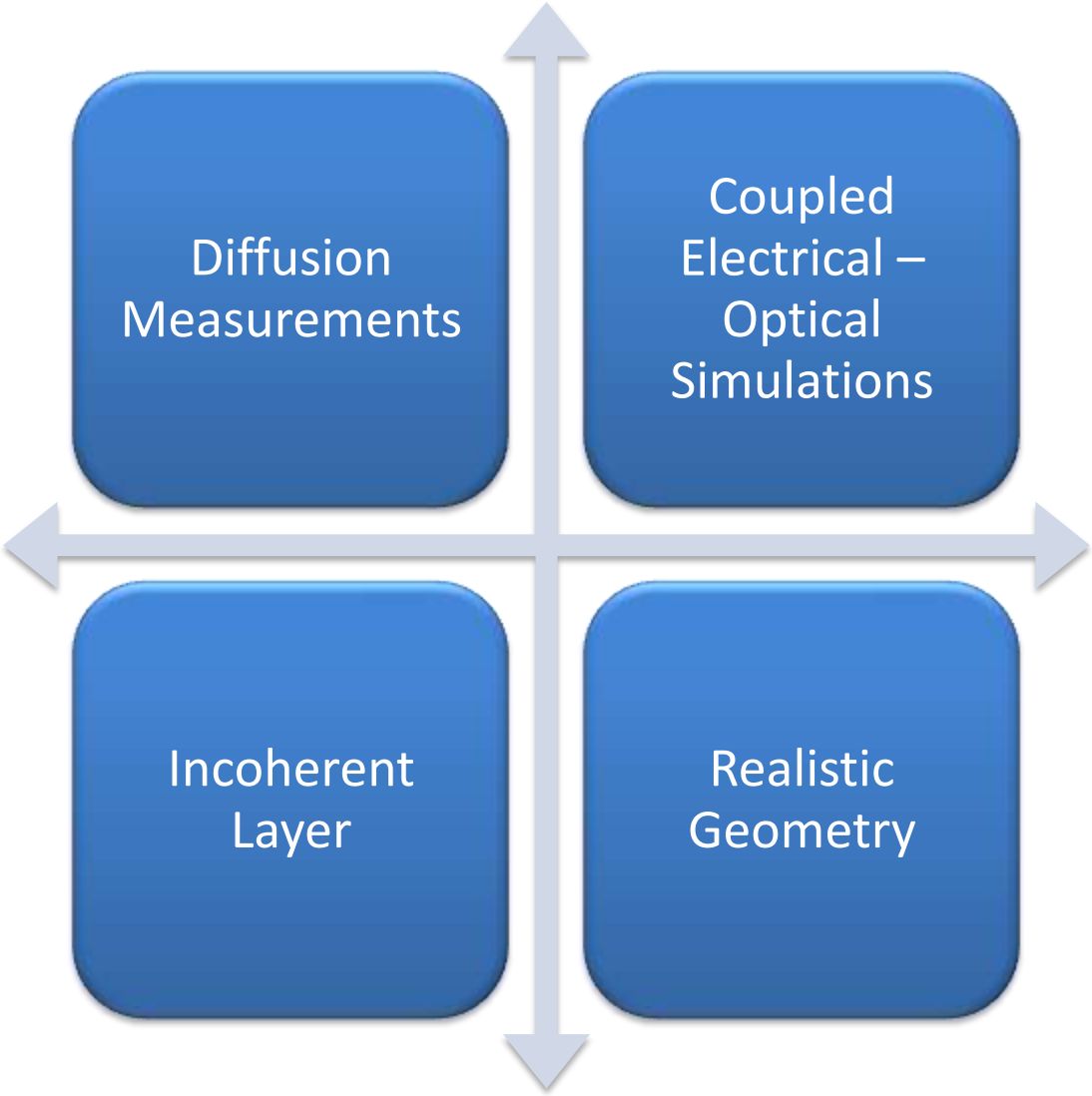


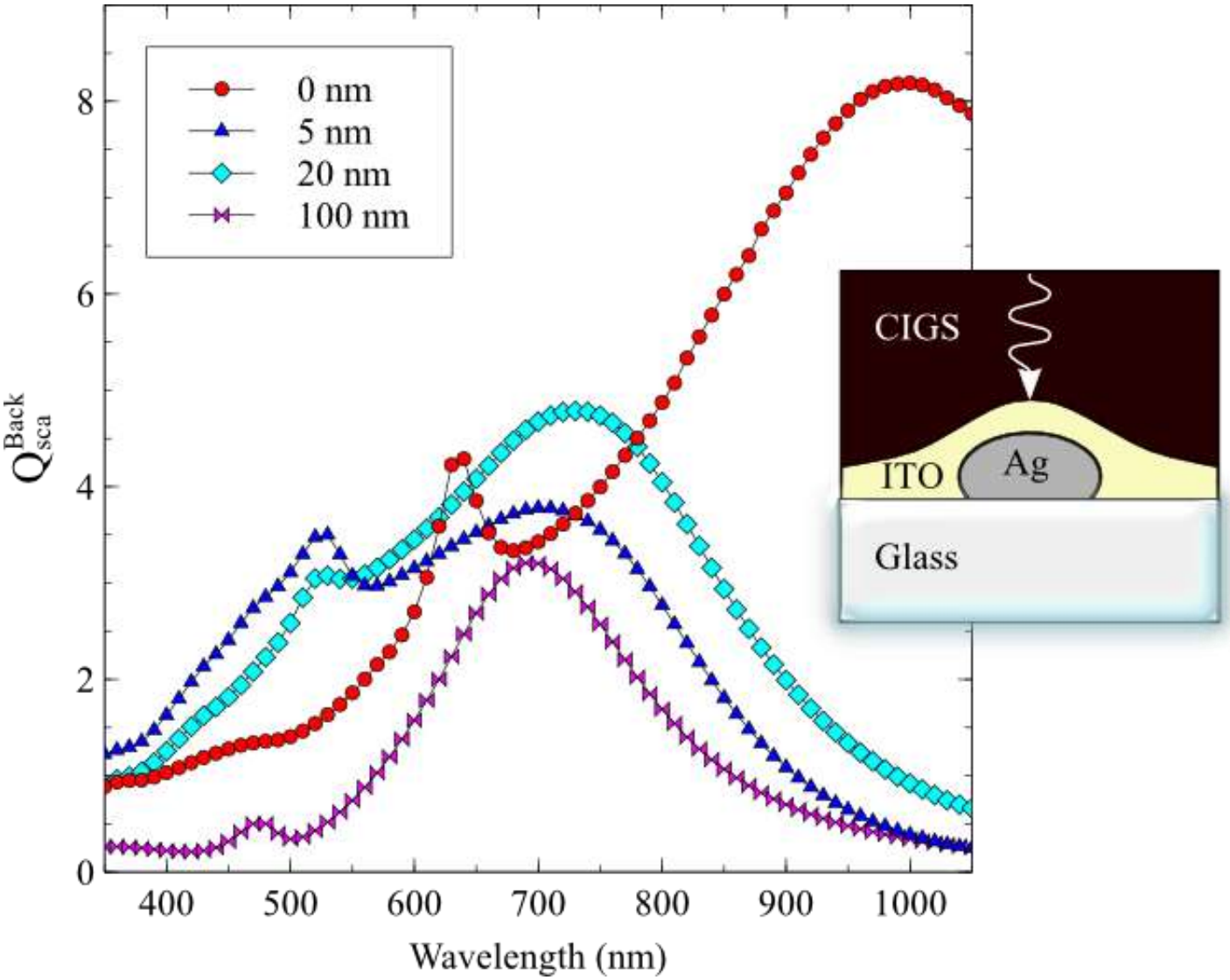

Window
500 nm
CIGSe
Ag
Glass

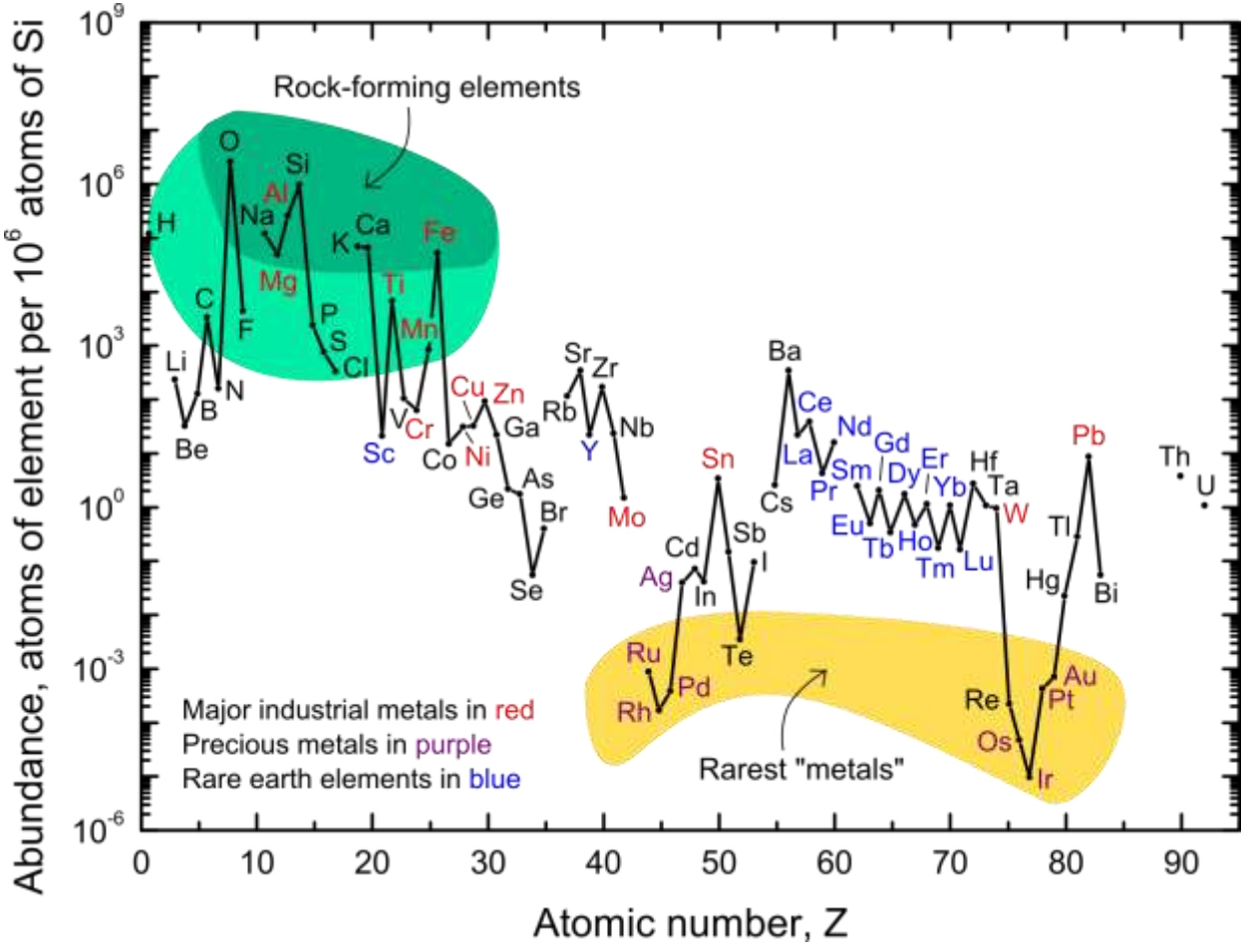

1
0,8
0,6
0,4
0,2
0
R,T,A
400
600
800
1000
1200
Wavelength (nm)
CIGSe
Reflection
Window
Ag
Transmission


Spectral Solar Flux (Wm-2nm-1)
1.5
1.25
1
0.75
0.5
0.25
0
500
1000
1500
2000
2500
Wavelength (nm)


1
0.8
0.2
0
Absorption
400
600
800
1000
1200
Wavelength (nm)
ITO BC CIGSe 378
ITO BC CIGSe 400
CIGSe 2µm


Diffusion Measurements
Coupled Electrical – Optical Simulations
Incoherent Layer
Realistic Geometry


0 nm
5 nm
20 nm
100 nm
Q_{sca}^{Back}
0
2
4
6
8
400
500
600
700
800
900
1000
Wavelength (nm)
CIGS
ITO
Ag
Glass



Element	Price by weight (USD/kg) [July 2013]
In	548
Ag	624

Source: Metalprices.com

Element	World Production (Tonnes/year) [2013]
In	770
Ag	26,000

Source: U.S. Geological Survey

Source: Gordon B. Haxel, Sara Boore, and Susan Mayfield, USGS