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Optoelectronically Optimized Nonhomogeneous Thin-Film Solar Cells

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Summary

- Ubiquitous deployment of thin-film solar cells as *local energy microsources* will help*:*
  - *Human progress to become truly unconstrained by energy economics*
  - *To reduce carbon dioxide emissions*
- Colored thin-film solar cells more acceptable on rooftops due to
  - *Aesthetics*
  - *Resemblance to conventional rooftops*
- Efficiency enhancement of thin-film solar cells requires optoelectronic optimization of:
  - *Bandgap grading of semiconductor layers*
  - *Periodically corrugated backreflector*
  - *Back-surface passivation*

Introduction

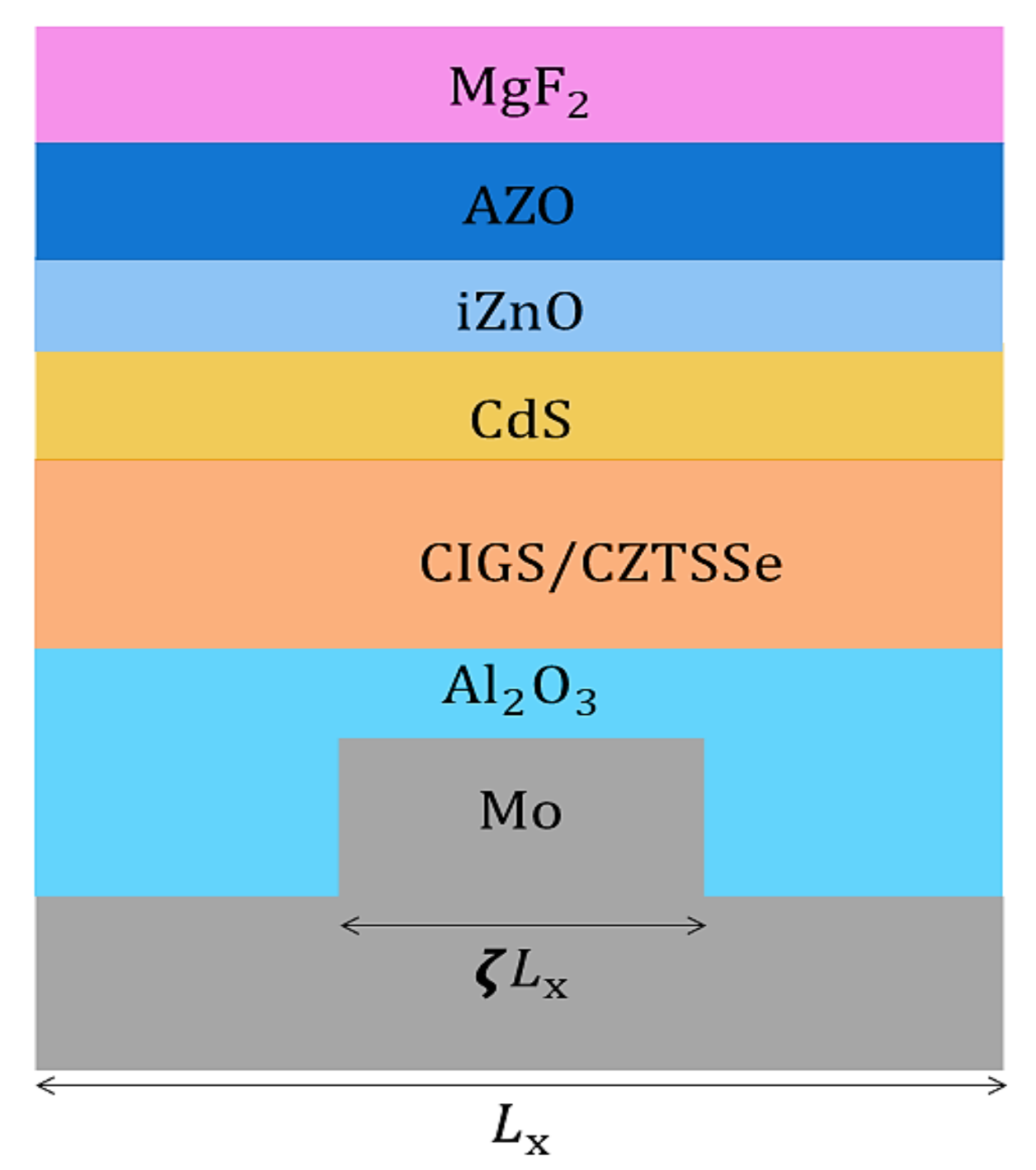
- Eco-friendly source of energy
- Key challenge: high efficiency at low cost
- Solution: Thin-film solar cells due to [1]:
  - *Reduced material consumption*
  - *Reduced manufacturing cost*
- Major concerns inhibiting widespread adoption:
  - *Scarcity and cost of rare materials such as In in CIGS and Te in CdTe solar cells [2]*
  - *Low efficiencies such as of a-Si and CZTSSe solar cells [3]*
- Large-scale adoption of solar cells to rooftops inhibited due to black or blue appearance [4]
- New strategies are required for thin-film solar cells:
  - *Ubiquitous adoption as local energy microsources*
  - *Enhance acceptance for rooftop deployment*

Objectives

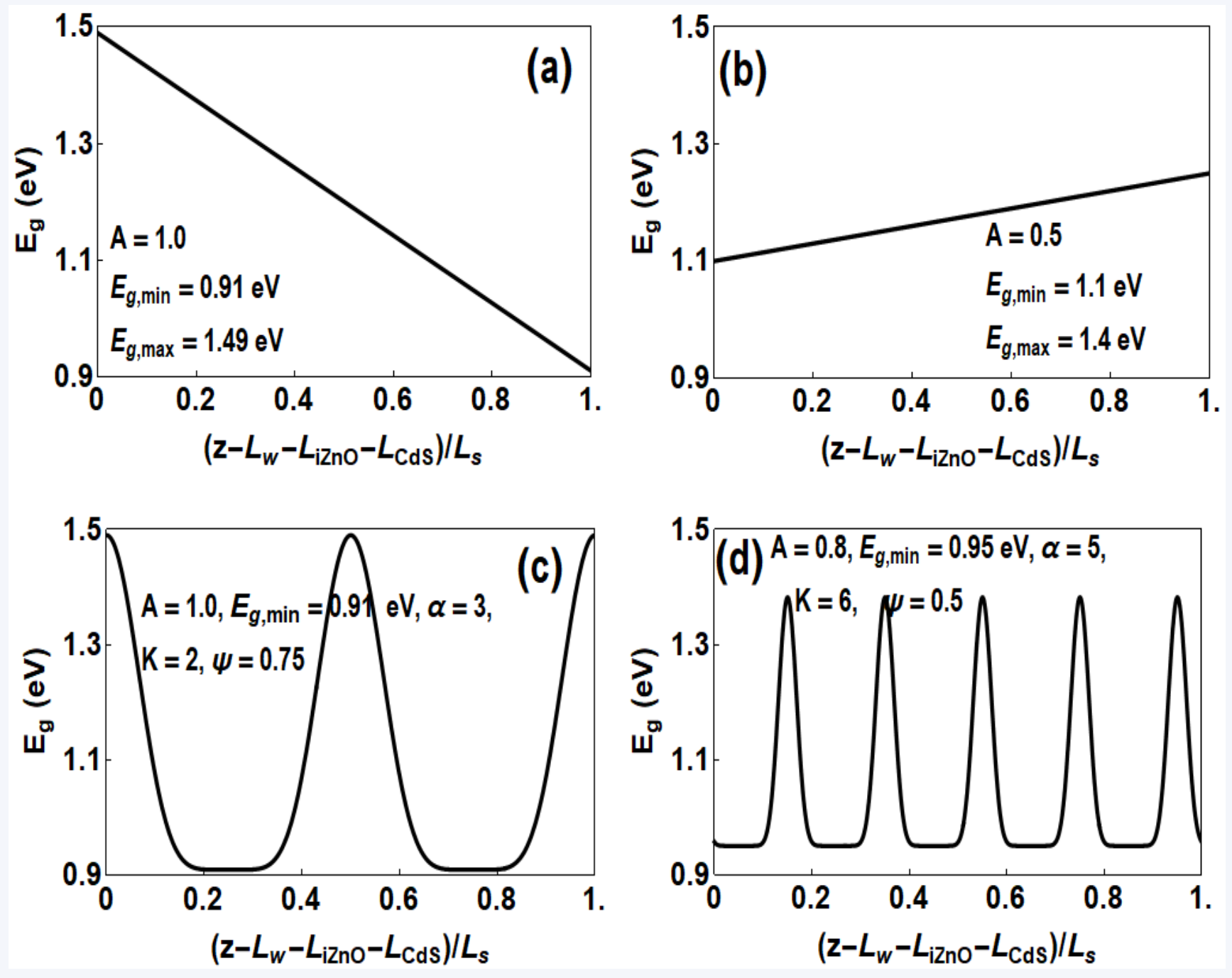
- Design and optimize novel thin-film solar cells to:
  - *Enhance efficiency*
  - *Reduce the material use*
- Estimate efficiency loss due to color-rejection filter

Design modifications

- Conventional CIGS and CZTSSe solar cells: antireflection coatings/AZO(front-contact)/iZnO-CdS(buffer layers)/CIGS or CZTSSe (absorber layer)/Mo (back-contact) [5, 6]
- Design modifications:
  1. *CIGS/CZTSSe bandgap grading*
  2. *Periodically corrugated backreflector*
  3. *Back-surface passivation (thin layer of alumina at the rear-side of CIGS/CZTSSe)*
- Efficiency maximization through optoelectronic optimization



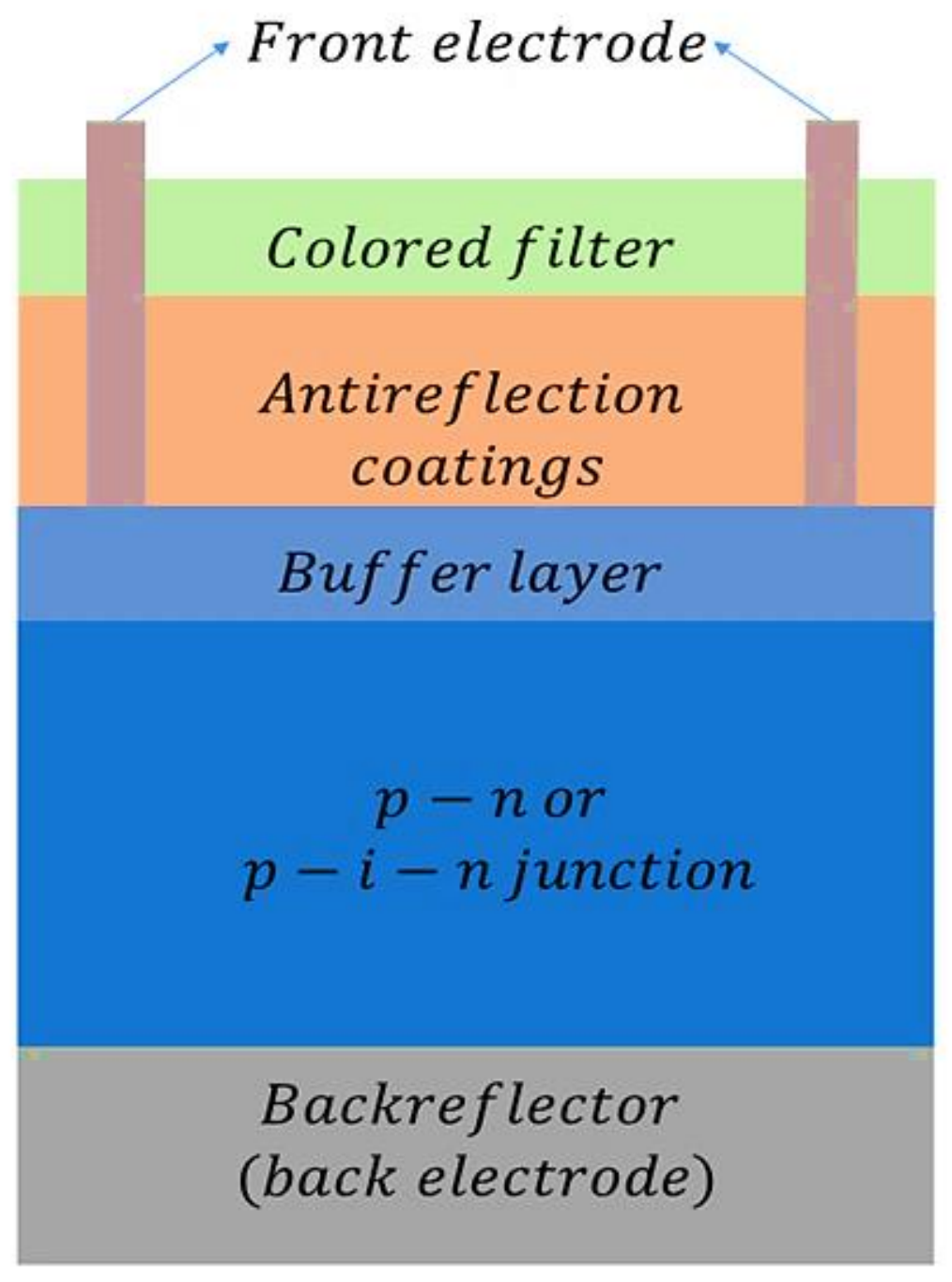
Unit cell of CIGS/CZTSSe solar cell



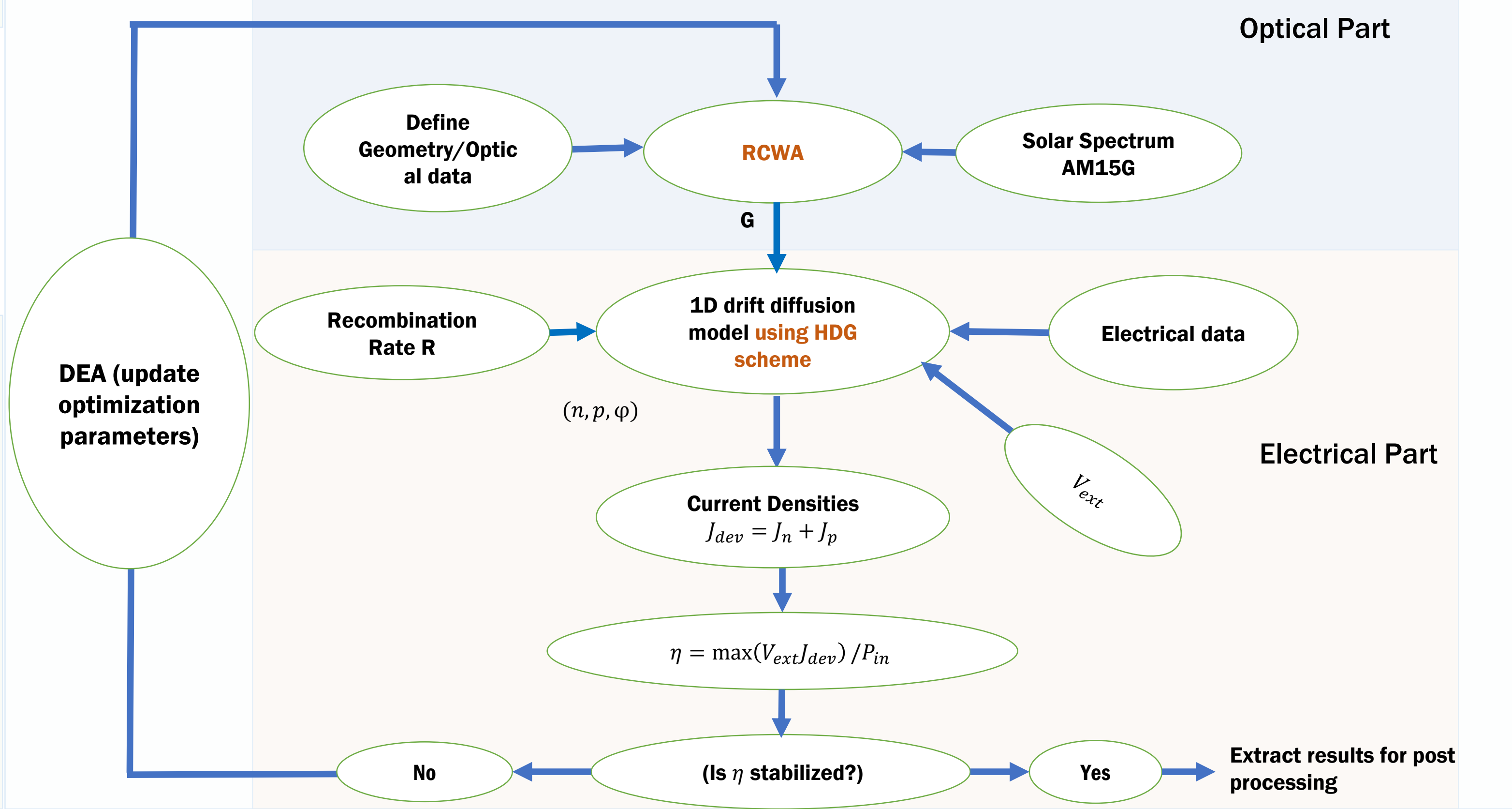
Representative profiles of (top) linearly and (bottom) sinusoidally graded bandgap

Colored Thin-film Solar Cells

- Color-rejection filter on top to reflect certain fraction of incident photons of certain colors
- Structural (non-pigmental) color
- Non-iridescent filters by:
  - *Dimensional scaling of biomimetic filters nano-imprinted to reproduce the Morpho blue [7]*



Optoelectronic modeling and optimization



Results

Optoelectronic optimization of CIGS and CZTSSe solar cells

Cell	Efficiency (η)	Ref.
Reference experimental CIGS solar cell	22.6%	[3]
Sinusoidally graded bandgap conventional thick CIGS solar cell	27.7%	Predicted [5]
Sinusoidally graded bandgap ultrathin 600-nm-thick CIGS solar cell	22.8%	Predicted [5]
Reference experimental CZTSSe solar cell	12.6%	[3]
Sinusoidally graded bandgap conventional thick CZTSSe solar cell	17.0%	Predicted [6]
Sinusoidally graded bandgap optimal 870-nm-thick CZTSSe solar cell	21.7%	Predicted [6]

Efficiency loss for red thin-film solar cells

Solar cell	Fraction of red photons rejected	Relative *efficiency* reduction
CIGS solar cell	50%	8.9±0.7%
	100%	17.6±1.4%
CZTSSe solar cell	50%	7.05±2.05%
	100%	15.8±2.7%

Concluding Remarks

- Experimental validation will help revolutionize thin-film solar cell technology
- Colored and cost-effective thin-film solar cells will increase large-scale production and ubiquitous adoption

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