Molecular Beam Epitaxy Application in Chalcogenide Based Solar Cell Technologies

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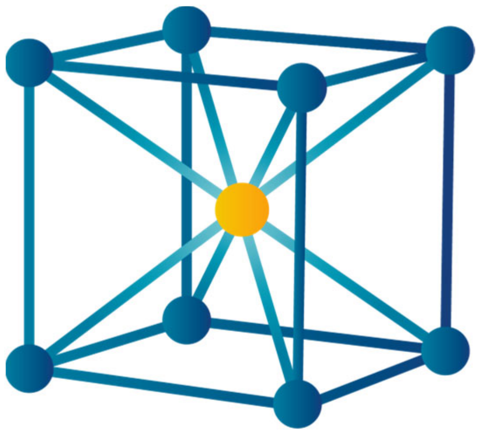
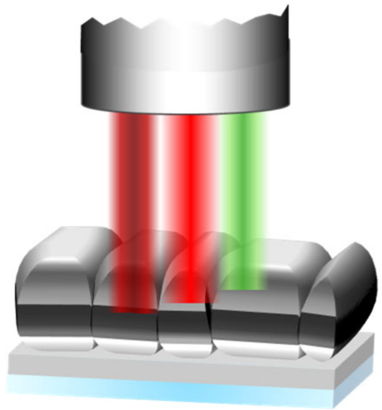
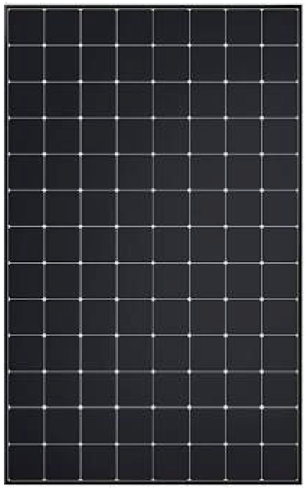
Objectives and goals



Advancing the knowledge of materials engineering (epitaxial growth)



Overview and introduction of new characterization techniques



Expanding the knowledge of solar cells

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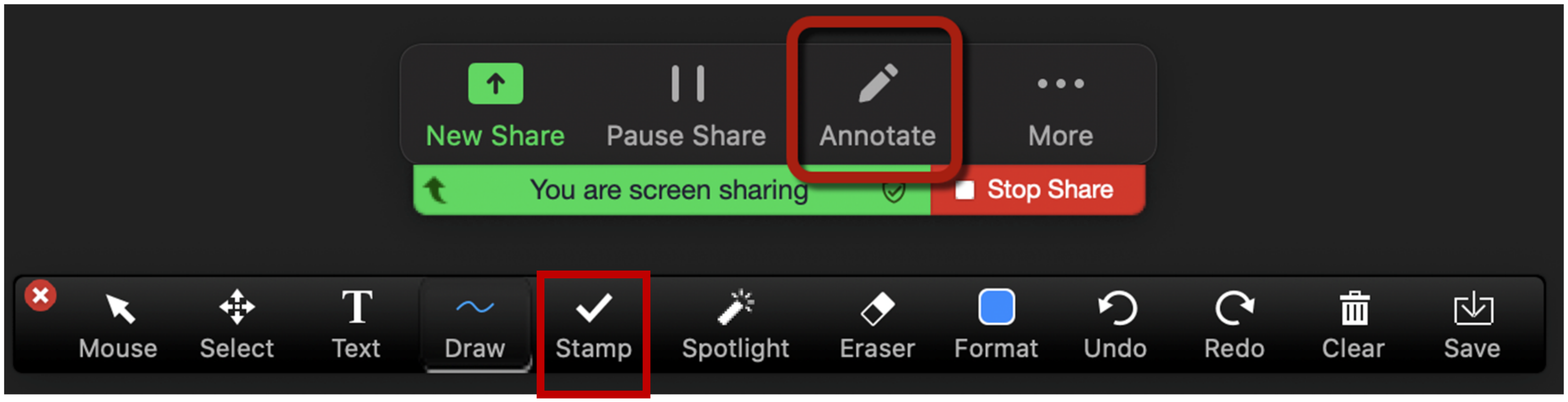

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Example:

Q1: Are you a cat or dog person?

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Overview

- Introduction into solar cells
- Application of epitaxial growth in chalcopyrites
- Application of epitaxial growth in kesterites

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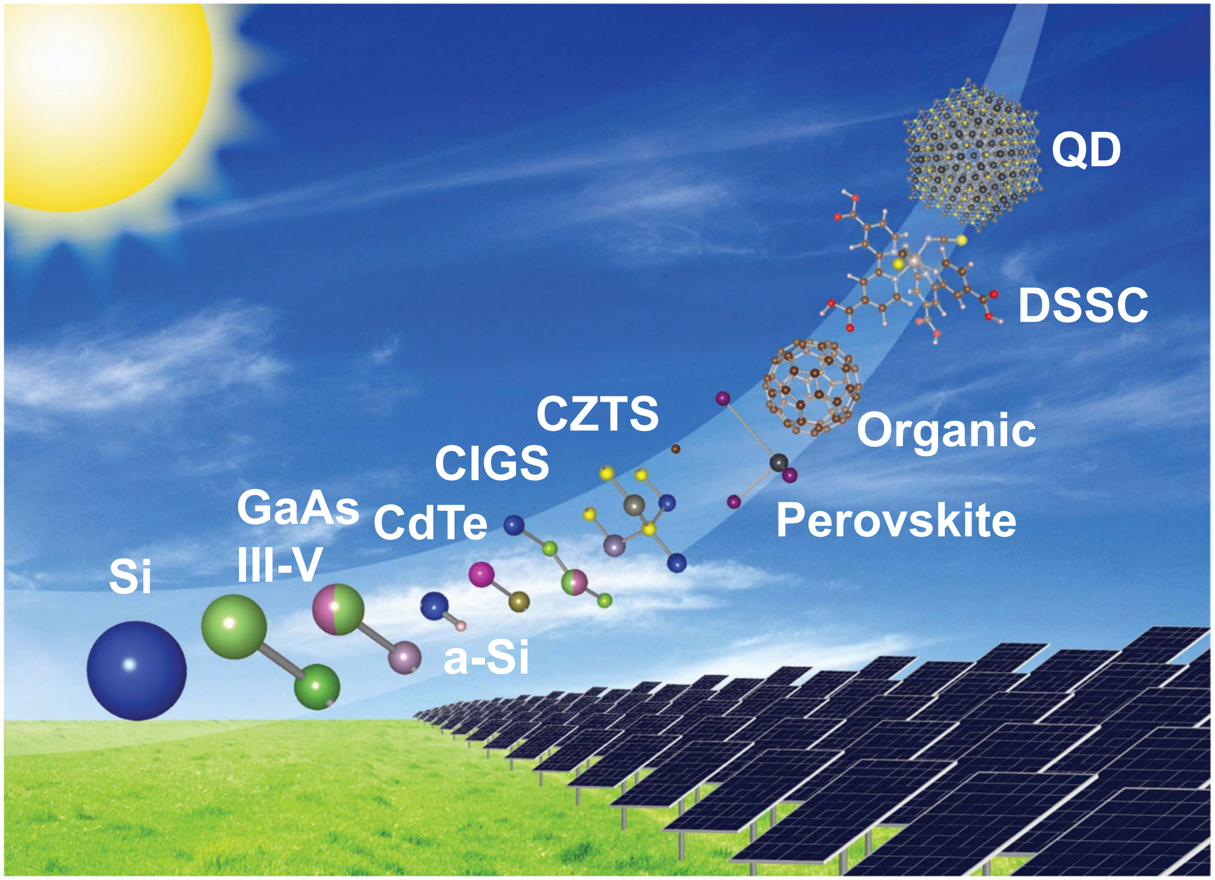
Introduction

Solar photovoltaics (PV):
- ✓ renewable, sustainable and carbon-free electricity generation technology
- ✓ fastest-growing energy technology in the world today
- ✓ a leading candidate for terawatt-scale deployment



J. Jean et al. Energy Environ. Sci., 2015, 8, 1200

Wide span of materials used as absorbers (the heart of the solar cell).

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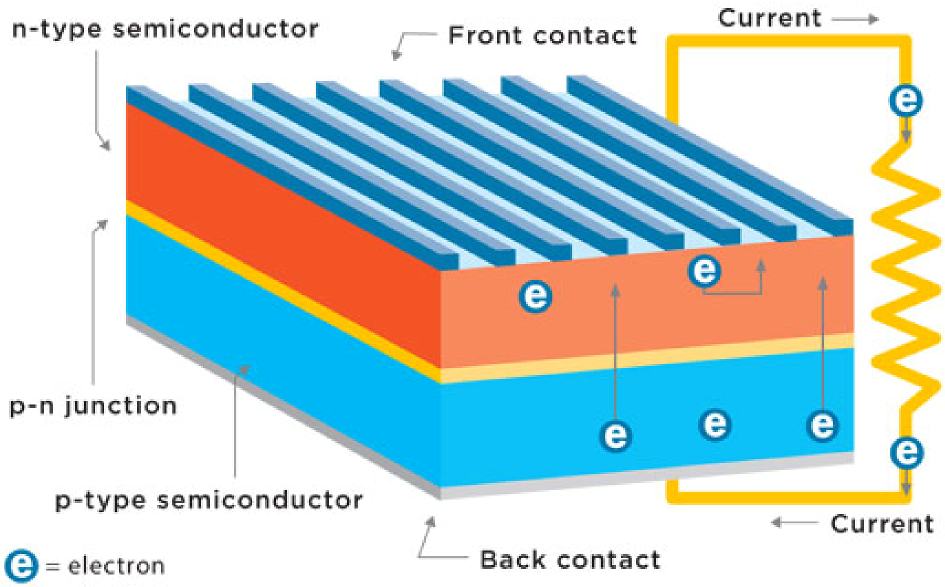
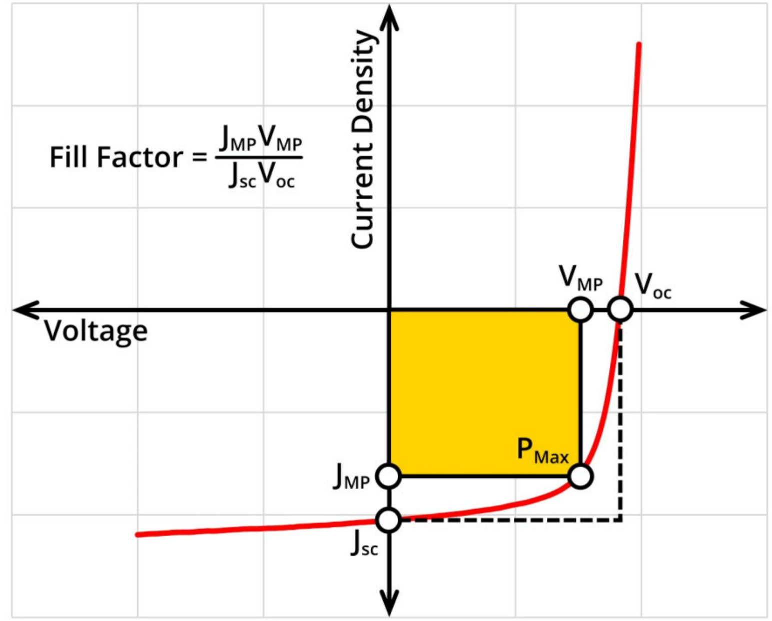
Solar cells: short overview

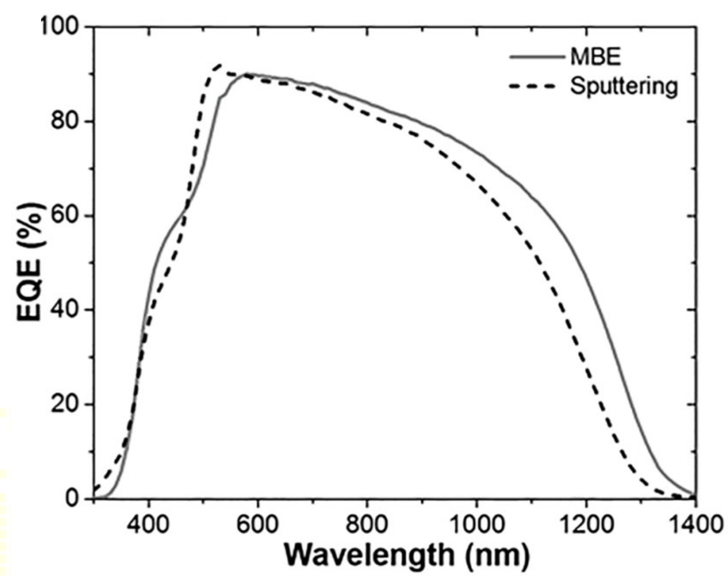
Working principle of a solar cell





Two main characterization techniques:
J-V and external quantum efficiency (EQE)

Main parameters:
Voc – open circuit voltage
Jsc – short circuit current
FF – fill factor
η - efficiency



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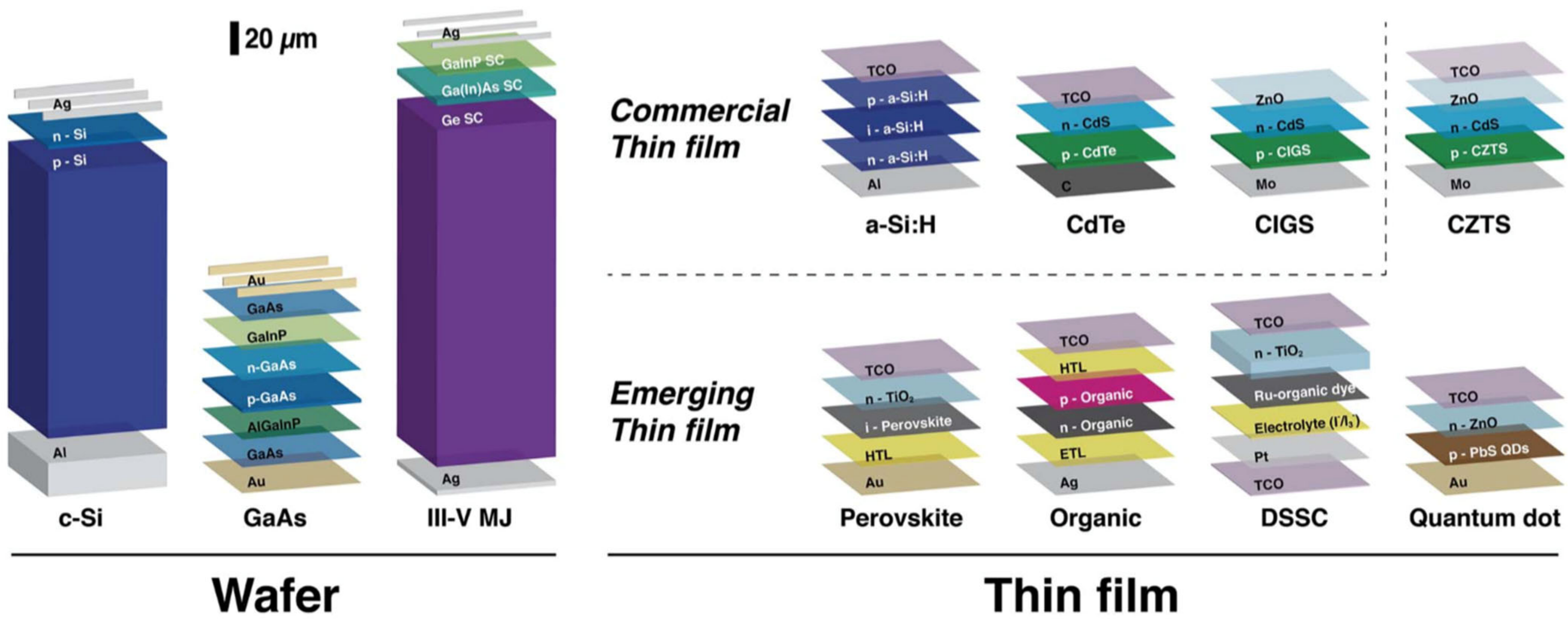
Solar cell structure in various technologies:



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Property		State of the art				
		Si	GaAs	CIGS	CZTSSe	Perovskite
E_g	Bandgap (eV)	1.1	1.5	1-1.5	1-1.5	1.5
	Record efficiency (%)	26	29	23	12	22
	Thickness (µm)	100 - 200	1	1	1	0.5
	Mechanical properties (flexibility)	✗	✓	✓	✓	✓
	Abundance	✓	✗ CRM: Ga	✗ CRM: In, Ga	✓	✗ CRM: Pb, and other
TOXIC	Toxicity	✓	✗ (As)	✓	✓	✗ (Pb)
	Recyclability	✓	✗ Difficult	✓	✓	✗ Difficult
$	Cost	$	$$$	$$	$	$

Objectives:

1) What is the role of epitaxial growth techniques in CIGS and CZTS solar cell?
2) Does epitaxial growth advance the technological development?
3) Does it increase efficiency of the cells?

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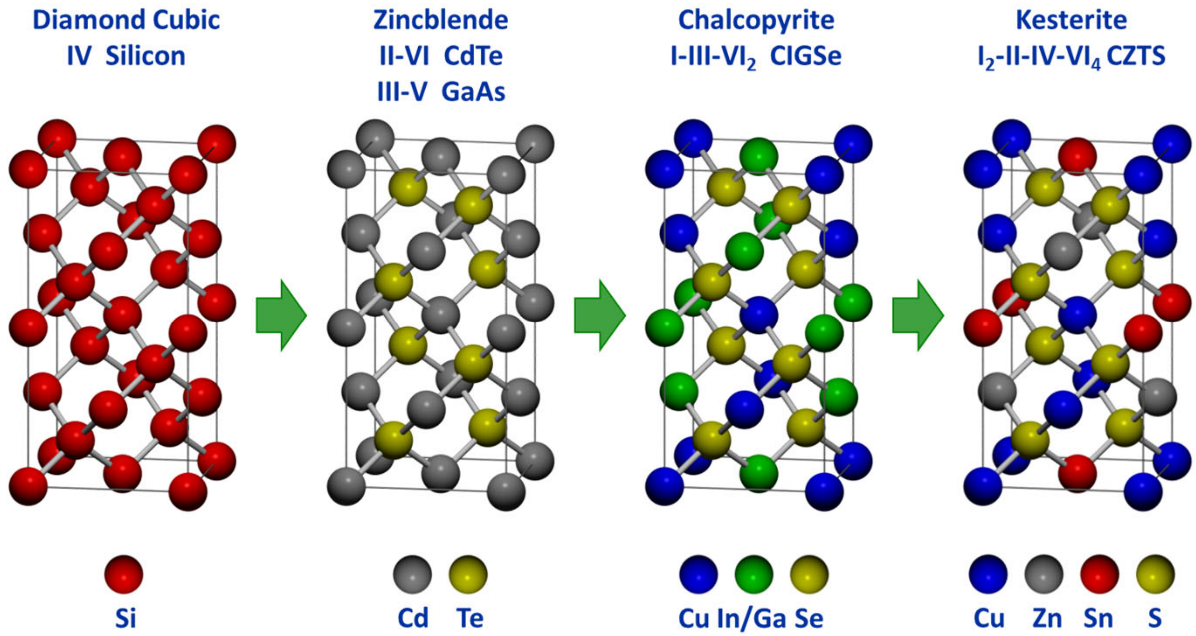
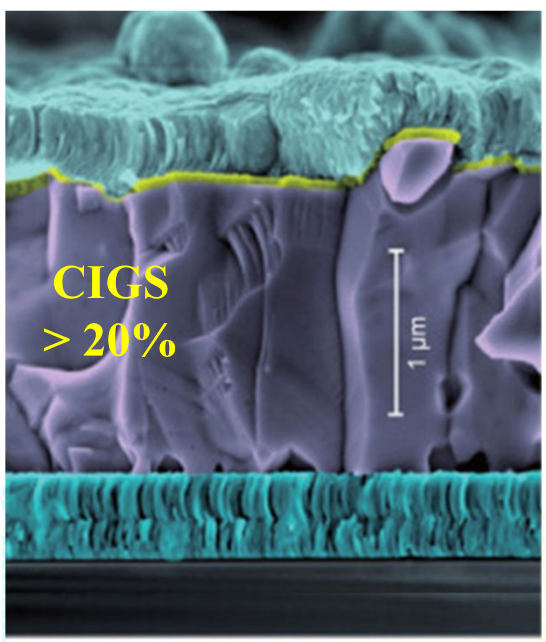
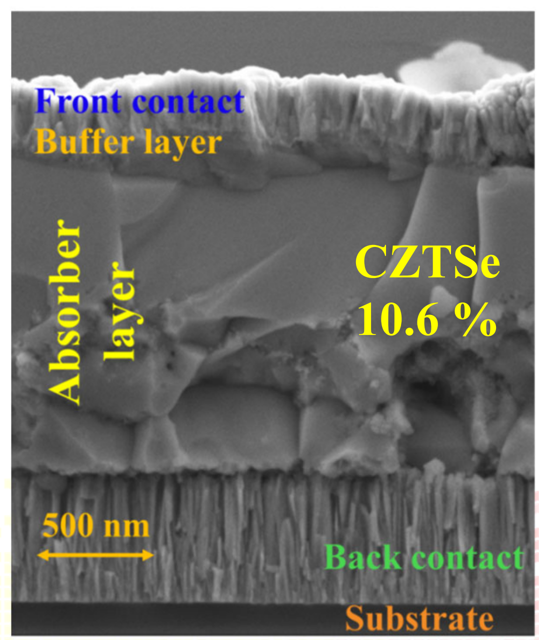
CIGS vs CZTS: structure and devices



Polycrystalline thin films





ZnO
CdS
CIGS/CZTS
Mo
Glass

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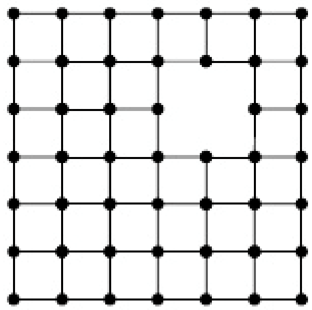
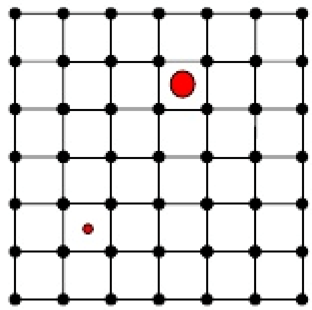
CIGS solar cells: role of structural defects?

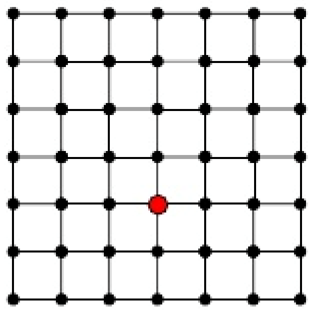
Point defects



Vacancy



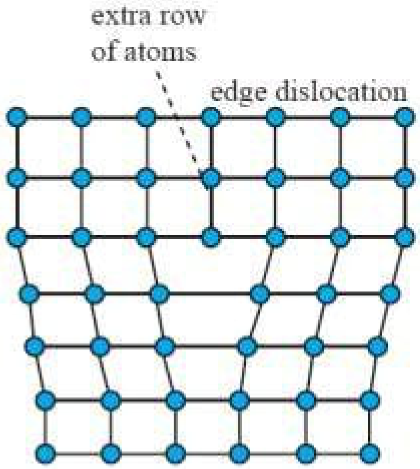
Interstitial

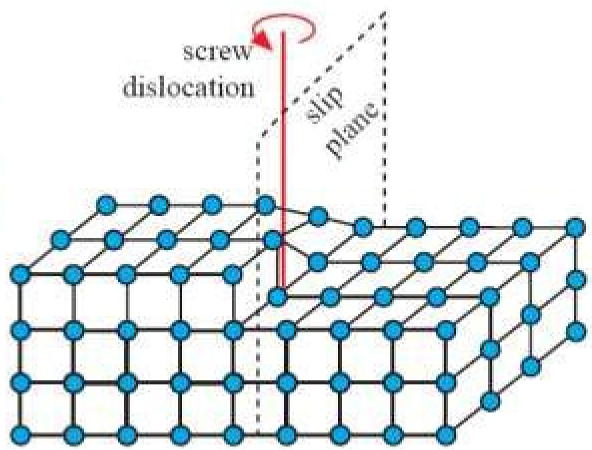


Substitutional

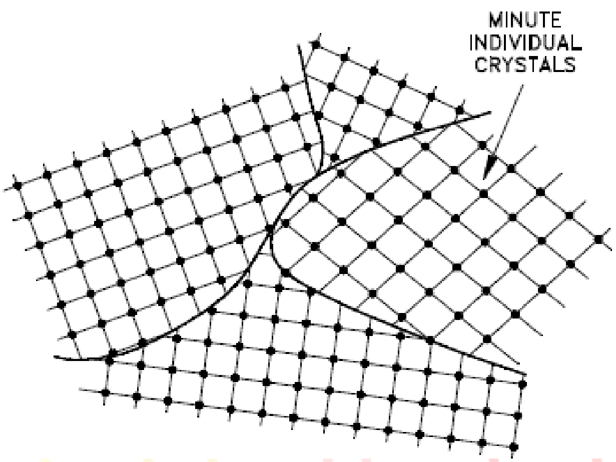
Beneficial of not?

Dislocations





Grain boundaries



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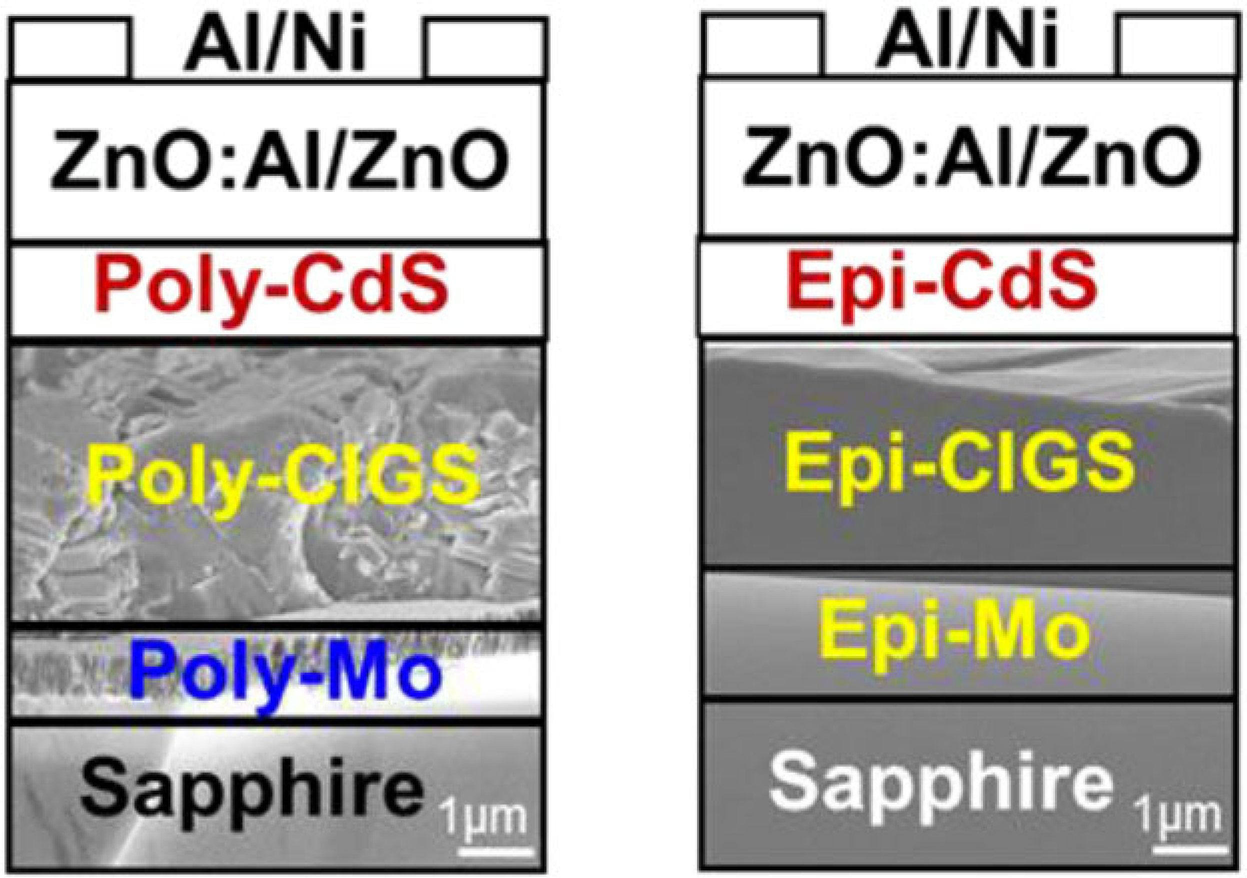
To understand the effect of grain boundaries and impurities, it is essential to compare the properties of epitaxial and polycrystalline CIGS films.



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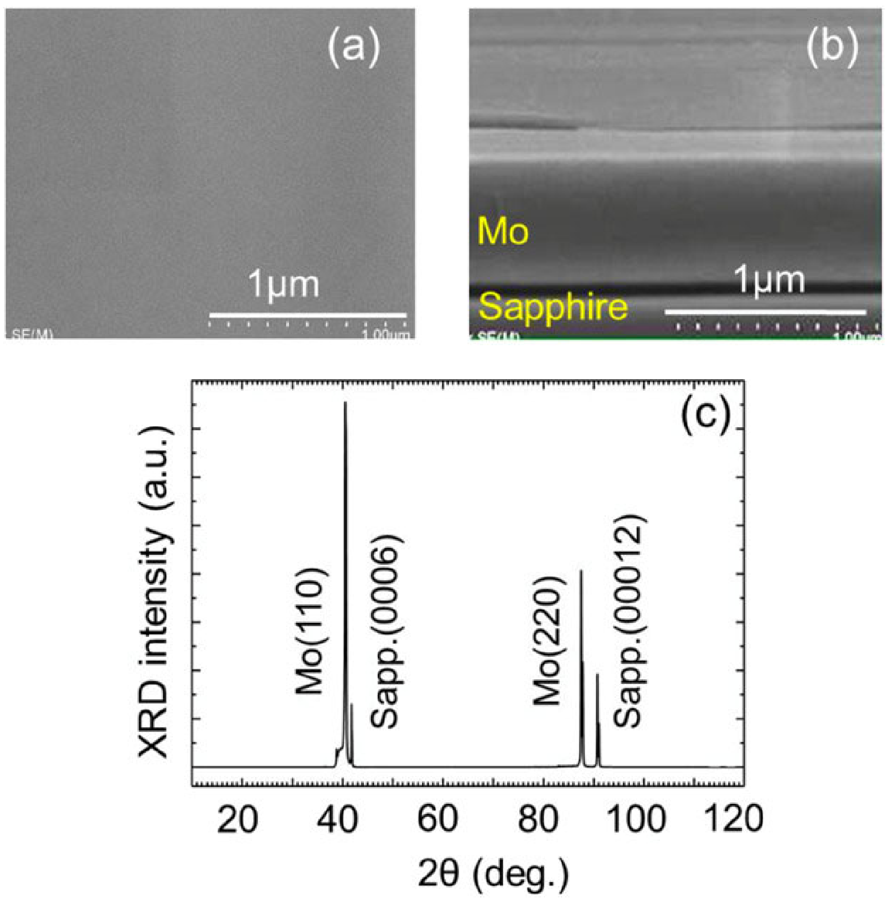
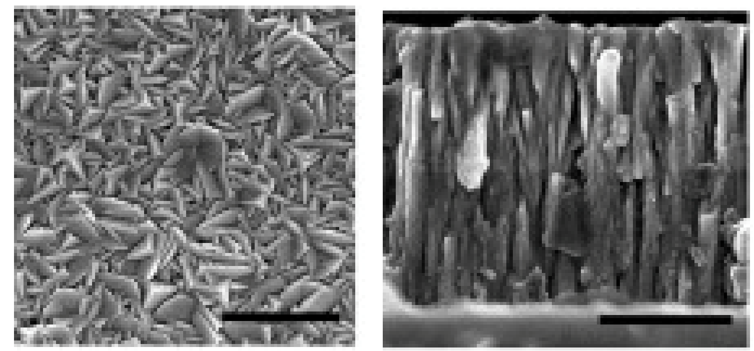
CIGS solar cells

Growth of Mo back contact

Epitaxial growth



Magnetron sputtering



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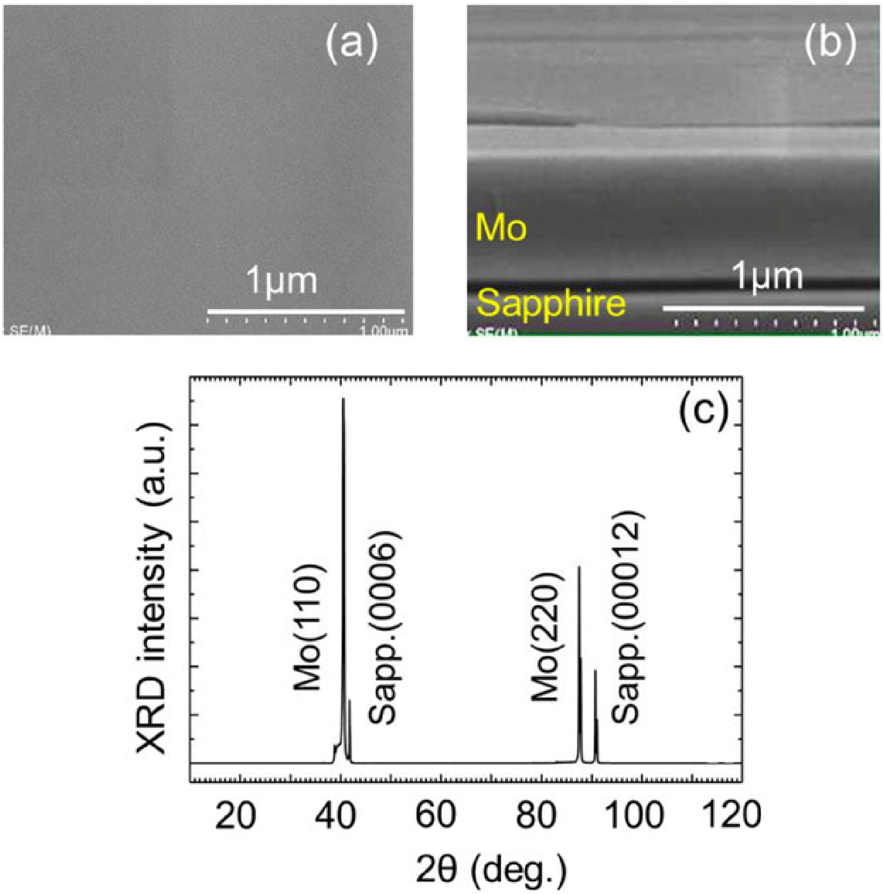
Growth of Mo back contact



Q: Based on the given XRD pattern, in which orientation did Mo {110} plane grow on the sapphire {0001} substrate?

Parallel

Perpendicular

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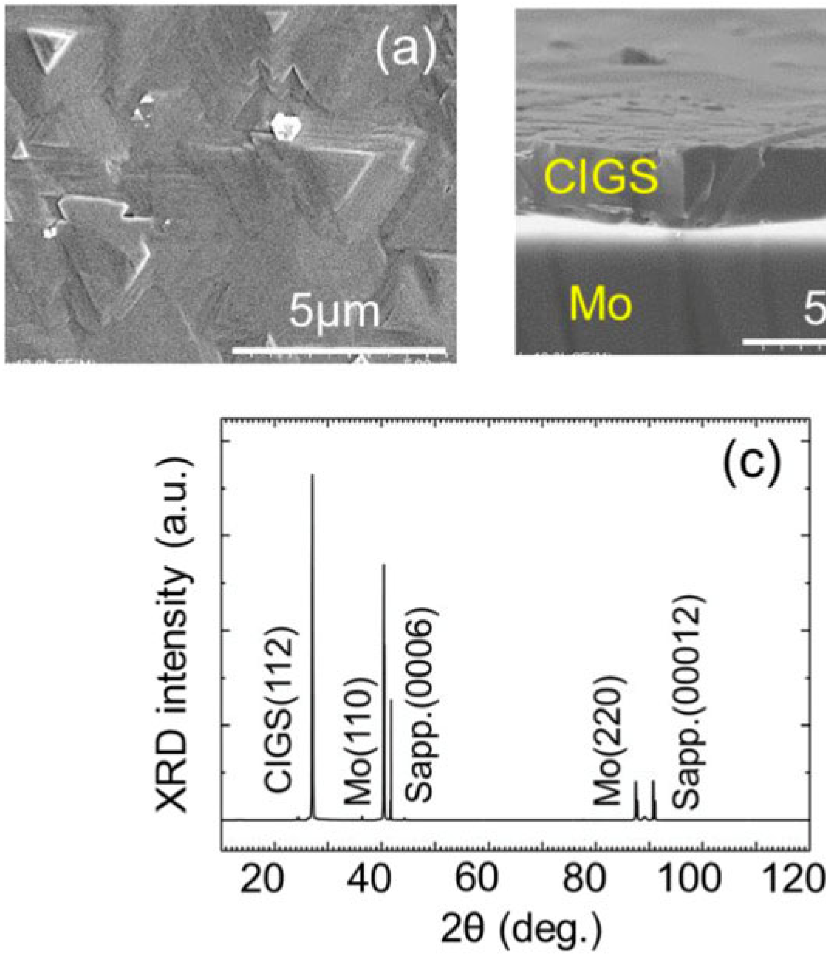
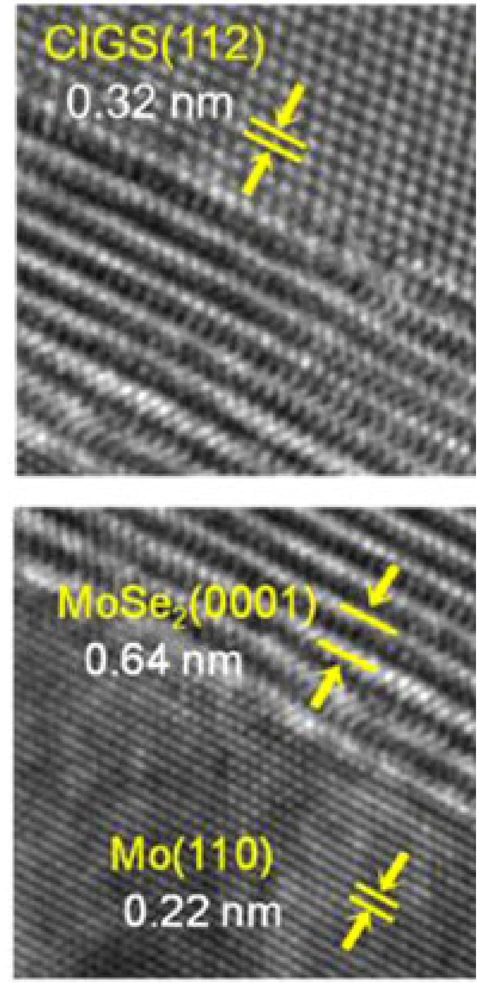
Growth of CIGS absorber



HRTEM



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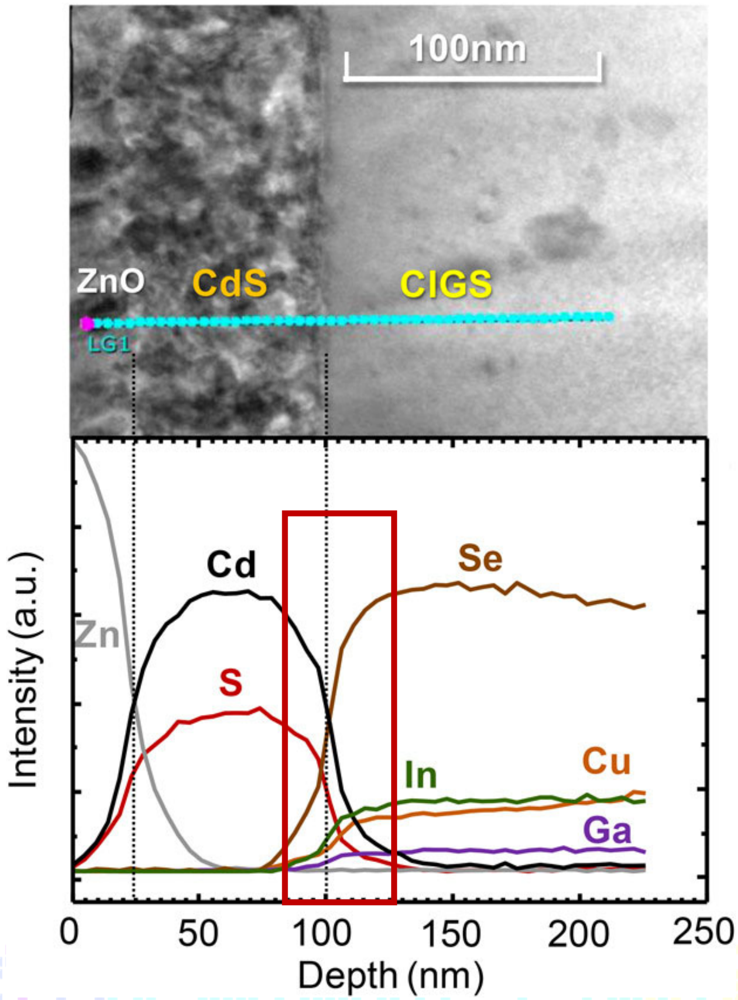
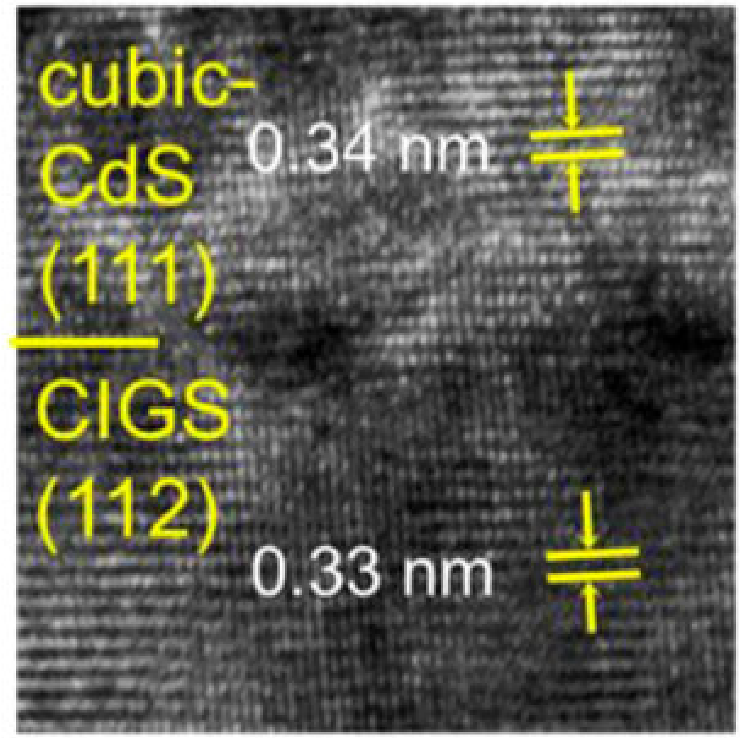
Growth of CdS buffer (CBD) and ZnO front contact

Complete cell EDX



HRTEM



Cd diffusion into CIGS layer

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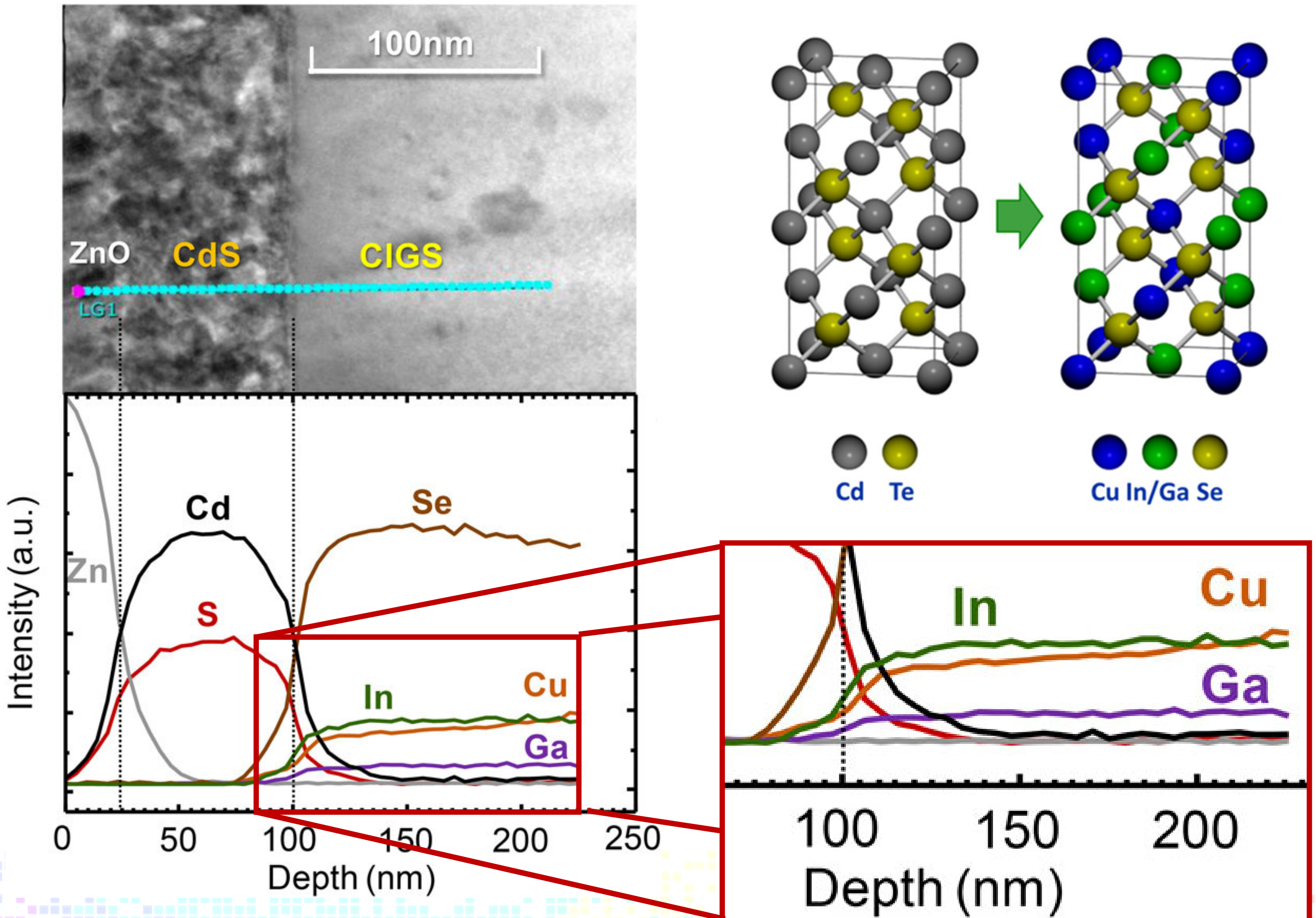
Growth of CdS buffer (CBD) and ZnO front contact

Complete cell EDX

Q: Where is Cd integrated in CIGS?



Cu

In

Ga

Se

Cd diffusion into CIGS layer

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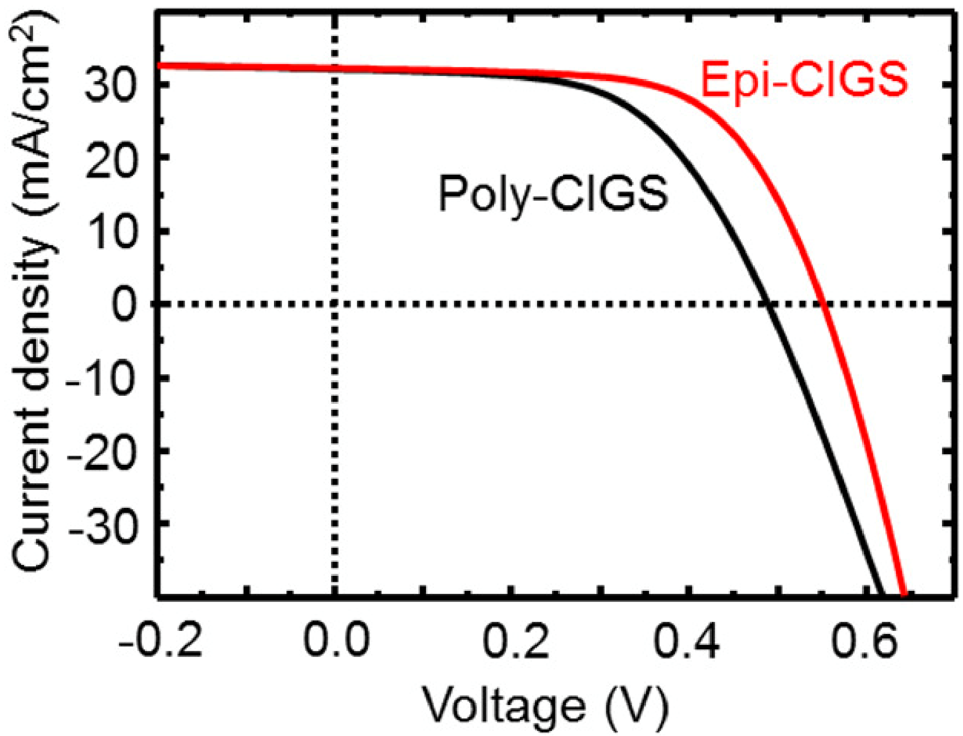
CIGS solar cells: optoelectronic parameters



Q: Which cell is better performing?

Epi-CIGS

Poly-CIGS

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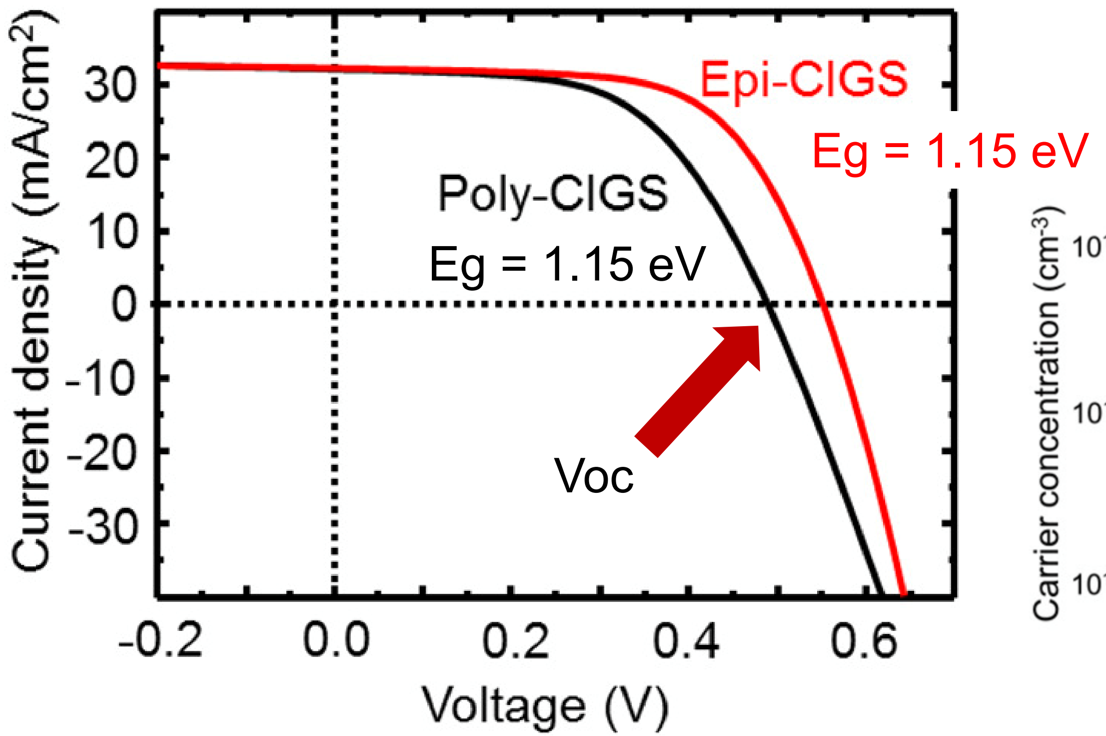
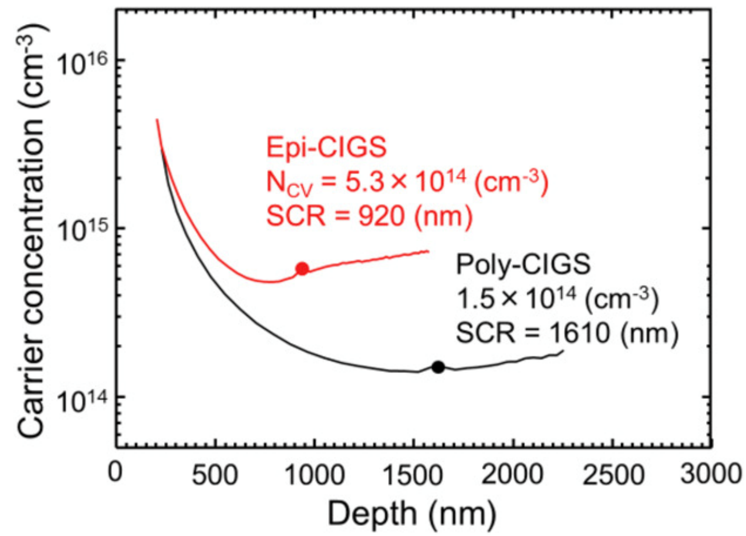
CIGS solar cells: optoelectronic parameters



C-V measurements



	J_{SC} [mA cm^{-2}]	V_{OC} [mV]	FF	Eff. [%]
Epi-CIGS	32.3	553	0.623	11.3
Poly-CIGS	32.2	489	0.570	8.95

Epitaxial growth :
reduction in the density of compensation defects leading to better performance

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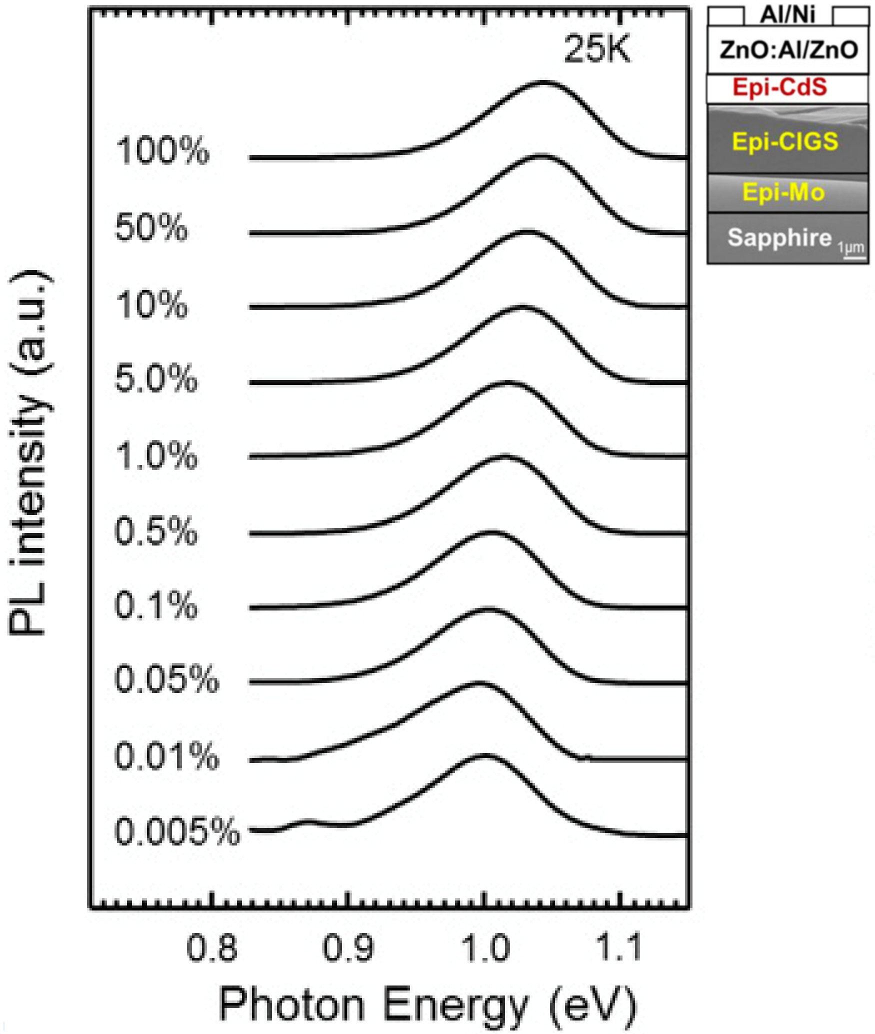
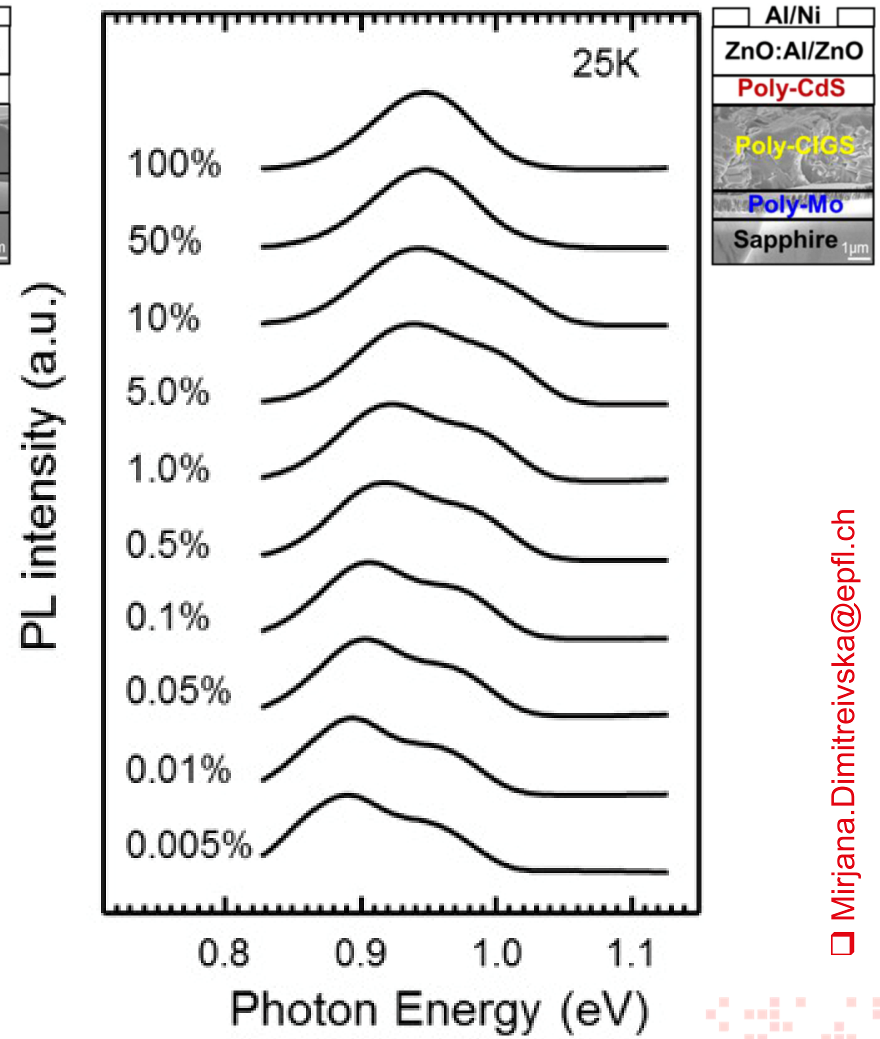
CIGS solar cells: optoelectronic parameters

Photoluminescence measurements





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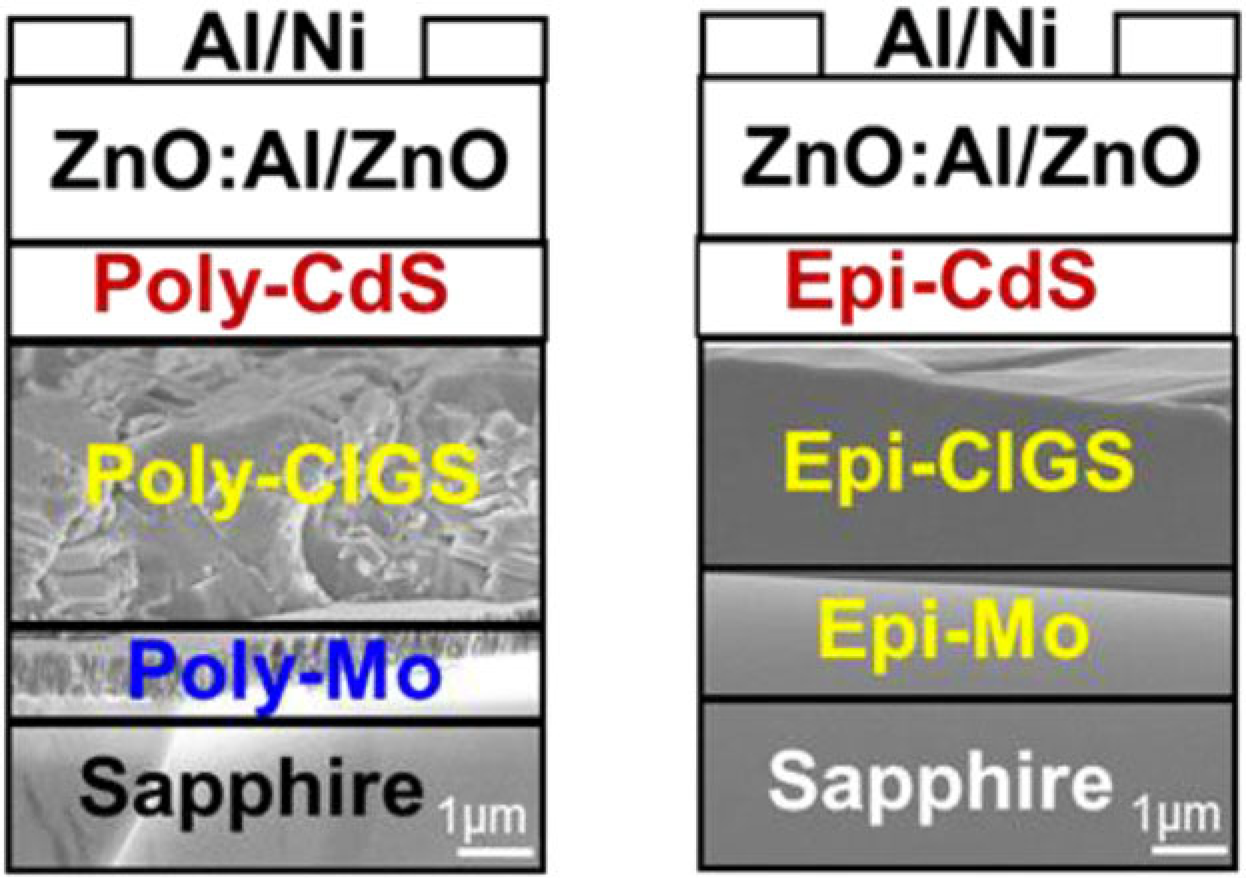
Epitaxial growth improved solar cell performance



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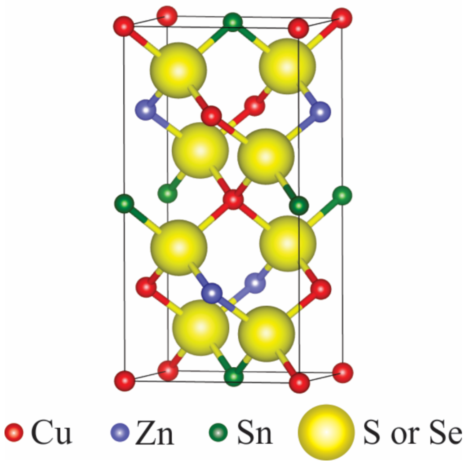
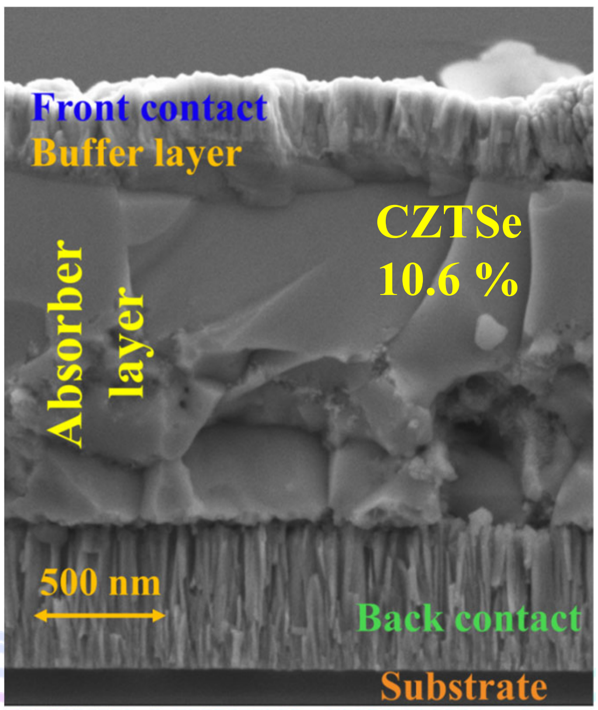
Kesterite solar cells: introduction

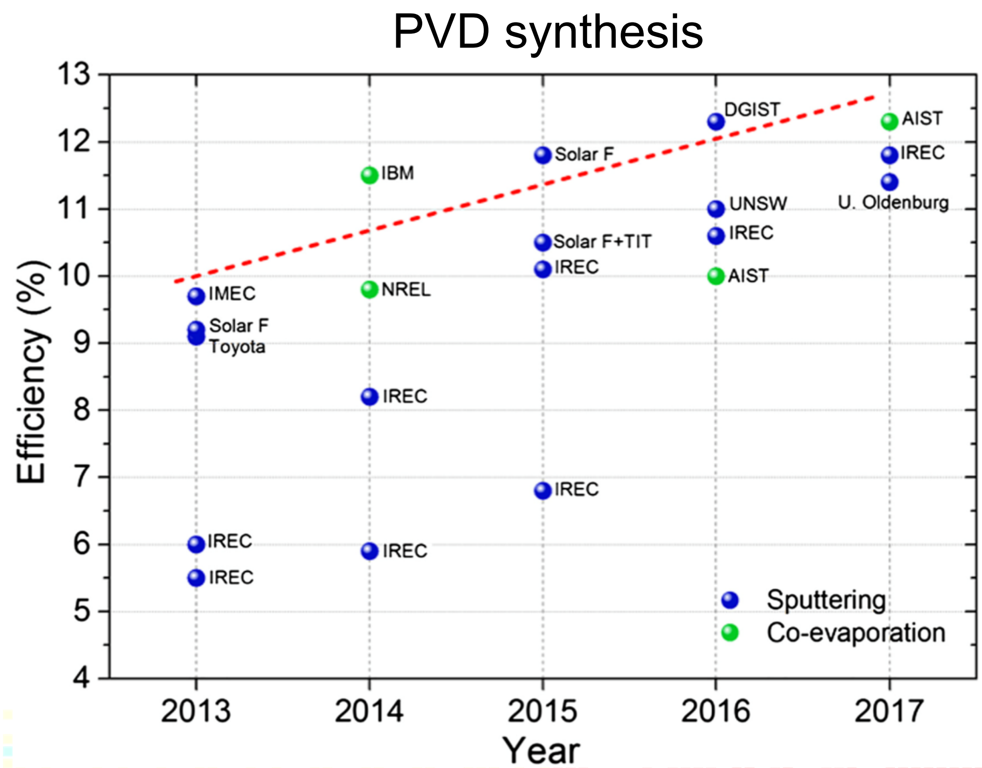
Kesterite solar cells are significantly newer technology than CIGS (more problems):

- Secondary phases
- Defect structure
- Decomposition
- Non-optimal device structure

Cu poor –Zn rich conditions







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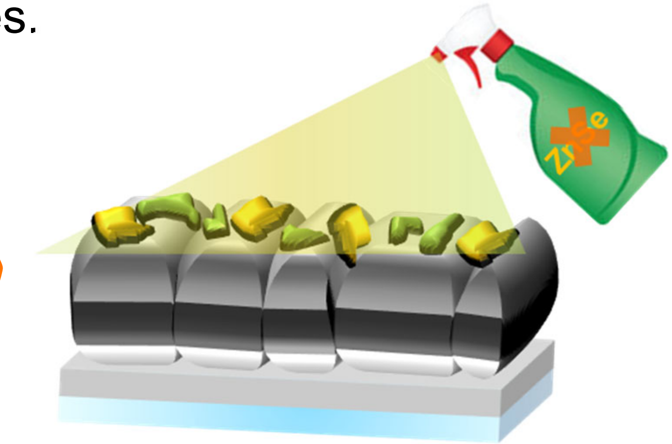
Kesterite solar cells engineering

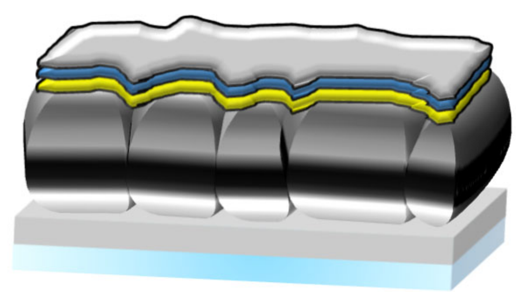
MBE technique is used for synthesis of metallic stack precursors: high control over the growth parameters compared to other techniques.

Metallic stack deposition

Annealing in Ge atmosphere (changes in the amount and temperature)



Chemical etching for removal of secondary phases



CdS/i-ZnO/ITO deposition

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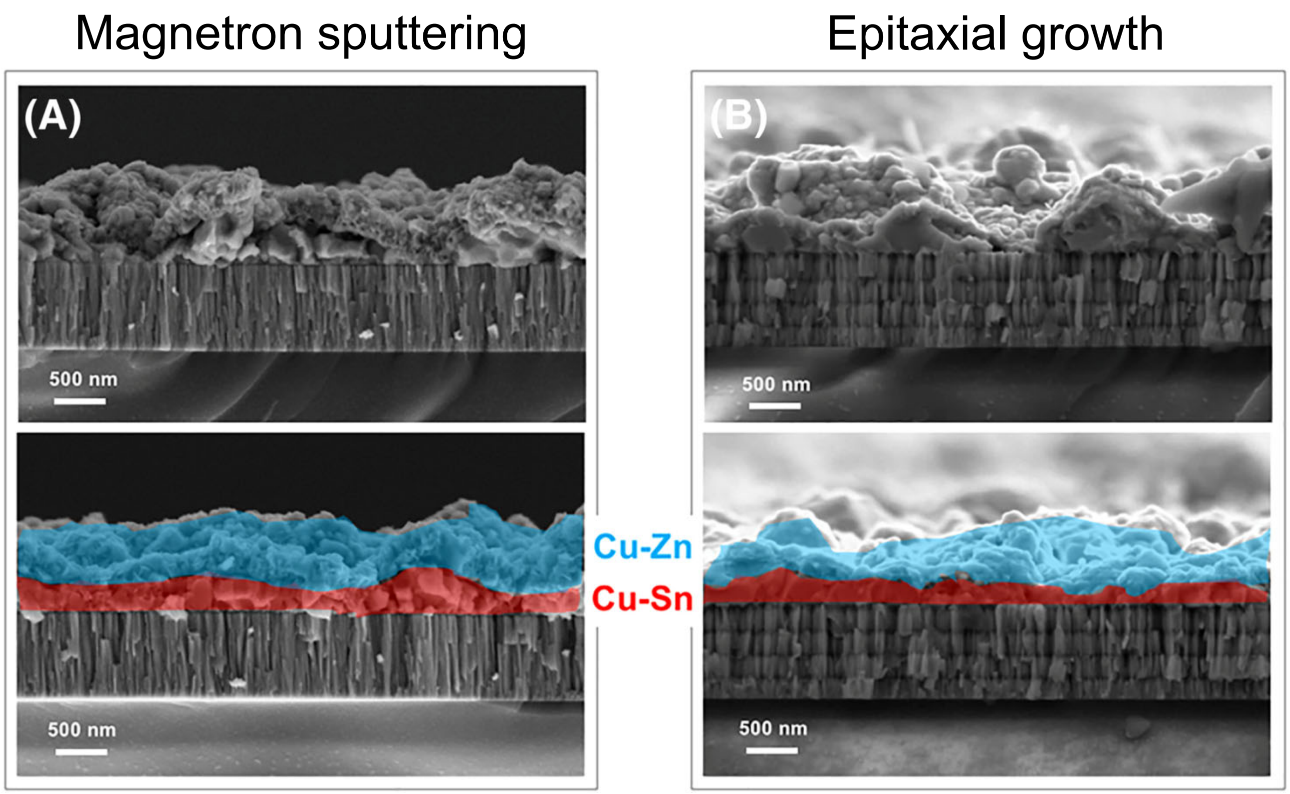
Metallic stack deposition



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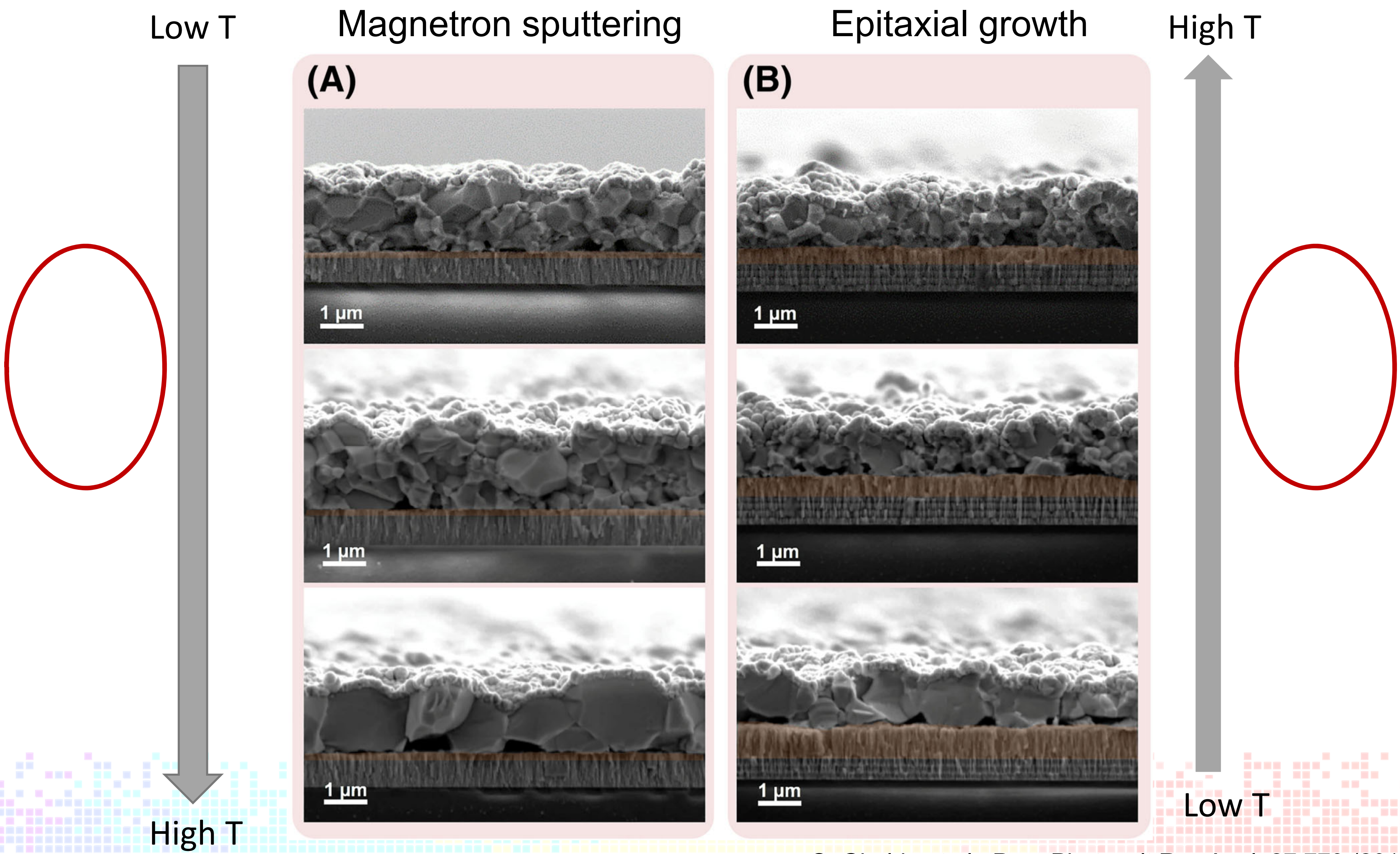
Kesterite solar cells engineering

Annealing under different temperatures

Q: How is the temperature changing?



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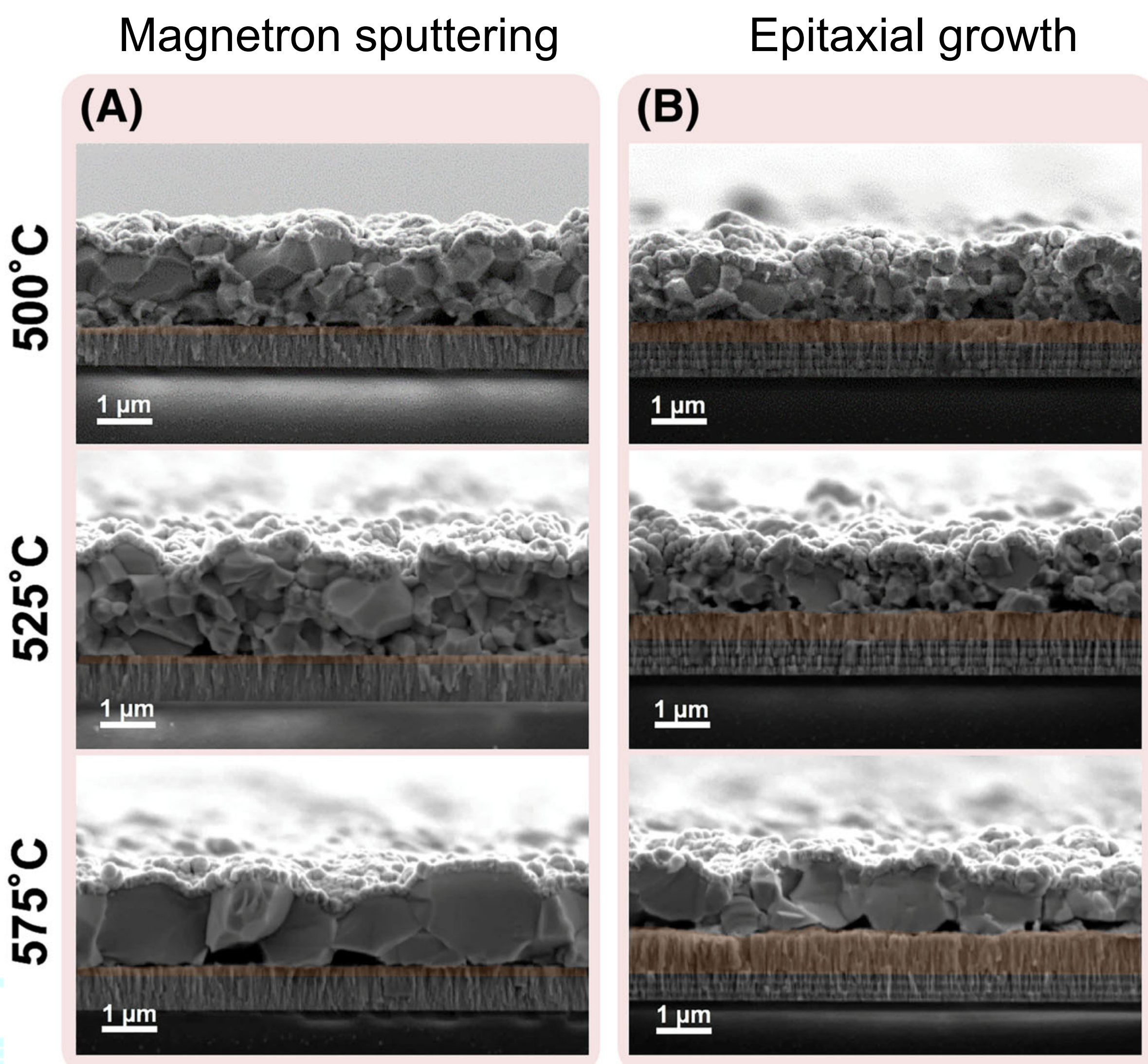
Annealing under different temperatures



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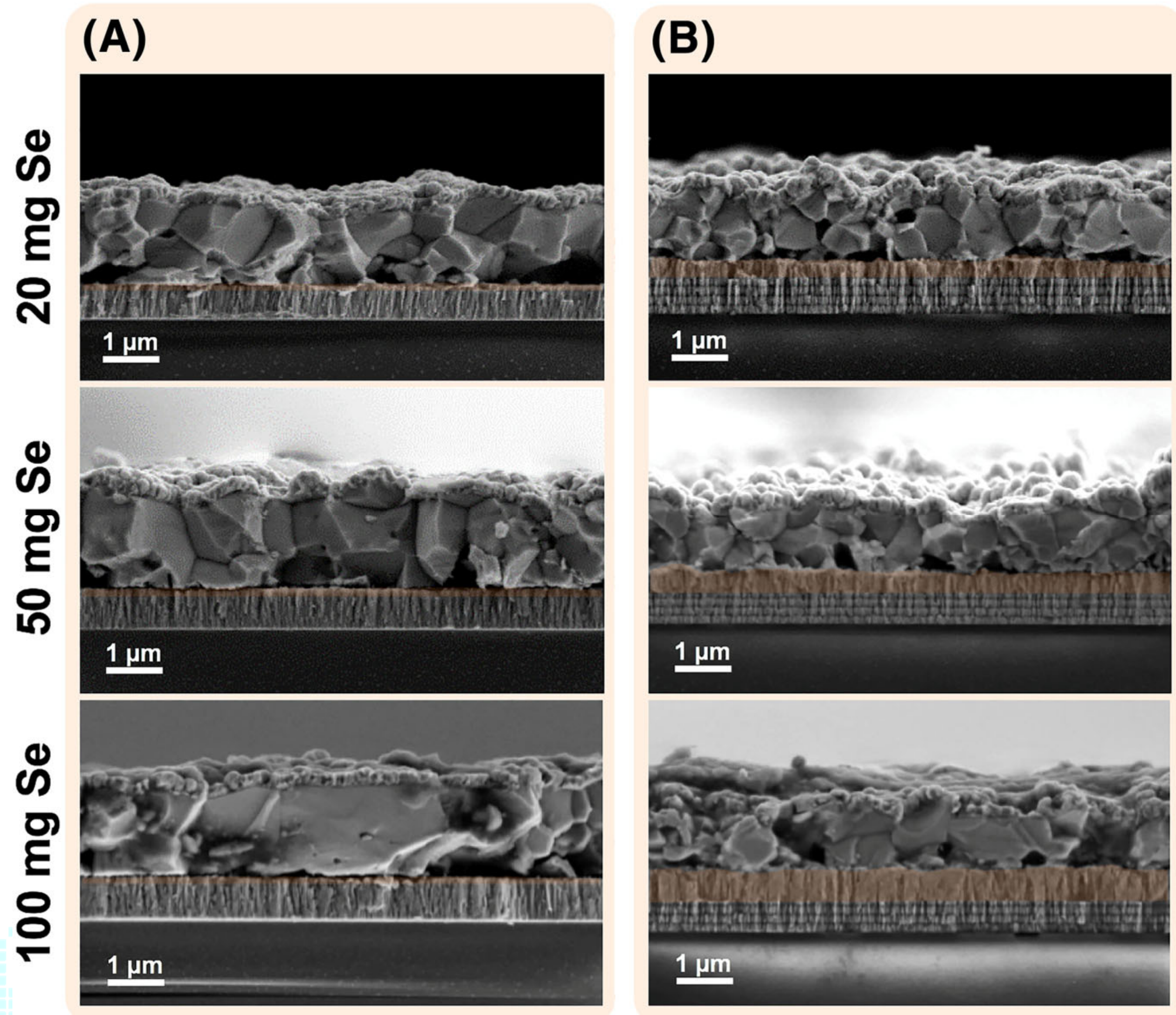
Annealing under with different amount of Se

Magnetron sputtering

Epitaxial growth



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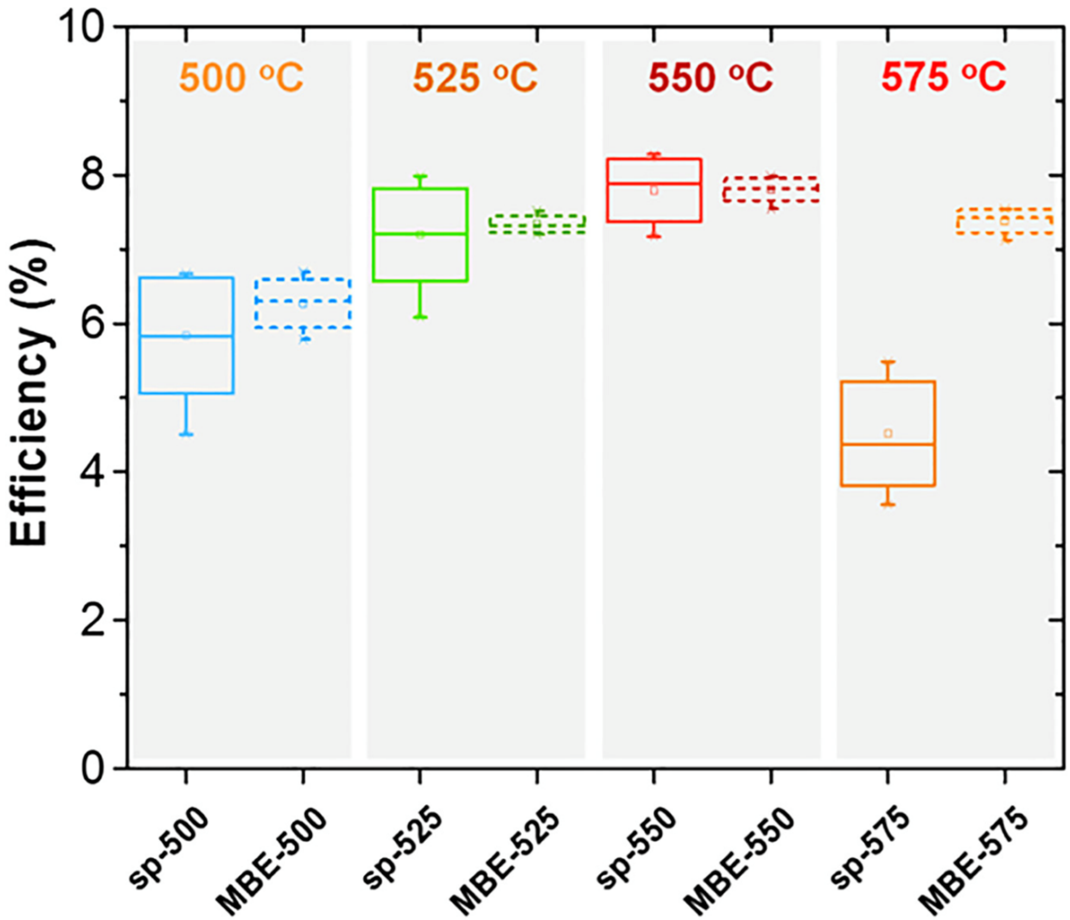
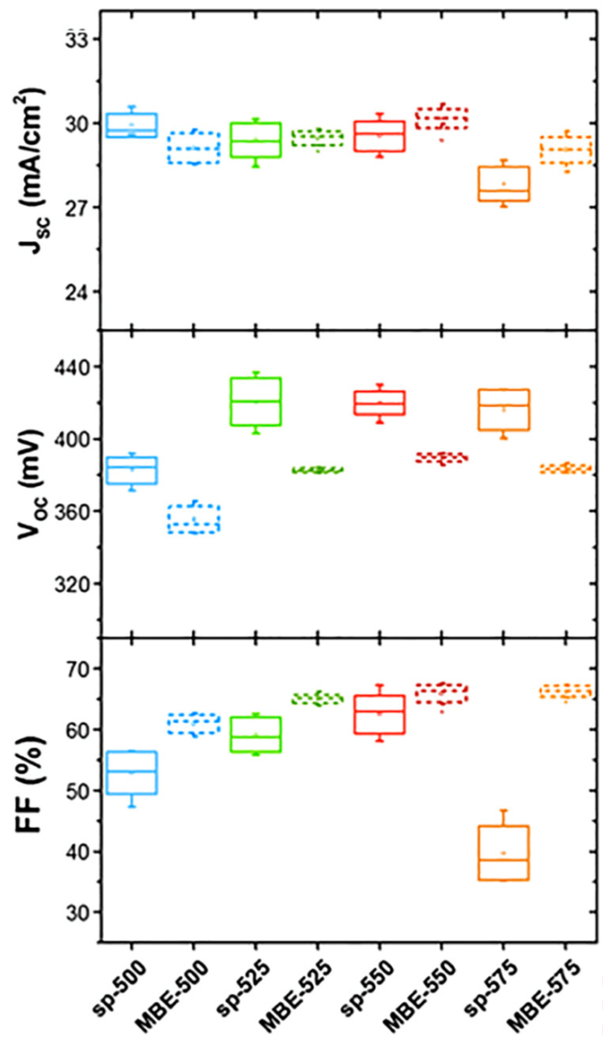
Kesterite solar cells: optoelectronic properties

Annealing under different temperatures

(full line) Magnetron sputtering (dotted line) Epitaxial growth





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Kesterite solar cells: optoelectronic properties

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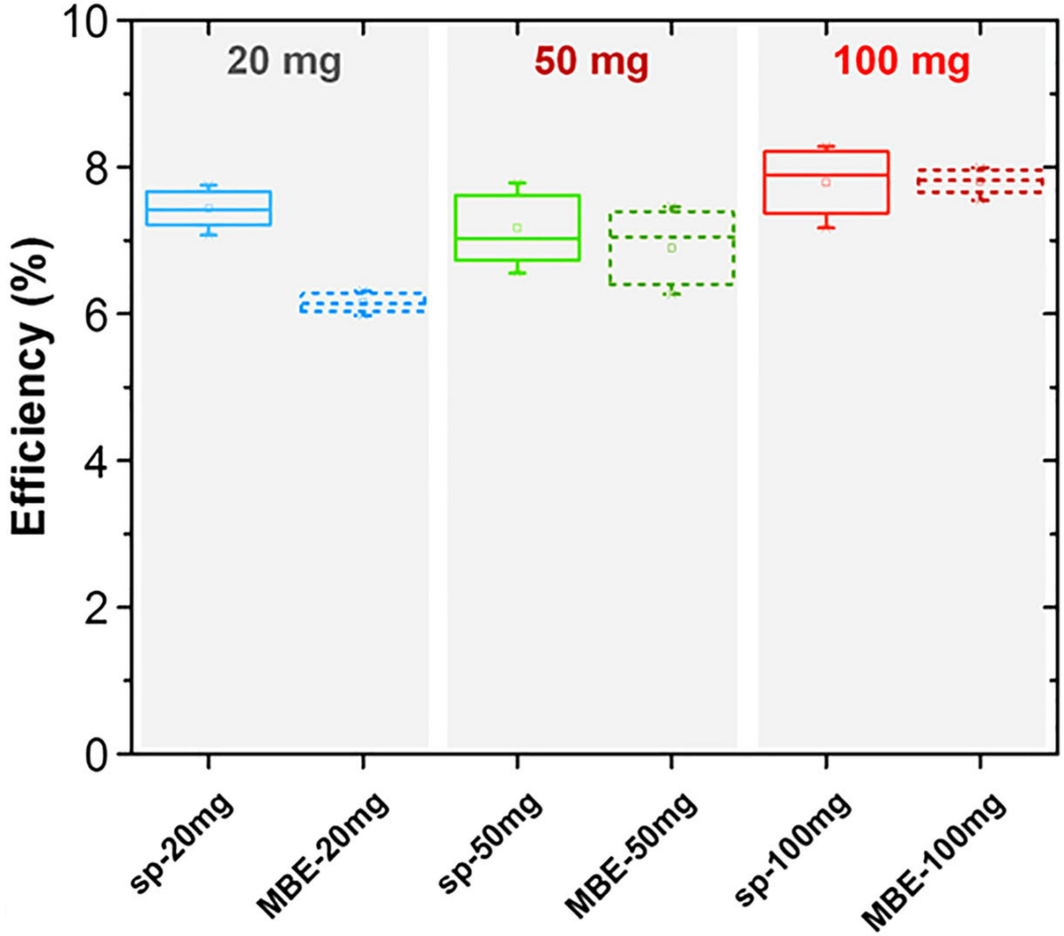
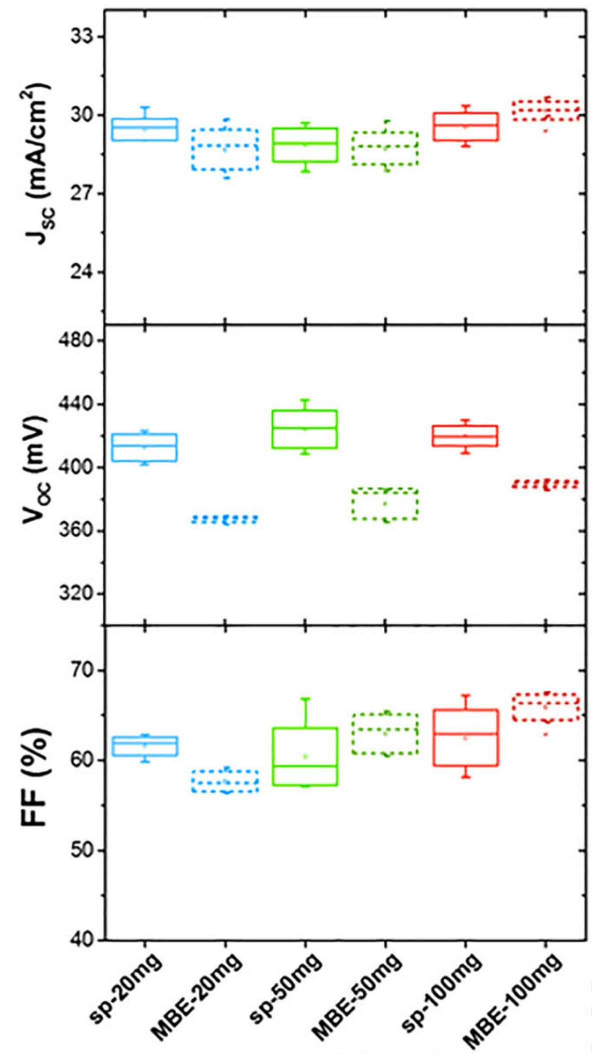
Annealing with different amount of Se

(full line) Magnetron sputtering (dotted line) Epitaxial growth





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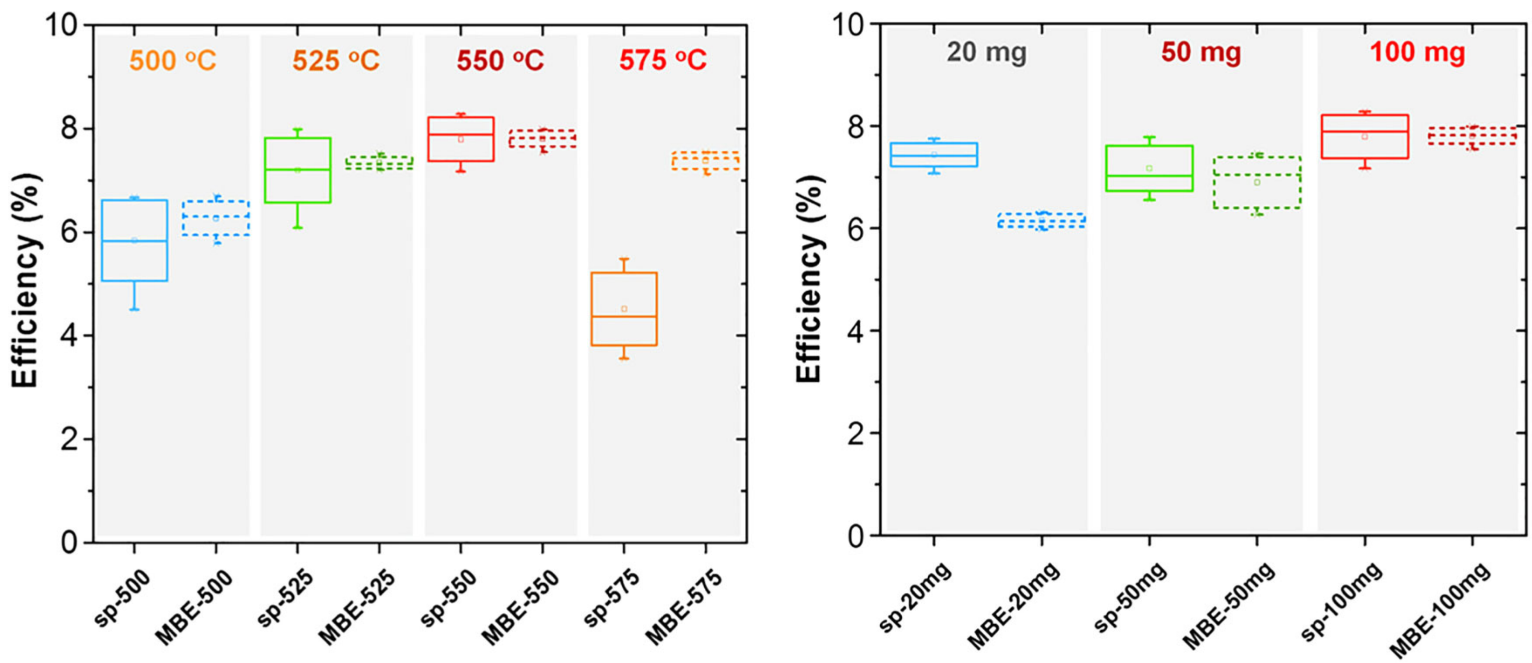
Kesterite solar cells: optoelectronic properties

Q: Which annealing conditions would you choose for the growth of the absorber for obtaining best performing solar cells?



T = 550 °C m (Se) = 100 g	T = 525 °C m (Se) = 50 g	T = 550 °C m (Se) = 50 g

(full line) Magnetron sputtering

(dotted line) Epitaxial growth

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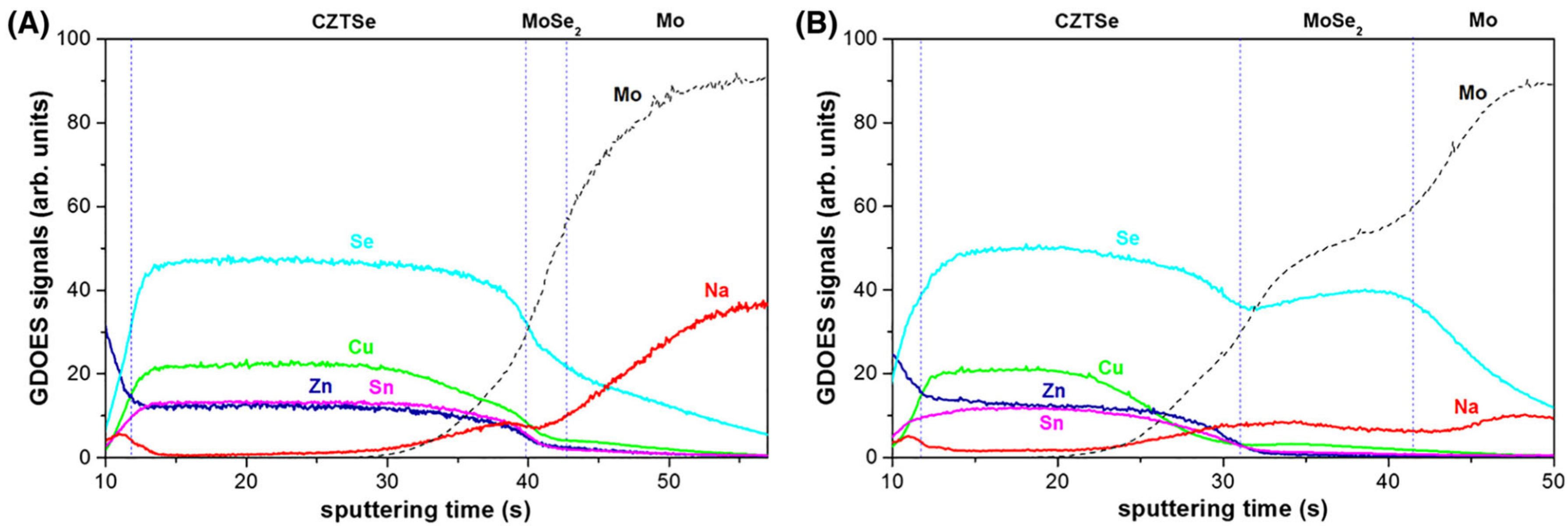
Kesterite solar cells: optoelectronic properties

Voc is always underperforming in case of epitaxial growth, related to substrate thickness?

Compositional profiling

Magnetron sputtering

Epitaxial growth



SL glass substrate (3 mm)

SL glass substrate (1mm)

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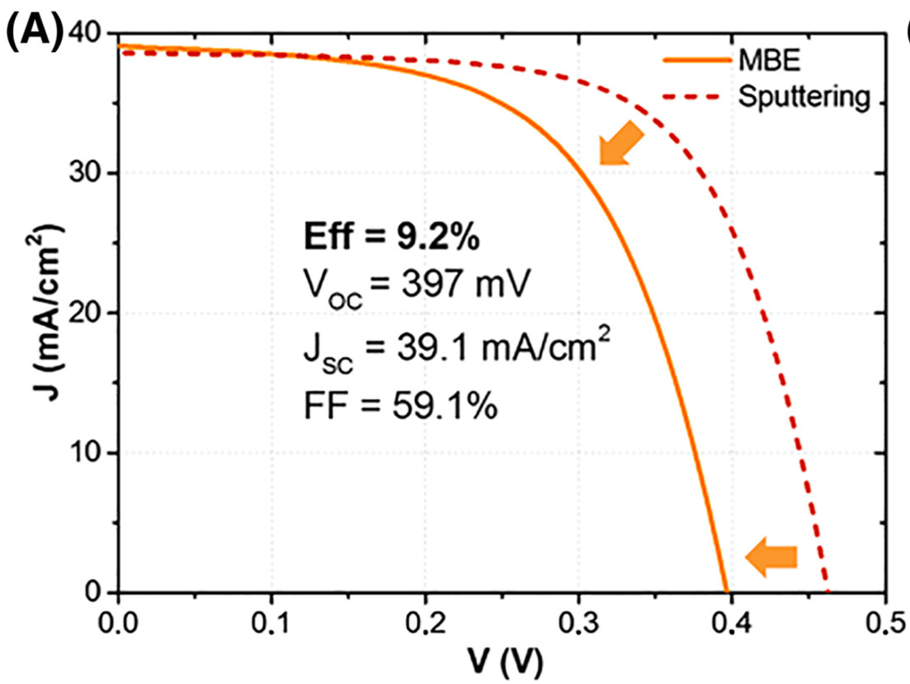
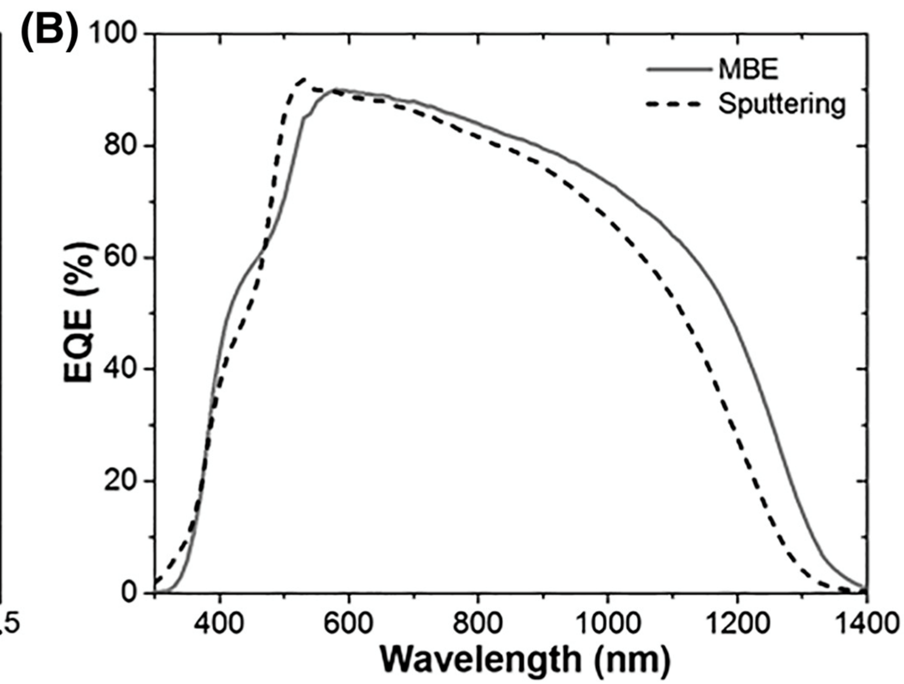
Champion solar cells





Epitaxial growth :
Did not improve the performance of solar cells, though there is still room for optimization.

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- The effect of epitaxial growth was investigated on two solar cell technologies : CIGS and kesterites
- CIGS technology is more suitable for epitaxial growth, leading to improved solar cell performance
- Kesterite based solar cell underperformed when grown with MBE in comparison to conventional methods (mostly due to the difference in alkali metal incorporation

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