Fabrication and Material Design of Next-Generation Solar Cells

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Outline

★Introduction

- Why New-Generation solar cells are needed ?

★Progress and Prospects of CIGS Solar Cells

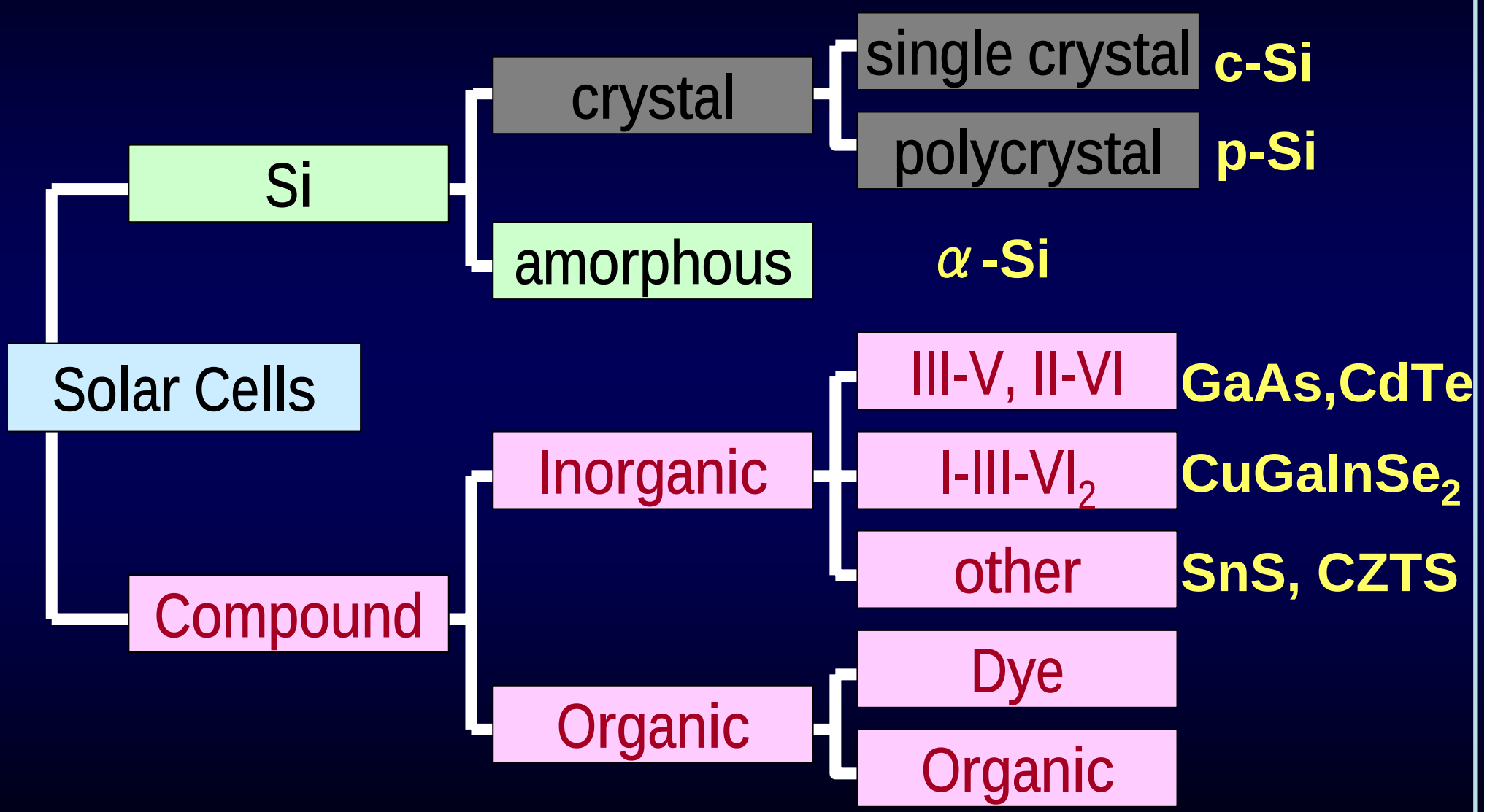
- Manufacturing Technologies

★Progress and Prospects of New Materials

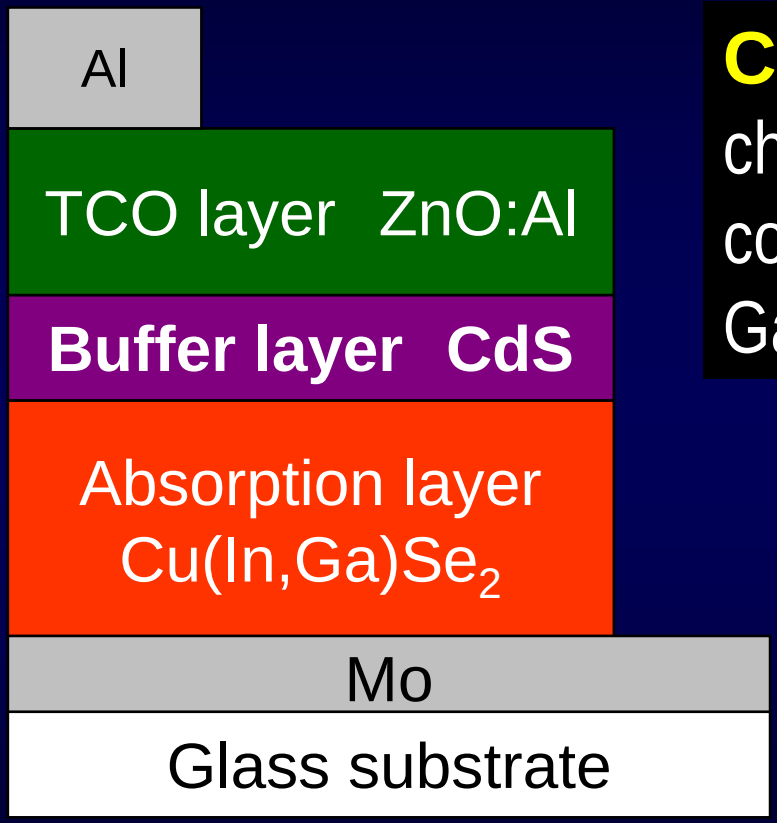
- Material Design of 3rd generation Solar Cells
- Material Design of Transparent Solar Cells

★Summary

Light absorbing materials



What is CIGS-related solar cell ?

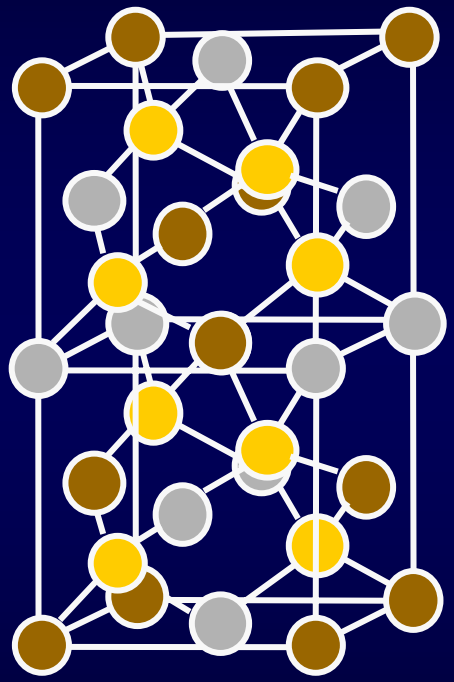


Typical structure of CIGS solar cell

CIGS:
chalcopyrite structured semiconductor composed of Copper (Cu), Indium (In), Gallium (Ga), and Selenium (Se).

CIGS-solar cells:
Thin film solar cell using CIGS layer as a light absorption layer.

Properties of CIGS Solar Cells



Chalcopyrite Structure

Group-I
Cu

Group-III
In
Ga

Group-VI
Se
S

★Highest efficiency
(among the thin film solar cells)

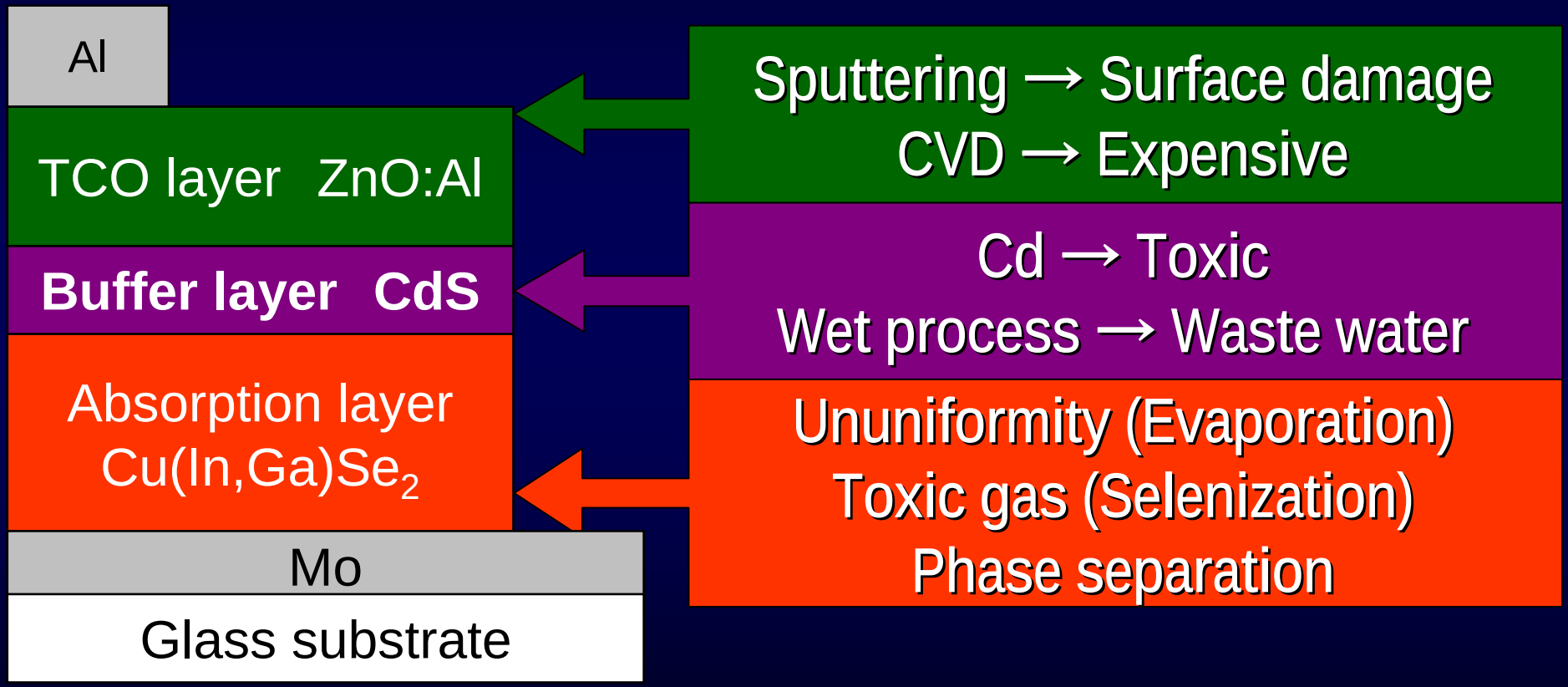
★High optical absorption coefficients

★Long life、radiation resistant

★Simple processes

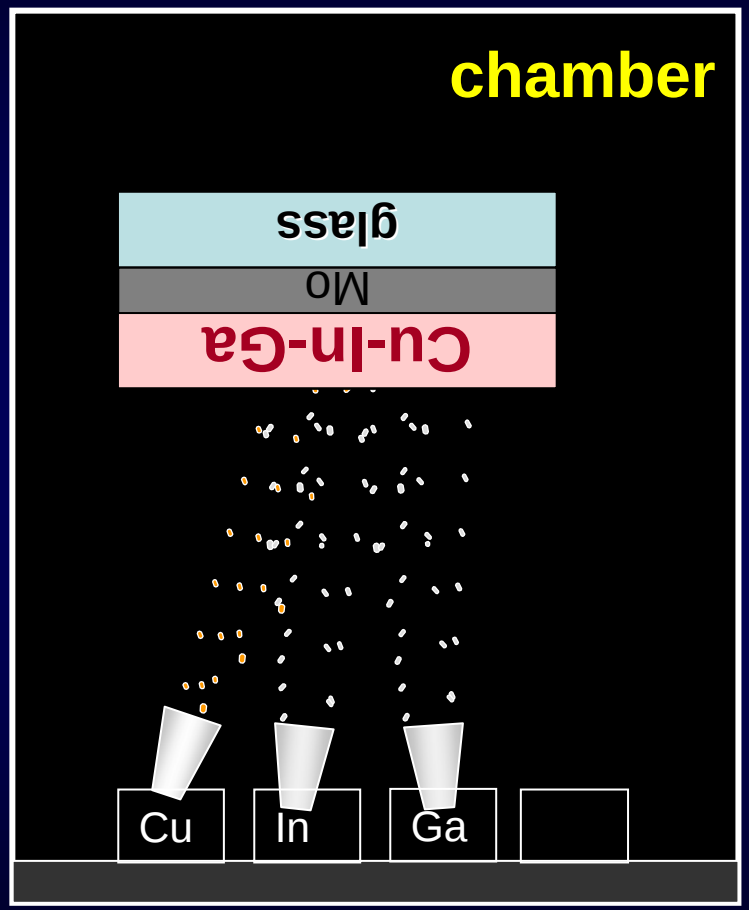
Rapid!, Cheap!, Good! Fabrication

Several problems of CIGS fabrication



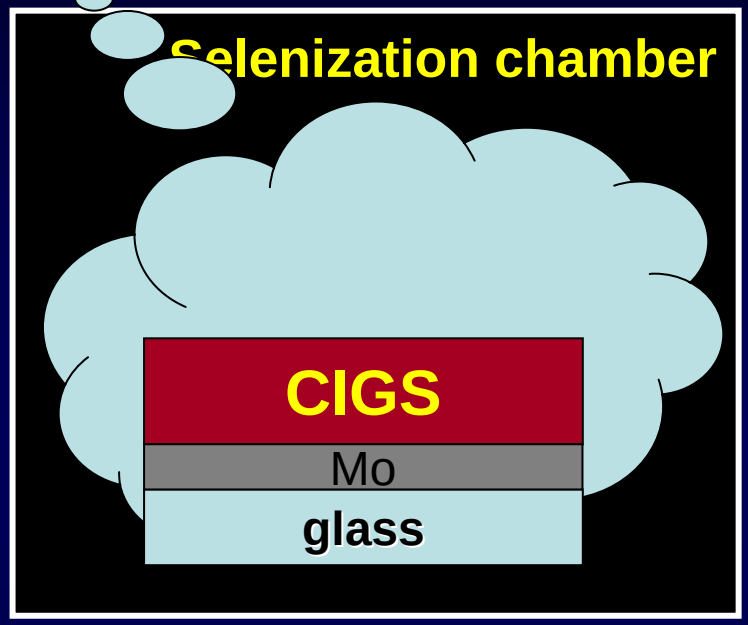
Typical structure of CIGS solar cell

Selenization method



Sputter, Printing,
Spin-Coating and so on

Se(Se vapor, H_2Se) etc.



○ Large area uniformity

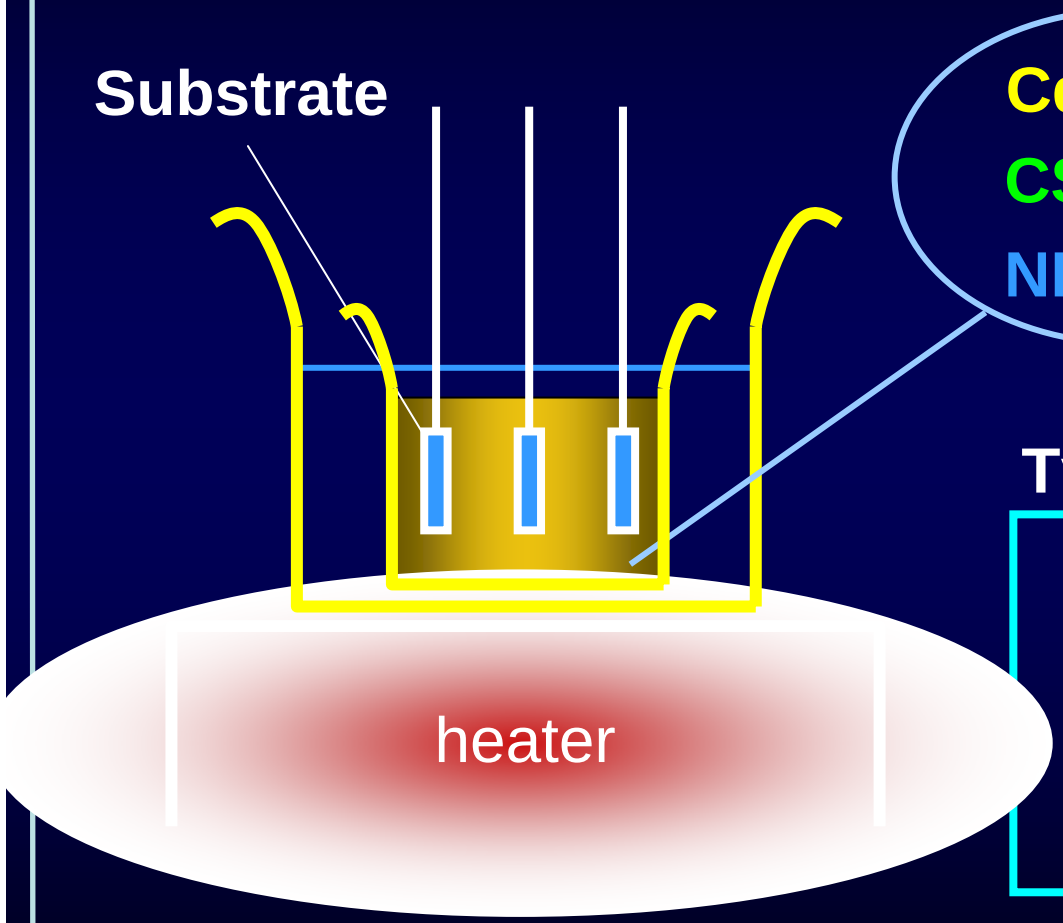
○ Simple equipments

× Phase separation between CIS and CGS

× Toxic gas (H_2Se)

CBD(chemical bath deposition) method

Fabrication of CdS buffer layer



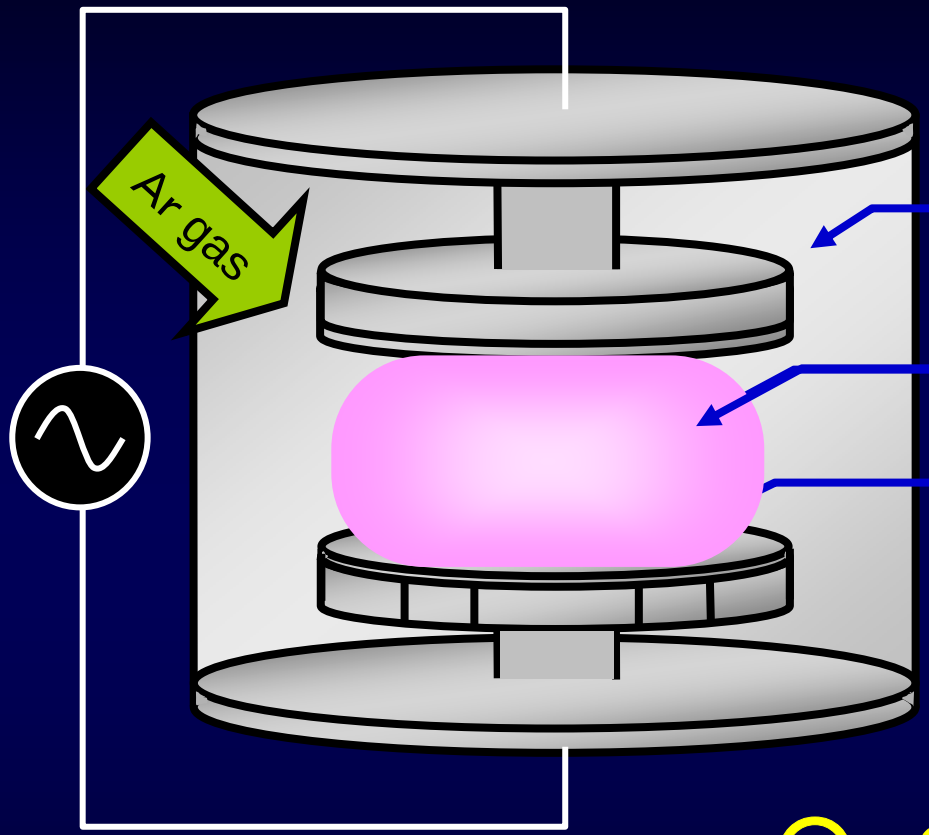
CdI_2
$CS(NH_2)_2$
NH_4OH

Typical condition

Growth temperature 70℃

CdI_2	0.001M
$CS(NH_2)_2$	0.05M
NH_4OH	1M

Sputtering method

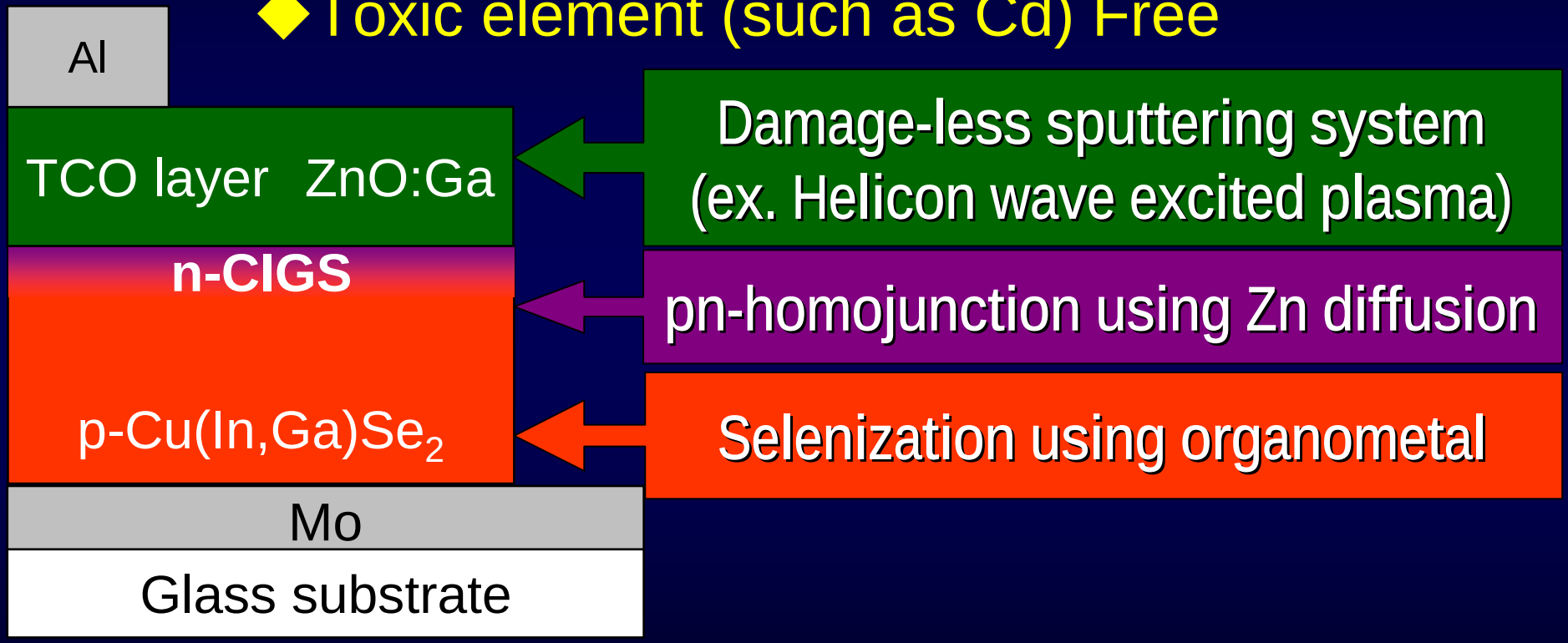


Fabrication of ZnO layer

- ○ Conventional technique
- ○ Not so expensive
- × plasma damage for cell

For the future …(in my case)

- All dry process
- Reduction of the number of the processes
- Toxic element (such as Cd) Free



Rapid!, Cheap!, Good! Fabrication

How to fabricate CIGS films

CIGS growth

Co-evaporation method

◎ η =19.5%(small cell)
△ Scaling up → Difficult

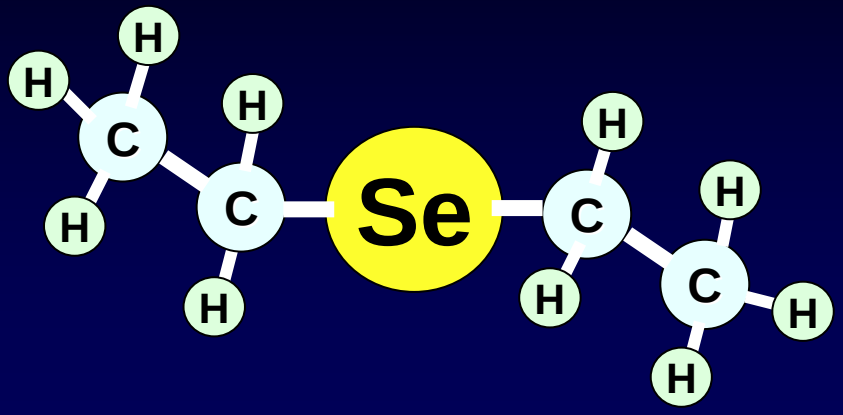
Selenization method

◎ Simple process
◎ Scaling up → Large cell

Se source for Selenization

H_2Se	Toxic, High pressure,….
Elemental Se	Low efficiency, …..
DESe	

Selenization using Diethylselenide (DESe)



Diethylselenide
(DESe)

Liquid at RT

Normal organometal

Safety

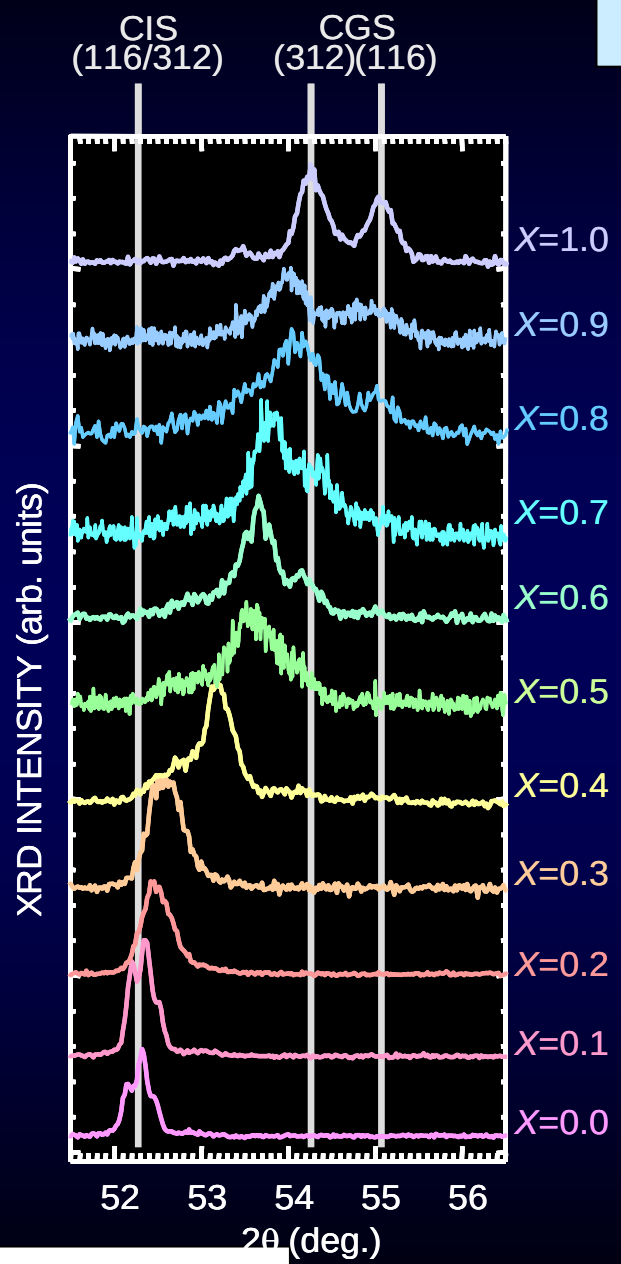
NOT so expensive

Easy to handle

CIS growth using DESe

- S.F.Chichibu *et al*. J.Cryst Growth, **243** (2002) 404.
- T.Yamamoto *et al*. J.Phys. & Chem. Solids, **64** (2003) 1855.

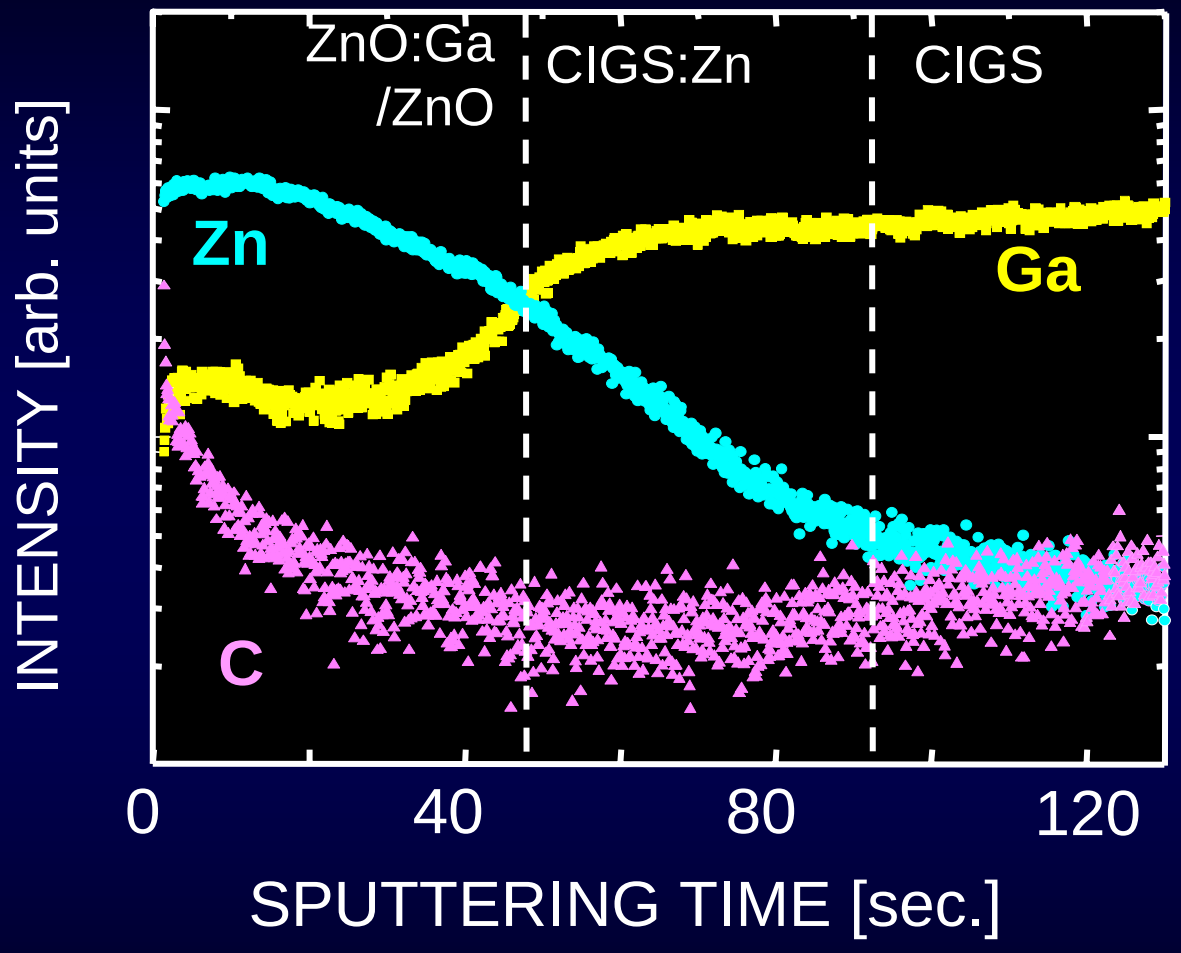
XRD pattern of CIGS films



- Simple EQIPMENT
- Simple PROCESS

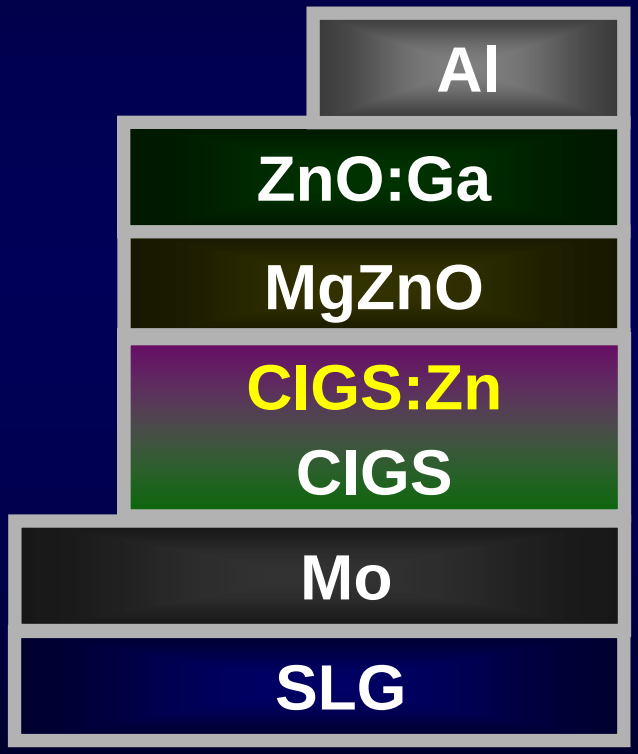
Highly advantageous for the development of low-cost solar modules

Depth profile of carbon in the cell



WITHOUT Carbon contamination!

CIGS solar cell structure



CBD-CdS

- ✕ *TOXIC element (Cd)*
- ✕ *Fabricated by WET PROCESS*

pn-homojunction (by Zn-doping)

- ○ *AVOID carrier recombination at the physical interface*
- ○ *Fabricated by DRY PROCESS*
- ○ *SAFE element（Zn, Cu, In etc.)*

Experiment

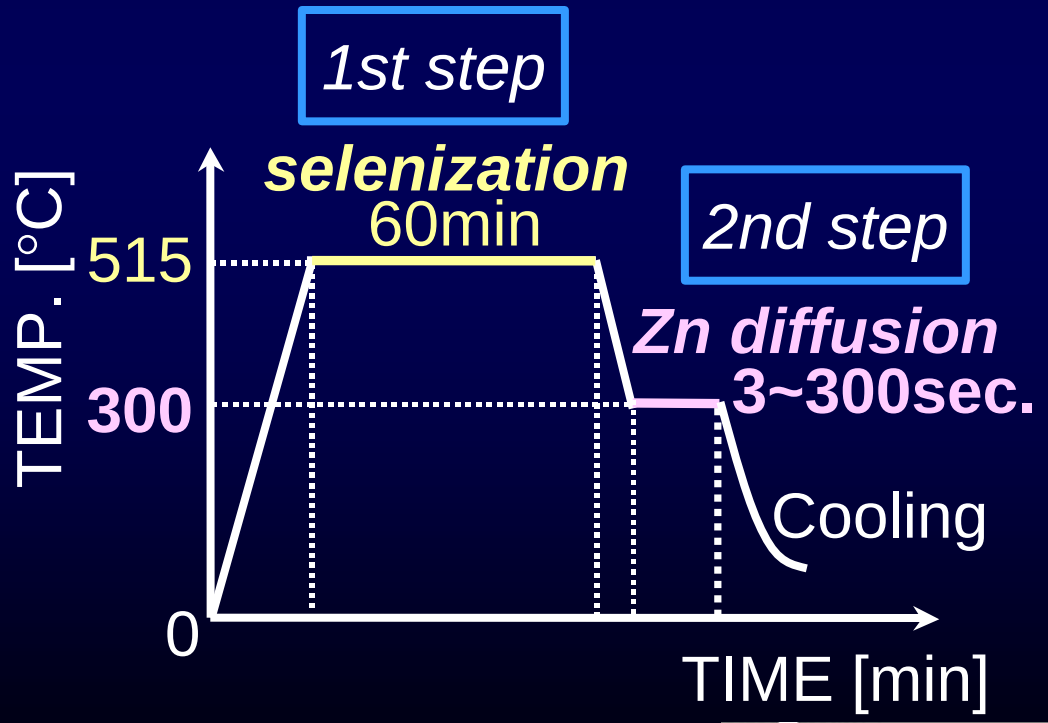
1st step
preparation of ***CIGS films***

[∗] Thin Solid Films 515 (2007) 5867.

Selenization method using ***Diethylselenide*** [∗]
or
3 stage method

2nd step
Zn-diffusion

@Atmospheric pressure
Dimethylzinc : 60μmol/min
[$(CH_3)_2Zn$: DMZn]
+ N_2 carrier gases: 2L/min



Experiment

3rd step
Fabrication of solar cells
ZnO:Ga/MgZnO/CIGS:Zn

Deposition by ***helicon-wave-excited-plasma sputtering (HWPS) method***

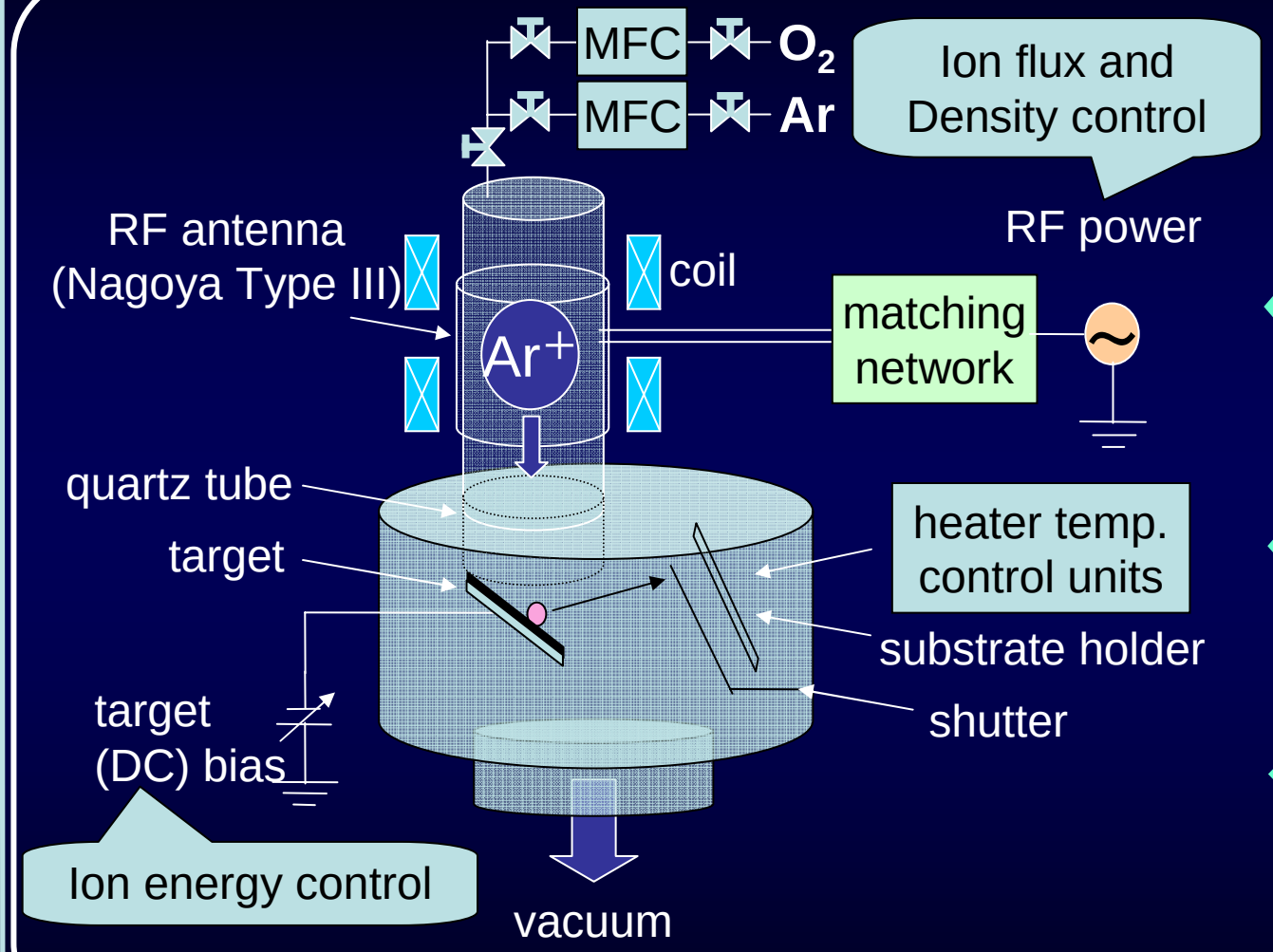
Appl. Phys. Lett. **72** (1998) 235.
We reported yesterday.

Characterization

Zn doped CIGS films*: XRD, GDOES, PL, I-V, C-V*

Zn doped CIGS cells*: I-V*

Helicon-Wave-Excited-Plasma Sputtering (HWPS) Method



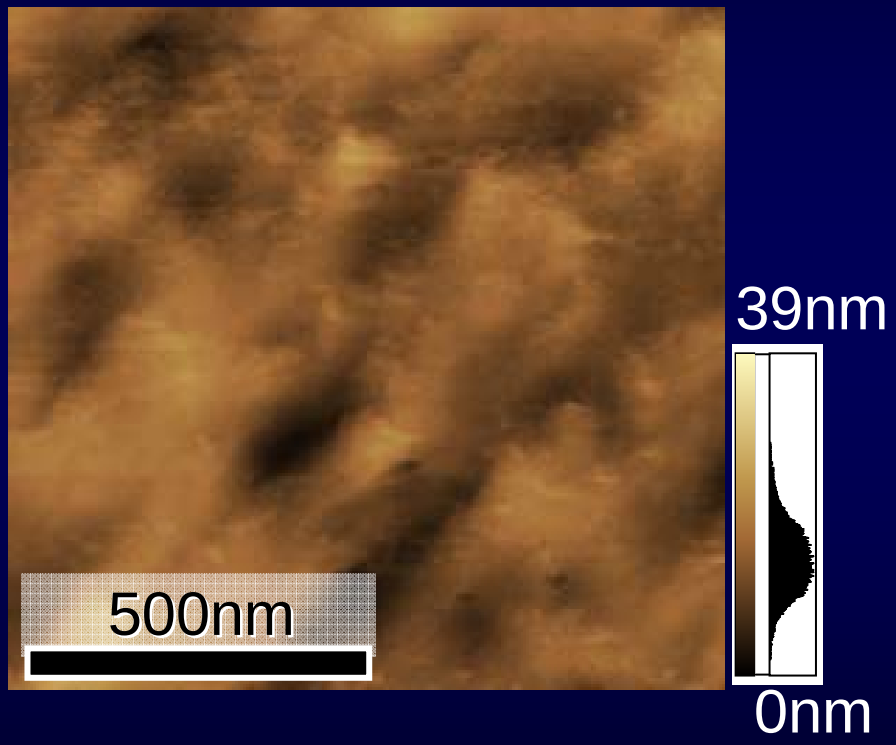
- Remote plasma
  Low damage on surface
- Independent control
  of ion flux and energy
- Low pressure
  Long mean free path

Appl. Phys. Lett. **72** (1998) 235.

Surface Morphology of ZnO:Ga

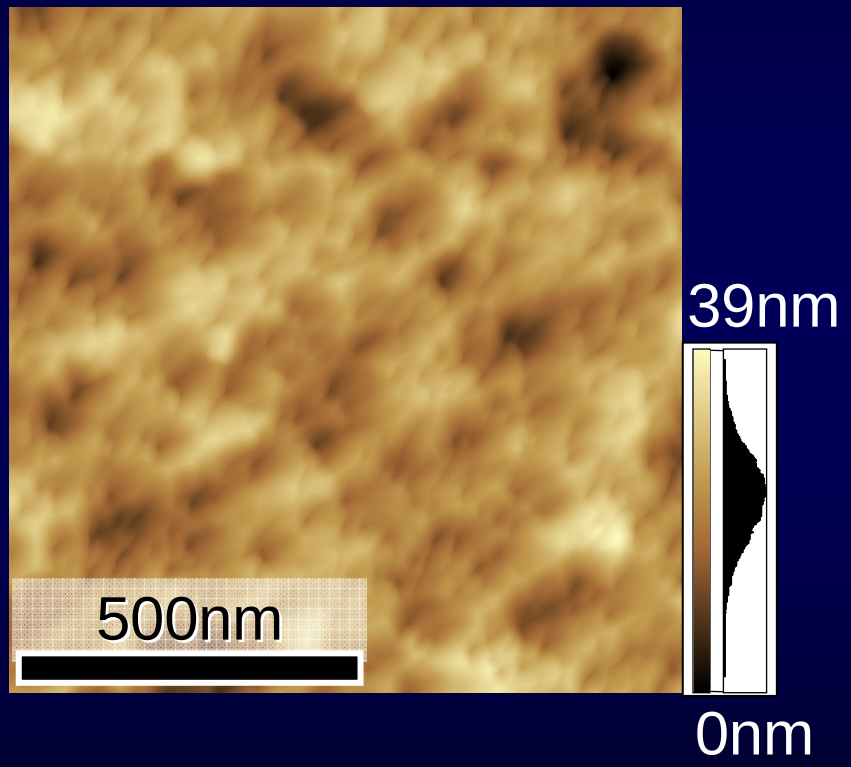
AFM images

200℃, 1.5 wt.%



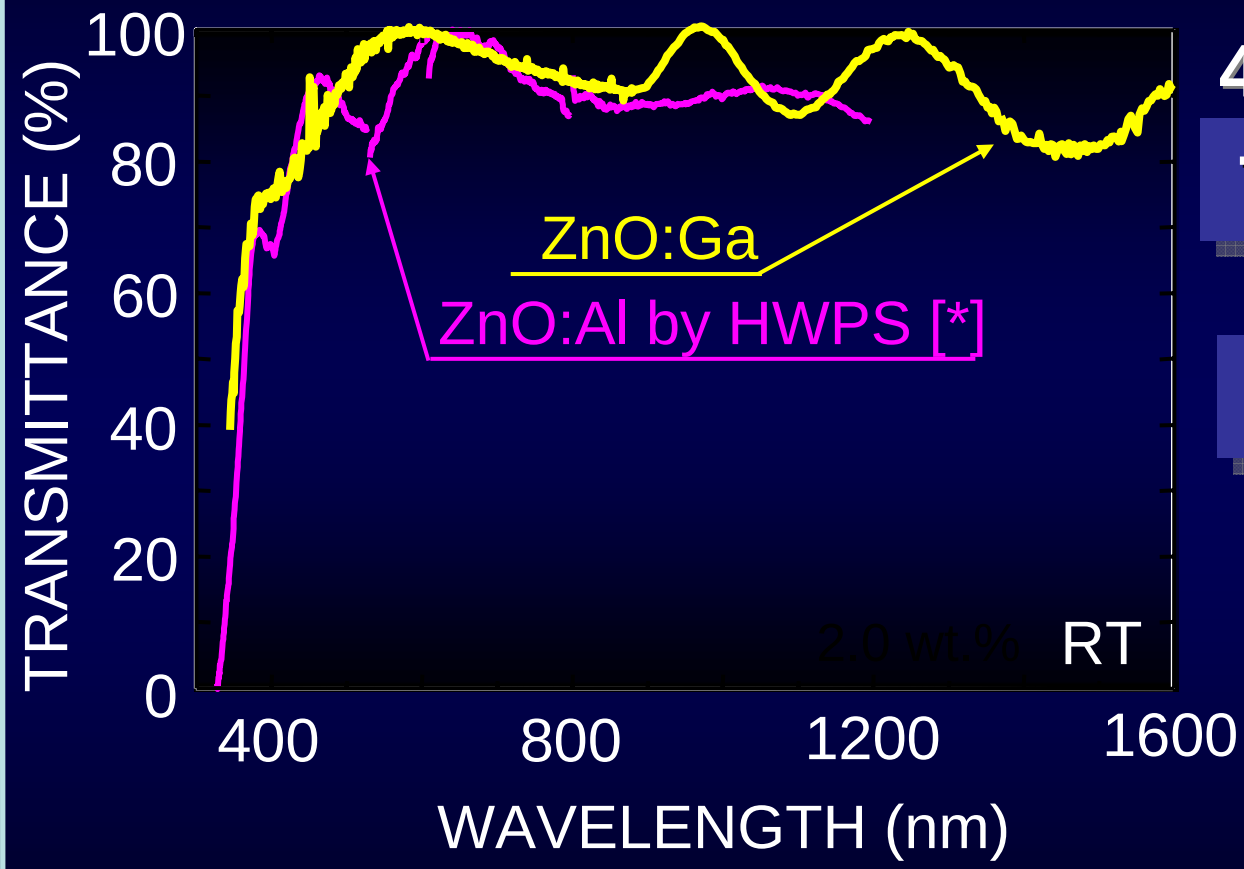
RMS = 4 nm

400℃, 1.5 wt.%



RMS = 5 nm

Optical Transmittance Spectrum



400–1600 nm

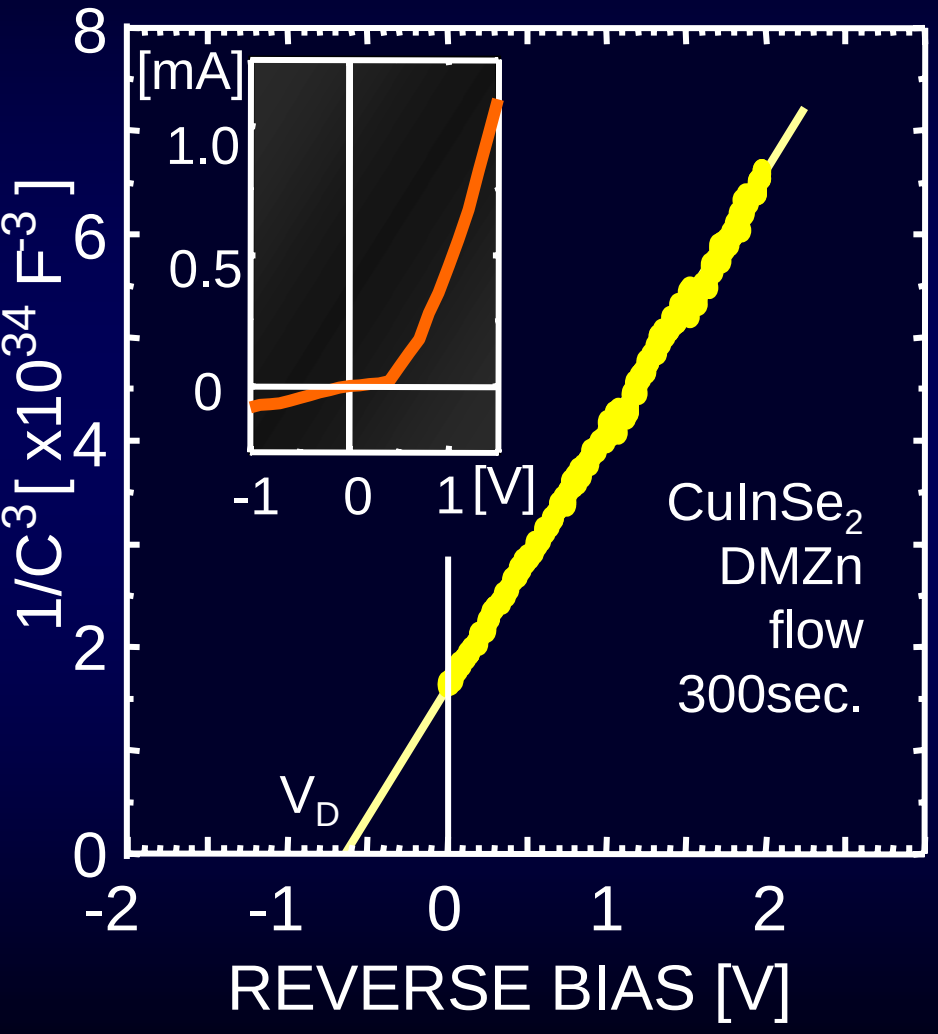
Transmittance ≥ 80%

Multiple interference

Smooth surface

[*] Appl. Phys. Lett. **72** (1998) 235.

1/C³-V curves of the Zn-diffused CIS/Mo/SLG



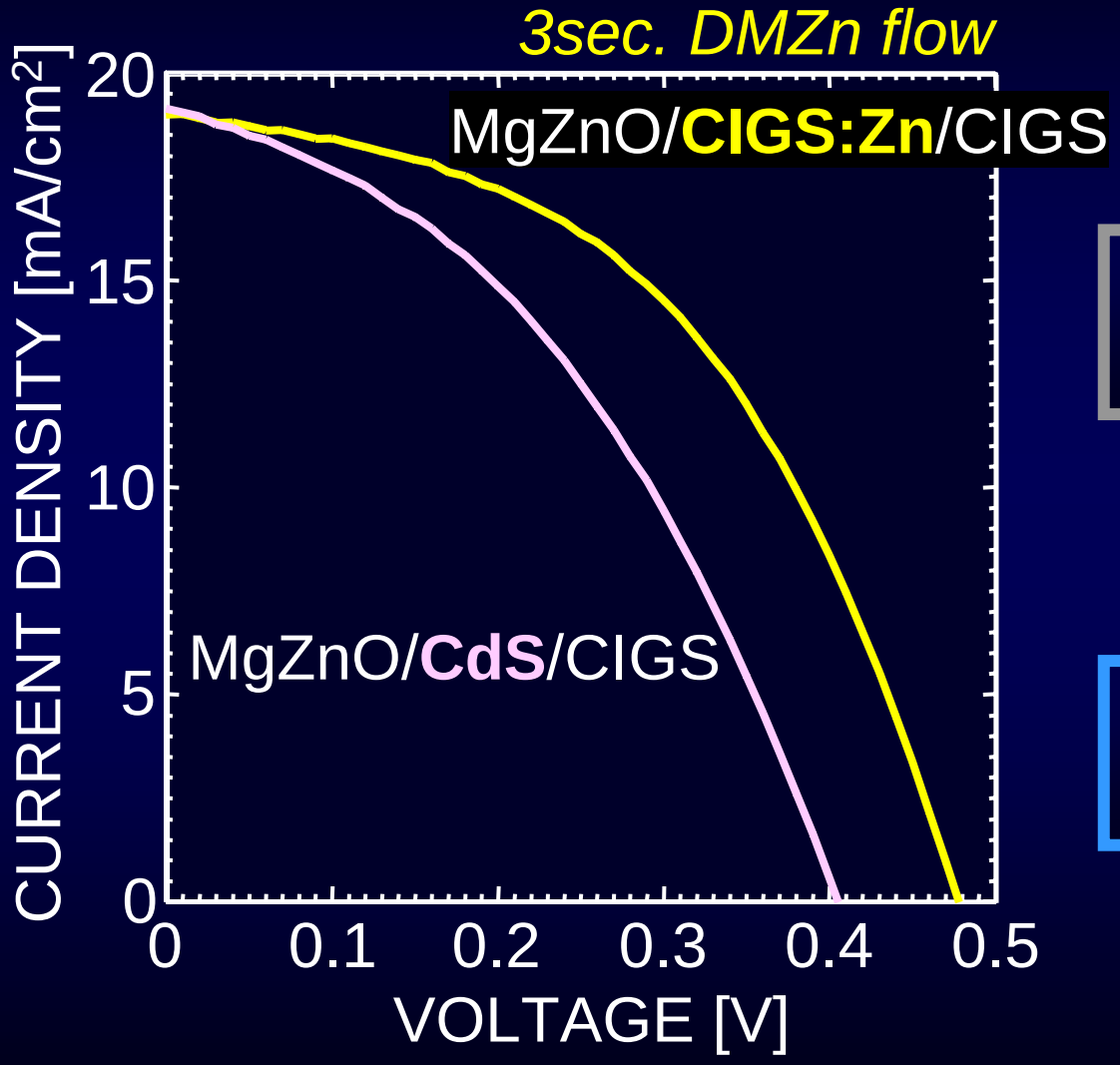
- *Surfaces of the films* → ***n-type***
- *I-V* → ***rectification property***

values of 1/C³ change linearly

linearly graded junction

pn-homojunction fabricated by thermal diffusion

Impact of introducing Zn-diffusion



By 3 sec. DMZn flow instead of CBD-CdS

Voc is improved approximately by 20 %

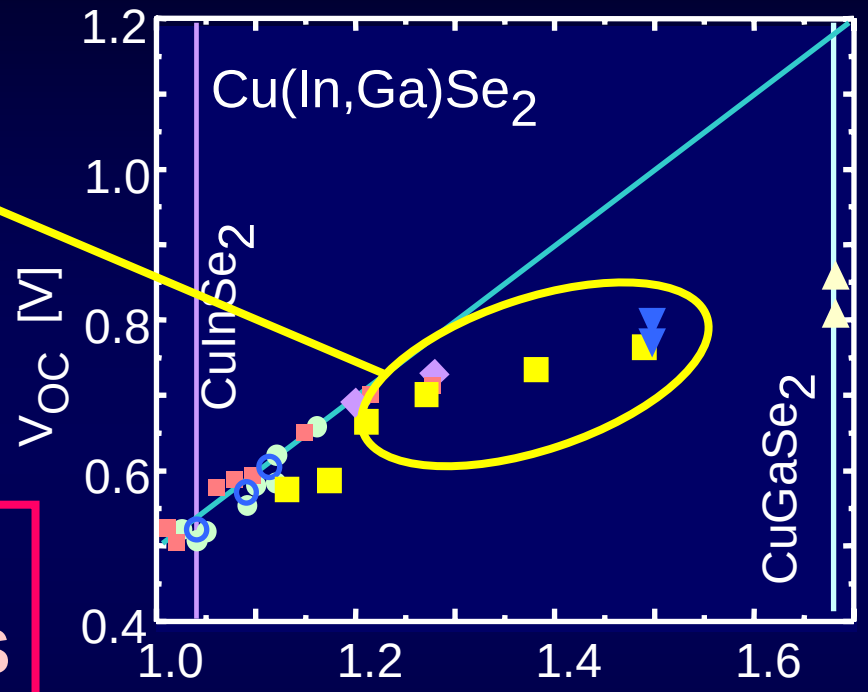
Issues of CIGS growth

at Eg>1.2eV

Crystal quality ↓
Device performance ↓

Due to the difference in the reaction rates of the CIS and CGS

Cu(In,Al)Se_2 (CIAS)



R. Herberholz et al. Sol. Energy Mater. Sol. Cells **49** (1997) 227.

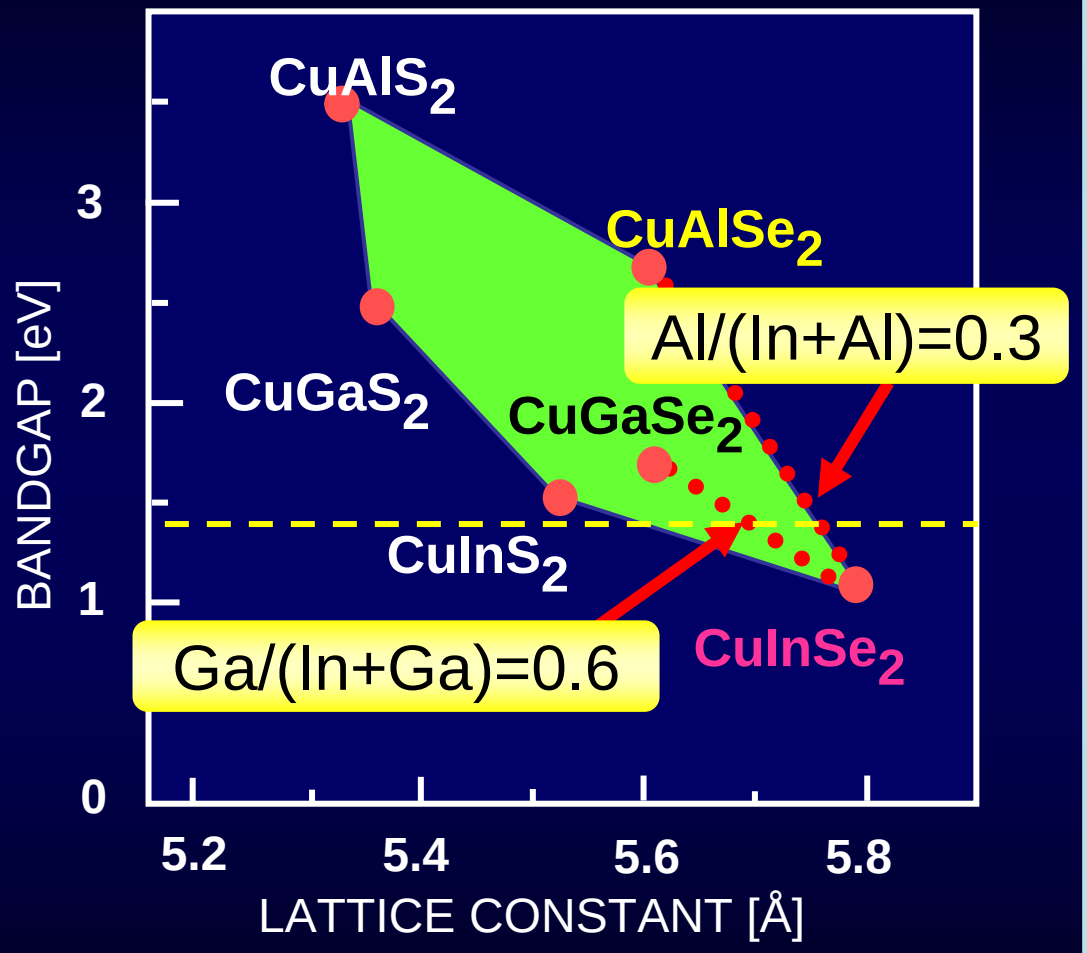
Issues of $Cu(In,Al)Se_2$ growth

Eg of CIAS
1.0～2.7eV
(CIS) (CAS)

CIAS

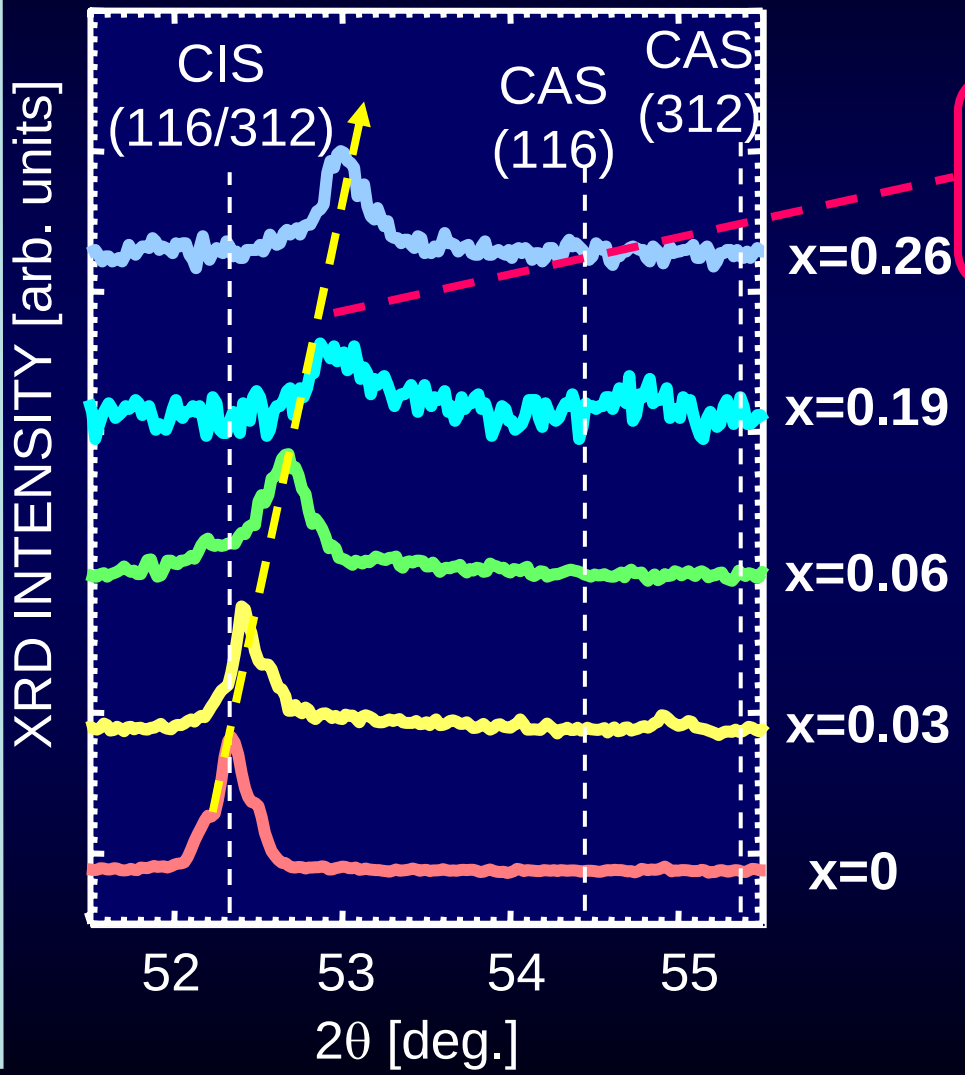
Ideal Eg 1.4eV

Ga/(In+Ga) ＞ Al/(In+Al)



Hopefully phase separation **less** **likely than CIGS films**

XRD patterns of CIAS as a function of x



the decrease in lattice parameter with the increase in **x**

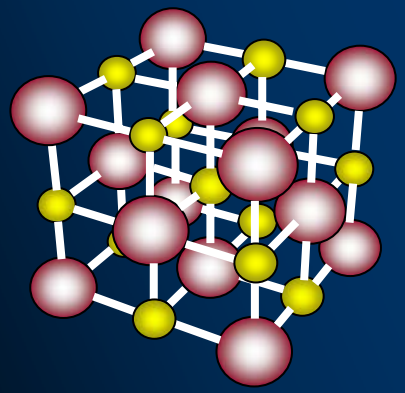
distinct peaks corresponding to CIS CAS or any combination of the two phases were not observed

Material Design for 3rd generation solar cell

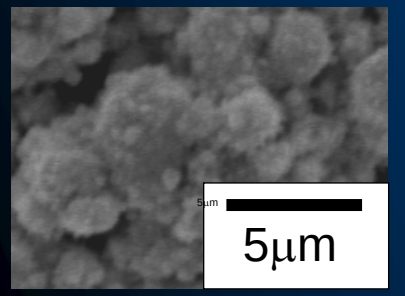
Tin Sulfide (SnS)

- direct gap : 1.3eV indirect gap : 1.1eV
  $\alpha \cong 10^5\ cm^{-1}$ [1]
- SAFE and CHEAP elements（Sn, S)
  Clarke numbers of the order of 31 and 15

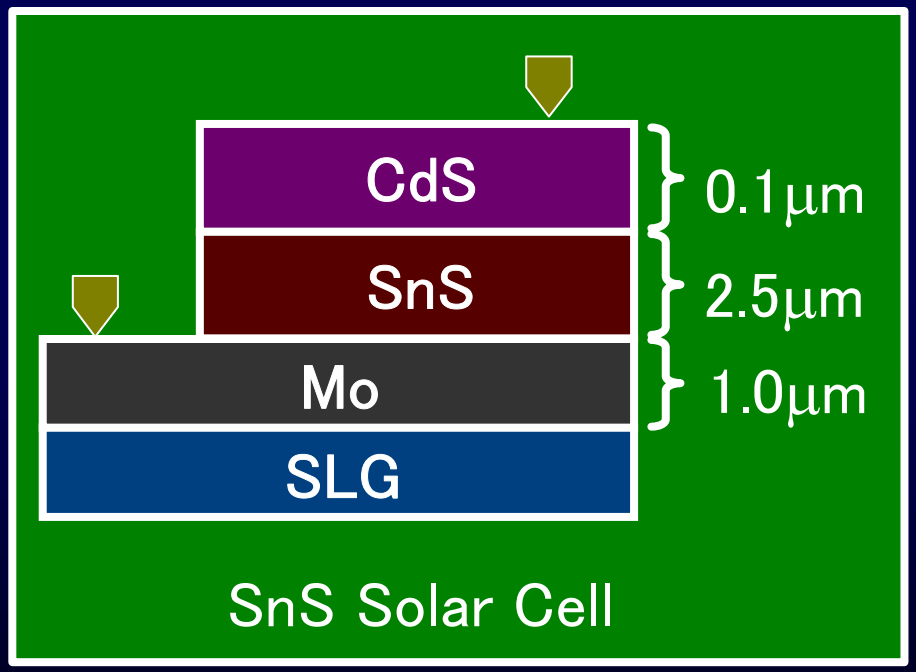
A promising candidate as a light-absorbing medium for next generation solar cells

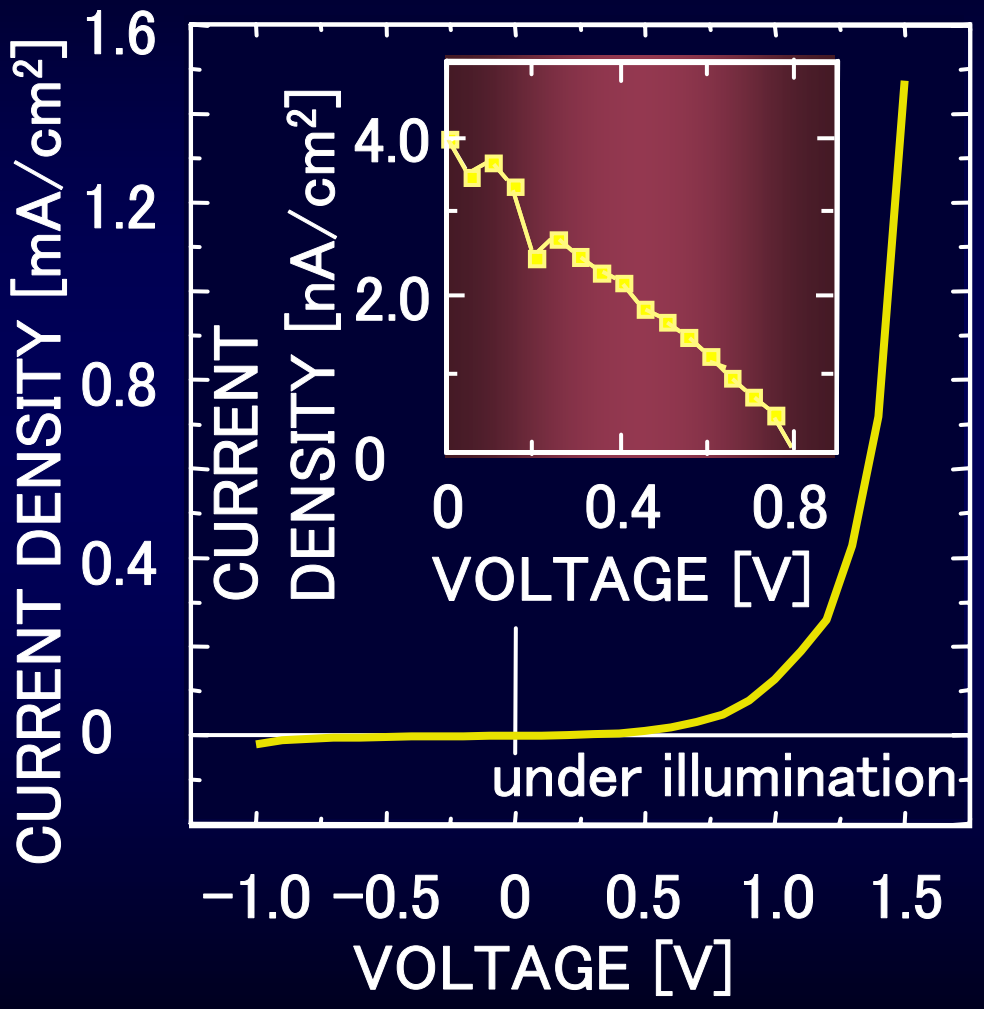


Orthorhombic structure



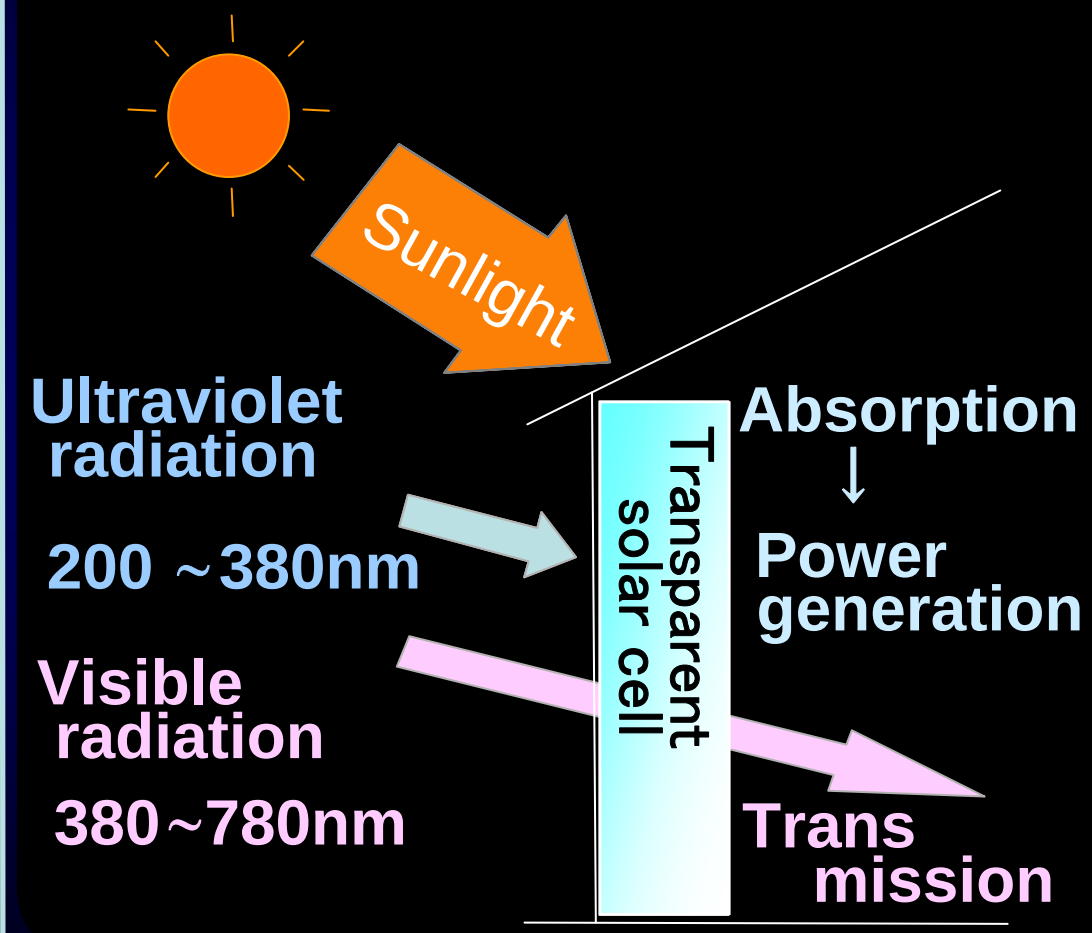
Fabrication of SnS Solar Cell





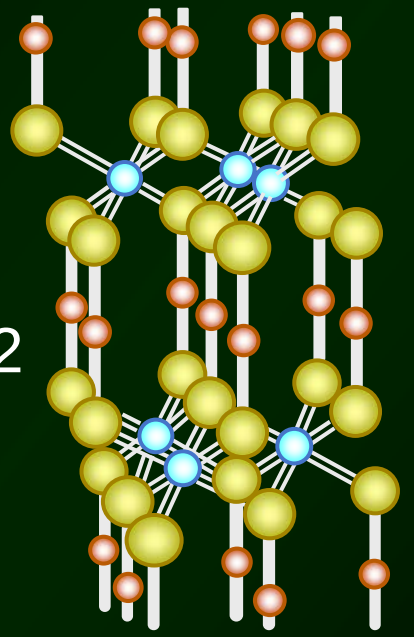
Material design for transparent solar cells

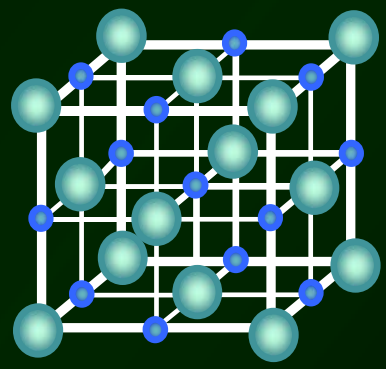
Ex: Transparent solar cell



Main *p*-type TCO

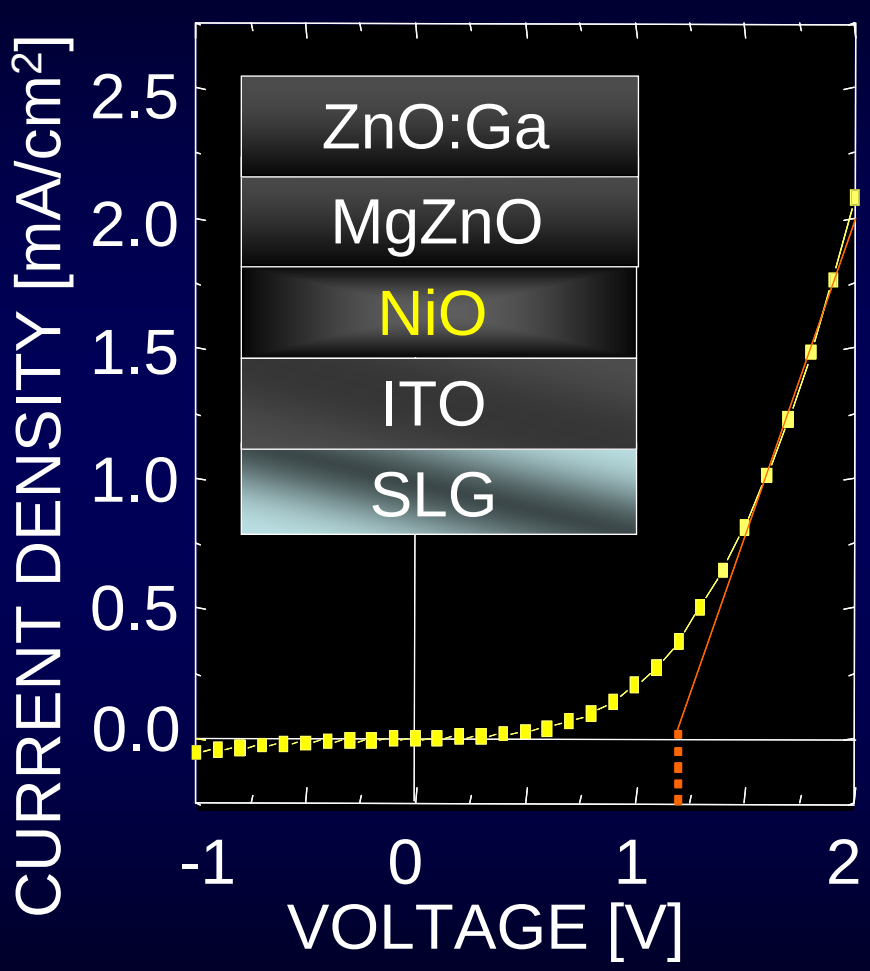
$CuAlO_2$
$CuGaO_2$
$CuInO_2$

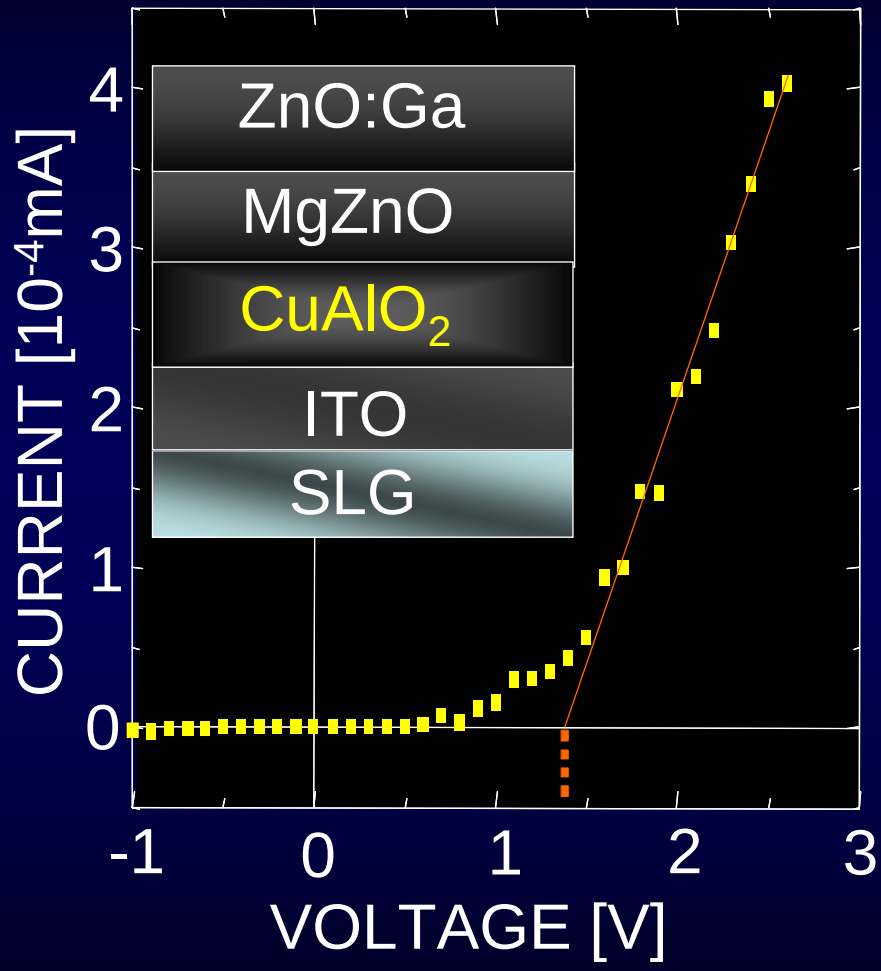




NiO

Transparent pn Diodes for Solar Cell





Summary

Progress and Prospects of
Next-Generation Solar Cells

- Simple and high efficiency solar cells
- Variety of fabrication technique
- Variety of Material

Rapid!, Cheap!, Good! Fabrication