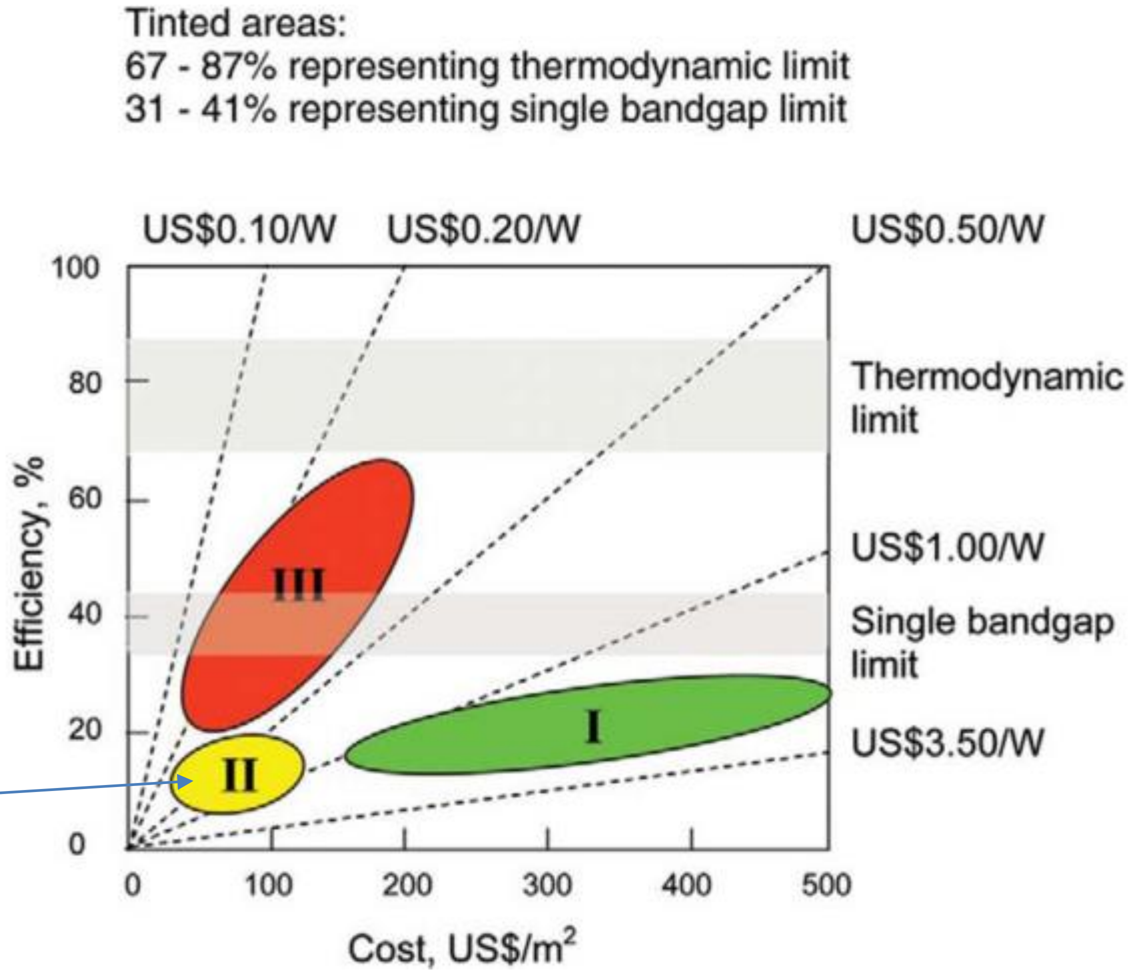
Presentation on: Photoluminescence study of the defect-induced recombination in Cu(In,Ga)Se_2 solar cell

Collin Brown

Condensed Matter Journal Club

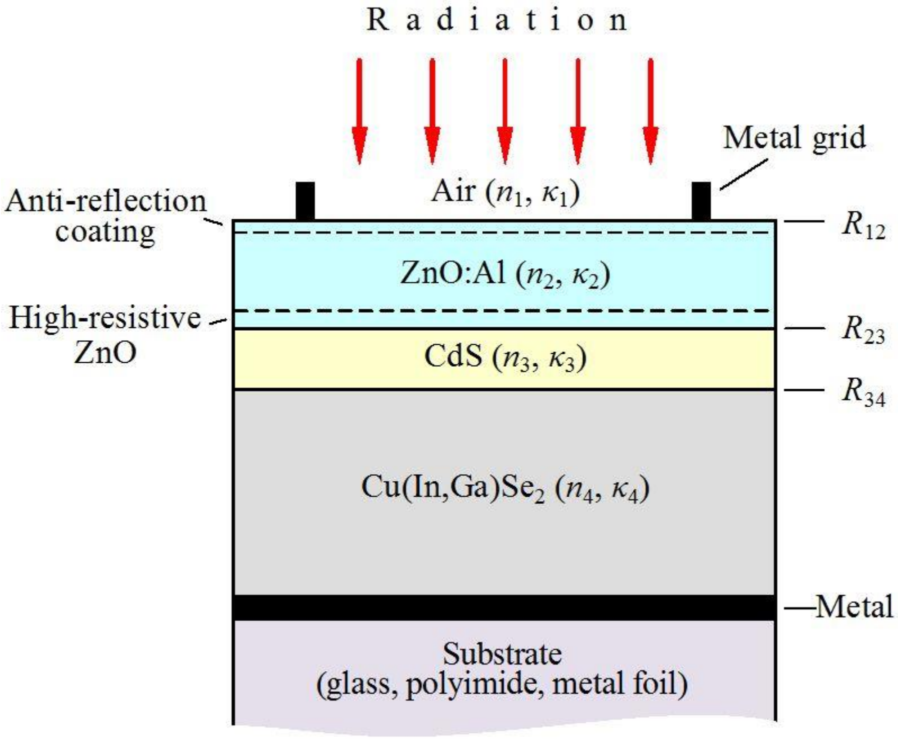
February 14th, 2017

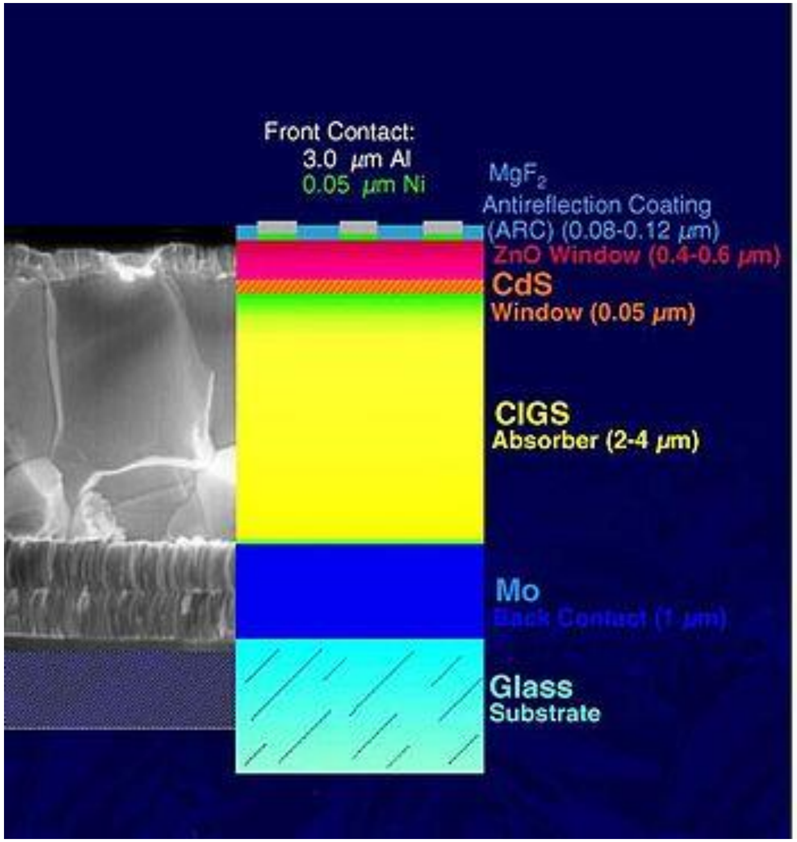


CIGS

G. Conibeer, 2007 Third-generation photovoltaics Material Today 10 11 44 50

$Cu(In,Ga)Se_2$ Solar Cells

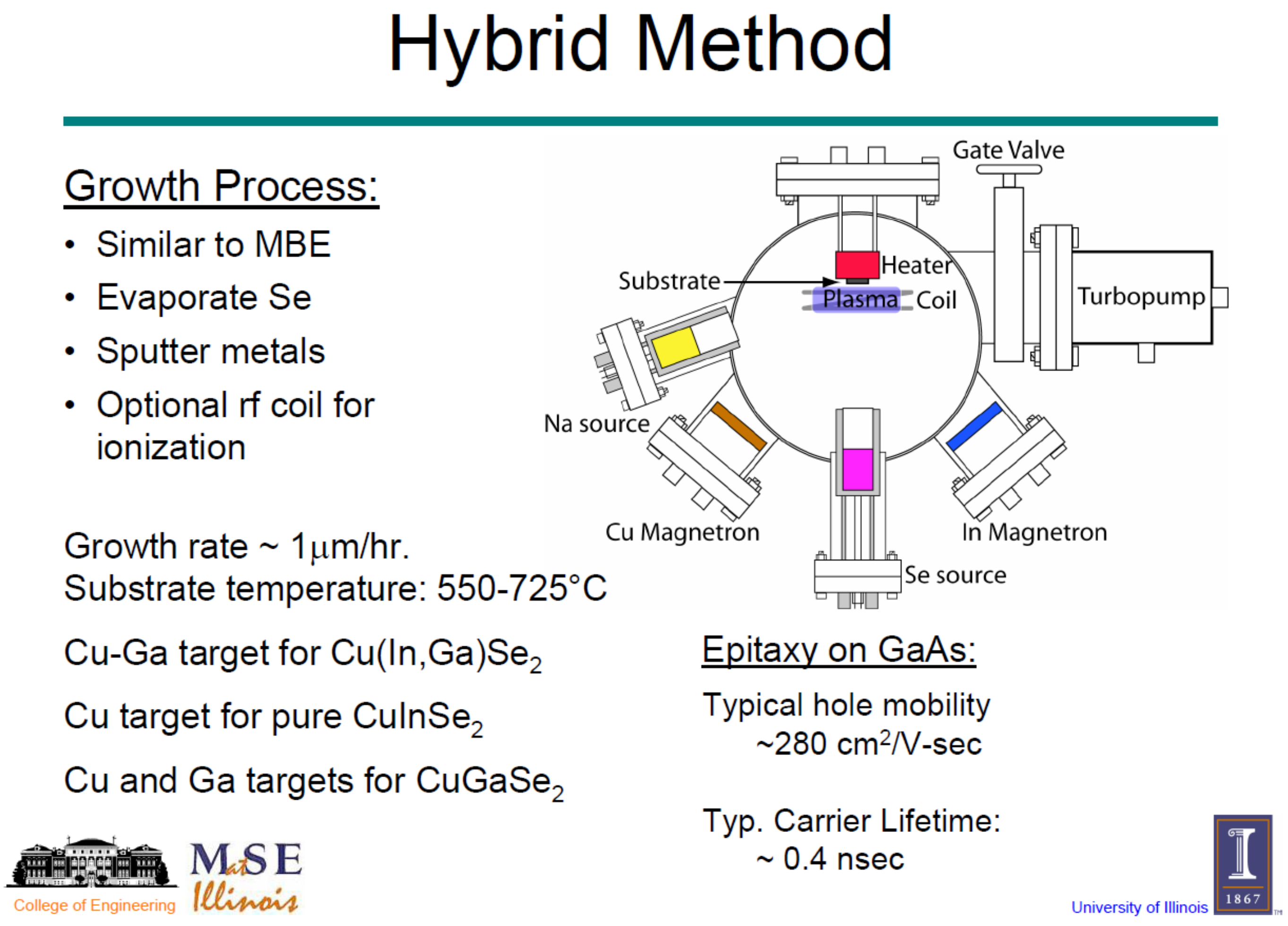




Leonid A. Kosyachenko, A Theoretical Description of Thin-Film Cu(In,Ga)Se2 Solar Cell Performance. (2015).

L. Kazmerski, NREL, 2005

Sputtering for deposition



Hybrid Method

Growth Process:

- Similar to MBE
- Evaporate Se
- Sputter metals
- Optional rf coil for ionization

Growth rate ~ 1μm/hr.
Substrate temperature: 550-725°C

Cu-Ga target for $Cu(In,Ga)Se_2$

Cu target for pure $CuInSe_2$

Cu and Ga targets for $CuGaSe_2$

Epitaxy on GaAs:

Typical hole mobility
~280 cm^2/V-sec

Typ. Carrier Lifetime:
~ 0.4 nsec

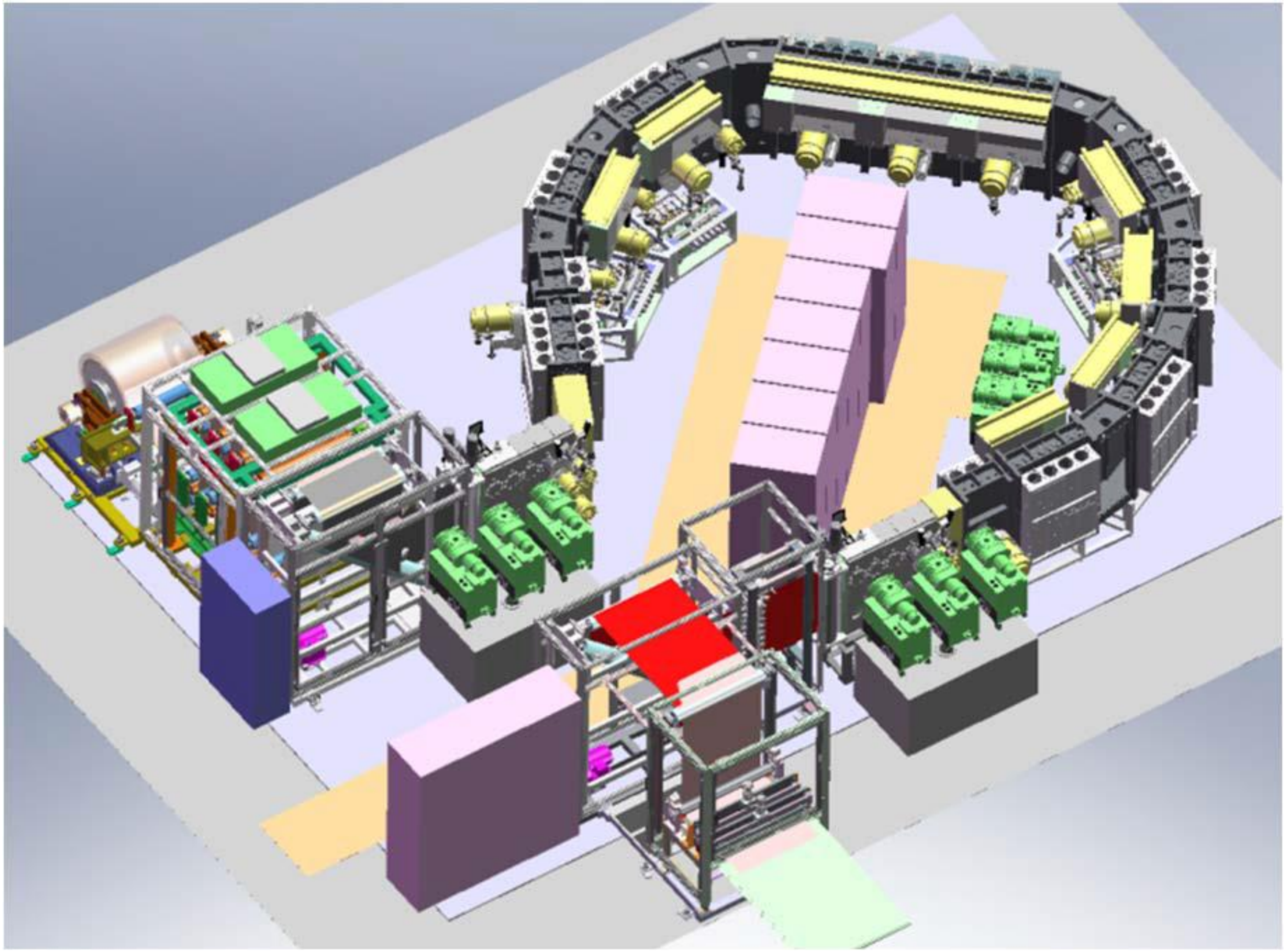
College of Engineering

MSE Illinois

University of Illinois 1867

Image Credit: Angus Rockett

MiaSole



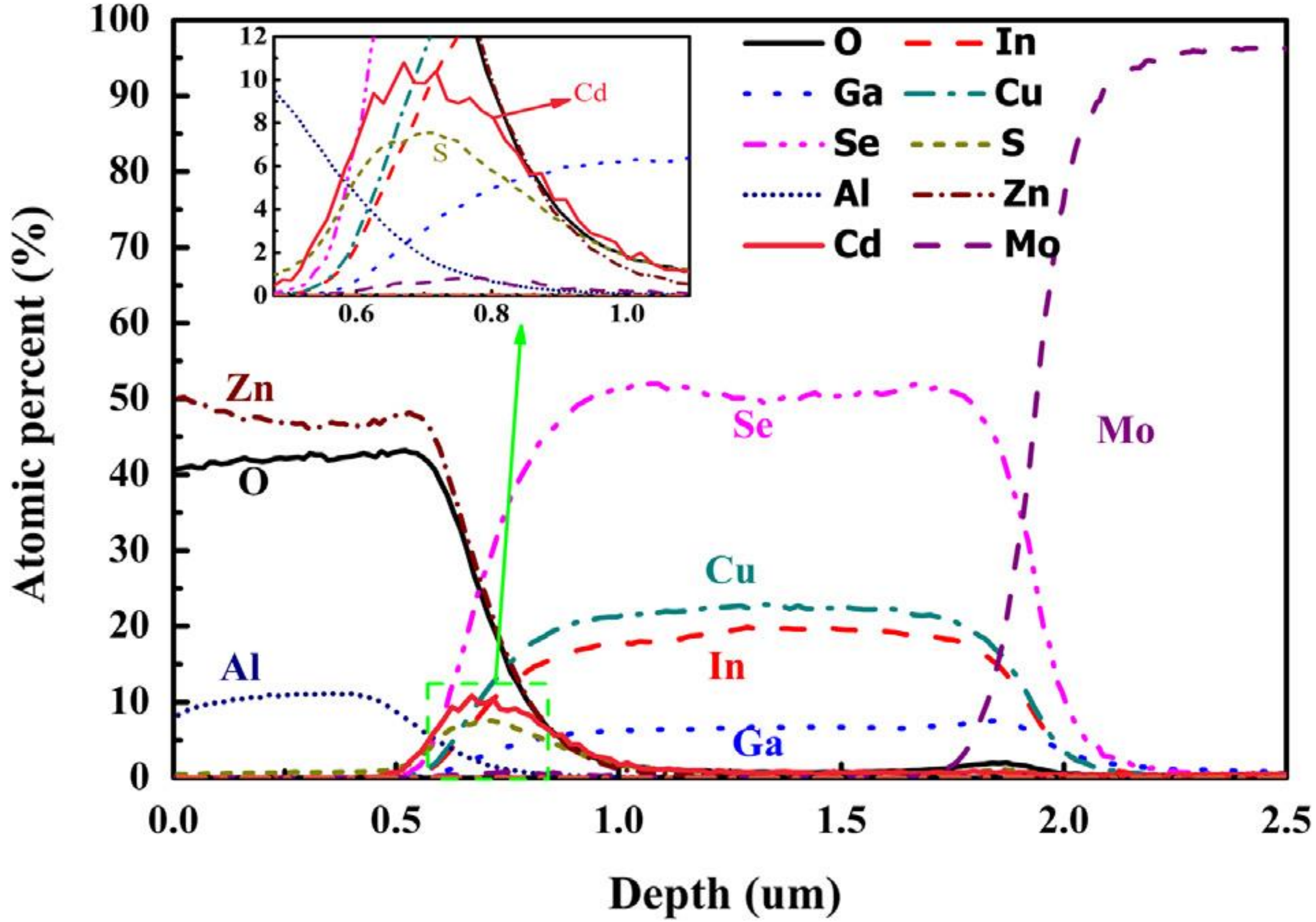
High throughput – All PVD process built on a roll of stainless steel

Image Credit: MiaSole

Experimental details

- CIGS samples deposited on soda lime glass (SLG) substrates by a 2 step sputtering process
- H_2Se in the second step for Selenization
- CdS layer by chemical bath deposition
- Other layers by Sputtering
- Annealed in N_2 gas ambient for 30s, with heating rate of 50°C/s
- SIMS to obtain compositional profile
- For PL, sample excited using 405 nm with 20 mW

Sims results



Photovoltaics Materials & Device Group, University of Oklahoma: http://www.nhn.ou.edu/~sellers/group/index.html

J-V curve results

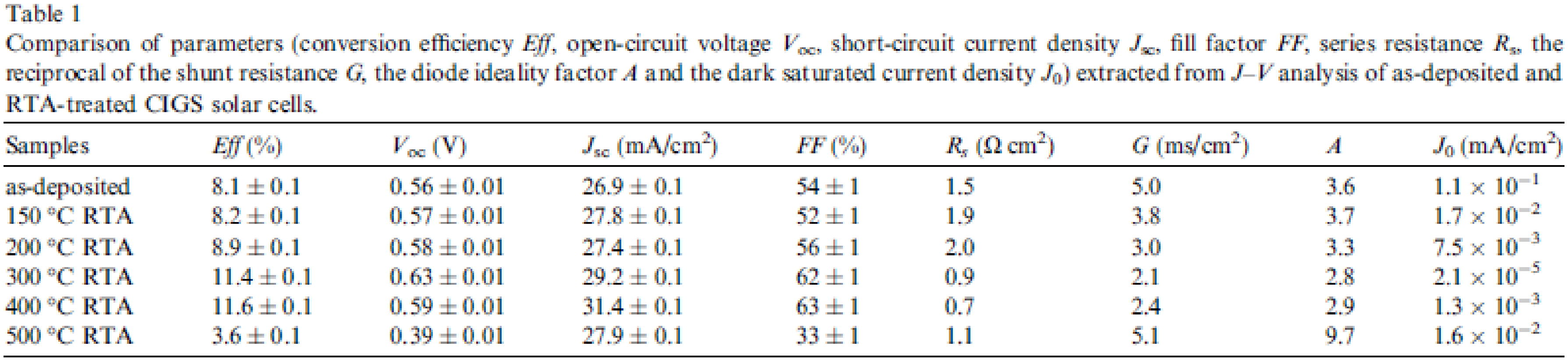


Table 1

Comparison of parameters (conversion efficiency *Eff*, open-circuit voltage V_{oc}, short-circuit current density J_{sc}, fill factor *FF*, series resistance R_s, the reciprocal of the shunt resistance *G*, the diode ideality factor *A* and the dark saturated current density J_0) extracted from *J–V* analysis of as-deposited and RTA-treated CIGS solar cells.

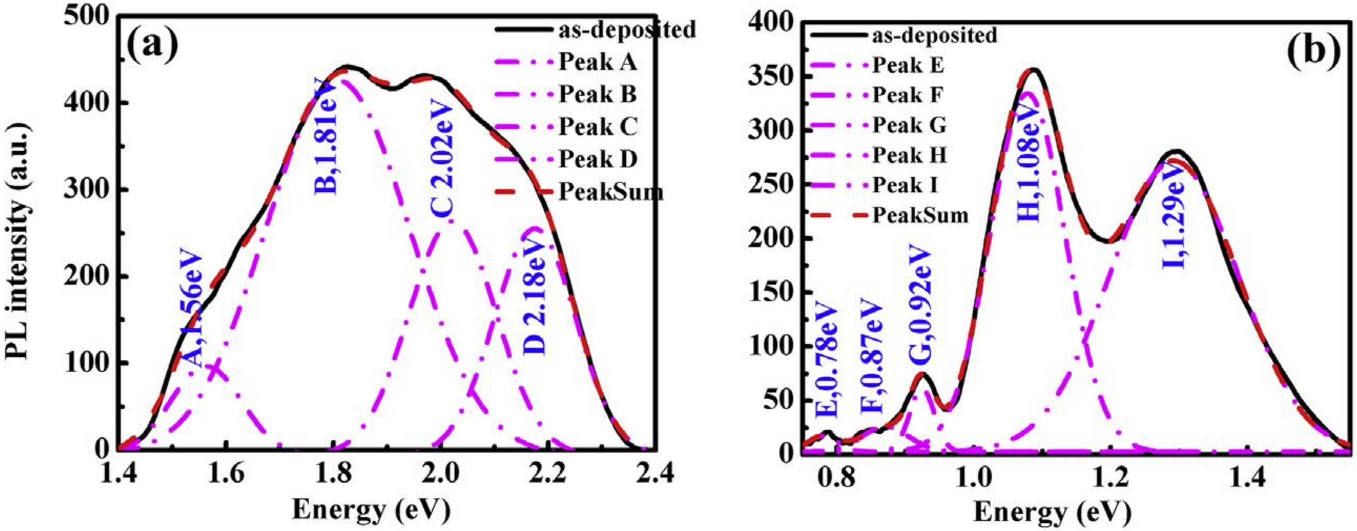
Samples	*Eff* (%)	V_{oc} (V)	J_{sc} (mA/cm^2)	*FF* (%)	R_s (Ω cm^2)	*G* (ms/cm^2)	*A*	J_0 (mA/cm^2)
as-deposited	8.1 ± 0.1	0.56 ± 0.01	26.9 ± 0.1	54 ± 1	1.5	5.0	3.6	1.1×10^{-1}
150 °C RTA	8.2 ± 0.1	0.57 ± 0.01	27.8 ± 0.1	52 ± 1	1.9	3.8	3.7	1.7×10^{-2}
200 °C RTA	8.9 ± 0.1	0.58 ± 0.01	27.4 ± 0.1	56 ± 1	2.0	3.0	3.3	7.5×10^{-3}
300 °C RTA	11.4 ± 0.1	0.63 ± 0.01	29.2 ± 0.1	62 ± 1	0.9	2.1	2.8	2.1×10^{-5}
400 °C RTA	11.6 ± 0.1	0.59 ± 0.01	31.4 ± 0.1	63 ± 1	0.7	2.4	2.9	1.3×10^{-3}
500 °C RTA	3.6 ± 0.1	0.39 ± 0.01	27.9 ± 0.1	33 ± 1	1.1	5.1	9.7	1.6×10^{-2}

Important parameters increase up to 300 or 400 C, then decrease.

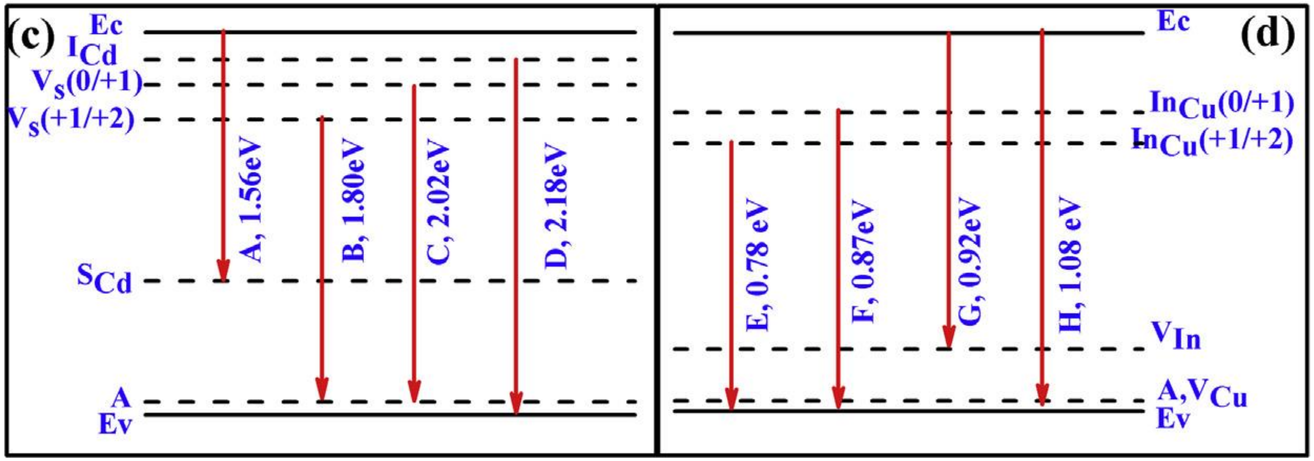
$$\begin{aligned} I_{PL}(t) = I_r(t) &= \int_0^x \frac{n}{\tau_r} dx \\ &= -S_0 \Delta n(0,t) + \int_0^x G_{ph}(x,t) - \frac{n}{\tau_{nr}} dx \end{aligned}$$

A(diode ideality factor) could be over 2 due to tunneling enhanced process (interface state)

PL fig 1

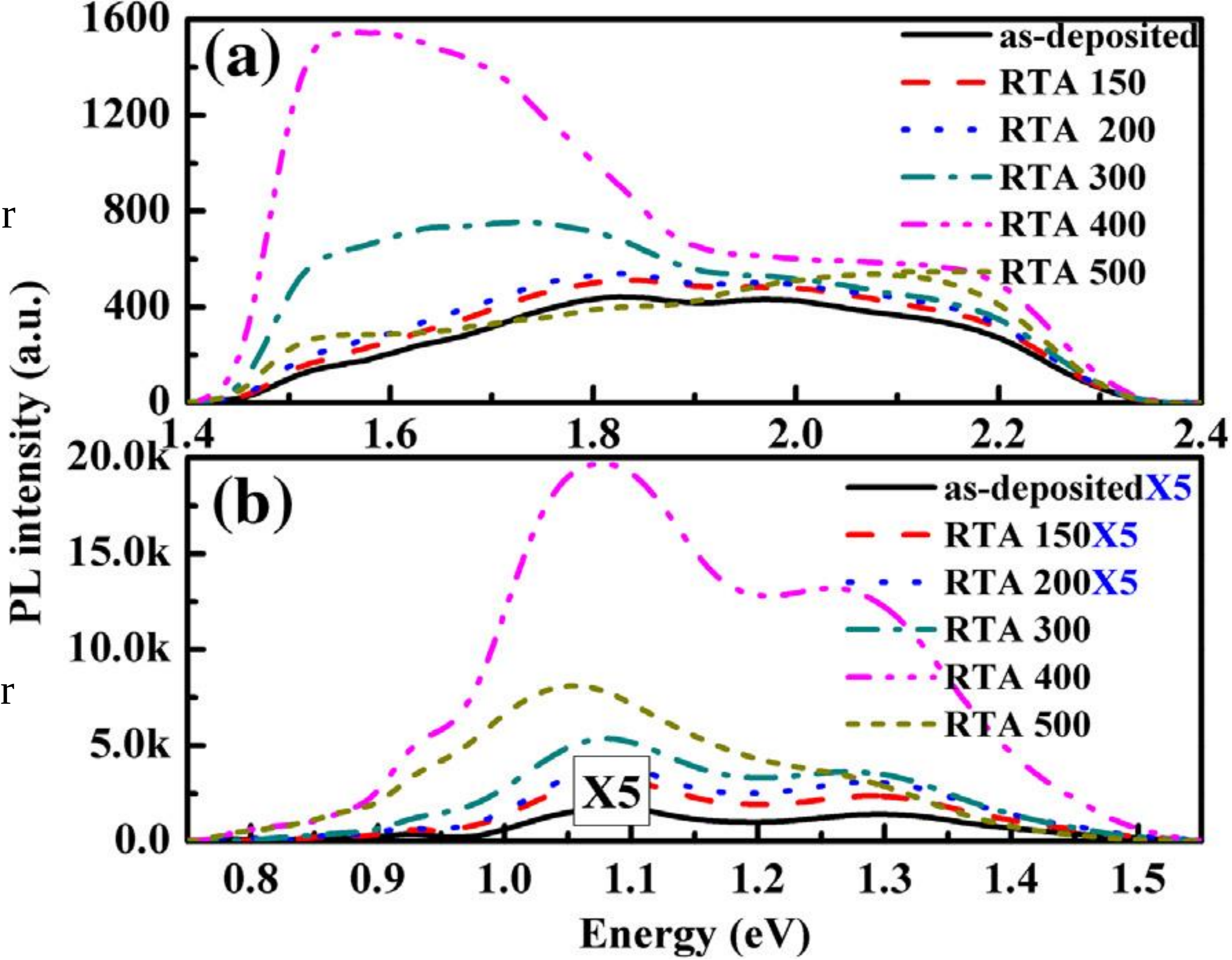


Visible range
-CdS layer



Near IR
-CIGS
absorber

PL fig 3

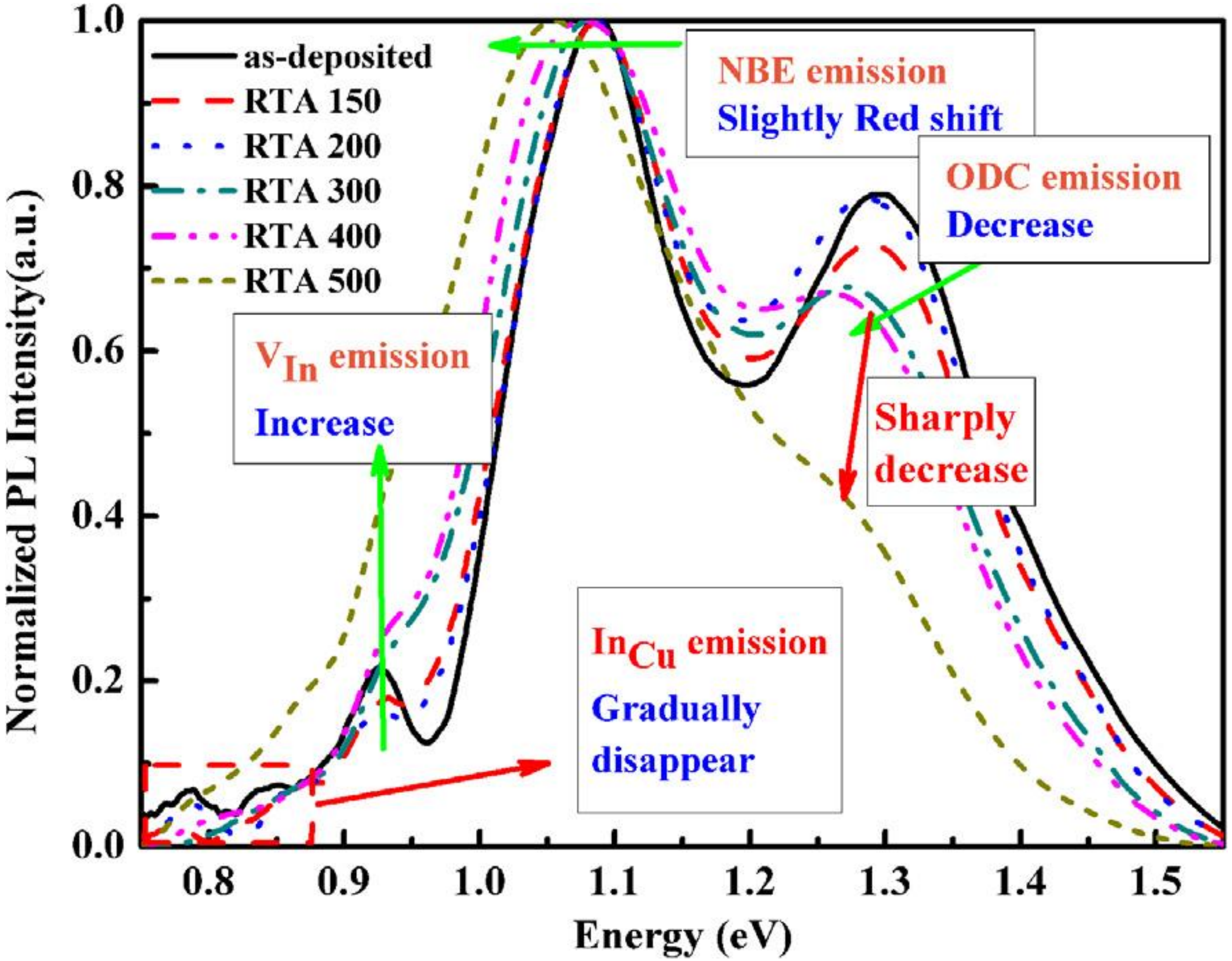


CdS layer

CIGS layer

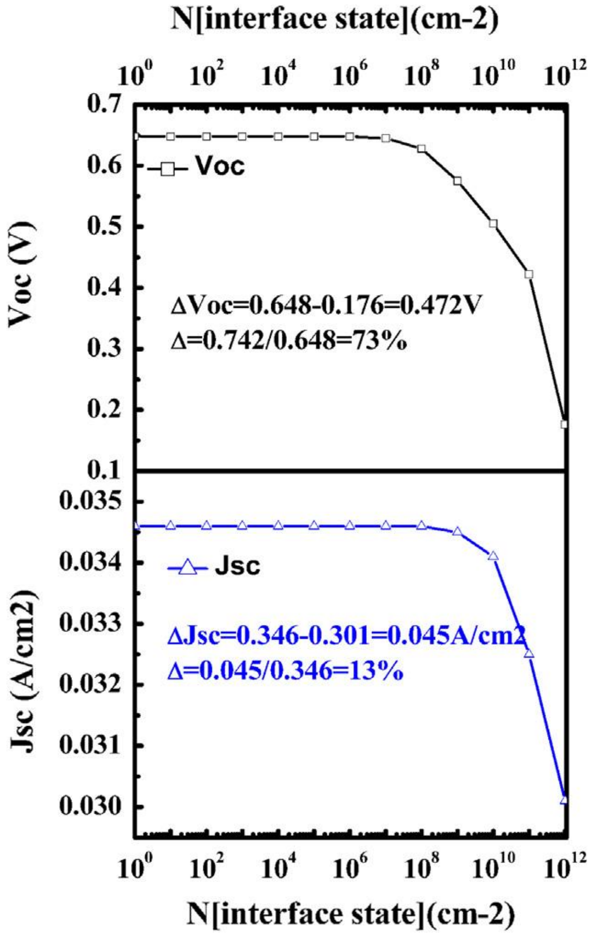
PL of CIGS layer is greatly increased. CdS layer has some increase, but not nearly as much.

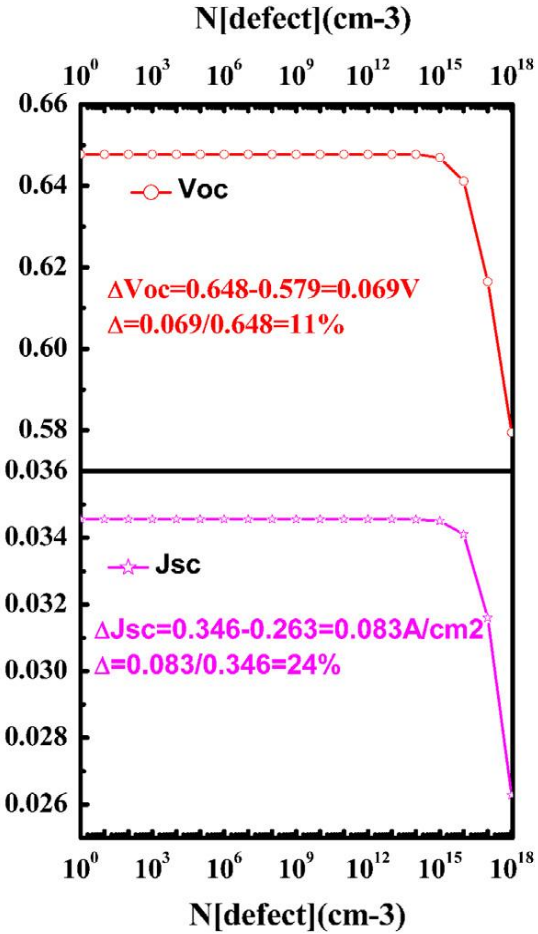
PL fig 4



No Mention of V_{Se} defect. This should probably been seen with annealing.

Simulation Results





Interface states affect mostly Voc

Defect states affect Jsc more.

J-V curve results

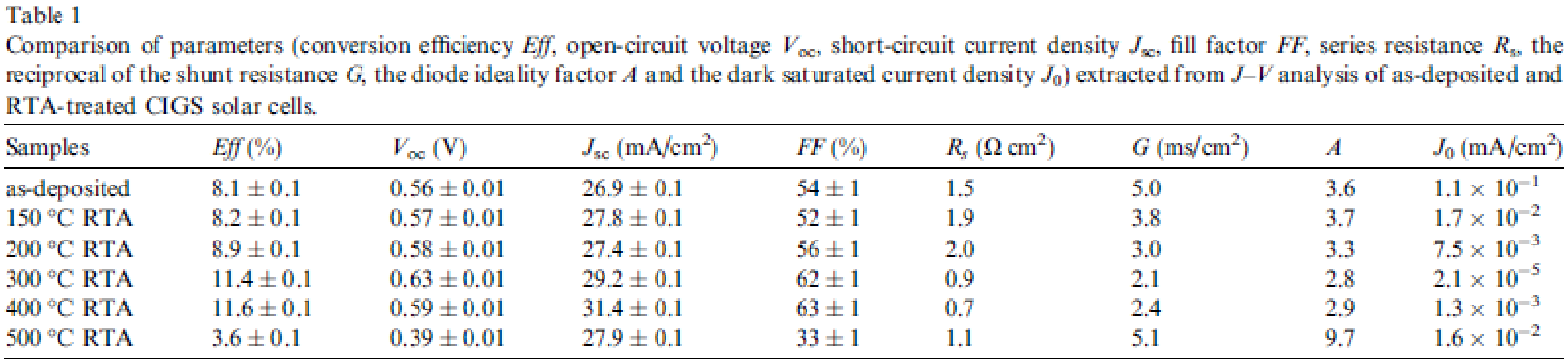


Table 1

Comparison of parameters (conversion efficiency *Eff*, open-circuit voltage V_{oc}, short-circuit current density J_{sc}, fill factor *FF*, series resistance R_s, the reciprocal of the shunt resistance *G*, the diode ideality factor *A* and the dark saturated current density J_0) extracted from *J*–*V* analysis of as-deposited and RTA-treated CIGS solar cells.

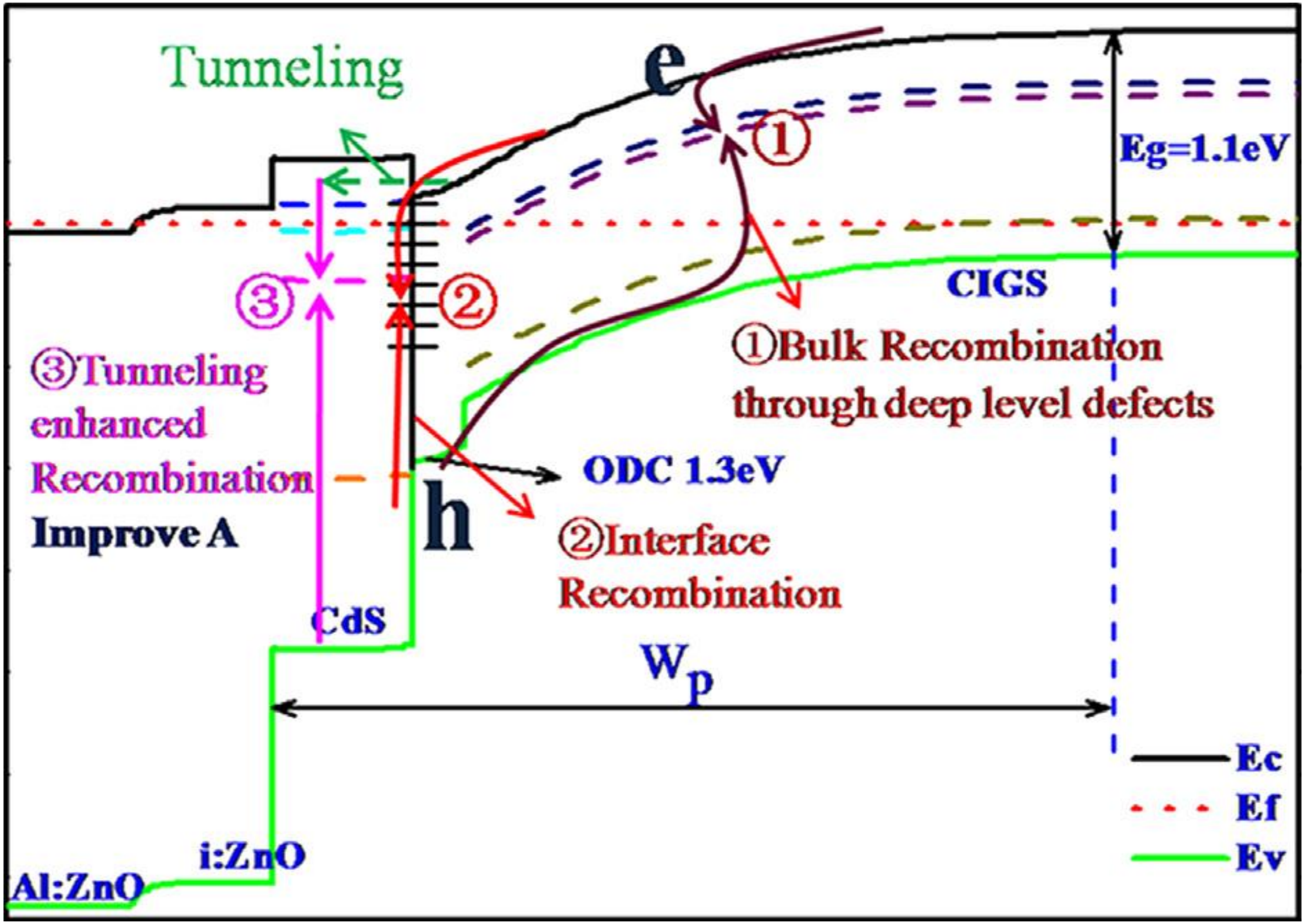
Samples	*Eff* (%)	V_{oc} (V)	J_{sc} (mA/cm^2)	*FF* (%)	R_s (Ω cm^2)	*G* (ms/cm^2)	*A*	J_0 (mA/cm^2)
as-deposited	8.1 ± 0.1	0.56 ± 0.01	26.9 ± 0.1	54 ± 1	1.5	5.0	3.6	1.1×10^{-1}
150 °C RTA	8.2 ± 0.1	0.57 ± 0.01	27.8 ± 0.1	52 ± 1	1.9	3.8	3.7	1.7×10^{-2}
200 °C RTA	8.9 ± 0.1	0.58 ± 0.01	27.4 ± 0.1	56 ± 1	2.0	3.0	3.3	7.5×10^{-3}
300 °C RTA	11.4 ± 0.1	0.63 ± 0.01	29.2 ± 0.1	62 ± 1	0.9	2.1	2.8	2.1×10^{-5}
400 °C RTA	11.6 ± 0.1	0.59 ± 0.01	31.4 ± 0.1	63 ± 1	0.7	2.4	2.9	1.3×10^{-3}
500 °C RTA	3.6 ± 0.1	0.39 ± 0.01	27.9 ± 0.1	33 ± 1	1.1	5.1	9.7	1.6×10^{-2}

Increase of both Voc and Jsc indicates reduction of both interface and defect states.

Large drop in Voc at 500C indicates major interface state formation.

Modest interdiffusion at the interface at low temperature provides beneficial effects, but large interdiffusion increases interface recombination centers.

Recombination Mechanisms



Photovoltaics Materials & Device Group, University of Oklahoma: http://www.nhn.ou.edu/~sellers/group/index.html