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CERTIFICATE
OF ACHIEVEMENT

The 4th International Conference on Mathematics and Sciences (ICMSc) 2022
proudly presents this certificate to

Igor Levi Satriani

as a

PRESENTER

in the conference that was held in Science Learning Center, Faculty of Mathematics and Natural Sciences, Mulawarman University, Samarinda - East Borneo, Indonesia. October 10th - 11th 2022.

Theme :
"The roles of tropical science in new capital nation planning"

Faculty of Mathematics and Natural Sciences
Mulawarman University

Dr. Eng. Idris Mandang, M.Si
Dean FMIPA Mulawarman University

Dr. Sifriyani, S.Pd, M.Si
Chairman

FMIPA UNMUL
The 4th ICMSc 2022
International Conference On Mathematics and Sciences

Optimalization of HIT *(Heterostructure with Intrinsic Layer)* Solar Cell Efficiency with Doping Layer

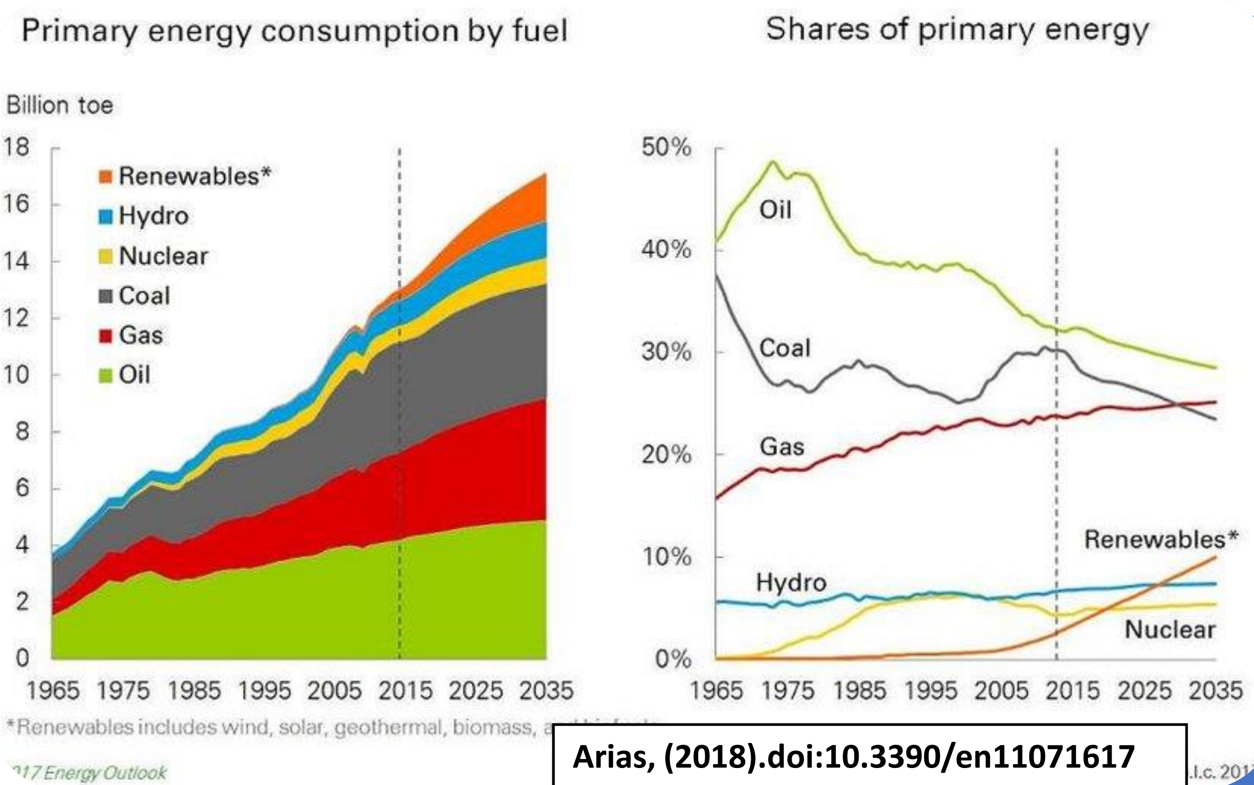
Meet Our Team

Dr. Dadan Hamdani, M.Si

Igor Levi Satriani

Rahmat Fadhillah

Energy Consumption



Arias, (2018).doi:10.3390/en11071617

GHG's Emission

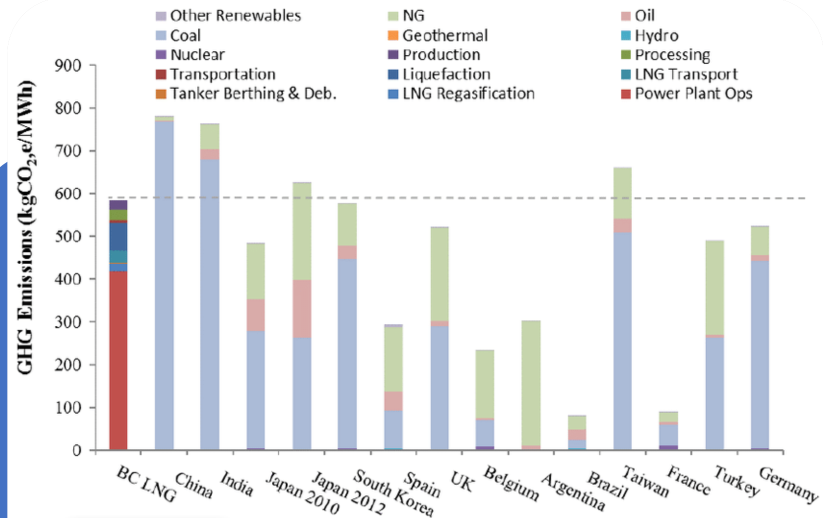
Fossil fueled industries has became the largest GHG's emission. Its causing many major environtment issues such as global warming or even an extreme climate changes.

~80%

More than 80% of total emission produce by fossil fuel

700+ $kgCO_2$/MWh

China were the top country produces GHG's emission



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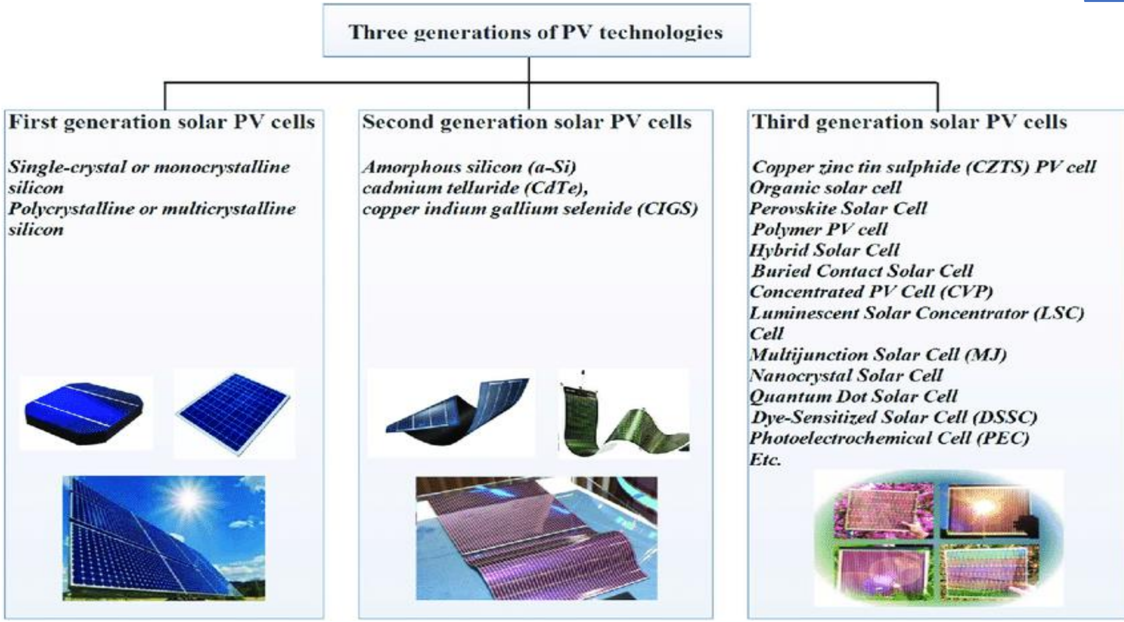
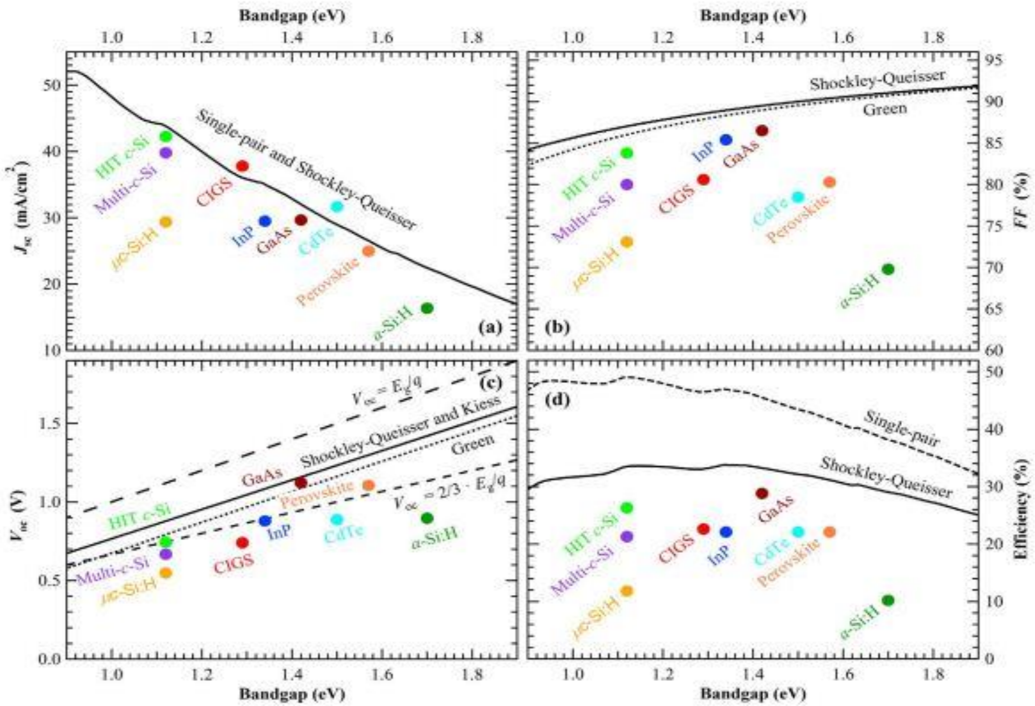
Coal Powerred Industries

Coleman,J (2018), doi:10.1021/acs.est.7b05298

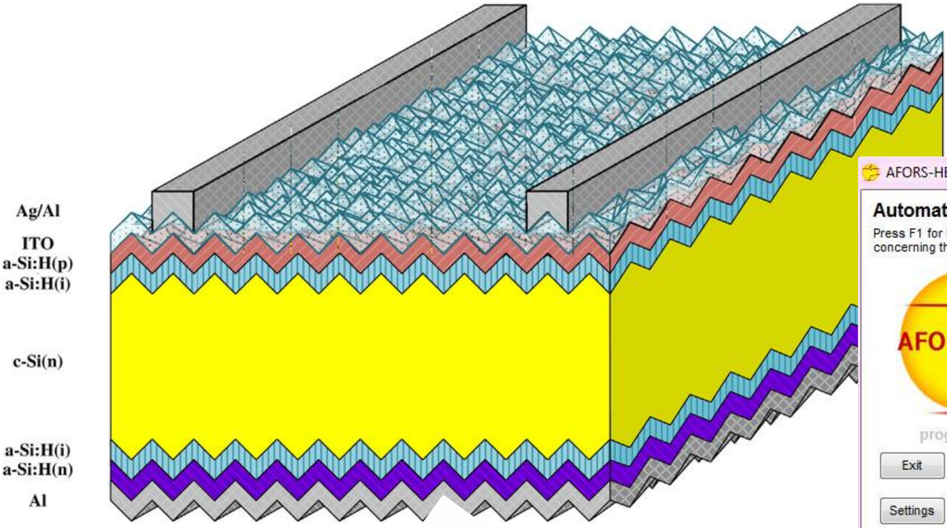
PV Tech generations

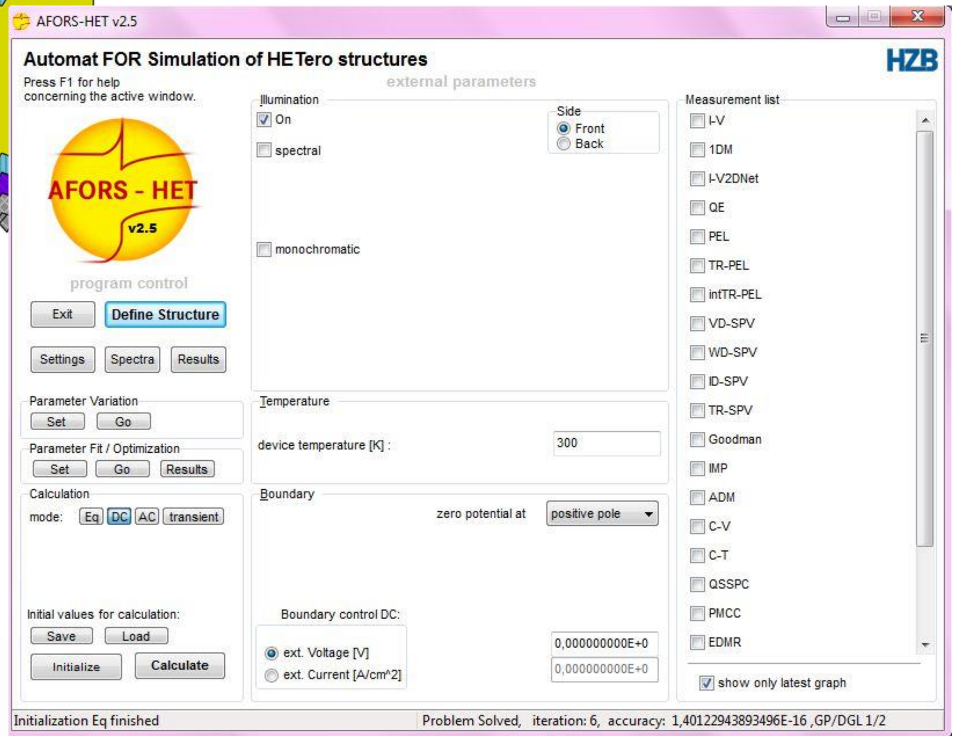




Stuckelberger,(2017). doi:10.1016/j.rser.2016.11.190

HIT & AFORS-HET





Main Goal

01 Validate HIT Solar Cell structure model by analysing ‘Figure of Merits’ (FOMs)

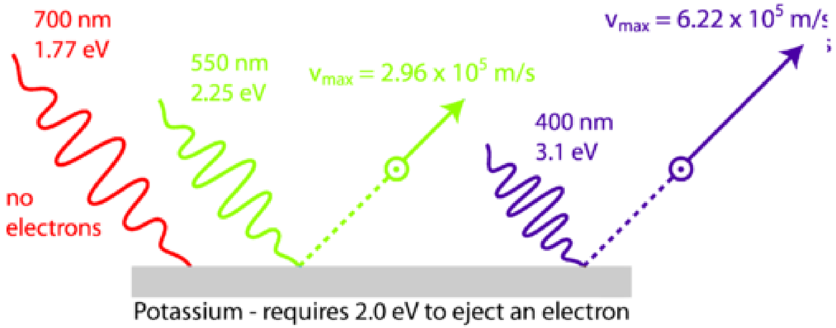
02 Enhanching HIT Solar Cell performance with simulationg input parameters.

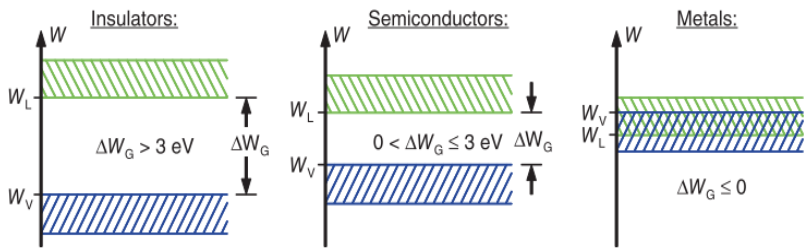
03 Getting the results of numerical data analysis for structure modelling that could be used on fabricated solar cell

Photovoltaic Introduction

Photoelectric effect

$E_{photon} = h\nu$



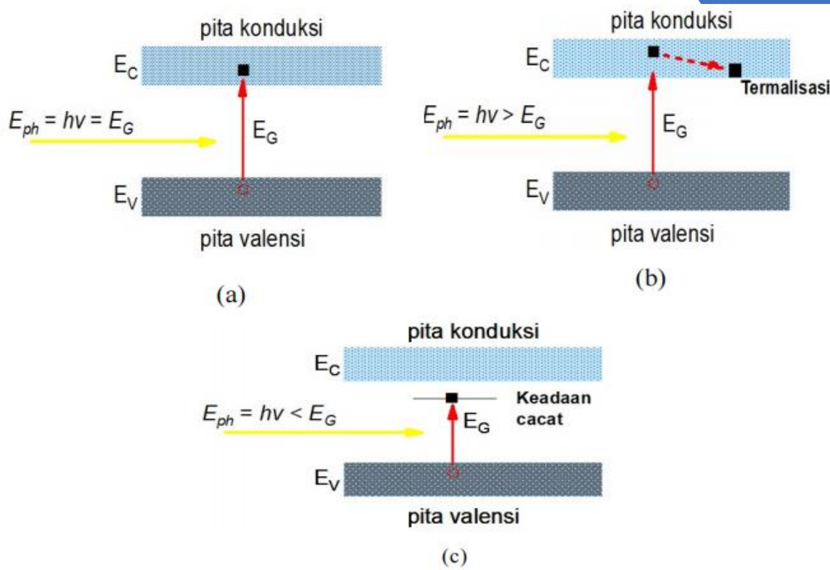


$$E^2 = (m_0c^2)^2 + p^2c^2$$

$$E^2 = p^2c^2$$

$$E^2 = \left(\frac{h}{\lambda}\right)^2 c^2$$

$$E = \frac{hc}{\lambda} = h\nu$$



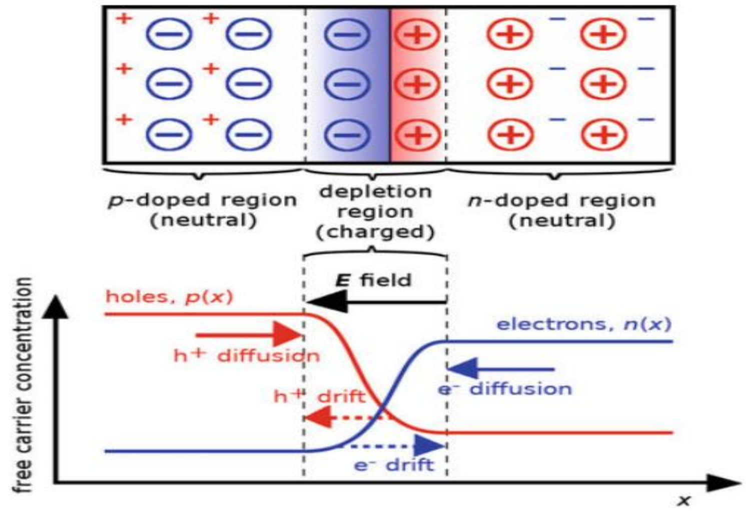
Material	Bandgap		References
	Value	Nature[a]	
Crystalline silicon (c-Si)	1.12	Indirect	[6, 7]
Hydrogenated microcrystalline silicon (μc-Si:H)	1.12	Indirect	[4]
Hydrogenated amorphous silicon (a-Si:H)	1.7–1.9	Non-direct	[4]
Crystalline germanium (c-Ge)	0.67	Indirect	[6, 7]
Hydrogenated amorphous germanium (a-Ge:H)	1.1	Non-direct	[4]
Hydrogenated amorphous Si-Ge alloys (a-Si,Ge:H)	1.1–1.8	Non-direct	[4]
Indium arsenide	0.36	Direct	[7]
Cadmium telluride (CdTe)	1.49	Direct	[6]
Copper indium selenide $CuInSe_2$	1	Direct	[8]
Copper-indium-gallium-selenide (CIGS) ($Cu_xIn_yGa_zSe_2$)	1–1.7	Direct	[8]
Kesterite $\{Cu_2ZnSn(S,Se)_4\}$	1–1.5	Direct	[8]
Cuprous oxide (Cu_2O)	2	Direct	[9]
Zinc telluride (ZnTe)	2.25	Direct	[6]
Gallium arsenide (GaAs)	1.43	Direct	[6]
Pyrite (FeS_2)	0.95	Direct	[10]

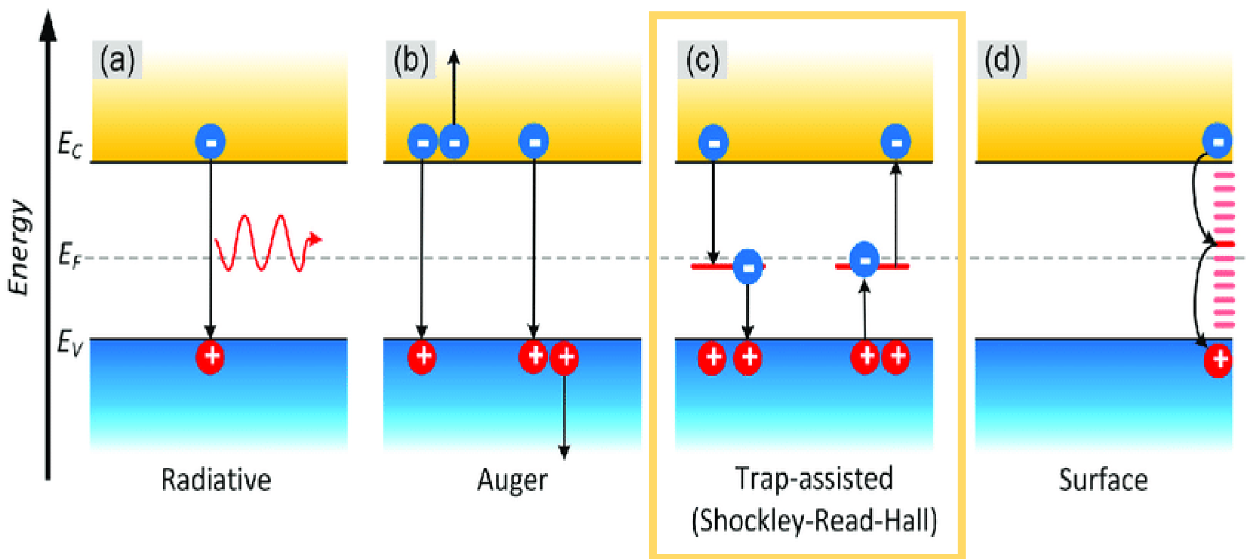
[a]See Sect. 3.2.2 for the description of direct, indirect and non-direct bandgaps

Recombination and Generation

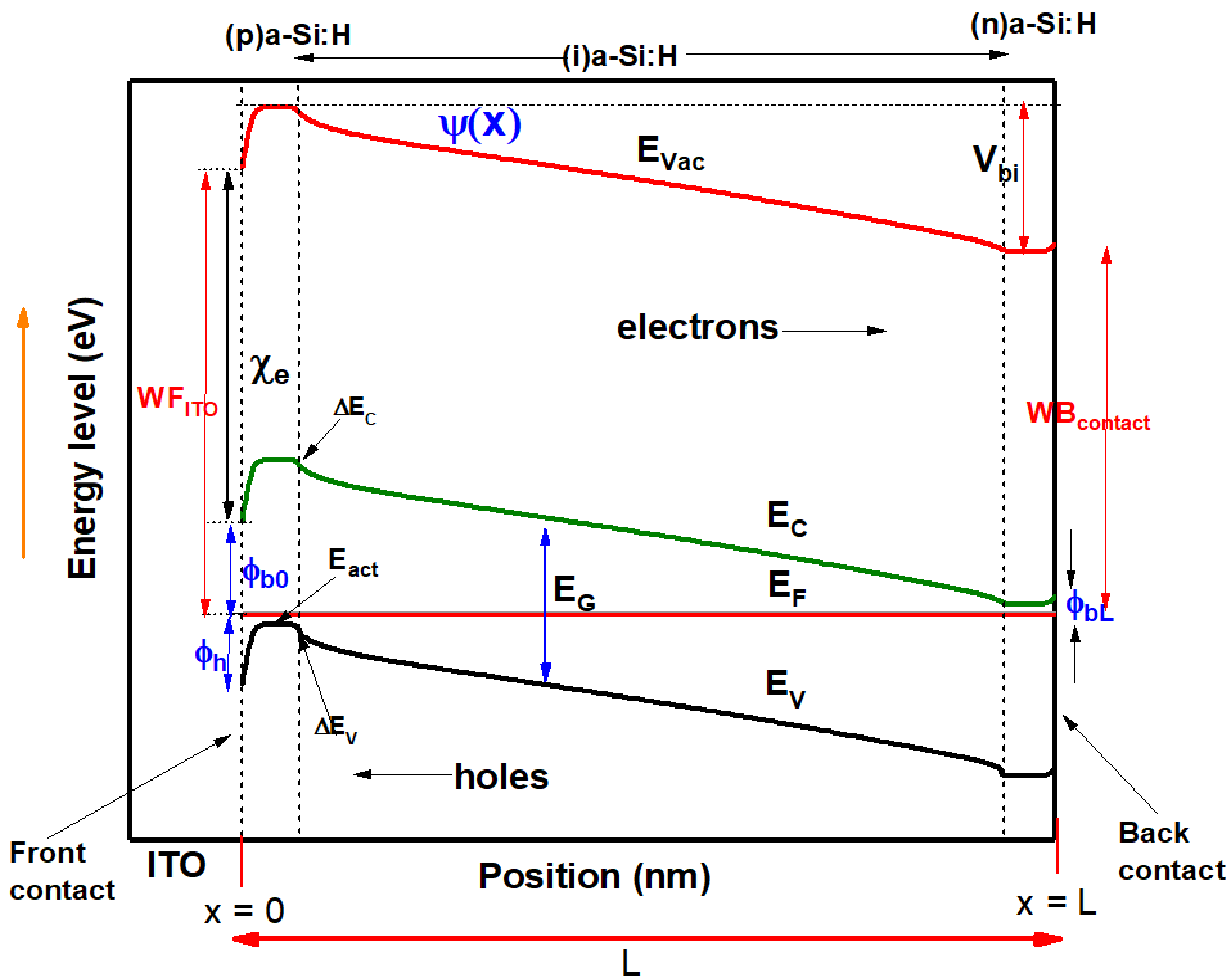
<u>SRH (Shockley-Read-Hall) Recombination</u>, it emerge caused by defect on crystalline structures.

It involving E_{trap} appearing, causing electrons on conduction band also holes on valence band to recombine each other.

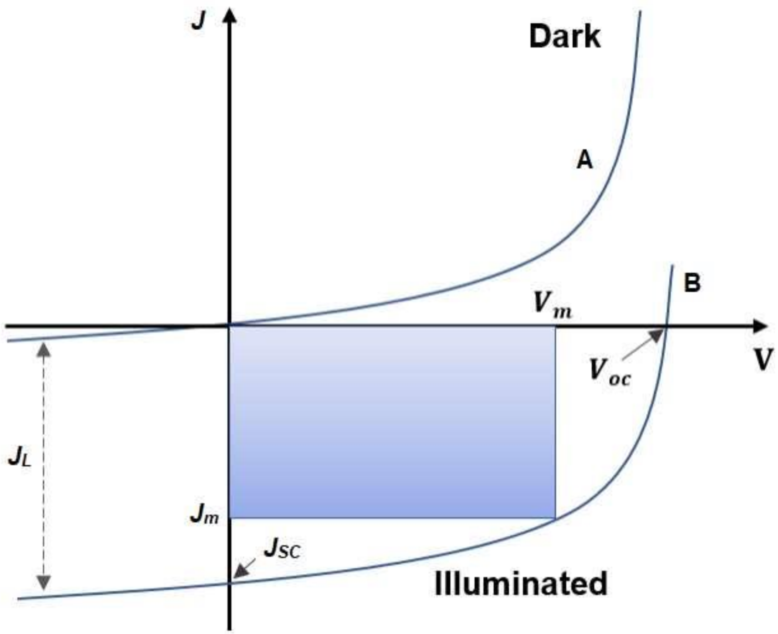




Energy Band Diagram



I-V Characteristics



$$J_{dark} = J_0\,(e^{\frac{qV}{kT}} - 1)$$

$$J_0 = J_{00}^{green}\ x\ e^{(\frac{-E_g}{kT})} \quad ($$

$$J_0 = 1{,}5\ x\ 10^8\ x\ e^{(\frac{-E_g}{kT})} \quad ($$

With J_{00}^{green} as a factor green worth of 1x10^8 (Shah,2020)

$$J_{illum} = J_{ph} - J_{dark}$$

$$J_{illum} = J_{ph} - J_0\,(e^{\left(\frac{qV}{nkT}\right)} - 1)$$

<u>**Key Parameters**</u>

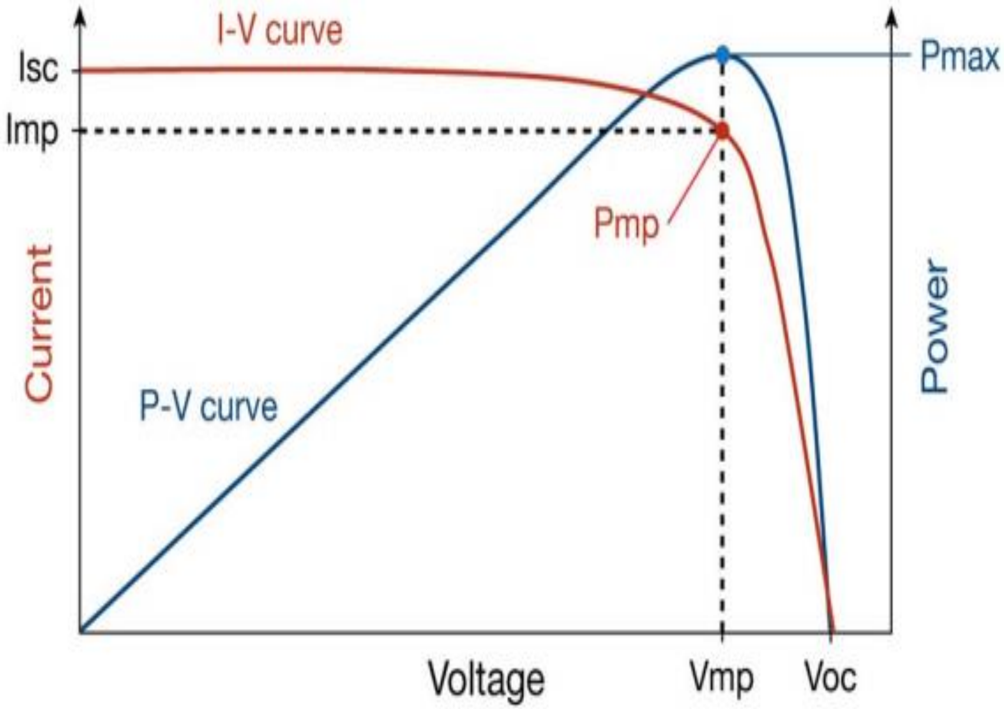
$$J_{SC} = 80\ (mA/cm^2) - 34\left(\frac{mA}{cm^2 eV}\right) x\ E_G$$

$$V_{OC} = \frac{kT}{q} ln\left(\frac{J_{ph}}{J_0} + 1\right) \approx \frac{kT}{q} ln\left(\frac{J_{ph}}{J_{00}}\right) + \frac{E_G}{q}$$

$$FF = \frac{V_m\ x\ J_m}{V_{OC}\ x\ J_{SC}}$$

$$E_{ff} = \frac{P_{maks}}{P_{input}} = \frac{FF\ V_{OC}\ J_{SC}}{P_{input}}$$

FOMs (Figure of Merits)



Electrical Models

$$J_{SC} = 80\ (mA/cm^2) - 34\left(\frac{mA}{cm^2 eV}\right) x\ E_G$$

$$V_{OC} = \frac{kT}{q} ln\left(\frac{J_{ph}}{J_0} + 1\right) \approx \frac{kT}{q} ln\left(\frac{J_{ph}}{J_{00}}\right) + \frac{E_G}{q}$$

$$FF = \frac{V_m\ x\ J_m}{V_{OC}\ x\ J_{SC}}$$

$$E_{ff} = \frac{P_{maks}}{P_{input}} = \frac{FF\ V_{OC}\ J_{SC}}{P_{input}}$$

Optical Models

$$EQE = \frac{Jsc\left(\frac{hc}{\lambda}\right)}{qI_0(\lambda)}$$

Short circuit

$$IQE = \frac{EQE}{1-R}$$

Charge Carrier

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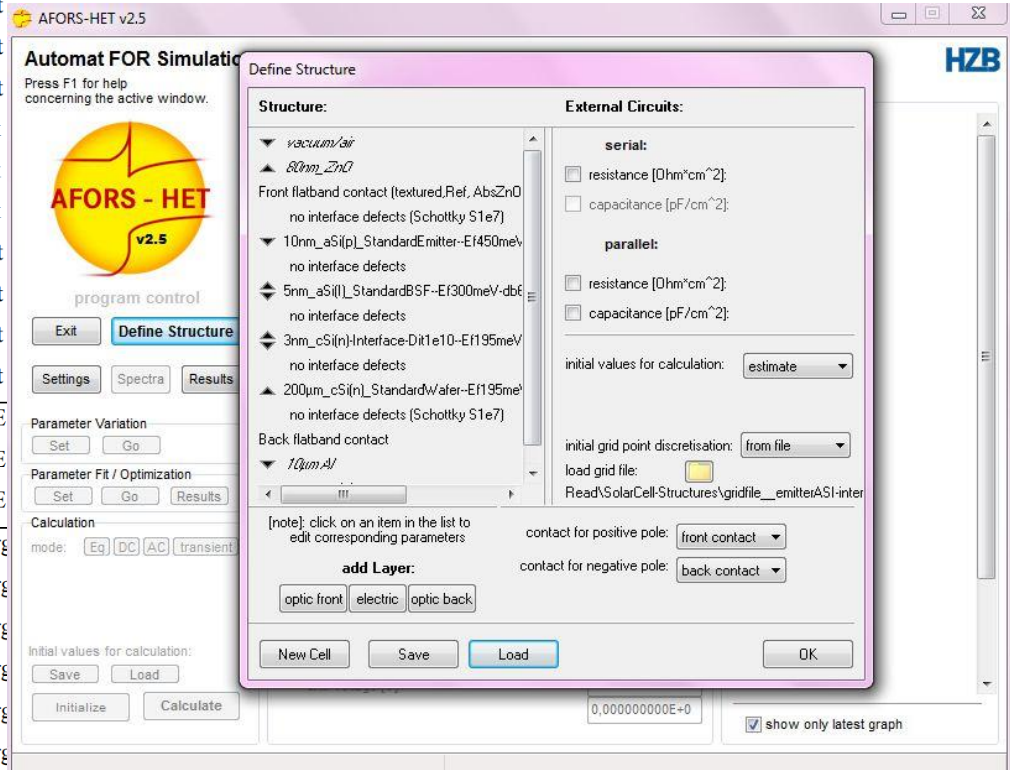
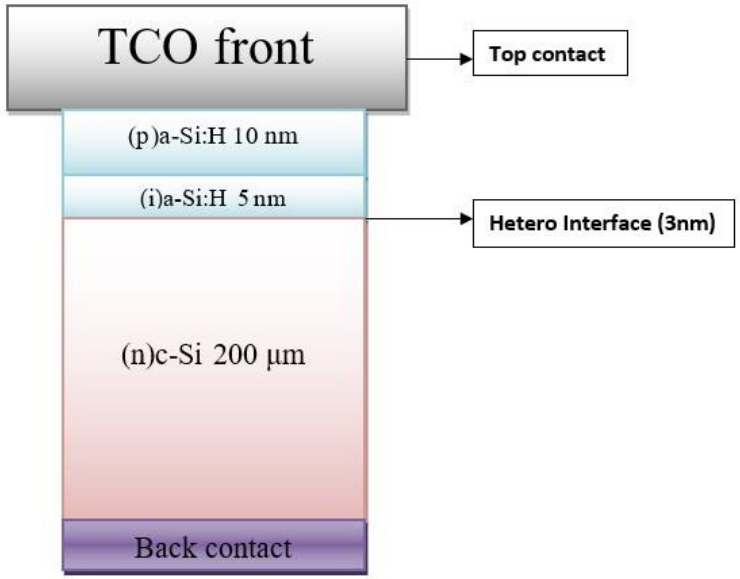
Parameter	Besaran	Satuan	Model Analisis
	J_{SC}	mA/cm^2	Kurva J-V Light
	V_{OC}	mV	Kurva J-V Light
	J_m	mA/cm^2	Kurva J-V Light
	V_m	mV	Kurva J-V Light
	J_0	mA/cm^2	Kurva J-V Dark
Electrical FOMs	$J_{0,Schottky}$	mA/cm^2	Kurva J-V Dark
	n	-	Kurva J-V Dark
	R_S	$\Omega.cm^2$	Kurva J-V Light
	R_{shunt}	$\Omega.cm^2$	Kurva J-V Light
	FF	%	Kurva J-V Light
	E_{ff}	%	Kurva J-V Light
	EQE	%	Karakterisasi QE
Optical FOMs	IQE	%	Karakterisasi QE
	SR	A/W	Karakterisasi QE
	Height barrier ϕ_{b0}	eV	Diagram pita energ
	Height barrier ϕ_{h0}	eV	Diagram pita energ
	Height barrier ϕ_{bL}	eV	Diagram pita energ
	Band offset konduksi ΔE_C	eV	Diagram pita energ
Analisis	*Band offset* valensi ΔE_V	eV	Diagram pita energ
	Surface band bending	eV	Diagram pita energ
	Medan listrik internal E_{int}	V/cm	Profil medan listrik
	Laju rekombinasi total	cm^{-3}	Profil laju rekombinasi
	Konsentrasi pembawa muatan	cm^{-3}	Profil pembawa muatan

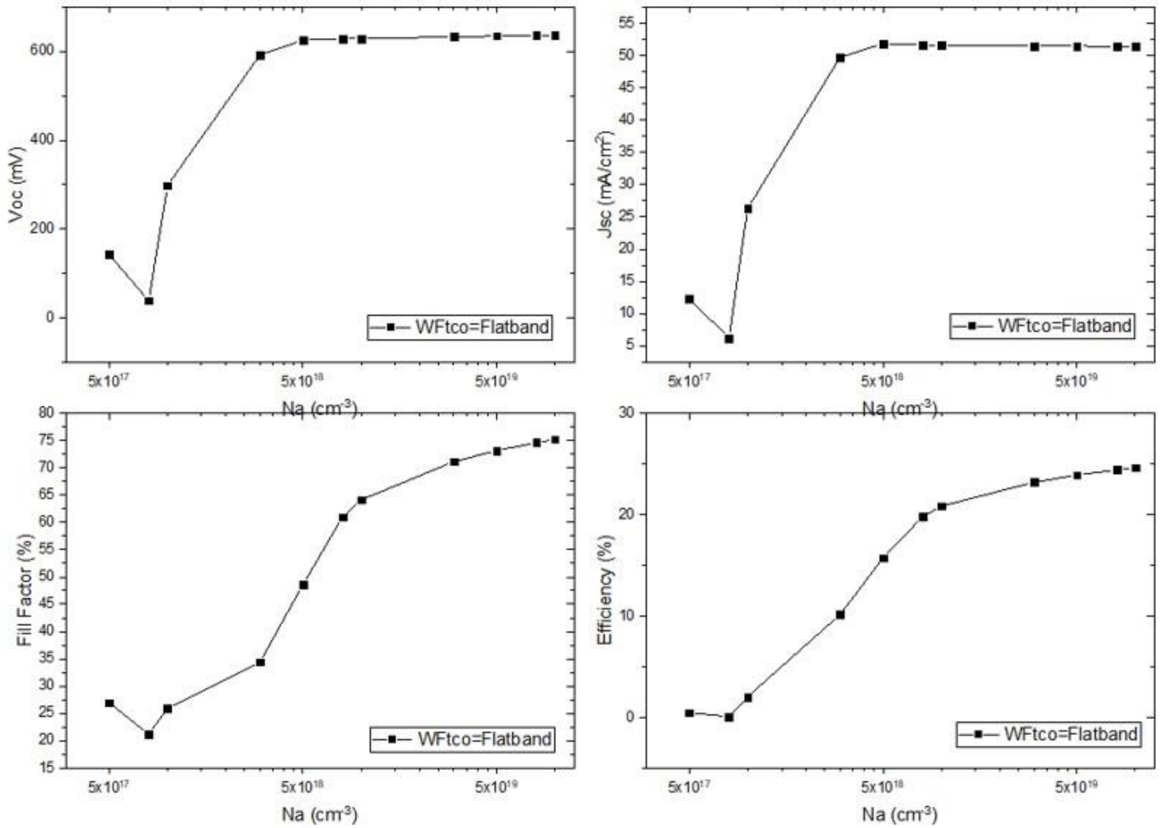


Input Parameters

Parameters	(p')a-Si:H	(i)a-Si:H	a-Si:/c-Si interface	(n)c-Si
Thickness (nm)	10	5	3	2 x 10^{5}
Dielectric constant	11.9	11.9	-	11.9
Electron affinity (eV)	3.9	3.9	-	4.05
Band gap (eV)	1.72	1.72	-	1.124
Effective conduction tape meeting ($^{cm-3}$)	2.5 x 10^{20}	2.5 x 10^{20}	-	2,846 x 10^{19}
Effective valence band meeting y ($^{cm-3}$)	2.5 x 10^{20} 1.0 x 10^{17}	2.5 x 10^{20}	-	2,685 x 10^{19}
Acceptor concentration, Na ($^{cm-3}$)	5.0 x 10^{17} 1.0 x 10^{20}	0	-	0
Donor concentration, Nd ($^{cm-3}$)	0	0	-	1.5 x 10^{16}
Electron mobility (cm$^{2\ V-1\ s-1}$)	20	20	-	1111
Hole mobility (cm$^{2\ V-1\ s-1}$)	5	5	-	421.6
Thermal rate for electrons ($^{cms-1}$)	1.0 x 10^{7}	1.0 x 10^{7}	-	1.0 x 10^{7}
Thermal rate for holes ($^{cms-1}$)	1.0 x 10^{7}	1.0 x 10^{7}	-	1.0 x 10^{7}
The tightness of the defects on the edges of the conduction band (valence) ($^{cm-3}$eV-1)	4.0 x 10^{21} (4.0 x 10^{21})	2.0 x 10^{21} (2.0 x 10^{21})	-	1.0 x 10^{14} (1.0 x 10^{14})
Urbach energy for the tail of the conduction band (valence) (eV)	0.06(0.03)	0.094(0.06 8)	-	-
Capture cross section σ_c (σ) conduction (cm^2)	1.0 x $^{10-17}$ (1.0 x $^{10-15}$)	7.0 x $^{10-16}$ (7.0 x $^{10-16}$)	-	-
Capture cross section σ_c (σ) for the tail of the valence band (cm^2)	1.0 x $^{10-15}$ (1.0 x $^{10-17}$)	7.0 x $^{10-16}$ (7.0 x $^{10-16}$)	-	-
Gaussian state meeting ($^{cm-3}$)	1.0 x 10^{18}- 1.5 10^{19}	7.0 x 10^{19}	-	-
Gaussian peak energy for donors (acceptors) (eV)	1.22(0.70)	0.5(0.60)	-	-
Gaussian standard deviation for donors (acceptors) (eV)	0.23(0.23)	0.21(0.21)	-	-
Capture cross section σ_c (σ) for donor-like Gaussian states (cm^2)	1.0 x $^{10-14}$ (1.0 x $^{10-15}$)	3.0 x $^{10-14}$ (3.0 x $^{10-15}$)	-	-
Capture cross section σ_c (σ) for acceptor-like Gaussian states (cm^2)	1.0 x $^{10-15}$ (1.0 x $^{10-14}$)	3.0 x $^{10-15}$ (3.0 x $^{10-14}$)	-	-
Total DOS D_n ($^{cm-2}$)	-	-	1.0 x 10^{9} 1.0 x 10^{11}	-
Midgap density of satay ($^{cm-3.eV-1}$)	-	-	-	1.0 x 10^{10}
Characteristic energy (eV)	-	-	-	0.56
Capture cross section for donor-like (cm^2)	-	-	1.0 x $^{10-14}$ (1.0 x $^{10-14}$)	1.0 x $^{10-14}$ (1.0 x $^{10-14}$)
Capture cross section for acceptor-like (cm^2)	-	-	1.0 x $^{10-14}$ (1.0 x $^{10-14}$)	1.0 x $^{10-14}$ (1.0 x $^{10-14}$)

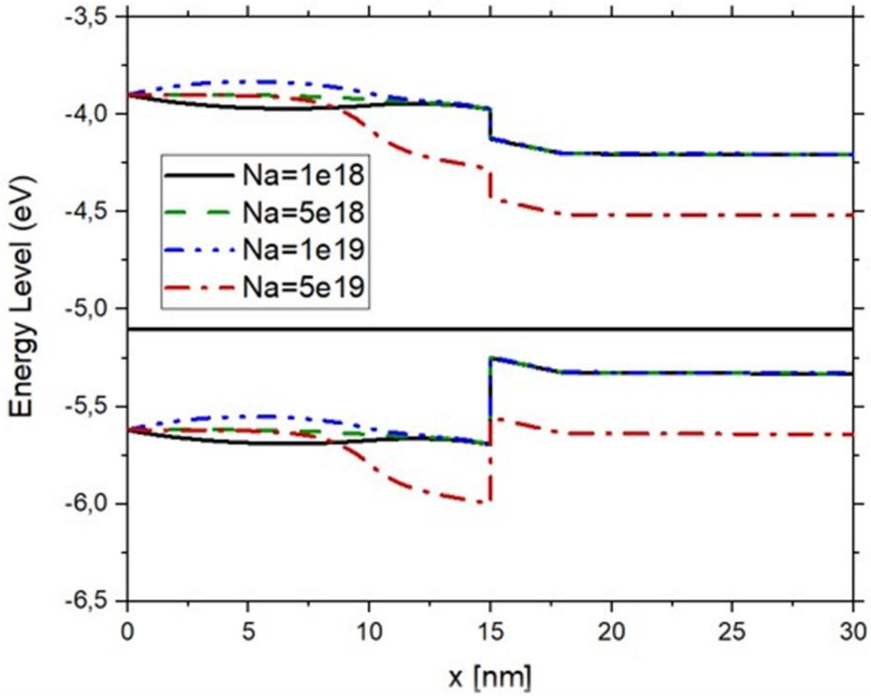


Doping Optimalization



Using various doping at 5x10^{17} cm^{-3}up to 1x10^{20} cm^{-3} observed. Doping with N_a=5x10^{18} cm^{-3} shows a rapid improvement on *Voc* & *Jsc*, with 15,73% Solar cell Efficiency

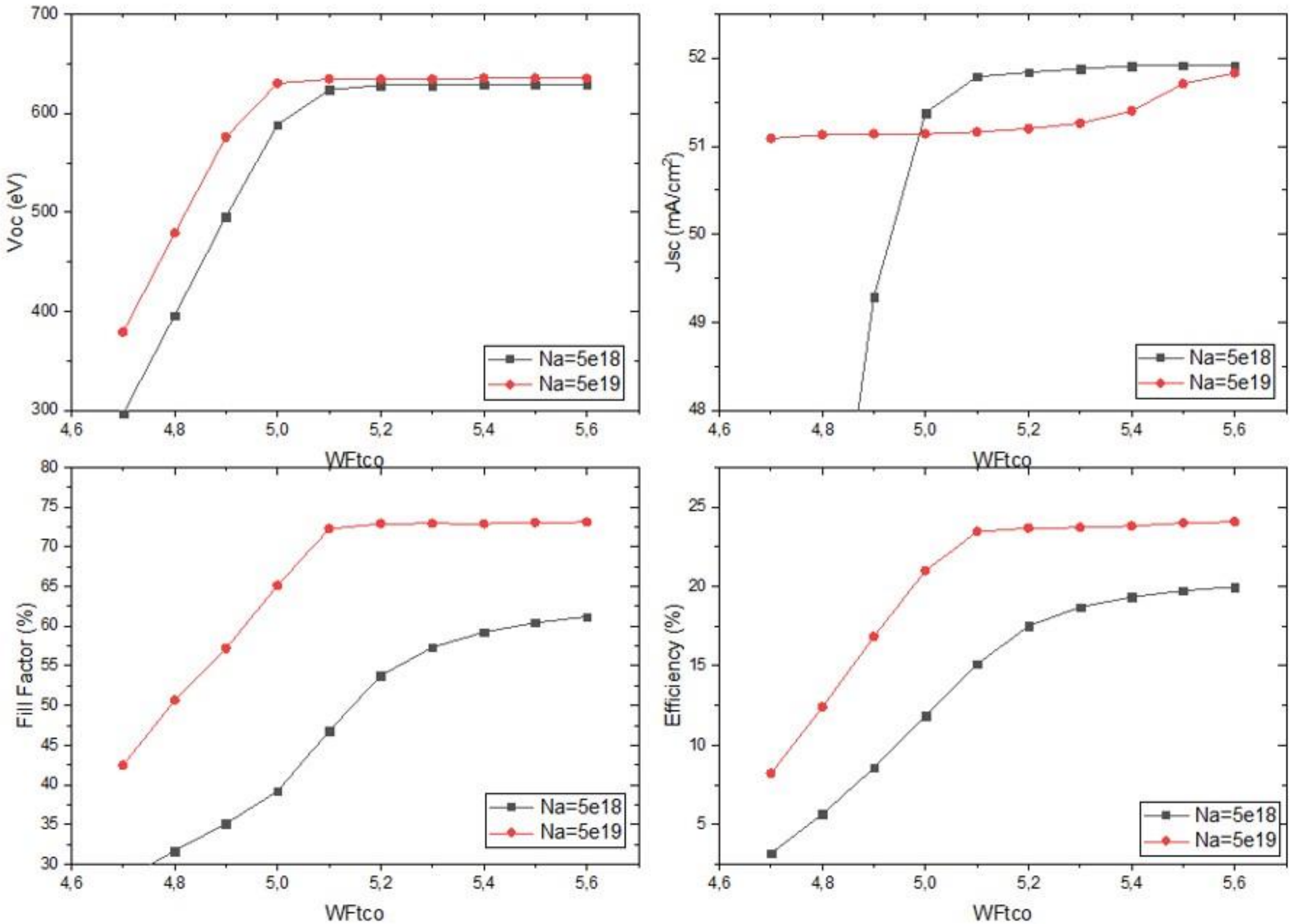
Doping Optimalization



Band Diagram with various doping N_A

With increasing doping N_a given on (p+) layer. Valence Energy band to move away from fermi level energy, need a higher energy for electron to excite.

WFtco Optimalization



Using optimum doping N_a, to achieve an effective Wftco Value for improving solar cell performance

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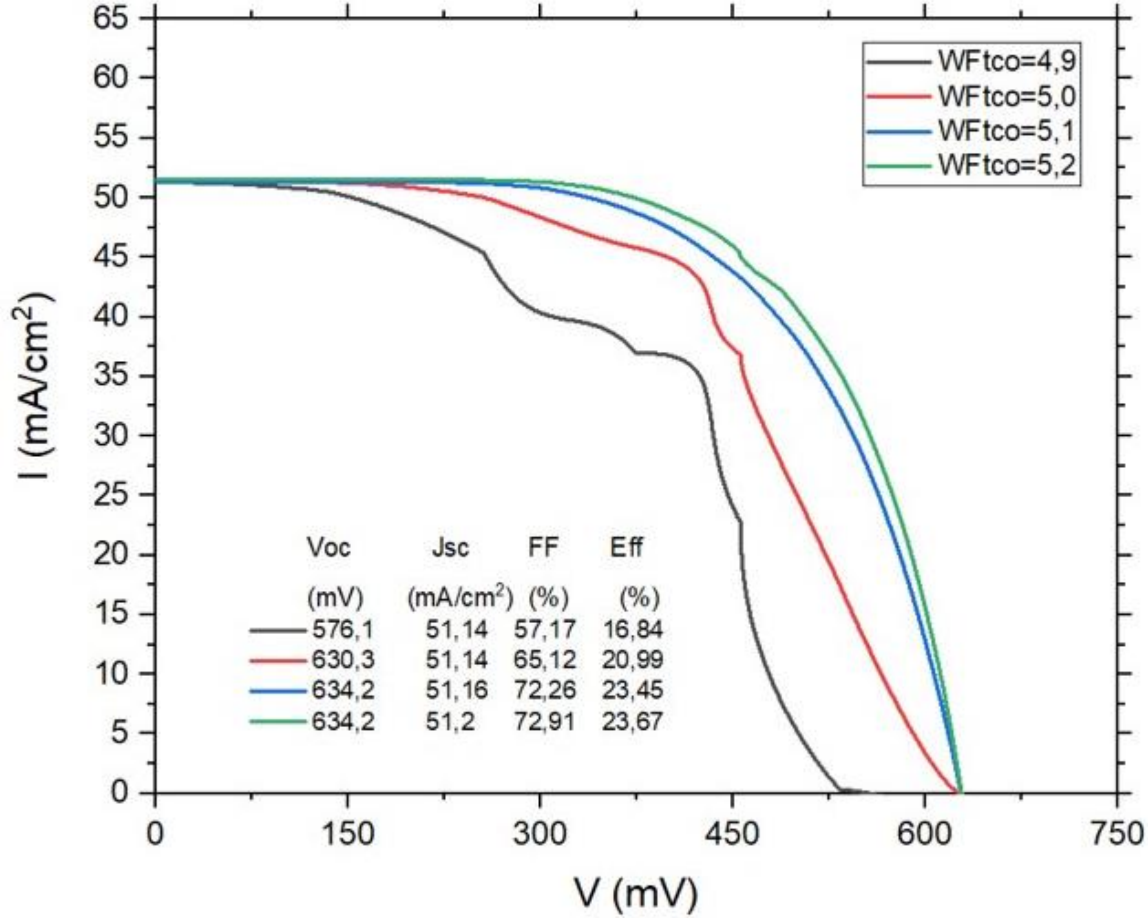
WFtco Optimalization



characteristic curve on HIT solar cells with TCO/(p+/i)a-Si structure:H/(n)c-Si/Al with variations in WF_{tco} values with AM1.5G irradiation spectrum and stable temperatures at 300K. Then also used the dopping concentration *of* N_A at optimum concentrations, namely $5x10^{19\ cm-3}$

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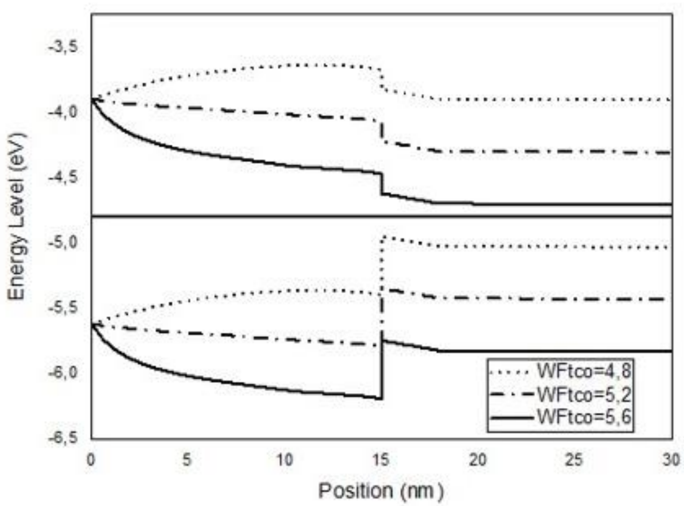
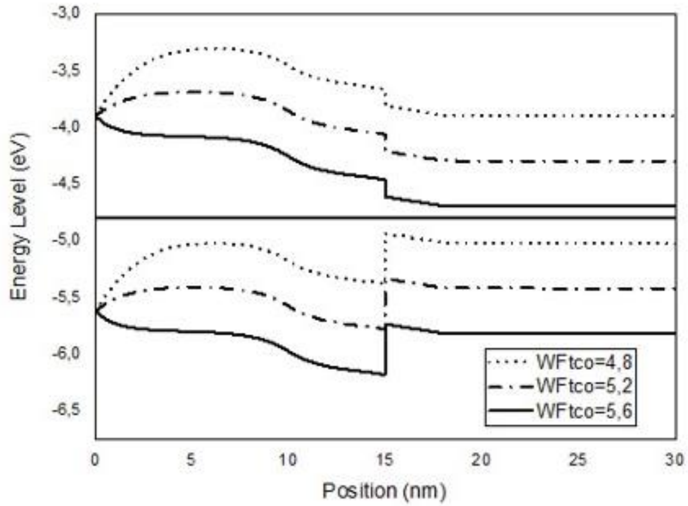
WFtco Optimalization





$$\varphi_B = \left(\chi_{a-Si:H} - E_{G(a-Si:H)}\right) - WF_{tco}$$

- At the value of WFtco < 5.0 eV, a significant decrease in the Voc voltage and the formation of Jsc current was found. Causes decreased performance of solar cells. The initial assumption is due to the formation of potential-barriers in the interface of the front-facing layer with the layer (p+) so that Schottky contact arises in this area of the interface
- At the WF tco value ≥ 5.0 eV, it experienced a significant increase in the Voc voltage and Jsc current when compared to the lower WFtco value. However, with the increasing value of the work function of the front contact, it is not monitored for significant changes with the Voc value ranging at 4 mV and Jsc in the range of 0.06 mA/cm2.

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Summary

- The provision of optimum NA acceptor dopping concentration with variations from minimum to maximum dopping shows that the N_a doping value significantly improves performance at $5x10^{18}$ cm-3 and keeping stable at $5x10^{19}$ cm-3. So that from the results of the WFtco variation, the value of the front contact work function used was optimal and combined with the N_a doping input so that the optimum result was shown at the dopping condition NA = $5X10^{19}$ cm-3 and the optimal WFtco at WFtco = 5.2 eV where the FOMs parameter value (Voc = 634.2 mV) was obtained; Jsc=51.2 mA/cm2; FF = 72.91 %) obtained optimum solar cell performance efficiency of 23.67%

- In the use of varied WFtco values, it was found that the occurrence of Achottky barrier on the front contact interface of the TCO/(p+)a-Si:H for a relatively smaller WFtco value (<5.0 eV), resulted in trapping the hole so that it could not move towards the front contact. Then at a high WFtco value (>5.0 eV) there is a tendency to form Ohmic contacts where a reverse barrier is formed so that hole injection into the (p+)a-Si:H layer and band-bending is increasingly visible, allowing the hole to be able to move to the front contact.

Thank You