Comparative simulation study between n- type and p- type Silicon Solar Cells and the variation of efficiency of n- type Solar Cell by the application of passivation layer with different thickness using AFORS HET and PC1D.

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ABSTRACT : - *In this paper, comparative study of p type and n type solar cells are described using two popular solar cell analyzing software AFORS HET and PC1D. We use SiN_x layer as Antireflection Coating and a passivated layer Al_2O_3 .The variation of reflection, absorption, I-V characteristics, and internal and external quantum efficiency have been done by changing the thickness of passivated layer and ARC layer, and front and back surface recombination velocities. The same analysis is taken by imposing surface charge at front of n-type solar Cell and we get 20.13%-20.15% conversion efficiency.*

Keywords: *- ARC coating, Surface recombination velocity, Passivation layer, Surface charge, AFORS HET, PC1D*

I. INTRODUCTION

Solar energy is an abundant source of green energy .It plays a crucial role due to increasing price of fossil fuel and acute shortage of them which also leads to global warming. At present more than 85% of the industrial solar cells are fabricated based on p type silicon material. The n-type solar cell is one of the interesting technological solution basically due to its lower recombination velocity, tolerance of higher temperature, higher carrier lifetime [1]. It offers high stabilized cell efficiencies because they do not suffer from light induced degradation(LID) caused by the simultaneous presence of boron and oxygen in the wafers[2], a phenomenon that in standard p-type silicon solar cells leads to a reduction of the module power output by usually two to three percent within the first weeks of installation. Second, n-type Si wafers are less sensitive to impurities that are usually present in silicon feedstock; consequently, fewer efforts have to be made to obtain n-type Si wafers with a high electronic quality.

On the other hand, one of the important reasons for decreasing efficiency for solar cell is the reflection of light from the air/silicon interface. This reflection reduces the external quantum efficiency. So an adequate layer of antireflection coating (ARC) can be used to match the optical impedance and reduce the reflection. SiN_x is most popular and commercially available ARC [3]. But SiN_x layer induces a positive surface charge density of the order of 10^{12} cm^{-2}[2, 4], so it has a detrimental effect on the efficiency of p+ / n or $p^+/n/n^+$ c-Si solar cell. To achieve a solar cell with higher efficiency, a highly effective surface passivation of the cell both at front and rear, should be required. Lower recombination velocity is achieved by using this passivation layer. Al_2O_3acts as good passivation layer [5]. So Al_2O_3 is sandwiched between SiN_x and p+ emitter of n type Solar cell. Weighted reflectance for Al_2O_3/SiN_x ARC stack is 10.50% [6] and it reduces the front surface recombination velocity upto10cm/s[7]. Al_2O_3 is a wide band gap dielectric (8.8 eV) with dielectric constant around 9 [8].

The aim of this study is to analysis the performance of the n-type solar cell and represents a comparison with p- type Solar cell using PC1D and AFORS HET. We also study the effect of positive and negative surface charges on the front surface of the n-type Solar Cell. To achieve maximum efficiency of n-type solar cell, we optimized the passivated layer thickness and the recombination velocity. This simulation is done by PC1D due to some difficulties facing during simulation with AFORS HET to increase the performance of solar cell.

II. SIMULATION AND RESULTS

The structure for the modeling of crystalline silicon solar cells used in this paper as shown in Fig.1. The background doping density of n-type base is 10^{16}cm^{-3}, and its thickness is 200µm. The p+ emitter has a peak density of 10^{19}cm^{-3}at the front surface, with the sheet resistance of ~100Ω/cm^2 and the emitter junction depth of 0.5µm.
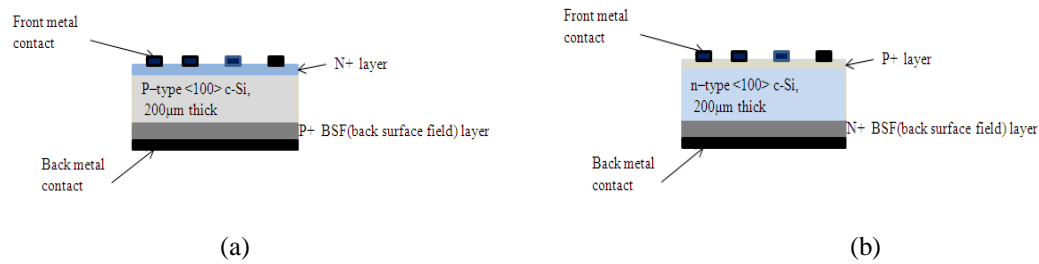
(a)   (b)

Fig 1: schematic diagram of simulated c-Si solar cell structure (a) n^+pp^+ and (b) p^+nn^+

The rear diffusion has a peak intensity of $10^{19} cm^{-3}$ with junction depth and sheet resistance. The electron and hole lifetime parameters were set at 100μs, for both n-type and p-type, the corresponding diffusion length of 400 μm and 139 μm respectively, with the background doping density of $1\times10^{16} cm^{-3}$ at the temperature of 300K. The front and back surface recombination velocities (FSRV) are about 1×10^{6} cm/s. The standard AM1.5G was chosen as the illumination source, corresponding to an intensity of 0.1W/cm^2 at 25°C. In addition, the texture depths of the front and rear surface were both 0.4μm, some important solar parameters of crystalline silicon solar cells are used in the simulations were shown in Table-1, and all of the other parameters were the default values in PC1D. Here both p- type and n-type cells are simulated and they both show more or less 12% efficiency.

Table 1: Variation of different parameters of N type Solar Cell

p-n-n+ type Solar Cell		n-p-p+ type Solar Cell	
Varying Parameters	Value	Varying Parameters	Value
Front and back side doping concentration	1E19	Front and back side doping concentration	1E19
Front side (p+) doping junction depth	0.4 um	Front side (n+) doping junction depth	0.4 um
Rear side (n+) doping junction depth	0.8um	Rear side (p+) doping junction depth	0.8um
ARC coating	No	ARC coating	No
Front and rear Side carrier recombination Velocity	1E6cm/s	Front and rear Side carrier recombination Velocity	1E6cm/s
Carrier life time	0.001s	Carrier life time	0.001s
AFORS HET simulation result : V_{oc}=620.7mV, J_{sc}= 23.94mA/cm^2, FF=83%, η =12.33%		AFORS HET simulation result : V_{oc}=672mV, J_{sc}= 23.26mA/cm^2, FF=83.82%, η=12.1%	
PC1D simulation result: V_{oc}=0.600mV, J_{sc}= 24.78 mA/cm^2, η=12.97%		PC1D simulation result: V_{oc}=0.595mV, J_{sc}=23.14 mA/cm^{2,} η=12.2%	

II.I AFORS HET SIMULATION GRAPHS FOR N TYPE SOLAR CELL

The reflection and transmission curve of the Solar cell at the particular condition using AFORS HET is shown in table 1. It has been observed that the Solar cell shows 40% reflectance, so the residual of the light should be absorbed into the cell.
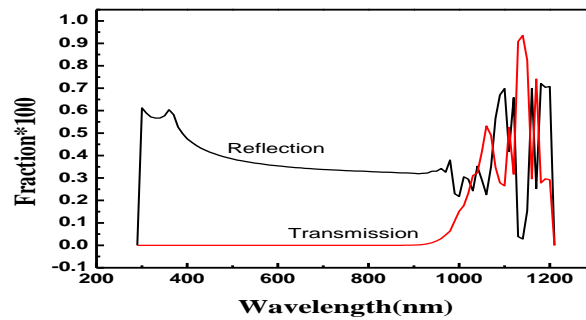
Fig.2: Reflectance and Transmittance curve for different   wavelengths

Neglecting the scattering and dispersion phenomenon the summation of reflection, absorption, and transmission will be 100%. In fig. 2 due to zero transmissions the residual light should be absorbed into the bulk material of the cell. Fig 3 shows the absorption with wavelength.
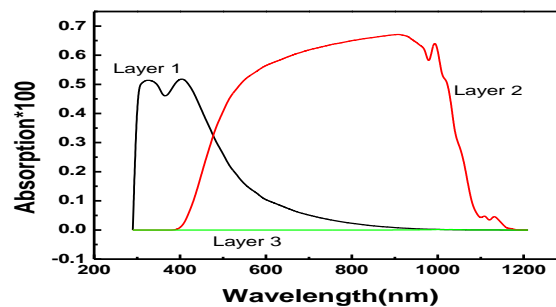
Fig.3: Absorbance curve for different wavelengths

The Fig. 4 indicates the simulated I-V curve of n-type solar cell. The open circuit voltage (V_{oc}) is the potential difference that is developed between the two terminals of the cell when external load resistance is large and the short circuit current (I_{sc}) is the current when load resistance is zero. The I_{sc} and V_{oc} are the key parameters for efficiency of the solar cell.
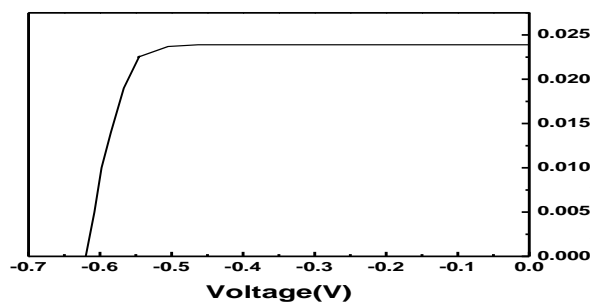
Fig.4.Current Vs Voltage curve of the Solar Cell

For increasing efficiency, the antireflection coating SiN_x is usually used on both p- type and n-type solar cell. Because of the high positive charge density of SiN_x film serves a poor performance for n-type solar cell than p-type [6]. The comparative result is shown in table 2.

Table2: Variation of efficiency in p- type and n- type Solar cell after giving SiN_x ARC

Description of ARC	Conversion Efficiency	
	N type	P type
PECVD(SiN_x) ARC coating thickness=75nm, refractive index=2.1	17.2%	18.2%

Surface recombination velocity plays an important role on the variation of short circuit current and open circuit voltage. Higher recombination rates at the top surface give a detrimental impact on short circuit current. Top layer surface recombination can be reduced by decreasing the dangling bonds of Silicon by using a passivation layer. It has already been reported that due to the presence of oxide layer Al_2O_3 serves as a good passivation layer for n type solar cell [5-7]. So in this paper Al_2O_3 is used to neutralize these dangling bonds which lead to decrease the surface recombination velocity (SRV) and increases the minority carrier lifetime. Table 4 shows the simulation result after giving Al_2O_3 on the surface of Si and above which we apply SiN_x Anti-Reflection coating [6]. The following result gives higher efficiency than the efficiency obtained in table 1 and 2.Al_2O_3/SiN_x stack layer reduces the FSRV up to 10cm/s[6].But before that operation SRV we adjust SiN_x and Al_2O_3 thickness for maximizing the efficiency[6].

The schematic structure of the p^+nn^+ crystalline silicon (c-Si) solar cell is used during simulation (AFORS HET) with SiN_x ARC and Al_2O_3 passivated layer as shown in Fig.5
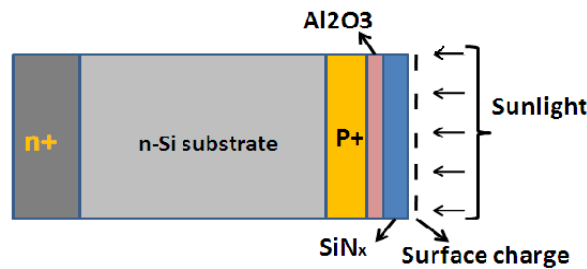

Fig.5 Schematic diagram for p^+nn^+ with SiN_x ARC and Al_2O_3 passivation layer

Table 3: Variation of efficiency with the variation of thickness with Al_2O_3 and SiN_x AR coating

Al_2O_3 thickness (nm)	SiN_x thickness (nm)	Efficiency ((%)
60	70	14.06
50	70	14.9
40	70	15.81
30	70	16.98
20	70	17.85
10	70	18.41
10	65	18.59
10	50	18.38
10	40	17.67

Table 4: Variation of efficiency with the variation surface recombination velocity with Al_2O_3 and SiN_x AR Coating

Front Surface Recombination Velocity (cm/s^2)	Rear surface Recombination Velocity (cm/s^2)	Efficiency (%)
1000	10000	19.94
100	10000	19.97
10	10000	20.12
10	1000	20.28
10	100	20.3
10	10	20.15
8	100	20.15
4	100	20.15

The final simulation analysis after development of Al_2O_3/SiN_x film above the emitter layer of n-type cell shows efficiency raises up to 7 % than the without Al_2O_3/SiN_x film on n type solar cell. The result is given below.

Table 5: Variation of different parameters of N type Solar Cell

Varying Parameters	Value	AFORS HET simulation result	PC1D simulation result
Surface passivation layer (Al_2O_3) thickness	10nm		
ARC coating thickness	60nm		
Front surface recombination velocity	10cm/s	Voc=750.3mV Jsc=37.12A/cm^2	Voc= 676.2mV ,Jsc= 35.3A/cm^2, η =20.13%
Rear Surface recombination velocity	100cm/s	FF=72.33%, η =20.15%	
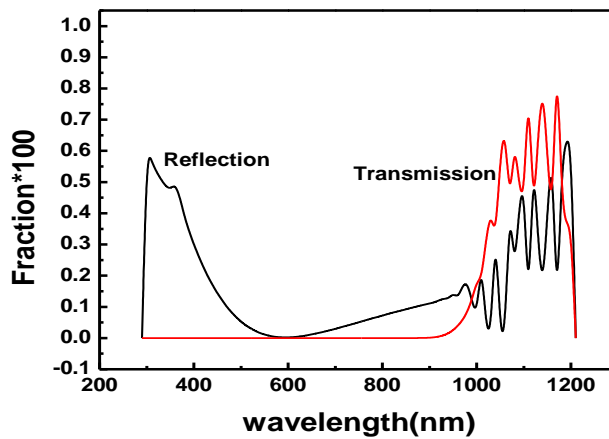
Fig.6 Reflectance and Transmittance curve for different

The reduction in reflection indicates the increase of absorption in bulk layer. We observed that the absorption is increases to 20% than the previous analysis as shown in Fig.7. The I-V characteristics graph as shown in Fig.8 provides a higher short circuit current density than the initial one. This implies due to the reduction of reflection and increasing the absorption the rate of generation of carriers has been raised, which increases the efficiency up to 20.13%. The simulation analysis shows standard reflection graph after giving Al_2O_3/SiN_x stack layer, which is shown in Fig 6.
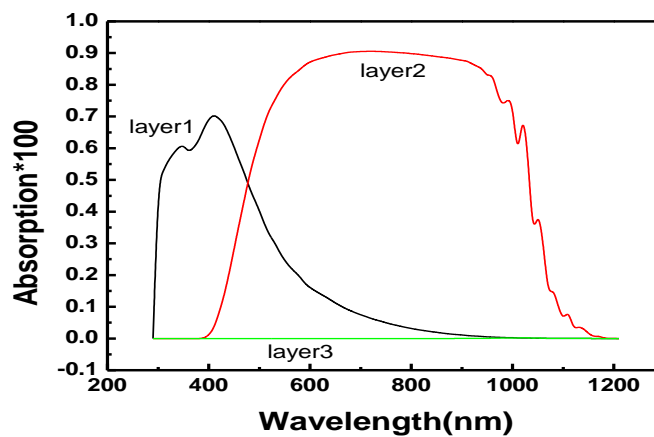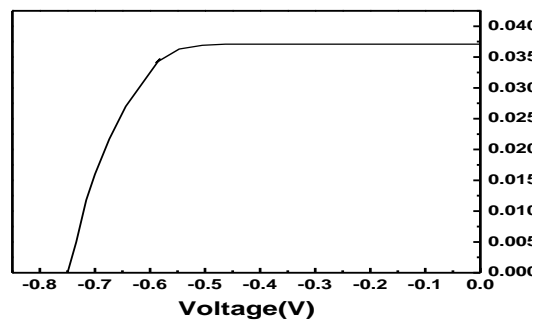
Fig.7 Absorbance curve for different wavelength

Fig.8 Current Vs Voltage curve of the Solar Cell

II.II QUANTUM EFFICIENCY VARIATION OF N TYPE SOLAR CELL WITH FSRV

The "quantum efficiency" (Q.E.) is the ratio of the number of carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell. The quantum efficiency may be given either as a function of wavelength or as energy. If all photons of a certain wavelength are absorbed and the resulting minority carriers are collected, then the quantum efficiency at that particular wavelength is unity. It is measured in electrons per photon or amps per watt. There are two types of quantum efficiency is generally considered. External quantum efficiency (EQE) which is the ratio of the number of charge carriers collected by the solar cell to the number of photons of a given energy incident on the solar cell from outside and the another one is internal quantum efficiency (IQE). It indicates the ratio of the number of charge carriers collected by the solar cell to the number of photons of a given energy that shine on the solar cell from outside and are absorbed by the cell. So the surface recombination velocity makes a deep impact on the variations of IQE and EQE. Higher surface recombination velocity implies that the rate of generation of charge carriers in the Solar cell reduces. So the IQE and EQE both must also be decreased with the increasing of surface recombination velocity. The simulation of the variation between front surface recombination velocity and IQE or EQE has been done by using both type of simulator such as PC1D and AFORS HET. The results are shown in the Fig. 9, 10, 11 and 12 respectively.
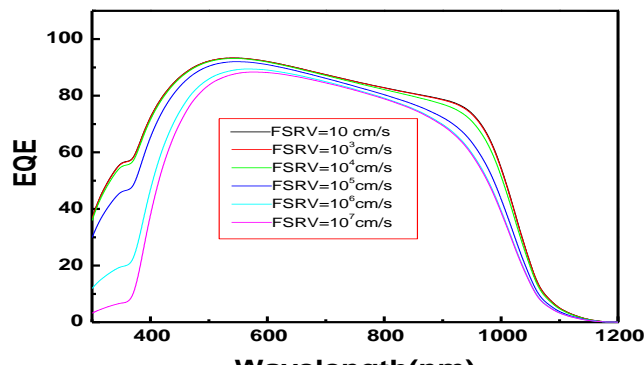

Fig9. Variation of EQE with different FSRV by using PC1D
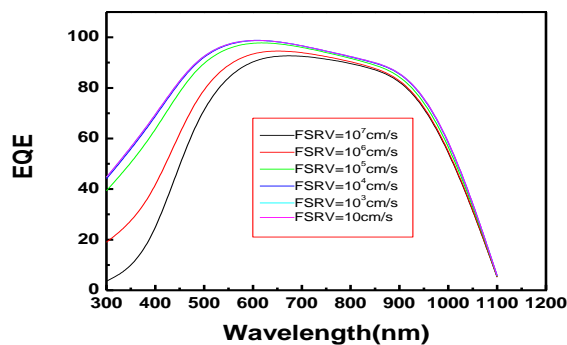

Fig10. Variation of EQE with different FSRV by using AFORS HET

Fig.9 and Fig.10 shows the variation of EQE with different FSRV. Both of the graphs indicate that the EQE reduces with the increase of FSRV due to the loss of carriers. In a similar way IQE also decreases with the increasing of FSRV. These results are shown in Fig. 11 and Fig.12 respectively.
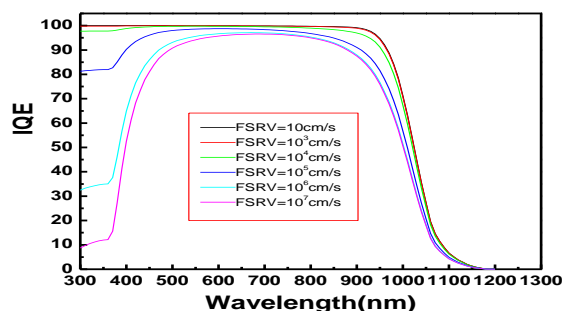
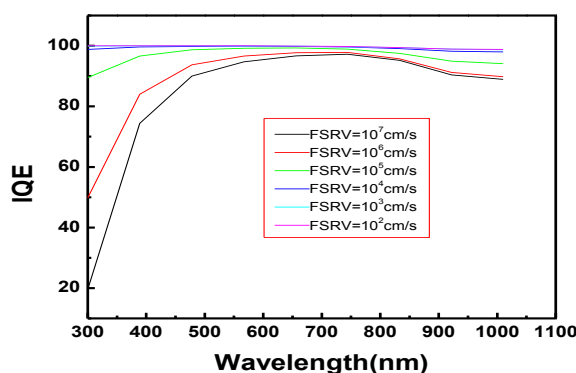Fig11. Variation of IQE with different FSRV by using PC1D

Fig12. Variation of IQE with different FSRV by using AFORS HET

II.III SURFACE CHARGE DENSITY ROLE ON SOLAR CELL EFFICIENCY

Now a different approach is performed by applying surface charge density at the front and rear surface of n-type Solar Cell [6]. Application of Surface charge density on the buffer layer Al_2O_3 enhances or reduces the recombination at the surface of the cell. This fact entirely depends upon the type of the polarity of the surface charge, doping of semiconductor layer and the type of buffer material. So positive and negative charge density has been imposed alternatively on the front surface of the cell and investigates the result. The effect of surface charge density is shown using PC1D simulation. For the simulations of Solar cell here FSRV 5000 cm/s, RSRV 100 cm/s is taken It has been observed from PC1D simulation results as shown in Fig.13 and table-7 that efficiency of the p^+nn^+ is increases with the presence –ve surface charge density on the front surface and maximum at -6.88×10^{12} cm^2. This amount of –ve charge can give maximum efficiency 19.87% of p^+nn^+ crystalline silicon solar cell(c-Si). On the other hand the efficiency of the c-Si solar cell is decreases with increase of +ve surface charge density as indicated in the Fig.13 and table-7.
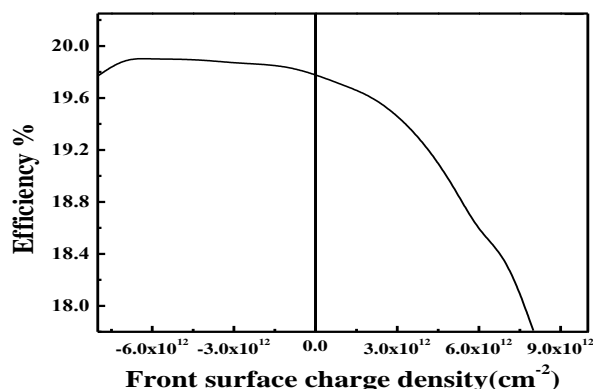
Fig.13 Variation of conversion efficiency with –ve and +ve front surface charge density

Table7: Change of Efficiency with the variation of Surface charge at SRV
FSRV=5000cm/s, RSRV=100cm/s

Surface Charge (cm-2)	Efficiency (%)	Short circuit current density(mA/cm^2)	Open circuit voltage(mV)
-8E12	19.77	36.17	-655.1
-7E12	19.91	36.24	-657.9
-6E12	19.9	36.24	-657.9
-5E12	19.9	36.24	-657.7
-4E12	19.89	36.24	-657.5
-3E12	19.87	36.23	-657.2
-2E12	19.86	36.22	-656.8
-1E12	19.84	36.21	-656.4
0	19.78	36.18	-655.3
1E12	19.7	36.14	-653.6
2E12	19.62	36.08	-651.8
3E12	19.47	35.99	-648.8
4E12	19.25	35.84	-644.7
5E12	18.95	35.61	-639.4
6E12	18.56	35.27	-633
7E12	18.39	35.1	-630.5
8E12	17.81	34.47	-622.3

III. CONCLUSION

We have reported that the fabrication process of n-type solar cells based on surface passivation layer leads to a record efficiency of 20.1% for large area crystalline silicon solar cell, while the same process on p-type solar cell resulted in 18.2% efficiency. By improving the front surface passivation somewhat higher efficiencies can still be obtained on n-type wafers by this process. High efficiencies may also be received on n-type solar cell if the –ve surface charge is imposed on the c-Si solar cell front surface by thin layer of Al_2O_3 passivated layer. With proper optimization of front surface charges more efficiency will be envisioned.

Acknowledgements

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