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Thickness and doping concentration optimization of a-Si/c-Si layers by computer aided simulation for development of performances solar cell

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***ABSTRACT*-The doping concentration and the thickness of different layers in the Hetero-junction with Intrinsic Thin layers solar cells (HIT) strongly influence their performances. We simulated, using AFORS-HET simulation software, the following layers structure: ZnO/a-Si:H(n)/a-Si:H(i)/c-Si(p)/a-Si:H(p)/Ag. We optimized the thicknesses and doping concentration of the emitter, buffer, absorber and the BSF layers.**

***Keywords*- Simulation, AFORS-HET, performance, HIT silicon solar cell.**

I. INTRODUCTION

Although the solar photovoltaic proportion in the global energy market is currently insignificant, there are signs that this is changing the demand is growing rapidly. This technology is attracting a large academic and industrial interest, and is considered by many to be the most promising for energy generation. Among many available different technologies for photovoltaic production, the HET silicon solar cells has been developed by SANYO Ltd 1994 [1,2].

The hetero-junction a-Si:H/c-Si is formed by depositing hydrogenated amorphous silicon on the crystalline silicon substrate. The resulting cells can achieve high conversion efficiencies while using thin film silicon processes to lower the cost in comparison with c-Si solar cells [3]. SANYO developed HIT with a very thin intrinsic hydrogenated amorphous silicon (a-Si:H(i)) layer which is inserted between two layers a-Si:H(p) and c-Si(n). However, most researchers concentrate on the exploitation of HIT solar cells on c-Si(p) substrates. This is motivated by the fact that the cost of c-Si(p) wafer is significantly lower than c-Si(n) on one hand and the fact that the microelectronic industries widely use p-type wafer for device fabrication on the other hand [1,4,5].

Numerical simulation is now almost indispensable for the understanding and design of solar cells. AFORS-HET (Automat FOR Simulation of HETero-structures) software has been developed by a group from the Hahn-Meitner Institute of Berlin and is used for simulating hetero-junction in solar cells [6]. The software provides a convenient way to evaluate the role of the various parameters (thickness, doping concentration, band gap, resistivity…) present in the fabrication processing of HIT solar cells [7,8].

In this paper, with the purpose to reduce the cost furthermore and promote the performance of hetero-junction solar cells, we optimized the doping concentration and the thickness of different layers of the solar cell.

II. SOLAR CELL STRUCTURE AND SIMULATION DETAILS

The simulated solar cell structure, as shown in Fig. 1, is ZnO/a-Si:H(n)/a-Si:H(i)/c-Si(p)/a-Si:H(p)/Ag. The emitter, absorber, buffer and BSF layers are a-Si:H(n), c-Si(p), a-Si:H(i) and a-Si:H(p), respectively. The ZnO layer is used as a front contact and the Ag layer as a back contact.

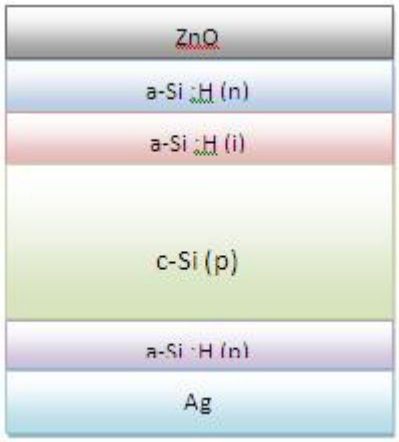

Figure I Schematic structure of the simulated solar cell

Figure 2 shows the distributions of the gap state densities of different layers in our solar cell. The defect density in crystalline silicon is chosen as single defect at 0.56eV with a concentration of 1x1010 cm-3. For amorphous layers, the density of states has been assumed to be both acceptor like states (in the upper half of the gap) and donor like states (in the lower half of the gap). Both of these acceptor and donor like states consist of exponential band tail and Gaussian mid-gap states.

The front and the back contacts were assumed to be flat band in order to neglect the contact potential influence. The surface recombination velocities of electrons and holes were both set to 107 cm/s (see Table 1). The solar AM1.5 radiation was adopted as the illuminating source with the power density of 100mW/cm2.

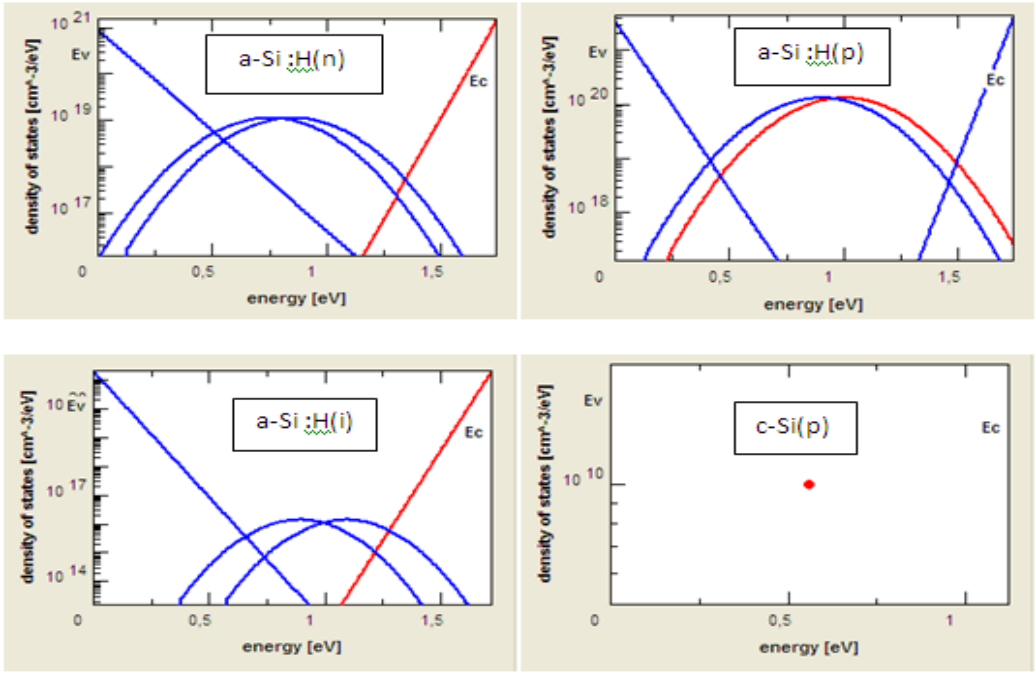

Figure II The gap state distribution of different types of a-Si:H layers and c-Si in the simulations

Many other standard parameters are taken into consideration in the present simulation. Their values are reported in table 1.

Tableau 1 Parameter values adopted for the bifacial HIT solar cell in the simulation

Parameter	a-Si :H (n)	a-Si :H (i)	c-Si (p)	a-Si :H (p)
Thickness (nm)	10	7	300.000	10
Dielectric constant	11,9	11,9	11,9	11,9
Electron affinity (eV)	3,9	3,9	4,05	3,9
Band gap (eV)	1,74	1,72	1,12	1,74
Effective conduction band density (cm^{-3})	10^{20}	10^{20}	$2,8x10^{19}$	10^{20}
Effective valence band density (cm^{-3})	10^{20}	10^{20}	$1,04x10^{19}$	10^{20}
Electron mobility ($cm^2V^{-1}s^{-1}$)	20	20	1040	20
Hole mobility ($cm^2V^{-1}s^{-1}$)	5	5	412	5
Doping concentration of acceptors (cm^{-3})	0	0	$1 x10^{16}$	$1x10^{20}$
Doping concentration of donators (cm^{-3})	$1 x10^{20}$	0	0	0
Thermal velocity of electrons (cm s^{-1})	10^7	10^7	10^7	10^7
Thermal velocity of holes (cm s^{-1})	10^7	10^7	10^7	10^7
Layer density (g cm^{-3})	2,328	2,328	2,328	2,328
Auger recombination coefficient for electron (cm^6 s^{-1})	0	0	$2,2x10^{-31}$	0
Auger recombination coefficient for hole (cm^6 s^{-1})	0	0	$9,9x10^{-32}$	0
Direct band-to-band recombination coefficient (cm^3 s^{-1})	0	0	$1,1x10^{-14}$	0

III. RESULTS AND DISCUSION

III.1 Optimization the doping concentration of different layers

The effects of the c-Si (p) doping concentration on the performance of the solar cell are shown in Fig.3. The results indicate that the doping concentration mainly influences VOC, the fill factor and the efficiency. Preferably NA is required to be higher than 8x1016cm-3 to obtain a good performance. Hence, it can be considered that NA of 8x1016cm-3 can be representative of the acceptable high doping concentration.

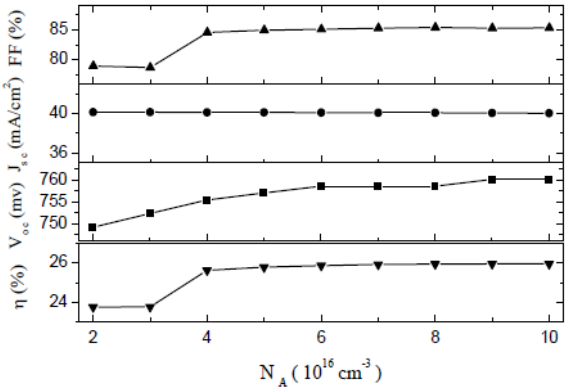

Figure III Effects of the c-Si (p) doping concentration on the performance of the solar cell

Figure 4 demonstrates the effect of the a-Si:H(n) layer doping concentration on the performance of the solar cell. The requirement for such a high doping concentration is due to the small conduction band offset between a-Si:H and c-Si, as well as the distribution of the gap states in a-Si:H and the interface states of a-Si:H/c-Si. We can see that when Ne increases, FF and the efficiency also increase. However, above a concentration of 3x1019 cm-3, the fill factor and the solar cell efficiency saturate. Therefore, an optimal concentration could just be 3x1019 cm-3. Moreover, a larger acceptor concentration is difficult to obtain in the laboratory.

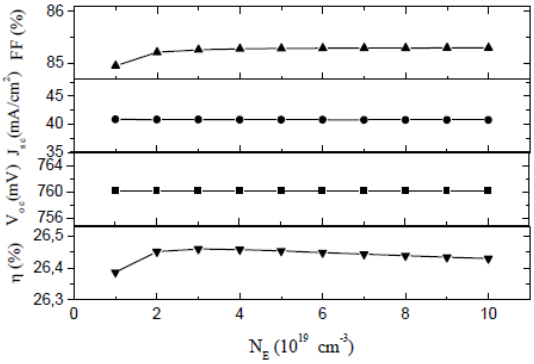

Figure IV Effects of the emitter doping concentration on the performance of the solar cell

Controlling the back surface field (BSF) is an effective way to enhance the performance of HIT solar cells. As seen in Fig.5, when the doping concentration of BSF layer increases, the performance of the solar cell also increases (VOC: 26,32 ~ 75,70mV; JSC: 4,8 ~ 40,8mA; FF: 36,65 ~ 84,83%; η: 0,4 ~ 26,46%). But when the doping concentration is higher than 8x1019 cm-3, the performances parameters of the solar cell remain constant.

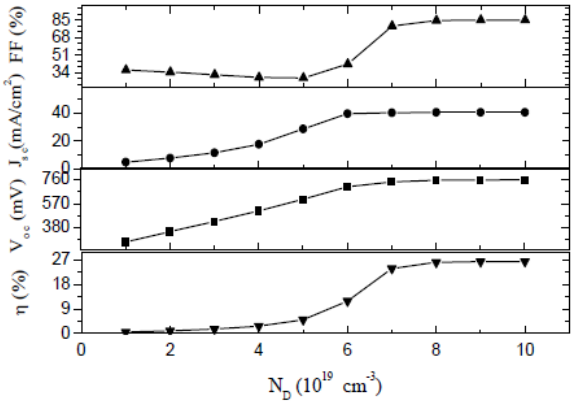

Figure V Effects of the a-Si:H (p) layer doping concentration on the performance of the solar cell

III.2 Optimization of thickness of different layers

The results of the variation of VOC, JSC, FF and η as a function of the absorber layer thickness are shown in Fig.6. It is clear that increasing the thickness of the absorber gives a reduction in VOC (from 792mV to 758mV), but it also produces an important increase in JSC (from 33mA to 40mA) and for η (from 23% up to 26%). In contrast, FF is almost constant (85%). the best performance is obtained with a thickness of c-Si equalizes to 300 µm, but we still can find good performances with a thickness inferior. for a thickness of 150, there is 772,6mV; 37,27mA; 85.46% and 24.61% for VOC, JSC, FF and η, respectively.

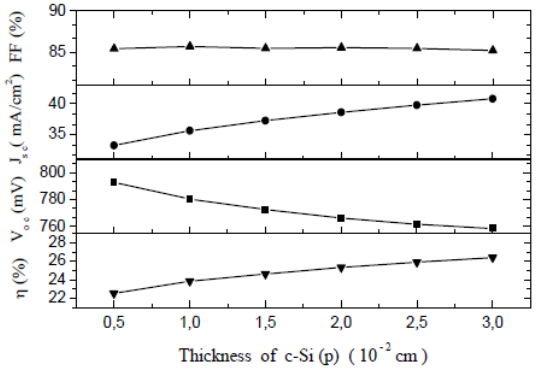

Figure VI Effects of the c-Si (p) thickness on the performance of the solar cell

With the purpose of lowering the cost of solar cells, we have chosen an absorber layer thickness of 150µm. The optimization of the thickness of the emitter layer a-Si:H(n) is performed by keeping the thicknesses of a-Si:H(i), c-Si(p) and a-Si:H(p) constant at 7nm, 150 µm and 10nm, respectively.

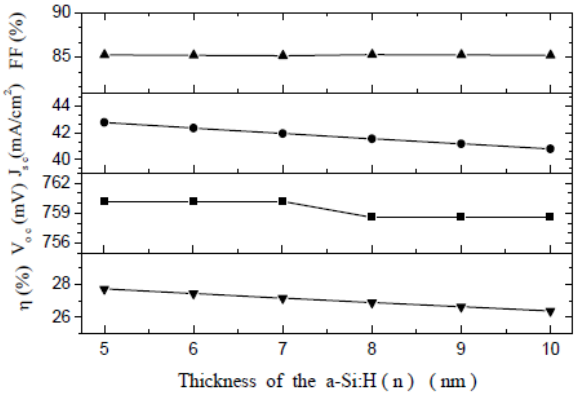

Figure VII Effects of the a-Si:H(n) thickness on the performance of the solar cell

The dependence of the cell performance on the thickness of the emitter layer is presented in Fig.7. The reduction of the considered thickness results in an increase of the JSC and η of the solar cell, although the VOC and the FF remain nearly constant. The simulation shows that a thickness of 1nm is optimal. This, however, is difficult to achieve in the laboratory, and a value of 5nm is therefore adopted.

According to figure 8, the thickness of a-Si:H(p) is chosen as 5nm.

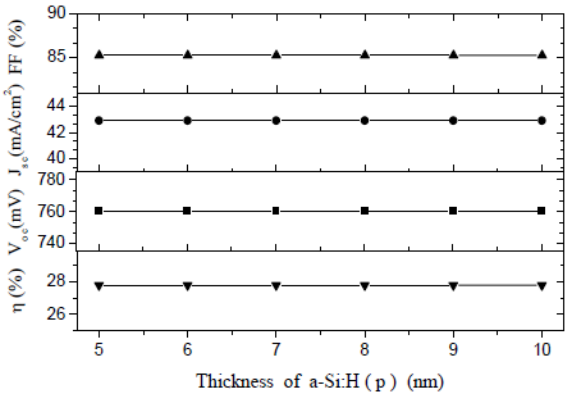

Figure VIII Effects of the a-Si:H(p) thickness on the performance of the solar cell

The dependence of the parameters VOC, JSC, FF and η on the thickness of the a-Si:H(i) layer is shown on Fig.9. it is seen that VOC and FF show no dependency and remain constant. JSC, on the other side, is found to drop from 42,40mA/cm2 to 41,29mA/cm2 when the thickness changes from 3nm to 10nm. Similarly η decreases from 28,1% to 27,3%.

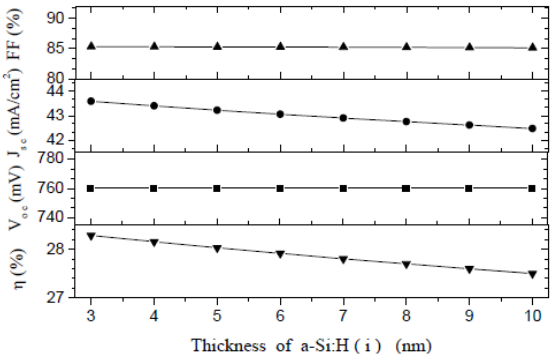

Figure IX Effects of the a-Si:H(i) thickness on the performance of the solar cell

IV. CONCLUSION

The effects of the doping concentration and the thickness of different layers on the performance of hetero-junction with intrinsic thin layer (HIT) solar cell have been studied using AFORS-HET simulation software.

It is shown that, after parameter optimization, a record efficiency of 28,1% could be obtained. Relevant parameters values are VOC(774,22mV), JSC (42,40mA/cm2) and FF of 85,57%. these results are obtained from the thickness of 5nm, 3nm, 150µm and 5nm of -Si:H(n) (emitter layer), a-Si:H(i) (buffer layer), c-Si(p) (absorber layer) and the a-Si:H(p) (BSF layer) , respectively. Concerning the concentration of doping, we have 3x1019cm-3, 8x1016cm-3 and 8x1019cm-3 at emitter, absorber and BSF layers, respectively.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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