International Journal of Scientific Research and Engineering Development-– Volume 3 Issue 2, Mar-Apr 2020

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Simulation of Interdigitated Back Contact Solar Cells for Efficiency Improvement

Chandana Sasidharan*, Som Mondal*

*(Department of Energy and Environment, Teri School of Advanced Studies, New Delhi

Email: chandana.sasidharan@gmail.com)

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Abstract:

Interdigitated Back Contact (IBC) solar cells are inherently energy efficient which can be made from both P and N type bulk region from wafers of sufficient quality. The most commercial successful models are made with N type bulk region. The manufacturing of N type bulk cells begins with P type wafer base and additional manufacturing stages increases the cost of production. The P type bulk manufacturing process is cheaper and simpler but suffers from defects especially due to Boron Oxygen Complexes.The purpose of this paper is to determine if it is possible to make efficient IBC cells fromCzochralski (CZ) crystals using P-type bulk, which is a cheaper alternative to N-type CZ. Simulation of IBC cells is performed using Quokka, a MATLAB based solar cell model. Taguchi arrays are used to reduce the number of simulations. Simulation results showed that for a 200 µm wafer thickness it is possible to reach a benchmark efficiency of 15% by maintaining surface recombination velocity around 10 cm/s if oxygen concentration below 10^{17}.

Keywords **—Interdigitated Back Contact Cells, Quokka, Solar Cell, MATLAB.**

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I. INTRODUCTION

Research on efficient and cost-effective solar cells is the need of the hour as there is an exponential increase in solar deployment globally.Interdigitated Back Contact (IBC) is an inherently energy efficientbut a costly Solar PV cell design. Due to its higher cost of manufacturing, IBC cell was originally designed for high concentration PV systems [1]. With improvements in manufacturing processes, IBC cells for terrestrial one-sun application became affordable[2]. Over the years IBC cells with Hetero-Junction technology havefound more success than Homo-junction technology[3][4].

There are a few manufacturers focusing on Homo-junction technology with Czochralski (CZ) wafers. SunPower[5]leads the manufacturing of high efficiency IBC cells from CZ crystals which have exhibited efficiency of 23.6%. Trina Solar [6] also makes IBC cells from CZ crystals using screen printing of contacts to reduce the cost. Another manufacturer ECN [7] has reported improvementtheir Mercury cell efficiency by 0.06% with innovative back surface design. However, the market penetration of Homo-Junction IBC will improve market if the manufacturing costs come down.

Most commercially successful IBC cellsare focused on N type of bulk region [5,6,7]. One of the ways to reduce the cost of manufacturing is by using P type bulk region. Theoretically IBC cells can be made from both P and N type bulk region from wafers of sufficient quality. One of the reasons why P type crystals don't make popular IBC cells is because they suffer from Boron-Oxygen(BO) complex defects [8]. The efficiency of IBC cells is directly proportional to the bulk minority carrier lifetime which is reduced by the recombination centers provided by BO complex [9].

The objective of the study is to determine if it is possible for IBC cells made from CZ with P type bulk to attain a sufficiently high efficiency level. Simulation of Interdigitated Back Contact cells was performed using Quokka, a MATLAB based solar cell model. The study intends to generate an optimized design for P type bulk cells to reduce major losses to improve efficiency.

II. LITERATURE REVIEW

Literature on simulations studies on IBC cells is available from the time they were originally conceived by Lammert and Schwartz.In IBC structure, the electron hole pairs generated in the bulk region is collected in the diffused junction at the back. Both the P and N junction being in the back the contacts are automatically in the back side of the cell. There are three major regions in back side: the Back Surface Field (BSF), Emitter and the Gap regionLammert and Schwartz performed simulations to understand the effects of parameters including bulk lifetime, front and back surface recombination velocity and thickness. [1]

Australian National University (ANU) has have championed IBC cells made from CZ with N-type bulk region. Quokka being an inhouse software has been extensively used by researchers at ANU. Franklin et.al [4] focused on back surface design optimisation in their Quokka based simulation study. Fong et al. [10] performed an optimization of back region of IBC Cells with N type bulk region using Quokka.Li et al. [11] has used Quokka and found that their simulation results and experiment results for IBC cells screen printed contacts match.

In p type CZ crystal which is boron doped and rich in oxygen recombination centers are created under illumination. These Boron Oxygen complexes are almost linearly related to Boron concentration and quadratically related to Oxygen concentration [12].The minority carrier lifetime in boron-doped and oxygen-contaminated silicon wafer is limited by a metastable defect caused by BO complex. This CZ specific defect [13] which acts as an attractive Coulomb center can be deactivated by annealing. Krühler et. al [14] found that dominant recombination process in solar cells made from compensated p-type CZ appeared to be proportional to the net doping rather than the boron concentration.

To the understanding of authors this is the first time a simulation study has been undertaken to design IBC cells with p type bulk focusing on the BO complexes. This is also the first case of use of Taguchi arrays to optimise the number of simulations.

III. METHODOLOGY

Recombination effects on the Open Circuit Voltage (V_{oc}), Short Circuit Current density (J_{sc}) and fill factor of Solar cells there by limiting the performance of the solar cells. The efficiency of the cell depends on the lifetime of minority charge carriers.

The tool that is used for simulation is Quokka and designs are checked to attain a benchmark efficiency level of 15%. As the model generated using Quokka is an electrical model, the optical modelling is performed using ray tracing. A unit cell of 400 x 100 µm and 80 µm thickness is modelled with P type bulk region with contact on back side. The back side of each unit cell is modelled with one emitter and BSF region each of 100 x100 µm. This left a gap region of 200 x 100 µm in the unit cell. The contacts in emitter and BSF region are 25x10 µm with a pitch of 50 µm.

Surface Recombination Velocity which is roughly the inverse of carrier lifetime, is used as the modelling parameter for front and back surfaces. The injectiondependent conductivities are calculated using Klaassen's [15]mobility model. Auger modelling was done based on Ritcher et al.[16]parametrization for the intrinsic lifetime of n-type and p-typecrystalline silicon at 300 K.

Taguchi methods are used to limit the number of simulations.TaguchiL9 arrays is employed to create orthogonal arrays toquantify the effects of the major factors affecting efficiency. The impact of four factors is determined by are captured in the using L9 arrays.Two sets of L9 arrays are used. The initial Low and High levels for the arrays are set based on literature review and later changes are made to the array based on simulation results. [17]

IV. RESULTS

A. *Effect of Surface recombination on efficiency*

All surface characteristics are captured using surface recombination velocity. From the simulations it was found that front surface recombination has an effect on both V_{oc} and J_{sc}, but not on fill factor. The results from the initial L9 (Table 1) array simulations showed that the highest efficiency achieved 19.98% corresponds to very high effective lifetime. The efficiency degrades to about 50% when the back- surface recombination velocity is in the order of 10000. The efficiency of the cell drops to about 25% when the FSF surface recombination velocity is the back surface is having very low surface recombination velocity is 1000 cm/s.

TABLE I
INITIAL TAGUCHI L9 ARRAY USED IN SIMULATIONS

No	Surface velocity in cm/s				Results
	FSF	Emitter	Gap	BSF	Efficiency [%]
1	1	1	1	1	19.98
2	1	10000	10000	10000	9.39
3	1	1000000	1000000	1000000	0.39
4	1000	1	10000	1000000	5.39
5	1000	10000	1000000	1	3.28
6	1000	1000000	1	10000	0.67
7	1000000	1	1000000	10000	0.55
8	1000000	10000	1	1000000	0.78
9	1000000	1000000	1000	1	0.05

The L9 array is refined based on the results additional simulations are run. The low, mid and high level of the recombination velocities to 10 cm/s, 100 cm/s and 1000 cm/s after in the second L9 array. The first observation from the simulation results is that there is only a 5% decrease in efficiency when surface recombination velocities increase to 10 cm/s from 1 cm/s. The emitter recombination up to 1000 cm/s does not seem to impact the fill factor and its effect on the efficiency seems slightly lower than Gap and BSF recombination, as the cell attains an efficiency on 14.6% when emitter is in high level, where FSF, BSF and Gap are in low and mid- level.

TABLE 2
REVISED TAGUCHI L9 ARRAY USED IN SIMULATIONS

No	Surface velocity in cm/s				Results
	FSF	Emitter	Gap	BSF	Efficiency [%]
1	1	1	1	1	19.0
2	1	10000	10000	10000	16.4
3	1	1000000	1000000	1000000	9.3
4	1000	1	10000	1000000	11.9
5	1000	10000	1000000	1	10.0
6	1000	1000000	1	10000	14.6
7	1000000	1	1000000	10000	6.1
8	1000000	10000	1	1000000	7.0
9	1000000	1000000	1000	1	7.2

The efficiency for front surface comes below 15% when the surface recombination velocity hits an order of 100 cm/s. The maximum surface recombination velocities for different regions in the back surface which is needed for the benchmark efficiency of 15% is BSF -300 cm/s, Gap- 800 cm/s and Emitter-1000 cm/s. The variation of efficiency with recombination velocity is available in Fig. 1.

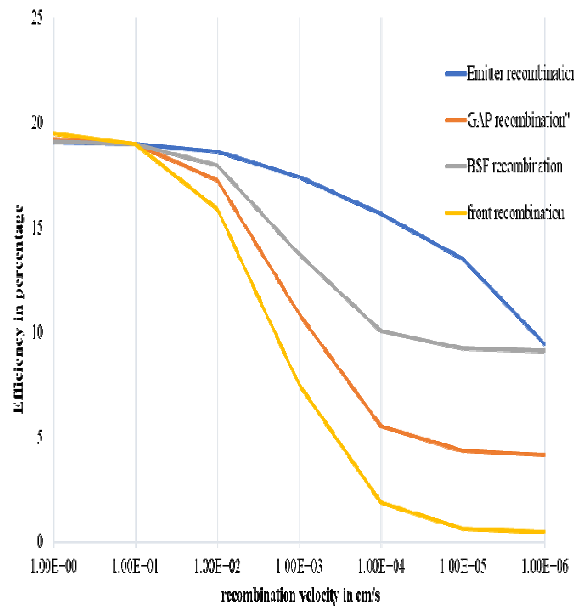

Fig. 1 Effect of surface recombination velocity on efficiency

B. *Effect of Boron Oxygen complex*

The modelling parameter for BO complex associated efficiency loss is through oxygen concentration. From simulations it was found that if oxygen concentration values are under

10^{17}benchmark efficiency can be achieved. The results are shown in Fig. 2.

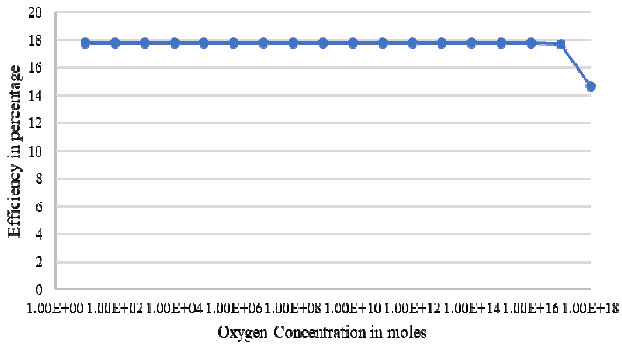

Fig. 2 Effect of oxygen concentration on efficiency

V. DISCUSSION

Manufactures have preferred CZ wafers cells of N type bulk over P type bulk for IBC cells which is reflected in research as well. A quick market review will reveal that most of the commercially successful IBC cells are of N type bulk. The demand for high quality bulk region explains the preference for N type bulk cells. The production of N type bulk cells requires specialized equipment like BBr3 diffusion furnaces.

The P type bulk region though rather unpopular in research and manufacturing community deserves a better look as the manufacturing process would be less complex and cost effective. With the increased deployment of solar power all over the world no stone should be left unturned. Increase in efficiency at a lower cost helps renewable energy compete with the conventional sources. The basic cell chosen for the study is a CZ Crystalline silicon cell with p type bulk, which exhibits the lower efficiency and is highly cost effective.

For a country like India this which is lagging in manufacturing facilities for solar cells a breakthrough of lowcost wafer, with standard industrial practices for a proven efficient cell structure can go longer way. Thus, the paradox of cost and efficiency of solar cells being inversely proportional to each other can be resolved.

In IBC cells to enhance the efficiency of IBC cells recombination in both bulk and surface regions should be reduced. Talking about surface recombination losses, increase in surface recombination velocity translates to decrease of effective lifetime and hence efficiency. The impact of recombination velocity on the efficiency can also be understood mostly from the variation happening in Open Circuit Voltage (Voc) and Short Circuit Current density (Jsc).

Among the surface recombination losses, the front recombination has significant effect than the recombination in back surfaces. Increase in front surface recombination velocity reduces both Voc and Jsc. To attain a benchmark efficiency of 15% the surface recombination velocity of front surface should be less than 100 cm/s. This value is applicable when the other recombination velocities are constant at 1 cm/s.

VI. CONCLUSION

A significant part of the losses in an IBC cell arises from recombination in surfaces and bulk region. P type crystals are generally not preferred for making IBC cell, but it is possible to obtain bench mark efficiency range of 15%. However, the simulation results are not verified experimentally.

The bulk region will have sufficient lifetime oxygen concentration of the crystal is less than 10^{17}. The impurities present in bulk region reduce the effective lifetime, hence benchmark efficiency level was not achieved.

For all the simulations, the short circuit current density is lower than the best commercially available cells though sufficiently high voltages are reached. The modelling done in Quokka is focused on electrical modelling and complex optical modelling is not undertaken.

Quokka does not allow modelling of junction depth and doping concentration for IBC cells. Though surface recombination velocity used in modelling depends on doping level and passivation at the surface, the precise effect of doping level on losses could not be considered. This is relevant especially for emitter contacted region where recombination losses and resistive losses needs to be balanced.

Emitter region is modelled using surface recombination velocity instead of dark saturation current density which is generally used. The recombination losses occurring in contacted regions are ignored for modelling and is not separately considered for analysis.

It is possible to conclude that p type bulk CZ crystals can be used to make efficient IBC cells if BO concentration is sufficiently within limits. Further research can be performed on optimization of front surface passivation as FSF has significant importance in IBC cells. Undertaking additional steps to include back surface geometry and contact area ratio for optimization. Another additional parameter important for efficiency is ratio of Emitter to BSF region. Improvement of modelling is possible only after fabrication and characterization of cell. Lack of research oh p- type bulk IBC cells was a constraint faced while modelling the base cell.

VII. ACKNOWLEDGMENT

The authors wish to express thanks to Andreas Fell and the team of Australian National University who developed Quokka. The team behind PVLighthouse.com is also acknowledged for their online resources on Quokka and setting file generator. This work was undertaken at Teri School of Advanced studies, the authors are thankful to the university for support.

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