New contact frame design for minimizing losses due to edge recombination and grid-induced shading

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ABSTRACT

Edge recombination and grid shading are two loss mechanisms which decrease solar cell efficiency. We introduce a new way for decreasing both significantly by a novel contact frame design which runs along the edge on the surface of a solar cell. No additional processing is necessary for preparing the contact frame. For a 100 cm^2 commercial c-Silicon (Si) solar cell the efficiency increased from 16.18 % to 16.83 % at 1 Sun (AM 1.5) as estimated by careful device simulation.

Keywords: edge recombination, shading losses, contact grid

1. Basic idea

A conventional p-i-n solar cell possesses an n^+ area (emitter) and p^+ area (Back Surface Field – BSF) which go very near the edge of the cell. At the edge losses occur due to imperfect passivation of the vertical edge area. In [1] the impact of loss mechanisms of the edge region on solar cell performance are described in detail.

Fig. 1 shows the basic circuit of a solar cell where the edge region is considered.

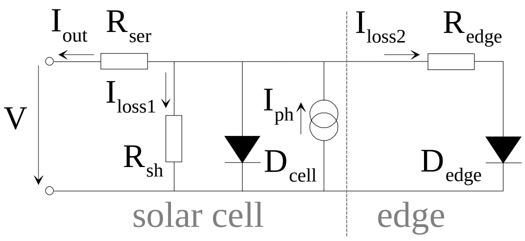

Fig. 1: circuit of solar cell with edge considered [1]

For minimizing the loss current I_{loss2} at the edge R_{edge} has to be as large as possible. Apart from the interruption of the conduction areas (n^+, p^+) a suppression of the optical generation of charge carriers G_{opt} near the edge would help reaching that goal. Hence the edge region without conductive areas should be shaded.

By using the area to be shaded for a contact frame [2] there are two main advantages:

a) reduction of G_{opt}, thereby increasing R_{edge} $\rightarrow$ reduction of I_{loss2}

b) substitution of contact bus bars by a contact frame which is situated in an ″inactive″ region (i.e. edge region) $\rightarrow$ reduction of shade loss induced by bus bars

2. Novel contact frame design

With the advantages mentioned a new contact grid design can be implemented. Due to increased length available for current collection the width of the frame can be reduced in comparison to the conventional bus bars.

Each corner of the solar cell can be contacted; that leads to a reduction of current per frame bar. The vertical ones have to conduct $^3/_{16}$ of I_{out}. The inner region of the solar cell is connected to the horizontal frame bars which therefore have to conduct $^5/_{16}$ of I_{out}. As a result the frame bars are roughly half as wide as the bus bars of the conventional solar cell so that no additional shading loss is induced.

Fig. 2 shows the new grid in comparison to a conventional one. Both cells consist of a 4″×4″ Si substrate.

Table 1 contains respective widths and total shading.

Table 1: dimensions and total shading of respective contact structures.

cell type	Finger [cm]	subbar [cm^2]	busbar [cm^2]	shaded area [cm^2]
conventional	0.01	---	0.2 (×2)	8.04
frame bar	0.01	0.02	0.1 (×4)	6.69

The contact frame is isolated from the active layer for preventing a short circuit to the edge. Hence the isolation of the active layer against the contact frame must be accomplished. For solar cells which do not use MIS tunnelling contacts that does not seem to represent a problem. Furthermore the frame must not reach the edge; a distance of 100 µm is assumed.

Fig.3 shows a cut through the frame cell near the edge.

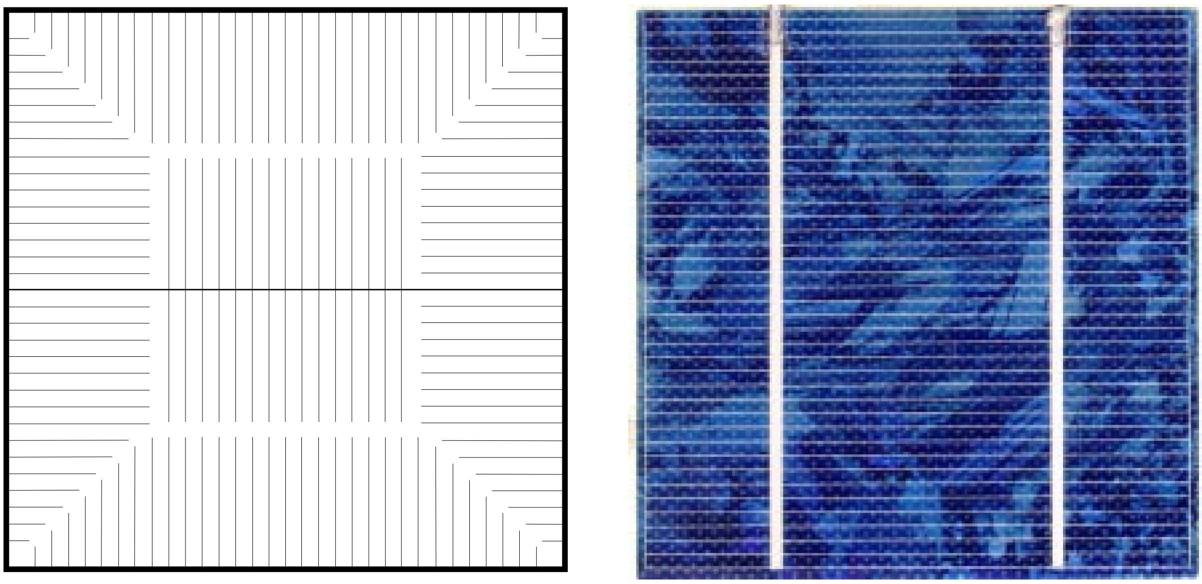

Fig. 2: novel (left) and conventional (right) contact grid design of solar cells

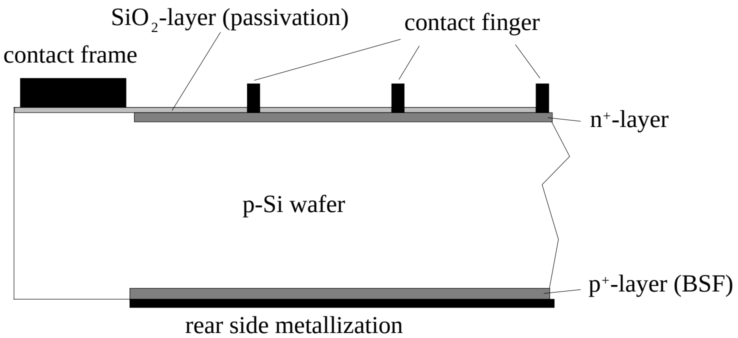

Fig. 3: cut through the frame cell near the edge

3. Technological aspects

For employing the contact frame no additional processes nor any modifications of existing processes are necessary. Only a new mask for printing of contact grid is required. The oxide window for preventing Phosphorous doping of the n^+ layer at the edge is used as insulating layer which is necessary for separating the frame from Si.

The Buried Contact Solar Cell [3] could be modified by cutting wider grooves along the edges which act as contact frame. However, the proper insulation of the frame against the n^+ layer may represent a problem.

4. Simulation results

For obtaining first results 2 dimensional simulations were carried out with TCAD 6.0 [4]. Respective shading was taken into account, concerning both shading width and position. The left end of simulation domain is the edge of the solar cell with a high recombination velocity.

A true scale simulation of the solar cells could not be carried out due to their lateral extension of 10^5 µm. Therefore a lateral downscaling with a factor of 125 was carried out, resulting in a lateral length of 400 µm for one half of the symmetric solar cell cross section. The thickness of the Si layer was set to 50 µm since there has to exist a significant bulk phase between n^+ emitter and p^+ BSF. The dimensions of the simulated devices and major parameters of the two solar cell structures are listed in table 2.

In figs. 4a,b the optical generation rate within the simulated solar cells is shown. Relations of illumination are clearly visible. The shading of the conventional solar cell is situated at the right end of the simulation domain (i.e. the contact grid leads to shading far away from the edge). The contact frame solar cell got its shaded area at the left end of simulation domain which represents the edge of the solar cells with a correspondingly high recombination velocity.

Table 3 shows the simulation results of the two solar cell structures.

The cells were simulated without structured surface (i. e. pyramids) as it is current standard of industrial manufacture. The shift of ray tracing was deactivated since the shading has to correspond exactly to the real cells.

Table 2: parameters of the respective simulated solar cell which differ from the ″Solar Cell″ example simulation project in TCAD 6.0.

magnitude	conv. solar cell	edge frame cell
S_{eff}(edge) [cms^{-1}]	5×10^{4}	
S_{eff}(front) [cms^{-1}]	1×10^{3}	
S_{eff}(rear) [cms^{-1}]	1×10^{3}	
τ_n(bulk) [µs]	1×10^{2}	
τ_p(bulk) [µs]	1×10^{2}	
base doping	1.41×10^{16}, Boron	
Q_{SiO2}(front) [cm^{-2}]	1.3×10^{11}	
Q_{SiO2}(rear) [cm^{-2}]	1.3×10^{11}	
w_{dev} [µm]	4×10^{2}	
d_{Si} [µm]	5×10^{1}	
FacetAngle(OPT.)	not activated	
shading (OPTIK) {proportional to actual shading}	first 26.76 µm at outer edge	first 32.16 µm at inner end of sim.-domain
shift (OPTIK)	not activated	

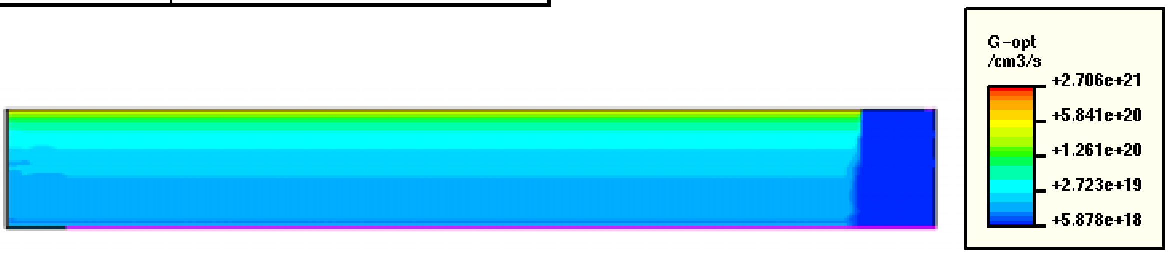

Fig. 4a: optical generation rate within simulation model of conventional solar cell

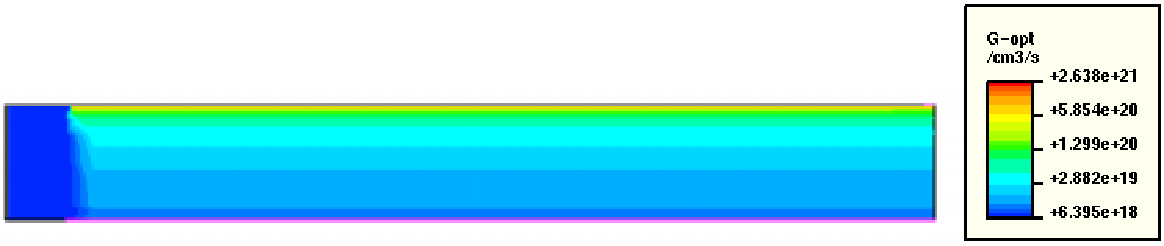

Fig.4b: optical generation rate within simulation model of solar cell with contact frame

Table 3: results of the respective simulated solar cells.

magnitude	conv. solar cell	edge frame cell
$\mathbf{J}_{SC}$ [$mAcm^{-2}$]	33.76	35.45
V_{OC} [mV]	605.5	634.8
$\mathbf{J}_{MPP}$ [$mAcm^{-2}$]	32.01	32.08
V_{MPP} [mV]	505.3	524.7
FF [%]	79.1	77.0
η [%]	**16.18**	**16.83**

Simulations of a conventional solar cell with shading loss identical to the edge frame cell (26.76 µm at inner end of simulation domain) revealed that *efficiency increases from 16.48 % to 16.83 % due to edge shading only*.

The increase in efficiency of 0.65 % absolute (4.02 % relative) seems to be rather small. However no change in solar cell manufacturing occurs apart from a new mask for the contact frame layout. Therefore the novel contact frame design can be employed immediately.

In principal the contact frame design is applicable to any type of solar cell which requires a contact grid.

5. Conclusion

The novel contact frame design introduced herein can improve solar cell efficiency on the order of 4 % relative to the efficiency of the same solar cell with a conventional grid design without altering the manufacturing process. A new mask for contact grid deposition is necessary only.

References

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