

# FRONT CONTACT MODELLING OF MONOCRYSTALLINE SILICON LASER GROOVED BURIED CONTACT SOLAR CELLS

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## ABSTRACT

Laser grooved buried contact solar cells (LGBC) are highly suitable for use in concentrator systems due to their comparatively low front contact shading and series resistance. A model has been developed to calculate the parasitic losses of the cell front contact considering series resistance and shading losses at the maximum power point. The details of this model are discussed with reference to different cell sizes, configurations and incident light concentrations. Using the optimum front contact design yielded by the model for a particular concentration and cell design, concentrator cells were fabricated using the LGBC cell process. Good agreement is found between the experimental results and the modeled data for concentration factors in the range 2X to 100X.

## INTRODUCTION

The current shortage of silicon feedstock favours the use of concentrating systems to extract more power from the available silicon supply. The actual deployment of concentrating PV systems has been limited to date with less than 1 MWp deployed in 2004. This is in part due to lack of proven robust concentrator technologies but also due to the lack of low cost concentrator cells. The ability of the LGBC cell technology to produce low cost concentrator cells has been previously described [1]. This current study describes the modeling of the front contact to determine the optimum cell size/design for different concentrations. The concentration versus efficiency flash test measurements for different cells modeled then fabricated are shown. This is to prove that the model produces cells with efficiency peaks comparable to the desired concentration values specified.

## LGBC SOLAR CELLS

The LGBC cell has been in high volume production for over 10 years and is currently being manufactured in large quantities by BP Solar in its Tres Cantos facility. In the LGBC process the front contact is plated into the groove. The copper contact is more conductive than the screen-printed silver contact fingers in the more traditional cell technology. This results in a lower LGBC cell series resistance and greater current carrying capability. Also the finger width in the LGBC cells is smaller than that of the screen printed technology resulting in lower cell

shading. LGBC cells have a selective emitter, the silicon nitride deposited early in the process is used as a mask so that the silicon directly under the grooves is more highly doped than the emitter. Therefore finger spacing can be reduced without a large effect on shading. This results in lower emitter resistive losses and lower contact resistance than the equivalent screen printed solar cells. These reasons make LGBC cells more suitable for use at concentration than traditional screen-printed technologies and they can be adapted to a range of concentrator applications from 2x to 100x.

## PARASITIC POWER LOSSES

When designing the front contact of a solar cell the parasitic power losses from the cell need to be minimized. These losses fall into two categories, shading losses and resistive losses. The shading losses come from the finite sizes of the fingers and busbars which prevent light from entering the cell directly below them. The resistive losses are the  $IR^2$  power losses from the resistive circuit. The resistive losses are made up from: the emitter resistive losses, the emitter/finger contact losses, the finger resistive losses, and the busbar resistive losses.

In order to gain the maximum power output, or minimum power loss, from a particular cell design there needs to be an optimization of power losses from the shading and resistive components. In order to produce designs for a range of concentrations a computer model has been developed to model efficiency losses at various light intensities. The model calculates the power output for a rectangular cell with the model variables being: the number and width of the busbars, the thickness of the tabbing (which is assumed to lie directly upon the busbars), the number of gridlines, metallization contact resistance and resistivity and the sheet resistance of the emitter.

## MODEL

Homogenous light is assumed to be incident at a fixed concentration upon the solar cell. For the simple case described here we assume that the spot size of the light produced by the concentrator lens is equal to the size of the concentrator cell being modeled. Using PC1D [2] and typical measured parameters for LGBC solar cells measured at the New and Renewable Energy Centre, Blyth, UK (NaREC) we obtain the current density and the

cell voltage at the maximum power point,  $J_{mp}$  and  $V_{mp}$  respectively.

As the light intensity is homogenous the  $J_{mp}$  and  $V_{mp}$  values are assumed constant across the cell. For simplicity the model assumes that current generated at one side of the midpoint between two fingers travels into the nearest finger. This current travels outwards towards the nearest finger in a perpendicular direction to the finger itself. The current then flows to the nearest busbar and out of the cell. Fig 1 shows a schematic of the current flow throughout the cell.

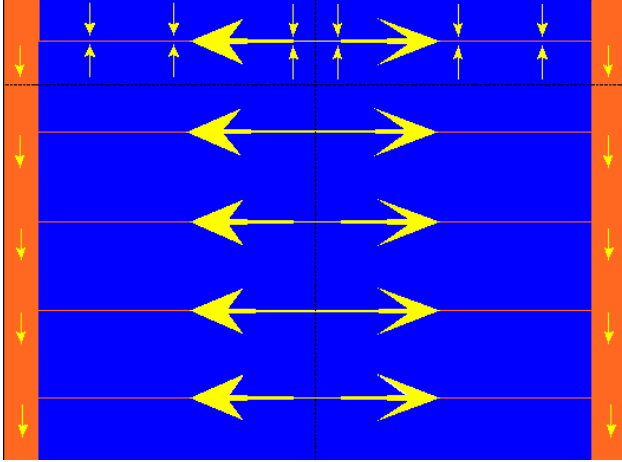


Fig. 1. Current flow through an idealised solar cell. Dotted lines indicate the bisectors between the fingers and the bisector between the two busbars.

The maximum power output of the cell design is calculated by multiplying the cell area by the  $J_{mp}$  and  $V_{mp}$  values.

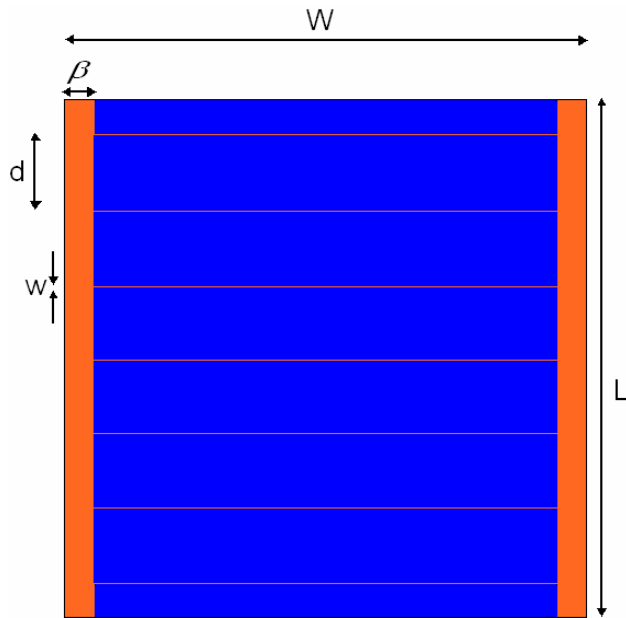


Fig.2. Solar cell dimensions used for equations 1-5.

The power losses from the resistive and shading components are calculated as shown in equations 1-5.

Busbar Resistive Losses:

$$P_{\Omega B} = \frac{4 \left( \frac{I_{\max}}{2} \right)^2 R_B L}{3Z\beta} \quad (1)$$

Contact Resistive Losses:

$$P_C = \frac{2R_C n_i \left( \frac{I_{\max}}{2n_i} \right)^2}{\left( \frac{W}{2} - \beta \right)} \quad (2)$$

Finger Resistive Losses:

$$P_{\Omega F} = R_F n_i \frac{2}{3} \left( \frac{I_{\max}}{2n_i} \right)^2 \cdot \left( \left( \frac{W}{2} \right) - \beta \right) \quad (3)$$

Emitter Resistive Losses

$$P_{\Omega e} = \frac{j^2 n_i (W - 2\beta) \cdot (d - w)^3}{12} \quad (4)$$

Shading Losses, Finger and Busbar.

$$P_{shad} = (n_i (W - 2\beta) w j V_{\max}) + (2\beta L j V_{\max}) \quad (5)$$

Where  $n_i$  is the number of fingers in a cell,  $R_e$  the emitter sheet resistance,  $R_b$  the busbar resistivity,  $R_f$  the finger resistance per unit length,  $R_c$  the contact resistance per unit length of finger,  $I_{\max}$  the total cell current and  $Z$  is the busbar thickness.

The constants needed in equations 1-5 not produced by PC1D or from the physical cell dimensions such as  $R_e$  and  $R_c$  are determined from measurement of solar cells produced by the same process method under the same process conditions. The busbar resistivity is assumed to be that of bulk copper.

The model can be used to work out the optimum front contact design for a particular concentration, the variables which can be modeled include all the parameters shown in Fig 2 and with slight modifications to the equations a different configuration and number of busbars can also be modeled [3].

## MODEL RESULTS

Fig 3 shows typical model outputs for a variation in the number of fingers. The size of the cell modeled was L=24mm and W=30mm with 3mm busbars for medium concentration.

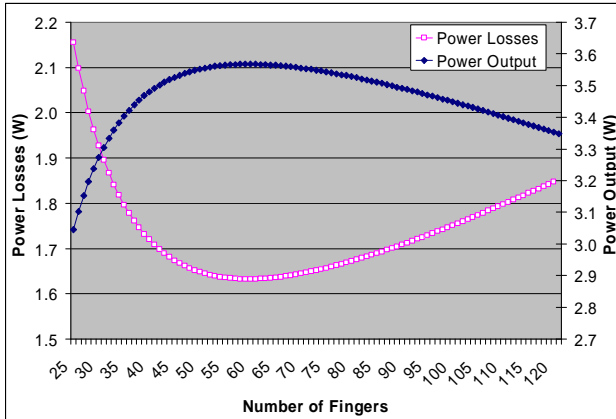


Fig. 3. Calculated power losses and power output for a two busbar cell designed for medium concentration.

Fig 4 shows the breakdown into its components of power losses for the cell for a varying number of fingers.

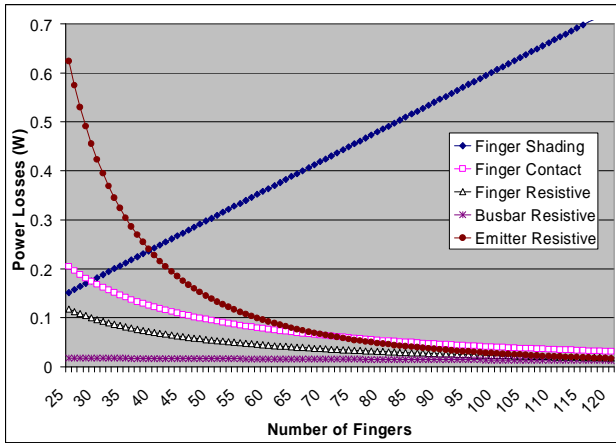


Fig. 4. Calculated power losses and power output for a two busbar cell designed for medium concentration

Fig 3 shows that the optimum number of fingers for this particular cell design is 60 as this gives the minimum power loss and therefore the maximum power output. The power loss components in Fig 4 show that increasing the number of fingers results in a decrease in all of the components described by equations 1-4, namely the resistive losses. This is mainly due to the area of the cell 'harvested' for current reducing as the number of fingers increases. However as the number of fingers is increased we observe an increase in the cell shading. At 60 fingers

we have a compromise between the power loss from the resistive losses and the shading losses. If we increase the number of fingers we reduce the resistive losses but the shading losses increase, reducing the overall power output.

## EXPERIMENTAL RESULTS

LGBC cells optimised using the model described for 10, 20 and 50X concentration were produced in small batches using standard CZ monocrystalline wafers with a bulk resistivity of around 1ohm-cm. The sizes of each of the cells and the sizes of the spots, and busbar widths for example, are all different for each cell type.

These cells were measured on a flash tester constructed by the Australian National University [4] modified to measure from 1-100 X concentration. The current density values were normalised to those previously obtained on the same cells from an Oriel solar simulator operating at AM1.5 and 1000W/m<sup>2</sup> luminance (1 sun). The Oriel Solar simulator 1Sun light level was set using a LGBC 1Sun cell calibrated at the Fraunhofer calibration laboratory in Freiberg at a temperature of 25°C.

Figs 5-7 show measurements of concentration versus cell efficiency for these cells.

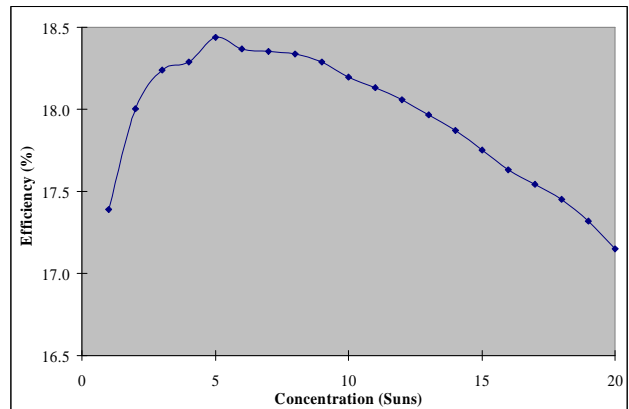


Fig. 5. Concentration vs efficiency for a typical cell optimised for 10X concentration.

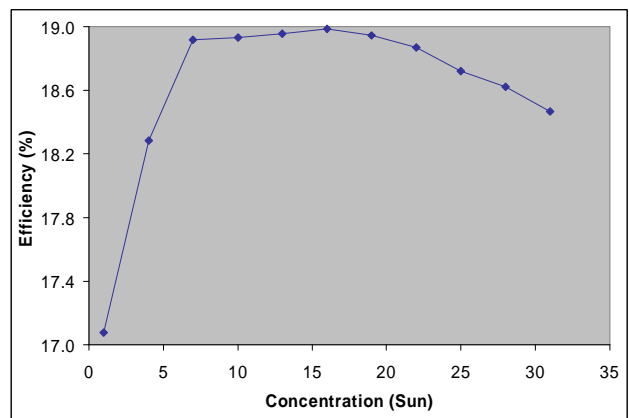


Fig. 6. Concentration vs efficiency for a typical cell optimised for 20X concentration.

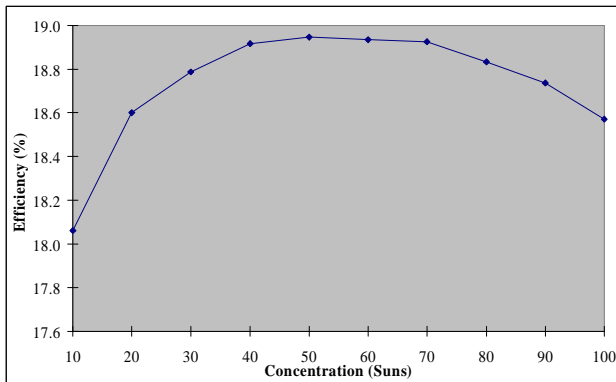


Fig. 7. Concentration vs efficiency for a typical cell optimised for 50X concentration.

The optimised cells yield a peak in the efficiency data at a concentration close to that at which the cells were initially designed to operate. Also we observe that the efficiency of the cells is always in the mid to high 18% range which is excellent for standard LGBC solar cells made through a low cost process. Indeed the 20X concentrator cells yield an efficiency of above 19% from a range 5-20X concentration. For more details of the technology potential of these LGBC solar cells the reader is directed to [5] at this conference.

A further experiment was carried out using the results of the model for 50X concentration. Three distinct cell batches were processed, the first batch with 6 less fingers than yielded by the model, the second batch with the optimum number of fingers and the third batch with 8 more fingers than the model suggested for optimum. The efficiencies of these cells at 50X concentration were generally highest (within processing parameters) for the number yielded as optimum by the model. The batch with fewer fingers was consistently poorer and the batch with more fingers was generally slightly poorer. This information is further evidence to suggest that the model works well.

## CONCLUSION

A simple model has been devised in order to calculate the optimum front contact design of a LGBC solar cell for a particular cell design and incident light concentration, details of the model were shown along with the typical outputs yielded. Small runs of concentrator cells were processed, the front contact designs used to manufacture these cells were the results of modelling. Concentration versus efficiency measurements were carried out on these cells and consistently produced high efficiency solar cells with peaks in efficiency close to the concentration parameter used in the model.

## REFERENCES

- [1] T. M. Bruton et al "Low Cost Concentrator Cells From One Sun Production Cell Technology" *Proceedings of the 2<sup>nd</sup> International Conference on Solar Concentration and Hydrogen, Scottsdale (2005)*
- [2] D.A. Clugston and P.A. Basore, "PC1D Version 5: 32-Bit Solar Cell Modelling on Personal Computers" *Proceedings of the 26<sup>th</sup> IEEE Photovoltaic Specialists Conference, (1997)* pp 207-.210.
- [3] A. Cole et al "Optimisation of the Front Contact for Low to Medium Concentrations in LGBC Silicon Solar Cells" *Proceedings of the 15th International Photovoltaic Science and Engineering Conference (PVSEC-15), Shanghai 2005. 1*, pp. 537-338.
- [4] W.M. Keogh, A.W. Blakers and A. Cuevas, "Constant Voltage I-V Curve Flash Tester for Solar Cells", *Solar Energy Materials & Solar Cells* **81** (2004) pp 183-196.
- [5] K. Heasman et al "Development of Laser Grooved Burried Contact Solar Cells for use at Concentration Factors up to 100X" *Proceedings of this conference.*