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Layout optimization for shingled solar cells

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ABSTRACT

Increasing a photovoltaic (PV) module's output power density is a reliable way to reduce electricity production costs. Along with improving solar cell conversion efficiency, another strategy is to minimize electrical and optical cell-to-module losses. The shingled photovoltaic module is a high-power PV module created by dividing and bonding cells with an electrically conductive adhesive (ECA). When compared to standard modules, the shingling approach has several advantages: lower ohmic losses, better area utilization, resulting in increased energy yield and better aesthetic appearance. As a result, it is critical to design the solar cell layout to achieve the best efficiency by limiting shading loss in the solar cell and must be planned accordingly. In this study, simulations are made using different finger and busbar numbers to determine the layout used to produce shingled cells. As a result of the simulations, managed the optimum efficiency and fill factor value with the number of 5 busbars and 110 fingers.

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1. INTRODUCTION

The interconnection pattern dates back to 1956 when a US Dickson Jr. filed a patent [1], two years after Chapin et al.'s first publication of a silicon solar cell [2]. Due to the intense competition in the solar module market and the desire to increase module power and efficiency without changing the module area, shingling has recently become a popular research topic among module manufacturers and research institutes worldwide. Small-scale or rooftop solar power generation exhibits a restricted installation area. Rooftop solar systems, in particular, require technologies that allow for high efficiency within the limited space of the roof area. As a solution, shingled cell design presents more power generation considering the same efficiency solar cell with a busbar [3]. In a conventional PV module, a metal ribbon is soldered to the busbar and connected to other solar cells. Therefore, the busbar corresponds to a shading area and the light-receiving active area is lost [4, 5]. Local heat transfer and soldering pressure to the cell can cause stress and microcracks [6,7]. However, it is experimentally proven that using ECA will essentially eliminate these potential problems [8].

When producing photovoltaic modules, the traditional usage of metal ribbon connections can be replaced with the electrically conductive adhesive (ECA) method of connecting solar cells [9]. Due to the cell connection in a busbar-free structure and the ability to produce high-power, high-efficiency modules, this technology expands the space that can be used for photocurrent production [10, 11]. The shingled PV modules are made using solar cell dividing and bonding technology. In the bonding process, an electrically conductive adhesive (ECA) is used to connect the cell strips, and the divided solar cell overlaps over busbars [12].

Since there are no need for more space to separate the cells, more divided cells can be placed into a module, increasing its density and output power compared to standard modules [13]. In addition, the divided cells have lower currents than before they were divided, which also reduces the electrical loss caused by the series resistance. However, the ECA used to connect the divided cells creates an extra resistance component whose value is affected by the curing conditions [14, 15].

In shingled cell manufacturing, there is no gap between the cells, enabling the creation of a high-density module to build a module with a higher output than a conventional module in the same space [16, 17]. Therefore, optimizing the mask design of the to be produced cell is crucial.

In this work, we performed front-side metal contact grid design of PERC solar cell and aimed to obtain better performance for the shingled module approach to design shingled cells with different busbar and finger numbers to obtain maximum power and efficiency using solar cell simulation software.

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2. EXPERIMENTAL

2.1. Method and Material

The mono-facial Passivated Emitter and Rear Contact (PERC) type solar cell structure investigated in this study for simulation purposes were designed on M2 type solar wafer (156.75 mm x 156.75 mm) size, p-type pseudo-square wafers. The sheet resistance value for the *n+* doped emitter region on the front of the solar cell is chosen as 80 Ω/sq as seen in Figure 1. Wafer bulk resistivity: 1.0 Ω.cm, cell thickness: 180 µm, and bulk lifetime: 300 µs are determined as simulation inputs as seen in Table 1. In addition to these, J_{01} and J_{02} were extracted from the literature and research of PERC solar cells fabricated on the production line of ODTÜ-GÜNAM for selected PERC cell structures [18].

Table 1. Solar cell parameters of PERC cells.

Emitter sheet resistance	*Cell thickness*	*Wafer resistivity*	*Bulk lifetime*
80 Ω/sq	180 µm	1.0 Ω.cm	300 µs

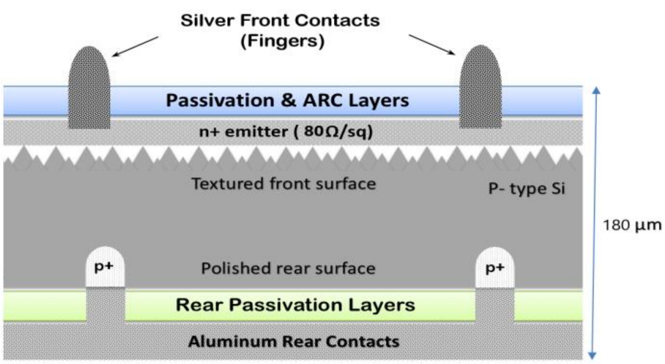


Fig. 1. Monofacial PERC-type cell diagram.

After reviewing the earlier research on the shingled cell, it was determined that 4 busbars, 5 busbars or 6 busbars production could be made in the shingled cell design, and simulation was performed in this direction. The finger width is 0.03 mm which is the same for every layout. For cell simulation, Griddler 2.5 PRO software has been used. This software is especially useful for metallization pattern designs in solar cells [19].

In recent years, the busbar width in the produced standard solar cells in the industry has been reduced to the range of 0.7-0.9 mm [20, 21]. The motivation for thinning the busbar thickness in normal modules is to reduce the shading on the front side of the solar cell without creating additional series resistance. In the case of a shingled module, since the busbars will not create shading on the front, the thickness of the busbar is in the direction of keeping the series resistance at a minimum level and creating a sufficient surface area for the slices to be properly bonded with ECA. In the simulations made in this study 1, 1.2, and 1.4 mm thicknesses were selected as busbar thicknesses.

The used values in simulations for J_{01} and J_{02} are listed in Table 2, which are the recombination parameters of the diffusion and the depletion region for the PERC solar cell.

As can be seen in Table 3, analyzes were performed using different busbar numbers, widths, and finger numbers to decide on cell design for the shingled module approach and efficiency optimization.

Table 2. Solar cell saturation current density values of the passivation and the metallization.

Saturation current density	*Front Side*		*Rear Side*
	Passivated area	*Metal contact*	*Metal contact*
J_{01}(fA/cm^2)	168	595	794.2
J_{02}(nA/cm^2)	0	5.66	0

Table 3. Cell layouts with different busbar widths and different finger numbers.

Busbar width	*Amount of busbar*	*Stripe width [mm]*	*Amount of fingers*
1 mm	4	37.06	86
			110
1.2 mm	5	28.26	120
			130
1.4mm	6	24.01	150

In this shingled cell design, when cutting the cell with the laser, 2 mm metal-free areas were left at the end of the fingers to prevent damage to the metal caused by the laser beam and deterioration of the cell. The overlap between the cell stripes varied between 1 and 1.5 mm.

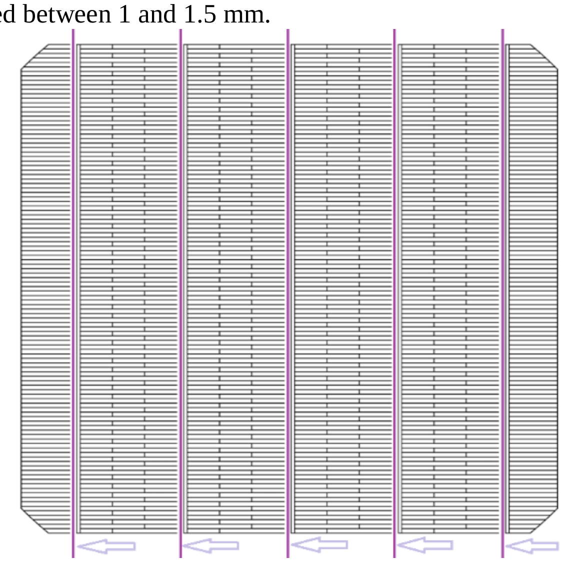


Fig. 2. The metallization design cutting the cell into five stripes.

Determining the number of fingers te defined on the cell and the optimal distance between the fingers is also important both electrically and optically due to shading. In this study, the number of fingers was changed by keeping the length of the cell constant, so the distance between the fingers decreases as the number of fingers increases. For this reason, simulations assist both to reduce the number of experiments and to achieve optimum results. In this study, different finger and busbar numbers were systematically categorized and analyzed.

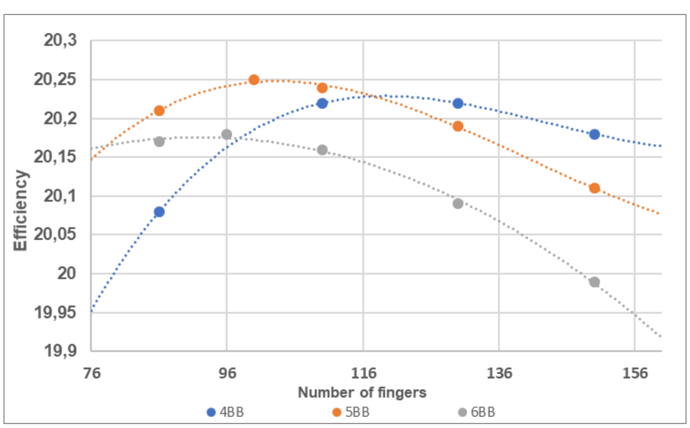
3. RESULTS AND DISCUSSIONS

For the selected PERC cell design, simulations were carried out in line with the parameters given above, and changes in cell efficiency are analyzed depending on busbar thickness, busbar, and, finger numbers. The graphs for three different busbar thicknesses are drawn separately and given below, respectively as in Figure 3 (a), (b), (c).

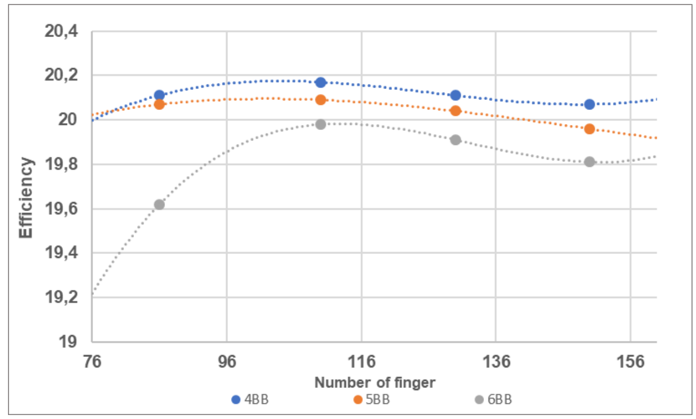
Here, depending on the metal grid design, the dominant parameters affecting the cell efficiency are; series resistance and fill factor (FF) changing depending on metal fraction, current density changing due to metal-induced shading, and open-circuit voltage values changing depending on metal-induced recombination rate. While deciding on the most suitable metal pattern design, all parameters should be at optimal values for the solar cell.

When the graphs given below are analyzed, it is observed that the efficiency values decrease after a point depending on the increase in the number of fingers. This is largely associated with a decrease in current density due to increased shading. Here, the increase in the metal-induced recombination rate due to the increase in the metal area is also an effective parameter. Depending on the increase in the metal area, the decrease in the series resistance and the increasing trend in the FF value were also confirmed in the simulations. For the fixed busbar thickness, an absolute increase of over 1% was observed in the FF value from 86 to 150 finger numbers. However, in the graphs related to cell efficiency, the downward trend in cell efficiency is seen after values of 110 fingers and above. This is largely associated with increased metal shading and metal recombination.
The simulations show that the cell simulated as 1/6 slices generates less series resistance (R_S) than the cell design with 1/4 slices; due to the shortening of the path that electrons have to travel from one end of the cell to the other end, i.e., the busbar area. In addition to all these, it was concluded that the 1 mm busbar thickness provides relatively better results than the other two thicknesses.

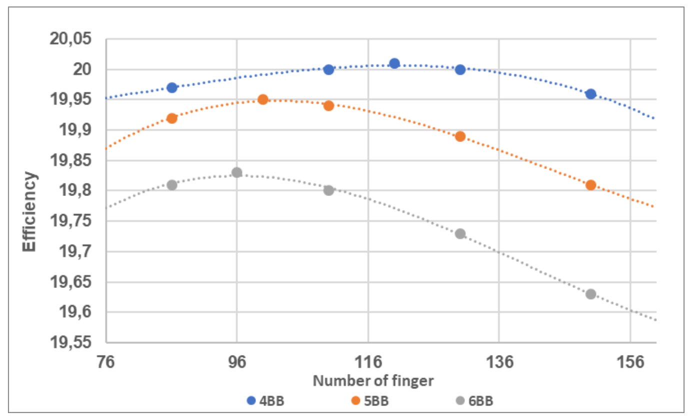
After all simulation results were evaluated in correlation, it was concluded that the combination of 5 busbars (1 mm) and 110 fingers is the most effective design for the front metal pattern design of the PERC cell, which has the potential to be used in shingled module production, in terms of the cell considered in this study. The cell simulation output for the specified combination is given in Figure 4.



(a)



(b)



(c)

Fig. 3. (a) Analysis results of 1 mm busbar width using different busbars and finger numbers, (b) analysis results of 1.2 mm busbar width using different busbar and finger numbers, (c) analysis results of 1.4 mm busbar width using different.

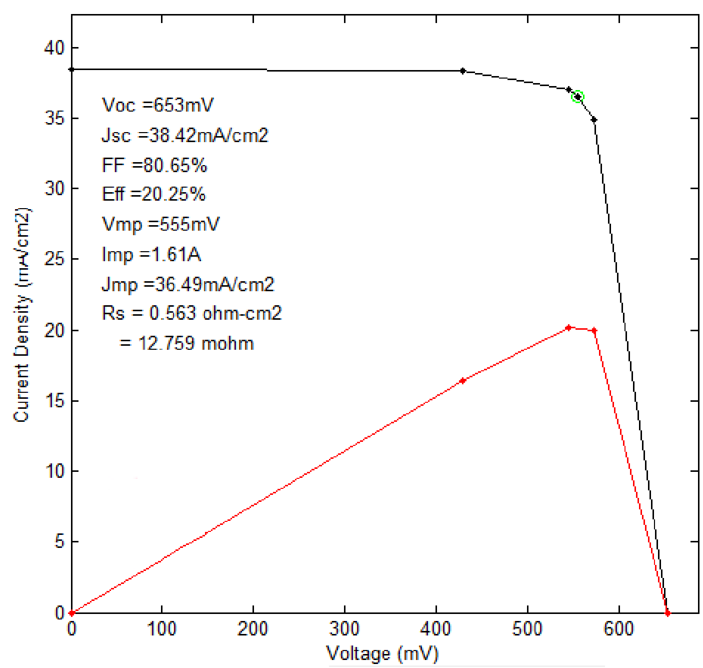


Fig. 4. Simulation results and I-V curve of 5 busbars 110 finger number design.

4. CONCLUSION

Shingled modules can be manufactured with all currently used cell technologies without requiring significant process changes, resulting in higher power density, improved energy efficiency, and superior reliability compared to regular modules.

In this study, the cell design was studied to meet the future expectations of shingled cells produced with different technologies.

According to the simulation results for the strips, we optimized the number of metal contacts we will use on the front surface of the cell to reduce the loss of efficiency. After then, for the shingled PV modules, we designed the busbar-free electrode layout for the crystalline silicon solar cells in this work. The new design makes it easier to apply electrically conductive adhesive, which will increase the production of shingled solar cells in comparison to conventional solar cells.

As a result, an effective front contact design for PERC cell structure is obtained and proposed by simulation results. Further studies will be in the direction of producing single modules using PERC-type cells with the design obtained with the proposed simulation approach and experimentally verifying the simulation results.

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Biographies

Ezgi Karahallı was born on January 7, 1996 in Antalya. She received a B.Sc. degree in Energy Engineering, from the Faculty of Engineering at Ankara University in 2021 and is continuing her M.Sc. degree in Micro and Nanotechnology at Middle East Technical University. She is currently a researcher at the Center for Solar Energy Research and Application (ODTÜ-GÜNAM). Her research interests performance, design, and optimization of solar cells for photovoltaic module applications.

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Talat Özden was born on August 27, 1976 in Gümüşhane, Turkey. In 1998, he finished his undergraduate degree at the University of Marmara. In 2008 and 2014, he graduated from KTU in the Department of Electrical and Electronic Engineering with MSc and Ph.D. degrees, respectively. He was at Dalarna University in Sweden as an Erasmus exchange student for one year in 2009. He worked as a lecturer at Gümüşhane University from 2002 to 2014. He has been working in the Department of Electrical and Electronics Engineering at Gümüşhane University as an Assistant Prof. since 2014. In the same period, he has been working as a researcher at ODTÜ-GÜNAM. His research interests are power management in renewable energy systems, photovoltaic system integration, system design and model-based control of agrivoltaics, and reliability and performance determination of solar power systems.

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