

Cell Size Effects on Concentrator Solar Cell Performance

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Abstract— The sun is an abundant power source that is clean and inexhaustible. Photovoltaic devices facilitate the collection of this energy. The practice of using relatively inexpensive optics to concentrate light to reduce the amount of expensive semiconductor required has been a large driver in terrestrial application of concentrator photovoltaics (CPV). Solar cell design is critical in optimizing the device for CPV conditions. The goal of this project was to design and optimize GaAs solar cells of sizes ranging from 0.0125cm² to 0.25cm² for operation under a light concentration of 500 suns. The parameter of cell size was investigated in this study, as it has major impacts on solar cell performance.

Index Terms—Concentrator Photovoltaics, GaAs, Solar Cell

I. THEORY

DECREASING cell size reduces the parasitic series resistance of the cell because lateral current transport is required over shorter distances. Decreasing the cell area also increases the perimeter-to-area ratio (P/A) of the cell. The sidewalls of the solar cell, left from the mesa (isolation) etch are unpassivated surfaces and can act as recombination centers for carriers. Smaller cells (higher P/A ratio) are much more susceptible to non-radiative recombination of photogenerated carriers which decreases collectable current density of the cell. Dark diode and one-sun I-V sweeps, and measurements under concentration (4.5-500X) were performed on all cells. At low voltages, diode current is dominated by recombination in the space-charge region, while at a higher voltage, recombination in the quasi-neutral regions becomes dominant. This is not always seen as series resistance can dominate at high current densities. A low diode ideality leads to high fill factors. The diode ideality factor (n) is an empirical fitting parameter in Shockley's diode model. It is indicative of the dominant recombination mechanism. An n of 1 shows that the majority of the current recombination occurs in the quasi-neutral regions, while an n value of 2 indicates that the majority of current recombination is in the space-charge region. Under concentration (high level carrier injection), device operation moves closer to the $n=1$ region and fill factor improves.

II. EXPERIMENT & RESULTS

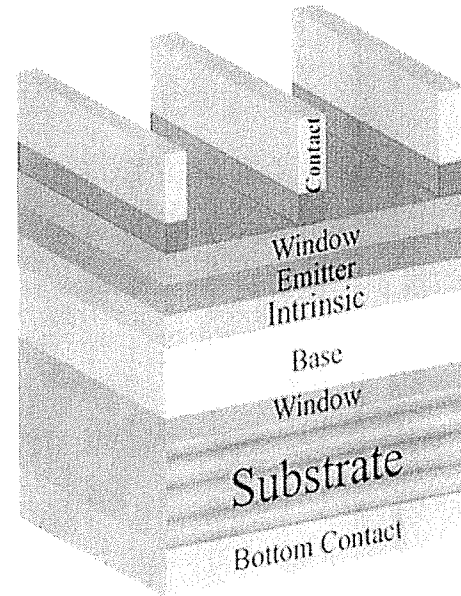


Fig. 1. Solar cell epitaxial structure.

Fig. 1 shows the pin diode structure. The epitaxial layers were grown in a metal organic chemical vapor deposition (MOCVD) reactor at NASA Glenn Research Center. The solar cells were processed at the RIT SMFL. A metal seed layer was evaporated onto the frontside of the 2" GaAs wafer, then the solar cell design was patterned and 6 μ m Au was electroplated. The metal seed layer was etched away and a mesa (isolation) etch was performed to electrically isolate each cell active area. The backside contact was evaporated.

Table 1. Cell size and 1-Sun performance results.

area (cm ²)	P/A	J_{sc} (mA/cm ²)	V_{oc} (V)	FF	η
0.0125	37.94	14.96	0.9168	79.23%	10.89%
0.01875	30.98	15.18	0.9309	79.41%	11.22%
0.025	26.83	16.33	0.9428	80.02%	12.32%
0.05	18.97	16.84	0.9602	80.40%	13.00%
0.125	12.00	17.94	0.9854	80.90%	14.30%
0.25	8.49	16.89	0.9962	81.19%	13.66%

Table 1 shows the solar cell sizes and 1-sun AM1.5G performance characteristics of photodiodes for the full range of cell sizes with busbar area removed from considered active

area. Only shadowing from the grid fingers is considered. At one sun, the power loss due to series resistance is very low, while the power loss due to shadowing is high since the design is optimized for higher concentration. Because of this, none of the benefits of using a smaller cell, mainly series resistance, are realized.

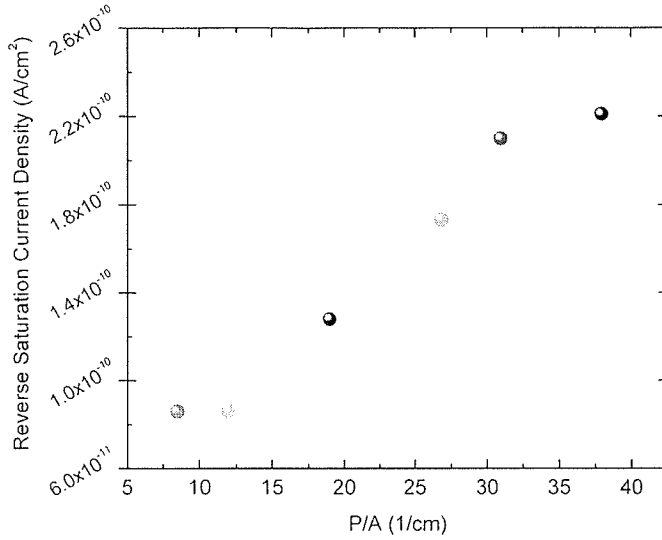


Fig. 2. Reverse Saturation Current vs. P/A Ratio

Reverse saturation current was extracted using a linear fit to the $n=2$ region of each photodiode. As shown in Fig. 2, reverse saturation current (J_0) scales linearly with P/A ratio. This shows that the total dark current is a function of a bulk contribution (J_{B0}) and a perimeter contribution (J_{P0}) to current where $J_0 = J_{B0} + J_{P0} \cdot P/A$. This term is the coefficient in the dark diode equation shown in Eq. 1.

$$\text{Eq. 1. } J_{\text{Dark}} = (J_{B0} + J_{P0} \left(\frac{P}{A} \right)) e^{\frac{qV}{n \left(\frac{P}{A} V_{oc} \right) kT}}$$

J_{B0} was $3.43 \cdot 10^{-11}$ A/cm² and the P/A dependent J_{P0} was $5.16 \cdot 10^{-12}$ A/cm².

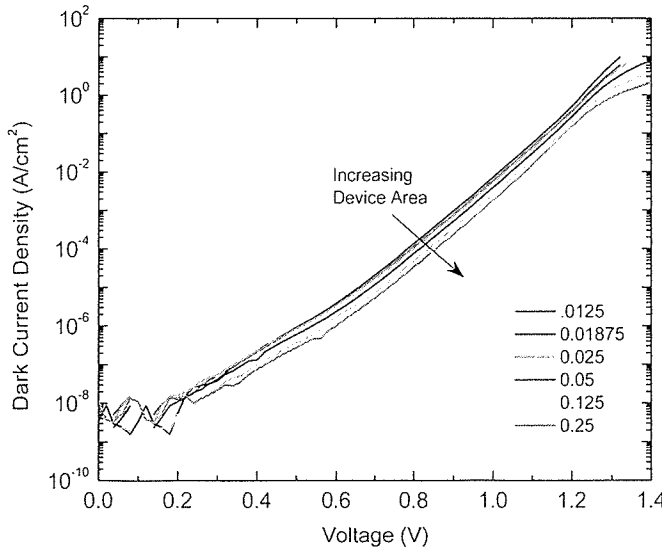


Fig. 3. Dark Current Density-Voltage sweeps for Cell sizes from 0.0125 to 0.25 cm².

Fig. 3 illustrates that diode dark current density scales with device size, with the highest current densities seen in the smallest devices, and the lowest current densities seen in the largest devices. This is consistent with expectations.

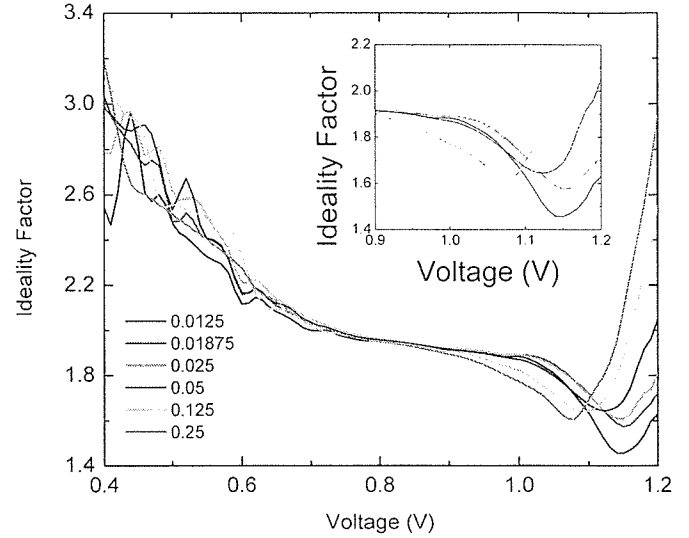


Fig. 4. Local Ideality Factor for Cell sizes from 0.0125 to 0.25 cm².

Fig. 4, the derivative of the log of the current with respect to voltage from the data in fig. 3, shows that as cell size decreases, the ideality factor approaches closer to $n=1$ before series resistance becomes the dominant component in the J-V relationship. The ideality factor also appears to stay closer to $n=2$ at higher voltages. This suggests that the perimeter component of the diode goes as $n=2$, as an increase in $J_{0(n=2)}$ would result in the $n=2$ diode characteristics continuing to be dominant at higher voltages.

Concentration measurements were taken at NASA Glenn research center on a Large Area Pulsed Solar Simulator (LAPSS). The wafer was placed on a chuck mounted on a monorail in the back of the room and a flash bulb was used to calibrate the system to 4.5-5 suns. The devices were moved closer (distance d) to the flash bulb, thereby increasing the effective solar concentration, proportional to $1/d^2$.

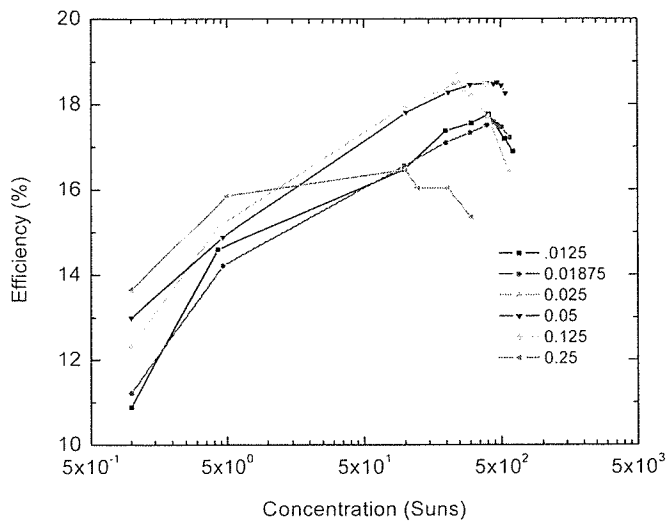


Fig. 5 Cell efficiency vs. LAPSS concentration for 0.0125 to 0.25 cm² cells.

As seen in fig. 5, Device efficiency peaked between 200-400x concentration as opposed to the 500x concentration they were designed for. A possible explanation for this would be a deviation from expected grid metal sheet resistance. This was measured to be $1.85 \times 10^{-2} \Omega/\square$ while the design used an expected sheet resistance of $3.69 \times 10^{-3} \Omega/\square$, using the resistivity of a 6 μ m gold film. Sheet resistance is determined by resistivity and film thickness, and the expected thickness of 6 μ m was achieved. This suggests that the resistivity of the gold film was higher than the pure bulk gold resistivity value used in the design. This can be caused by a high defect density in the gold, which has been seen in electroplating processes when the pH of the electrolyte solution deviates from the optimal value [2]. The smaller cells may have peaked closer to the 500x target because they are less sensitive to the increase in series resistance caused by finger resistivity.

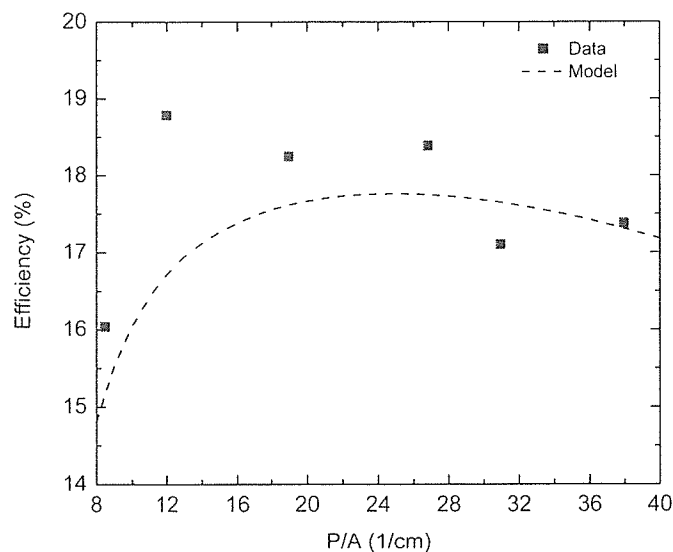


Fig. 6 200 Sun efficiency model and data.

At 200 suns, peak efficiency was projected to occur at a P/A ratio of 25 using a model derived from the P/A dependence of

Voc, J0, and n, and an empirical fill factor model[3], shown in Fig. 6. At this point, the power loss increase in dark current dominated over the decrease in power loss from series resistance. A heavy dependence on cell size was seen both in dark current and in diode series resistance. The deviation between the data and the model might be explained by deviation in peak concentration between cells. The falloff in efficiency after the peak concentration is less steep than the increase in efficiency as the solar concentration approaches the designed concentration. Since the larger cells are closer to, and past the peak concentration at 200 Suns, they may outperform the smaller cells, which peaked at higher concentrations.

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