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Electrical Circuit Analogues of Third-Generation Solar Cells

Chan K, Conibeer G, Shrestha S

School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney Australia

E-mail: kai-yuen.chan@unsw.edu.au

The general impetus of third generation solar cell technology has been to overcome the Shockley-Quiesser limitation, typically by reducing spectral losses during absorption. There are four spectral converters that change the nature of photon energies, split between the infrared focused (intermediate band solar cell and up conversion) and the ultraviolet focused (multiple exciton generation and down conversion). There are also two other types, in tandem cells and hot carrier cells, which have different mechanisms. As of yet, only up conversion has demonstrated effective enhancement with first-generation solar cells. Intermediate-band solar cells have considerable voltage retention issues, and both down-converters and multiple exciton generation have not achieved sufficient external quantum efficiency to properly act as an effective secondary device for a single-junction cell.

However, despite the similarities between them the practical differences to achieve the desired effect are distinct enough that there is difficulty in making progress by comparing across the four categories. This project makes a new approach in the field through the use of electrical circuits in the form of solar cells as absorbers, to be measured against the current devices. The use of circuits can also develop a model that has the backing of all the knowledge associated with electrical engineering. Given the state of the field, the ability to separate the fundamental processes and limitations from the material and fabrication issues would be a great benefit.

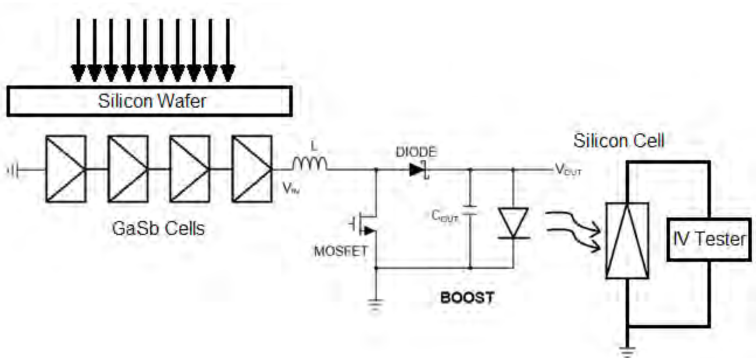

Figure 1. Schematic for the up-conversion circuit.

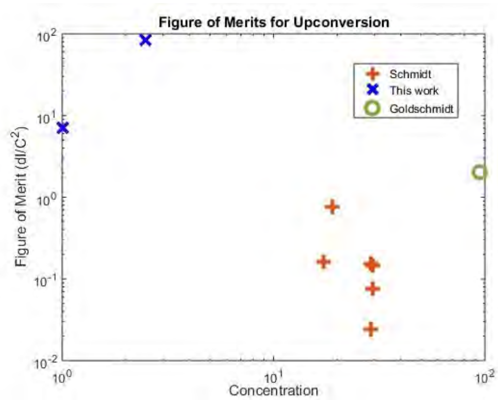

Figure 2. Up converter result comparisons.

In the last two years, the infrared conversion circuits that model the related third-generation technologies have demonstrated effective current gain at one-sun concentration, which other technologies have not been capable of showing. The up converter (Fig. 1) was created from an absorber array of four gallium antimonide cells, and a photon output using above-silicon band gap infrared LEDs. The array was run through a boost converter in order to raise the voltage to an appropriate level for the LEDs. The total device surpassed the current record (Fig. 2) for up conversion by Goldschmidt [2] by virtue of the fact that it operates at one sun with a reasonable short-circuit current boost. The figure of merit was a metric designed by Schmidt to normalise performance in relative to concentration, as the triplet-triplet annihilation organic molecules are known to scale quadratically and others should act similarly. Goldschmidt has a higher generated current, but at a concentation of 94 suns, whereas this experiment could generate a microamp current but closer to one sun.

The IBSC analogue (Fig. 3) used the gallium antimonide array connected in parallel with a silicon cell, which generated a 4% boost of the normal short-circuit current with no loss in voltage, as the array had a greater open-circuit voltage than the receptor cell. Performance of most devices in this field suffer from the detioration of voltage despite the significantly higher current gain [3].

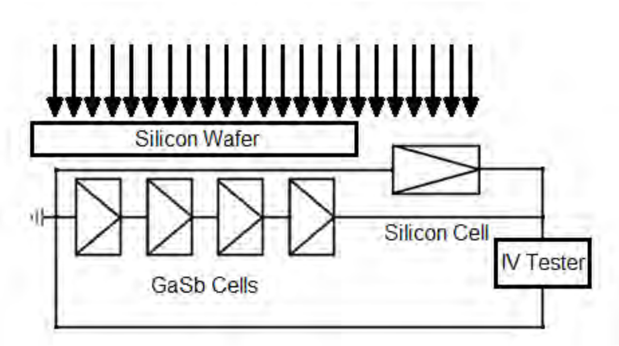

Figure 3. Schematic for the intermediate-band solar cell analogue circuit.

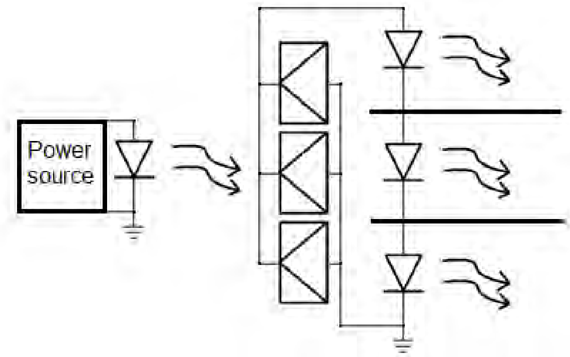

Figure 4. Schematic for down converter.

The ultraviolet spectrum devices have greater difficulties to demonstrate, but down conversion (Fig. 4) has been shown through the use of a gallium nitride solar cell with three indium gallium arsenide LEDs, though without accurate numbers for the quantum efficiency. The multiple exciton generation analogue (Fig. 5) is still under construction.

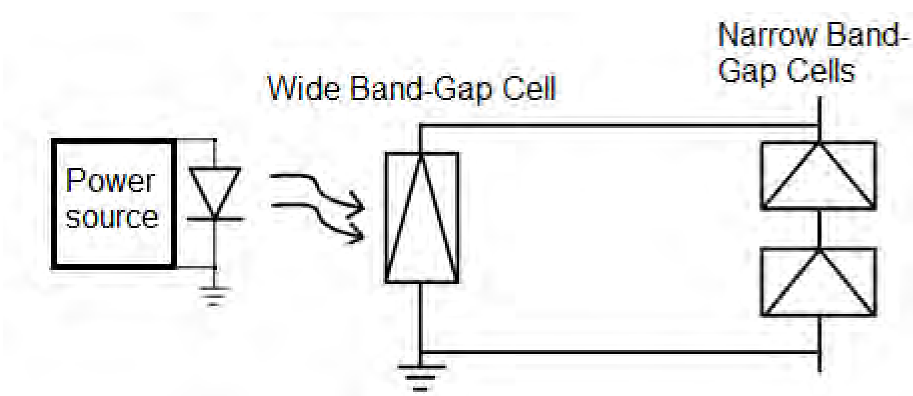

Figure 5. Potential schematic for multiple-exciton generation analogue.

All these designs are still under development, but their results show promise as a basis for comparison between the third-generation technologies.

References:

[1] Trupke, Thorsten, et al. "Efficiency enhancement of solar cells by luminescent up-conversion of sunlight." *Solar Energy Materials and Solar Cells* 90.18-19 (2006): 3327-3338.

[2] Fischer, Stefan, et al. "Record efficient upconverter solar cell devices with optimized bifacial silicon solar cells and monocrystalline BaY2F8: 30% Er3+ upconverter." Solar Energy Materials and Solar Cells 136 (2015): 127-134.

[3] Okada, Y., et al. "Intermediate band solar cells: Recent progress and future directions." *Applied physics reviews* 2.2 (2015): 021302.