Characterizing CPV in a Lattice Mismatched World

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1. Background

During the last decade, the explosive growth of multi-junction solar cell efficiency has led to resurgence in concentrator photovoltaics (CPV). During this time, the state of the art for characterization of CPV modules has been improving, with new equipment, such as solar simulators [1], being introduced, and many articles about characterization methods indoors and out, [2]–[4]. This body of knowledge is now being partly codified in a new IEC standard, 62670-3. However, during this time almost all extent CPV modules have used lattice-matched triple junction GaInP/GaInAs/Ge (LM-Ge) solar cells. This architecture has certain aspects which simplify its spectral characterization:

- Most importantly, the third junction produces far more current than the other two, so that we can assume that it is never the limiting subcell. Thus the light spectrum can be completely characterized by a single spectral matching ratio, SMR_{Mid}^{Top}, and in general the amount of energy beyond 900nm can be ignored. This holds true for both indoor as well as outdoor measurements.
- The bandgap of the second junction is high enough such that all effects of perceptible water vapor on the solar spectrum fall almost entirely into the third junction such that SMR_{Bot}^{Mid} is mostly related to the atmospheric variables that Air Mass (AM) and Aerosol Optical Depth (AOD), whereas Perceptible Water Vapor (PWV) is mostly seen to affect SMR_{Bot}^{Mid} [5]

Now, higher-efficiency alternatives to LM-Ge cells are moving from the laboratory to industry. In 2012, Semprius signed an agreement with Solar Junction and exclusively use their GaInNAs-based (1eV bottom) LM cells. In 2014, Azur Space, switched their commercial line-up of terrestrial multi-junction cells to 42% efficient upright metamorphic, with a Germanium bottom, but top and middle subcells with lower bandgaps than that imposed by the Germanium lattice constant. Also in that year, the world record was set for the first time by a four-junction wafer-bonded device. It is clear that the world is moving on from the LM-Ge cell.

2. Experimental

In this work, we discuss difficulties we have faced while characterizing non-LM-Ge based CPV modules at the Instituto de Energía Solar, including:

1. For MJ cells with a 1eV bottom, bottom sub-cells may be current matched to the other two cells at reference spectrum. Even in cases where JBot > (JTop = JMid) if the bottom cell fill factor is low, such as in the case of a GaInNAs cell, variations the amount of energy in the bottom cell will impact the overall cell IV curve. We find this to be especially important in our indoor measurements. Our Xenon source, unfiltered exhibits SMR_{Bot}^{Mid} of approximately 0.83. In this work we measure a GaInNas-based CPV module using a custom water filter to ensure a triple-match ($SMR_{Mid}^{Top} = SMR_{Bot}^{Mid} = 1$) and show that measurements made without this filter may cause estimations of module power. (Figures 1 and 2)
2. In the case of metamorphic sells, with lower bandgaps in the middle cell, we find that certain spectral artifacts that previously had little influence on the middle cell (and therefore on ratio of J_{Top} to J_{Mid}) are now more important. The absorption peak caused by PWV, or in the case of indoor measurements, Xenon's spectral lines, have a far-greater effect on the middle cell than previously. This will cause measurement errors if LM-Ge isotypes are used for spectral characterization. (Figures 3 and 4)

References

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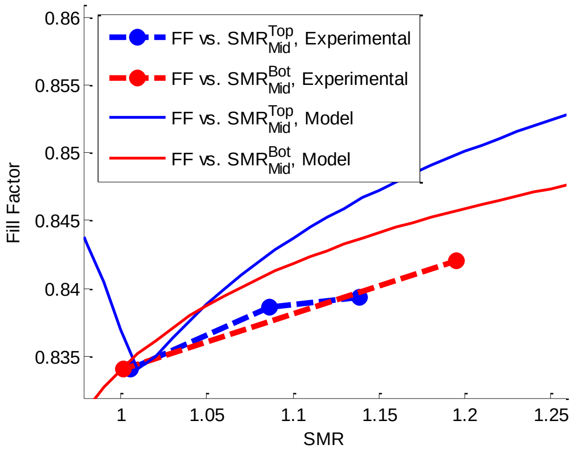

Figure 1: Fill factor for a module using GaInNAs bottom cells. The SMR on the x-axis show excess of energy as compared to the middle. (SMR_{Mid}^{Bot} is shown rather than SMR_{Bot}^{Mid}). SMR are measured with GaInNAs-based isotype cells. We observe that an excess in either the top or bottom bands as compared to the middle causes approximately the same increase in fill factor, that is the two SMR are equally important for a correct measurement of Fill Factor.

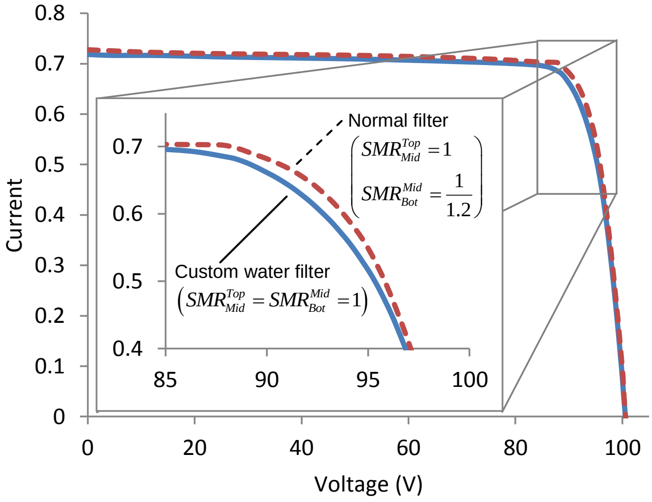

Figure 2: IV curve of the GaInNAs module with normal spectral filtering applied (allows 20% excess energy in the bottom cell), dashed lines, as compared to that obtained with the custom water filter (triple spectral match), solid lines. The inset shows the knee of the curve, where the overestimation of FF in the first case, due to over-saturation of the bottom cell, is apparent.

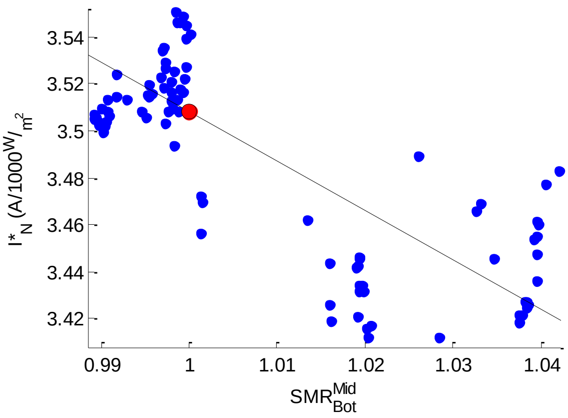

Figure 3: The short circuit current normalized to irradiance, filtered for $SMR_{Mid}^{Top}=1\pm.01$, is shown over a number of days w.r.t. SMR_{Bot}^{Mid} . The sensor used to measure the SMR values in this case were LM-Ge isotype cells. The inverse relationship scene is due to loss of current in the middle cell as PWV increases. In other words, LM-Ge isotype cells cannot correctly characterize the spectrum for modules using these cells.

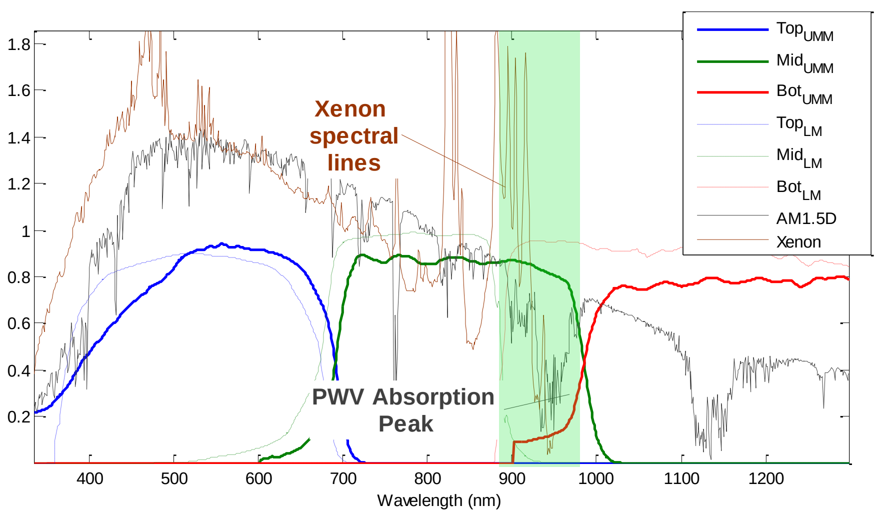

Figure 4: The quantum efficiency of the UMM cells for the module investigated in Figure 3 are compared to those of LM-Ge cells. The spectral zone that was previously in the bottom region but is now in the middle region is shaded pale green. It can be seen that certain important spectral phenomena are now affecting the middle cell: The first large water absorption peak is now completely in the middle spectral zone, as well as all of the Xenon spectral lines.