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A New GaInP/GaAs/GaInAs, Triple-Bandgap, Tandem Solar Cell for High-Efficiency Terrestrial Concentrator Systems

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S. Kurtz, M. Wanlass, C. Kramer, M. Young, J. Geisz, S. Ward, A. Duda, T. Moriarty, J. Carapella, P. Ahrenkiel, D. Albin, K. Emery, K. Jones, M. Romero, A. Kibbler, J. Olson, D. Friedman, W. McMahon, and A. Ptak

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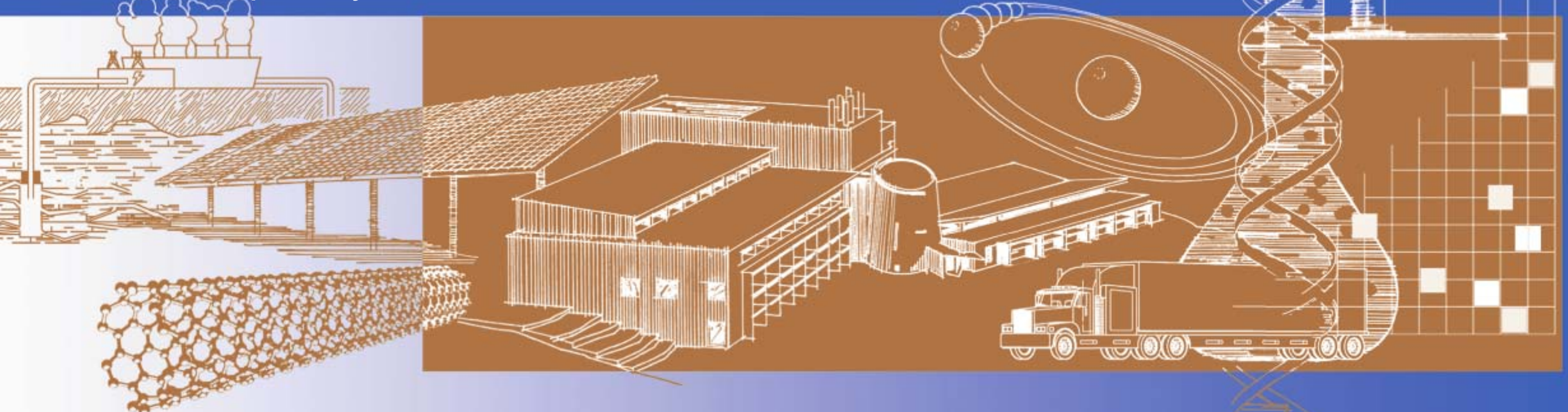

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A New GaInP/GaAs/GaInAs, Triple-Bandgap, Tandem Solar Cell for High-Efficiency Terrestrial Concentrator Systems

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ABSTRACT

GaInP/GaAs/GaInAs three-junction cells are grown in an inverted configuration on GaAs, allowing high quality growth of the lattice matched GaInP and GaAs layers before a grade is used for the 1-eV GaInAs layer. Using this approach an efficiency of 37.9% was demonstrated.

1. Objectives

The Solar Program seeks to develop technologies that can provide cost-effective electricity generation. One strategy to reduce cost is to use concentrating optics to focus the sunlight on small, highly efficient solar cells. Multijunction solar cells have achieved the highest efficiency (39%) of any technology and have the theoretical potential to achieve efficiencies equivalent to or exceeding all other approaches. This project seeks to push the efficiency higher with innovative combinations of materials.

2. Technical Approach

There is wide agreement that multijunction cells have the practical potential to achieve the highest efficiencies. The challenge has been to identify material combinations that can be integrated while still retaining excellent performance of each individual junction. The approach explored in this project was an innovation by Mark Wanlass in which the high-band-gap layers are grown first, and the more challenging, 1-eV, mismatched layer is grown last. After growth, the cell is attached to a convenient handle and the original substrate is removed. This approach provides a practical way to implement a high-quality 1-eV cell into the already successful GaInP/GaAs cell, and could provide a reduction in manufacturing cost by using cheaper or reusable substrates.

3. Results and Accomplishments

Three-junction GaInP/GaAs/GaInAs cells were fabricated as described elsewhere.[1-4] A record efficiency of 37.9% was set under the low concentration of ~ 10X in spring of 2005. Although this record has now been surpassed, this result is very exciting, especially because the record device was one of the first grown and has not been fully optimized. The efficiencies that have been achieved with the GaInP/GaAs/GaInAs structure are summarized in Table 1. Quantum efficiency and other data are summarized in figures 1-3.

Table 1. Efficiency, open-circuit voltage, short-circuit current and fill factor for the specified measurement conditions.

Cell	Condition	Effic. (%)	Voc (V)	Jsc (mA/cm^2)	FF (%)
MF602	LoAOD @ 10 suns	37.9	3.112	139	88.2
MF602	AM1.5 global	31.1	2.910	12.2	87.5
MF602	AM0	29.7	2.938	15.9	86.6
MF973	AM0 on Kapton	26.5	2.912	15.1	82.5

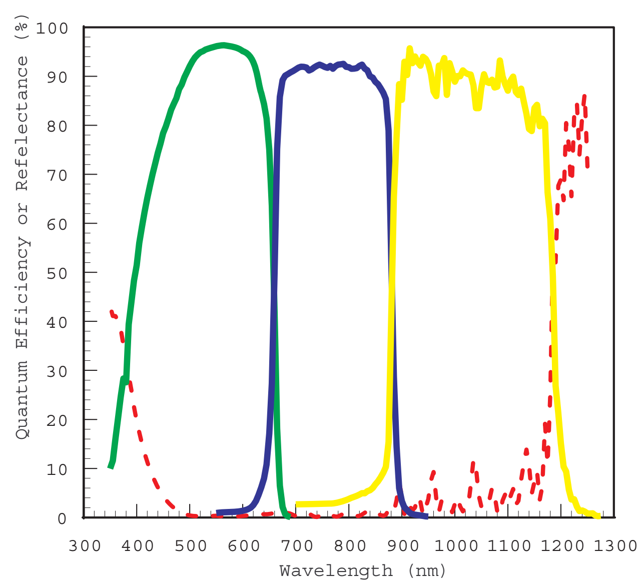

Fig. 1. Absolute external quantum efficiency (solid lines) and spectral reflectance (dotted line) data for an ultra-thin, handle-mounted GaInP/GaAs/GaInAs series-connected tandem solar cell. The individual junctions are characterized through light biasing to limit the performance of the series-connected cell by the junction of interest.

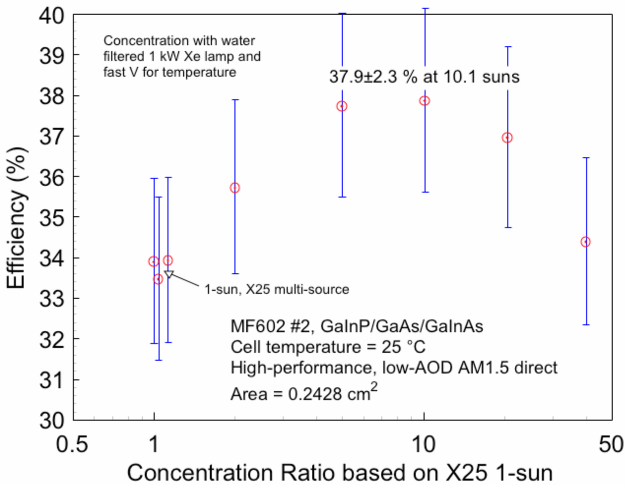

Fig. 2. Conversion efficiency of a three-junction GaInP/GaAs/GaInAs cell as a function of concentration.

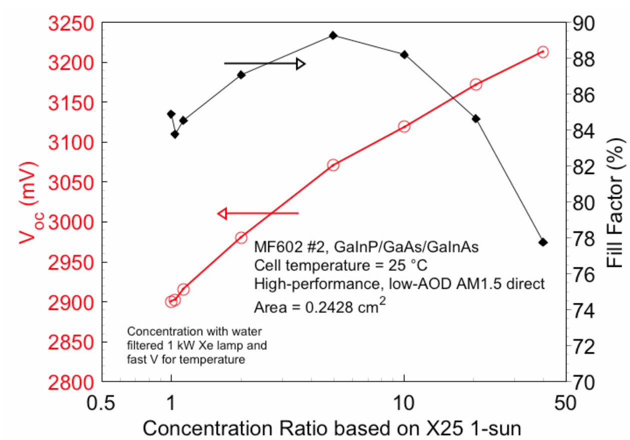

Fig. 3. Open-circuit voltage and fill factor as a function of concentration for a three-junction GaInP/GaAs/GaInAs cell.

The extension of these results to higher concentration is limited by a series resistance for these early cells. The complex cell structure contains many layers, and higher performance will be obtained when every layer has been optimized. Work is underway to reduce the series resistance and test these cells at higher concentations. Progress has been hampered because of a catastrophic failure problem that may be associated with localized heating of the cell under the busbar. The source of the failures has not yet been pinpointed, but could be caused by voids in the adhesive between the cell and "handle."

The practical efficiencies for fully opimized cells can be estimated by comparing these results with that of GaInP/GaAs/Ge cells. Assuming that the performance of the lattice-matched GaInP and GaAs subcells can be equivalent, the key boost in performance will come from the higher photovoltage of the 1-eV GaInAs junction compared with that of the Ge junction. The photocurrent generated by the Ge junction is larger than needed to match that of the GaInP and GaAs cells. The GaInAs photocurrent is adequate for 37.9%, but to reach higher efficiencies this photocurrent may need to be increased. In the record efficiency cell described above, the reflectivity in the GaInAs response region was about 10%. Reduction of the reflectivity with a broadband anti-reflection coating and/or reduction of the band gap of the GaInAs cell should allow adequate photocurrent in the GaInAs cell. The primary advantage of the GaInAs cell is the voltage boost. We have observed open-circuit voltages of 0.55-0.60 V for GaInAs cells. This is 0.2-0.3 V higher than what is usually achieved for a Ge junction. Thus, we may anticipate that any performance demonstrated with a GaInP/GaAs/Ge cell can be surpassed in performance by 0.2 – 0.3 V with a GaInP/GaAs/GaInAs cell when both are fully optimized. Using this simplistic approach, we estimate that an efficiency of 41% - 43% should be achievable with the GaInP/GaAs/GaInAs cell under high concentration conditions.

4. Conclusions

The three-junction, GaInP/GaAs/GaInAs cell is a promising new multijunction cell. A record efficiency of 37.9% was achieved with an early prototype. Additional work is underway to increase this efficiency.

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[4]Presented at the SPRAT meeting, September, 2005.

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