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Progress Toward a 30%-Efficient, Monolithic, Three-Junction, Two-Terminal Concentrator Solar Cell for Space Applications

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Component efficiencies of 0.2-cm^2 cells at $\sim$ 100$\times$ AM0 light concentration and 80°C temperatures are now at 15.3% for a 1.9-eV AlGaAs top cell, 9.9% for a 1.4-eV GaAs middle cell under a 1.9-eV AlGaAs filter, and 2.4% for a bottom 1.0-eV InGaAs cell under a GaAs substrate. The goal is to continue improvement in these performance levels and to sequentially grow these devices on a single substrate to give 30%-efficient, monolithic, two-terminal, three-junction space concentrator cells.

The broad objective is a 30%-efficient monolithic two-terminal cell that can operate under 25 to 100$\times$ AM0 light concentrations and at 75 to 100°C cell temperatures. Detailed modeling predicts that this requires three junctions. Two options are being pursued, and both use a 1.9-eV AlGaAs top junction and a 1.4-eV GaAs middle junction grown by 1-atm OMVPE on a lattice matched substrate. Option 1 uses a low-doped GaAs substrate with a lattice-mismatched 1.0-eV InGaAs cell formed on the back of the substrate. Option 2 uses a Ge substrate to which the AlGaAs and GaAs top junctions are lattice matched, with a bottom 0.7-eV Ge junction formed near the substrate interface with the GaAs growth. The projected efficiency contributions are 16%, 11% and 3%, respectively, from the top, middle and bottom junctions.

The best component cell efficiencies so far are 15.4% for the top AlGaAs, 10.8% for the middle GaAs under a 1.9-eV AlGaAs filter layer, and 3.0% for the bottom 1.0-eV InGaAs under a GaAs substrate. All of these are for $\sim$ 100$\times$ concentration and 25°C measurements in a flash simulator. At 80°C and $\sim$ 100$\times$, these efficiencies decrease a small amount to 15.3%, 9.9% and 2.4%, respectively. Figure 1 shows the 80°C AlGaAs cell I-V data measured in Sandia's elaborate and expensive flash simulator. The simpler and less expensive Varian simulator gave the 80°C I-V data for the GaAs and InGaAs cells shown in Figs. 2 and 3. The comparisons show the Varian measurements approach the more accurate Sandia results to within 10 relative percent or less.

The one-sun short circuit current densities of these best component cells at 25°C are 15.5, 15.1 and 10.0 mA/cm^2, respectively, indicating that the current from the bottom InGaAs junction needs to be increased by about 50% to match the top two for two-terminal operation. The peak external quantum yield of this InGaAs cell of

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50% indicates that it has the potential for this improvement when compared to the 80-85% peak external quantum yields of the AlGaAs and GaAs component cells. Such improvement requires that a better accommodation be made for the lattice mismatch between the GaAs substrate and the InGaAs junction. The best Ge device so far was obtained by growing n-GaAs onto an n-Ge substrate. The resulting Ge junction had a peak quantum yield of 53% and a 25°C short-circuit current at one sun of 15.1 mA/cm^2. This is sufficient for current matching. However, the remaining challenges for the Ge cell are to obtain high enough V_{oc} and FF values for 3% efficiency performance, and to maintain this efficiency while both the AlGaAs and GaAs junctions are grown on top of it.

The AlGaAs and GaAs junctions have been grown on GaAs substrates and processed into two-terminal, two-junction cells. A metal busbar was deposited into an etched groove to interconnect the junctions. At 100× and 25°C, the best measured V_{oc} was 2.64V that compares well with the V_{oc} values of 1.54V and 1.12V from the best component AlGaAs and GaAs cells, respectively. This same two-junction cell had a two-terminal short circuit current density at one sun of 14.7 mA/cm^2 after application of a prismatic cover glass to remove the obscuration of the metal interconnect. Further improvements in multijunction current are expected as the growth techniques are perfected.

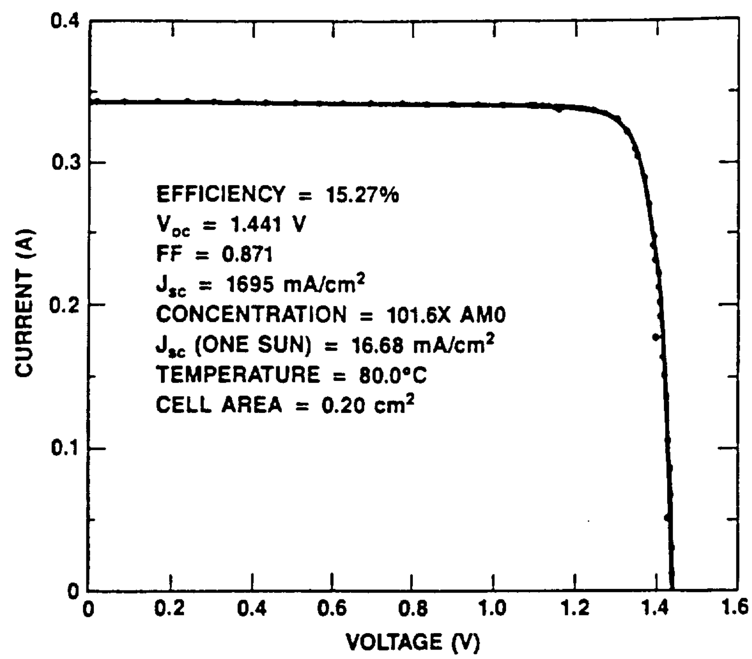

Fig. 1 A top 1.9-eV AlGaAs cell with 15.3% AM0 efficiency at 80°C and 102X concentration as measured in Sandia's flash simulator.

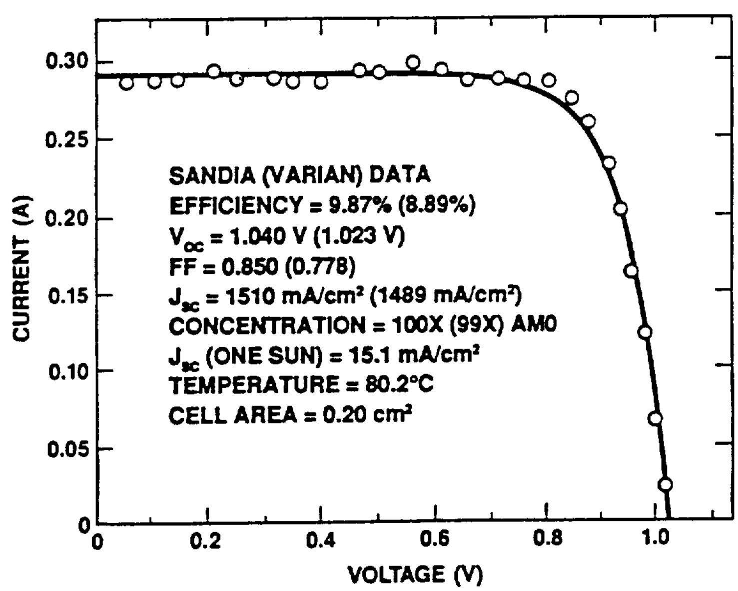

Fig. 2 A GaAs middle cell under an 1.9-eV AlGaAs filter at 80°C as measured in Varian's flash simulator. For comparison, the Sandia-determined 9.9% AM0 efficiency, V_{OC}, FF and X values are shown for the specified J_{SC}.

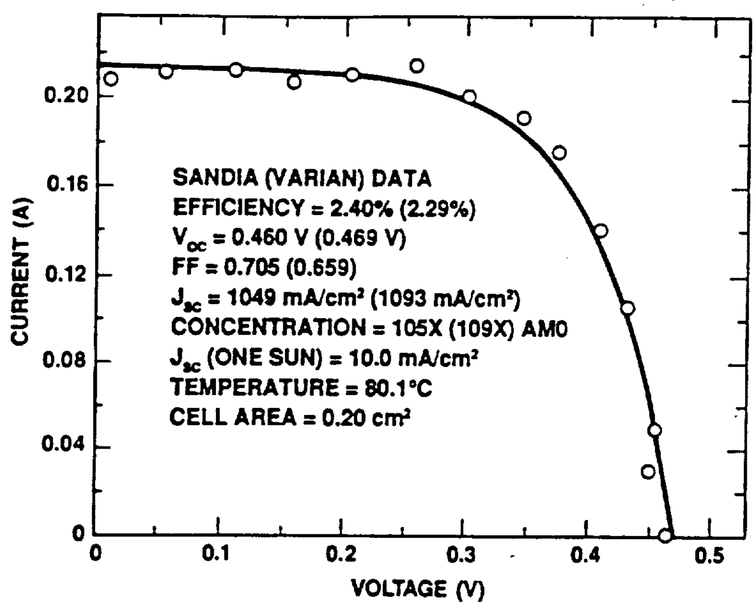

Fig. 3 A bottom 1.0-eV InGaAs cell under a GaAs substrate at 80°C as measured in Varian's flash simulator. For comparison, the Sandia-determined 2.4% AM0 efficiency, V_{OC}, FF and X values are shown for the specified J_{SC}.