DEVELOPMENT OF SPACE SOLAR CELLS AT SPECTROLAB

J. Boisvert, D. Law, R. King, D. Bhusari, X. Liu, S. Mesropian, D. Larrabee, R. Woo, K. Edmondson, D. Krut, D. Peterson, K. Rouhani, B. Benedikt, and N. Karam

Boeing-Spectrolab, Inc., 12500 Gladstone Ave., Sylmar, CA 91342 U.S.A.

ABSTRACT

High efficiency Inverted Metamorphic (IMM) and Semiconductor Bonded Technology (SBT) multi-junction solar cells have been under development at Spectrolab for use in space and near space applications. This paper will review the present state-of-the-art of this technology at Spectrolab with an emphasis on performance characterization data at operating conditions that these solar cells will experience in flight. Solar cell current-bias characteristics under illumination (LIV) at AM0 28°C are presented along with external quantum efficiency measurements that are used to verify the X-25 solar simulator LIV short circuit current density. A mechanical and thermal stress model has been used to predict mechanical stresses on a ultra-lightweight panel assembly in orbit and will be discussed.

INTRODUCTION

High efficiency IMM and SBT multi-junction solar cells [1-5] have been under development at Spectrolab for use in space and near space applications. This paper reviews the present state-of-the-art of this technology at Spectrolab with an emphasis on performance characterization data at operating conditions that these solar cells will experience in flight.

Under the AFRL IBIS program a coupon utilizing large area, low mass IMM solar cells has been assembled. A cross section of an IMM solar cell is shown in Figure 1.

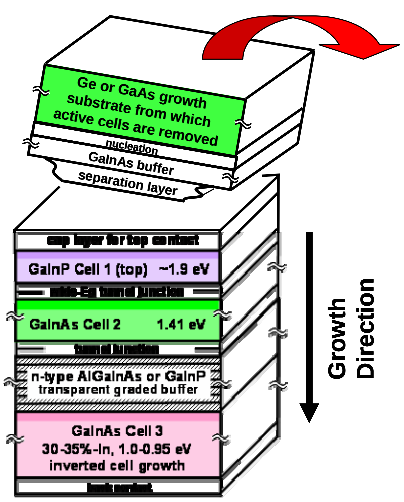


Figure 1. A typical IMM solar cell that is grown in an inverted configuration on a Ge or GaAs substrate. The grown structure is affixed to a handle and the growth substrate removed.

In a typical 3-junction IMM space cell three constituent GaAs-based subcells are grown in an inverted configuration. Large volume production MOVPE reactors are used to grow these solar cells on 100 mm substrates. The widest bandgap alloy (top cell) is grown first followed by the middle cell, buffer layers and finally a low bandgap metamorphic cell lattice mismatched to the growth substrate. Subsequent wafer processing places the inverted multijunction solar cell in an upright configuration and the growth substrate is removed. Processes typical of standard, high-volume semiconductor wafer processing are used to complete fabrication. Cell-Interconnect-Coverglass (CICs) are then assembled based on typical production assembly processes.

TEST ARTICLES

A variety of solar cell test articles have been constructed for use in this technology development. Small area (1 cm^2) as well as large area (26 cm^2) cells for use in 1 sun AM0 environments have been fabricated and tested. Low concentration small area 2.5 cm^2 cells have also been fabricated and will be reported on in this paper. Because specific metal grid patterns vary with design, performance data for the concentrator cells is reported for cell aperture areas only.

CHARACTERIZATION DATA

Typical current-bias characteristics for Spectrolab 3J IMM solar cell under 1 sun AM0 solar simulator illumination (LIV data) are shown in Figure 2. These simulator data were collected on an AX-25 solar simulator using calibrated IMM Lear Jet flight standards; to date no IMM balloon flight standards have been flown. Typical spectral response measurements for these cells are shown in Figure 3 and are agree with the measured Jsc data shown in Figure 2.

Low concentration IMM cells were subjected to additional characterization at both 1 sun and ~12X concentration. Typical LIV characteristics at 25 °C are shown in Figure 4. Low mass 26.62 cm^2 IMM cells and Coverglass-Interconnect-Cells (CICs) have been fabricated for use on the AFRL IBIS program. Figure 5 displays the backside handle of this cell. A cavity structure has been fabricated in the handle to reduce the total cell mass. A finite element mechanical and thermal analysis of an IBIS panel consisting of these CICs affixed to a metalized Kapton substrate has been performed. This analysis predicts that the structure will withstand exposure to -180 °C which a space solar panel can be subjected to on orbit. The stress distribution for the half plane of this structure is shown in Figure 6. The maximum anticipated stresses on the

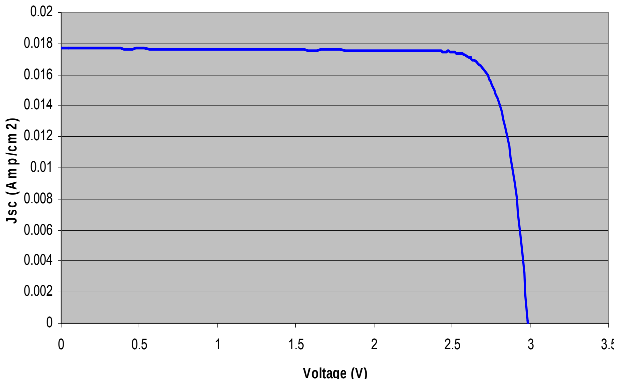


Figure 2. The LIV characteristic of a 1x1 cm^2 3J IMM cell at 28 °C. This cell was designed for 1 sun AM0 applications and has an AM0 conversion efficiency of 32.6%. The reported efficiency is based on Lear Jet IMM calibration standards.

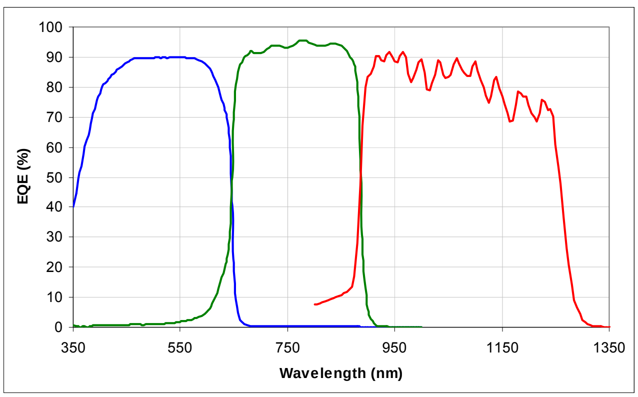


Figure 3. Typical external quantum efficiency characteristics collected on the 3J IMM solar cells shown in Figure 2.

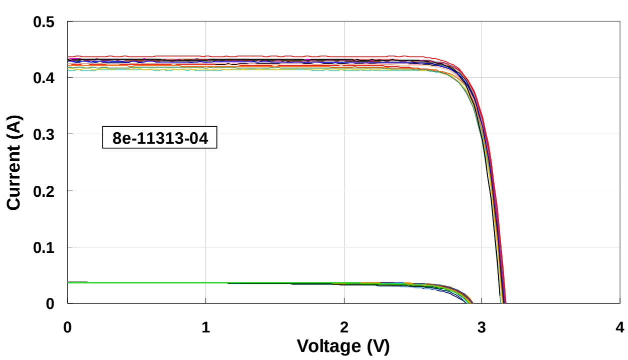


Figure 4. 25 °C LIV characteristics of low concentration IMM cells at 1X AM0 and ~12X AM0 concentration.

Figure 5. The low mass IBIS 3J IMM cell handle.

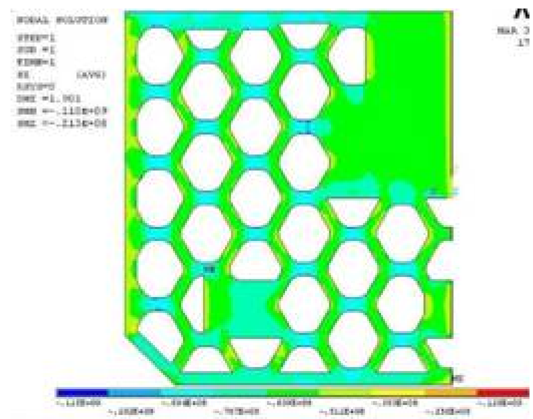


Figure 6. The low concentration 3JIMM half-plane stress model.

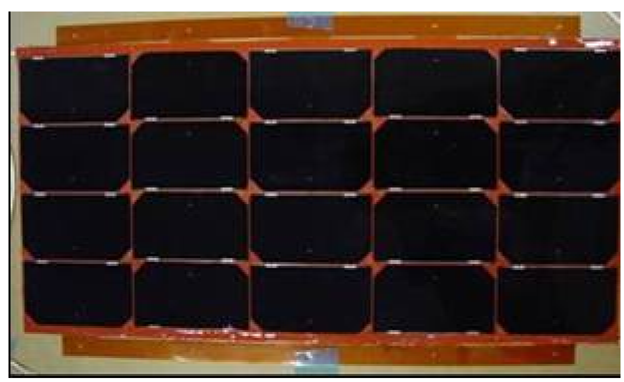


Figure 7. An assembled IBIS coupon.

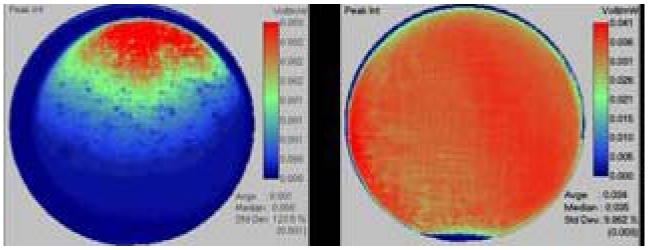


Figure 8. Photoluminescence maps of 1 eV metamorphic wafers show recent progress in material quality.

structure are on the order of 10 MPa, much less than the failure strengths of the cell materials.

A coupon of low mass IMM CICs was assembled for the AFRL IBIS program and is shown in Figure 7. Spectrolab continues to make progress on MOVPE growth of metamorphic material quality. Figure 8 displays photoluminescence maps of two wafers demonstrating that progress. The PL signal shows much better uniformity on the more recent wafer. That uniformity is reflected in 3J IMM cell performance shown in Figure 9 along with large area cell performance data collected solar cells fabricated from similar material. Large area 3J IMM cells presently display about 31% AM0 efficiency as measured on an AX-25 solar simulator set up to a Lear Jet flight calibration.

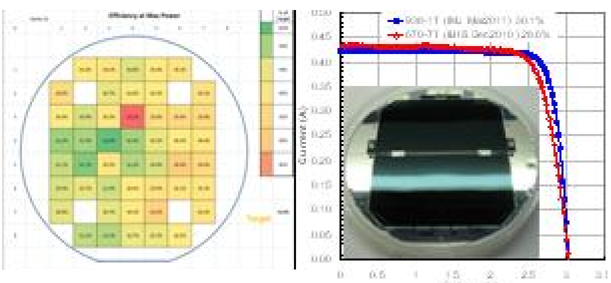
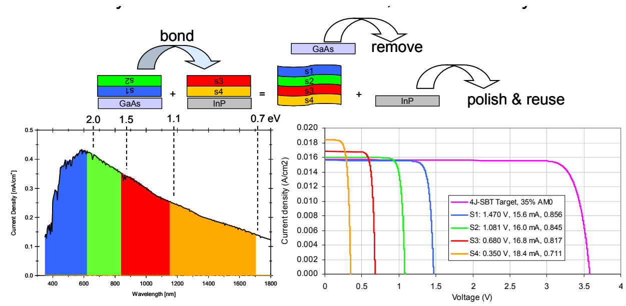


Figure 9. A wafer uniformity map of 1x1 cm^2 3J IMM cells and LIV characteristics of large area 26 cm^2 cells built from similar material.

Spectrolab is also pursuing semiconductor bonded solar cells for space applications. A 4J SBT solar cell is shown in Figure 10. This cell has the advantage that all subcells can be grown lattice-matched to independent substrates which leads to improved material quality and higher subsequent performance. The trade is that large area wafer bonds require very low surface roughness to be held over the entire wafer. Spectrolab has succeeded in fabricating large area bonds as shown in Figure 11. 4J SBT cells have been characterized and shown to have 33.5% AM0 conversion efficiency as measured on an AX-25 solar simulator set up to 3J IMM Lear Jet standards – Figure 12. The external quantum efficiency (as measured using a spectrometer set up to NIST-traceable calibration standards) of one of these cells is shown in Figure 13 and demonstrates that all 4 subcells exceed 90% EQE.



Target parameters: $V_{OC} \approx 3.6$ V, $J_{SC} \approx 16$ mA/cm², FF ≈ 84%, **eff. 35% AM0**

Figure 10. A 4J SBT utilizes lattice-matched subcells grown on two different substrates (in this case GaAs and InP) that are bonded together and subsequently processed similarly to an IMM cell.

Figure 11. A 4J SBT wafer fabricated with 1x1 cm^2 cells.

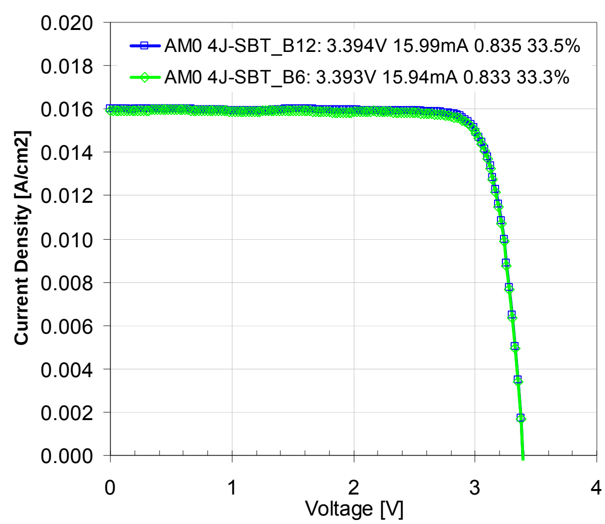


Figure 12. The AM0 LIV characteristics of 1x1 cm2 4J SBT cells.

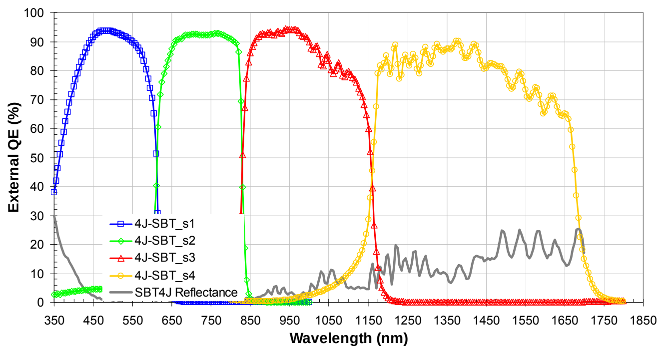


Figure 13. The external quantum efficiency versus wavelength as measured on a 4J SBT solar cell.

CONCLUSIONS

Spectrolab continues development of inverted metamorphic solar cell technology for high efficiency space and near space applications. IMM solar cells with 1X AM0 efficiency greater than 32.5% at 28 °C have been demonstrated. These efforts have led to development of 3J IMM low concentration cells. 3J IMM CICs have been measured at 28 °C under concentration and have demonstrated greater than 34% efficiency. A coupon with 3J IMM CICs has been fabricated under the IBIS program. 4J SBT solar cells have been fabricated and demonstrate 33.5% AM0 efficiency at 28 °C.

ACKNOWLEDGEMENTS

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