RECENT PROGRESS IN HIGH-EFFICIENCY MULTIJUNCTION SPACE SOLAR CELLS AT SPECTROLAB

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ABSTRACT

Boeing-Spectrolab achieved promising results on inverted metamorphic (IMM) 3-junction space solar cells. Spectrolab conservatively reports the IMM3J cell efficiency at 32.4% as measured on X-25 (UTJ standard) due to the lack of dedicated balloon flight or LEAR jet standards available to calibrate the solar simulator accurately. The inverted metamorphic 3J cell achieved an open-circuit-voltage of 2.97V, a short-circuit current-density of 17.4 mA/cm2, a fill factor of 0.85, and an efficiency of 32.4%. Spectral response measurement of the IMM3J cell revealed excellent external quantum efficiency performance for each subcell. We are confident that further improvement in subcell current balance and performance characterization will result in 33%-efficient IMM3J cells. The inverted metamorphic cells are fabricated into two configuration: (1) rigid cells with mechanical properties similar to current 3-junction cells, and (2) lightweight cells that are flexible and have an specific power >500 W/kg. Recently, we also demonstrated monolithic 5-junction space solar cells using direct semiconductor-bonding technique. Large-area, high-mechanical strength, and low-electrical resistance direct-bonded interface was achieved to support the high-efficiency solar cell structure. Preliminary 1-sun AM0 testing of the 5-junction cells showed encouraging results. One of the direct-bonded solar cell achieved an open-circuit-voltage of 4.7V, a short-circuit current-density of 11.7 mA/cm2, a fill factor of 0.79, and an efficiency of 31.7%. Spectral response measurement of the five-junction cell revealed excellent external quantum efficiency performance for each subcell and across the direct-bonded interface. Improvements in crystal growth and current density allocation among subcells can further raise the 1-sun, AM0 conversion efficiency of the direct-bonded 5-junction cell to 35 - 40%.

INTRODUCTION

Recent progress in III-V multijunction space solar cell technology has led to production triple-junction space cells with an average 1-sun efficiency close to 30% (AM0, 28ºC, 1-sun) [1]. The triple-junction cells are based on GaInP/GaAs/Ge device structure that is lattice-matched to Ge substrates. Future space solar cells will likely utilize new technology pathways such as 4- to 6-junction cell structure, highly metamorphic materials, inverted crystal growth, direct semiconductor-bonding, or their combinations to achieve 35% or higher 1-sun, AM0 efficiency [2-13].

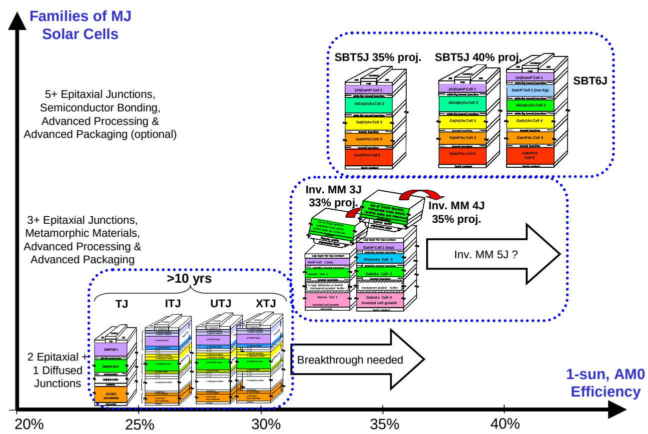

Fig. 1 Technology pathways to achieve 33 - 40% AM0 efficiency.

RESULTS AND DISCUSSIONS

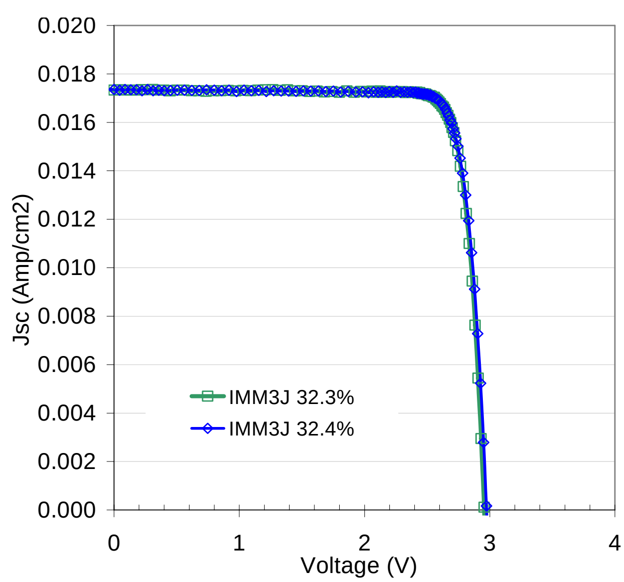

Fig. 2 Illuminated current-voltage characteristic of two inverted metamorphic 3-junction solar cells.

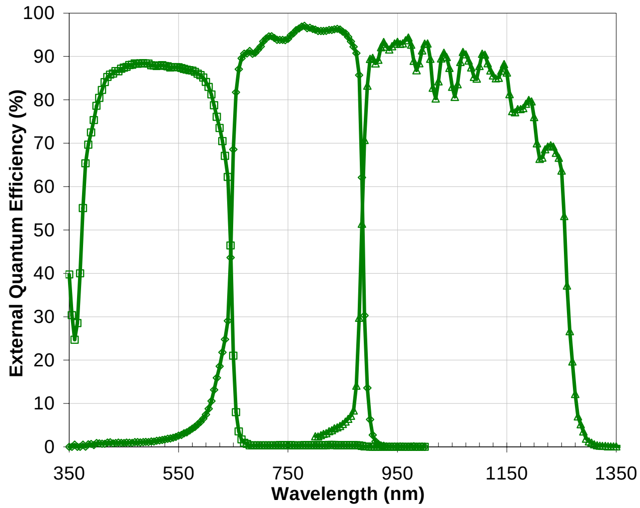

Fig. 3 External quantum efficiency data of the inverted metamorphic 3-junction cell.

Figure 2 plots the illuminated current-voltage (LIV) characteristic of two inverted metamorphic 3-junction solar cells. One of the 3-junction cell measured an open circuit voltage (V_{OC}) of 2.97V, a short-circuit current density (J_{SC}) of 17.4 mA/cm^2, a fill factor of 0.85, and an AM0 efficiency of 32.4%. External quantum efficiency (EQE) data of the IMM3J cells are plotted in Fig. 3. Subcell 1 shows peak EQE performance close to 90% while Subcell 2 and 3 show peak EQE well exceed 90%.

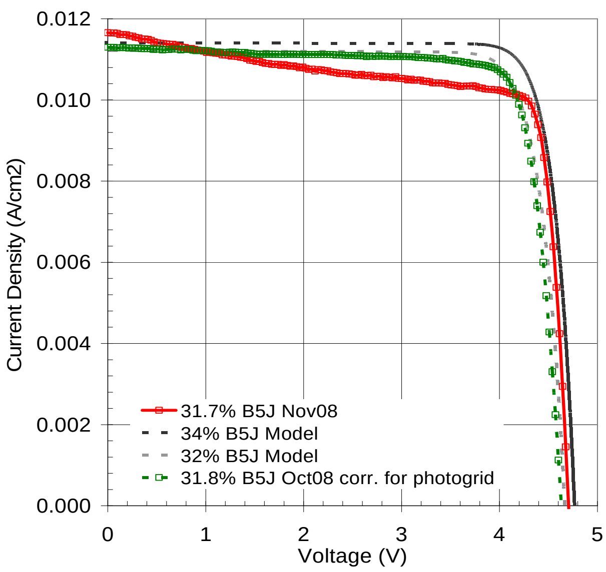

Fig. 4 Illuminated current-voltage characteristic of two bonded 5-junction solar cells, as well as a 32% and a 34% modeled LIV curves.

Figure 4 plots the illuminated current-voltage (LIV) characteristic of two bonded 5-junction solar cells. One of the 5-junction cells measured an open circuit voltage (V_{OC}) of 4.7V, a short-circuit current density (J_{SC}) of 11.7 mA/cm^2, a fill factor of 0.79, and an AM0 efficiency of 31.7%. Modeled LIV outputs of a 32% and a 34% 5-junction cell with the same bandgap combination as the bonded cell are included for comparison. External quantum efficiency (EQE) data of the bonded 5-junction cells are plotted in Fig. 5. Subcell 1, 2, 3, and 4 show peak EQE performance ranging from 80% to 90%. Note that the cumulative EQE exceeds 90% across Subcell 3 (on GaAs substrate) and Subcell 4 (on InP substrate) where the bonded interface is located. In addition, the EQE data of Subcell 4 and Subcell 5 in the bonded 5-junction cell is nearly identical to that of the stand-alone (non-bonded) component dual-junction cells for wavelength range beyond Subcell 3 band-cutoff. These results suggested that the bonded interface is highly transparent for wavelength range greater than 850nm.

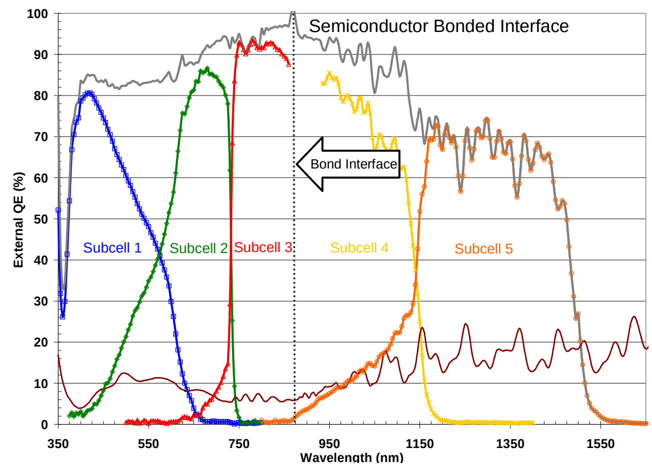

Fig. 5 External quantum efficiency data of the semiconductor-bonded 5-junction cell.

CONCLUSION

Boeing-Spectrolab continues to develop high efficiency solar cells for space power systems. The inverted metamorphic 3-junction solar cells achieved an 1-sun AM0 efficiency of 32.4%. We have also demonstrated 5-junction cells using direct wafer-bonding technique. The direct bonded 5-junction cells reported an 1-sun AM0 efficiency of 31.7% and a 7-suns AM0 efficiency of 35.7%. More importantly these results validate the feasibility to integrate ultra-high efficiency solar cell architectures through the use of highly metamorphic materials or direct semiconductor bonding. Further advancement in crystal growth and current density allocation will allow the IMM3J cells to exceed the 33% target and the bonded 5-junction cells to reach an AM0 efficiency of 35-40%.

ACKNOWLEDGEMENTS

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