Measurements of monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells

Haifeng Meng, Junchao Zhang, Limin Xiong,Yingwei He, Bifeng Zhang, Chuan Cai, Shuai Man and Meng Wang

National Institute of Metrology, Beijing, P. R. China
Corresponding e-mail address: menghf@nim.ac.cn

For the sake of the three composed sub-cells, that is $GaInP_2$, InGaAs and Ge sub-cell, the monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells can make use of solar irradiance in the wavelength range of 300 nm to 1800 nm, so that achieve high efficiency. They have become the main energy source for space on-orbit applications, and should be assembled into space solar array for use. Their photo-electric parameters were critical for space energy system setting. In this paper, we will present methods for their spectral responsivity and I-V characteristic measurement.

INTRODUCTION

Because of the high efficiency and high power weight ratio, triple-junction $GaInP_2$/InGaAs/Ge solar cells were always assembled into arrays and wings for space energy use. Three composed sub-cells, $GaInP_2$, InGaAs and Ge are epitaxial grown on one substrate and sub-cells are interconnected in series by tunnel diodes leading to a standard two-terminal contact, as the scheme shown in Figure 1. Efficiency more than 30% and V_{OC} higher than 2.5 V were previously reported [1,2]. Before assembled to an array, their current-voltage characteristics under AM0 STC should be measured to obtain key parameters, such as short circuit current, open circuit voltage and maximum output power, etc. Solar cells with similar current would be picked out for an array to achieve rated performance parameters, also to avoid power shortage or other safety problems causing by current mismatch. And match the link voltage of the spacecraft system by making use of reasonable series and parallel design.

In this paper, by appropriately adjusting the wavelength range and irradiance intensity of the bias light, the direction and value of the bias voltage, we would present the measurement of spectral responsivity for monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells. Then combine with spectral mismatch analysis technique, we employ a high spectral matched double-light solar simulator to measure the I-V characteristic for monolithic triple-junction $GaInP_2$/InGaAs/Ge solar cells. Small mismatch error makes our results more reliable. Hope it will help to obtain reliable results for multi-junction solar cells' photo-electric parameters under AM0 STC.

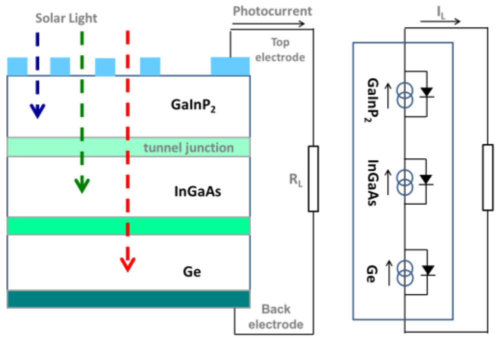

Figure 1. Scheme of structure of monolithic triple-junction $GaInP_2$/InGaAs/Ge solar cells.

CALIBRATION

As shown in Figure 2, a facility of spectral responsivity measurement for monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells based on monochromatic light system was built [3]. It is aimed to measure the spectral responsivity for monolithic multi-junction solar cells, but it also suitable for single-junction solar cells. Various bias light and optional bias voltage were critical for multi-junction solar cell's measurement, which made the untested junctions saturated and the junction under test to be the current-limiting junction.

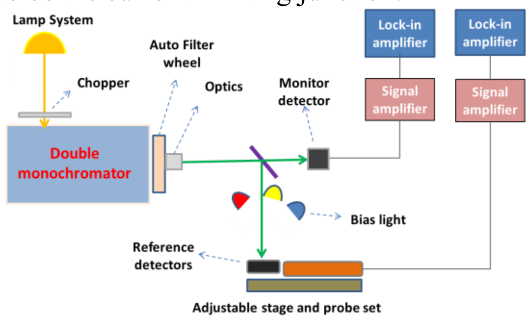

Figure 2. Scheme of the spectral responsivity measurement facility for monolithic triple-junction solar cells.

By using calibrated Si detector and Ge detector as standard, the measurement wavelength range can cover 300 nm to 1800 nm, and directly traceable to the national standard equipment for detector's spectral responsivity in NIM (National Institute of Metrology, China). Figure 3 was shown the measurement results for two types (S1 and S2) of $GaInP_2$/InGaAs/Ge triple-junction solar cells with different band-gap design. Because the Ge bottom junction's current is far greater than other two junctions, it cannot be the current-limiting junction. So we only discuss about the top and middle junction herein. According to Figure 3, red-shift was obviously observed when compare S2 to S1.

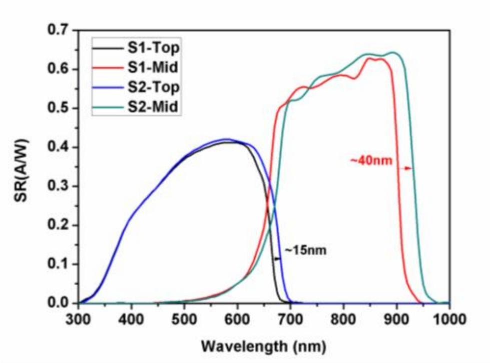

Figure 3. Curves of the spectral responsivity for two types monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells.

Based on the spectral responsivity results, a high spectral matched double-light AM0 solar simulator was employed for I-V measurement. Firstly, according to IEC 60904-7 [4], we theoretically calculate the mismatch error caused by solar simulator's spectrum. Table 1 shown that the errors for S1 were both smaller than 1%, an acceptable value, while for S2, it is different.

Table 1. Mismatch error calculation results of two types of triple-junction solar cells, by using a high spectral matched solar simulator.

	S1-Top	S1-Mid	S2-Top	S2-Mid
I_{STC}	71.15	72.02	75.13	75.67
I_{SS}	71.21	71.40	75.31	74.41
Error	0.09%	-0.85%	0.24%	-1.66%

Then we change the route, isotypes were used. Figure 4 was shown the spectral responsivity curves for all-structure monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells and their isotypes.

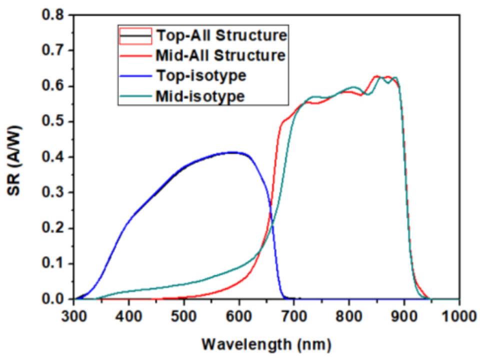

Figure 4. Curves of the spectral responsivity for all-structure monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells and their isotypes.

Further analysis was conducted for spectral mismatch according to equation (1).

$$MMF = \frac{\int_{\lambda_1}^{\lambda_2} E_{ref}(\lambda)s_{ref}(\lambda)d\lambda \int_{\lambda_1}^{\lambda_2} E_{source}(\lambda)s_{test}(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} E_{ref}(\lambda)s_{test}(\lambda)d\lambda \int_{\lambda_1}^{\lambda_2} E_{source}(\lambda)s_{ref}(\lambda)d\lambda} \qquad (1)$$

It turns out the error for top junction and middle junction was 0 and 0.06%, both were negligible. So, we use the isotypes to calibrate the double light AM0 solar simulator, and keep the state unchanged to measure the I-V curve for monolithic triple-junction solar cells. Temperature also should be controlled and monitored. Figure 5 demonstrated the measured I-V curves of four monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells.

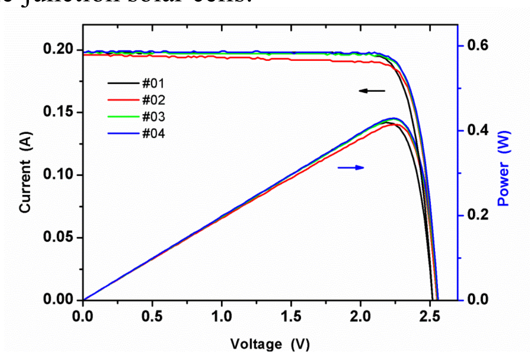

Figure 5. I-V curves for four monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells measured under AM0 STC.

CONCLUSIONS

This work stated the measurement for monolithic triple-junction $GaInP_2$/InGaAs/Ge solar cells, including spectral responsivity and I-V characteristic. It will provide strong support for their space application.

REFERENCES

1. S. Bailey, R. Raffaelle, [Handbook of Photovoltaic Science and Engineering]. Edited by A. Luque and S. Hegedus, John Wiley & Sons, Ltd, Space Solar Cells and Arrays, 413-448, 2003.
2. M. A. Green, K. Emery, Y. Hishikawa, W. Warta, E. D. Dunlop, D. H. Levi, A. W. Y. Ho-Baillie, Solar cell efficiency tables (version 49). Progress in Photovoltaics: Research and Applications, 25 (1) 3-13, 2016.
3. H. Meng, L. Xiong, J. Zhang, Y. He, B. Zhang, C. Cai, Spectral responsivity measurements of monolithic $GaInP_2$/InGaAs/Ge triple-junction solar cells, Proc. SPIE, 2019.
4. IEC 60904-7 (Ed. 3.0) Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices, 2008.