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OPTICAL FIBER BASED SPECTRAL RESPONSE MEASUREMENT SYSTEM FOR MULTI-JUNCTION SOLAR CELLS

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We report an optical fiber based spectral response measurement system for multi-junction solar cells. We have also fabricated single junction GaAs cells on GaAS and Ge substrates and measured lighted I-V characteristics. Preliminary quantum efficiency measurements on these devices are also presented.

Keywords: *MULT- JUNCTION SOLAR CELLS, QUANTUM EFFICIENCY, Ge-GaAs-InGaP, OPTICAL FIBER, BIAS LIGHT.*

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1. INTRODUCTION

Triple junction solar cells (InGaP/GaAs/Ge) with efficiency ~ 40 % have been reported in the literature for operation at ~ 240 suns [1]. Design, fabrication and testing of these cells are challenging tasks. In optimally designed cell, base layer thickness of each sub-cell is chosen so as to maximize the current flowing in all the sub-cells in series. To check the sub-cell limiting the current, quantum efficiency for each sub-cell has to be measured, with little influence of the other sub-cells. To accomplish this, say in a triple junction cell, two out of the three junctions in the cell are generally biased by using suitable light and voltage biasing [2], and short circuit current of the third junction is measured as function of wavelength by using chopped light. In this work, we report preliminary findings of a set up of spectral response measurements for a commercial triple-junction solar cell, as well as of some single-junction GaAs solar cells fabricated by us.

2. EXPERIMENTAL

We have designed a set up for the measurement of spectral response of sub-cells in a triple junction solar cell. It consists of a fiber cable assembly, which has three input legs and one output leg (Fig. 1). Each input leg is a bundle of 1mm diameter close pack of 14 fibers of 0.22 NA (200/220/245 μm) terminated in SMA 905 connector.

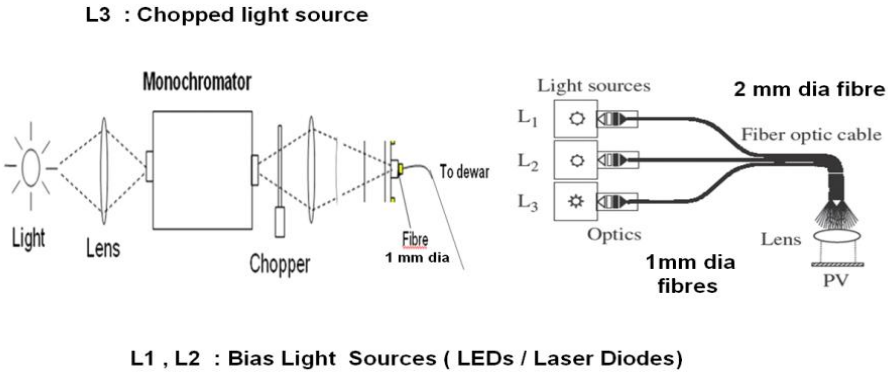

Fig. 1 *– Quantum efficiency measurement set up with* 532 *nm,* 860 *nm &* 1310 *nm bias light*

The output leg combines 42 fibers (14 from each input leg) in a 2 mm diameter close pack nominal salt and pepper mapping, terminated in SMA 905 end connector. Three fiber coupled diode sources (0.53, 0.86 and 1.3 μm) are selected for bias light. The probe light for quantum efficiency measurement is a tungsten halogen lamp in combination with 1/8 m monochromator. Light from output slit of monochromator is chopped and is incident on one of the three legs of the input bundles. The other two legs carry the bias light. The output leg combines the bias light and the probe light, which are coincident on the device under test. Spectral response measurements on the sub cells of a commercial triple junction cell consisting of Ge / GaAs / InGaP sub-cells are reported with and without bias light. Effect of dc voltage biasing is not investigated in this presentation.

We have initiated efforts to fabricate the multi-junction structures with single junction GaAs cells. This work is at initial stage. Single junction GaAs cells have been fabricated from structures grown by us using (i) liquid phase epitaxy (LPE) on GaAs substrates (cell A), and (ii) organo-metallic vapour phase epitaxy (MOVPE) on Ge substrates (cell B). Cell A consists of n-GaAs substrate (2×10^{17} cm^{-3}), 0.8 μm thick p-GaAs, 0.5 μm thick p^+- $Al_{0.75}Ga_{0.25}As$ window layer (~ 10^{18} cm^{-3}) and 100 nm thick p^+-GaAs contact layer (~ 3×10^{18} cm^{-3}); while Cell B consists of n^+-Ge substrate (5×10^{18} cm^{-3}), followed by 300 nm n^+ - GaAs layer (1.5×10^{18} cm^{-3}), 1.8 μm thick n-GaAs base layer (2×10^{17} cm^{-3}), 170 nm thick p - GaAs emitter (5×10^{18} cm^{-3}) and 50 nm thick contact layer of p^+ – GaAs (2×10^{19} cm^{-3}). No AlGaAs window layer was grown in cell B. Preliminary results of measurements on these devices are also presented.

3. RESULTS AND DISCUSSION

Fig. 2 shows the spectral response of triple junction cell without any bias light in the wavelength range 650 nm to 950 nm. From the nature of this measurement, it is clear that we observe a composite response of the triple junction cell with the band edges of GaAs and InGaP marked by the arrows. A small current is observed below the band edge of GaAs cell also, which is due to the Ge cell. However, it is relatively small. The above measurement is

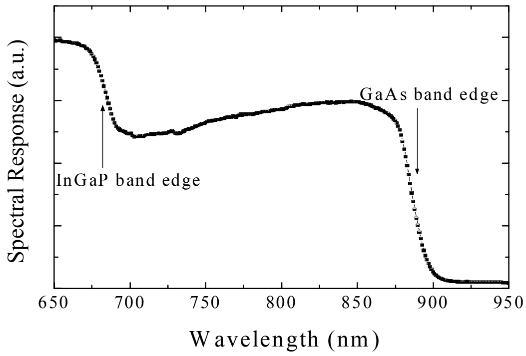

***Fig. 2** – Spectral response of the triple-junction cell without any bias light. Arrows show the GaAs and InGaP band edges*

far from the short circuit condition assumed for the spectral response measurement. Fig. 3 shows that shining bias light at 532 nm which is strongly absorbed by the InGaP sub-cell completely changes the shape of the response curve and it is more representative of the GaAs sub-cell. A small response from the InGaP sub-cell is still present and further tweaking of biasing parameters (light and voltage) is required to isolate the GaAs sub-cell response. We also see some current flowing below 900 nm, which must be due to the Ge sub-cell. To eliminate this, we show in Fig. 4, the response curve by shining both 532 nm and 1310 nm bias lights.

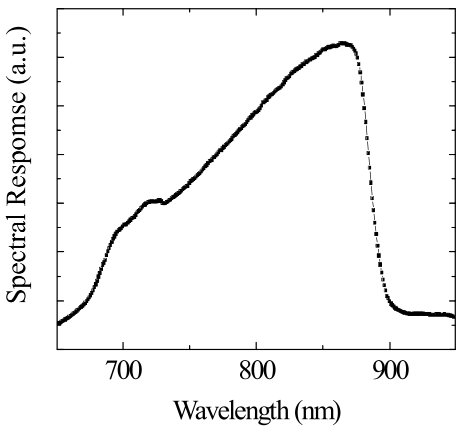

***Fig. 3** – Spectral response of GaAs sub-cell with 532 nm bias light*

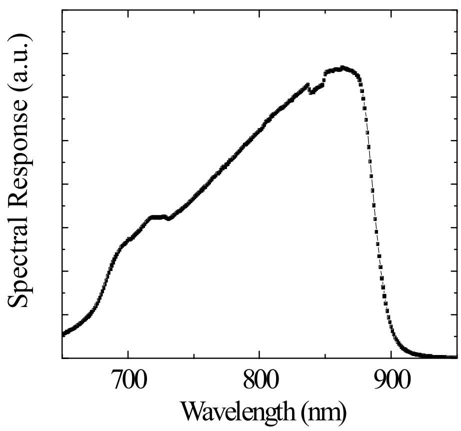

***Fig. 4** – Spectral response of GaAs sub-cell with 532 nm & 1310 nm bias light*

A dramatic reduction is seen in the response beyond 900 nm, completely eliminating the interference in the response of the GaAs sub-cell from the Ge sub-cell. By biasing with band gap dc light, both InGaP and Ge cells are forward biased and provide a reverse bias to the GaAs cell so that the ac current due to chopped light is representative of the GaAs sub cell short circuit current response. A small notch observed at about 850 nm (as compared to Fig. 3) shows the effect of turning off the 1310 nm dc bias on the response of GaAs sub-cell within the regime of its sensitivity.

Fig. 5 shows the spectral response of the InGaP sub-cell in the wavelength range 350-700 nm. We see that shining of 860 nm dc bias light has eliminated the interference from the GaAs sub-cell in the wavelength range greater than 700 nm in comparison to the response curve of Fig. 2, where a substantial response of the GaAs sub-cell was seen. The response of Ge sub-cell obtained by shining 532 nm bias light bias light is presented in Fig. 6. As compared to Fig. 2, where the response from Ge sub-cell was considerably suppressed, a significant improvement in the measured response of the Ge sub-cell is seen in the wavelength regime 900nm to 1700 nm. Work on optimizing the spectral response measurement of multi-junction solar cells is continuing.

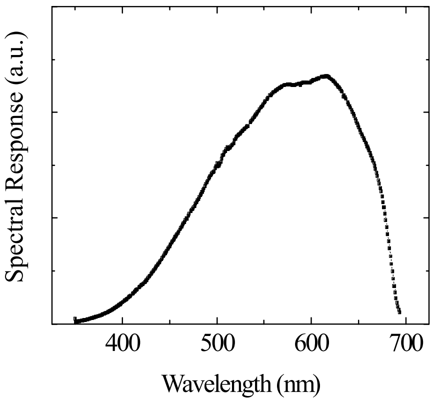

***Fig. 5** – Spectral response of InGaP sub-cell with 860 nm bias light*

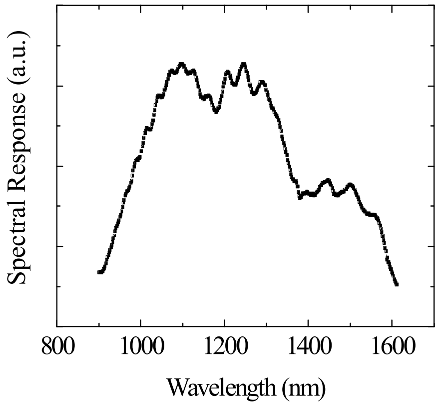

***Fig. 6** – Spectral response of Ge sub-cell with 532 nm bias light*

Lighted I-V measurements of single junction GaAs cells show that the short circuit current of cell A (grown on n^+ – GaAs substrate with AlGaAs top window layer) is nearly double that of cell B (grown on n^+ – Ge substrate without AlGaAs window but having TiO_2 anti reflection coating). Spectral response measurements of these two cells are compared in Fig. 7. It is seen

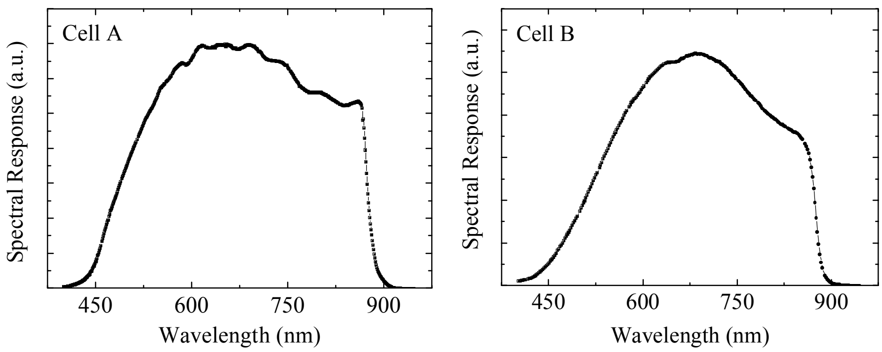

***Fig. 7** – Spectral response of single-junction GaAs solar cells: Cell A (a)& Cell B (b)*

that cell A has much better spectral response than the cell B in the wavelength range 450 to 600 nm because AlGaAs is much better window for surface passivation of GaAs than TiO_2, the top coating used for cell B. TiO_2 coating does improve the response, because it acts as antireflection coating but it is not as good as AlGaAs for interface passivation. Even response on the longer wavelength side in cell B is not as good as in the cell A. This may be related to back field reflection. Adding an AlGaAs hetero-layer between the GaAs base layer and Ge substrate could improve the long wavelength response for the cell B also. Further efforts to synthesize structures, incorporating high Al concentration AlGaAs window in the front and a low Al concentration back field reflector, on Ge substrates are currently underway. The next step then will be to move into two junction cells.

4. CONCLUSION

An optical fiber based spectral response measurement system for multi-junction solar cells is described. Typical spectral response curves for individual sub-cells in a triple junction (InGaP/GaAs/Ge) solar cells are obtained by using light biasing. Further refinement including voltage biasing is being tried. The refined measurements will be used to estimate the short circuit current expected and compared with the actual measurement in future. Preliminary results on GaAs solar cells fabricated on GaAs substrates by LPE and on Ge substrates by MOVPE are described.

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