Optimum Design of InGaP/GaAs Dual-Junction Solar Cells

J. W. Leem[1], J. S. Yu[1,*], and Y. T. Lee[2]
[1]Department of Electronic and radio Engineering, Kyung Hee University, Yongin 446-701, Korea
[2]Department of Information and Communications, GIST, Gwangju 500-712, Korea
*jsyu@khu.ac.kr

***Abstract* - We designed the InGaP/GaAs dual-junction solar cells by optimizing short-circuit current matching between top and bottom cells using a Silvaco ATLAS. The relatively thick base layer of top cell exhibited a larger short-circuit current density (J_{sc}) while the thicker base layer of bottom cell allowed for a smaller J_{sc}. A maximum J_{sc} of 11.86 mA/cm^2 was obtained, leading to the increased conversion efficiency. The base thicknesses of top InGaP and bottom GaAs cells were optimized at 650 nm and 2 µm, respectively. For the optimized solar cell structure, the J_{sc}= 11.86 mA/cm^2, V_{oc} = 2.32 V, and fill factor = 88.42% were obtained under AM0 illumination, exhibiting a conversion efficiency of 24.27%. The effect of tunnel diode structure, i.e, GaAs, AlGaAs, and InGaP, on the characteristics of solar cells was investigated.**

***Index Terms* – InGaP/GaAs, solar cells, dual junction, tunnel diodes, short-circuit current matching**

I. INTRODUCTION

Solar cells have been used for various applications such as electric power supplies for satellites, electronics, and other communications equipment. III-V monolithic multi-junction solar cells based on the InGaP/GaAs have attracted much attention because of their high conversion efficiencies. Recently, the state-of-the art conversion efficiency of ~ 40.8% was reported [1]. But, it is difficult to optimize experimentally solar cell structures due to complexity, high cost and time-consumption. Numerical modeling and simulation help to optimize the solar cell structure, thus decreasing the time and costs for development. For the dual-junction (DJ) solar cells, the tunnel diode structure and the current matching conditions between top and bottom cells should be optimally designed to achieve high conversion efficiency [2].

In this presentation, we report the design of InGaP/GaAs DJ solar cells, in comparison with the previously reported experimental results, through optimized current matching between both cells by varying the thickness of base layer in top and bottom cells using the Silvaco ATLAS [3]. The conversion efficiency and external quantum efficiency (EQE) were investigated for different tunnel diode structures.

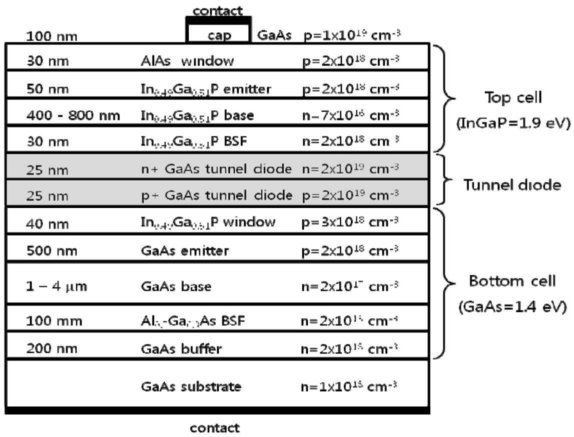

Fig. 1. Schematic diagram of InGaP/GaAs DJ solar cell structure.

II. SIMULATION

The theoretical simulation of InGaP/GaAs DJ solar cells was verified from the experimentally reported device structure in Ref [4]. Then, the structure was optimized to improve the conversion efficiency. Fig. 1 shows the schematic diagram of InGaP/GaAs DJ solar cell. For optimizing the DJ solar cell structure, the characteristics, i.e., I-V parameters, maximum power (P_{max}), fill factor (FF), conversion efficiency, etc., of single junction InGaP and GaAs solar cells, respectively, was studied by varying the base thicknesses of 400 - 800 nm for top InGaP cell and 1 - 4 µm for bottom GaAs cell. The EQE of the optimized structures was obtained for GaAs, AlGaAs, and InGaP tunnel diodes. We carried out the simulation under 1-sun AM0 (air mass zero, 100 mW/cm^2) and AM1.5g (air mass 1.5g, 100 mW/cm^2) of ASTM standard spectra.

III. RESULTS AND DISCUSSION

Fig. 2 shows the energy band diagram of InGaP/GaAs DJ solar cell at bias voltage of 0 V. The window layers with higher bandgap are used for potential barriers to carriers. The back surface field (BSF) layers act as a reflector of the minority carriers towards p-n junction. Fig. 3 shows the short-circuit current density of the top InGaP and bottom GaAs cells as a function of the base thickness of top cell in a monolithic InGaP/GaAs DJ solar cell for the AM0 solar spectra. As the base thickness of the top InGaP cell is increased, the J_{sc} increased (decreased) for the top (bottom) cell.

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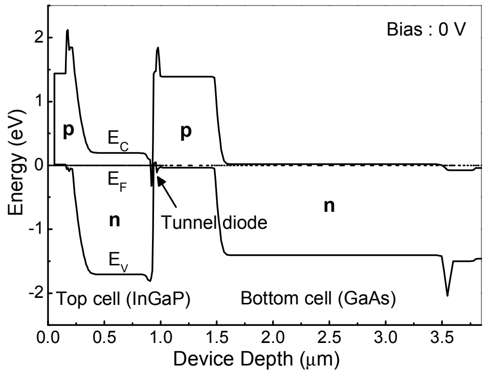

Fig. 2. Energy band diagram of InGaP/GaAs DJ solar cell at bias voltage of 0 V.

At 650 nm of the base thickness of top cell, a maximum short-current density of J_{sc} = 11.86 mA/cm^2 was obtained, leading to an optimum current matching between top and bottom cells. Parameters of the optimized InGaP/GaAs DJ solar cell structure with the GaAs/GaAs tunnel diode is calculated in Table I. By optimizing the device structure, the conversion efficiency was increased up to 24.27% compared to that of the Ref. [4].

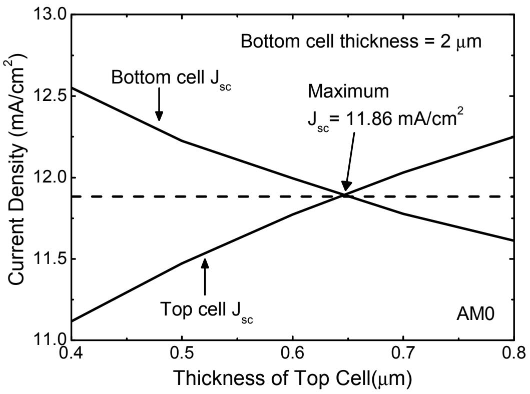

Fig. 3. Short-circuit current density of the top InGaP and bottom GaAs cells as a function of the base thickness of top cell in a monolithic InGaP/GaAs DJ solar cell for the AM0 solar spectra.

TABLE I
PARAMETERS OF THE OPTIMIZED INGAP/GAAS DJ SOLAR CELL STRUCTURE WITH THE GAAS/GAAS TUNNEL DIODE (AM0)

Spectrum (ASTM)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	Conv. Eff. (%)
Optimized structure	2.32	11.86	88.42	24.27
Ref. [4]	2.34	13.08	82.5	21.9

Fig. 4 shows the EQE of the InGaP/GaAs DJ solar cells as a function of wavelength for InGaP/InGaP, AlGaAs/AlGaAs and GaAs/GaAs tunnel diodes. For the bottom cell, the InGaP/InGaP tunnel diode exhibits a higher EQE compared to the GaAs/GaAs tunnel diode. This is ascribed to the higher absorption coefficient of InGaP at the shorter wavelength region. It is noted that a part of long-wavelength of spectrum is absorbed for the GaAs/GaAs tunnel diode. Table II shows the parameters of optimized InGaP/GaAs solar cells with different tunnel diodes. The use of InGaP/InGaP tunnel diode results in an increased conversion efficiency of 26.39%.

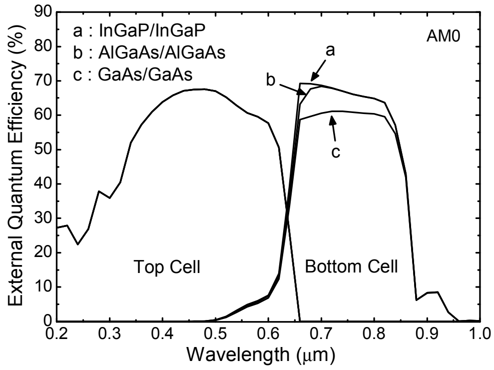

Fig. 4. EQE of the InGaP/GaAs DJ solar cells as a function of wavelength for different tunnel diodes.

TABLE II
PARAMETERS OF OPTIMIZED INGAP/GAAS SOLAR CELLS WITH DIFFERENT TUNNEL DIODES (AM0).

Tunnel diode structure	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	Conv. Eff. (%)
InGaP/InGaP	2.33	13.07	87.23	26.39
AlGaAs/AlGaAs	2.33	12.84	87.55	26.03
GaAs/GaAs	2.32	11.86	88.42	24.27

IV. CONCLUSION

The InGaP/GaAs DJ solar cells with different tunnel diodes were designed by maximizing the J_{sc} matching point between top and bottom cells. The base thicknesses of top and bottom cells were optimized. For the optimized structure, the conversion efficiency was improved from 21.9% to 24.27% under AM0 illumination for the GaAs/GaAs tunnel diode. The solar cells with InGaP/InGaP tunnel diode exhibited an improved conversion efficiency up to 26.39%. This result provides a better understanding of III-V multi-junction solar cells.

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