Impacts of bonding-layer resistance of Si bottom cells on interface resistance in InGaP/GaAs/Si hybrid triple-junction cells

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***Abstract*—We fabricate InGaP/GaAs/Si hybrid triple-junction (3J) cells with different sheet resistances of bonding layers in Si bottom cells. We estimate resistances across the p-GaAs/n-Si bonding interfaces of the respective 3J cells by measuring the potentials of the bonding layers. We find that the interface resistances are higher in 3J cells with the bonding layers of Si bottom cells with higher sheet resistances.**

I. INTRODUCTION AND BACKGROUND

The low-temperature bonding method such as surface-activated bonding (SAB) has successfully been applied for fabricating multi-junction solar cells that are practical candidates for high-efficiency and low-cost photovoltaics [1]. The electrical properties of bonding interfaces, which is a part of the series resistance, could limit the performances of such hybrid multi-junction cells. Although low-resistance (10^{-1} $\Omega\mathrm{cm}^2$ or lower) GaAs/Si interfaces were obtained using SAB of heavily-doped GaAs and Si substrates and annealing [2], [3], the interface resistance in the actual III-V/Si hybrid multi-junction cells is not yet fully understood. We recently fabricated InGaP/GaAs/Si hybrid triple-junction (3J) cells with tap contacts connected to p-GaAs and n-Si bonding layers: The resistance across the GaAs/Si bonding interfaces was estimated by analyzing the relationship between the difference in potentials of the bonding layers and the cell current [4].

In this work, we extract the interface resistance of 3J cells with different bonding layer structures of bottom cells and discuss the correlation between the interface resistance and the sheet resistance of the bonding layer.

II. RESULTS

We prepared two types of Si bottom cells, which are hereafter referred to as (A) and (B), respectively, by implanting phosphorous (P) ions with different acceleration energies in forming emitter layers, which also worked as bonding layers ((A): 10 keV, (B): 10/30 keV). The doses of P ions in (A) and (B) were the same (4.3×10^{14} cm^{-2}). Using the transmission line method, the sheet resistances of the bonding layers of (A) and (B) after the surface-activation process were found to be 1420 and 800 $\Omega/\square$, respectively. The difference in the sheet resistance is likely to be due to nm-level etching of the bonding layer during the surface-activation process.

We fabricated InGaP/GaAs/Si n-on-p hybrid 3J cells, i.e, 3J(A) and 3J(B), by the SAB of InGaAs/GaAs 2J-cell structures and each of Si bottom cells (A) and (B). The tap contacts were additionally formed so as to measure the potentials at p-GaAs and n-Si bonding layers. The InGaP/GaAs mesa area was 2.02 mm by 2.02 mm.

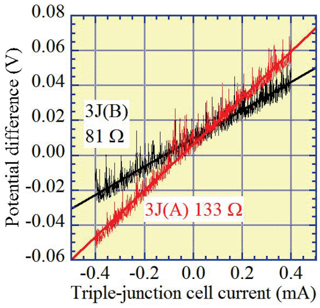

Fig. 1. The relationship between the difference in potentials at the bonding layers and the cell current for 3J(A) and 3J(B).

We measured the potentials of the bonding layers of the respective 3J cells while a bias voltage was applied between their emitter and base. The 3J cells were placed under the solar irradiance of AM1.5G/one sun. The relationship between the difference in potentials and the current across the 3J cell is shown in Fig. 1. The resistance across the bonding interface, which corresponds to the slope of each curve, was estimated to be 133 and 81 Ω for 3J(A) and 3J(B), respectively. A higher interface resistance was observed in 3J(A), or the 3J cell with the n-Si bonding layer with a higher sheet resistance. The obtained results indicate that the resistance across the bonding interfaces in hybrid multi-junction cells is sensitive to the structural parameters of the bonding layers of sub cells such as their carrier densities and thicknesses.

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REFERENCES

[1] Naoteru Shigekawa, *et al.* "Current-voltage and spectral-response characteristics of surface-activated-bonding-based InGaP/GaAs/Si hybrid triple-junction cells", Jpn. J. Appl. Phys. **54**, 08KE03 (2015).
[2] J. Liang, *et al.* "Surface-activating-bonding-based low-resistance Si/III-V junctions", Elec. Lett. **49** (13) pp. 830-832 (2013).
[3] Jianbo Liang, *et al.* "Investigation on the interface resistance of Si/GaAs heterojunctions fabricated by surface-activated bonding", Jpn. J. Appl. Phys. **54**. 030211 (2015).
[4] Naoteru Shigekawa and Jianbo Liang,"Measurements of Potentials at Tap Contacts and Estimation of Resistance across Bonding Interfaces in InGaP/GaAs/Si Hybrid Triple-Junction Cells", submitted to 2017 IEEE PVSC-44.