Rear-side resistance and contact coverage analysis for low surface recombination velocities in local back contact crystalline silicon solar cells

Cheolmin Park¹, Kyungyul Ryu¹, Seunghwan Lee¹, Jungmo Kim¹, Nagarajan Balaji¹, Minkyu Ju¹, Youn-Jung Lee¹, Hoongjoo Lee² and Junsin Yi¹*

> ¹ Sungkyunkwan University, Suwon, 440-746, Republic of Korea Phone: +82-31-290-7139 E-mail: yi@yurim.skku.ac.kr
> ² Sangmyung University, Cheonan 330-720, Republic of Korea

Abstract

In this paper, local back contact (LBC) technology which is usually applied for high efficiency crystalline silicon solar cell, applied to mass productive solar cell to achieve high open circuit voltage and short circuit current with low surface recombination from rear side. Thermal SiO₂/SiN_X double layer which has superior thermal stability is formed on rear surface as passivation layer, then 1% of the whole rear surface area is locally contacted with aluminum. Finally, the cell has been fired at high temperature and the cell process has complete. The fabricated LBC cells conversion efficiency was 18.0% with 625 mV of open-circuit voltage (V_{OC}), 37.58 mA/cm² of current density (J_{SC}), 76.3% of fill-factor (FF) at 5% contact coverage, respectively.

1. Introduction

Recently, the importance of solar cell research has emerged due to emerging social issues such as environmental pollution problems and rising oil prices. Accordingly, each company is studying to make solar cell of more high efficiency. There are two major techniques that apply to the rear to fabricate high efficiency solar cells. One is complete passivation of the surface using a thermal oxide and the other one is the formation of LBSF (Local BSF) [1]. Since a number of recombination sites are present on the surface due to a large number of dangling bonds or defects, it is important to have successfully incorporated passivation process. LBSF reduces series resistance by increasing carrier concentration around contact area and prevents carriers to come to surface where recombination sites exist.

In this paper, the electrical and recombination loss are analyzed varying the contact coverage through simulation. SiO_2 / SiN_X double layer which has superior thermal stability is formed on rear surface as a passivation layer and then 1% of the whole rear surface area is locally contacted with aluminum by photolithography. Finally, the cell has been fired using IR-firing belt. After the completion of fabrication, the cells were characterized.

2. Experiments

Local contact c-Si solar cell simulation was progressed for characteristics evaluation about the electrical and recombination losses. The size of contact dot was fixed at 20 μ m, but rear contact coverage was changed from 1% to 80% by changing the pitch. To confirm the simulation results, SiO_2 / SiN_X layer was deposited on both sides of the polished p-type silicon and patterned by photo lithography process. Contact coverage was changed from 1 to 100%. The lifetime was measured by QSSPC (Quasi-steady-state Photoconductance) method and recombination velocity (S_{eff}) was calculated.

LBC cell was fabricated on (100) 2.0 Ω -cm, 200 µm thickness, CZ, solar grade wafer. Texture barrier was deposited on rear-side and texture process was carried out to lower the reflectivity of the cell. After texturing process, only front-side of the wafer was doped with phosphorus to form p-n junction by diffusion in a tube furnace. After the doping process, the sheet resistance of the emitter layer was found to be 50 ohm/sq.

The formed SiO_2/SiN_X double stack layers on the front and rear acted as double layer anti-reflection (DLAR) coating and passivation, respectively.

Ag paste was printed on the front side and then annealed. Rear passivation layer was opened through photolithography. Opening area was formed less than 1% of the entire cell area in order to maximize the LBC effects and minimize the degradation of lifetime. Rear electrode was stacked with 2 μ m thick aluminum layer by evaporator and contact was formed through firing process. It was annealed in gas atmosphere (H₂ 5% + Ar 95%) for 30 minutes at temperature of 450°C.

3. Results and Discussion

LBC cell and conventional crystalline silicon solar cell (rear all-aluminum contact) have a physical difference in mechanism of electrical and recombination losses. For conventional crystalline silicon solar cells, the electrical loss is dependent on resistivity, base thickness and contact resistance between rear-side silicon surface and electrode. However, LBC cells have more elements that affect the electrical and recombination losses.

The geometric shape of contact such as dot size and pitch, the presence or absence of BSF, the recombination rate on the rear electrode and passivated region as well as the resistivity of the rear contacts affect the electrical loss. For recombination loss in rear-side LBC cells is dependent on the recombination velocities of passivated region on rear side, LBSF (Local Back Surface Fields), total coverage of locally contact electrode and resistivity of base.

The electrical and recombination loss parameters and mechanisms are shown in Figure 1. Electrical and recom-

bination loss at rear-side in LBC cell can be expressed by the following equations. Physical properties of electrical and recombination loss on the LBC cell possible to quantitatively analyze both of the above equations (1) and (2). [2, 3]

$$R_{b} = p^{2} \frac{\rho}{2\pi r} \arctan(\frac{2W}{r}) + \rho W(1 - \exp(1 - \frac{W}{p})) \quad (1)$$
$$S_{rear} = \left(\frac{R_{b} - \rho W}{\rho D} + \frac{1}{fS_{met}}\right)^{-1} + \frac{S_{pass}}{1 - f} \quad (2)$$

Where, R_s is base resistance, p is pitch of rear contact, ρ is base resistivity, W is base thickness, r is radius of rear contact and D is diffusion coefficient of wafer. S_{rear} is a function of the surface recombination velocities in metallized S_{met} and passivated areas S_{pass} and the contact coverage f.

Fig. 1 is depicts the result of series resistance at base region by contact coverage. Series resistance was sharply decreased from contact coverage 0.5% to 5%, and beyond that the series resistance was slowly decreased. R_b was sharply decreased to 5% contact coverage and saturated beyond 5% in numerical simulation results. R_b value had some gap between numerical simulation and experiment results due to numerical simulation was not considered contact resistance of rear-side ($R_{c.rear}$). In case of LBC cells contact resistance also dependent on contact coverage and rear-side contact resistance calculated above equation



Fig. 1 Series resistance on the rear side as a function of contact coverage in LBC solar cell.

Contact resistivity ρ_c dependent on contact electrode radius, f_{rear} is contact fraction or contact coverage of contact electrode. R_{c.rear} was indirectly analyzed by simulation result of base series resistance, R_b substitution in experiment series resistance at base region R_b + R_{c.rear} [R_b + R_{c.rear} - R_b (simulation result) = R_{c.rear}]. So, calculated R_{c.rear} was shown in Fig. 1 using this methods. As shown in Fig. 4, distinctions between $R_{c,rear} - R_b$ and R_b closer by increasing contact coverage. In this results of rear-side resistance calculation, $R_{c,rear}$ was decreased by increasing contact coverage in LBC cells.

Fig. 2 shows relationship between fill factor and series resistance of fabricated LBC cell respect to the contact coverage variation 0.5, 1, 5, 25, 75 and 100%, respectively. As shown in Fig. 5, series resistance was sharply decreased to contact coverage 5% and beyond 5%, slowly decreased to 100%. Series resistance experiment result was shown same trend to numerical simulation that relationship between series resistance and contact coverage. Fill factor of fabricated LBC cells was increased by increasing contact coverage and decreasing series resistance because of fill factor of LBC cells dependent on series resistance.



Fig. 2 Characteristics between the series resistance and fill factor as a function of contact coverage in LBC solar cell.

4. Conclusions

Recombination losses and series resistive losses that occurred in the rear of the LBC cell were analyzed using numerical simulation. In order to compare the experiment and numerical simulation results; the variable unit process experiment was progressed according to changing of contact coverage to obtain surface recombination velocities and series resistance. As a result, the results of analyzed have the same trend to the results of simulation. When contact coverage was 5%, the fabricated cell's conversion efficiency was 18.0%, with 625 mV of V_{OC} , 37.58 mA/cm² of J_{SC} and 76.3% of fill-factor, respectively.

References

- [1] M. A. Green, Prog. Photovoltaics 17, (2009) 183
- [2] H. Plagwitz et al., *Progress in Photovoltaics: Research and Applications* (2006) 1.
- [3] A. Wolf et al., Journal of Applied Physics 108 (2010) 124510.