Impact of Laser Enhanced Contact Optimization on solar cells with screen-printed Aluminium contact

Minh Tien Tran[1], Yuchao Zhang[2] and Yajie Jiang[2]

[1]School of Science, Computing and Engineering Technologies, Swinburne University of Technology, Melbourne, Australia
[2]School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, Australia
103179013@student.swin.edu.au

Introduction

In photovoltaic technologies, optimal metal-semiconductor contacts are vital for high-efficiency solar cells, usually formed by the screen-printing and co-firing process with metal pastes, such as Ag, Ag/Al or Al(1). Despite the favour of Ag for its high electrical conductivity, the LCOE of PV-generated electricity is expected to be significantly impacted by the silver price(2). To reduce the Ag-dependence, aluminium is used as an alternative but is limited due to its low conductivity and complexities of forming proper contacts with n-type silicon.

A promising method to improve the metal-semiconductor contact is laser-enhanced contact optimization (LECO)(3). This process utilises two components: a laser at the front side to induce high carrier injection and a negative bias voltage applied simultaneously (Figure 1), generating significant current densities at the contact interface(3). Previous studies indicated that LECO mitigated emitter damage, improving 0.14% efficiency for p-type ultra-low doped homogenous emitter cells(4). Additionally, it effectively lowered contact resistivity on both sides of TOP-Con cells fired at a lower temperature, improving cell efficiency by 0.6%(5).

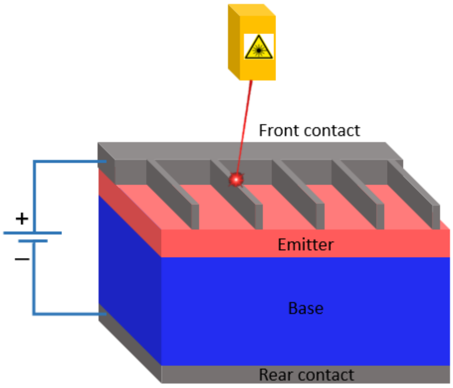

Figure 1: LECO process schematic diagram(3).

However, previous works only applied LECO treatment on the cell with silver contact. This project first studies the effect of LECO on the contact resistivity and metal-induced recombination of the Al/Si contact. Besides, despite LECO's advantages, its working principle remains incompletely understood. A previous study proposed the low-ohmic contact points (CFCs) formation hypothesis, but this model still needs more investigation(6). Therefore, in this project, we replaced the original LECO process by using the DR hydrogen laser to elucidate the laser's role in LECO treatment.

Experiment and aim

Two experiments were designed to investigate the impact of laser treatment on Al/Si contact resistivity and metal-induced recombination, respectively. Experiment 1 sample was prepared by screen-printing and co-firing to form non-firing through Al contacts on non-metallized phosphorus diffused p-type Cz Si wafer precursor. The sample underwent DR hydrogenation laser treatment, and the contact resistivity was measured by the Transfer Length Method (TLM) (Figure 2). This experience aims to investigate the impact of laser on Al/Si contact resistivity.

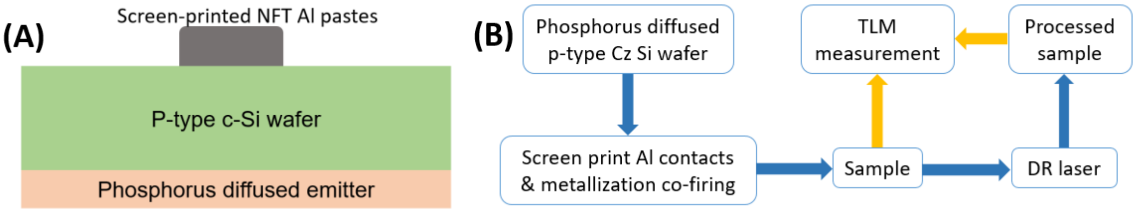

Figure 2: (A) Sample 1 schematic diagram. (B) Experiment 1 process.

For experiment 2, the same aluminium pastes were screen-printed on the rear side's top half of TOPCon cell precursors and fired through at different peaking temperatures (Figure 3). PL imaging was taken from the cell's front side to avoid any optical shading from printed contacts in PL images. This experiment examines the effect of the laser process on metal-induced recombination of screen-printed Al contact cells.

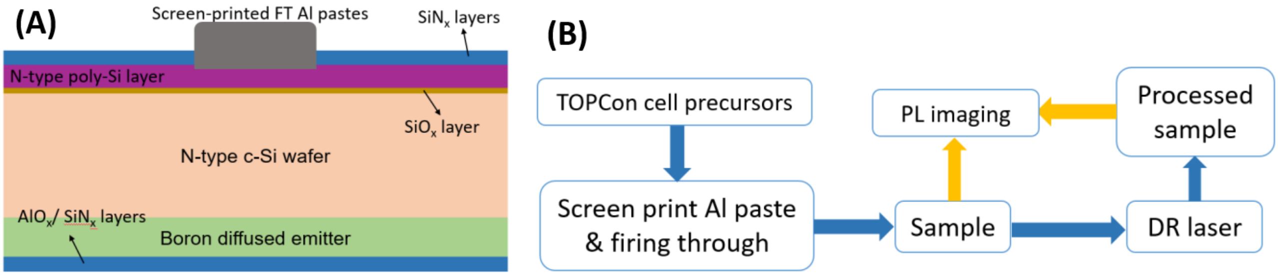

Figure 3: (A) Sample 2 schematic diagram. (B) Experiment 2 process.

Laser conditions: 1500W power with varied processing temperatures and exposure times.

Experiment 1: Impact of laser treatment on contact resistivity between Al and Si

Figure 4 shows the metal–semiconductor contact resistivity (ρc) before and after laser treatment for six different samples. Post-treatment, ρc of samples 1, 2, 4, and 5 slightly increased, and the variance reduced significantly. Notably, higher laser temperature applied escalated the impact on ρc. At 250^{o}C, the laser increased ρc by 3.86% after 5s processing and by 5.90% at 300^{o}C. The increase in contact resistivity after applying hydrogenation laser can be explained by the hydrogen-induced degradation(7). However, when we extended the processing time up to 20s, we observed a decrease in contact resistivity for both temperatures, for $T_{process}$ = 250^{o}C, from 4.68 ± 0.56 mΩ.cm^2 to 3.89 ± 0.21 mΩ.cm^2, and for $T_{process}$ = 300^{o}C, from 4.79 ± 0.60 mΩ.cm^2 to 4.42 ± 0.48 mΩ.cm^2, indicating that better contact formed with longer treatment time applied.

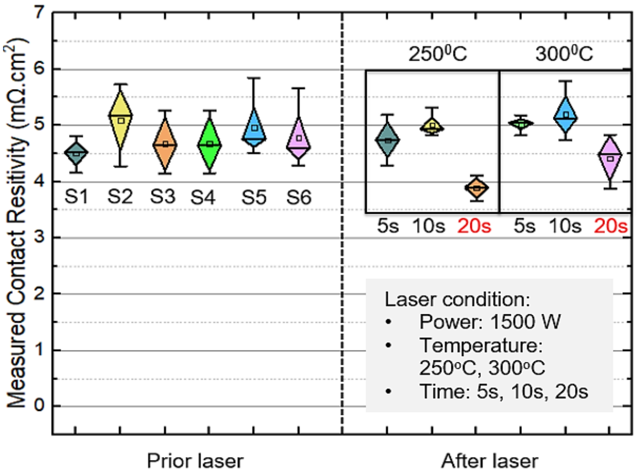

Figure 4: Contact resistivity (ρc) prior to and after laser treatment.

Experiment 2: Impact of firing temperature on contact resistivity and metal-induced recombination

Figure 5 indicates the temperature-dependent metal/semiconductor resistivity of TOPCon solar cells. Higher firing temperature enables Al finger to penetrate the AlO_x/SiN_x layer to contact the semiconductor, significantly reducing contact resistivity but resulting in higher metal-induced recombination. Figure 6 shows that the PL counts in metallized regions for firing temperatures higher than 760°C substantially reduced, possibly due to excessive Al diffused into n-poly layers or Al finger punched through poly/oxide stacks, compromising surface passivation.

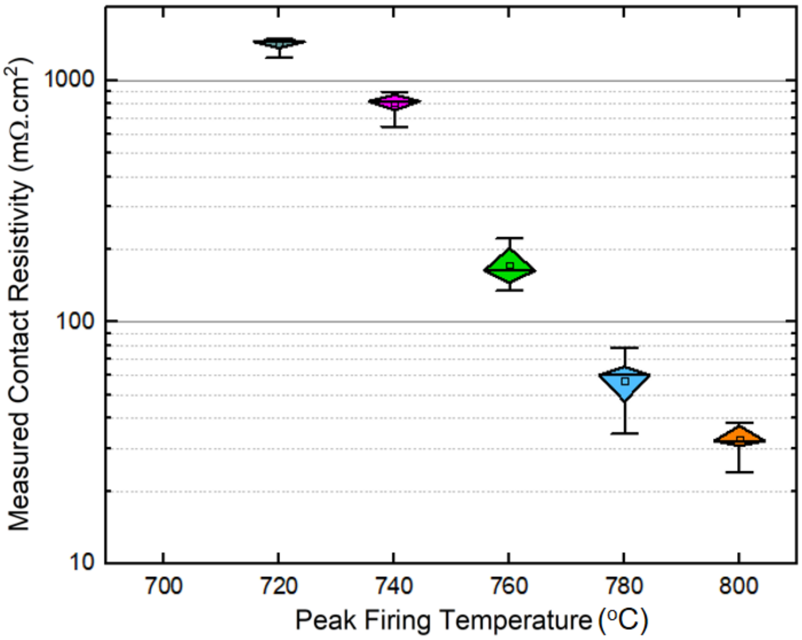

Figure 5: Contact resistivity on the rear-side of TOPCon sample with firing temperature.

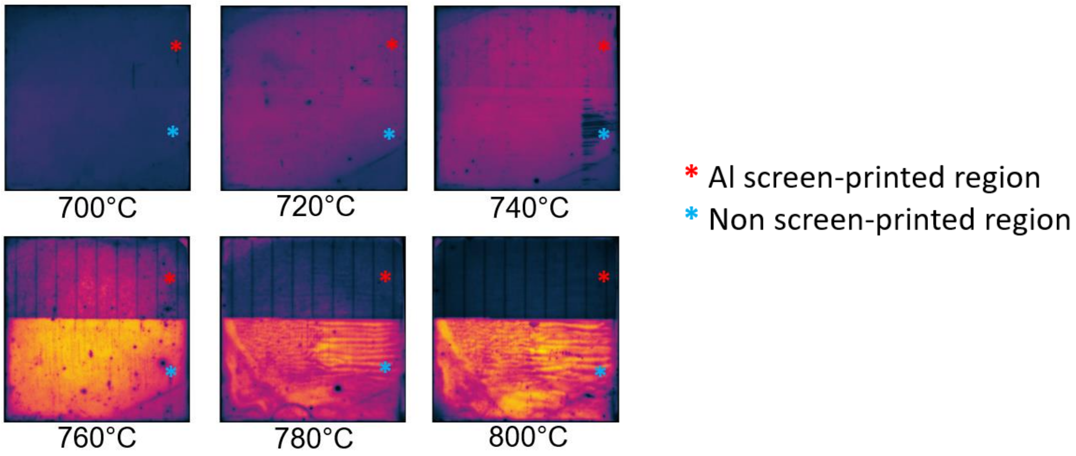

Figure 6: PL imaging results for samples at different firing temperatures prior to laser treatment

Experiment 2: Impact of laser treatment on metal-induced recombination

Figure 7 shows that DR laser treatment improved metal-induced recombination by the appearance of the brighter region on the metallized region after processing samples with the laser. This result can be explained by the hydrogen passivation process incorporating minority carrier injection to passivate the structural defects(8). However, we observed higher effectiveness on samples treated with 5s and 20s than that of 10s, indicating the importance of time control in applying the laser to improve the metal-induced recombination of Al/Si contacts.

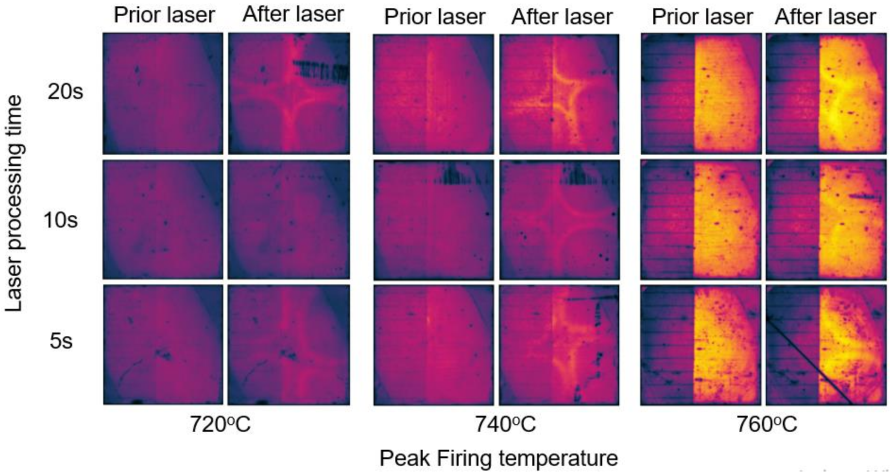

Figure 7: PL imaging result before and after laser treatment.

Conclusion and Future Direction

The application of DR laser reveals that only laser is not the main driving factor in the LECO process. Specifically, for Al/Si contact, the laser treatment increases contact resistivity due to hydrogen-induced degradation(7) while concurrently reducing metal-induced recombination via carrier injection and surface passivation(8). Moreover, adjusting the processing time also yields different effects on contact resistivity and metal-induced recombination.

Although our research indicates the processing time dependence of the result during the laser treatment, further study with varied laser conditions is essential to gain comprehensive insight. In the future, we aim to explore optimal laser conditions that balance cell degradation, contact resistivity and metal-induced recombination, potentially replacing the conventional LECO process with a more cost-effective method for improving cell efficiency.

References

1. Tepner S, Lorenz A. Printing technologies for silicon solar cell metallization: A comprehensive review. Progress in Photovoltaics: Research and Applications. 2023;31(6):557-90.
2. Zhang Y, Kim M, Wang L, Verlinden P, Hallam B. Design considerations for multi-terawatt scale manufacturing of existing and future photovoltaic technologies: challenges and opportunities related to silver, indium and bismuth consumption. Energy & Environmental Science. 2021;14(11):5587-610.
3. Höffler H, Simon F, Krassowski E, Greulich J, editors. Understanding current paths and temperature distributions during ‘Laser Enhanced Contact Optimization’(LECO). AIP Conference Proceedings; 2023: AIP Publishing.
4. Mayberry R, Myers K, Chandrasekaran V, Henning A, Zhao H, Hofmüller uE, editors. Laser enhanced contact optimization (LECO) and LECO-Specific pastes–A novel technology for improved cell efficiency. 36th European Photovoltaic Solar Energy Conference and Exhibition; 2019.
5. Fellmeth T, Höffler H, Mack S, Krassowski E, Krieg K, Kafle B, et al. Laser‐enhanced contact optimization on iTOPCon solar cells. Progress in Photovoltaics: Research and Applications. 2022;30(12):1393-9.
6. Großer S, Krassowski E, Swatek S, Zhao H, Hagendorf C. Microscale contact formation by laser enhanced contact optimization. IEEE Journal of Photovoltaics. 2021;12(1):26-30.
7. Hallam BJ, Hamer PG, Ciesla née Wenham AM, Chan CE, Vicari Stefani B, Wenham S. Development of advanced hydrogenation processes for silicon solar cells via an improved understanding of the behaviour of hydrogen in silicon. Progress in Photovoltaics: Research and Applications. 2020;28(12):1217-38.
8. Hallam BJ, Ciesla AM, Chan CC, Soeriyadi A, Liu S, Soufiani AM, et al. Overcoming the challenges of hydrogenation in silicon solar cells. Australian Journal of Chemistry. 2018;71(10):743-52.