Hydrogenated bifacial PERL silicon PV cells with laser doping and plated contacts - Project results and lessons learnt

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Executive Summary

High efficiency industrial screen-printed passivated emitter and rear cells (PERC) face several performance and cost limitations. Firstly, PERC cells have significant metal/silicon interface recombination and high metal shading losses. Transforming PERC into passivated emitter, rear locally diffused (PERL) cells has the potential to increase cell efficiencies from 22% to 25% through addressing these performance limitations. Secondly, they are generally plagued by light-induced degradation (LID), which significantly affects performance and therefore increases costs. Additionally, PERC cells require expensive silver and aluminium pastes to form the metal contacts. This project addressed these performance and cost limitations of current PERC technology by enabling their transformation into a bifacial plated contact PERL structure through the integration of three proven UNSW technologies: 1) laser doping, 2) plating and 3) advanced hydrogenation. The aim of the project was to develop a breakthrough low-cost, next-generation high-efficiency industrial PERL cell technology and innovative, high-throughput commercial production processes and equipment, building on the successful technological outcomes of three previous ARENA projects.

Over the project, all three technologies were integrated successfully, and after further optimisation work an efficiency of 23% was achieved on a laser doped bifacial plated and hydrogenated PERL cell fabricated using industrial equipment, along with a 21.3% efficient module. We demonstrated the compatibility of green lasers (cheaper than UV lasers) with plating technology which could reduce some of the initial cost barriers associated with transition to plated contacts. Over the course of the project we developed new prototype bifacial plating equipment, starting from the initial stages of designing a tool that would allow simultaneous bifacial plating, to optimising the design for reliability in terms of plated contact uniformity and adhesion, and finally to safety in operation. This new prototype bifacial plating tool, which is installed in the Solar Industrial Research Facility at UNSW, can be easily scaled, and has the potential to greatly assist the industry in the transition to plated contacts.

Project Overview

Project summary

This project integrated three separate UNSW-developed solar cell technologies to fabricate high efficiency and low-cost hydrogenated PERC and PERL solar cells.

The first technology is the laser-doped selective emitter technology, used on both the front and rear surfaces to create a bifacial PERL cell structure for optimum current generation and collection. The second technology is plating for metal deposition, which has been developed together with the laser doping process. This low temperature metal deposition technique is self-aligned, avoids using expensive silver and aluminium screen-print pastes, and results in thinner metal line widths than achievable with screen printing. The third technology is advanced hydrogenation, which improves the quality of commercial grade silicon wafers, eliminates light-induced degradation (LID) and passivates laser induced defects introduced during the laser doping process through controlling the charge state of hydrogen atoms within the device

By combining these three proven technologies to create the next-generation of high-efficiency solar cell, we aimed to overcome the performance and cost limitations of the industrially dominant screen-printed PERC cell.

Project scope

The project was undertaken to address performance and cost limitations of screen-printed PERC cells and demonstrate a pathway to a high-efficiency next-generation bifacial plated PERL cell. We sought to replace the costly screen-printed silver and aluminium pastes with copper plating, which in turn has performance benefits of reduced shading and improved metal silicon interfaces when combined with the laser doping technology. We sought to address the optical limitations of traditional PERC technology through use of laser doped selective emitters, and improve on wafer quality and light-induced degradation susceptibility through the use of advance hydrogenation. Specific problems needing to be addressed were how to best effectively plate to the p-type contact, and how best to achieve uniformity of the plated contacts on both sides of the cell. Additionally, we endeavoured to determine the best lasers and laser doping sources for plated contact formation, as well as the best way in which to integrate advanced hydrogenation into the solar cell fabrication sequence. Overall, the project aimed to develop a new fabrication process for solar cells that incorporated laser doping, bifacial plating and hydrogenation, together with an industrial bifacial plating tool to enable the fabrication process to be transferred rapidly to industry.

Outcomes

We have successfully integrated the three technologies with ongoing optimization to fabricate hydrogenated bifacial PERC and PERL solar cells with laser doping and plated contacts. These cells have been fabricated using 6-inch commercial silicon wafers. The laser doping and self-aligned plating form closely placed narrow fingers with significantly reduced shading losses, that form low resistance contacts to the silicon with minimal recombination losses. Smooth and uniform metal deposition on both the n-type surface and p-type surface has been achieved. The developed process has also been transferred to an industrial partner and they have fabricated such cells using industrial equipment and reaching efficiencies of up to 23%. Both types of cells have been light soaked to test for LID. Using an industry standard light soaking process, the cells lose less than 1% relative efficiency due to LID. A 21.3% bifacial module of bifacial plated PERC cells has also been made.

The promising result indicates we are well on track to develop a breakthrough low-cost, high-efficiency PERL cell technology and innovative, high-throughput commercial production processes and equipment. The project has significantly improved the technology readiness of the bifacial plated PERL cell technology. A significant barrier to the adoption of the process by the industry is, however, the constant improvement in screen-printing pastes that has occurred over the past few years and continues to occur. As such, plating technology has had its advantages over screen-printing somewhat reduced, meaning the industry is less willing to move away from conventional screen-printing technology at this time. The concerns around sustainability of silver in screen-printed pastes could, however, see more of the industry turn to plating in the future. This project, having developed a high-throughput industrial bifacial plating tool, is likely to greatly aid in this transition.

A surprising result was the discovery that we could use lasers with green wavelength light for the laser doping process, without sacrificing on the quality of the subsequent plated contact. This was as the result of our UV laser breaking down during the project and no alternative option but to use a green laser to keep making progress at UNSW. Green lasers are much cheaper than UV lasers, but typically result in inferior plated contacts. However, we were able to find that by pre-treating the surface of the laser doped regions appropriately, equivalent results could be obtained. This could allow for a significant reduction in the upfront cost associated with moving to plated contacts.

Transferability

Hydrogenated PERL solar cells now dominate the PV market with more than 80% market share. However, for the current industrial implementation, they focus on using aluminium screen printing to form the local PERL contacts rather than laser doping, and also use silver screen printed contacts on the front side. Laser doping is also commonly used underneath the front silver contacts. The industry has also shifted to bifacial technology (more than 60% of cells are now bifacial, set to increase to over 80% in the next 10 years). Plating is a preferred approach for bifacial solar cells due to the narrow line-widths achievable, and the avoidance of silver consumption, which has both cost and sustainability concerns. One of the main hurdles to its implementation in industry is the lack of access to high-throughput, reliable plating equipment. The new prototype bifacial plating tool developed and built during this project, can be easily scaled, and has the potential to greatly assist the industry in the transition to plated contacts and provide greater incentive to manufacturers to license the technology for the fabrication of bifacial solar cells.

Conclusion and next steps

We have successfully achieved the goals in the final stage of the project of incorporating the three key technologies. Promising cell and module results have been achieved, which are expected to promote manufacturers' interest and confidence in using plating metallization to overcome limitation in screen-printing thereby achieving higher efficiency at low cost. The constant improvements in screen-printing technology that have occurred over the past few years are expected to slow this transition, however the avoidance of using expensive and scarce silver reserves means plating remains a very attractive option. Future work will involve further optimisation of the industrial prototype tools to achieve desired and reliable plating metallization in not only PERL but also other types of high efficiency solar cells (e.g. TOPCon, SHJ).

Lessons Learnt

Lessons Learnt Report: Surface treatment of laser doped region plays a critical role in plated contact formation

Project Name: HYDROGENATED BIFACIAL PERL SILICON PV CELLS WITH LASER DOPING AND PLATED CONTACTS

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	NSW

Key learning

In the past we found that silicon surface conditions directly influence the plated contact properties and hence the cell efficiency. However, different contact patterning methods (e.g. different lasers, different laser doping conditions) lead to different silicon surface conditions. We found that to achieve good plating quality, there were preferred lasers and preferred laser conditions.

However, we have now learnt that the hydrofluoric acid (HF) pre-treatment applied to the silicon surface prior to plating, plays a critical role in plating metallization, especially when different laser doping conditions are used. This is mainly because the uniformity of conductivity throughout the laser doped area would significantly influence the start of plating thereby the final plating results. Nowadays, there are various types of laser resources available and their functions and cost could vary greatly. However, it has been frequently reported one kind (e.g., wavelength, emission duration) is superior for the purpose of contact patterning and such preference in type of laser may limit the deployment of plated contacts. We found that by applying appropriate HF pre-treatment and plating conditions, samples with different laser doping conditions could have similar plating results. This provides a wider window for laser selection and, perhaps, other pattern developing methods thereby reducing the entry requirements and potentially cost barriers for manufacturers interested in plating technology.

Implications for future Projects

Future projects need not be so selective in laser choice, as it is possible for excellent plated contacts to be achieved even with laser sources that might be considered less than ideal. In particular, HF pre-treatment conditions should be carefully investigated, as these have great influence on the uniformity of surface conductivity before plating and therefore the plating quality.

Knowledge gap

These learnings have identified a gap in knowledge of the background fundamentals of the impact of the HF pre-treatment on plating morphology. Future work should look at improving the knowledge around the fundamental mechanisms behind this relationship and further investigating the effect on plated contacts and cell performance, thereby finding an ideal trade-off between the cost, processing, and efficiency. We suspect the different HF pre-treatment needs of samples doped with different laser wavelengths originate from their different doping profiles. However, we are unable to obtain the actual doping profiles of the laser patterned line due to characterization limitations. The commonly used methods for measuring doping profiles are ECV and SIMS, both are not suitable in our cases; ECV has a minimum measurement area larger than the laser doped line width and the SIMS shows not only the "active" dopant distribution, which does not correctly reflect the dopants that affect the contact formation. Moreover, the Gaussian power distribution laser used here would also increase the inaccuracy of measurement.

Background

Objectives or Project requirements

We previously showed that the quality of plated contacts was heavily dependent on the laser doped silicon surface conditions, which was in turn dependent on laser choice and laser doping conditions. Unfortunately in the later stages of the project, the UV laser we were using for laser doping failed and could not be repaired. This brought about significant delay to the project, as the only other alternative laser we had available (green wavelength) was found to give inferior plating results. We needed to find a suitable option for laser doping that would allow us to continue with the project at UNSW.

Process undertaken

We explored varying the conditions of a hydrofluoric acid (HF) surface preparation treatment on laser doped surfaces with non-ideal surface conditions for plating. We found that with the appropriate surface treatment conditions, as well as appropriate plating conditions, we were able to form good quality plated contacts even when using a green wavelength laser for laser doping. We now know:

- What the critical processing parameters are that may affect the plated contacts growth
- What necessary changes or add-ons should be made for achieving desired plating results

We suspect that different laser conditions resulted different surface conditions which may greatly influence the start of plating metallization thereby the plated contact quality and cell efficiency. This is because uniform conductivity before plating is critically important to plating uniformity. However, some laser conditions are unable to be adjusted due to tool capabilities (e.g. wavelength etc.) which may limit its application range or increase manufacturing cost. We found appropriate HF pre-treatment could be an efficient and economical solution.

Supporting information (optional)

N/A