LIGHT INDUCED ELECTROLESS PLATING OF SILVER FOR EFFICIENCY IMPROVEMENT AND COST REDUCTION OF SILICON SOLAR CELLS

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ABSTRACT: In an effort to increase solar cell efficiencies while simultaneously reducing materials costs, a two-step metallization process for the production of silicon solar cells is presented. A novel, cyanide-free electroless silver plating solution (LIEP – light induced electroless plating) was developed, which has the benefits of higher conductivity than printed paste, simple equipment requirements and a wide process window. LIEP silver plating was demonstrated to increase efficiency of poorly conducting production cells by reducing series resistance. Additionally, printing of fine line patterns and thickening the contacts with LIEP silver combines the benefits of better electrical performance while reducing silver usage and associated costs. The LIEP silver deposit is denser than sintered paste, providing a platform for improved soldering, increased ribbon peel strength, and improved module reliability.
Keywords: silicon, wet chemical metallization, electrodeposition, cost reduction

1 INTRODUCTION

Screen printing of silver paste conductors on silicon solar cells is a mature, low-cost production process. However, cell manufacturers are continuously looking for ways to further reduce costs, and silver metal now represents a significant portion of the cell's overall cost [1]. Additionally, printing of silver paste suffers from poor aspect ratio resulting in excessive shading of the front side of the cell, which reduces the short circuit current and overall cell efficiency. Firing of silver paste also struggles to make good contact to higher resistance emitters. New paste formulations and better printing techniques continue to utilize lower paste quantities and improve efficiency [2], but the limits of traditional screen printing are within sight.

The use of silver plating chemistry and a light-induced plating (LIP) approach has been previously reported as an improvement over the traditional screen printing processes [3]. In the first step, a grid is screen printed with narrower fingers using a smaller quantity of paste. After the paste is fired under optimal conditions to make contact to silicon, the conductor grid is plated in a silver electrolyte in order to reduce contact and line resistance. Wet chemical metallization techniques benefit from depositing a denser, more conductive material at a higher aspect ratio than what is achievable with standard paste printing. This results in the ability to create narrower fingers with higher conductivity, which allows for higher cell efficiencies and lower overall silver consumption [4].

However, LIP requires complicated equipment and continuous contact to the cell during plating, which can lead to breakage and loss of yield. Additionally, high silver concentrations in the plating bath result in significant drag-out costs and associated operating expenses. This paper proposes a novel, alternative silver plating chemistry based on a Light Induced Electroless Plating (LIEP) mechanism.

1.1 Light induced electroless plating

LIEP silver is a cyanide-free, electroless plating chemistry and plating process. However, LIEP is unlike traditional electroless processes, which normally utilize a reducing species to drive reduction of ionic silver from the plating solution. These baths are especially prone to extraneous plating and plate-out, decomposition, and general instability. By contrast, LIEP silver plating uses the energy generated by irradiating the cell with light to drive front side chemical deposition of Ag on the contact areas. To counterbalance the cathodic deposition of silver on the front side, a small amount of aluminum is anodically dissolved from the rear of the wafer. Figure 1 schematically depicts the LIEP plating mechanism.

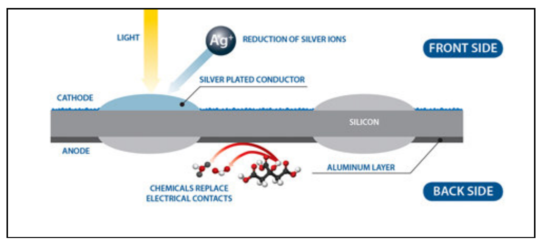

Figure 1: LIEP silver plating schematic.

As a result of this new plating mechanism, the LIEP silver chemistry is ultra-stable, with a wide operating window. Since this is a self-aligned deposition process, plating is uniformly distributed throughout the cell, with no burning at the cell edge. Figure 2 demonstrates the ability of the LIEP silver chemistry to 'fill in' the space between silver flakes, which greatly decreases the line resistance of the paste. It also has minimal drag-out loss of silver due to low metal concentration in the working bath. Finally, equipment needs are simpler for LIEP than with the LIP process; there is no requirement for rectification, expensive silver anodes, or making electrical contact to the cell.

The benefit of LIEP silver plating is demonstrated in two specific areas: 1) repair of standard production cells with improper contact and high series resistance, and 2) use in combination with reduced paste printing, whereby silver cost is spared while providing equivalent or better cell conversion efficiency. Figure 3 represents a production flow chart including standard cell fabrication and the two candidate LIEP silver process flows.

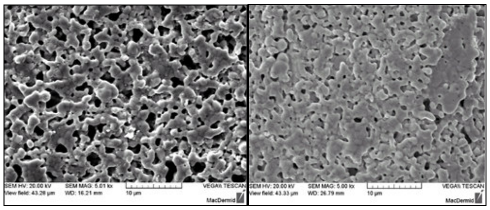

Figure 2: SEM images of seed silver paste before (left) and after (right) LIEP Ag plating.

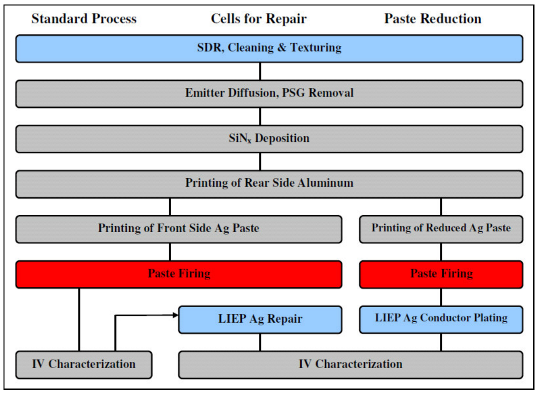

Figure 3: Standard Ag paste printing vs. cell repair and paste reduction processes utilizing LIEP Ag plating.

2 CELL REPAIR

The first potential application of LIEP silver plating is for repair of underperforming "B Class" production cells. At the end of the fabrication process, the efficiency of each cell is measured, and the cells are sorted and binned according to performance. The lower performance of production cells can be attributed to a number of factors. Often times, the efficiency suffers because of poor contact of the seed paste to the emitter layer, which may be due non-optimized firing conditions and normal variation in materials. Additionally, excess line or grid resistance of the silver paste conductor contributes to higher series resistance, reduced fill factors and lower efficiency.

In this experiment, a number of 156 mm mc-Si cells with lower efficiency was selected from a standard production cell line. The IV parameters were measured and recorded using a cell tester. These cells showed a wide variation of fill factors and efficiencies, but typically had higher series resistance when compared to "A Class" cells. The cells were plated with 20-30 mg LIEP silver in a single-step horizontal process, then rinsed and dried. IV characteristics were measured again for comparison. The average values of 166 cells tested before and after LIEP plating are shown in Table I.

The main effect of LIEP plating in this test sample is the reduction (>40%$_{rel}$) in series resistance, which results in the corresponding increase in fill factor and efficiency. More specifically, the *range* of R_{series} values among the sample group was significantly narrowed after plating (figure 4). The change in both V_{oc} and J_{sc} after plating is negligible within experimental error, although it is expected that the J_{sc} will decrease with thicker plating, since the cell will have more shading on the front side.

Table I: Average IV results of B Class repair cells before and after LIEP plating.

	V_{oc} (mV)	J_{sc} (mA/cm^2)	R_{series} (Ωcm^2)	FF (%)	η (%)
As Printed	614	34.5	2.49	65.7	13.8
After LIEP	617	34.4	1.47	73.7	15.6

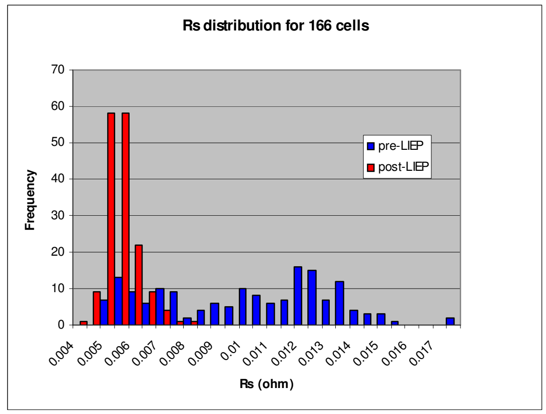

Figure 4: Distribution of R_{series} for repair cells before and after LIEP Ag plating.

3 PASTE REDUCTION

The second application of LIEP silver plating is for reducing paste consumption while maintaining, or improving, overall performance. Paste reduction experiments rely on the conductivity advantage of chemically deposited silver, which forms a dense, continuous layer with resistivity comparable to bulk silver (6.3x10^7 S/m). This value is as much as three times higher than screened silver paste [5], which has a higher resistance due to the porous nature of the fired paste and the inclusion of impurities such as glass frit in the paste composition. By printing thinner, narrower fingers, and then thickening the conductor using LIEP, an equivalent line conductivity can be achieved with significantly lower silver consumption. Additionally, since the printed paste is only a 'seed' layer in this situation, it is easier to achieve fine line printing because aspect ratio is no longer critical. This offers the added benefit of less cell shading, which results in higher J_{sc} and increased efficiency.

For this experiment, 60 wafers of 156 mm mc-Si were printed and fired with a reduced quantity of paste. Fine line printing was achieved by using a finer mesh screen with thinner wire diameter and a narrow finger pattern. After firing, the fingers were approximately 55 µm wide and 9-10 µm thick, with an average front side silver mass of 68 mg. The cells were then plated with 25 mg LIEP silver. IV measurements were made before and after plating; the average values appear in table II.

Table II: Average IV results of reduced paste cells before and after LIEP plating

	Total Ag Mass (mg)	Voc mV	Jsc mA/cm^2	R_{series} Ωcm^2	FF %	η %
As Printed	68	625	35.1	1.52	75.4	16.5
After LIEP	93	624	35.2	0.92	77.5	17.0

Similar to the results of the first experiment, LIEP plating of paste-reduced cells resulted in a significant decrease in series resistance, which led to higher fill factor and efficiency. Furthermore, these wafers represent a large reduction in front side silver usage, even after silver plating. If standard production cells are currently printed with 150 mg of silver front side paste, then this experiment demonstrates comparable efficiency while using only 62% of the silver. Further improvement of seed pastes and deposition techniques in conjunction with silver plating will allow for equivalent, if not superior, performance with <50% of the current front side silver usage.

4 ADHESION AND RELIABILITY

In order to quantify the effect LIEP silver has on overall cell and module reliability, testing was performed on commercially produced cells, manufactured with and without LIEP silver plating. The wafers were soldered with solder-coated copper ribbon and a low-acid, low-solid flux according to standard production practices. Comparison of the initial peel strength showed that the LIEP process not only produced higher median peel strength values but with less variation. Peel strength testing was also performed on tabbed cells that were exposed to 200 temperature cycles from -40°C to 85°C, with measurements at 50 cycle intervals (figure 5). Measurement of peel strength as a function of temperature cycling shows a significant difference between cells manufactured with and without LIEP, even after just 50 temperature cycles. In contrast, the LIEP plated cells continue to show stable peel strength up to 200 cycles. This can be attributed to the better soldered contact to cells with LIEP, since the plated silver surface is more dense and continuous, with less overall topography and pores.

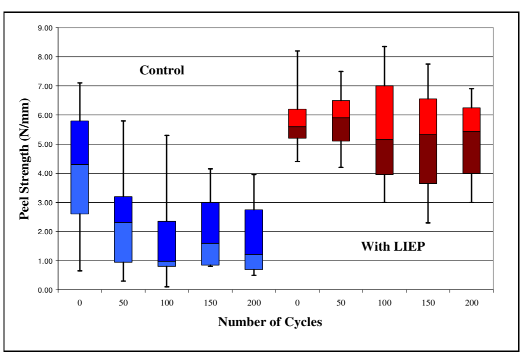

Figure 5: Peel strength of LIEP vs. control through thermal cycle testing

For reliability characterization, cells from each process were soldered, built into 3x3 modules, and subjected to 200 thermal cycles as well as a 1000 hour damp-heat test. After both thermal cycling and damp-heat testing, both groups of modules were comfortably within the IEC-61215 degradation limit of -5% (figure 6). While no statistical difference is observed in module performance, the peel strength data suggests that for long term field reliability and extended thermal cycling, LIEP processed cells may show superior reliability.

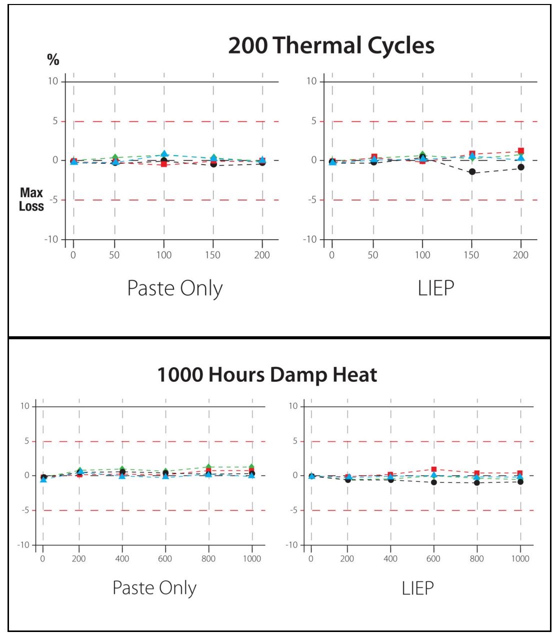

Figure 6: IV results of module through thermal cycling and damp-heat testing

5 CONCLUSIONS

A novel light-induced electroless silver plating chemistry is introduced for plating of silicon solar cells. The chemistry, when employed in a conveyorized contact-less plating method, demonstrates the ability to consistently reduce series resistance and improve efficiency of underperforming cells. Additionally, the use of LIEP silver in a two-step paste reduction metallization process shows the ability to maintain efficiency while reducing silver usage costs. Adhesion and module reliability data demonstrates equivalent, and often better reliability results from the LIEP processed cells. Follow-up experimentation on improving the seed layer printing process will further optimize the front side metallization and lead to even greater cost savings and IV performance benefits.

6 REFERENCES

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