THE COMMERCIAL APPLICATION OF LIGHT INDUCED ELECTROPLATING FOR IMPROVING THE EFFICIENCY OF CRYSTALLINE SILICON SOLAR CELLS

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ABSTRACT: This paper describes the development of an industrial process for increasing the efficiency of crystalline silicon solar cells by improving the front grid line conductivity without a concurrent increase in shading loss. The methodology to achieve this was to deposit silver (Ag) metal using light induced plating (LIP) onto a seed layer grid of conventional thick film screen printed Ag paste and apply this on an industrial scale. The feasibility of this technique had been previously reported on a laboratory scale with a cyanide based Ag electrolyte [1]. This paper details how this methodology was implemented in an industrial setting but using a non-cyanide Ag plating electrolyte and purpose built in line horizontal equipment. The capability of achieving efficiency gains typically between 0.2 - 0.4% absolute is shown.
Keywords: Electrodeposition, Light Induced Plating, Manufacturing and Processing

1 BACKGROUND

As solar cell substrate areas grow in size, ohmic loss due to the front grid fingers becomes an increasingly important factor adversely affecting cell performance. In this the screen printed thick film Ag paste manufacturing route has drawbacks which include:

- Screen print feature geometry tends towards flat structures with adverse effect on shading loss.
- Ag paste is much less conductive than bulk Ag metal so requires a substantial cross section to maximise conductivity which further exacerbates shading loss
- Ag paste is an expensive consumable

Prior laboratory scale studies have demonstrated the feasibility of enhancing cell efficiencies by 0.3-0.4% absolute with deposition of several microns of Ag metal using Light Induced Plating (LIP) onto a seed layer of conventional screen printed Ag paste. [1]

2 OBJECTIVE

Principal objectives were as follows

- To develop an industrially viable process for increasing the efficiency of Silicon solar cells by improving the front grid line conductivity without a concurrent increase in shading loss.
- To achieve this by depositing silver (Ag) metal over a seed layer grid of conventional screen printed thick film Ag paste.
- Deposit the Ag metal using Light Induced Plating from a non-cyanide electrolyte in custom designed horizontal equipment.

3 LIGHT INDUCED PLATING (LIP)

The light induced plating (LIP) technique was initially patented in 1979 by Solarex [2] but did not achieve significant industrial application. Latterly Fraunhofer ISE had pioneered LIP with a cyanide Ag electrolyte as a metallization approach for high efficiency cells. What makes LIP attractive compared to conventional electroplating is that the electric current is generated internally which simplifies the electrical contact system and provides a more uniform current density distribution. The principles are shown in figure 1.

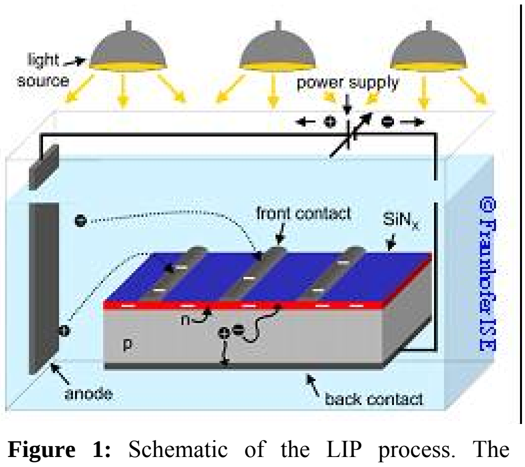

Figure 1: Schematic of the LIP process. The positively charged metal cations are deposited onto the negative n doped front surface (cathode), induced by the photovoltaic effect under illumination.

4 DEVELOPMENT

4.1 Equipment prototype

Initially an in line horizontal prototype equipment set was developed and used for confirmation of process feasibility, characterisation of process parameters and grid geometry influence.

4.2 Ag plating electrolyte

A non-cyanide Ag plating electrolyte was tested, characterised and successfully validated for LIP applications.

4.3 Process

Several microns of Ag metal were deposited by LIP over a seed layer of screen printed Ag paste. Tests included both multi-crystalline cells and those from string ribbon substrate.

4.4 Production Scale-up

A prototype production LIP line capable of some 400-500 wafers per hour capacity was installed at a cell fabricators facility (shown in figure 2). The LIP technique eliminated the need for plating jigs enabling cells to be directly loaded onto the transport system with ready integration into production flows. Following qualification the line was extended to ~1500 cells per hour capacity.

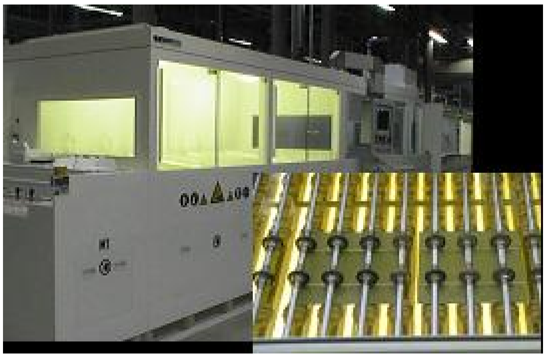

Figure 2: In line LIP process equipment showing plating cell

5 RESULTS

5.1 Non CN electrolyte characterisation

Characterisation of the non-cyanide Ag plating electrolyte and comparison with a cyanide based system was conducted on a laboratory basis. This showed very similar cell performance improvements after LIP for both electrolyte types. Table 1 shows comparative testing conducted on 150x80 mm string ribbon cells. JI refers to whether an additional junction isolation step was conducted after the plating operation.

Bath type	JI after plating	# cells	η before LIP [%]	η after LIP [%]	Voc [mV]	Jsc [A]	FF [%]	η change [% abs.]
Ag CN	yes	23	13.54	14.15	601.8	3.83	73.66	**0.61**
	no	23	13.40	14.15	602.4	3.834	73.49	**0.75**
Enlight™ non CN	yes	83	13.66	14.17	600.9	3.809	74.29	**0.51**
	no	57	13.37	14.14	600.7	3.815	73.53	**0.77**
Non plated (control)	no	50	13.76	13.76	598.8	3.766	73.23	-

Table I: Comparison of cyanide and cyanide free plating chemistries for LIP

The effect of LIP deposited Ag in lowering the Bus to Bus Resistance versus standard thick film paste cells as reference "control" is shown in Figure 3. This was conducted on 150x80mm string ribbon cells.

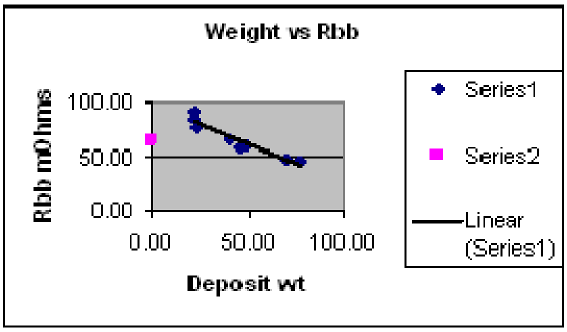

Figure 3: Series 1 shows the effect of increasing LIP Ag deposit weight on Rbb compared to thick film paste production cell reference, series 2

5.2 Production prototype and scale up:

Production scale runs were conducted processing many thousands of wafers to quantify cell performance, characterise the process and validate end product attributes such as solderability, module assembly and accelerated ageing.

With the LIP route typical efficiency gains of 0.2 - 0.4 % absolute were achieved when compared to standard production screen printed cells on 156x156mm multi-crystalline wafer substrates.

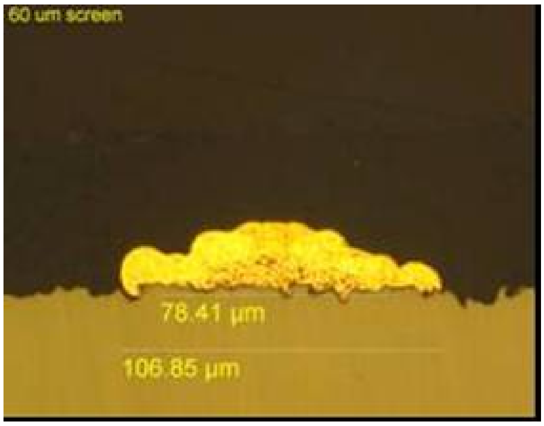

Figure 4: Cross section of plated grid line showing thick film seed with over layer of LIP deposited Ag

The consumption of Ag paste for LIP seed layer was typically 50% of that used in the standard screen print production route.

Table II shows results for large scale runs, and table III those for neighboured cell including comparison of differing grid finger dimensions. These refer to the screen dimensions of the seed layer rather than the width of the printed grid which is somewhat greater due to spread during printing.

Test lot	#cells	Process type	η [%]	Voc [mV]	Jsc [mA/cm2]	FF [%]
1	5220	LIP	15.60	606.34	-	77.05
2	12667	LIP	15.39	603.14	32.99	77.39
		Production	14.97	602.31	32.61	76.23

Table II: Comparison of large scale runs of LIP process with productions cells (non matched) run at similar time period. 156x156mm multi-crystalline substrate

LIP on80µm grid fingers						
# of cells	ηcell [%]	Voc [mV]	Isc [mA/cm²]	Rs [?cm²]	Rsh [k?cm²]	FF [%]
65	15.84	611.03	34.02	0.94	12.45	76.22
47	15.80	610.33	33.79	0.91	14.84	76.60
Average	15.82	610.74	33.92	0.93	13.45	76.38
Difference (abs) vs production route cells	0.35	0.33	-0.22	-0.59	-6.67	2.11

LIP on60µm grid fingers						
# of cells	ηcell [%]	Voc [mV]	Isc [mA/cm²]	Rs [?cm²]	Rsh [k?cm²]	FF [%]
65	15.95	611.33	34.14	0.91	13.03	76.45
47	15.72	609.67	33.88	0.92	5.51	76.11
Average	15.86	610.66	34.03	0.91	9.88	76.31
Difference (abs) vs production route cells	0.38	0.25	-0.11	-0.60	-10.24	2.05

Table III: Comparison of LIP process on differing seed layer grid dimensions versus production cells route with matched neighboured cells. 156x156mm multi-crystalline substrate

A general relationship showing greater efficiency gains on narrower printed grid seed layer was apparent and is summarised in Figure 4.

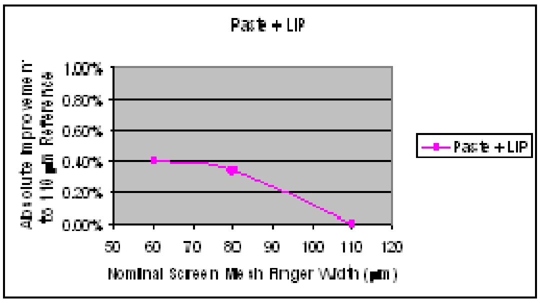

Figure 4: Relationship between screen mesh grid widths versus absolute efficiency gains

Another feature seen was the ability to "recover" some poorly performing cells. The mechanism and impact of this has yet to be quantified however the observation seen is that some poorly performing standard cells show very substantial gains after LIP presumably due to "repair" of defective screen printed grid.

6 CONCLUSIONS

A light induced silver plating process over a seed layer of conventional screen printed silver paste has been developed and qualified in an industrial environment. Efficiency gains of 0.2-0.4% absolute have been demonstrated relative to standard thick film paste production cells. The process utilises horizontal in line Light Induced Plating equipment with a cyanide free Ag electrolyte.

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