INKJET PLATING RESIST FOR IMPROVED CELL EFFICENCY

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ABSTRACT

The use of a resist applied before nickel and silver plating can greatly reduce background plating while helping to control plated line width spread on the front side of the solar cell grid. Reduced line spread helps to minimize shadowing and has a positive impact on cell efficiency.

Experimental Objectives

- Investigate hot melt ink as resist for both hydrofluoric acid etching and metal plating
- Create high resolution line widths using inkjet as a plating mask to reduce the light shadowing effect
- Eliminate background plating caused by imperfections in the silicon nitride
- Optimize the inkjet and plating processes to maximize cell efficiency

Background

The standard method for metallizing the solar cell bus bars and fingers is by applying a silver paste by screen printing techniques and firing the metal through the silicon nitride to form contact with the emitter[1]. The paste can either be a thin seed layer which is followed by electroplated silver or a full thickness silver paste.

Alternative processes are being developed that would allow for lower cost alternatives like copper plating in place of silver. One approach would be the use of an electroless nickel barrier layer followed by light induced copper plating. In order to plate the electroless nickel, the silicon nitride needs to be removed in advance. Several methods exist to remove the silicon nitride including laser ablation, direct etching gels and masked, HF wet chemical etching. Most of the materials act exclusively to open the silicon nitride and generally do not directly interact with the plating process.

A new ink has been developed that can not only withstand HF etch of the nitride but can remain behind on the wafer through the nickel and silver/copper plating process.

By remaining behind during plating, the following benefits can be achieved:

(1) Background plating is eliminated with the ink acting as a protective coating and preventing plating to pinholes or scratches in the silicon nitride;

(2) Less shadowing of the cell and smaller plating lines are possible because the ink helps to constrain the plating line growth;

After plating, the ink can be safely stripped from the wafer in a process that does not cause backside aluminum attack.

Factors that Affect the Cell Efficiency

Pre-existing silicon nitride (SiNx) defects have a significant impact on the final plated cell efficiency. One common defect of silicon nitride coating deposited by the PECVD process is blister formation, especially on the saw damaged mc-Si surface[2].

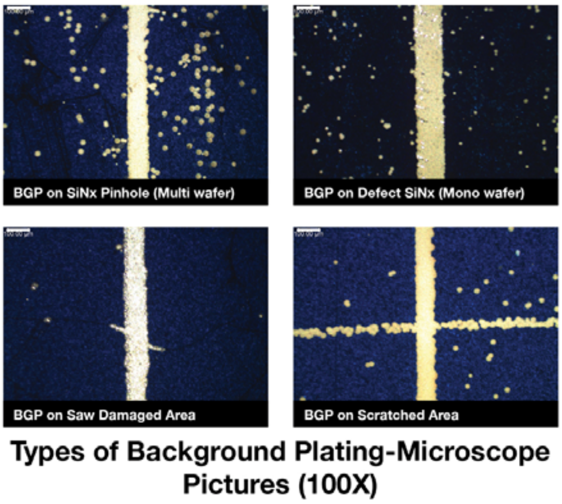

Figure 1- Low Magnification of Background Plating

Another common defect is the randomly located pinholes on the SiNx coating, especially on the tips of the pyramids of mono crystalline texture wafers. Both blisters and pinholes are indicated by the bright spots in the SiNx coating under microscope. During the Ni and LIP Ag plating, metals will deposit in the same way in these defect areas as the areas where the SiNx has been intentionally opened. This undesirable plating, or background plating (BGP) as shown in top pictures of Figure 1 and Figure 2, not only increases the light shadowing, but also reduces the Isc values and overall cell performance (table 1).

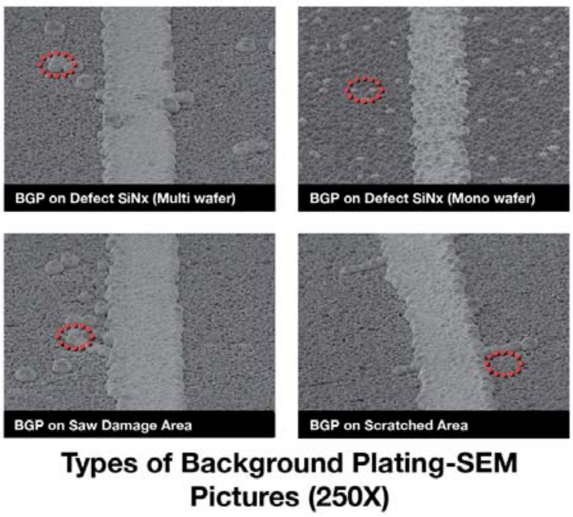

Figure 2- High Magnification of Background Plating

Scratches on the SiNx coating are an indication of handling problems during the process[3]. This defect is more visible after the plating as shown in both the microscope picture (Figure 1, bottom right) and SEM picture (Figure 2, bottom right).

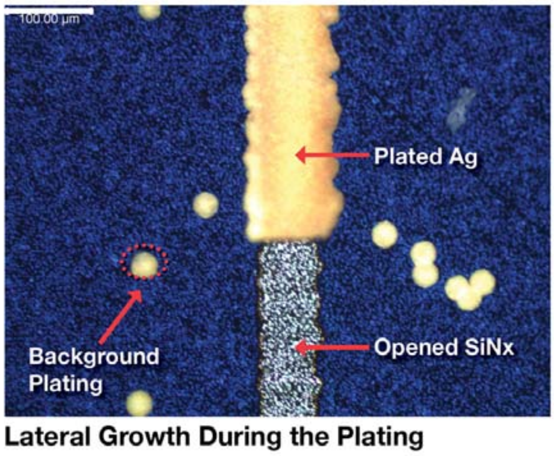

Figure 3- Plated Line and Surrounding Area

Another factor that impacts the cell efficiency is the lateral growth of the plated finger when the plating thickness increases as shown in Figure 3. This lateral growth causes higher front side light shadowing and reduces the cell efficiency.

Inkjet Resist Capabilities

The most common use of an inkjet resist in the manufacture of a solar cell is as a means of opening the silicon nitride coating before nickel seed plating. The inkjet technique allows for improve resolution as compare to conventional screen printing of finger lines[4]; moreover, as compared to other higher resolution techniques like laser ablation[5], the inkjet plating resist process offers the ability to protect the non-plated areas from potential background plating.

All inkjet printing was performed on a Schmid DOD 300® ink jet printer for laboratory applications; incorporating a Spectra ® SE128 AA print head. The

SE-128 is a 128 nozzle, native 50 dpi, piezoelectric, ink jet printhead; with a 30 picoliter calibrated drop size and an operating temperature up to 90° C.

"Fingers" were printed perpendicular to the printhead movement in order to utilize a line enhancement feature. A resolution of 846.67 dpi by 800 dpi was chosen as optimal. This decision was based on a combination of guaranteed total coverage of desired masked areas, optimal advantage of the line enhancement feature, aspect ratio of resist height to finger opening, and capabilities of the printer. Jetting temperature was around 82° C at the printhead. Table speed was varied from 100 mm/s to 300 mm/s, resulting in a printing frequency range of 3.33 KHz to 10.0 KHz.

In the print direction (x), ink jet printers are limited in travel increments by the accuracy of the encoder (5 micron). A resolution of 846.67 dpi represents an incremental step of 30 microns. Drop diameter for a 30 picoliter volume size is approximately 60 micron as deposited on the wafer. Therefore, the minimum line width for the first line printed by any given nozzle is equal to the diameter of the drop, i.e. 60 micron.

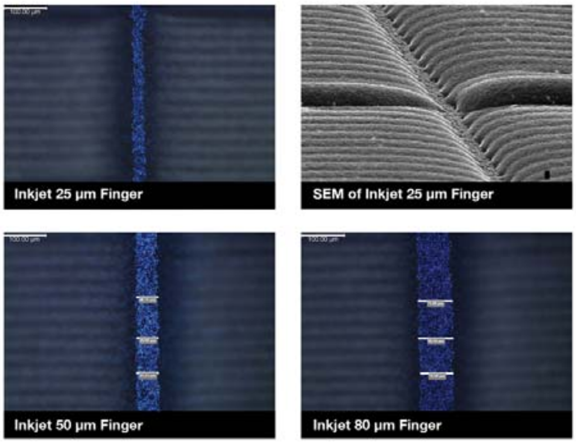

Figure 4- Resolution Capability Using Inkjet Printing

However, each subsequent line printed will print at a 30 micron increment. Half of the drop (30 micron) will cover the first (or previous) printed line and the other half of the drop (30 micron) will cover the wafer. In order to form a "finger" line during plating, a gap is produced by not printing a line during the print sequence. As illustrated in Figure 4, the gap can be resolved down to 25 micron resolution.

Other factors will also contribute to the final finger width. Texture / surface energy of the substrate, jetting temperature, and print parameters will influence both the size drop and spread of the drop on the substrate. With manipulation of these factors the end finger size can be altered a few microns in either direction.

Beyond the jetting capabilities and resolution of the resist, adhesion of the resist after HF etch and nickel and silver plating is also important for resist performance. Etching in HF or a buffered oxide etch can be quite challenging for the adhesion of the ink when applied to silicon nitride or silicon oxide surfaces. The challenge is a combination of two factors: (1) penetration capability of the HF etchants and (2) the hydrophilic nature of the silicon nitride and silicon oxide surfaces. One common method for measuring the hydrophilic / hydrophobic nature of the surface is by water contact angle (Figure 5).

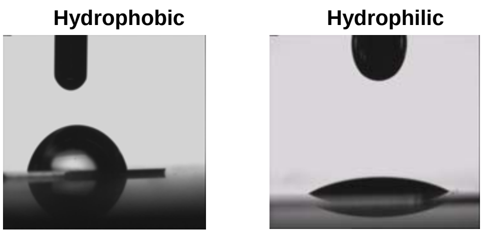

Figure 5 - Water Contact Angle Measurement

More water spread and lower contact angle indicates a more hydrophilic surface. Since the ink is hydrophobic, better adhesion and conformation to the surface is achieved with the surface having a higher water contact angle. In addition to the ink wetting properties, the hydrophilic nature of silicon nitride and silicon oxide allows for a faster HF etching rate. As the etch rate increases, the nitride or oxide is etched so quickly that it is removed from beneath the still adhering resist. By balancing the ink type, surface and etchant, adhesion can become optimized.

Once the adhesion and performance is optimized for the HF etching process, the next focus is on the plating resistance of the ink formulation. Conventional hot melt inks tend to be sensitive to temperature and alkaline pH so a curing step is generally recommended for those types of inks. After printing the ink to the wafer surface, the ink is cured with UV radiation at an energy level of 120 mJ/cm^2. The UV curing enables the ink chemistry to stand up to higher temperature plating bathes (greater than 40 C). After curing, the resist shows no attack during either nickel or silver plating. Examples in Figure 6 show lines plated with a nickel seed followed by light induced silver plating.

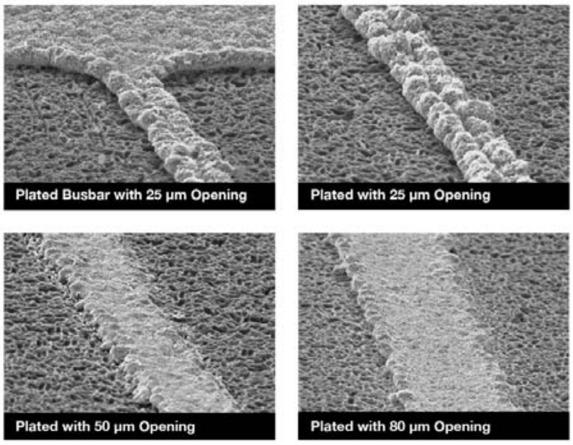

Figure 6- Plated Line After Resist Stripping

After plating, the resist is then stripped from the surface using a stripper composed of alkaline and/or surfactant chemistries.

Improved Background Plating

By applying the resist to the substrate before plating, the pinholes or scratched areas on the silicon nitride can be protected. An example of the advantages of the plating resist process is illustrated in Figure 7.

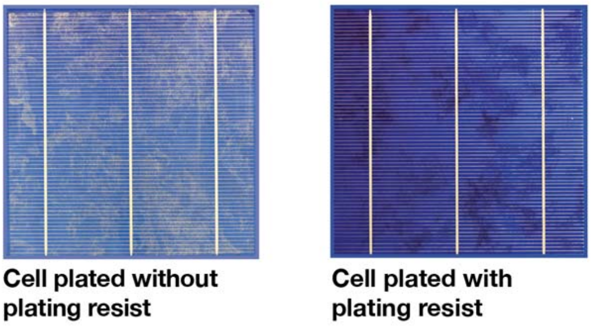

Figure 7- Improved Background Plating

Without the resist, large areas of background plating are observed.[6] When a resist is used prior to plating, no background plating is present. The advantages are both cosmetic and practical. With less background plating, less shadowing occurs so light can more effectively penetrate the cell[7].

Controlled Lateral Growth

In addition to the reduction of background plating, less shadowing can also be achieved using a plating resist because of the improvements to line width control (Figure 8).

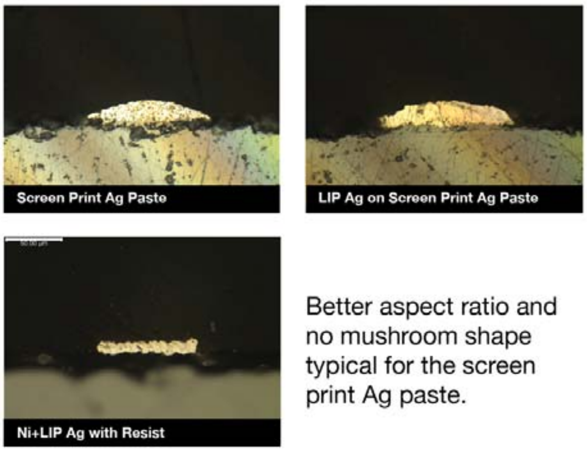

Figure 8 - Less Line Shadowing and Increased Cross Sectional Area

Essentially, a more narrow plated line track has the potential to block less light when using a front grid design. However, to collect the same amount of current, narrowing lines generally means more lines need to be printed to achieve the proper series resistance. In the case of the plating resist, narrow lines are achieved in combination with more uniformity to the plated deposit (Figure 8, bottom left). The more rectangular plated deposit would allow for lines with more cross-sectional volume and thus, less potential series resistance for a given plated line width and height[8] (see Figure 9).

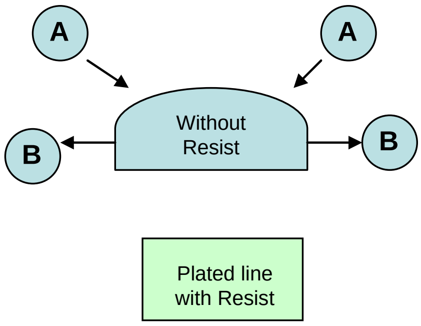

Figure 9- Rectangular Plated Deposit Versus Standard Semi-Circular Standard Deposit (A = lower cross sectional area; B = Line Spread)

This in turn minimizes the need for increased finger lines which has a positive impact on the line shadowing and the associated efficiency improvement (Table 1).

	Isc (mA/cm2)	Voc (mV)	FF (%)	η (%)
Screen Print Ag Paste (Control)	33.73	613	75.2	15.5
Plating w/o Resist	33.56	611	71.5	14.7
Plating w/ Resist	34.88	616	75.8	16.3

Note: significantly higher Isc values and cell efficiency for the cell plated with the resist.

Table 1- Cell Efficiency Comparison - With and Without Inkjet Resist

Final Process Recommendations

To etch the silicon nitride from the wafer, the ink is applied which is followed by HF etching and then the resist is stripped prior to the plating process steps (Figure 10, left side).

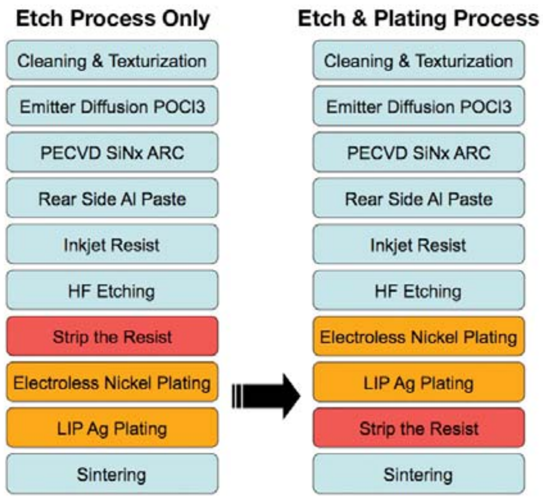

Figure 10- Process Recommendations

In the case of using the ink as a combined etching and plating resist, the ink is applied at the same stage but is stripped only after all the plating is complete.

Overall Conclusions

With the use of an inkjet plating resist, the following improvements can be observed:

- The new ink has been demonstrated to withstand both HF etching and subsequent plating chemistry.
- By leaving the resist on during the plating, background plating due to the imperfection of SiNx is completely eliminated.
- The plated line width is constrained to the dimensions of the nitride opening with no "mushrooming" of the plated deposit extending beyond the opening. As a result, less shadowing is observed.

- A better cross-sectional area of the plated metal is also observed as a result of the resist being constrained to a more rectangular geometry. Rather than a semicircular plated deposit, a more uniform rectangular deposit is achieved. The increased plated area has less series resistance and as a result, less collector lines are required which minimizes shadowing.

- Cell efficiency gains of 1.6% and 0.8% absolute using the plating resist are achieved compared with the cells plated without the plating resist (Table 1).

Acknowledgements

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