Screen Printing

For Crystalline Silicon Solar Cells

APPLIED MATERIALS

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INTRODUCTION

One of the most crucial steps for producing crystalline silicon solar cells is creating the grid of very fine circuit lines on the front and back sides of the wafer that will conduct the light-generated electrons away from the cell. This metallization process is most commonly done with screen printing technology, where a metal-containing conductive paste is forced through the openings of a screen on to a wafer to form the circuits or contacts.

A typical crystalline silicon solar cell manufacturing process flow requires multiple screen printing steps that take place towards the end of manufacturing process flow. Usually, there are two separate printing steps for the front (contact lines and busbars) and the back (contact/passivation and busbars) sides of the cell [figure 1].

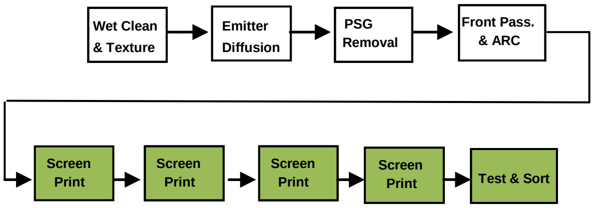

Figure 1: Multiple screen printing steps are used in the fabrication of crystalline silicon solar cells. The green boxes are steps Applied Baccini supports.

Over the years, improvements in the precision and automation of solar screen-printing equipment have resulted in equipment capable of overlaying multiple printed layers at repeatable micron-level accuracy. This development has led to new advanced applications such as double-printed contact lines and selective emitter metallization.

Today, the company responsible for many advancements is the company that developed screen printing technology for microelectronics in the 1970s and extended it to solar for contact metallization in the 1980s. This company is Baccini Spa which is now Applied Materials' Baccini Group.

BASIC SOLAR SCREEN PRINTING

The printing process begins as a silicon wafer is placed onto the printing table. A very fine-mesh print screen, mounted within a frame, is placed over the wafer; the screen blocks off certain areas and leaves other areas open, where the paste can go through [figure 2]. The distance between wafer and screen is carefully controlled (called the 'snap-off' distance). Screens used for frontside printing typically have a much finer mesh size than do backside screens, due to the finer metal lines required on the front side.

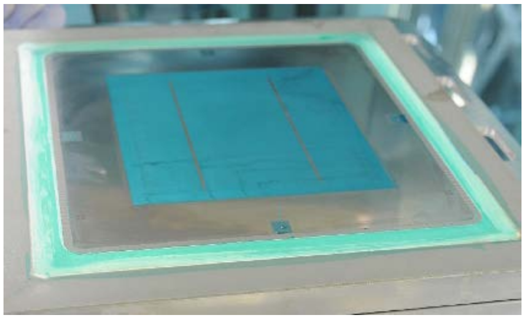

Figure 2: The print screen contains a pattern of open and closed spaces that allow paste to wafer transfer.

After a measured amount of paste is dispensed onto the screen, a squeegee distributes the paste over the screen to uniformly fill the screen openings. As the squeegee moves across the screen, it pushes the paste through the screen openings and onto the wafer surface [figure 3]. This process must be tightly controlled for temperature, pressure, speed, and many other variables.

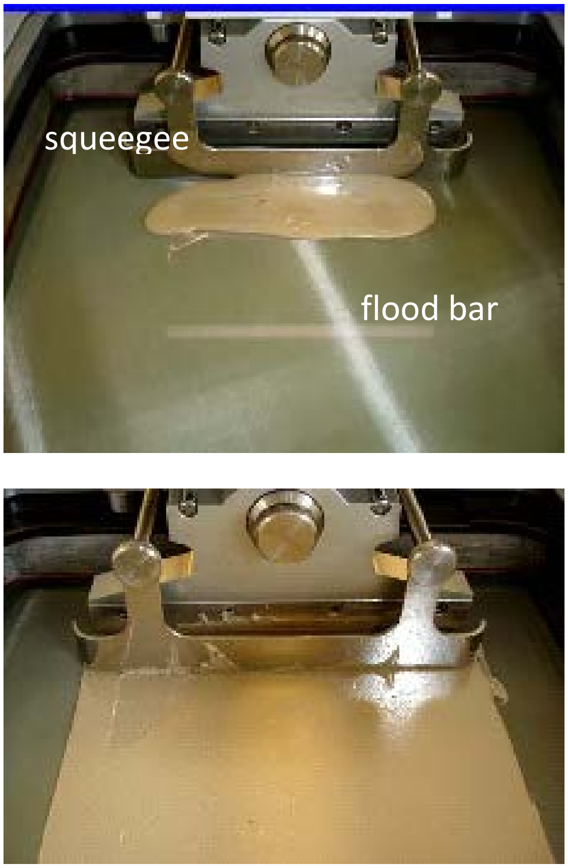

Figure 3: After conductive paste is dispensed onto the screen, the squeegee spreads it across the screen and presses it through onto the wafer.

After each printing step the wafer goes to a drying furnace to solidify the paste. The wafer is then transferred to another printer for printing additional lines on either the front or back side of the wafer. When all printing steps are completed, the wafer is 'co-fired' in a high-temperature furnace.

PRINTING BOTH SIDES OF THE WAFER

Each solar cell has conductive lines [figure 4] on both front and back sides that are deposited using screen printing and which have different functions. The frontside circuit lines are much more narrow and delicate than those on the backside; some manufacturers perform the backside print steps first, and then flip the wafers over to deposit the frontside circuits, minimizing the potential for damage during handling.

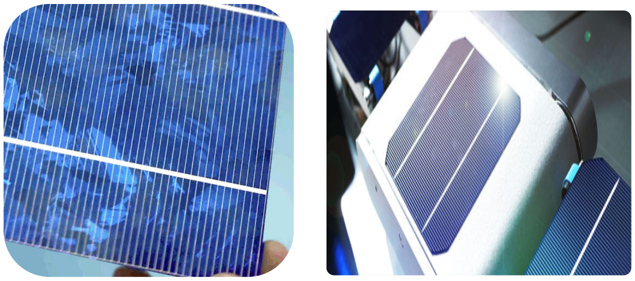

Figure 4: The frontside of the wafer after printing shows large and small contact lines that collect electricity from the active regions.

On the front side, which will face the sun, most crystalline silicon solar designs use a grid of very fine circuit lines ('fingers') that collect and conduct the light-created electricity from the active regions to larger collecting lines, called 'busbars,' and then to the module's electrical system. The frontside finger lines, which can be as narrow as 80µm, are much smaller than the circuit lines on the backside.

On the wafer's backside, for a traditional cell, the printing requirements are less technically rigorous than on the frontside. Instead of a grid of very thin circuit lines, the first backside print step deposits a uniform sheet of aluminum-based material that conducts electricity, and also reflects uncaptured light back into the cell. This layer also 'passivates' the solar cell, sealing off unwanted molecular pathways that can capture mobile electrons. A second backside print step creates the busbars that interface with the outside electrical system.

NEXT-GENERATION SCREEN PRINTING APPLICATIONS

As crystalline silicon solar cells progress from today's average 16% efficiency to an industry goal of more than 20%, screen printing tools offer a variety of methods to enable this improvement. Conventional PV cells with screen printed and co-fired metal contacts are already exceeding 18% efficiency in industrial production for monocrystalline silicon wafers.

DOUBLE-PRINTED CONTACT LINES

One of the unwanted effects of the frontside circuit grid is shadowing: the lines block a small amount of sunlight from reaching active parts of the cell, reducing conversion efficiency [figure 5]. To minimize this shadowing effect, the lines must be made as narrow as possible. However, to maintain adequate conductivity, they also have to be taller in order to have the same cross-sectional area.

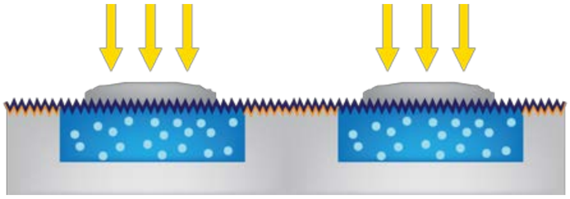

Figure 5: Conducting lines block light from the active area of the cell.

The solution to achieve finer, taller contacts is to print multiple lines on top of each other. This means the screen printer must be capable of precisely and repeatedly overlaying extremely fine lines – the current standard line is as small as 70 - 80µm, or about the thickness of an average human hair.

Most metal circuit lines today are 110-120µm wide and 12-15µm thick after firing. To decrease the efficiency loss due to shadowing, the line width can be reduced; at the same time, the line conductivity must be optimized by increasing line thickness [figure 6]. The potential conversion efficiency gain in moving from 120µm width / 12µm line thickness to 70µm width / 30µm thickness is 0.5% absolute.

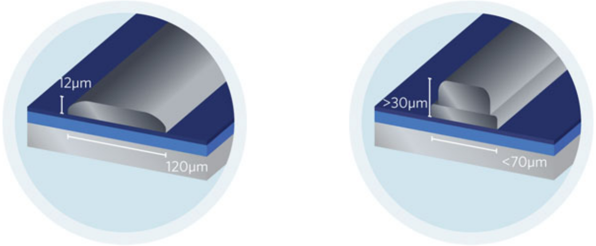

Figure 6: Decreasing line width reduces shadowing of the active area, increasing potential efficiency.

Applied Baccini's approach is to overlap two prints made by two separate printers. The latest process achieves a <70µm line width and >30µm average line thickness in a production environment. This method reduces shading loss by approximately 20%, while keeping low series resistance. This multiple printing approach can be easily and cost-effectively implemented in existing production lines through the addition of an additional screen printer and drying oven.

Alignment accuracy is the most critical metric for double-printed contacts (and other advanced printing applications), because the second print layer must be perfectly placed above the first. Applied Baccini's Esatto Technology^{TM} enables an alignment repeat of the second print of better than +/-15µm. This Esatto Technology Solution provides superior alignment accuracy utilizes multiple high resolution cameras, advanced illumination sytems and new software algorithms that feature an automatic tuning procedure to allow additional control on print start-up. The Advanced Post Print Vision System provides further improvements to within 10µm alignment accuracy among thousands of wafers.

Double printing requires both the paste composition and the screen design to be carefully co-optimized to maximize the screen printing hardware and process effectivity. The pastes and screens must interact to deliver the expected pattern.

Double printing drives down cost/watt by increasing efficiency of the cells as well as a reduction in paste consumption. This is enabled by optimizing the bus bar formation, resulting in reduction of paste by at least 15%.

SELECTIVE EMITTERS

Another emerging application is selective emitter, a technique that places a heavily-doped n+ region precisely under the screen-printed metal lines in order to further reduce electrical contact resistance and improve surface passivation, contributing to increased efficiency [figure 7].

Several techniques are available to fabricate these emitter regions, all of which require multiple printing steps which must be overlaid with high accuracy and repeatability.

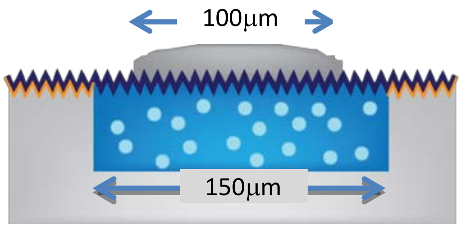

Figure 7: The selective emitter is a heavily-doped region placed directly under the metal line.

The increase in efficiency resulting from the selective emitter process must be balanced with the increased cost from additional processing steps. Applied's selective emitter process accomplishes this by using a standard printer to deposit dopant paste in a grid-like pattern so that a standard single-step dopant diffusion simultaneously forms a local low-resistance emitter and an everywhere-else high resistance emitter with an attendant increase in both photocurrent and photo voltage [figure 8].

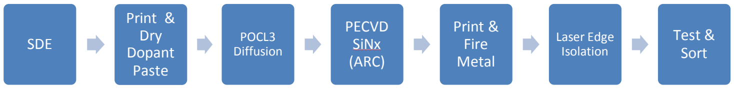

Figure 8: Selective emitter dopant paste process

Regardless of the technique used, the emitter region must be formed with a width just slightly larger than the metal line above it: for a metal line 100µm wide, an emitter region approximately 150µm wide would be considered optimal. It is critical that the subsequent metal line be aligned with high precision directly above the emitter region, otherwise its efficiency advantages will be lost. Applied Baccini Esatto Selective Emitter Solution can provide 0.5% improvement in cell efficiency.

As with double printing and other advanced screen printing processes, pastes and screens for selective emitter processes must meet certain requirements. Non-metal screens must be used with the dopant paste to prevent metal contamination and screens must meet rigorous quality standards.

Selective emitter can be combined with double printing to maximize the increase in efficiency of the cells [figure 9]. Applied Baccini's screen printing technology is the method of choice for creating these cell designs, due to its advantages in technical maturity, alignment accuracy, low cost and high speed. Further, Esatto Technology's alignment accuracy, qualified consumables and process BKMs provide manufacturers a ready to use selective emitter solution that gets them to market faster.

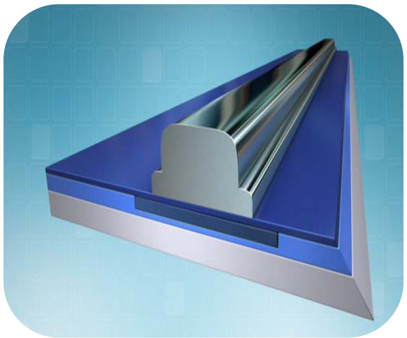

Figure 9: Double printing over selective emitter

ADVANCED CELL STRUCTURES

Efficiency is a key driver to allow solar to fully compete head-to-head in diverse high-volume markets with the price of less-clean forms of energy.

The solar equipment space is already well optimized, requiring manufacturers to move to advanced cell structures in order to drive higher efficiency at low cost. Moving to advanced cell structure high volume production requires an understanding of tool and process interaction in order to implement this shift. Equipment suppliers must provide volume manufacturing-ready integrated solutions which include advanced technology tools, qualified consumables and process recipes.

Baccini is the technology and market leader in high-volume cell manufacturing with the Rotary Line and the Soft Line being cornerstones of several solar factories around the world. Applied Materials' has been a leader in the semiconductor and display arena for over 40 years with a rich legacy of process innovation. Baccini's equipment engineering excellence combined with Applied Materials' process expertise and global R&D capabilities delivers a truly unique and powerful combination. Applied Baccini is positioned to take cell manufacturers to the next level through holistic solutions focused on state-of-the-art equipment, process know-how and consumables management.

CONCLUSION

Screen printing for crystalline silicon solar cells is a cost-effective, extendible technology for depositing metal lines and other applications. The latest screen printing systems are highly automated and capable of extremely high throughput operation, including the handling of ultra-thin wafers. The exceptional alignment and fine-line capabilities of Applied Baccini's advanced screen printers, along with Esatto Technology Solutions, are uniquely enabling emerging applications such as double-printed contact lines and selective emitter technologies. These technology solutions will raise cell efficiency and reduce overall manufacturing cost per watt.

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