Title: New Precision Coating Deposition Method for Photovoltaic Selective Emitter Process

The thin, uniform application of dopant is critical to the successful formation selective emitters on photovoltaic cells.

By: Stuart Erickson, President – Ultrasonic Systems, Inc
Dr. Yang Song, Senior Engineer – Chinalight Solar Co., Ltd.
Ye Duan, Deputy Director R&D – Chinalight Solar Co., Ltd.
Youzhong Li, Deputy General Manager – Chinalight Solar Co., Ltd.

Introduction

Considerable effort is ongoing to improve the efficiency of photovoltaic cells. Recently, much attention has been given to the formation of selective emitters to significantly improve the efficiency of the solar cell. Selective emitters are formed by applying dopant to the wafer surface, using lasers to heavily dope selected areas of the emitter surface and electroplating these heavily doped areas to form metal grid fingers with superior properties compared with grid fingers formed by conventional screen printing methods. The application of a thin, uniform layer of liquid dopant to the surface of the photovoltaic cell is critical to the successful implementation of this process. A brief description of the process steps for selective emitter formation will be provided. However, the focus of this paper will be a description of a method for applying a thin, uniform layer of dopant to the surface of the photovoltaic cell.

Emitter Layer Formation Process

One of the first steps in the manufacturing process of silicon photovoltaic cells is to form a p-n junction. This is accomplished by the thermal diffusion process in which a dopant is applied to the surface of the wafer and then the wafer is exposed to a high temperature of 900 to 1,000 degrees Celsius for a period of time.

Dopant is used as a source for “impurity atoms” to form the n-layer on a p-type silicon wafer by the thermal diffusion process. The emitter layer is formed by introducing an n-type dopant (phosphorous) to a p-type silicon wafer and exposing the wafer to heat for a period of time. As a result of the thermal diffusion process, the wafer, as shown in Figure 1, has an n-type or electron producing emitter layer region on a p-type or electron accepting base region.

The thermal diffusion process produces a “lightly doped” n-layer approximately 2 to 3 microns in thickness on a 200 micron thick p-type silicon wafer. This process produces a semiconductor which is the basis of the photovoltaic cell.

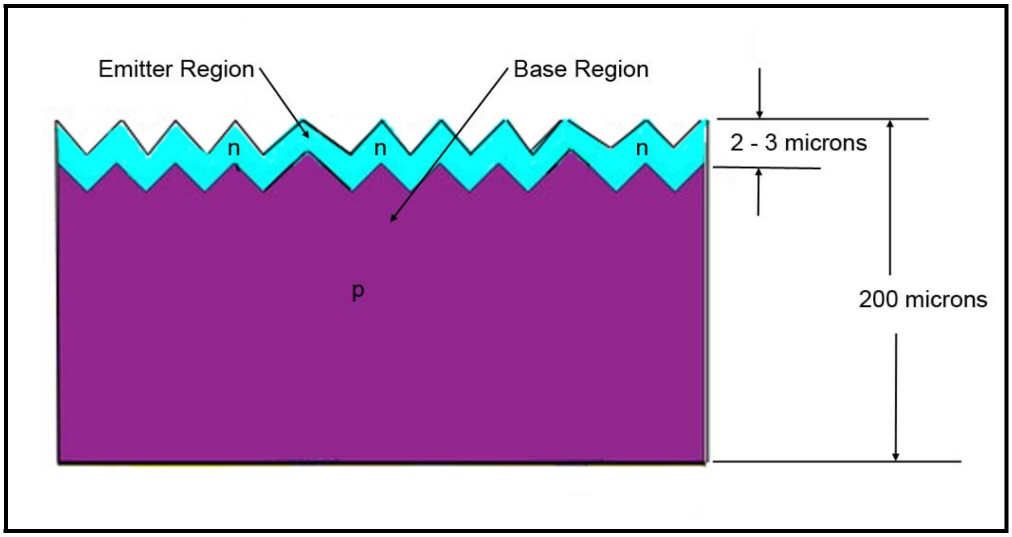

Figure 1
Standard Silicon Solar Cell

"The silicon solar cell performance is controlled by the quality of the p-n junction and its impact on the bulk lifetime during the phosphorous deposition and drive-in. Phosphorous emitters for solar cells can be formed by spray, spin, or print deposition of dopant followed by a belt furnace drive-in or by a liquid source using POCl3 source in a conventional tube furnace."(2)

Since the dopant is the source from which the emitter layer is formed, it is critical that the dopant is applied uniformly at the proper thickness prior to thermal diffusion. The application method of dopant for the thermal diffusion process is not the subject of this paper; it is referenced here to emphasize that a uniform layer of dopant is essential to this process.

Selective Emitter Formation Process

Photovoltaic engineers are continually investigating methods to improve the efficiency of solar cells and each 0.1 % improvement is considered a worthy endeavor. One promising area for efficiency gain is to improve the properties of the metal grid lines on the emitter surface of the solar cell. This can be accomplished by reducing the size of each grid line, increasing the number of grid lines and optimizing the electrical contact between the metal grid line and silicon wafer. The process for formation of selective emitters has been developed to achieve these objectives. This process has been shown to increase cell efficiencies for both mono- and multicrystalline cells by up to 2 percent in absolute terms. This is a 10 percent improvement over more traditional screen printed cells. Understandably, this has created a huge amount of interest in the industry. (1)

The selective emitter cells feature a heavily doped contact area underneath the metalized region and a lightly-doped emitter area between the front fingers. (3) A cross-section of a selective emitter silicon solar cell is shown in Figure 2.

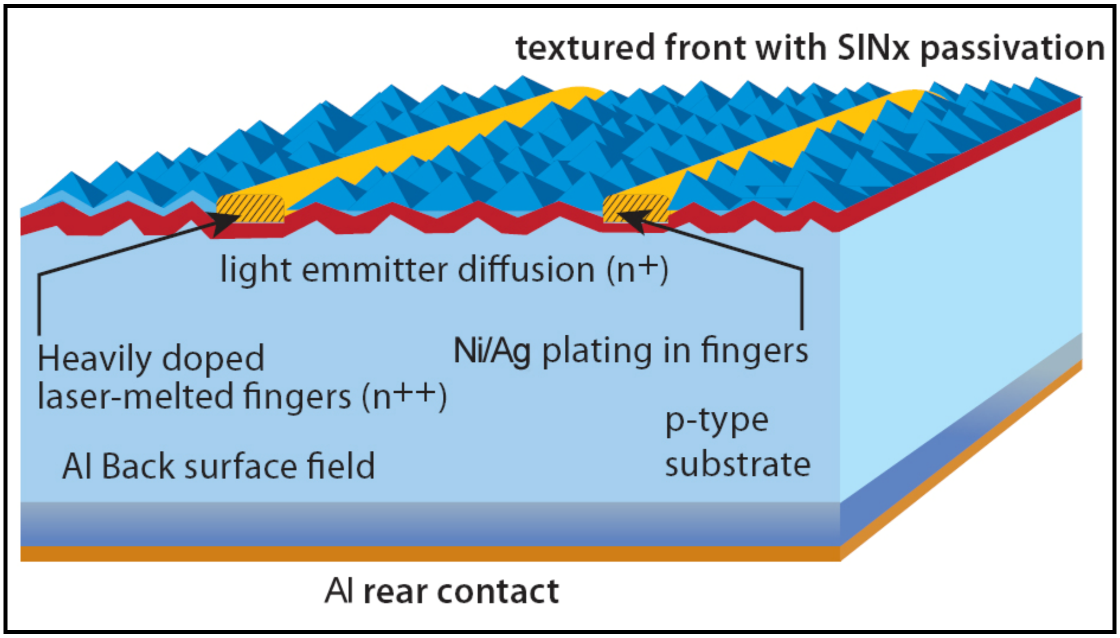

Figure 2
Selective Emitter Silicon Solar Cell

The process for selective emitter formation is shown in steps 7, 8 and 9 in Figure 3. Steps 1 through 6 illustrate the basic processes that take place prior to the selective emitter formation process.

1) Acid etch and clean: p-type wafers are exposed to acid to texture the wafer surface.
2) Shallow emitter diffusion (thermal diffusion): dopant is applied to the wafers and the wafers are transferred to a diffusion furnace creating a lightly doped n$^+$ emitter region.
3) Hydrofluoric acid-etch and AR coating deposition: the wafers are exposed to HCL to remove the phosphor-silicate glass and a thin-film coating of silicon nitride (SiNx) on the wafer surface is applied.
4) Printing of backside contact
5) High temperature furnace
6) Application of dopant: a thin layer of a phosphorous acid based n-type dopant is applied to the wafer surface.
7) Laser doping: a laser simultaneously ablates the SiNx and melts the underlying silicon. Phosphor almost instantaneously migrates into the silicon while it is in liquid phase to create a shallow, highly doped n^{++} region. (1)
8) Electroplating: the excess dopant is washed off the wafer surface and the highly doped n^{++} regions are electroplated to create self aligned contacts

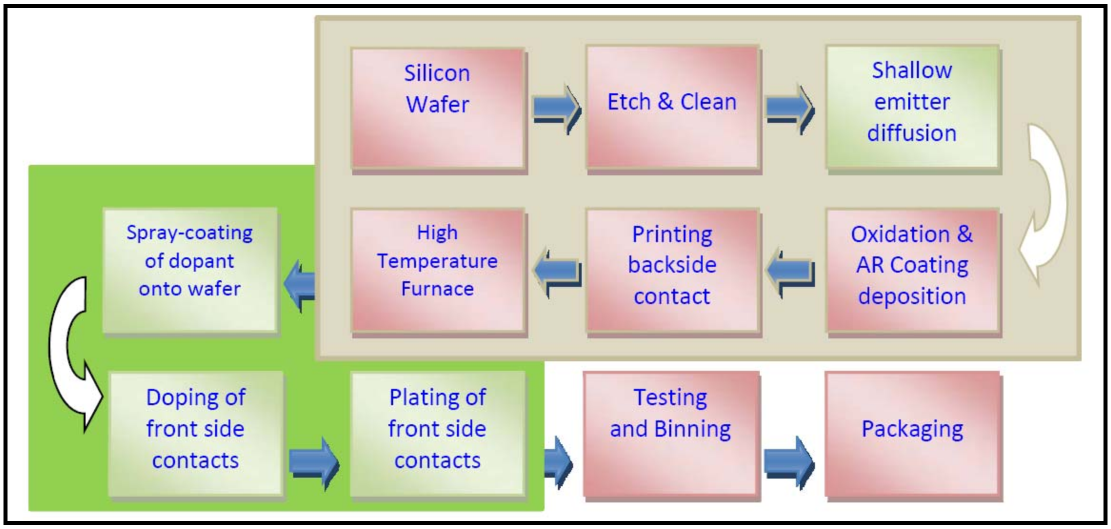

Figure 3
Selective Emitter Formation Process

As with the thermal diffusion process, the liquid dopant is the source from which the heavily doped selective emitter regions are formed. Therefore, the uniformity and amount of dopant applied to the wafer surface is critical to forming these regions that will be beneath the much narrower and more numerous metal finger contacts.

The remainder of this paper is a detailed description of Step 5 of the selective emitter formation process - a precision method for the application of the liquid dopant layer to the wafer surface. Subjects included are: the ideal properties of the liquid dopant layer on the wafer surface, various dopant application techniques, a “nozzle-less” ultrasonic spray technology for deposition of thin films and a coating system platform suitable for high volume application of dopants to solar wafers.

Ideal Properties of the Liquid Dopant Layer on Wafer Surface

The first step of the selective emitter formation process is to apply a thin layer of phosphorous-based dopant on a properly prepared silicon wafer. It should be noted that the silicon wafer has already gone through the thermal diffusion process, the aluminum back plane and silver buss bars have already been applied to the back surface and the anti-reflection coating has already been applied to the front surface.

The amount of dopant typically required for this process is in the range of 0.04 to 0.06 mg/cm^2. For a 156 x 156 mm wafer, this translates to a coating thickness of phosphoric acid in the range of 0.21 to 0.33 µm. Since the surface texture of the silicon wafer has “peaks and valleys” in the range of 5 µm, it is very difficult to apply pure phosphoric acid to the wafer surface, directly, at the required thickness. The amount of liquid is so small (0.005 to

0.008 ml) that it is not possible for this liquid volume to form a film over the entire wafer surface. Therefore, the phosphoric acid is mixed with a carrier solvent; the solvent is usually deionized (DI) water, Ethanol or a combination of both. This technique allows the deposition of a "wet" coating at a thickness that will form a liquid film over the peaks and valleys of the wafer surface. The carrier solvent then evaporates and the "dry" layer of phosphoric acid dopant remains on the wafer surface - at the same uniformity as the thicker "wet" layer of phosphoric acid and carrier solvent. In other words, the distribution of the dry layer of phosphoric acid will be the same as the distribution of the wet layer of phosphoric acid and carrier solvent, only much thinner.

The ratio of phosphoric acid to carrier solvent is typically in the range of 3 to 5 % phosphoric acid. For example, if the dopant is mixed at a concentration of 3% phosphoric acid, the "wet" thickness applied to the wafer surface will be in the range of 7 to 11 µm. After the dopant is applied, the solvent carrier evaporates, leaving a "dry" layer of phosphoric acid at a thickness in the range of 0.21 to 0.33 µm. It should be noted that the phosphoric acid layer on the wafer surface remains a liquid until it is diffused by the laser.

The "wet" layer of phosphoric acid plus carrier solvent on the wafer surface and the resulting "dry" layer of phosphoric acid after evaporation of the carrier solvent are shown in Figure 4.

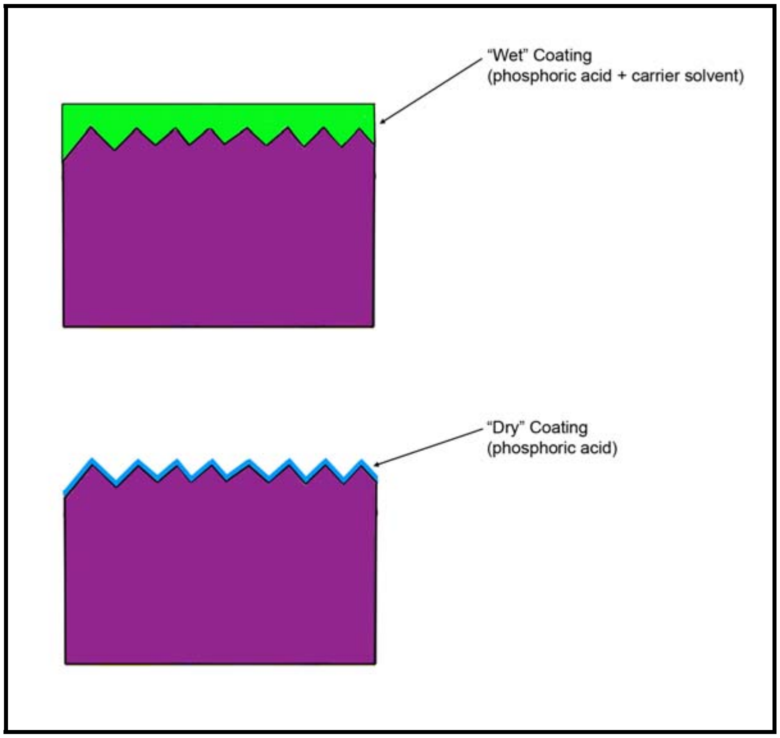

Figure 4
Liquid Dopant Layer on Wafer Surface

Ideally the dopant layer on the wafer surface needs to be uniform at the required deposition density (thickness) to successfully implement the laser doping process. The focus of this paper describes the means for achieving a dopant layer of this quality.

Dopant Application Methods

There are several methods available for the application of dopants to the wafer surface including: spin coating, fog coating, and direct spray.

Spin Coating

Spin coating entails spinning the wafer at a high speed and applying the dopant to the surface of the rotating wafer. The dopant forms a thin film on the wafer as it is “spun-off” due to the centrifugal forces from the high speed rotation. The thickness of the dopant layer is inversely proportional to the rotation speed of the wafer and the length of time that it is rotated. The spin coating technique produces a very thin and uniform coating layer on the wafer surface. However, the process is inherently slow because each wafer needs to be processed one at a time. Additionally, over 90% of the dopant is “spun-off” during the spin coating process. The excess dopant would need to be recovered for reuse or is wasted. Therefore, the spin coating method is not suited to high-volume production because of the slow processing speed and the waste of dopant.

Fog Coating

Fog coating systems consist of an array of stationary atomizers that produce a very fine mist similar to humidification. The wafers are exposed to the fine mist as they pass beneath the atomizers. The thickness of the dopant layer is proportional to the density of the fog and inversely proportional to the wafer transport conveyor speed. However, fog coating systems are highly susceptible to the surrounding ambient conditions; changes in temperature and humidity as well as spurious air currents will influence the deposition of the dopant mist onto the wafers, thus making process control difficult.

Direct Spray

An array of stationary spray nozzles mounted over a moving wafer transport conveyor is another method of applying dopant to solar wafers. The dopant is applied to the wafers as they pass beneath the bank of spray nozzles. The thickness of the dopant layer is proportional to the liquid flow rate and inversely proportional for the wafer transport conveyor speed. Spray nozzles characteristically produce a conical spray pattern and hence a parabolic distribution of dopant on the wafers. This results in a non-uniform distribution of dopant on the wafers with more dopant at the center of the nozzles and less at the edges. Additionally, spray nozzles have a minimum flow rate at which they can produce a stable spray pattern, which limits the ability of the nozzles to apply a thin dopant layer. With these limitations, spray nozzle systems are not ideally suited for the application of a thin, uniform dopant layer that this process requires. Figure 5 shows the spray pattern produced by a typical spray nozzle; note the conical pattern and the overspray.

Figure 5
Spray Pattern Produced with Spray Nozzle

The use of a traversing ultrasonic nozzle has also been used to apply dopants to silicon wafers. Ultrasonic nozzles, like conventional spray nozzles, produce a conical spray pattern and therefore a non-uniform distribution of dopant on the wafer surface. Figure 6 shows the pattern produced using a typical ultrasonic nozzle; note the conical pattern and the uncontrolled trajectory of the drops. In order to control the spray produced by ultrasonic nozzles, various spray shaping techniques are employed using air flow. These techniques involve injecting the ultrasonic spray into an airstream to shape and accelerate the drops. However, these spray shaping techniques do not produce a uniform coating distribution on the wafer, because it is not possible to transform a conical pattern into the flat rectilinear pattern required for a uniform coating application. Whether the coating system is configured using an array of stationary ultrasonic nozzles or using a single traversing ultrasonic nozzle, the inherent non-uniformity of the spray pattern cannot be overcome.

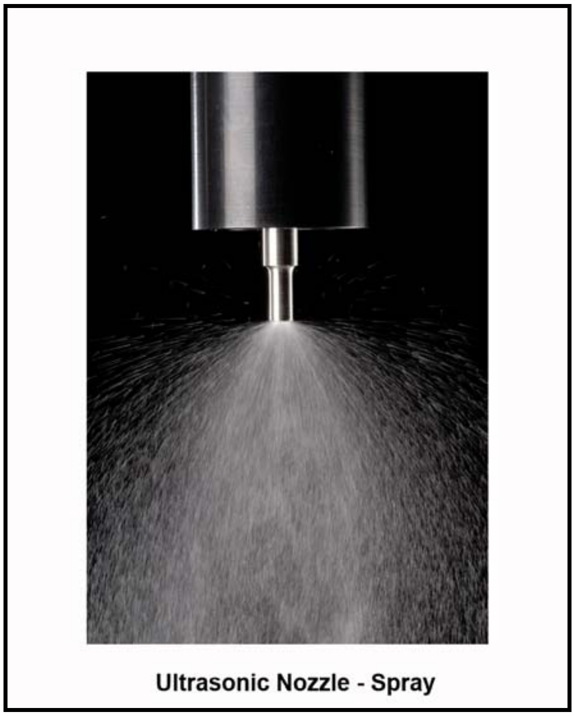

Figure 6
Spray Pattern Produced with an Ultrasonic Nozzle

Another direct spray method is the use of a single, traversing nozzle-less ultrasonic spray head for the application of dopant to the wafer surface. This application method is the focus of the remainder this paper.

New Method to Produce Thin Films

A new technique for the application of very thin liquid films to photovoltaic wafers has been developed, which consists of a traversing nozzle-less ultrasonic spray head coupled with a precision liquid delivery system combined into in a high capacity coating system platform.

In order to produce a thin, uniform liquid film on the wafer surface by the direct spray method, each area of the wafer surface must be exposed to a liquid spray with the same properties. In other words, the sprayed liquid must be applied with the same density and drop size distribution to every square mm of the wafer surface. Thus, the spray technology must produce a spray pattern with a uniform and stable shape, a stable liquid flow rate and a uniform distribution of the drop size produced. Since the wafers are flat, the ideal shape of the spray pattern is rectangular; a rectangular spray pattern has the same distribution of sprayed dopant across the entire width of the pattern, producing a rectilinear coating distribution on the wafer surface. Figure 7 shows a spray device that produces the ideal coating distribution for a flat substrate; a coating pattern with a rectangular, lineal shape. It is also important that the drops produced by spray device are of a uniform size distribution within the coating pattern. When the sprayed drops contact the wafer surface, they flow out and form a film. Drops that have the same size distribution density will tend to produce a uniform film thickness as they flow out over the wafer surface. The liquid flow rate must also be stable in order ensure that a uniform coating layer can be applied.

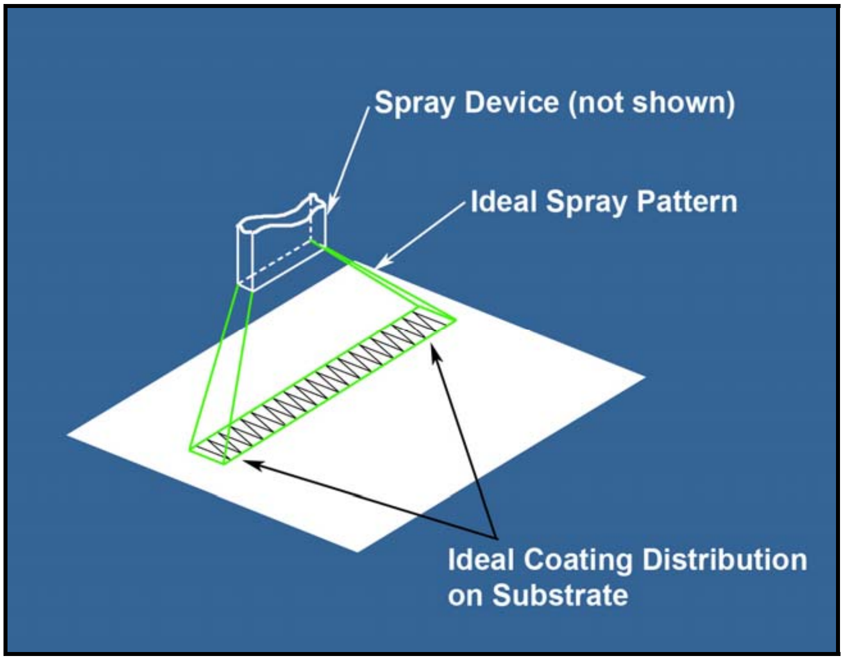

Figure 7
Ideal Coating Pattern for Flat Substrate

Nozzle-Less Ultrasonic Spray Technology

The technology that produces a spray with the desired properties for the application of the dopant layer utilizes a nozzle-less ultrasonic blade head (Figure 8) to produce a rectangular, lineal coating deposition on the wafers. This deposition technique uses ultrasonic energy to break up liquid into very small drops in conjunction with a low-pressure air stream to shape the spray pattern produced by the ultrasonic spray head. The blade head assembly consists of an ultrasonic transducer with a spray forming tip, an external liquid applicator, air directors and an ultrasonic generator. The ultrasonic blade head is nozzle-less because the liquid is supplied to the spray-forming tip via an independent external liquid applicator, rather than through the center of the ultrasonic transducer and horn assembly.

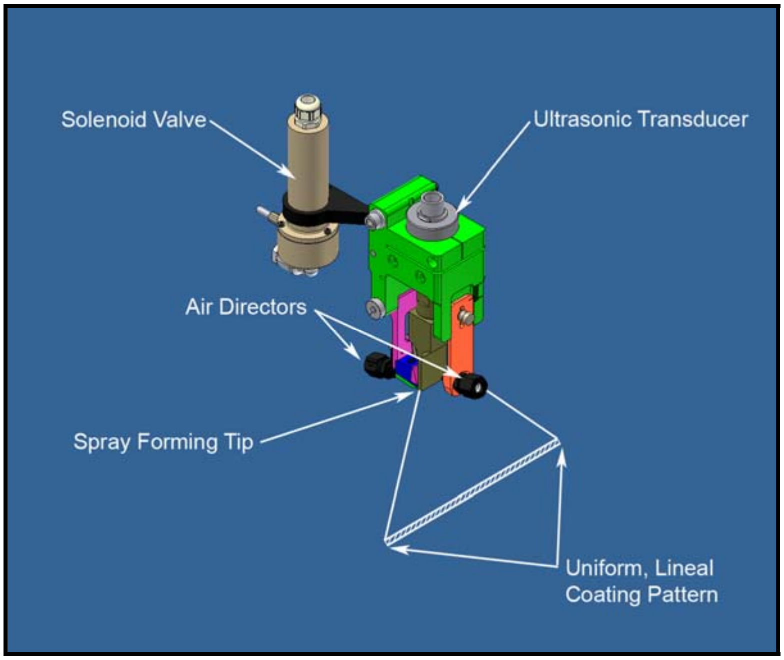

Figure 8
Nozzle-Less Ultrasonic Spray Head (Blade Type)

Spray Pattern and Drop Size Distribution

The liquid is fed directly to the vibrating spray forming tip of the spray head via the liquid applicator. The shape of the spray forming tip is rectangular and the liquid is delivered to the entire surface. The liquid forms a thin film on the vibrating tip of the spray head and the ultrasonic vibrations form capillary waves in the liquid film. The ultrasonic vibrations then break the capillary waves into small drops. The small drops are propelled from the spray forming tip in a flat sheet-like pattern due to the shape of the spray forming tip. Air directors produce air streams to expand the width and to gently accelerate the ultrasonically produced spray. The coating pattern produced is rectilinear in shape due to the shape of the spray forming tip.

The size of the drops produced by the ultrasonic vibrations is determined by many factors including ultrasonic frequency, amplitude of the vibrating spray forming tip, liquid flow rate, and the thickness of the liquid film formed on the spray forming tip. In general, the median drop size is inversely proportional to the ultrasonic frequency and directly proportional to the amplitude of vibration, liquid flow rate and film thickness.

There are two important factors for producing a uniform coating layer: 1) shape (evenness) of the spray pattern and 2) uniformity of drop size produced within the spray pattern. The air directors are employed to expand the width of the ultrasonic spray pattern to produce a uniform coating distribution across the wafer surface. However, the factor that most influences the uniformity of drop size within the spray pattern is the film thickness of the liquid on the spray forming tip. In other words, drop size variation is directly proportional to the liquid film thickness variation on the spray forming tip. Figure 9 illustrates the relationship between the film thickness on the spray forming tip and the drop size produced by the ultrasonic vibrations. The liquid applicator and the spray forming tip are specially designed to ensure that a uniform liquid film is delivered to the spray forming tip. These proprietary design features minimize the film thickness variation on the vibrating tip and thus minimize variation in the size of the drops produced as shown in Figure 10.

The coating pattern width is proportional to the distance between the spray forming tip and the substrate and can be as wide as 210 mm from a 19mm wide spray forming tip. The flow capacity for the ultrasonic blade head ranges from 10 ml/min to 100 ml/min. This nozzle-less ultrasonic spray, supplemented with low velocity air streams, provides a transfer efficiency ranging from 95 to 99% ensuring that very little coating is wasted due to overspray.

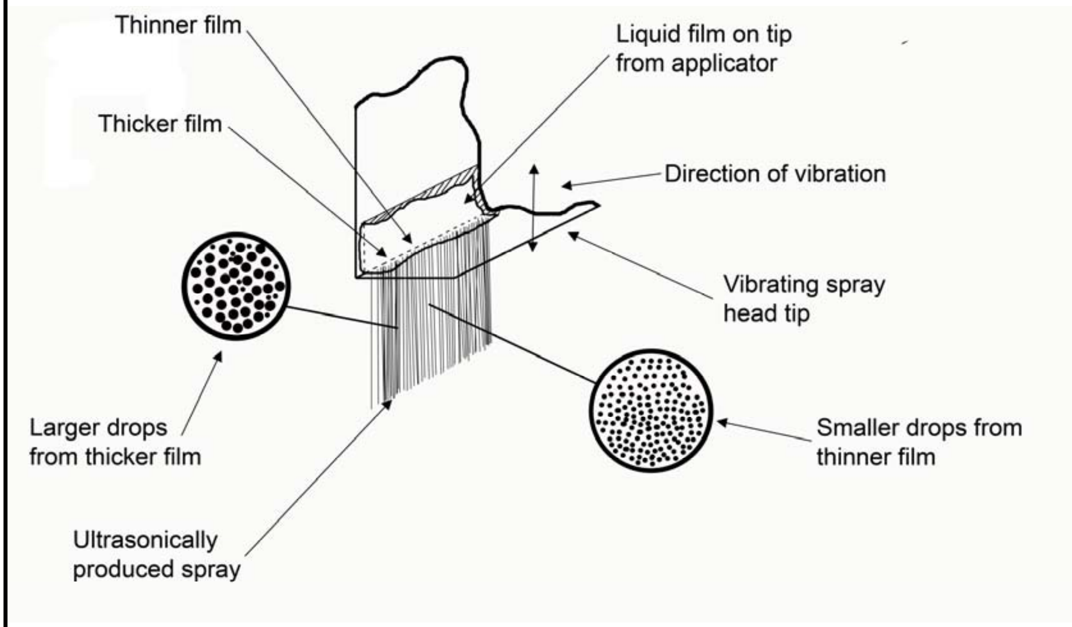

Figure 9
Drop Size Variation vs. Film Thickness

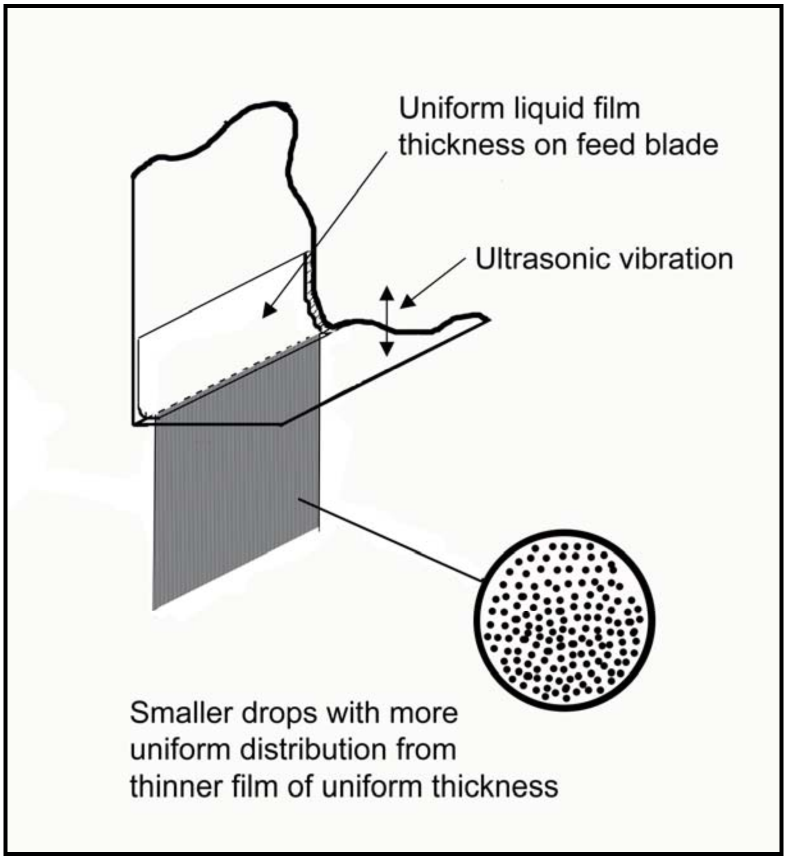

Figure 10
Uniform Drop Size with Uniform Film Thickness

Liquid Delivery System

The dual precision metering pump liquid delivery system (Figure 11) consists of a PFA reservoir to store the liquid dopant, two servo driven positive displacement metering pumps, and flow control valves. The dopant in the metering pump is delivered to the spray head by the positive displacement of the piston. When the head is spraying wafers the spray on/off solenoid valve is activated and the servo drive moves the piston at the programmed speed. The dopant flows from the metering pump to a solenoid valve then to the spray head at a flow rate directly proportional to the movement of the piston. The piston is driven by a closed-loop servo drive to ensure a uniform speed and therefore a uniform and stable liquid flow rate. The system has two pumps to ensure continuous operation. When pump number 1 empties, pump number 2 activates and pump number 1 refills from the coating reservoir; this ensures that dopant flow to the spray head is always available for high-volume production. This is the most precise and robust method of delivering the dopant to the spray head.

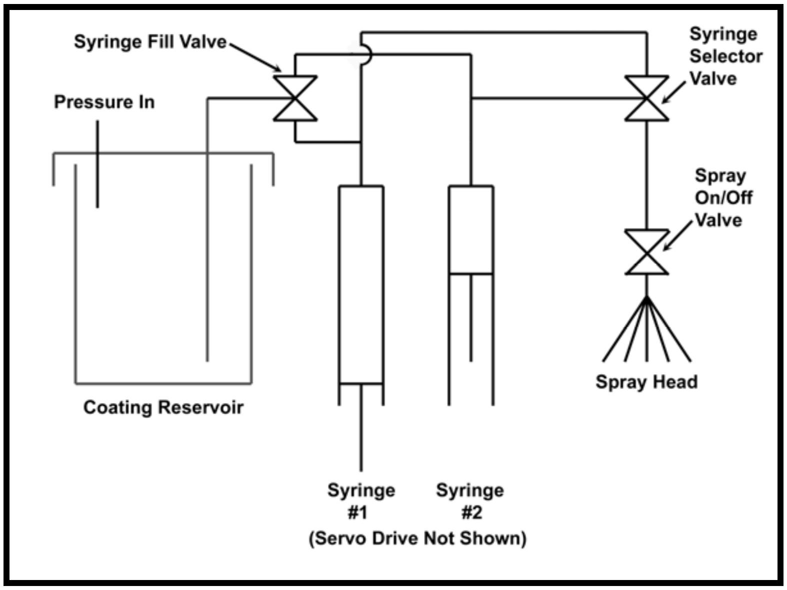

Figure 11
Precision Metering Pump Liquid Delivery System

Coating System Platform

The coating system platform (Figure 12) utilizes a non-metal mesh belt conveyor to transport the wafers and servo-driven traversing mechanism for the ultrasonic blade head.

The wafers are transported through the coating system with the self-cleaning mesh belt conveyor. The mesh belt is constructed from Teflon® coated Kevlar® and is compatible with all currently available dopant formulations. The conveyor cleaning process utilizes a water-based cleaning bath to remove the dopant from the mesh belt and an air blow-off and IR drying module to ensure that belt is clean and dry to transport new wafers though the coating process. The conveyor width is 914 mm and can accommodate up to six (6) rows of 125 mm wafers. The conveyor transport speed is adjustable up to 1.8 m/min. The maximum production capacity 43,00 wafers (125 mm size) per hour at a conveyor speed of 1.8 m/min.

Figure 12
Coating System Platform

The nozzle-less ultrasonic blade head is mounted to the traversing mechanism, which is mounted at an adjustable angle with respect to the direction of conveyor travel. The coating is applied to the wafers using the synchronized traversing head technique in which the motion of the spray head and spray activation are synchronized to the conveyor speed and process width to deliver a single, uniform coating to the moving wafers.

Figure 13 illustrates the traversing mechanism arrangement for the spray head with respect to the wafers traveling on the mesh belt. The wafers are traveling on the belt from the left to the right and the spray head traverses over the wafers to apply the coating pattern perpendicular to the direction of wafer travel. In order to apply the coating perpendicular to the wafer travel direction, the traversing mechanism is mounted at an adjustable angle with respect to the conveyor. The angle is adjusted based upon the traversing speed of the spray head and the speed of the conveyor so that the dopant will be applied in straight, rectangular coating segments that are perpendicular to the conveyor direction.

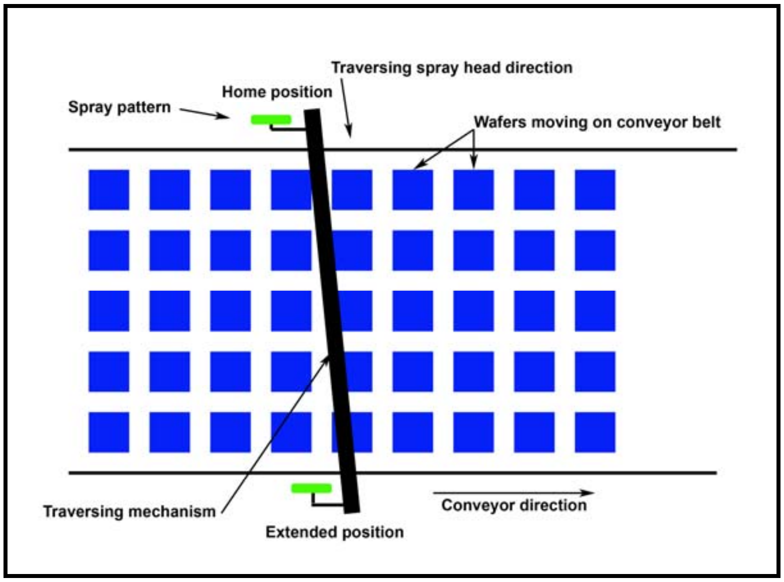

Figure 13
Synchronized Traversing Head - Schematic

Coating Application Process

The coating application process, utilizing the synchronized traversing head technique, consists of three steps: 1) the spray stroke; 2) the return stroke; and 3) the dwell period.

The coating application process is described as follows:

During the *spray stroke*, the spray head starts from the “home” position and traverses across the moving conveyor with the spray activated. The spray head applies a rectilinear coating pattern equal to the width of the wafers on the conveyor. In order to apply a spray segment that is perpendicular to the conveyor belt, the traversing mechanism is mounted at an angle to compensate for the conveyor speed. The particular angle is set in proportion to the conveyor speed and traversing speed of the spray head according to the formula: **Angle (Ө) = ASIN (Conveyor speed ÷ Traversing speed)**; where the units for both conveyor speed and traversing speed are in mm/sec. The traverse speed for the spray stroke can be up to 1,800 mm/sec.

Once the head reaches the programmed process width, it immediately returns to the home position with the spray deactivated; this is the *return stroke*.

The head waits at the home position until the wafers have traveled a distance equal to the programmed coating segment width; this is the *dwell period*.

For example, if the coating segment width is 76 mm, a spray stroke will be initiated every 76 mm of conveyor travel when wafers are under the spray station. The spray stroke, return stroke and dwell period sequence repeats as long as wafers are present on the conveyor.

Double Overlap – Application Sequence

The actual width of the spray pattern produced by the ultrasonic blade head is approximately 152 mm. Therefore, it is possible to apply the dopant to a row of wafers with a single spray stroke. However, this requires that the wafers be precisely lined up on the conveyor in even rows with a specific spacing. It is not realistic, in most production facilities, to expect the wafers to be loaded onto the conveyor in neat evenly spaced rows. In order to provide a uniform application of dopant on wafers, independent of their spacing on the conveyor, the double overlap application sequence is utilized. With the double overlap application technique, a spray stroke is initiated at an interval equal to one half of the actual spray pattern width. For example, if the actual spray pattern width is 152 mm, the programmed “coating segment” will be 76 mm. In this case, a spray stroke will be initiated every 76 mm of conveyor travel when wafers are beneath the spray station.

The double overlap application sequence is illustrated in Figure 14. The “individual coating segments” are shown at the right side of the figure; one coating segment is shown with forward slashes and the next sequential segment is shown with backward slashes. The first spray stroke is initiated to coat the leading edge of a row of wafers with the center of the spray pattern width; 76 mm on the wafers and 76 mm on the conveyor in front of the wafers. The next spray stroke is initiated after the conveyor travels 76 mm and each successive spray stroke is initiated at intervals of 76 mm. The areas of “double overlap” are represented by a cross hatch pattern; every area within the cross hatch pattern has received two coats of dopant. It can be readily seen that all wafers within the cross hatch pattern will receive the same amount of dopant regardless of their location on the conveyor.

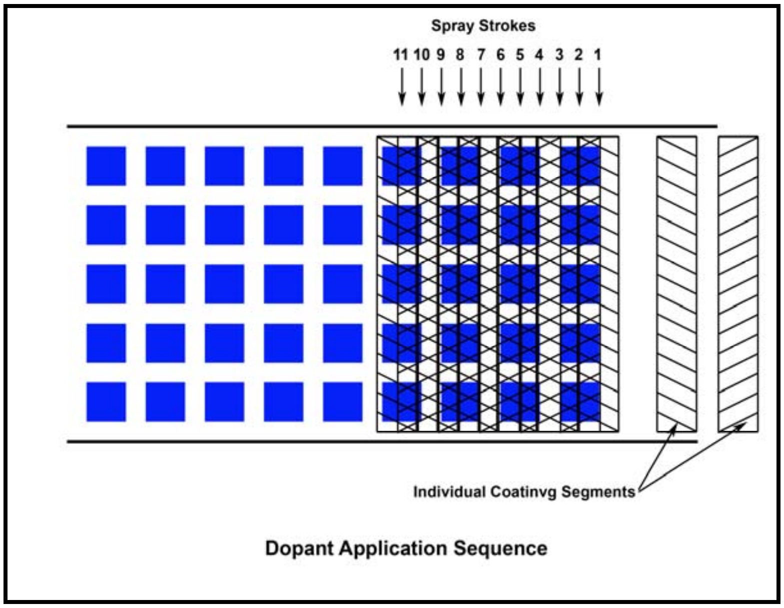

Figure 14 Dopant Application – Overlapping Coating Segments

Uniformity of Dopant Application

The uniformity of dopant application to the wafers is affected by several factors including the uniformity of the spray pattern produced by the ultrasonic blade head, the consistency of the traversing speed of the spray head and the stability of the liquid flow rate.

The traversing speed of the spray head and the liquid flow rate are both controlled with closed-loop servo drive systems, so the variation in head speed and liquid flow rate is negligible. The uniformity of the spray pattern is somewhat more difficult to characterize, because of the small amount of liquid being applied to the wafers. A sub-micron coating thickness of wet phosphoric acid on the 5 micron textured surface of the wafer cannot be easily measured.

The uniformity across the width of the spray pattern can be characterized visually, by inspecting the coated area of a single spray application. One method it to locate the spray head over a stationary substrate and active the spray for a short period of time without moving the spray head. The result with be a coated area on the substrate with a shape that shows the actual coating pattern. The shape of the coated area and the coating distribution within the area indicates the uniformity of the spray pattern.

Figure 15 shows the coating pattern produced by activating a stationary ultrasonic blade head for about 1 second. The blade head was positioned over a piece of acrylic and liquid sprayed was water. It can be readily seen that the width of the coating pattern is a little over 150 mm, the shape of the pattern is substantially rectangular (with light feathering at each side) and the distribution of liquid is uniform within the substantially rectangular area. This method yields a good visual indication of spray pattern uniformity produced by the blade head.

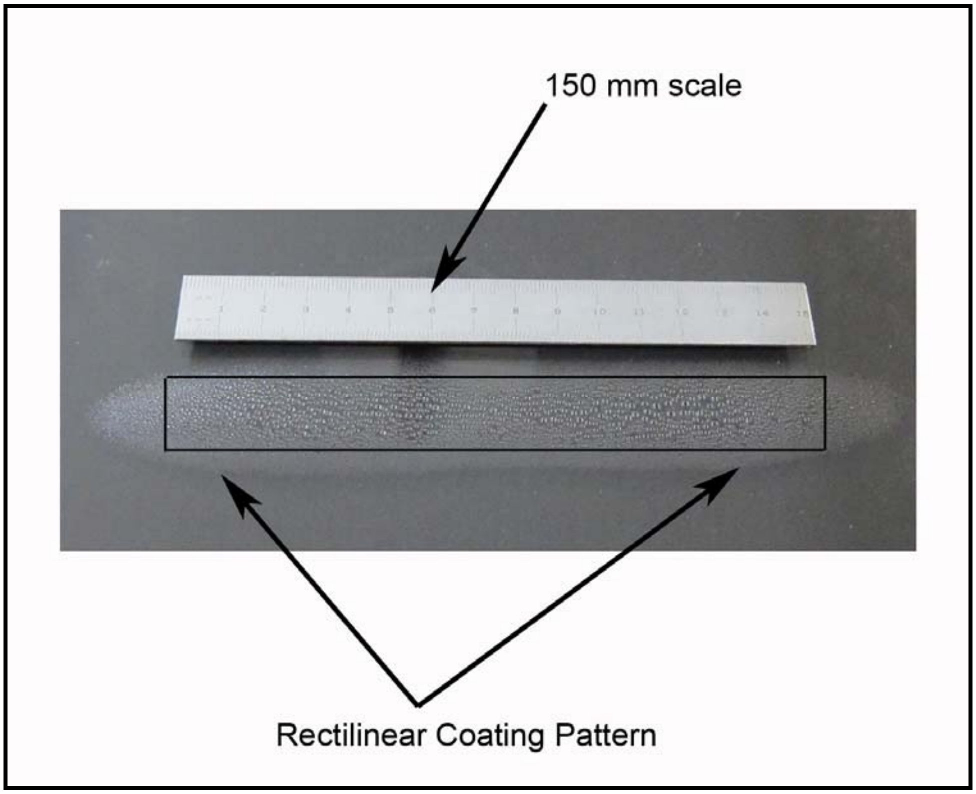

Figure 15
Coating Pattern Produced by Ultrasonic Blade Head

The uniform, rectilinear coating pattern shown in Figure 15 in conjunction with the double overlapping application sequence shown in Figure 14 typically yields a coating deposition variation on the substrate of ± 5% or better. Measurements of coating uniformity have been taken for two similar solar applications: 1) in-line thermal diffusion and 2) anti-reflective coating for thin film solar cells.

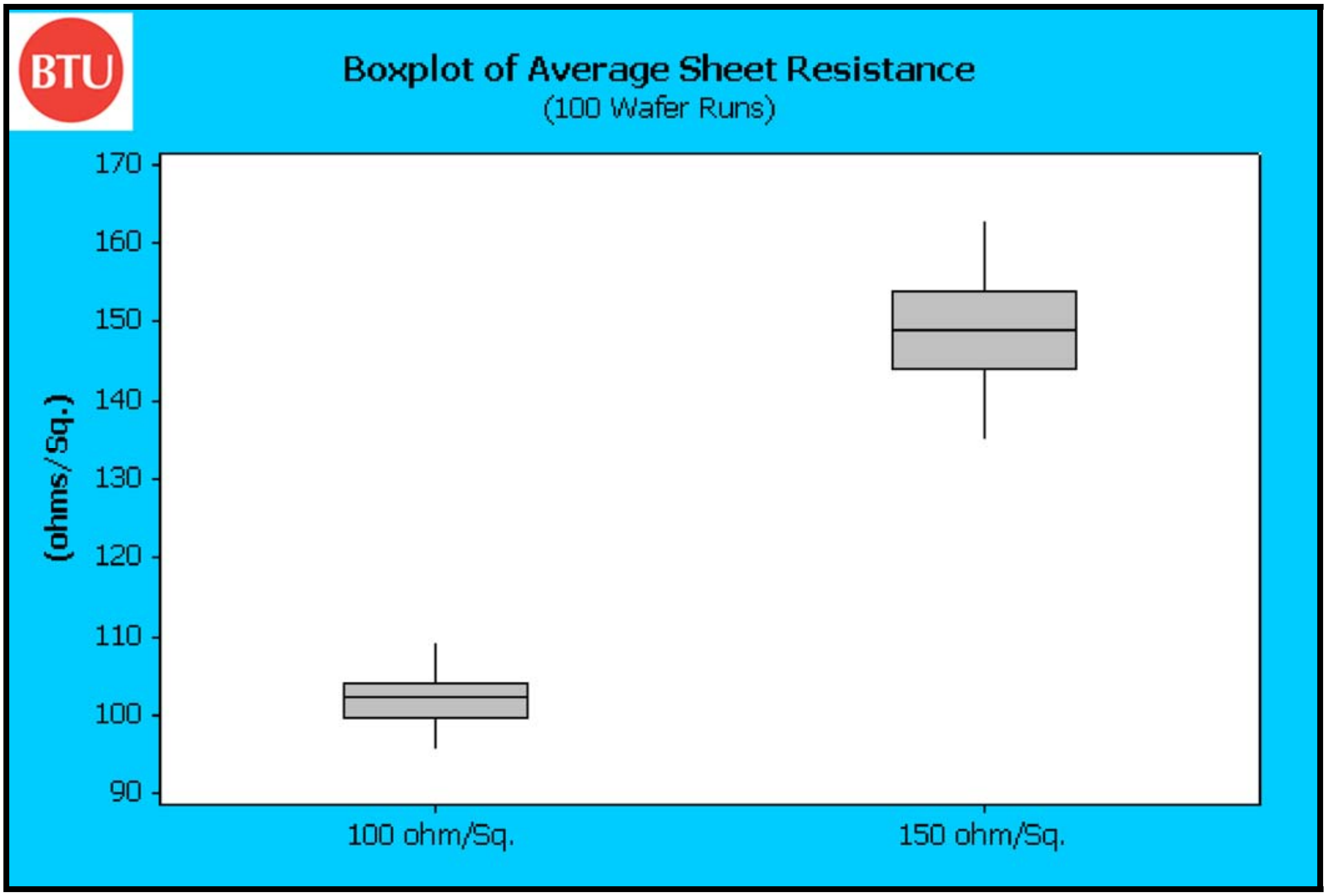

Figure 16 Sheet Resistance Data (Courtesy of BTU International, Inc.)

The in-line thermal diffusion process, as referenced earlier in this paper, is almost identical to the selective emitter process with regard to the application of dopant to a silicon wafer. In this case the dopant is applied to a textured wafer and then processed with an in-line diffusion furnace. While the uniformity of the wet dopant applied to the wafer cannot be measured, the sheet resistance across the wafer surface after the diffusion process is easily measured. A sample of sheet resistance data taken from a production run of 100 wafers is shown in Figure 16: The measurement points are across all wafers process through the system including lane-to-lane, wafer-to-wafer and within wafer sheet resistance. The sheet resistance data is shown in Table 1 for target sheet resistance settings of 45, 60 100 and 150 ohms per square. Although this data is not a direct measurement of the uniformity of the dopant applied to the wafer, it implies that the wafer was doped uniformly because non uniform coating have resulted in larger deviations in sheet resistance.

Target SR (Ω/□)	Average	Min	Max	S.D.
45	44.6	43	46	0.65
60	58.8	53	63	2.34
100	102	95.7	109.3	3.1
150	148.9	135	163	6.6

Table 1
Sheet Resistance Data

The application of anti-reflective coatings to thin film solar panels requires depositing a very thin dry coating on a glass plate the size of 1.2 m x 0.6 m. The required dry coating thickness is 120 nano meters after the solvent carrier evaporates. The actual dry coating thickness can be directly measured on a plane glass plate. A sample of measured coating thickness data across the surface of the glass plate is shown in Table 1. The coating thickness data was taken across 81 points on the glass plate.

Target Thickness (nm)	Average	Min	Max	S.D.
120	120.2	117.5	122.9	2.1

Table 2
AR Coating Thickness Data

This data gives a very good indication of the coating uniformity that can be achieved with the ultrasonic blade head and the synchronized double overlapping coating technique.

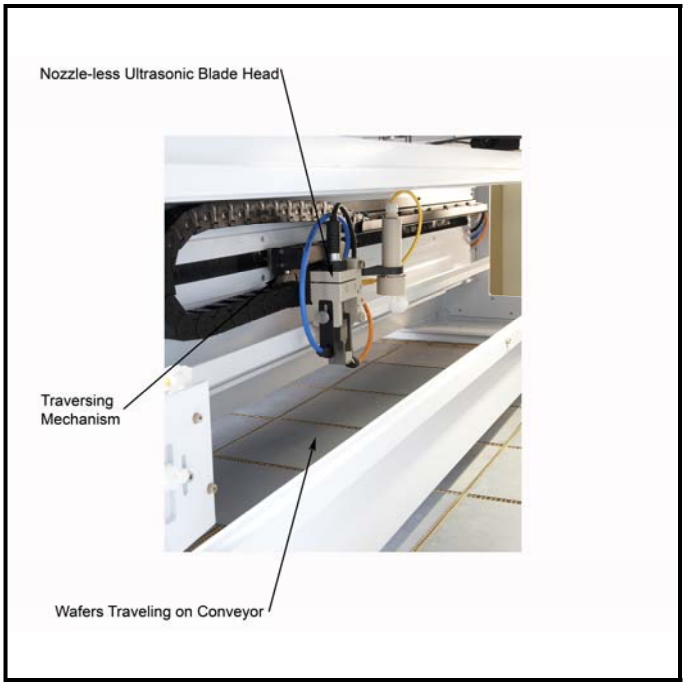

Figure 17 Spray Head Coating Wafers

Coating Process Example

A typical requirement for a phosphoric acid doping process might be 10 mg of acid applied to each 156 mm x 156 mm wafer. If the Dopant has an acid concentration of 4.25%, the total amount of liquid Dopant per wafer needs to be 0.13 ml. The wafers are transported through the coating system in rows shown in Figure 17. The system is programmed to operate as shown in Figure 14 to apply two coats to the surface of the wafers. If the traversing speed of the spray head is set to 1,000 mm/sec, the required liquid flow rate is 21.4 ml/minute to achieve a deposition of 0.13 ml per wafer or 0.0005 ml/cm^2.

Since these process settings are at the midpoint of both the traversing speed and liquid flow rate ranges, it is easily seen that the process window using this coating deposition method is very wide.

Conclusion

With a demonstrated increase of up to 2%, the formation of selective emitters is an important advancement in improving the efficiency of silicon solar cells. A key factor for the successful implementation of this process in production is the capability of applying a uniform layer of liquid dopant to the surface of the silicon wafers.

A new technique for the application of very thin coatings of dopant to photovoltaic wafers has been developed, which consists of a traversing “nozzle-less” ultrasonic spray head coupled with a precision liquid delivery system combined into in a high capacity coating system platform. This new system has the capability for high-volume production that is necessary for the successful implementation of the selective emitter process.

Contact: Stuart Erickson – President
Ultrasonic Systems, Inc.
135 Ward Hill Avenue
Haverhill, MA 01835 USA
978-521-0095
serickson@ultraspray.com
www.ultraspray.com

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