Title: **New Precision Coating Deposition Method for Photovoltaic Manufacturing**

Significant improvements in coating deposition control can be achieved with advanced ultrasonic coating technology that provides precise control of the film thickness.

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Introduction

Considerable effort is ongoing to improve the efficiency and to move towards high-volume manufacturing of photovoltaic cells. Much attention has been focused on developing in-line processes to replace the current batch processes. A critical process to improve the performance of solar wafers is the application of Dopants. The basic requirement for this process is an automated method for applying a very thin, uniform film of Dopant to the silicon wafer as part of an in-line manufacturing process.

The application of Dopants in a uniform, very thin film presents many challenges with the application method and the material handling. Some of the challenges include the ability to apply a uniform, thin liquid film, the consistency of the coating application method and the compatibility with the various Dopant formulations.

This paper considers a particular advancement in precision application of phosphorous-based Dopants and other proprietary coatings to silicon wafers using a “nozzle-less” ultrasonic spray head coupled with an advanced liquid delivery system contained in a coating system platform that employs the synchronized traversing head technique.

Coating Application Requirements

For most photovoltaic manufacturing processes, the amount of Dopant applied to a silicon wafer is in the range of 0.0002 to 0.002 ml/cm^2 of liquid. This translates to a wet film thickness in the range of 2 to 8 μm. This is very challenging considering that the surface roughness is about 5 μm for many photovoltaic wafers.

New Method to Produce Thin Films

A new technique for the application of very thin coating 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.

Nozzle-Less Ultrasonic Spray Technology

The automated coating system utilizes a “nozzle-less” ultrasonic blade type head (Figure 1) 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 from the tip of the 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.

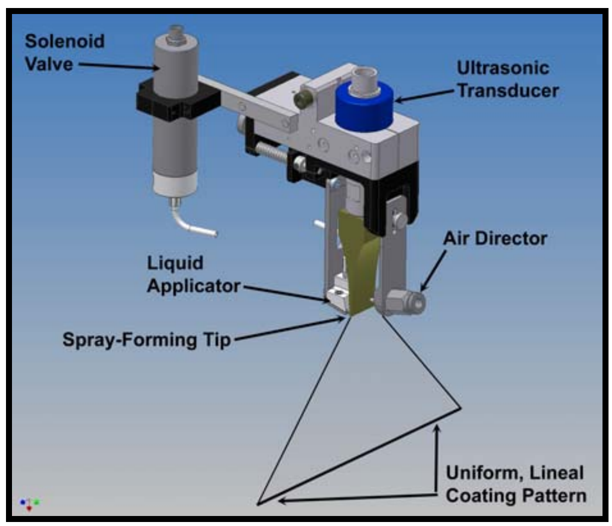

Figure 1 Nozzle-Less Ultrasonic Spray Head

The liquid is stored in a sealed reservoir and fed to the liquid applicator with a precision liquid delivery system. The ultrasonic vibrations of the spray-forming tip break the liquid into small drops and propel them from the tip in the form of a spray. Resulting in a very low velocity spray in a flat “sheet-like” pattern.

Air directors are used to produce air streams to shape and gently accelerate the ultrasonically produced spray. The coating pattern produced is rectilinear in shape. The coating pattern width is proportional to the distance between the spray forming tip and the substrate. The spray pattern can be as wide as 200 mm. 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%. Very little coating is wasted due to overspray with this technology.

Liquid Delivery Systems

Two basic liquid delivery systems are utilized with this coating system approach: a gear pump-based system and a dual precision metering pump based system. The selection of the liquid delivery system depends upon the properties of the coating material and the coating deposition requirements.

The closed-loop control gear pump based liquid delivery system (Figure 2) meets most coating application requirements. It consists of a PFA reservoir to store the coating liquid, a precision gear pump, flow meter and flow control valves. When the head is spraying wafers, the liquid is pumped from the reservoir to a 3-way valve located near the spray head which directs the coating material to the spray head; the spray head solenoid valve opens to deliver the liquid to the liquid applicator. When the head is not spraying wafers, the liquid is diverted back to the coating reservoir. This recirculating liquid delivery system provides quick activation and deactivation of the spray in concert with the synchronized traversing spray head technique. It is also well suited for most low viscosity liquids that have an acid concentration of less than 15% by volume.

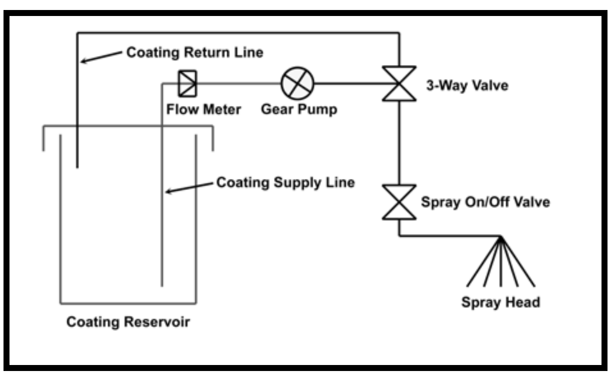

Figure 2 Liquid Delivery System

A dual precision metering pump based liquid delivery system is available for applications that require a lower liquid flow rate and/or for Dopants with acid concentrations above 20%.

Coating System Platform

The coating system platform (Figure 3) consists of a self-cleaning 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 most of the currently available Dopant formulations. The conveyor utilizes a water-based cleaning system and an IR drying system to ensure that coating liquid is not transferred to the bottom side of the wafers. The conveyor width is 914 mm and can accommodate up to six (6) rows of 125 mm wafers. The conveyor transports the wafers at a constant speed up to 1.25 m/min. The production capacity is up to 3,000 wafers (125 mm size) per hour at a conveyor speed of 1.25 m/min.

The ultrasonic blade head is mounted to the traversing mechanism, which moves 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.

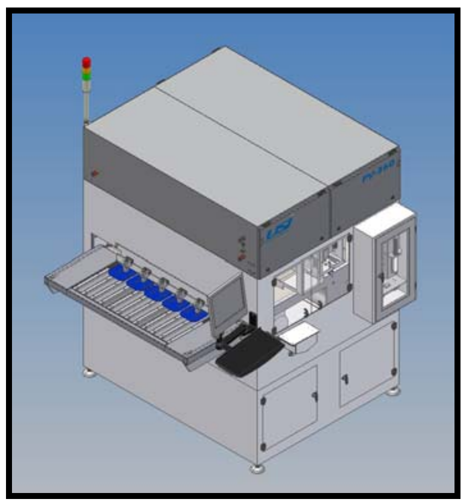

Figure 3 Coating System Platform

Coating Application Process

The coating application process (Figure 4), 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 at 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. The head speed for the spray stroke can be up to 2,000 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 their spacing on the conveyor belt in the direction of travel; this is the dwell period.

The spray stroke, return stroke and dwell period sequence repeats as long as wafers are present on the conveyor.

The uniformity of the coating application is proportional to the variation in traversing speed and the variation in liquid flow rate as the head moves across the conveyor. A closed-loop servo drive linear actuator controls the speed of the head. A closed-loop gear pump or a servo drive syringe pump controls the coating flow rate. These closed-loop controls ensure that the coating is applied uniformly and repeatably.

Coating Process Example

A typical requirement for a phosphoric acid doping process might be 10 mg of acid applied to each 125 mm x 125 mm wafer. If the Dopant has an acid concentration of 4.25%, the total amount of liquid Dopant per wafer needs to be 0.14 ml. The wafers are transported through the coating system in evenly spaced rows of wafers as shown in Figure 4. The system is programmed to apply a single coating pass to each row of wafers. If the traversing speed of the spray head is set to 500 mm/sec, the required liquid flow rate is 40 ml/minute to achieve a deposition of 0.14 ml per wafer or 0.0009 ml/cm^2.

Since these process settings are at the mid point 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.

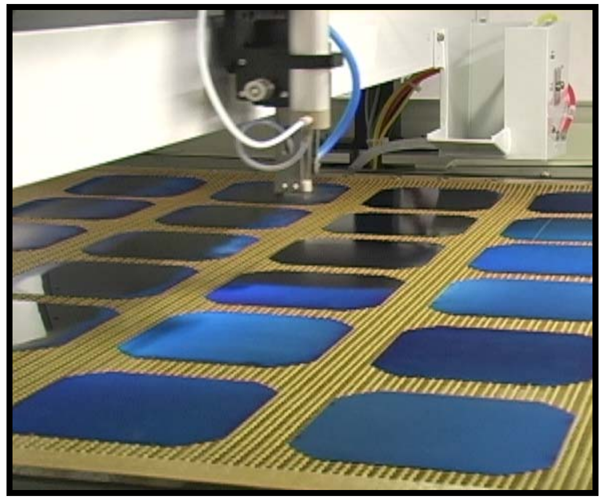

Figure 4 Coating Application Process

Conclusion

As in-line processes replace batch processes in the manufacture of photovoltaic wafers, there is an increasing need for a high-volume method to apply various coatings in a thin, uniform film. The unique combination of a nozzle-less ultrasonic spray head, an advanced liquid delivery system and a high volume coating system platform is a significant advancement towards meeting this demanding requirement.

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