ULTRASONIC SYSTEMS, INC.

Title: **Nozzle-Less Ultrasonic Spray for Photoresist Application**

Significant improvements in coating deposition control can be achieved with advanced ultrasonic coating technology that provides precise control of film thickness for the application of photoresist to various kinds of substrates.

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Introduction

There are a large variety of substrates that require the application of photoresist where conventional spin coating methods do not produce a uniform layer. The types of substrates include: wafers with various degrees of topography and micro vias, small glass lenses used for wearable devices, non-circular substrates, large panels, etc. The traditional spin coating method is often ineffective in applying a thin, uniform layer of photoresist to this class of "non-standard" substrates. The spin coating technique tends to clog the micro vias, will not produce a "conformal" layer to regions with high aspect ratio features, and has difficulty achieving a uniform layer to non-circular and large substrates. Additionally, spin coating generates significant waste of photoresist.

Spray coating for the application of photoresist to these non-standard substrates has proven to be a viable alternative to spin coating. Various methods to produce a spray have been utilized including air-atomized spray valves, ultrasonic nozzles and "nozzle-less" ultrasonic spray heads. Air atomizing spray valves produce excessive overspray, have a tendency to clog easily, produce a non-uniform spray pattern and have difficulty maintaining accurate control of the liquid flow rate. Ultrasonic spray nozzles produce a softer, more efficient spray but have several shortcomings including the inability to spray higher solids formulations of photoresist, non-uniform coating layers due to the conical or elliptical spray pattern shape, and inability to precisely start and stop the liquid spray.

An automated method for the precise application of photoresists has been developed that utilizes a "nozzle-less" ultrasonic spray head, a precision liquid delivery system with a high performance X-Y-Z motion control platform. The "nozzle-less" ultrasonic spray head uses ultrasonic energy to break the liquid into small drops to form the spray; however the liquid does not pass through the device. Liquid is applied externally to the spray forming tip, which is vibrating at an ultrasonic frequency (>20kHz).

Directed air streams are used to expand the ultrasonically produced spray, providing a rectangular, uniform spray pattern. The airflow to the spray head is electronically controlled, providing complete control of the spray pattern shape and velocity. The liquid flow is controlled using a precision metering pump to meter the coating to the ultrasonic spray head. This “nozzle-less” ultrasonic spray technology is widely used for applying various coatings across multiple industrial markets.

This paper considers a particular advancement in thin film application of photoresists using the “nozzle-less” ultrasonic spray head known as *Ultra-Spray* technology, a precision liquid delivery system and an X-Y-Z motion control platform.

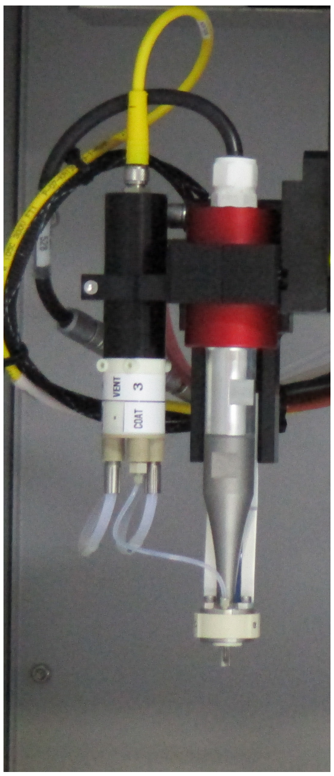
Ultra-Spray Head Assembly

The Ultra-Spray Head is an integrated assembly consisting of an ultrasonic transducer with a spray forming tip, a liquid applicator and air directors.

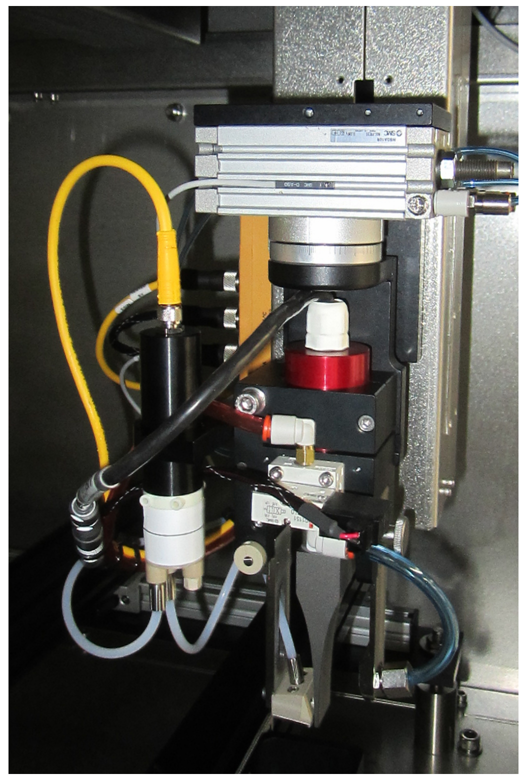
The ultrasonic transducer vibrates at an ultrasonic frequency (> 20 kHz). The ultrasonic transducer is resonant at a particular ultrasonic frequency of for example, 35 kHz, 45 kHz, or 60 kHz and is driven by an ultrasonic generator with a corresponding frequency. The particular ultrasonic frequency is selected based upon the material to be sprayed and the coating application requirements. In general a lower frequency ultrasonic transducer is capable of spraying a higher viscosity liquid and producing higher flow rates. The amplitude of vibration of the spray-forming tip is also set with the ultrasonic generator.

The photoresist is delivered to the spray-forming tip on the ultrasonic transducer by liquid applicator. The liquid photoresist is stored in a reservoir and fed to the liquid applicator at a precisely controlled flow rate. The ultrasonic vibrations of the spray-forming tip break up the liquid into small drops and propel them from the tip in the form of a spray. The spray produced with ultrasonic energy alone is a very low velocity “sheet-like” pattern. The width of the spray pattern produced is equal to the width of the spray-forming tip (2 mm to 20 mm).

Air directors are used to produce air streams to shape and accelerate the ultrasonically produced spray. The air director impinges a jet of air on tip of the spray head opposite the liquid feed side. The resulting airflow entrains and expands the ultrasonically produced spray to produce a flat (rectilinear) pattern up to 5 times the width of the pattern produced by the ultrasonic energy alone. The width of the spray pattern is proportional to the distance between the spray head tip and the substrate.



***Ultra-Spray* CAT ILDS Head**



***Ultra-Spray* Blade Head**

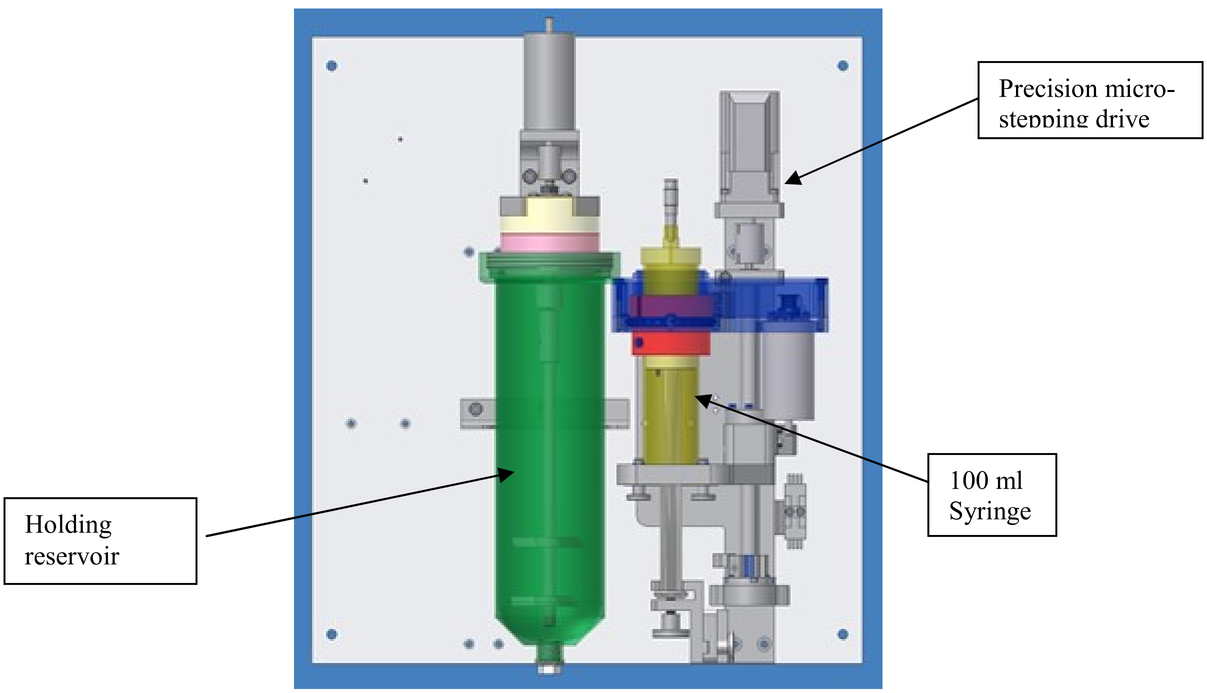
Two spray head types are available: the CAT ILDS Head and the Blade Head. The ILDS head produces a spray pattern width in the range of 3 mm to 30 mm while the Blade Head produces a spray pattern width up to 100 mm. The ILDS head is used for smaller substrates and for substrates with topography. The blade head is used for larger substrates.

With nozzle-less ultrasonic spray and low velocity air spray shaping, transfer efficiencies as high as 99% can be achieved. In other words, less than1% of coating is lost due to overspray, which results in less waste and a cleaner process.

All process parameters for the *Ultra-Spray* Head are set electronically including liquid flow rate, air flow rate, head height, head path, and head speed.

Liquid Delivery

The method used to deliver the coating liquid to the liquid applicator on the ultrasonic spray head is critical to achieving the desired coating thickness and uniformity. A precision metering pump is used to meter the coating flow to the ultrasonic spray head. The pump consists of a 100 ml capacity cylinder and a micro-stepping positive displacement piston to deliver the liquid at the required flow rate. The pump automatically refills from a sealed holding reservoir. This system delivers a stable, reproducible flow rate which is one of the key elements in producing a uniform thin coating on a substrate.



Precision Metering Pump

Motion and Positioning Platforms

One or two Ultra-Spray heads are mounted to a high performance X-Y-Z motion and positioning system. The system utilizes a Windows based Graphical User Interface (GUI) coupled with a state-of-the-art Ethernet based motion control system. The GUI is used to set all operating parameters, create process programs, display alarms and machine status. The main screen displays a graphical image of the entire coating system platform with "hot spots" for each machine subsystem or function. The operator uses a mouse to select a hot spot which brings up a window with the parameters or status information for the subsystem or function. Hot spots are provided for the spray head, precision metering pump, material handling, coating process program, I/O and alarms.

The following coating system platforms are available according to the user's requirements:

- Prism 400 – for R&D and "lab-scale" applications. This is a "bench-top" system with a range of motion in the X&Y axes of 400 mm.
- Prism 500 – for R&D and production applications. This is a "stand-alone" system with a range of motion in the X&Y axes of 500 mm. Many options are available including: clean room configurations, automated loading and unloading, dual spray heads and liquid delivery systems and many other options specific to user's needs.
- Prism 800 – for high volume production. This is a "large-format" system with a range of motion in the X&Y axes of 800 mm. This system is designed for high-speed, high volume production and for coating of large substrates. The same system configurations and options are available on both the Prism 500 and Prism 800 platforms.

Prism 400

Prism 500

Prism 800

Photoresist Coating Process

In general there are two basic processes for the spray application of photoresist: 1) the application of a single, thin layer to a flat substrate and 2) the application of a “conformal” layer of photoresist to a substrate with some type of topography.

Single Layer of Photoresist to Flat Substrate

Photoresist consists of a base resin plus various solvents and is generally formulated to be applied by the spin coating method. With spin coating, the film or layer of photoresist on the substrate is formed by the centrifugal force of the rapidly spinning substrate. The thickness of the film depends upon the spin speed, spin duration and the properties of the photoresist.

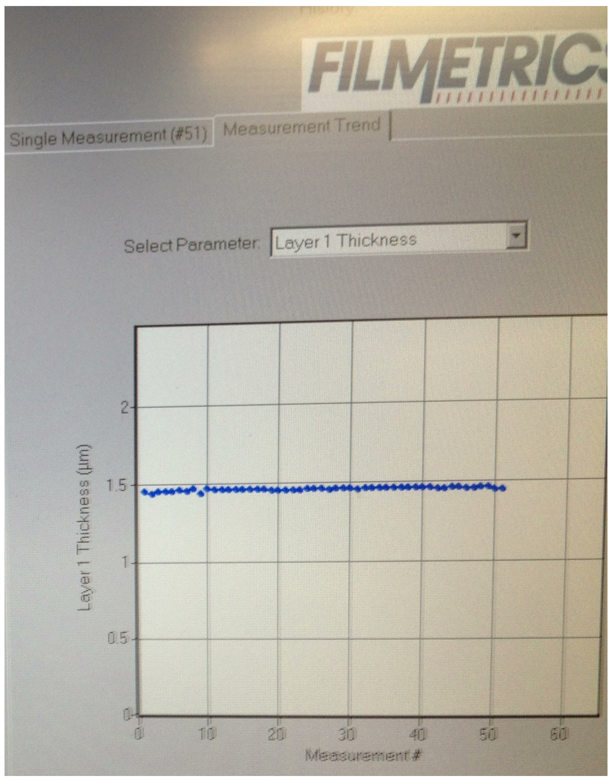
With spray coating, the film of photoresist is formed with an entirely different mechanism. First the photoresist is broken into small droplets and sprayed onto the surface of the substrate. Then the sprayed droplets flow together on the substrate surface to form a wet film. The uniformity of the film is highly dependent on the ability of the spray device to produce a uniform spray pattern, the stability of the liquid delivery method and control of the head speed as it passes over the substrate to apply the sprayed coating. Finally the carrier solvent must be carefully evaporated without disturbing the uniformity of the applied wet film.

The thickness of the dry layer of photoresist is proportional to the wet layer thickness and the ratio of base resin to solvent in the photoresist formulation. In general, the wet film of photoresist can be formed on a flat substrate by the spray process at a thickness between 10 and 25 µm without producing an edge bead. The actual minimum wet thickness depends upon the surface properties of the substrate and the properties of the photoresist.

To achieve a particular dry layer thickness both the “solids” (base resin) content of the photoresist and the wet film layer thickness can be adjusted. For example, if a 5 µm dry layer is required, the photoresist can be formulated at 20% solids and the coating system process parameters are set to apply a 25 µm wet layer thickness on the substrate. The dry layer thickness is approximately the ratio of solids in the photoresist to the wet layer thickness; 25 µm multiplied by 20% (0.2) resulting in 5 µm.

Various size and shape flat substrates can be coated with photoresist including silicon wafers, glass plates, and metal plates. The spray coating technique is particularly amenable to coating large substrates and substrates that are not circular shaped.

The combination of Ultra-Spray ultrasonic technology and the Prism coating system platform can produce a very uniform coating on a flat substrate. For example, the figure below shows the measured 1.5 µm dry layer thickness of photoresist across the surface of a silicon wafer.



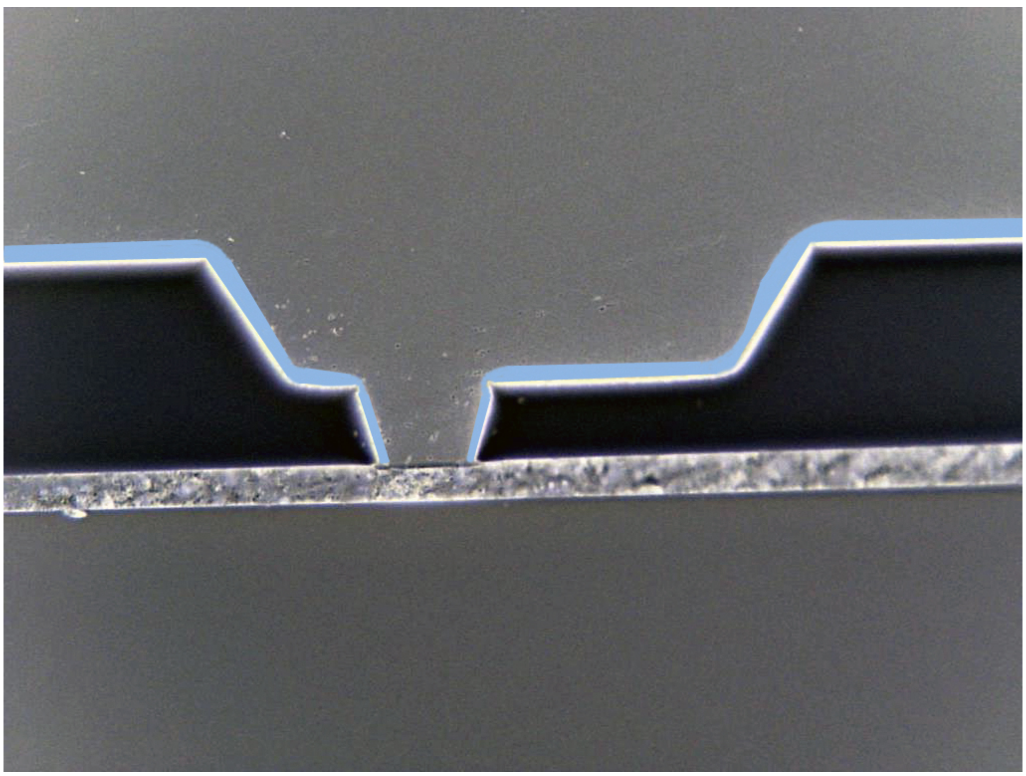
Photoresist Thickness on Flat Wafer

Conformal Layer of Photoresist on Substrate with Topography

Many substrates have some type of topography, like trenches, grooves, micro-vias and other three-dimensional features. In these cases the dry layer of photoresist must "conform" to the topography. The spray coating technique is ideal for producing a conforming layer of photoresist because many very thin layers can be applied successively to the substrate. Each very thin layer is applied such that a wet film does not form and the liquid photoresist does not flow down the side surfaces of the three-dimensional features on the substrate.

In order to produce very thin layers that do not "flow" several practices are employed including: adding a fast evaporating solvent to the photoresist, heating the substrate during the coating process, and increasing the traversing speed of the spray head relative to the substrate. Using these practices, multiple, very thin layers can be applied with minimal liquid flow to achieve a conformal dry layer onto the structured substrate surface.

For example the figure below shows the cross-sectional image of a wafer (black areas) with a layer of conformal photoresist (blue areas) applied using a CAT ILDS Ultra-Spray head in a Prism coating system. In this case the thickness of the wafer is 150 µm. The thickness of the photoresist on the top flat surfaces is approximately 12 µm, the thickness on the sloping surfaces is approximately 10 µm and the thickness on the sharp edges is approximately 4 to 6 µm.



"Conformal" Layer of Photoresist on a Wafer with Topography

Coating Process Steps

The process steps for the application of photo resist to substrates using the spray coating are fairly straight forward:

1. Prepare substrate for coating. The substrate must be clean and may also be pre-treated with plasma or some other surface preparation process.
2. Load the substrate in the spray coating system work area. This may be done manually for a low-volume batch process or may be automated. The options for automation include feeding the coating system with an automated loader and unloader or using a robot.
3. Activate the spray coating sequence. The preprogrammed coating recipe is then activated either manually for a batch process or remotely for an automated in-line process.
4. Evaporate the carrier solvent. The substrate is then moved to a hotplate or oven to drive off the carrier solvent before going to the next step in the photolithography process.

Conclusion

There are numerous requirements to apply a thin, uniform layer of photoresist to non-standard substrates including large substrates, and substrates with three-dimensional features. Traditional methods used for the application of photoresist such as spin coating and conventional nozzle-based spray coating have not been effective in meeting these requirements. The combination of the nozzle-free Ultra-Spray head, a precision, liquid delivery system and the versatile Prism X-Y-Z motion and positioning platform provides the capability to meet these increasingly challenging requirements.

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