	Resist Coating Methods	
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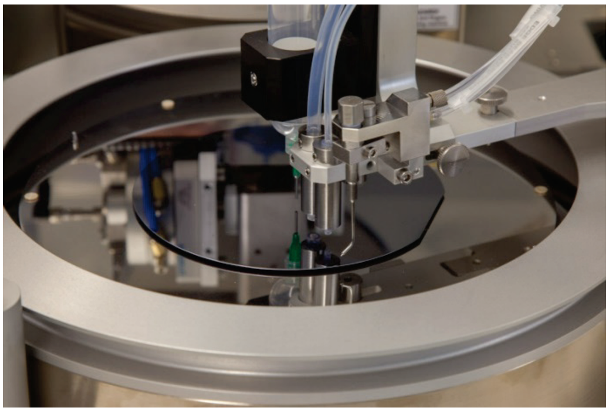
- SCOPE: An overview of techniques for the uniform coating of a substrate with photoresist

A crucial requirement to ensure repeatable, reliable and acceptable results with photolithography, is to have a uniform coating of a photoresist over the surface of the substrate. Photoresist is typically dispersed in a solvent or aqueous solution and is a high viscosity material. There are a number of options available to coat a photoresist depending on the process requirements:

- Spin-coating
- Spray-coating
- Dip-coating
- Ink-jet printing
- Slot-die coating

Spin- coating

Spin-coating is the most common method used when coating a substrate with photoresist. It is a method that presents a high potential for throughput and homogeneity. The principle of spin-coating is that typically a few millilitres of photoresist are dispensed on a substrate which is spinning at several 1000 rpm (typically 4000 rpm). The resist can either be dispensed when the substrate is stationary and then accelerated up to speed (static spin-coating), or it can be dispensed once the wafer is already rotating (dynamic spin-coating). Any excess resist is spun off the edge of the substrate during the spinning process.



Nozzles for automatic dispensing of photoresist

The centrifugal force experienced by the resist on the surface of the wafer causes the viscous resist to spread out into a uniform thin film. The height of this film is directly controlled by the rotational speed of the substrate, allowing the operator to achieve the desired film thickness.

Alongside the spin speed the spin time can also be used to control the film thickness. This is due to the evaporation of some of the solvent or aqueous liquid used to disperse the resist, which causes further thinning of the resist. The loss of the solvent also results in the stabilisation of the film, so that it will not collapse during later handling of the substrate.

The main advantages of spin-coating are that the coating step is quite short, typically 10-20 seconds, which when combined with the dispensing and handling time, can lead to process times less than 1 minute. The other advantage is that the films obtained are very smooth and the thickness can be reproducibly controlled very accurately.

The disadvantages and limitations of spin-coating arise when using non-circular substrates or thick (very viscous) resists. In these cases the air turbulences at the edges and especially the corners cause the resist to dry in an accelerated manner. This excess drying then supresses the spin-off of the resist from these regions, causing a bead of resist to build up at the perimeter of the substrate; this built up sidewall of resist is referred to as an edge bead. In more advanced spin-coat systems, techniques for removing this edge bead by precise application of solvent, or limiting its growth by controlling the air turbulences, have been developed.

The other limitation that can impact spin-coating is if the surface of the substrate has a large number of features or a varied topography, then the homogeneity of the film thickness can be affected. With build-up of resist in holes or spaces leading to thicker films and thinner films on the edges of the features. This can be overcome by a two-stage spin profile, or by using one of the alternate coating techniques.

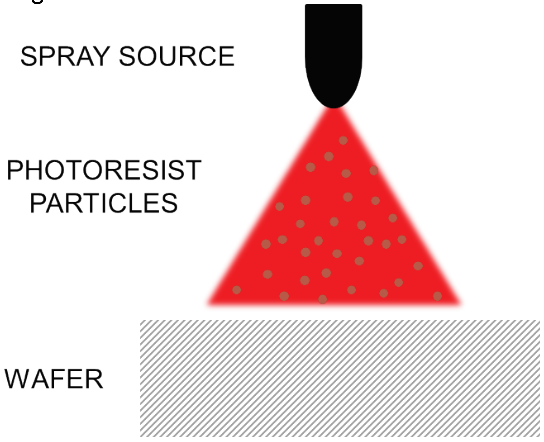
Spray-coating

Spray-coating is an alternative to spin-coating, particularly when the substrate surface or morphology means that the photoresist cannot be coated with the required uniformity. The basic principle of spray-coating is that the resist film is formed from the deposition of photoresist that is atomised into droplets in the µm range.

The formation of the droplets is possible through a variety of techniques; the simplest is to produce an atomised spray from a nozzle similar to what is used in a conventional airbrush gun and a nitrogen nozzle. Nitrogen is preferred, as it helps to reduce contamination of the resist with humidity or particles and produces a dryer mist of droplets.

The second standard method to generate an atomised spray is through the use of an ultrasonic atomiser. The ultrasonic atomiser creates the droplets of resist via the high frequency mechanical vibration of the resist media, which is then transported to the substrate by a carrier gas.

The droplets of resist are then deposited on the surface of the substrate where they form a continuous thin film of the photoresist. Spray-coating is thus able to cover the entire surface of the substrate even in arbitrary shapes and to provide a conformal coating regardless of the topology. Additionally, there is less photoresist wasted allowing for a higher yield in comparison to spin-coating.



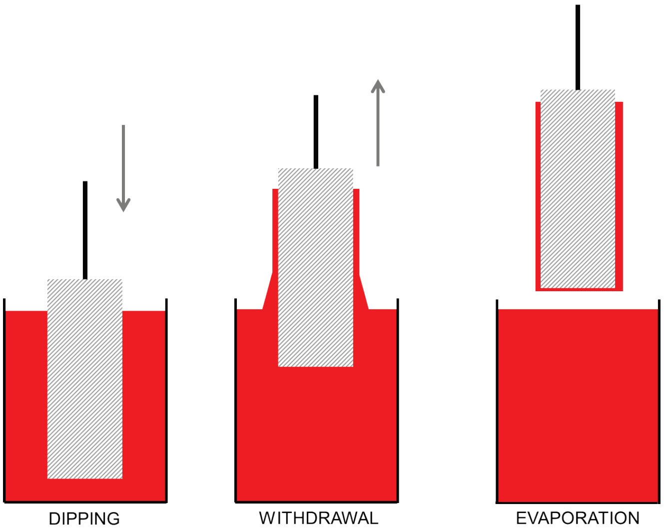
A typical spray-coating process

To be able to spray-coat a photoresist, the resist must have a suitably low viscosity. Typically this is a few cSt and may require the dilution of the resist with a solvent. Dilution of the resist can lead to the resist ageing process accelerating and to particle formation within the media. The other limitation of spray-coating, is that formation of films <1 μm is difficult given the stochastic distribution of droplets landing on the surface. To form a continuous film requires a minimum critical resist droplet density to be reached, which increases the minimum film thickness as well as increasing the processing time.

Dip-coating

Dip-coating is used as a solution for resist coating if the size and type of substrate is not suitable for spin-coating and the photoresist represents a significant cost to the overall process, that even when compared with spray-coating, the consumption of resist must be further reduced.

The process of dip coating is that a wafer is submerged vertically in a cuvette of resist and lifted out slowly. The resist film then forms on the surface and thins out as the substrate is removed from the bath of photoresist. The thickness of the resist is controlled by the dwell time in an atmosphere saturated with solvent, which controls the rate of solvent evaporation. The higher the withdrawal speed from the resist bath, the thicker the photoresist film.



Schematic of a dip-coating process

As a result of this process, the yield of resist can be 100% if both sides of the substrate need coating, representing a huge increase in resist yield compared to spin and spray-coating. The tank may have to be replaced if the resist expires before it is consumed, which will decrease the yield but still offers the most cost effective of the three coating methods covered.

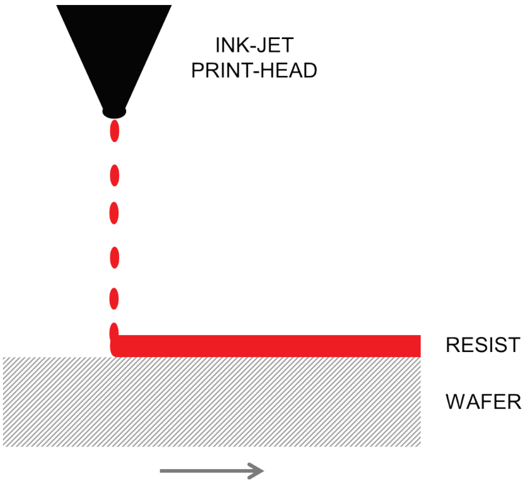
The photoresist often must be significantly diluted, which can significantly increase both the ageing of the resist film and the frequency with which the tank must be replaced. Additionally, substrates with large changes in surface topography are not suitable as the resist can flow over the substrate and significantly reduce the surface homogeneity.

Ink-jet printing
An alternative method utilised to dispense resist is ink-jet printing. This works in a similar fashion to spray-coating, producing droplets of photoresist. Unlike spray-coating however, these drops are produced in a stream rather than a mist. This stream of droplets can then be precisely controlled and patterned onto the substrate.

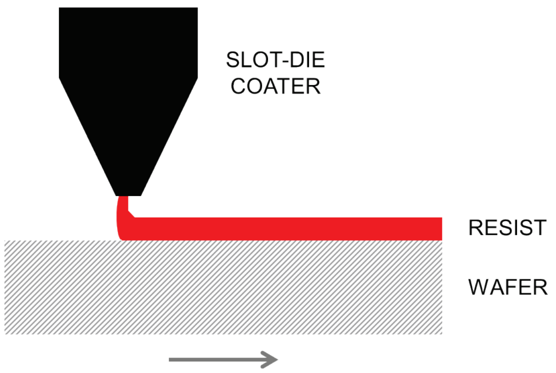
Ink-jet printing differs from the other coating methods, in that whilst it can be used to produce a thin homogeneous film of photoresist, the real advantages in its use come from using it to directly pattern the substrate. This can dramatically save the amount of resist used by only depositing where required, reducing both the cost and environmental impact of the photolithographic process. Additionally, it is possible to directly deposit some materials such as organic semiconductors and conductive inks onto the surface, without needing to run a photolithographic process.

The disadvantages of the increased flexibility and versatility of ink-jet printing, are an increased coating time leading to a reduced throughput of coated wafers and substrates. This can be offset however through the use of multiple print-heads and path optimisation. Additionally, ink-jet printing is not the ideal solution for the coating of thicker resists, as the layer thickness is typically only a few microns.

Slot-die Coating
The final method of coating photoresist discussed here is slot-die coating. Slot-die coating is a scalable manufacturing technique used in a range of industrial processes to produce uniform films and coatings. The principle of slot-die coating is shown in the image above. The print-head continuously dispenses the photoresist onto the moving surface of the substrate, producing a uniform film of photoresist. As the solvent within the wet photoresist evaporates, the photoresist film dries leaving a uniform thin film that can then be processed further.



Ink-jet printing of photoresist



Schematic of a slot-die coating process

Slot-die coating is a pre-metered coating technique; this means that all the material that is dispensed from the print-head of the coater is used to coat the surface of the substrates. This enables very low (to no) levels of photoresist wastage, which is a great advantage if the photoresist represents a large material cost. The other advantages of slot-die coating are that it is a readily scalable technique, allowing the number of substrates to be greatly increased. Slot-die coating is also perfectly suited to coating flexible substrates and to being used in a roll-to-roll manufacturing process. Beyond the coating of photoresists, slot-die coating (like ink-jet printing) can be utilised to coat any functional material that can be dispersed into a printable ink.