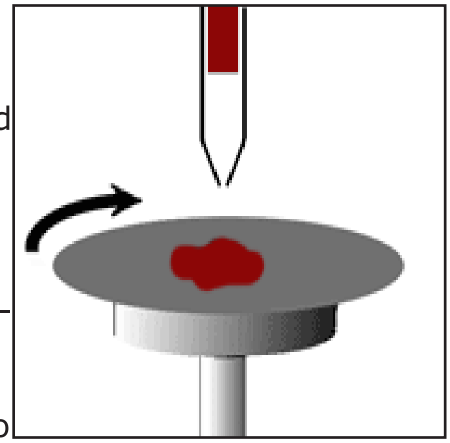
# Spin Coat Theory

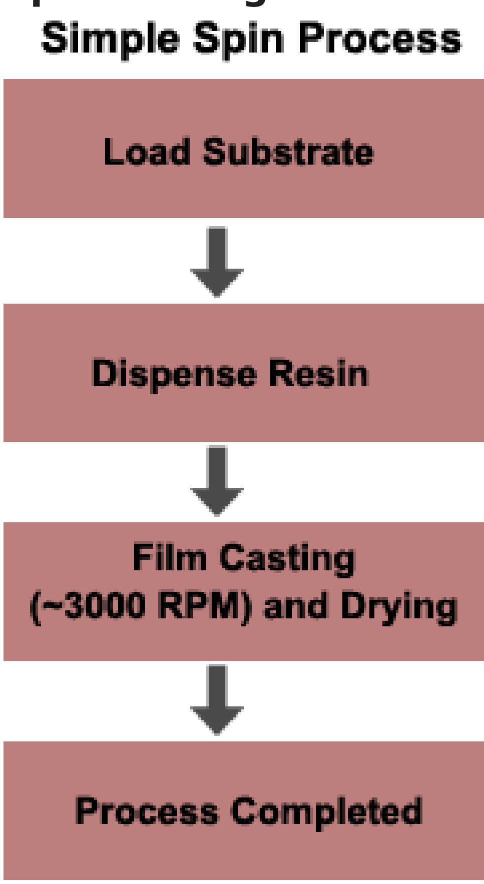
## Spin Coating Process Theory



Spin coating has been used for several decades for the application of thin films. A typical process involves depositing a small puddle of a fluid resin onto the center of a substrate and then spinning the substrate at high speed (typically around 3000 rpm). Centripetal acceleration will cause the resin to spread to, and eventually off, the edge of the substrate leaving a thin film of resin on the surface. Final film thickness and other properties will depend on the nature of the resin (viscosity, drying rate, percent solids, surface tension, etc.) and the parameters chosen for the spin process. Factors such as final rotational speed, acceleration, and fume exhaust contribute to how the properties of coated films are defined.

One of the most important factors in spin coating is repeatability. Subtle variations in the parameters that define the spin process can result in drastic variations in the coated film. The following is an explanation of some of the effects of these variations.

## Spin Coating Process Description




A typical spin process consists of a dispense step in which the resin fluid is deposited onto the substrate surface, a high speed spin step to thin the fluid, and a drying step to eliminate excess solvents from the resulting film. Two common methods of dispense are Static dispense, and Dynamic dispense.

Static dispense is simply depositing a small puddle of fluid on or near the center of the substrate. This can range from 1 to 10 cc depending on the viscosity of the fluid and the size of the substrate to be coated. Higher viscosity and or larger substrates typically require a larger puddle to ensure full coverage of the substrate during the high speed spin step. Dynamic dispense is the process of dispensing while the substrate is turning at low speed. A speed of about 500 rpm is commonly used during this step of the process. This serves to spread the fluid over the substrate and can result in less waste of resin material since it is usually not necessary to deposit as much to wet the entire surface of the substrate. This is a particularly advantageous method when the fluid or substrate itself has poor wetting abilities and can eliminate voids that may otherwise form.

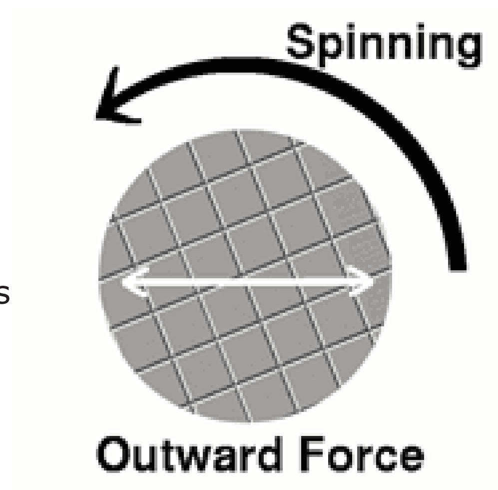
After the dispense step it is common to accelerate to a relatively high speed to thin the fluid to near its final desired thickness. Typical spin speeds for this step range from 1500-6000 rpm, again depending on the properties of the fluid as well as the substrate. This step can take from 10 seconds to several minutes. The combination of spin speed and time selected for this step will generally define the final film thickness.

In general, higher spin speeds and longer spin times create thinner films. The spin coating process involves a large number of variables that tend to cancel and average out during the spin process and it is best to allow sufficient time for this to occur.

A separate drying step is sometimes added after the high speed spin step to further dry the film without substantially thinning it. This can be advantageous for thick films since long drying times may be necessary to increase the physical stability of the film before handling. Without the drying step problems can occur during handling, such as pouring off the side of the substrate when removing it from the spin bowl. In this case a moderate spin speed of about 25% of the high speed spin will generally suffice to aid in drying the film without significantly changing the film thickness. Each program on a Cee spin coater may contain up to ten separate process steps. While most spin processes require only two or three, this allows the maximum amount of flexibility for complex spin coating requirements.

## Spin Speed

Spin speed is one of the most important factors in spin coating. The speed of the substrate (rpm) affects the degree of radial (centrifugal) force applied to the liquid resin as well as the velocity and characteristic turbulence of the air immediately above it. In particular, the high speed spin step generally defines the final film thickness. Relatively minor variations of ±50 rpm at this stage can cause a resulting thickness change of 10%. Film thickness is largely a balance between the force applied to shear the fluid resin towards the edge of the substrate and the drying rate which affects the viscosity of the resin. As the resin dries, the viscosity increases until the radial force of the spin process can no longer appreciably move the resin over the surface. At this point, the film thickness will not decrease significantly with increased spin time. All Cee spin coating systems are specified to be repeatable to within ±5 rpm at all speeds. Typical performance is ±1 rpm. Also, all programming and display of spin speed is given with a resolution of 1 rpm.

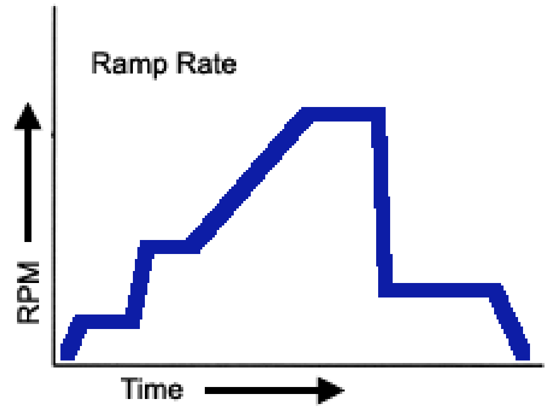



## Acceleration

The acceleration of the substrate towards the final spin speed can also affect the coated film properties. Since the resin begins to dry during the first part of the spin cycle, it is important to accurately control acceleration. In some processes, 50% of the solvents in the resin will be lost to evaporation in the first few seconds of the process.

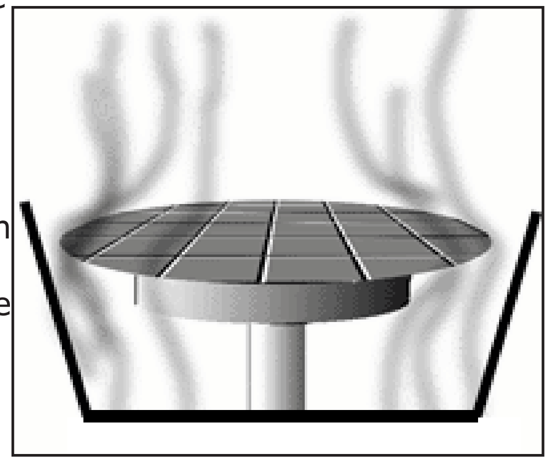
Acceleration also plays a large role in the coat properties of patterned substrates. In many cases the substrate will retain topographical features from previous processes; it is therefore important to uniformly coat the resin over and through these features.

While the spin process in general provides a radial (outward) force to the resin, it is the acceleration that provides a twisting force to the resin. This twisting aids in the dispersal of the resin around topography that might otherwise shadow portions of the substrate from the fluid. Acceleration of Cee spinners is programmable with a resolution of 1 rpm/second. In operation the spin motor accelerates (or decelerates) in a linear ramp to the final spin speed.



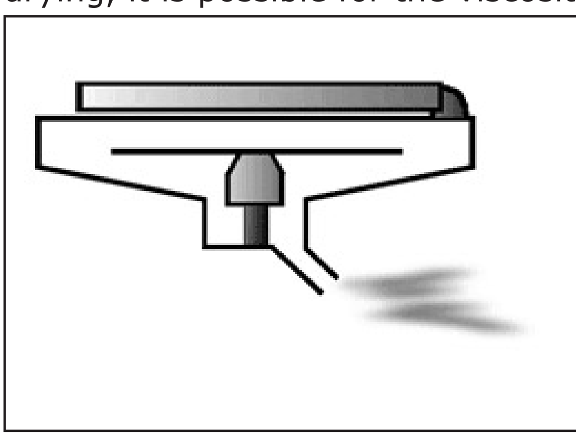

## Fume Exhaust

The drying rate of the resin fluid during the spin process is defined by the nature of the fluid itself (volatility of the solvent systems used) as well as by the air surrounding the substrate during the spin process. Just as a damp cloth will dry faster on a breezy dry day than during damp weather, the resin will dry depending on the ambient conditions around it. It is well known that such factors as air temperature and humidity play a large role in determining coated film properties. It is also very important that the airflow and associated turbulence above the substrate itself be minimized, or at least held constant, during the spin process.



All Cee spin coaters employ a “closed bowl” design. While not actually an airtight environment, the exhaust lid allows only minimal exhaust during the spin process. Combined with the bottom exhaust port located beneath the spin chuck, the exhaust lid becomes part of a system to minimize unwanted random turbulence. There are two distinct advantages to this system: slowed drying of the fluid resin and minimized susceptibility to ambient humidity variations.

The slower rate of drying offers the advantage of increased film thickness uniformity across the substrates. The fluid dries out as it moves toward the edge of the substrate during the spin process. This can lead to radial thickness nonuniformities since the fluid viscosity changes with distance from the center of the substrate. By slowing the rate of drying, it is possible for the viscosity to remain more constant across the substrate.

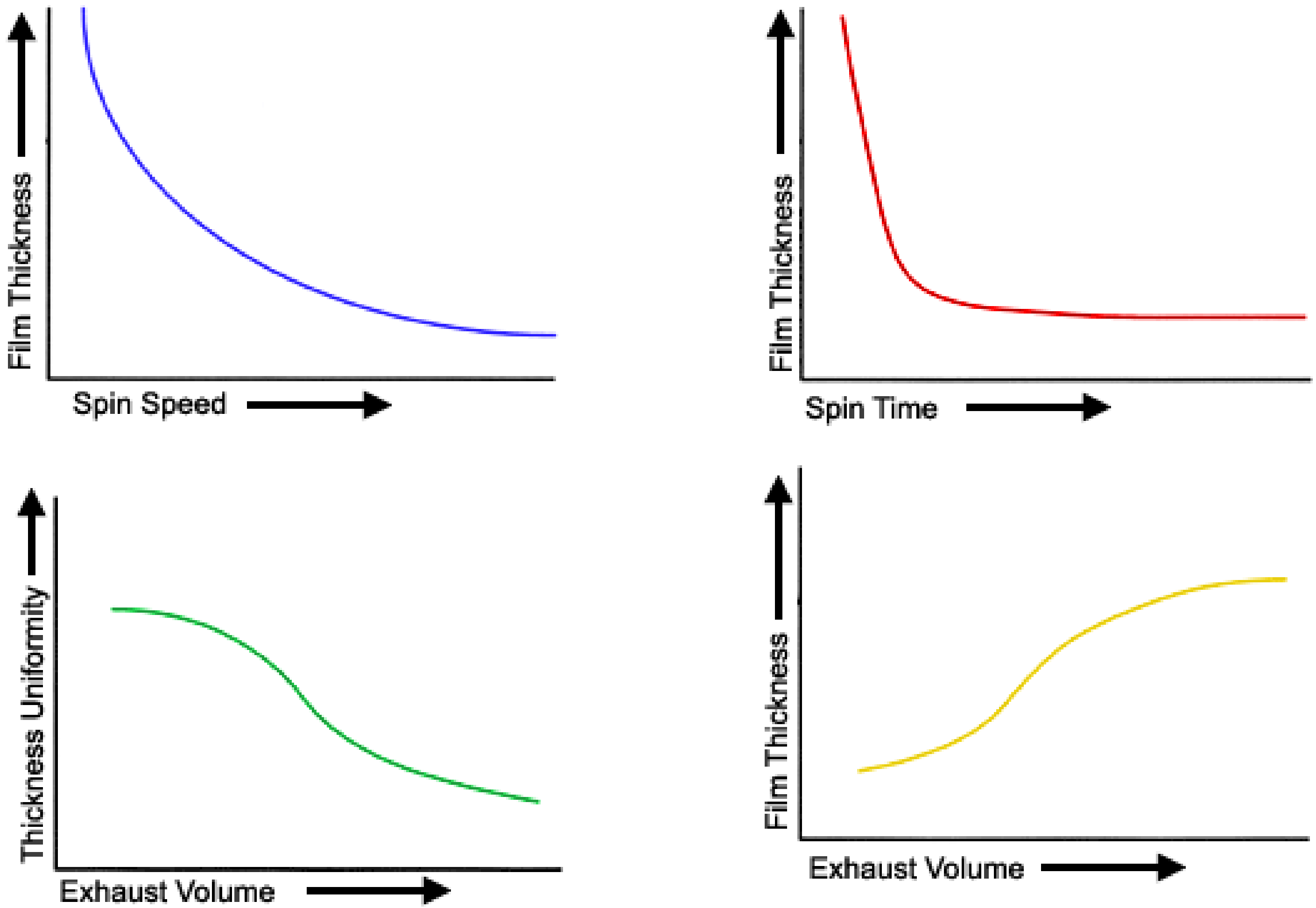


Drying rate and hence final film thickness is also affected by ambient humidity. Variations of only a few percent relative humidity can result in large changes in film thickness. By spinning in a closed bowl the vapors of the solvents in the resin itself are retained in the bowl environment and tend to overshadow the affects of minor humidity variations. At the end of the spin process, when the lid is lifted to remove the substrate, full exhaust is maintained to contain and remove solvent vapors.

Another advantage to this “closed bowl” design is the reduced susceptibility to variations in air flow around the spinning substrate. In a typical clean room, for instance, there is a constant downward flow of air at about 100 feet per minute (30m/min). Various factors affect the local properties of this air flow. Turbulence and eddy currents are common results of this high degree of air flow. Minor changes in the nature of the environment can create drastic alteration in the downward flow of air. By closing the bowl with a smooth lid surface, variations and turbulence caused by the presence of operators and other equipment are eliminated from the spin process.

## Process Trend Charts

These charts represent general trends for the various process parameters. For most resin materials the final film thickness will be inversely proportional to the spin speed and spin time. Final thickness will be also be somewhat proportional to the exhaust volume although uniformity will suffer if the exhaust flow is too high since turbulence will cause non uniform drying of the film during the spin process.




## Spin Coating Process Troubleshooting

### Spin coater

As explained previously, there are several major factors affecting the coating process. Among these are spin speed, acceleration, spin time and exhaust. Process parameters vary greatly for different resin materials and substrates so there are no fixed rules for spin coat processing, only general guidelines. These are explained in the "Spin Coating Process Description" section. Following is a list of issues to consider for specific process problems.

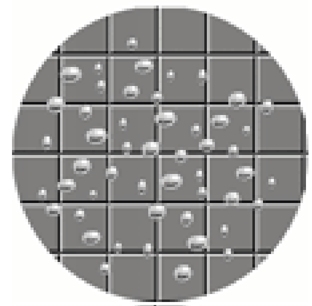
**Film too thin**

| | |
|---|---|
| Spin speed too high | Select lower speed |
| Spin time too long | Decrease time during high speed step |
| Inappropriate choice of resin material | Contact resin manufacturer |

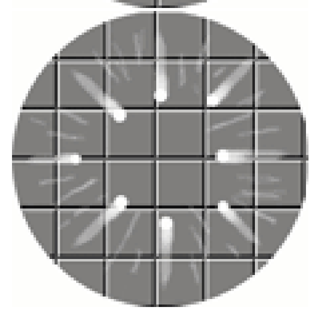
**Film too thick**

| | |
|---|---|
| Spin speed too low | Select higher speed |
| Spin time too short | Increase time during high speed step |
| Exhaust volume too high | Adjust exhaust lid or house exhaust damper |
| Inappropriate choice of resin material | Contact resin manufacturer |

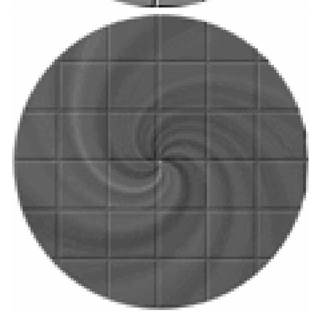
**Air bubbles on wafer surface**
Air bubbles in dispensed fluid (resin)
Dispense tip is cut unevenly or has burrs or defects



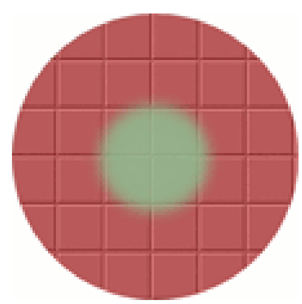
**Comets, streaks or flares**
Fluid velocity (dispense rate) is too high
Spin bowl exhaust rate is too high
Resist sits on wafer too long prior to spin
Spin speed and acceleration setting is too high
Particles exist on substrate surface prior to dispense
Fluid is not being dispensed at the center
of the substrate surface



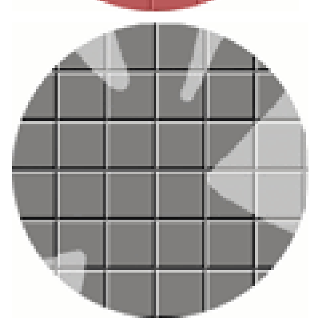
**Swirl pattern**
Spin bowl exhaust rate is too high
Fluid is striking substrate surface off center
Spin speed and acceleration setting is too high
Soin time too short



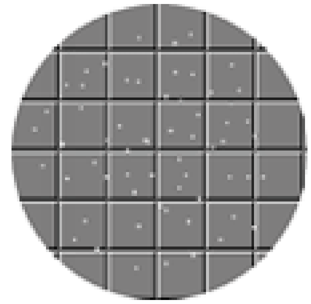
**Center circle (Chuck Mark)**
If the circle is the same size as the spin chuck,
switch to a Delrin spin chuck



**Uncoated Areas**
Insufficient Dispense Volume



**Pinholes**



Air bubbles
Particles in fluid
Particles exist on substrate surface prior to dispense

**Poor reproducibility**

| | |
|---|---|
| Variable exhaust or ambient conditions | Adjust exhaust lid to fully closed |
| Substrate not centered properly | Center substrate before operation |
| Insufficient dispense volume | Increase dispense volume |
| Inappropriate application of resin material | Contact resin manufacturer |
| Unstable balance in speed / time parameters | Increase speed / decrease time or visa versa |

**Poor film quality**

| | |
|---|---|
| Exhaust volume too high | Adjust exhaust lid or house exhaust damper |
| Acceleration too high | Select lower acceleration |
| Unstable balance in speed / time parameters | Increase speed / decrease time or visa versa |
| Insufficient dispense volume | Increase dispense volume |
| Inappropriate application of resin material | Contact resin manufacturer |