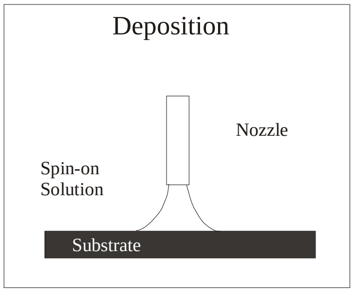
Spin Coating Technology

Spin Coating Process

Spin coating is used for many applications where relatively flat substrates or objects are coated with thin layers of material. The material to be made into the coating must be dissolved or dispersed into a solvent of some kind and this coating solution is then deposited onto the surface and spun-off to leave a uniform layer for subsequent processing stages and ultimate use. Some technologies that depend heavily on high quality spin coated layers are: (1) Photoresist for defining patterns in microcircuit fabrication; (2) Dielectric/insulating layers for microcircuit fabrication, e.g. SOG, SiLK, etc, (3) Magnetic disk coatings - magnetic particle suspensions, head lubricants, etc., (4) Flat screen display coatings. - Antireflection coatings, conductive oxide, etc., (5) Compact Disks DVD, CD ROM, etc., (6) Television tube phosphor and antireflection coatings. There are four distinct stages to the spin coating process. Stage 3 (flow controlled) and Stage 4 (evaporation controlled) are the two stages that have the most impact on final coating thickness.

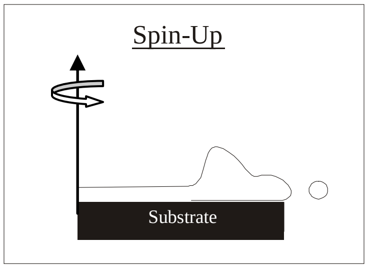
Stage One: The first stage is the deposition of the coating fluid onto the wafer or substrate.

It can be done using a nozzle that pours the coating solution out, or it could be sprayed onto the surface, etc. Usually this dispense stage provides a substantial excess of coating solution compared to the amount that will ultimately be required in the final coating thickness. For many solutions it is often beneficial to dispense through a sub micron sized filter to eliminate particles that could lead to flaws. Another potentially important issue is whether the solution wets the surface completely during this dispense stage. If not, the incomplete coverage can result.



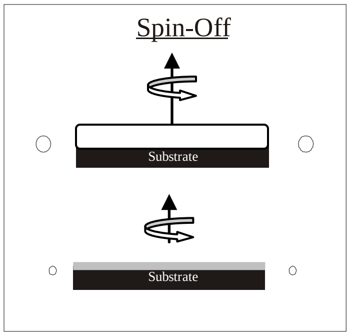
Stage Two: The second stage is when the substrate is accelerated up to its final, desired, rotation speed.

This stage is usually characterized by aggressive fluid expulsion from the wafer surface by the rotational motion. Because of the initial depth of fluid on the wafer surface, spiral vortices may briefly be present during this stage; these would form as a result of the twisting motion caused by the inertia that the top of the fluid layer exerts while the wafer below rotates faster and faster. Eventually, the fluid is thin enough to be completely co-rotating with the wafer and any evidence of fluid thickness differences is gone. Ultimately, the wafer reaches its desired speed and the fluid is thin enough that the viscous shear drag exactly balances the rotational accelerations.



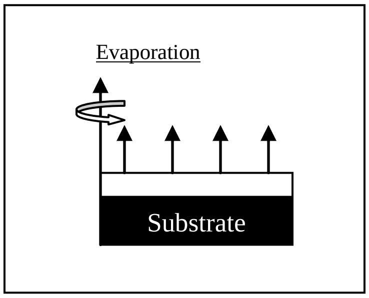
Stage Three: The third stage is when the substrate is spinning at a constant rate and fluid viscous forces dominate fluid thinning behavior.

This stage is characterized by gradual fluid thinning. Fluid thinning is generally quite uniform, though with solutions containing volatile solvents, it is often possible to see interference colors "spinning off", and doing so progressively more slowly as the coating thickness is reduced. Edge effects are often seen because the fluid flows uniformly outward, but must form droplets at the edge to be flung off. Thus, depending on the surface tension, viscosity, rotation rate, etc., there may be a small bead of coating thickness difference around the rim of the final wafer. Mathematical treatments of the flow behavior show that if the liquid exhibits Newtonian viscosity (i.e. is linear), and if the fluid thickness is initially uniform across the wafer then the fluid thickness profile at any following time will also be uniform. This leads to a uniform final coating (under ideal circumstances).



Stage Four. The four stage is when the substrate is spinning at a constant rate and solvent evaporation dominates the coating thinning behavior.

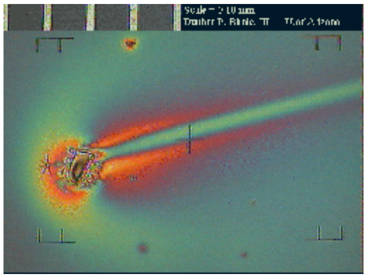
As the prior stage advances, the fluid thickness reaches a point where the viscosity effects yield only rather minor net fluid flow. At this point, the evaporation of any volatile solvent species will become the dominant process occurring in the coating. In fact, at this point the coating effectively "gels" because as these solvents are removed the viscosity of the remaining solution will likely rise - effectively freezing the coating in place. After spinning is stopped many applications require that heat treatment or "firing" of the coating be performed (as for "spin-on-glass" or sol-gel coatings). On the other hand, photoresists usually undergo other processes, depending on the desired application/use.



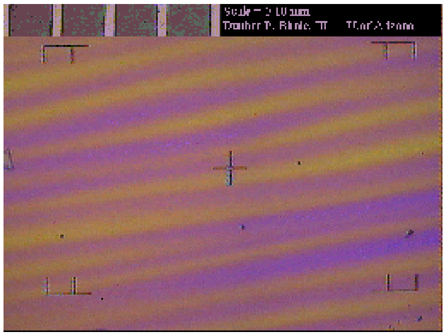
Common Defects Found When Spin Coating

There are a number of defects/features that are characteristic of spin-coated films.

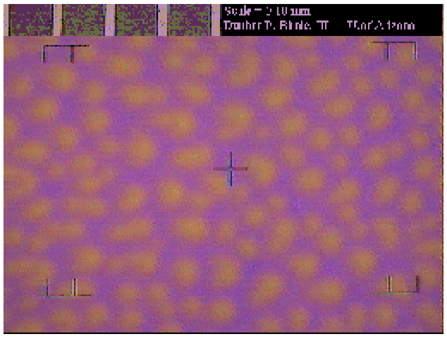
Comets: These usually occur when relatively large solid particles impede the normal flow patterns of the solution on the spinning wafer. Except during "spin up", the flow is normally smooth and radial in nature (having a gradient in radial velocity governed by the applicable force balances and viscosity constraints. The presence of comets can be reduced or eliminated by working in cleaner environments and by filtering coating solutions as part of the dispense process. Right figure: Sol-Gel Silica-titania on silicon. 1000RPM spinning speed. Nominal coating thickness = 300nm.



Striations: Striations are radially oriented lines of thickness variation in the as-coated film. Usually they are quite smoothly varying thickness variations with a spacing or periodicity in the 50-200 micron range, or so. Their orientation corresponds the direction of major fluid flow (which is running horizontally in the first optical micrograph shown below). Their occurance is thought to arise because of evaporation driven surface tension effects. The early evaporation of light solvents can cause an enrichment of water and/or other less volatile species in the surface layer. **If**, the surface tension of this layer is larger than the starting solution (and what still exists at deeper levels), then an instability exists where the higher surface tension actually draws material in at regular intervals and the spaces in-between are more able to evaporate, and surface relief develops. This is essentially due to the Marangoni effect which governs the development of structures in the drainage patterns of wine down the sides of a wine glass: ethanol evaporates first leaving an ethanol-depleted wine layer that gathers into rivulets and drains down the glass wall.

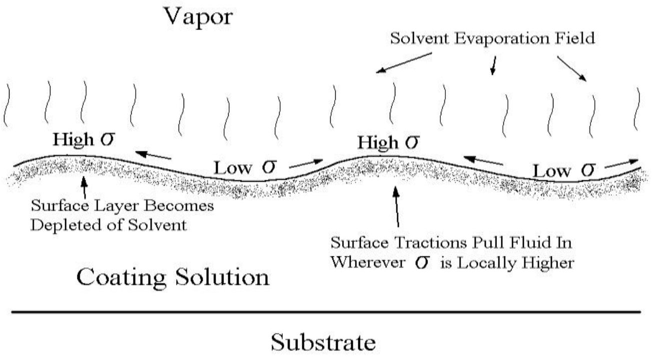


Sol-Gel PZT viewed near edge. 3000RPM - average thickness not resolved in ellipsometry

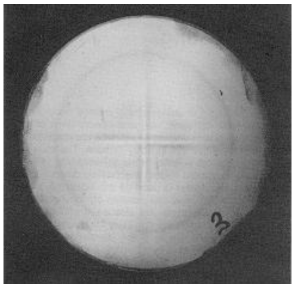


Sol-Gel PZT viewed at center. Same sample as figure to left. Radial flow of fluid stretches out the cellular features shown above.

Evaporation driven surface tension effects can create striation, as shown in the figure on the next page. The evaporation process makes the top layer have a different composition and therefore a different surface tension. The top surface then can become unstable to "long wavelength" perturbations that grow unstably. The exact conditions that control what is stable and what is unstable are still not well known. Our preliminary model is that you would like the evaporation process to be driving the local surface tension to lower values and that this would tend to stabilize the system. This is currently being tested on a number of sol-gel and polymer coating systems.



Chuck Marks: These patterns can be created by thermal "communication" between the solution on top of the wafer and the metal vacuum chuck on the back side of the wafer. Thus, the thermal conductivity of the substrate material is very important as is the thermal driving force (mainly evaporative cooling, but could also be due to temperature differences between solution and substrate and chuck). The figure below has a single layer sol-gel-derived coating on a glass substrate. Silicon wafers, because of their higher thermal conductivity, will usually have smaller thickness differences compared to glass or plastic.



Environmental Sensitivity: When making coatings in the ambient environment, it is possible for the surroundings to have an influence on the coating quality. One critical variable is the humidity of the surrounding air. For many solutions, water can play an important role in the chemistry of the solution itself, so when varying amounts of water are present in the surroundings then varying coating quality can result. This can manifest itself as coating roughness, microcracking of the coating upon further drying, exaggerated striation formation in the coating, etc. Obviously, close control of the environment around the spin coater is crucial.

Wafer Edge Effects: The edges of the substrate will always be areas of concern. If better uniformity can be maintained out to the edges then more area can be used for device fabrication. The edges are problems for several reasons. First, surface tension effects make it difficult for solution that is flowing radially outward to detach from the wafer. Thus a small "bead" of liquid can stay attached around the entire perimeter and result in thicker coatings in this rim zone. In addition, if substrates are not exactly round and especially if they are square or rectangular, then the air flows over the protruding parts (corners) will be perturbed. Although the flow may still be laminar, it will have different flow history and will usually result in non-uniformity in coating thickness in these corner areas.