2.2.2 SPIN COATING TECHNIQUE

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1. INTRODUCTION

Spin coating is a simple process for rapidly depositing thin coatings onto relatively flat substrates. The substrate to be covered is held by some rotatable fixture (often using vacuum to clamp the substrate in place) and the coating solution is dispensed onto the surface; the action of spinning causes the solution to spread out and leave behind a very uniform coating of the chosen material on the surface of the substrate. The spin coating process has been studied extensively in the past and much is known about factors that control coating deposition and the final thickness of the deposit that results [1-10].

The present review of spin coating emphasizes features of particular relevance to sol-gel derived solutions, especially related to coating defect identification and defect prevention [11]. The next section gives a short summary of the physics of fluid flow and solvent evaporation that establishes the conditions common to most spin coating protocols. These boundary conditions are often responsible for various defects that form. Then the following section covers a range of defects that sometimes arise when making sol-gel coatings. Suggestions are made for ways to prevent these defects from forming.

2. SPIN COATING PHYSICS

The physics of the substrate rotation leads to a fluid flow condition where the rotational accelerations are exactly balanced by the viscous drag felt within the solution. This flow condition was first described by Emslie, Bonner, and Peck (EBP) [1] and this paper has been the foundation for many more recent studies. Meyerhofer considered the fact that solvent evaporation is also occurring simultaneously out of the top surface of the solution. The Meyerhofer treatment is especially instructive because he split the spin-coating run into two stages: one controlled predominantly by viscous flow and the second controlled by evaporation [2]. With this approach he was able to predict the final coating thickness, $h_f$, in terms of several key solution parameters, according to:
where \( e \) and \( K \) are the evaporation and flow constants, defined below, and \( x \) is the effective solids content of the solution. The evaporation and flow constants are defined, respectively, as:

\[
e = C \sqrt{\omega}
\]

\[
K = \frac{\rho \omega^2}{3\eta}
\]

where, \( \omega \) is the rotation rate, \( \rho \) is the solution’s density, \( \eta \) is its viscosity, and \( C \) is a proportionality constant that depends on whether airflow above the surface is laminar or turbulent, and on the diffusivity of solvent molecules in air (since it is basically limited by diffusion of the evaporating molecules through the aerodynamic boundary layer above the surface of the wafer during spinning). In prior work, we have simply determined \( C \) experimentally using a laser interferometry technique [12-14]. Others using laser interference effects have dubbed the method “optospinography”, which seems appropriate and it sounds nice [15-17].

Once the rotation dependencies for the viscous flow rate and the evaporation rate are included, then it is found that the final coating thickness should vary with the spin speed, \( \omega \), according to the \(-\frac{1}{2}\) power and this is supported by many experimental tests, though exponents can deviate from \(-\frac{1}{2}\), especially with less volatile solvents where the flow/evaporation cross-over assumed by Meyerhofer may not have been reached.

Typical coating thickness values are usually below 1 micron when sol-gel films are deposited by spin coating. This is partly due to the relatively low solids loading that sol-gel solutions usually provide and the large amount of physical shrinkage that must accompany drying and film solidification. Attempts to make thicker coatings can result in profusely cracked coatings.

3. SPIN COATING DEFECT ANALYSIS

As noted above, spin coating often makes very uniform thin coatings on flat substrates, yet there are times when the coatings have thickness variations or flaws that cannot be tolerated in the final application. Some important defects and possible solutions are presented below.

Striation Defects. These defects are radial ridges and thickness undulations that point nearly directly along the fluid flow direction during the spin coating process. Figure 1 shows two optical micrographs of striation patterns that occurred in a sol-gel-derived PZT coating [18]. The left view shows the central region of the wafer where rotational accelerations are lower and therefore fluid flow is slower; the right view shows radially-oriented features found on most parts of the wafer. Size scale is such that each full frame is approximately 800