Spin-On-Dielectrics: Planarity Modeling

John A. Smythe

Research Report
Prepared in partial fulfillment of
Ph.D. Qualifying Evaluation

University of Washington

October 8, 2006

Materials Science and Engineering
1 Introduction

The idea of replacing chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), and sputter oxide materials, among others, with a spin-on approach has been of interest in the Semiconductor industry for the last two decades. The basic technique draws from the planarizing nature of a liquid when applied to surface topography. The method was initially known as Spin-On-Glass (SOG) and has more recently taken on the more general acronym of Spin-On-Dielectric (SOD). The focus over the years has been to make the material as close to oxide (SiO$_2$) as possible after a cure step or series of cure steps in various ambient gases, temperatures and pressures. The many works have addressed issues including, but not limited to, crack resistance, etch rate in both wet and dry etch chemistries, resistance to photo resist stripping conditions, film stress control, particulate control and planarity characteristics to a lesser degree. Planarity characteristics have not been addressed with rigor needed to predict the interaction between underlying topography in terms of the degree of local and global planarization. The general concepts, from an empirical perspective, are widely known in the industry but little has been done to provide models that guide the 2D-layout rules of semiconductor circuit design. Some relevant work has been done outside the industry, in the paint and photo coatings areas for example. The process technology known as Chemical-Mechanical-Polishing (CMP) has conversely received focus in this area with many papers and Doctoral Theses, particularly at MIT, on the subject of modeling such interactions. Now that widely used SOD materials have been sufficiently refined and new materials developed, it is appropriate to develop models that will guide optimization of layout to facilitate optimum benefit from implementation of SOD materials in sub 100 nm semiconductor process technologies.
The work by J.K. Chu et al.\textsuperscript{1} provides insight to some of the integration issues associated with implementation of SOG materials. Though they studied many other aspects, planarization results are relevant to this work. With regards to planarization, they report that “the amount of SOG remaining in the device depends on the underlying metal aspect ratio and the initial CVD dielectric thickness”. It is this point that continues to motivate the development of robust spin-on planarization models. They provided an empirical definition for percent planarization (Equation 1-1 and Figure 1-1).

\begin{equation}
\%P = \left[1 - \left( \frac{Z}{X} \right) \left( \frac{\theta}{90} \right) \right] \times 100
\end{equation}

where: $\theta$ = step coverage angle
$X$ = step height
$Y$ = step space (not in definition of $\%P$, see Figure 1-1)
$Z$ = dip from top of oxide to lowest SOG point

The workers did provide an initial figure of merit for planarity but did not provide parameters for material viscosity, bare wafer thickness and other factors related to how a liquid coats a surface with topography. Though some data was shown over a range of $X/Y$ values, the so-called aspect ratio, a fit model was not proposed.
Vines and Gupta\textsuperscript{2}, in a joint work, report on inter-metal dielectric planarization using Allied Chemical Accuglass 204 and 105/305 materials. They report that the Accuglass 105 forms a thinner layer on top of metal lines than the 305. The distinction between 105 and 305 is that 105 has a lower viscosity and is blended to achieve a lower thickness on a bare wafer for a given set of spin conditions. This result suggests that viscosity has more than just a mean thickness target effect.

Another Inter-Metal Dielectric (IMD) approach by Rey and coworkers\textsuperscript{3} is discussed that integrates a non-etch back approach. Though the researchers did not suggest a predictive model, they report that planarization for a given bare (blanket) thickness target is a direct function of the aspect ratio of the steps to be coated.

Film shrinkage is a known effect during evaporation of carrier solvent. Elkins at al.\textsuperscript{4} in their work to understand the effects of material shrinkage during cure reported a 10 percent film thickness reduction after cure. Their results suggest that degree of planarity may decrease as a result of cure shrinkage. Pei-Lin Pai and coworkers\textsuperscript{5} reported that stress (tensile) can be attributed to film shrinkage. The equation for stress based on induced wafer curvature is given by Equation 1-2 (Stoney’s equation).

\begin{equation}
\sigma_i = \frac{E_s t_s^2}{6(1 - \nu_s)} \frac{t_f}{R t_f}
\end{equation}

where: 
\begin{align*}
\sigma_i (+) &= \text{tensile (concave on coated side)} \\
\sigma_i (-) &= \text{compressive (convex on coated side)} \\
t_f &= \text{film thickness} \\
R &= \text{radius of curvature} \\
\nu_s &= \text{Poisson’s ratio of Si (0.064)} \\
t_s &= \text{wafer thickness} \\
E_s &= \text{Young’s modulus of Si [1.689E11 N/m2 for (100)]}
\end{align*}

Stress was collected as a function of heating to 600\degree C and cooling back to room temperature. However, if the material is not capable of viscous flow, it is not likely that the stress would be a factor in the final degree of planarity.
The work of Naguib et. al\(^6\) examined the implementation of SOG in a 1.2 um design rule double metal process. The researchers propose a metric of planarity as a function of the line-space pitch. The general idea is that a small gap (relative to the coat thickness) can be near 100 percent planar while larger features are only smoothed. At the time, the idea of global planarity was not seriously considered.

Yen and Rao\(^7\) conclude that, “coating behavior of the SOD depends not only on its viscosity but also on its composition.” They defined the degree of planarization as shown in Equation 1-3 and is consistent with the definition by Chu\(^1\).

\[
\text{Percent Planarity} = \left[1 - \frac{\text{Step after coat}}{\text{Step before coat}}\right] \times 100
\]

The value of \(\text{Percent Planarity}\) was found to have different ranges depending on step for the same spacing as shown in Table 1-1. The numeric order reflects the expected relation that for a given step height and coating thickness, the percent planarity will increase as the spacing decreases. This is one example of how useful a comprehensive model would be for definition of materials requirements and layout rules.

<table>
<thead>
<tr>
<th>Step (um)</th>
<th>Spacing Range (um)</th>
<th>% Planarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>8 to 1</td>
<td>70 to 90</td>
</tr>
<tr>
<td>1.1</td>
<td>8 to 1</td>
<td>50 to 70</td>
</tr>
</tbody>
</table>

One of the benchmark materials studies was by Nakano and Ohta\(^8\). Gap fill was successful down to 0.09 um for some of the SOG materials evaluated (Table 1-2). Radial striations were reported to be a result of the carrier solvent used. Materials with molecular weights from 1200 to 14000 were evaluated. They propose that the solvent (Table 1-3) is the dominant factor for film quality and coating characteristics.
Table 1-2: Table III\textsuperscript{8} For Viscosity from 2.44 to 5.33 mPa-s

<table>
<thead>
<tr>
<th>SOG</th>
<th>Main Solvent</th>
<th>Sub Solvent</th>
<th>Viscosity at 25\textdegree C (mPa S)</th>
<th>Striation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Methanol</td>
<td>1-Propoxy-2-propanol</td>
<td>4.61</td>
<td>+</td>
</tr>
<tr>
<td>B</td>
<td>Methanol</td>
<td>1-Propoxy-2-propanol, water</td>
<td>5.22</td>
<td>+</td>
</tr>
<tr>
<td>C</td>
<td>Ethanol</td>
<td>Butyl acetate, Butanol</td>
<td>2.18</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>Methanol</td>
<td>1-Propoxy-2-propanol, water</td>
<td>4.79</td>
<td>++</td>
</tr>
<tr>
<td>E</td>
<td>Methanol</td>
<td>2-Propanol, 2-Methylpropyl acetate</td>
<td>2.44</td>
<td>-</td>
</tr>
<tr>
<td>F</td>
<td>Ethanol</td>
<td>2-Propanol, Acetone, Butanol</td>
<td>2.54</td>
<td>-</td>
</tr>
<tr>
<td>G</td>
<td>Ethanol</td>
<td>2-Propanol, Acetone</td>
<td>3.15</td>
<td>+ or -</td>
</tr>
</tbody>
</table>

Note: For reference, 10 Poise = 1 Pa – sec, or 1 cP = 1 mPa-sec, where the units of mPa-sec are often used in other works.

After extensive study, the researchers provide the following broad conclusion:

“There appears to be no obvious relation between gap filling properties and the chemical compositions. Gap filling phenomena relate not only to a complex behavior of the surface tension and viscosity change of the solution as a function of its concentration and the spinning speed, but also interfacial tension between the solution and the under layer film.”

The work of Nakano and Ohta was reported in 1995 and covered a great amount of analysis detail. In spite of the excellent work, relations that would support a useful model were not forth coming. Most of those practiced in the art of SOG application had general
rules of thumb after sufficient experience but most simple models broke down as soon as pattern thickness or feature size (line or space) changed.

Stillwagon and Larson have provided some of the benchmark work in planarity modeling and updated their two-stage flow-shrinkage model to account qualitatively for solvent evaporation. In the introduction, they point out the simple relation of the balance between capillary (i.e. surface tension) and centrifugal forces. The issue of solvent evaporation is included because of the effect on viscosity. The general idea then is to maintain capillary effects as long as possible because they drive leveling (i.e. planarization). The centrifugal forces drive the film to a uniform thickness. The prime example is the casting step in any spin-coat sequence: The rpm selected sets the film thickness on a bare wafer, and in most cases, on large features (e.g. 1000 um). Their model is a good candidate as a starting point because it includes: density of fluid, surface tension of fluid to air, angular velocity of spinning substrate, feature width, feature depth and radial position from center. To first order, the only missing factors would be a term to describe the nature of the feature before and after the depression being filled. The work of Stillwagon and Larson is very detailed and will be studied and exercised to a great extent.

Peurrung and Graves followed Stillwagon and Larson to develop a simulation to predict the effect of an isolated block that disturbs the path of flowing material. They also include the evaporation effect and specifically point out that drying does not effect the film shape until the fraction of solvent drops such that the viscosity is high enough to effectively freeze the film in position. If we follow their assumption that the fraction shrinkage is constant without regard to thickness, a perfectly planar (global or local) surface after coat will have depressions where the film is of greatest thickness. This would suggest that the only method to achieve even local planarity would be to use many coats. However, present day experience says that such planarity can be achieved even after high temperature curing of a single coating. Hence, the need for a model that comprehends not only the coat and dry parameters but also the scaling effects.
Hirasawa and coworkers\textsuperscript{11} studied the surface-tension driven flow of liquid (i.e. SOG) on a two-dimensional grooved substrate during the drying or shrinkage phase. Their modeling approach makes the assumption that spreading (i.e. flow) driven by centrifugal force occurs mainly in the first 2 to 3 seconds and the dry shrinking occurs in the following 10 seconds (approximately). Therefore, they treat the two effects separately. The equation for the surface tension force includes a term for the pressure of the surrounding gas. They report some useful empirical relations that will guide development of models that are fine tuned for smaller ranges of conditions.

Control of evaporation during the spin process is covered by various U.S. Patents (circa 1997 to 2000) and reflects the general idea that slowing the evaporation process increases the length of time that surface tension driven forces can improve planarity. One example is by Fairchild Technologies Corp.\textsuperscript{12}. They demonstrated improvements in local planarity of both large (up to 200 um) and small features with 0.7 um steps. The other example is by Silicon Valley Group\textsuperscript{13}.

Kucherenko and Leaver\textsuperscript{14} report on spin coating work in the integrated optics and micromechanics area. They model features in 2D from 0.6 um to as high as 6 um. Their simplifications and range of features will provide guidance in developing more fine tuned models for the range of features encountered in deep sub micron semiconductor processing.

Gurer and coworkers\textsuperscript{15} report on the closed cup approach to DUV lithography coatings and low-k SOD materials. Because of the cost of DUV chemicals, one driving force is to reduce the amount dispensed per wafer. They report the ability to reduce the amount from 2 cc to as low as 0.4 cc for a 200 mm wafer. With chemical costs in the thousands per liter, this is a very important achievement. Their model results indicate that it is possible to planarize large steps if the evaporation rate can be sufficiently slowed.
Haas and coworkers\textsuperscript{16} studied the source of striations that can form in SOD coatings. They point out that surface tension gradients can develop. These gradients cause high surface tension regions to draw material from low surface tension regions. It is likely that this is a key factor in modeling the interactions relative to the position of a given feature from the center of the spinning wafer.

Osredkar\textsuperscript{17} reported on his work to study the limits of SOG planarization. He concludes that a planarization factor (i.e. fractional step reduction) of 0.9 may be achievable with multiple coat/cure steps in local but not global regions.

### 1.1 Section 1 Notes


2 Research Objectives

An introduction to planarization from SOD methods has been provided in Section 1. Planarity prediction has not been addressed with rigor relative to the interaction between underlying topography and degree of local and global planarization. The general concepts are widely known in the industry but little has been done to provide models that guide the 2D-layout rules of semiconductor circuit design. The main objective is to develop a finite element model structure that includes variables related to the dispensed liquid properties, the layers contacted by the liquid, ambient gas and the topography to be planarized. The basic technique draws from the planarizing nature of a liquid when applied to surface topography. A useful model must deal with, at a minimum, the two characteristics that are important for integration of SOD materials: prediction of local and global planarity in terms of the specific feature or features of interest. This work reviews some of the details behind modeling the local and global planarization character of SOD materials in the context of underlying topography and how those results would be used to guide 2D-layout rules and define limitations in the 3D sense.

3 Results and Discussion

Stillwagon and Larson\(^1\) updated their two-stage flow-shrinkage model to account qualitatively for solvent evaporation. In the introduction, they point out the simple relation of the balance between capillary (i.e. surface tension) and centrifugal forces. The issue of solvent evaporation is included because of the effect on viscosity. The general idea then is to maintain capillary effects as long as possible because they drive leveling (i.e. planarization). The centrifugal forces drive the film to a uniform thickness. The prime example is the so-called casting step in the spin-coat sequence: The rpm selected sets the film thickness on a bare wafer, and in most cases, on large features (e.g. 1000 um). Their model is a good candidate as a starting point because it includes: density of
fluid, surface tension of fluid to air, angular velocity of spinning substrate, feature width, feature depth and radial position from center. To first order, the only missing factors would be a term to describe the nature of the feature before and after the depression being filled. The work of Stillwagon and Larson is very detailed and will be studied and exercised to a great extent.

For the flow stage of the model, planarization is given as P₁. The value of P₁ is calculated based on fundamental lubrication analysis for features with high values of w/d. Where w is the feature (eg. a trench) width and d is the feature depth. In deep sub-micron semiconductor applications the concept of aspect ratio is given as the opposite relation d/w, or more commonly, h/w. In this case, h is later used to refer to the coating film thickness so d will be kept as the parameter representing the depth of the feature or step-height to be planarized. The lubrication analysis is based on a balance between capillary and apparent centrifugal forces.

They give the following relation as Equation 3-1  $$\Omega_i^2 = \frac{\rho \omega^2 w^3 r_o}{\gamma h_1}$$ to express this balance:

**Equation 3-1**  $$\Omega_i^2 = \frac{\rho \omega^2 w^3 r_o}{\gamma h_1}$$

Ω = dimensionless value
ρ = density of the fluid (SOD Material of interest)
γ = surface tension against air
w = width of feature (at depth d)
h₁ = film thickness on flat featureless area (i.e. un-patterened substrate or very large area)
r₀ = radial distance of the feature from the center of the feature (this definition is not supported by any kind of schematic)
The model predictions are for trenches arranged in concentric rings. One can interpret this to mean that the estimates apply to the infinitesimal case where the flow is normal to the step to be planarized.

In the case of the common 200 mm wafer used in semiconductor applications, the two factors angular velocity and \( r_o \) are inter-related in the sense that for a given RPM, the value of angular velocity changes with \( r_0 \). Hence, and ideal model would need to comprehend the complete wafer condition. For example, in the controlled studies, individual features could be examined for fixed \( r_0 \) and variable omega. While for the whole wafer case, we must somehow comprehend the effects of omega changing with \( r_0 \). The value \( P_1 \) is then plotted against values of \( \Omega^2 \) with different curves for various values of \( h_1/d \) for isolated trench-like features.

Stillwagon and Larson make reference to the work of Emslie et al. who provided the flow relation:

\[
H = \left[ 1 + \frac{4}{3} \left( \frac{\omega}{r_o} \right) T \right]^{-1/2}
\]

where \( H \equiv \frac{h}{h_f} \) and \( T \equiv \frac{t}{t_c} \).

From this, Stillwagon and Larson define \( t_c \) as centrifugal time. The value is given by

\[
t_c \equiv \frac{w \eta}{\left( h_f \right)^2 \rho \omega^2 r_o}
\]

where \( \eta \) is the material viscosity. The centrifugal time is defined as the time required for the local film profile over the feature to come to equilibrium with the centrifugal field given a fixed film thickness far from the feature. The other factor is called the spin-down time and is given by

\[
T_s \equiv \frac{t_s r_o}{w}
\]
The third time factor is the time $t_L$ (Equation 3-4) required for leveling from capillary forces. In the absence of centrifugal forces, this, in general, describes the condition when the film becomes level. This idea assumes that there is sufficient material to fill the feature. That is, $h_f$ is greater than $d$.

Equation 3-4 \[ t_L = \frac{\eta \omega^4}{\gamma h_f} = t_c \Omega^2 \]

In a prior work\(^2\), Stillwagon and Larson gave typical values for the variables. Those are reproduced for reference in Table 3-1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numeric Range</th>
<th>Unit of Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>1</td>
<td>g/ml</td>
</tr>
<tr>
<td>$\omega$</td>
<td>200-850 (2000-8000)</td>
<td>rad/sec (RPM)</td>
</tr>
<tr>
<td>$w$</td>
<td>1-200</td>
<td>um</td>
</tr>
<tr>
<td>$r_o$</td>
<td>1-10</td>
<td>cm</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>20-50</td>
<td>dyn/cm</td>
</tr>
<tr>
<td>$h_f$</td>
<td>0.5-2</td>
<td>um</td>
</tr>
</tbody>
</table>

$h_f$ is the film thickness far from the feature

$d$, the feature depth, is stated to be typically 1 um

For present day semiconductor applications, angular velocity extends down to 1000 RPM, $w$ extends down to below 0.1 um (100 nm), surface tension can be near 10, film thickness extends down to below 0.2 um (200 nm) and $d$ can be in the range of 0.2 to 2 um.

Peurrung and Graves\(^3\) followed Stillwagon and Larson to develop a simulation to predict the effect of an isolated block that disturbs the path of flowing material. They also include the evaporation effect and specifically point out that drying does not effect the film shape until the fraction of solvent drops such that the viscosity is high enough to effectively freeze the film in position. If we follow their assumption that the fraction shrinkage is constant without regard to thickness, a perfectly planar (global or local) surface after coat will have depressions where the film is of greatest thickness. This would suggest that the only method to achieve even local planarity would be to use many
coats. However, present day experience says that such planarity can be achieved even after high temperature curing of a single coating. Because of the nature\textsuperscript{1-6} of spin-coating, the model structure will be divided into two parts. The first will focus on the initial spreading and sloughing off of surplus material. The second will focus on the conditions driven by surface tension, capillary force and drying\textsuperscript{5,6}.

The next phase of the work is to take the details of published models, create FEMLAB models and calculate results for common materials (eg. HSQ, MSQ, polysilazane) as applied to various step height features. The first pass will only cover enough points to determine where the various approaches fail to predict the observed planarization profiles as a function of radial location, w, d and the critical aspect ratio of d/w. Prior works have used the ratio w/d but for this work, the more relevant ratio is the inverse as noted in earlier discussion.

Initial data collection plan is to measure planarity and density for w from 80 nm to 800 nm, d from 250 nm to 400 nm and r\textsubscript{o} from 0 (i.e. < 2 mm) to 90 mm. The longer view is to extend to values of w from 8000 nm (8 microns) to 100s of microns.

An example of large feature planarity is shown in Figure 3-1. The plot is created from the stylus deflection signal of a surface profiler. The double-ended arrow shows the degree of planarity from the base plane achieved for spaces that are a factor of 30 smaller. Ten units in the Z-axis are equal to one unit in the X-axis.
The zoomed view of Figure 3-1 depicted in Figure 3-2 shows the symmetry of the space planarity. The results are from an initial test of a thick coat HSQ material using a dynamic dispense, casting spin and dry step.
The preceding figures and associated observations provide a baseline for more detailed study of the factors that influence the planarization effect. The work is expected to proceed in an iterative fashion: collect data (completed); make model (in progress); calculate outcomes; generate prediction for comparison to observations; refine the model and parameters; repeat. The desired outcome is to create a family of models that will guide development of new SOD materials, coat techniques, and layout/structural rules for future technology.

An initial interpretation of the Stillwagon and Larson model\textsuperscript{1,2} is provided here for various conditions to be evaluated. The interpretation examines the unit-less term $\Omega^2$ in the regime of surface tension from 10 to 20 dyne/cm and values of $w$ from 0.1 to 5 microns. The full range is shown in Figure 3-4 while the sub-micron range is shown in Figure 3-5. The general relation reported in prior works predicts increased planarity for values of $\Omega^2$ below $10^{-2}$. The figures show the predicted effect of surface tension of the SOD in relation to the surface being coated. The inputs to $\Omega^2$ are SOD density (SOD in solvent), wafer angular velocity, trench width, and radial position of trench (9 cm) and SOD surface tension.

![Figure 3-4](Image)
3.1 Experimental Results

The topography wafers were prepared in a manner consistent with semiconductor photo and dry etching technologies. Test structure layout, coating material and sampling detail have been reviewed in detail in the Master’s work by the author⁷. The step height was measured using a Tencor model P-20H surface profiler. The instrument uses a stylus to collect z-axis changes at fixed intervals during a linear scan. Each scan results in from 900 to near 2000 pairs of X and Z data pairs that are then used to represent the cross-sectional surface profile of the area of interest. Prior to saving the raw data, a leveling algorithm is used in the P-20H software to normalize all z-axis values consistent with a selected pair of regions expected to be at the same z-axis position. The samples were then spin coated with the SOD material of choice (Table 3-2). A dispense volume of 2 ml was used with casting RPM in the range of 1000 to 4000. After spin dry, the wafers are processed through the appropriate hot plate conditions to remove solvents and cross-link the polymers as appropriate. The samples were then scanned again using the P-20H. Collected z-axis results are leveled using the same method as used for the pre-coat step profiles using regions expected to be level in reference to the z-axis. For example, from
other work, it is known that features with a width greater than, say, 500 microns will tend to have a final thickness near that of an un-patterned wafer.

Table 3-2: Sample Treatment

<table>
<thead>
<tr>
<th>Material</th>
<th>Sample (date)</th>
<th>Nominal Step</th>
<th>Casting RPM</th>
<th>Spread/Stop Step (seconds)</th>
<th>Bare Thickness Average/%σ (Angstroms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOD1</td>
<td>7114 03</td>
<td>1.4 µm</td>
<td>1000</td>
<td>5/90</td>
<td>~11600</td>
</tr>
<tr>
<td>SOD1</td>
<td>7114 08</td>
<td>1.4 µm</td>
<td>1000</td>
<td>3/0</td>
<td>11195/0.88%</td>
</tr>
<tr>
<td>SOD1</td>
<td>7114 09</td>
<td>1.4 µm</td>
<td>2000</td>
<td>3/0</td>
<td>7685/0.43%</td>
</tr>
</tbody>
</table>

Three wafers were coated and hot plate baked prior to being measured. Two samples used a typical spin-coat method and one used a method that employs a short stop after the initial spread of the material. The results for the typical spin-coat are reported here. The nominal film thickness for all samples was on the order of 7 to 12 thousand angstroms. The optical measurements were made using the Optiprobe multi-wavelength system from ThermaWave Inc. Because of the color fringes and the need to measure within the 20 micron space, a 1 um spot was used to measure at the sites indicated by red spots in Figure 3-6.

Figure 3-6: Optical microscope example of measurement points
To represent the global height, the measured thickness was added to the silicon reference. An example of the resulting measurement is shown in Figure 3-7 where the bars are a schematic representation of the silicon islands. For comparison, the same measurement scheme was used to examine the global planarity from one pattern to the next. This is shown in Figure 3-8 and reflects similar results though the space between quadrants is 400 microns less. Subsequent surface profile results support the minima and maxima relation shown by the optical readings.

The fill efficiency can then be described by expressing the test wafer thickness as a percent of the step to be planarized and plotting it against the percent fill in the space of interest. This result is shown in Figure 3-9. The initial data suggests that the gap would have been completely filled with a test wafer thickness of 57 to 58 percent of the step. The data for the 600 um space shows that the fill is essentially the bare test wafer.
thickness using any of the three comparison methods. This suggests that there is a 
threshold at which the amount of fill begins to exceed the bare wafer coat thickness. The 
planned model is expected to predict this threshold for a given coat material, thickness 
target, step height and gap width.

![Fill Efficiency for 20 µm Gap and 1.4 µm Step](image)

**Figure 3-9:** Fill Efficiency for 20 µm gap 7500 Å and 11000 Å nominal

The surface curvature over trenches has been shown to have symmetry using SEM 
section, stylus profiling and AFM. Based on the strength of this observation, one can 
take advantage of this to simplify the model structure. The model should then be able to 
show when surface curvature approaches infinity (i.e. planar) over a trench feature.

### 3.2 Section 3 Notes


4 Conclusions and Future Work

4.1 Conclusions

Review of the literature supports the value of developing a robust planarity model for complex structures and a variety of material parameters. The combined results of SEM section, optical thickness measurement and surface profile measurement (stylus and AFM) show that the characteristic planarity as a result of applying SOD material to a topography pattern has symmetry that will permit useful modeling of short range curvature. This work justifies continuation of effort to develop a planarity model to address both local and global planarity transitions.
4.2 Model Development Plan

Model development will be completed using COMSOL’s FEMLAB™ 3.3 software. The following is taken from introductory notes provided by application specialist Leigh Soutter in private communication.

The finite element method (FEM) is a numerical method designed to estimate the solution of a PDE (partial differential equation) by solving a system of equations that closely approximates the PDE. The first step in FEM, is to define an integral equation that will approximate the PDE. The second step is to choose the type of function of “basis function” that will be used to transfer the integral approximation to each location in the model domain. Next, the geometry to be analyzed is discretized, creating a mesh of elements with a characteristic shape. The integral approximations (including boundary conditions) are applied to all locations on the mesh. In this way, the PDE is replaced by a system of equations, which is solved at each time step.

From the previous literature reviews, the initial models will be derived from the approaches taken by Stillwagon and Larson¹,², Peurrung and Graves³, as well as the benchmark work of Washo⁴. The first model will demonstrate ability to predict blanket wafer coating thickness for given material and coater input parameters. The second model will predict local planarity⁵,⁶ for various gap features. The final model objective is to predict both local and global planarity for combinations of gap features.

4.3 Section 4 Notes