Large Area Processing: Meniscus Coating of Thin Film Polymer Dielectric & Photoresist

Philip Garrou  
Dow Chemical Company  
3021 Cornwallis Road  
Research Triangle Park, North Carolina 27709  
Phone: 919-248-9261  
Fax: 919-248-9265  
e-mail: pegarrou@dow.com

Brian Martin, Timothy Rehg*, and Robert Heistand^  
Dow Chemical Company  
1712 Building  
Midland, Minnesota 48674  
Phone: 517-636-1406  
*e currently with Allied Signal Corporation  
^ currently with AVX Corporation

Eric Chieh, Jim Lykins, and Chung Ho  
Micro Module Systems (MMS)  
10500 A Ridgeview Court  
Cupertino, California 95017  
Phone: 408-864-7489  
Fax: 408-864-5950  
e-mail: chieh@mms.com

Abstract

The desire to reduce thin film MCM costs has led practitioners to Large Area Processing (LAP) of these structures on panel sizes and using tools similar to the flat panel display industry. While IC fabrication has traditionally used spin coating for the deposition of polymeric formulations such as photoresists, new large format processes allow the use of high efficiency techniques such as meniscus coating. The authors have examined the coating of photo BCB and photoresist on 400 mm panels using a SCS Cavex™ meniscus coater and found they can achieve 2% or better intra panel uniformity and panel to panel variation of < 4.5% at translation speeds up to 15 in per minute. Material utilization is > 90%. Drying of the panels and residence time in the coater are found not to affect the concentration of temperature sensitive cross linkers in the formulations. Meniscus coating has been shown to be a viable technique for large area processing of dielectric and photoresist materials.

Key words:

Meniscus Coating, Large Area Processing, BCB, and Thin Film Technology.

1. Introduction

Reducing the cost of thin film single and multichip interconnect is of great interest. Similar to the economics of IC fabrication, the economics of thin film substrates (single chip or MCM) are directly related to the number of parts that can be produced, per unit operation, on a given size substrate (Si, ceramic, aluminum or laminate), that is throughput. There are two basic methods of increasing throughput: fabrication of very small MCM structures as exemplified by the recent work of AT&T, where 9.5 mm x 6.65 mm substrates are fabricated on a 125 mm wafer or fabrication of larger MCM substrates on large area (> 300 mm) carriers.

The potential economic advantages of large panel MCM production were first described by Motorola/Dow in 1992. It was deduced that the equipment advances being implemented in the flat panel display industry could also have a major impact on reducing the price of thin film MCM-D manufacturing if such large panel techniques could be adopted by the emerging thin film MCM industry. Z-Systems and IMC Microsystems published the first work on a 350 mm x 350 mm FPD format (Al / BCB thin film interconnect on glass) and proposed that larger panel production was possible. The very favorable economics of large panel processing are depicted in Figure 1, where 10 times more modules are fabricated on a 350 mm x 350 mm panel than is possible on a 150 mm diameter wafer. Even considering the greater cost of producing the larger panels...
due to more expensive capitalization and anticipated initial lower yields, it was predicted that the overall cost of substrate fabrication would be reduced. Several groups have addressed the economics of such processing with a more quantitative analysis.

A collaborative effort between groups at Dow and Motorola have evaluated various LAP manufacturing scenarios using LCD equipment lists and about 10 fold cost differential was projected for specific 150 mm IC equipment based processing versus 350 mm LAP processing. Workers at IBM\(^8\) have also examined the cost impact of Large Area Processing and their results supported the advantage of larger format substrates in driving down thin film MCM-D processing costs.

### 2. Dielectric Coating

Whether utilizing large area processing or traditional IC wafer fab processing, polymer coatings (photoresist and/or dielectric) need to achieve the desired thickness in the fewest coating applications possible, exhibit thickness uniformity across the substrate, and produce a smooth, planar, and pinhole free film.

Photoresists and organic dielectrics have typically been applied by spin coating. The spin coating technique is depicted in Figure 2. The polymer is (a) dispensed onto the wafer, (b) spread across the wafer (ca. 500 rpm), (c) spun at higher speed (2000-4000 rpm) to achieve a uniform coating of desired thickness, and (d) the “edge bead” is removed using a backside wash cycle which causes solvent to curl back over the lip of the wafer and wash off the “bead” that is created due to the of surface tension at the edge of the wafer. Spin coating produces excellent film quality at the sake of materials utilization. The typical open bowl spin coater deposit consists of about 5 - 15% of the polymer initially dispensed on the wafer.

It is expected that new deposition techniques will be required for LAP processing to replace the open bowl spin coating typically associated with IC thin film fabrication. Spin coaters are being challenged by high efficiency coating techniques such as Meniscus, Extrusion, Patch, or Curtain. Curtain coating is currently being used by IBM Yasu and their licenses in their “SLC” LAP processing on laminate\(^6\). The authors have previously described extrusion coating studies which have been part of the DARPA sponsored LAP consortium\(^10\)\(^11\).

### 3. Meniscus Coating

In earlier screening studies\(^12\), the researchers described meniscus coating as a viable coating option for large area processing. In this paper, further detail on this technique as it applies to the coating of photo BCB dielectric and photoresists is presented.

A Schematic of the Cavex™ Meniscus coater is shown in Figure 3. Coating fluid is circulated by a explosion proof pneumatically driven vane pump through an applicator roll. The applicator roll is constructed of porous sintered stainless steel. The fluid passes through the porous wall (10 µm pores) of the applicator roll and forms a wet film (about 12 mil thick), see Figure 4, on the outer surface of the roll. The fluid drains into a reservoir, where it is circulated to the applicator roll. Evaporation is minimized by automatic covering of the applicator with an o ring sealed lid when panels are not being coated. The tool can accommodate up to four recirculation systems for four coating solution formulations. The recirculation system is modular and can be removed by the operator and stored in a freezer to prolong the life of photosensitive materials. The recirculation system can be equipped with on line filtering, on line viscosity control and on line solution make-up. Viscosity control is accomplished by solvent injection in advance of the vane pump where the mixing occurs.

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**Figure 1. The advantage of larger panel sizes.**

**Figure 2. Schematic of the spin coating process.**

**Figure 3. Schematic of the SCS Cavex™ meniscus coater (1. Control panel, 2. Tubular frame, 3. Load/unload station, 4. Hot plate, 5. Vacuum chuck, 6-8. Applicator tank, 9. megasonic cleaner, 10. Exhaust plenum, 11. Drive system).**
The substrate is secured to the chuck by vacuum action. The robot compatible vacuum chuck is then inverted so that the substrate is suspended 8 - 10 mil above the applicator. The chuck is capable of heated or cooled operation. Temperature variation across the chuck has been measured as < 0.5°C at steady state condition. The chuck is translated past the applicator (or optionally the applicator translated past the chuck) at a translation speed of 0 to 48 inches per minute.

As the substrate passes beyond the applicator roll, the meniscus splits and recoils both towards the applicator and the substrate. If this recoiling is severe, it can form intolerable coating defects. To avoid this problem, the chuck is equipped with a “knife” that is butted against the leading and trailing edges of the substrate. The knives are cleaned by an automated mechanical wiper between the substrates or alternately by a Megasonic cleaner (item 9 in Figure 3).
successively fit to the Landau Levich equation. The result is given by equation (4),

$$h_{dry} = 186 \omega (\mu U)^{0.067} ; R^2 = 0.99$$  \hspace{1cm} (4)

where $\mu$ and $U$ are in cgs units, $h_{dry}$ is in microns, and the volume fraction, $\omega$, is calculated from the weight fraction of the BCB solution. Note that a faster translation speed results in a thicker coating.

Figure 6. Film thickness as a function of weight % BCB.

The data in Figure 5 is replotted in Figure 6 to identify the solids loading required to achieve a desired thickness at a target process rate.

7. Thickness Uniformity

Film Uniformity versus translation speed is shown in Figure 7.

Figure 7. Relative standard deviation of film thickness as a function of translation speed for 26 wt% BCB formulation.

As the translation speed increases, the thickness uniformity decreases. This effect may be a consequence of film drying and not a property of the coating technique (see later discussion on Marangoni flow in wet films). It is clear that under the current experimental conditions, one can achieve a ca. 2% or better uniformity at translation speeds up to about 15 in/min. Taking into account panel transfer time, this would correspond to about 1.5 minutes per panel process rates when using robotic load unload stations.

Table 2. Inter and intra panel uniformity for 22 wt % BCB formulation.

<table>
<thead>
<tr>
<th>Panel #</th>
<th>Process Rate (min/panel)</th>
<th>Average Thickness (µm)</th>
<th>Variation with in panel (RSD %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>6.09</td>
<td>1.64</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>6.15</td>
<td>0.76</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>6.55</td>
<td>1.13</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>6.65</td>
<td>1.13</td>
</tr>
<tr>
<td>5</td>
<td>1.5</td>
<td>6.27</td>
<td>1.08</td>
</tr>
</tbody>
</table>

From the data in Table 2, panel to panel variation is calculated as 4.35% RSD. The chuck temperature was not controlled under these experiments and thus, the results would be expected to improve when this control is implemented. Variation within a panel, as shown in Figure 7, is < 2 %.

Table 3. Inter and intra panel uniformity for AZ™ photoresists.

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Process Rate (min/panel)</th>
<th>Thickness (µm)</th>
<th>Variation within Panel (RSD, %)</th>
<th>Panel to Panel Variation (RSD, %)</th>
<th>Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ P4110</td>
<td>2.75</td>
<td>10.26</td>
<td>1.3</td>
<td>N/A</td>
<td>22</td>
</tr>
<tr>
<td>AZ P4210</td>
<td>1.00</td>
<td>19.4</td>
<td>&lt;2.1</td>
<td>0.4</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 3 details thickness uniformity for two Hoechst Celanese AZ™ photoresists.

8. Materials Utilization

The transfer efficiency (% of the polymer solution used up by the application that ends up in the final coating, for example if 10 cc are dispensed per panel and 8 cc end up on the panel after processing the transfer efficiency would be 80%) of the meniscus coater is excellent. The only material not remaining on the panels during steady state operation is the material deposited on the leading and trailing "knives". The knives used in these trials had a width of 6.35 cm, thus, the transfer efficiency for a 400 x 400 panel would be 86%. It is expected that the width of the knives could be decreased to 3 cm, thereby increasing the transfer efficiency to about 93%.

9. Drying Instabilities

One advantage of spin coating is the fact that solvent is evaporating as the film is uniformly spun out. In fact, for BCB formulations, very little solvent remains to be removed by hot plate baking. In meniscus and/or other high efficiency coating techniques, the wet films contain nearly all of the solvent they started with (88 - 69 % in these studies). When drying such “wet films” before exposure, one must pay attention to the uniformity of the temperature source due to
“Marangoni” flow. Marangoni instability is characterized by equation (5),

\[ M_a = \frac{\delta \sigma \Delta T}{\delta T \mu \alpha} \]  

where \( \Delta T \) is the local temperature variation, \( \delta \sigma / \delta T \) is the rate of change of surface tension with temperature, \( \mu \) is the thickness of the film, and \( \alpha \) is the thermal diffusivity. For a given environment, equation (5) shows that thicker films are less stable than thinner ones and in fact the \( M_a \) of a film coated at 24 inches per minute is 5X that of a film coated at 2 inches per minute solely due to the increase in wet film thickness. Thus, the uniformity shown in Figure 7 should be taken as an upper bound and it is likely to be increased by better hot plate drying control.

Another issue with drying is the issue of potential thermal degradation of the photocrosslinker while raising the film temperature to drive off the solvent. The authors have examined this issue by monitoring the crosslinker concentration as mesitylene solvent is removed at various temperatures. The researchers find that the crosslinker degradation is not an issue under the running conditions.

### 10. Residence Time

A concern with all coating techniques used for photosensitive materials that must be stored cold is the residence time of the formulation in the dispenser. The photo BCB formulation has a recommended five day lifetime at room temperature before resolution and other properties change enough to affect processing. The residence time for the photo formulation was calculated assuming the reservoir is automatically refilled after the coating of each panel. For a 6.67 micron coating on these 350 mm panels, this would amount to the addition of 6 cc of solution to the 400 cc reservoir.

\[ \text{Average Residence Time (hours)} \]

\[ \text{Time (hours)} \]

The residence time is calculated assuming the reservoir remains well mixed throughout the steady state operation. In fact, the applicator roll can be filled with inert beads to provide additional static mixing. Figures 8 and 9 show the average residence time of the coating solution calculated this way, and the volume fraction of material having a given residence time. As shown, less than 0.02% of the initial charge of 400 cc should be left after 35 hours of continuous operation.

### 11. Conclusions

Meniscus coating has been shown to be a viable technique for large area coating of photo BCB and photoresists. Panels can be processed every one to two minutes resulting in intrapanel uniformity of < 2.0% RSD (photoresist and BCB) and interpanel uniformity of 2.9 to 4.35 % RSD (photoresist and BCB, respectively). Uniformity is expected to improve with better control of drying temperature. Hot plate drying of the film does not degrade the performance of the photo BCB resin. BCB residence time in the reservoir is about 4X less than the recommended shelf life at room temperature.

### References

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About the authors

Philip Garrou is currently Chief Scientist for Dow Chemicals Microelectronics Activities. He received his B.S. and his Ph.D. Degrees in Chemistry from North Carolina State and Indiana University, respectively. During his 23 years at Dow, Dr. Garrou has been involved with many technology areas including electroceramics and polymers for microelectronic packaging applications. He has authored and co-edited the books “Thin Film Multichip Modules” (1992) and the MCM Handbook (1997). Dr. Garrou is Associate Editor of the International Journal of Microcircuits and Electronic Packaging. Dr. Garrou is a Senior member of IEEE where he was elected to the CPMT Board of Governors (1994-1996; 1997-1999) and has served as Chairman of TC-5 (Technical Committee on Materials, 1992-1994). He was elected President of IMAPS (1997) where he has also served as Technical VP (1995-1996); Chairman of the MCM/Advanced Packaging subcommittee of the National Technical Committee (1991-94), and Chairman of the ISHM Materials Division (1992). He was Technical Chair of the 4th International MCM Conference (Denver, 1995). Dr. Garrou is the 1998 IMAPS President.

Dr. Robert H. Heistand II is the Thin Film Research & Development Manager at the Advanced Products & Technology Center for AVX Corporation in Myrtle Beach, South Carolina. He received his Ph.D. and B.S Degrees in Chemistry from Cornell University and Bucknell University, respectively. He has worked in the area of electronic material R& D for the last 16 years. Recent areas of focus have been on large area processing of high density interconnect with Dow Chemical and integrated passive components with AVX. Dr. Heistand has over thirty professional publications and eight patents. He is chairman of the Materials Sub-committee of IMAPS National Technical Committee.

Brian Martin graduated with a B.Sc. Degree in Chemistry from the University of London, and a Ph.D. Degree in Organosilicon Chemistry from the University of Leicester, UK. Dr. Martin is a specialist in the technology, product formulation, and application processes of adhesives and coatings.
Jim Lykins received his B.A. Degree from San Jose State and his M.S.S.M. from the University of Southern California. He is presently employed at Micromodule Systems in Cupertino, California. He is working in the process development group as a principle engineer. He has been involved in the selection and start up of all wet processing equipment.

Eric Chieh received his B.S. Degree in Chemistry from National Tsing-Hua University in Taiwan and his M.S. and Ph.D. Degrees in Materials Science from University California - Davis. Dr. Chieh has worked at IBM, Memtech, DEC, and Micromodule Systems. He is presently employed at Candescent Technologies Corp. as senior program Manager.

Chung Ho received his B.S. Degree in Electrical Engineering from National Taiwan University and his M.S. and Ph.D. Degrees in Electrical Engineering from the University California Berkeley. He has worked at U.C. Berkeley as a faculty member, IBM, DEC and Micromodule Systems. He is currently serving as Chief Technical Officer at MMS in Cupertino, California.

Timothy Rehg biography was not available at the time of publication.