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PHOTORESIST APPLICATION
BY ROLLER COATING

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PHOTORESIST APPLICATION BY ROLLER COATING

BDX-613-1288, Published August 1976

Prepared by L. E. Schantz, D/842, under PDO 6984726

Application of AZ1350J photoresist by roller coating was investigated as an economical means of coating 3.75- by 4.50-inch (95 by 114 mm) substrates for multiple hybrid microcircuit fabrication. The most important technical aspect of the resist coating is the thickness uniformity. The large rectangular substrate made photoresist application by spinning technically unsatisfactory; spray coating, although technically acceptable, represented a capital equipment investment 10 to 15 times that of roller coating costs. Resist viscosity, doctor bar pressure, roller/substrate interference, and roller thread configuration were optimized to achieve maximum thickness uniformity. The correlation between resist thickness and dimensional control of the photoresist image was established, and a predicted distribution of thin-film line widths was made and verified.

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CONTENTS

Section	Page
SUMMARY.	7
DISCUSSION	9
SCOPE AND PURPOSE.	9
PRIOR WORK	9
ACTIVITY	10
<u>Photoresist Coating Process Selection.</u>	10
<u>General Operating Description of Roller Coater</u>	10
<u>Methods of Resist Application</u>	16
<u>Resist Viscosity</u>	20
<u>Doctor Bar Pressure Adjustments.</u>	30
<u>Roller Size.</u>	33
<u>Roller/Substrate Interference.</u>	35
<u>Thin-Film Surface Effects on Resist Thickness.</u>	43
<u>Edge Effects and Substrate Orientation</u>	43
<u>Resist Thickness and Expected Line Width Deviation</u> . .	49
<u>Thickness Uniformity Distributions</u>	49
<u>Line Width Distributions</u>	52
<u>Recommended Operating Procedure.</u>	53
ACCOMPLISHMENTS.	61
FUTURE WORK	61
APPENDICES	
A. START UP AND SHUTDOWN PROCEDURES	62
B. MAINTENANCE AND FACILITY REQUIREMENTS.	64
C. MICROCOATER TROUBLESHOOTING GUIDE	65
DISTRIBUTION	66

ILLUSTRATIONS

Figure		Page
1	Gyrex Micro 9 Roller Coater (P-82611)	11
2	Resist Reservoir and Pump (P-82616)	12
3	Threaded Rubber Roller and Doctor Bar (P-82613)	13
4	Effects of Doctor Bar Pressure	15
5	Substrate Carrier (P-82615)	17
6	Resist Coating Thickness Versus Resist Viscosity.	21
7	Resist Viscosity Versus Resist Temperature.	23
8	Doctor Bar Pressure and Resist Coating Thickness (Viscosity 21, Roller E-10)	25
9	Doctor Bar Pressure and Resist Coating Thickness (Viscosity 55, Roller E-10)	26
10	Doctor Bar Pressure and Resist Coating Thickness (Viscosity 21, Roller E-6).	27
11	Doctor Bar Pressure and Resist Coating Thickness (Viscosity 35, Roller E-6).	28
12	Adjustment for Uniform Doctor Bar Pressure (P-82608)	31
13	Roller Coater Controls (P-82610).	32
14	Roller Size and Thread Configuration.	34
15	Resist Coating Thickness Versus Interference (Viscosity 21, Roller E-10)	36
16	Resist Coating Thickness Versus Interference (Viscosity 55, Roller E-10)	37
17	Resist Coating Thickness Versus Interference (Viscosity 22, Roller E-6).	38
18	Resist Coating Thickness Versus Interference (Viscosity 35, Roller E-6).	39
19	Interference and Doctor Bar Pressure (Viscosity 21, Roller E-6) (P-89011)	41

20	Interference and Doctor Bar Pressure (Viscosity 35, Roller E-6) (P-89012).	42
21	Gold Versus Tantalum-Nitride Effects on Resist Thickness	44
22	Resist Thickness by Positional Measurements (Straight Substrate Entry)	45
23	Resist Thickness by Positional Measurements (Angle Substrate Entry)	46
24	Resist Thickness Histogram (Angle Substrate Entry)	47
25	Resist Thickness Histogram (Straight Substrate Entry).	48
26	Line Width Change Versus Resist Thickness (5-mil Lines)	50
27	Line Width Change Versus Resist Thickness (3-mil Lines)	51
28	Resist Thickness Versus Exposure Energy	52
29	Resist Thickness Distribution Measured at 9 Positions, Run-to-Run ($\bar{X} > 3.0 \mu\text{m}$)	53
30	Resist Thickness Distribution Measured at Center of Substrate, Run-to-Run ($\bar{X} > 3.0 \mu\text{m}$)	54
31	Resist Thickness Distribution Measured at 9 Positions, Run-to-Run ($\bar{X} < 2.0 \mu\text{m}$)	55
32	Resist Thickness Distribution Measured at Center of Substrate, Run-to-Run ($\bar{X} < 2.0 \mu\text{m}$)	56
33	Line Width Distribution Measured at 9 Positions, Run-to-Run ($> 3.25 \mu\text{m}$ Resist Thickness).	57
34	Line Width Distribution Measured at Center of Substrate, Run-to-Run ($> 3.25 \mu\text{m}$ Resist Thickness)	58
35	Line Width Distribution Measured at 9 Positions, Run-to-Run ($< 2.0 \mu\text{m}$ Resist Thickness)	59

36	Line Width Distribution Measured at Center of Substrate, Run-to-Run (<2.0 μm Resist Thickness)	60
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TABLES

Number		Page
1	Roller Thread Size Versus Coating Thickness.	14
2	Reflow Philosophy.	18
3	Limited-Reflow Philosophy.	19

SUMMARY

Roller coating of AZ1350J photoresist onto 3.75- by 4.5-inch (95 by 114 mm) substrates was investigated as an integral part of an overall, cost-effective hybrid microcircuit (HMC) photolithography process. This process involved making several HMCs on a single substrate and was accordingly termed *Multiple HMC Processing*. New equipment was needed to process these multiple HMCs with sufficient parameter control to achieve the designed electrical characteristics. The roller coater study centered around the investigation and the control of those parameters which influence the dimensional quality of the thin-film, resistor-conductor pattern. General system operation, orientation to other processing equipment, and maintenance-facility considerations were also studied.

The most important technical aspect of the photoresist coating is the thickness uniformity followed by the overall photoresist thickness. Three equipment variables: doctor bar pressure, roller/substrate interference, and roller thread configuration were found to control the overall resist thickness and thickness uniformity. Photoresist viscosity was also identified, with its relation to the roller thread configuration, to control the thickness and thickness uniformity.

Increasing the doctor bar pressure was found to decrease the resist thickness on the substrate. The resist thickness was discovered to be less dependent upon the interference than the doctor bar pressure. The interference primarily controls the continuity and the uniformity of the resist coating. The larger thread configurations were found to transfer larger amounts of resist to the substrate and therefore increase the thickness. The resist viscosity was shown to affect both thickness and thickness uniformity and can be effectively manipulated to optimize each. The viscosity was also linked to the edge build-up of resist and bubbles in the coating. Fortunately the viscosity values which achieve the optimum uniformity also affect reduced edge build-up and bubbles. It therefore becomes important to maintain control on the resist viscosity.

The doctor bar pressure is the most effective operational adjustment for the control of resist coating thicknesses; however, the relation between doctor bar pressure and resist thickness is not consistent. Doctor bar pressure values are relative numbers and cannot be used universally as they depend upon the initial set-up procedures. Roller size and viscosity are fixed, measurable parameters. The viscosity is conveniently measured with a Zahn cup and the roller size is fixed by the manufacturer.

There are four roller sizes available, representing successively larger thread sizes and therefore coating thicknesses.

The determination of the proper resist thickness and thickness uniformity is largely empirical and related to the proper exposure energy and prebake conditions. However, the following general rules can be used as a guide:

- Increasing doctor bar pressures decreases the resist thickness on the substrate;
- Resist thickness is not predictably dependent upon the interference except at high interference levels, and any contribution it makes to overall thickness is decreased at higher doctor bar pressures;
- Increasing the roller thread size increases the overall resist thickness on the substrate;
- Increased resist viscosity provides for more consistent but generally thicker resist coatings; and
- Consecutively smaller size rollers, which produce thinner overall resist coatings, are more consistent in repeating a specific coating thickness when all other parameters are held constant.

DISCUSSION

SCOPE AND PURPOSE

Roller coating of AZ1350J photoresist onto thin-film mirrors* was investigated as an integral part of a larger, cost-effective hybrid microcircuit (HMC) production philosophy, termed *Multiple Hybrid Microcircuit Processing*. Multiple processing, the fabrication of more than one HMC on a single ceramic substrate, was initiated to support HMC production schedules at economical production costs. Since more than one HMC was to be made from a single substrate, the substrate must be larger than those previously used [3.75- by 4.5-inch versus 1.5- by 1.5-inch (95 by 114 mm versus 38 by 38 mm)], which required a different photoresist coating technique than that used on single HMC substrates. Roller coating was chosen as an expedient and economical processing technique capable of coating the 3.75- by 4.5-inch multiple HMC substrates.

The identification and necessary control of roller coating parameters which influenced the dimensional quality of the final HMC resistor-conductor network was the subject of this investigation. General system operation, orientation to other processing equipment, maintenance, and facility considerations were also studied. The characterized technology was to be transferred to Process Engineering and implemented into production.

PRIOR WORK

There has been no prior work towards multiple HMC processing on 3.75- by 4.5-inch substrates except to confirm that the present photoresist application method, spinning, was not satisfactory in either a technical or an economical sense. Literature searches and contacts within the HMC industry identified two possible photoresist coating techniques for the larger substrate size-- roller coating and spray coating. Roller coating was recommended at the close of PDO 6984719** because of substantially lower capital equipment costs.

*A ceramic substrate with thin-film metallization on one or both surfaces used in the fabrication of resistive and conductive electrical networks. The metallized surface has a mirror-like finish.

**Lee E. Schantz, *Hybrid Microcircuit Photolithographic Process* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-678, July 1973.

ACTIVITY

Photoresist Coating Process Selection

Multiple HMC processing was proposed as an overall cost-effective photolithographic approach to the production of thin-film HMCs. Using the industry standard 3.75- by 4.5-inch, unglazed, alumina substrate required a complete change-over in the photolithography processing equipment. Photoresist coating was only one of seven photolithographic process steps, each of which required a unique piece of equipment to define the thin-film, resistor-conductor network. Two resist coating techniques, roller coating and spray coating, were determined capable of coating the larger substrates.

Roller coating was chosen for initial development and investigation because of its substantially lower capital equipment cost (\$5000 versus \$30000).^{*} However, it was never proposed that one coating method was technically superior for production than the other, but only that an initial purchase cost advantage existed for the roller coater^{**}. Both techniques have been successfully employed by various thin-film HMC manufacturers.

The Gyrex Micro 9 roller coater (Figure 1) was chosen for the development activity because it was the most widely accepted roller coating system in the HMC industry and was the least expensive. Three equipment variables -- doctor bar pressure, roller/substrate interference, and roller thread configuration -- were described by the manufacturer to control the final photoresist thickness on the substrate. Photoresist viscosity was also identified with its relation to the roller thread configuration. Photoresist thickness and thickness uniformity were the principal criteria by which the coating quality was judged.

General Operating Description of Roller Coater

The photoresist is supplied by a one-half gallon (0.0019 m³) reservoir located beneath the roller coater (Figure 2). The resist is pumped from the reservoir through a 5.0 μ m sintered silver filter to the doctor bar on the roller coater (Figure 3). The resist flows along the doctor bar from one end to the other

^{*}Not including installation costs.

^{**}Lee E. Schantz, BDX-613-678.

Figure 1. Gyrex Micro 9 Roller Coater

Figure 2. Resist Reservoir and Pump

Figure 3. Threaded Rubber Roller and Doctor Bar

and then gravity returns it to the reservoir where the cycle is repeated. The continuous flow provides a relatively constant resist viscosity and temperature at the doctor bar where it is applied to the roller.

The doctor bar contacts the threaded rubber roller (Table 1) along its entire length as shown in Figure 3 and transfers the resist from the doctor bar to the roller in an amount proportional to the doctor bar pressure on the roller. Figure 4 is a line drawing of the doctor bar and roller interface which shows the relative amounts of resist transferred as a function of the doctor bar pressure. In general, the greater the doctor bar pressure, the less resist is transferred to the roller. With less resist on the roller, less resist can be transferred to the substrate. Hence the first rule:

- Increasing doctor bar pressures decreases the resist thickness on the substrate.

Table 1. Roller Thread Size Versus Coating Thickness

Roller Size	Threads/Inch (mm)		Manufacturer's Published Coating Thickness Range (μm)
E-6	166	(25.4)	0.5 to 1
E-10	100	(25.4)	1 to 2
E-16	62	(25.4)	2 to 3
E-22	45	(25.4)	3 to 5

Increasing doctor bar pressure flattens the threads and squeegees a fixed amount of resist onto the roller. The thickness of resist on the roller is theoretically equal to the thread depth minus the portion of thread depressed by the doctor bar; however, there is always some residual amounts of resist left on the thread walls and crest connecting each thread.

The roller then rolls into contact with the substrate and depending upon the pressure of the roller on the substrate (termed *interference* and measured in thousandths of an inch) the resist is transferred in a reverse fashion to the substrate. The substrate is conveyed under the roller at the tangential velocity of the roller; therefore, no slipping exists between the substrate and roller. The dependence of resist thickness on the substrate is not as strongly dependent upon the interference as upon the doctor

VIEW B₁

VIEW B₂

VIEW B₃

VIEW AA'

ZERO DOCTOR BAR PRESSURE ALLOWS FOR ROLLER THREAD TO BE COMPLETELY FILLED WITH RESIST AND ALLOWS FOR SOME RESIST LEAKAGE. (VIEWS AT RIGHT SHOW THE RESIST/THREAD CONDITION JUST PRIOR TO CONTACT WITH SUBSTRATE.)

(EACH THREAD FULL)

PARTIAL DOCTOR BAR PRESSURE ALLOWS FOR ROLLER THREADS TO BE PARTIALLY FILLED WITH RESIST BY FLATTENING THE TOPS OF EACH THREAD AGAINST THE DOCTOR BAR.

(EACH THREAD PARTIALLY FILLED)

FULL DOCTOR BAR PRESSURE ALMOST COMPLETELY FLATTENS THREADS AND ALLOWS ONLY A SMALL AMOUNT OF RESIST TO ENTER THE THREADS.

(THREADS NEARLY VOID OF PHOTORESIST)

Figure 4. Effects of Doctor Bar Pressure

bar pressure, and the interference becomes even less effective in the control of overall resist thickness as the doctor bar pressure increases. The interference primarily controls the continuity and uniformity of the resist coating. The second rule can now be stated:

- Resist thickness is not predictably dependent upon the interference except at high interference levels, and any contribution it makes to overall thickness is decreased at higher doctor bar pressures.

There is an obvious dependence of total resist thickness on the thread size. The thickness range for each roller, as stated by the manufacturer, is given in Table 1. The third rule can be stated as follows:

- Increasing the roller thread size increases the overall resist thickness on the substrate.

Substrates, regardless of size, are placed on a substrate carrier to be passed beneath the roller (Figure 5). Since the optimum interference is nearly equal to the substrate thickness [~ 25 mils ($635 \mu\text{m}$)], the area on the roller, not in contact with the substrate, would contact the conveyor and transfer part of its resist to the conveyor if the carrier were not present. It is highly undesirable to get resist on the conveyor; therefore, the substrate carrier is used. Any unwanted resist transfer will be to the carrier which is easily cleaned and reused.

Figure 3 shows a seam in the conveyor. If the substrate-carrier is placed on this seam, the seam imprint will be visible in the resist coating. Consequently the seamed area is avoided.

Methods of Resist Application

There are two general resist coating philosophies:

- Reflow Technique, applying the photoresist in a sufficiently fluid state as to allow the resist to reflow to a self-leveling condition and therefore help eliminate any non-uniformities in the coating thickness; and
- Limited-Reflow Technique, applying the resist in a higher viscosity condition and controlling the coating parameters to achieve satisfactory thickness uniformity.

There are several other factors to consider besides the thickness uniformity in both techniques and there must be some trade-off on each. Tables 2 and 3 list several advantages and disadvantages of each philosophy and some of the trade-off considerations.

Figure 5. Substrate Carrier

Table 2. Reflow Philosophy*

Advantages	Trade-Off Remarks
No initial adjustment of resist viscosity required Less sensitive to changes in resist viscosity	
Disadvantages	
Larger edge build-up effect Requires leveling time $\pm 1.2 \mu\text{m}$ resist uniformity (E-10 roller) Increased minimum thickness limit (greater overall thickness) Requires that substrate go through coater at an angle to minimize resist build-up on substrate edges More susceptible to entrapping airborne dust	HMC must be recessed from edge of substrate Increase dwell time between coating and IR prebaking Loosen tolerance on thin-film resistor values Maintain tighter control on exposure light energy and resist thickness uniformity for acceptable line width control Resist thickness uniformity is made worse Special handling required Reduces capacity of coater Greater incidence of pinhole and a decreased yield
*20 Zahn Number 2 cup seconds at 72°F (0.053 Pa·s at 22°C)	

The prime responsibility of the photolithographic operation is to faithfully reproduce the photomask image in the thin-film coating with sufficient dimensional control to maintain the designed electrical circuit characteristics. Thinner resist coatings minimize the effect of non-uniformities in resist

Table 3. Limited-Reflow Philosophy*

Advantages	Trade-Off Remarks
Greater resist thickness uniformity (E-6 and E-10 rollers)	Provides for greater control on line widths
No edge build-up	Allows HMC patterns to extend to substrate edge
Allows for thin, consistent resist coatings	Minimizes the effect of non-uniform resist coating on line width deviation
Disadvantages	
Requires initial thickening of resist	24-hour thickening period with minimal operator effort
More difficult to filter	Use larger (5 to 10 μm filter)
20 percent increase in resist usage costs	
*35 to 40 Zahn Number 2 cup seconds at 72°F (0.105 $\pm$ 0.003 Pa·s at 22°C)	

thickness in consideration of the proper exposure energy* for two reasons. First, the resist thickness deviation from the average is relatively constant at $\pm 0.6 \mu\text{m}$ for average thicknesses between 2 and 5 μm , but only about $\pm 0.2 \mu\text{m}$ at lower average thicknesses ($< 2.0 \mu\text{m}$). Second, changes in resist thicknesses at lower thicknesses are less dependent upon exposure energy than at greater thicknesses. It is the decreased dependence upon the proper exposure energy and tighter thickness uniformities that afford the increased dimensional control for a fixed resist thickness uniformity. The ability to obtain thin and consistent resist coatings justifies the limited-reflow techniques with its requirement for an initial increase in resist viscosity.

*The proper exposure energy is defined as the amount of light energy in J/cm^2 in the 350 to 450 nm region required to maintain the photoresist line width deviation (ΔLW) within the specified tolerance. Generally ΔLW must be ± 2 percent of the line width or $\pm 0.1 \text{ mil}$ ($2.54 \mu\text{m}$) whichever is smaller. ΔLW = photoresist line width minus the mask line width.

Resist Viscosity

Shipley AZ1350J photoresist has a normal viscosity of 20 ± 2 Zahn Number 2 cup seconds ($0.055 \pm \text{Pa}\cdot\text{s}$). The resist can be used at this viscosity using an E-6 or E-10 roller; however, significant difficulties are encountered in edge build-up of resist*, bubbles in the coating, and non-uniformity in the resist thickness. If the resist is thickened to approximately 35 to 40 Zahn Number 2 cup seconds (0.092 to $0.105 \text{ Pa}\cdot\text{s}$), nearly all of the above difficulties can be minimized or avoided entirely. With all other parameters held constant, the higher viscosity results in thicker resist coatings as shown in Figure 6.

The general increase in coating thickness as the viscosity increases is expected. However, the measured** resist coating thickness is not constant as indicated by the $1 \mu\text{m}$ range in values of Figure 6. The cause for the variation is not well understood, but appears to be related to variations in one or a combination of the following parameters:

- Interference,
- Substrate Thickness,
- Substrate Surface Conditions (cleanliness, roughness),
- Resist Temperature, and
- Resist Age.

In general, the coating thicknesses are not highly consistent at lower viscosities, but can be made more consistent with high viscosities and higher doctor bar pressures. The fourth rule can now be stated as follows:

- Increased resist viscosity provides for more consistent but generally thicker resist coatings.

At first thought, rule 4 indicates that resist viscosity and doctor bar pressures are the only variables which affect the resist thickness and variations in each cause a corresponding

*Gross changes in the resist thickness near the substrate edge which is not removed during developing and this prevents pattern definition in that area. The buildup may extend 0.125 to 0.250 inch (3.175 to 6.35 mm) into the substrate from the edge.

**Measurements were made at 9 positions across the 3.75 - by 4.5 -inch (95 by 114 mm) substrate.

Figure 6. Resist Coating Thickness Versus Resist Viscosity

variation in the thickness uniformity. However, this deduction is not necessarily valid in all cases. It appears that each can be a secondary variable which interacts with the primary variable causing thickness variation. This is not to imply that variations in the resist viscosity do not cause changes in the coating thickness, but that they are not independently responsible for all measured variations in the coating thickness.

Such an example would be a non-uniform thread pattern on the roller or an out-of-round roller. As the doctor bar pressure is increased, it tends to nullify irregularities in the threads and minor out-of-roundness. Therefore, the primary cause for thickness variations could be the roller and not the doctor bar.

A second example is the cohesion between the substrate surface and the wet resist. The cohesion variation is primarily dependent upon substrate surface conditions. Again, increasing the resist viscosity tends to nullify the variations in substrate surface conditions. Therefore, manipulation and control of resist viscosity becomes the control for a distinctly different parameter.

Figure 6 shows the change in coating thickness to be 0.006 μm per Zahn Number 2 cup second. If the average coating thickness is to be maintained to $\pm 2 \mu\text{m}$, then the resist viscosity must be held to ± 3.3 Zahn Number 2 cup seconds. Viscosity control to ± 3 seconds at the doctor bar is not difficult provided the following four conditions are met:

- First, resist viscosity is adjusted to the nominal value prior to starting the roller coater;
- Second, the volume of resist in the reservoir is at least 0.4 gallons (0.0015 m³);
- Third, resist flow along the doctor bar is sufficient to prevent resist scumming on the doctor bar or roller; and
- Fourth, resist temperature is maintained to $\pm 3.5^{\circ}\text{C}$ from the resist temperature when the first condition was met (usually room temperature).

At a constant resist temperature, the resist viscosity does not change in excess of the tolerance limits in a 4-hour operating period. The resist does show a general trend toward higher viscosities with continued use as the solvent gradually evaporates. Therefore, the viscosity should be checked prior to each time the roller coater is used and adjusted as necessary.

Experience has shown that the resist temperature may not remain constant as pump heat can raise the resist temperature by 5 to 15°F (2.8 to 18.3°C), over an 8-hour operating period, depending upon the volume of resist in the reservoir. Figure 7 shows the change in viscosity as a function of resist temperature.

If the resist temperature is raised sufficiently above the nominal, the overall resist coating thickness will change and coating parameter adjustments will be required to hold the coating thickness within tolerance. A second problem exists at resist temperatures which are significantly higher than the nominal. As the resist flows across the doctor bar it may cool-off forming a resist temperature gradient and therefore a viscosity gradient. This produces uneven wetting of the roller and an uneven resist coating on the substrate. Coating parameter adjustments will not compensate for this situation; however, the resist temperature gradient problem is not often encountered if the second and third conditions are maintained.

It is desirable, in terms of proper exposure energy, to maintain the most consistent thickness uniformity possible. Figure 6 shows that higher viscosities result in greater thickness uniformity but generally thicker overall coatings. It is known that thin coatings ($\sim 2.0 \mu\text{m}$) are best for close dimensional control on the circuit image, therefore it seems there must be some trade-off on uniformity and overall thickness. However, using a smaller roller thread configuration affords the benefits of both a thinner coating thickness and higher resist viscosities to be realized. Such an example is shown in the E-6 roller curve of Figure 6. It can be seen that a $1.7 \mu\text{m}$ overall thickness $\pm 0.2 \mu\text{m}$ can be obtained at 35 Zahn Number 2 cup seconds using

Figure 7. Resist Viscosity Versus Resist Temperature

the E-6 roller. Furthermore, changes in overall coating thicknesses are less dependent upon changes in the resist viscosity using the smaller roller.

All difficulties involving changes in resist viscosity, whatever the cause, can be avoided by efficient and intelligent production scheduling of parts through photolithography. The roller coater has a sufficiently large production capacity that it only needs to be operated for a minimum time period per shift. (See section on General Operating Procedure.) If all substrates can be scheduled or held for resist coating in a single, 2-hour operating period at the beginning of each shift, then viscosity problems during roller coating can be minimized. Scheduling the 2-hour coating period at the beginning of each shift allows ample time for completion of all remaining photolithography operations.

Viscosity Adjustment

The as-received AZ1350J photoresist viscosity is increased by allowing the resist solvents to evaporate. This is accomplished by filling a flat stainless steel pan with about 0.7 gallon (0.0026 m^3) of photoresist and allowing the solvents to evaporate in a class 100 exhaust hood for approximately 24 hours. The exact evaporation time depends upon the room temperature and the final viscosity desired. The viscosity can be conveniently monitored using a Zahn Number 2 cup viscometer. The resist is then transferred to the reservoir for use on the roller coater.

The solvent continues to evaporate during usage and the viscosity will gradually increase. Therefore, the viscosity should be measured prior to starting the roller coater each shift and adjusted as necessary. Adjustments are made by adding sufficient quantities of as received resist (which also helps replace used resist) to bring the viscosity down to the desired value. In some cases, viscosity adjustments may require too great a quantity of as received resist and AZ thinner is used to decrease the viscosity. In either case, the added ingredient must be thoroughly stirred into the bulk of resist.

Doctor Bar Pressure

The doctor bar pressure is the single, most effective operational adjustment for the control of resist coating thicknesses. The first rule states the relation between the doctor bar pressure and coating thickness as: increased doctor bar pressures produce decreased coating thicknesses. The exact relation is not well controlled for individual cases as shown in Figures 8 through 11. The decreasing resist thickness is not a smooth function of doctor bar pressure at lower interference levels, and there is not a uniform family of curves for each inter-

Text continued on page 29.

Figure 8. Doctor Bar Pressure and Resist Coating Thickness (Viscosity 21, Roller E-10)

Figure 9. Doctor Bar Pressure and Resist Coating Thickness
(Viscosity 55, Roller E-10)

Figure 10. Doctor Bar Pressure and Resist Coating Thickness
(Viscosity 21, Roller E-6)

Figure 11. Doctor Bar Pressure and Resist Coating Thickness
(Viscosity 35, Roller E-6)

ference level. As the roller/substrate interference increases, the relation becomes smoother and at high interference levels, the curves become relatively flat indicating a decreased influence of doctor bar pressure on the coating thickness. The previous terms of low, medium, and high interference levels are relative to a single resist viscosity and roller size as are the doctor bar pressure settings.

Doctor bar pressures, although indicated in exact numerical settings, are relative numbers. The particular doctor bar pressure ranges shown in Figures 8 through 11 are germane only to the set of conditions shown with each figure. With all other conditions equal and the initial pressure adjustments made in the same manner, the numerical pressure settings may be considered essentially equal for purposes of comparing its effect. Such circumstances exist between Figures 8 and 9, and 10 and 11 where the only difference is the resist viscosity. Therefore, Figures 8 and 9, and 10 and 11 not only demonstrate the dependence of resist thickness on doctor bar pressure, but also upon the resist viscosity at equal doctor bar pressure settings.

Increasing doctor bar pressures generally decreases the resist coating thickness. Some irregularity in the generally decreasing thickness trends can be accounted for in terms of the interference setting, roller size, and resist viscosity. For instance, the operating pressure range becomes less influential on resist thickness as the interference increases, as the viscosity increases, and as the roller size becomes smaller (compare Figures 8 through 11 for each case).

As the interference becomes large, as compared to the thread configuration, the interference becomes the dominant control on thickness and changing doctor bar pressures have a diminished effect. The magnitude of the interference value where it becomes dominant over the doctor bar is a function of the thread depth and resist viscosity. In the same manner as the dynamic control on resist thickness by the doctor bar decreases with smaller thread depths (comparison of Figures 8 and 10, and 9 and 11), so does the interference. However, as will be discussed later, the interference is not used to control the overall resist thickness but rather the thickness uniformity and continuity. The doctor bar remains the dynamic controller of overall resist thickness.

As the doctor bar pressure becomes large (upper end of pressure range) the interference becomes less effective on the overall resist thickness. High doctor bar pressures transfer only limited quantities of resist on to the roller and regardless of how much interference is used, only a portion of the same limited quantity of resist can be transferred to the substrate. At most all interference settings between 5 and 30 mils (127 to 762 μm) the

interference exceeds the thread depth and essentially all available resist is transferred to the substrate. The term *essentially all available resist* is primarily dependent upon the doctor bar pressure and the resist viscosity.

There is a measurable increase in coating thickness for higher viscosity resists at the same doctor bar pressure and interference settings. The cause for the increased resist coating thickness is believed to be linked to increased transfer of resist from the doctor bar to the roller, from the roller to the substrates, or both. It has not been possible or necessary to determine the exact mechanism. It remains that high doctor bar pressures provide more consistent, substrate-to-substrate, overall thickness; therefore, the second rule can be stated.

- Resist thickness is not predictably dependent upon the interference except at high interference levels, and any contribution it makes to the overall thickness is decreased at higher doctor bar pressures.

Doctor Bar Pressure Adjustments

The doctor bar pressure must be periodically adjusted to achieve a uniform pressure along the roller. Such periodic adjustment is necessitated by roller wear, roller swelling, shrinking caused by absorption, desorption of resist solvents, and roller replacement. Regardless of the cause the adjustment procedure is the same.

Figure 12 shows the procedure for adjusting the doctor bar to achieve a uniform pressure. The pressure is adjusted by turning two screws, located on each side of the conveyor, while checking the pressure along the bar with a 0.002-inch (50.8 μ m) feeler gage. The roller is thoroughly wetted with resist solvent and the pressure control (Figure 13) is adjusted until one end or the other of the doctor bar is almost contacting the roller. The parallelity adjustment screws (Figure 12) are adjusted alternately until the entire doctor bar is in near contact with the roller. The near contact determination is made visually such that a small uniform gap exists between the doctor bar and the roller. The pressure indicator is then set at zero by loosening the allenhead screw in the center of the dial (Figure 13) and moving the dial to indicate zero pressure. This in a sense *calibrates* the indicator for each roller.

The feeler gage is placed between the roller and the doctor bar at one end of the bar and the pressure control is turned until a slight drag is felt on the shim. The shim is moved from one end of the roller to the other and the relative drag is determined. The parallel adjustment screws are again adjusted alternately until the drag is the same at each end of the roller. The

Figure 12. Adjustment for Uniform Doctor Bar Pressure

Figure 13. Roller Coater Controls

roller is kept thoroughly wetted with resist thinner during the pressure adjustment procedure. When the drag is equal at each end of the roller, the final adjustment can be made while photoresist is flowing through the system.

While photoresist is flowing along the doctor bar and transferring to the roller, the roller surface will assume a sheen proportional to the amount of resist on the surface. Since the amount of resist on the roller is proportional to the doctor bar pressure, any differences in sheen from one end to the other indicates a non-uniform doctor bar pressure. Final adjustments to achieve uniform pressures are made by obtaining a uniform sheen along the entire roller. It may be found that substantial adjustments may still be required. Where a uniform sheen exists and then disappears (skips), the roller may be out-of-round or may have other mechanical flaws. Experience has shown that minor skips in the roller sheen may be ignored and satisfactory coating can be obtained. Once adjusted, the pressure uniformity should be checked periodically by the sheen method.

Roller Size

The manufacturer makes four roller sizes for the Micro 9 roller coater. The actual size of the roller does not change but the thread configuration does. Figure 14 shows the thread configuration and lists the thread dimensions for the E-6 through E-22 roller sizes. It is obvious the greater the thread size the larger amount of resist it will hold and the thicker the average resist coating will be on the substrate. Figures 8 and 10 show the overall coating thickness for an E-10 and E-6 roller respectively, where all other parameters were held essentially constant and equal. A 1 to 2 μm difference in coating thickness is apparent between these two rollers, which is greater than that specified by the manufacturer (Figure 14). Also noticeable is the smaller dynamic control the doctor bar has on the smaller roller as opposed to the larger one.

Average or overall resist coating thicknesses are, in the machine sense, controlled by the resist viscosity and the roller size. Since neither of these are considered as operator controlled variables, their contributions are considered as non-dynamic system characteristics. Nevertheless, they are important factors. Differences in thicknesses between results obtained and those specified by the manufacturer are best explained by the resist viscosity, the substrate material inclusive of the type of thin-film on the substrate, and the machine parameters. By adjusting the viscosity lower than 20 Zahn Number 2 cup seconds and coating on very smooth substrates (glass or silicon), the specified thickness range can be achieved. However, the Al_2O_3 ceramic is relatively textured as compared to glass or silicon and has a tendency to *pulloff* more resist from the roller than the smoother

ROLLER	S	d	T	B	MANUFACTURER'S SPECIFIED COATING THICKNESS RANGE
E-6	6.0 mils (152.4 μm)	2.0 mils (50.8 μm)	~ 1.0 mils (25.4 μm)	~ 1.0 mils (25.4 μm)	0.5 TO 1 μm
E-10	10.0 mils (254 μm)	4 mils (100.16 μm)	~ 1.0 mils (25.4 μm)	1.0 mils (25.4 μm)	1.0 TO 2.0 μm
E-16	16.0 mils (406.4 μm)	7 mils (177.8 μm)	~ 1.0 mils (25.4 μm)	1.0 mils (25.4 μm)	2.0 TO 3.0 μm
E-22	22.0 mils (558 μm)	10 mils (254 μm)	~ 1.0 mils (25.4 μm)	1.0 mils (25.4 μm)	3.0 TO 5.0 μm

Figure 14. Roller Size and Thread Configuration

substrates. Furthermore, operating at an interference not to exceed the substrate thickness necessitates a higher viscosity which produces greater coating thicknesses. Therefore, it is not unusual that an E-6 roller may result in greater than 1.0 μm resist coatings.

The dynamic thickness range achieved by varying the doctor bar pressure is approximately 1.5 to 2.0 μm for the E-10 roller and 0.4 to 0.8 μm for the E-6 roller. The result is in perfect agreement with the resist transfer and roller size statements made previously. It may also be stated that each consecutively smaller roller affords more consistent overall resist coatings than the next larger size. Hence the fifth rule can be stated as:

- Consecutively smaller size rollers, which produce thinner overall resist coatings, are more consistent in repeating a specific coating thickness with all other parameters held constant.

It was shown earlier that the same effect is true for increased viscosities.

Roller/Substrate Interference

The roller/substrate interference value (View AA' of Figure 4) is adjusted by the control shown in Figure 13. Also shown in Figure 13 is the interference indicator which is set by aligning the total substrate and carrier thickness (dial on left) opposite the desired interference level (dial of right). For example, the substrate is 27-mils thick (686 μm) and the carrier is 123 mils (3.12 mm), giving a total of 150 mils (3.8 mm). The 150 mark is opposite the 22-mil interference value (Figure 13) indicating a 22-mil (558 μm) interference setting.

The effect of interference on overall coating thickness is visible in Figures 8 through 11. The behavior of the interference values appears to be somewhat erratic; however, when plotting the resist coating thickness at constant doctor bar pressures over varying interference levels and analyzing the results in terms of resist transfer to and from the roller, this behavior becomes more reasonable, although not always predictable. Figures 15 through 18 show the dependence of resist thickness on interference for various sets of conditions. Using Figure 15 as an example, it can be seen that the resist thickness varies at lower doctor bar pressures with increasing interference but becomes less dependent on interference at higher doctor bar pressures.

At lower doctor bar pressures (<4) the roller threads are relatively full of resist if not overfilled depending upon the viscosity and not a great deal of interference is required to retrieve the resist from the threads. As the interference increases, more and more resist is transferred from the roller threads to the substrate until a point where the thread size is no longer consequential to the transfer process and there begins to squeegee the resist out between the roller and the substrate in a lateral direction. On the E-10 roller at a viscosity of 21 Zahn Number 2 cup seconds (Figure 15), the inflection point between transfer of resist by the threads to a squeegee action is approximately 20 mils (508 μm). This is shown by point B in Figure 15.

As the doctor bar pressure increases, the resist is deeper in the threads and greater interference values are required to retrieve the resist. (Points A and A' of Figure 15 demonstrate this.) For a doctor bar pressure of 6, a minimum of 10 mils (254 μm) interference is required before larger interferences retrieve more resist; while 15 mils (381 μm) interference is required at a doctor bar pressure of 8. (The point A for doctor bar pressure 4 is off the graph to the left.) The initial decrease in resist thickness with increasing interference for pressures of 6 and 8

Text continued on page 40.

Figure 15. Resist Coating Thickness Versus Interference (Viscosity 21, Roller E-10)

Figure 16. Resist Coating Thickness Versus Interference
(Viscosity 55, Roller E-10)

Figure 17. Resist Coating Thickness Versus Interference
(Viscosity 22, Roller E-6)

Figure 18. Resist Coating Thickness Versus Interference (Viscosity 35, Roller E-6)

can be attributed to the residual resist on the flat thread crests (Figure 14) being forced back into the thread troughs or being spread thinner on the substrate because of the depression of the threaded crests. At high doctor bar pressures (>10) the interference point of retrieval (Point B) does not exist in the same sense as in medium pressures (4 through 8) and the thickness is relatively independent of the interference values.

Interference Versus Coating Thickness

Even though the relation between coating thickness and interference may be explained in terms of resist transfer from the threads, the interference level is not typically used to control the overall resist thickness. The interference has more obvious effects on thickness uniformity, trailing edge buildup, and bubbles in the resist coating. Figures 19 and 20 are photographs of a matrix of 1.5- by 1.5-inch (38 by 38 mm) gold thin-film coated substrates at the noted interference and doctor bar pressure settings. It can be seen that at a constant doctor bar pressure there is an increase in the trailing edge buildup (dark area at the right edge of each substrate) as the interference increases. This effect begins to disappear as the doctor bar pressure increases. At lower interference levels the coatings have bubbles as can be seen in the left-hand part of the matrix; therefore, higher interference values are necessary which in turn require higher doctor bar pressures. A second advantage of higher interference levels is the greater thickness uniformity held across larger substrate areas. The higher interference and doctor bar pressure values result in the most acceptable resist coatings, but have the distinct disadvantage of wearing out the roller quicker as evidenced by the larger amounts of rubber in the resist filter.

An alternative to higher interference levels to eliminate bubbles in the coating and to decrease trailing edge buildup, is to increase the resist viscosity. This minimizes some of the above problems, but also produces a thicker resist coating which is also undesirable. The optimum results are obtained at viscosity, interference, and doctor bar pressure levels which produce coatings for good product yields at acceptable wear on the roller. This condition is generally an empirical derivation where the relations shown in Figures 8 through 11 and 15 through 18 are used only as guides to achieve the desired overall thickness level. The actual operating conditions are determined by measuring the resist thickness uniformity and associated line widths after proper exposure and adjusting the parameters to achieve a distribution tight enough to meet the design criteria.

Figure 19. Interference and Doctor Bar Pressure
(Viscosity 21, Roller E-6)

Figure 20. Interference and Doctor Bar Pressure
(Viscosity 35, Roller E-6)

Interference Dial Calibration

The interference dial is calibrated while resist is flowing through the system, at a medium to high doctor bar pressure, by passing a "part" through the coater and noting whether or not resist was transferred to the part. The part, such as the glass substrate carrier of Figure 5, must be flat, rigid, and of constant thickness. The part is repeatedly passed through the coater, each time increasing the interference until the roller just barely touches the part and transfers some resist to the part. The interference is decreased until no resist is transferred to the part. (The part is cleaned between passes.) The thickness of the part in mils is found on the substrate dial (Figure 13) and set opposite the zero interference mark by loosening the allenhead setscrew shown in Figure 13. This process may be repeated several times to assure accuracy; however, such a calibration is probably never more accurate than ± 2 mils ($50.8 \mu\text{m}$). It may be found that the coating roller and backup roller (Figure 4) are not quite parallel and one side of the part may have some resist on it while the rest may not. In such cases the difference between partially-coated and non-coated interference values should be split and the dial calibrated at that setting.

Thin-Film Surface Effects on Resist Thickness

It had been noted that different thin-film materials on the alumina ceramic "retrieve" the resist from the roller in different amounts. Figure 21 shows the histogram of resist thickness measurements on gold and tantalum-nitride surfaces. The $\bar{X}$ for gold and tantalum-nitride differs by approximately $0.2 \mu\text{m}$ because of an apparent difference in cohesion between the resist and the respective thin-film materials. Although the difference does not appear large, when added to the normal $\pm 0.2 \mu\text{m}$ deviation, it becomes quite significant in terms of the proper exposure energy required to hold and acceptable tolerance in the image dimensions. Figure 21 shows the difference for an E-6 roller. The difference in resist thickness for an E-10 roller is even greater.

Edge Effects and Substrate Orientation

To eliminate the resist buildup around the substrate edges, the most prominent of which is the trailing edge buildup, the substrates were run through the roller coater at an angle; that is, with a corner contacting the roller first rather than the straight edge of the substrate. Although this practice was successful in reducing the edge build-up, it also decreased the resist thickness uniformity in localized areas. Figures 22 through 25 show the results of the angle versus the straight substrate orientation. Although the histograms of Figures 24 and 25 are not obviously

Figure 21. Gold Versus Tantalum-Nitride Effects on Resist Thickness

Figure 22. Resist Thickness by Positional Measurements
(Straight Substrate Entry)

Figure 23. Resist Thickness by Positional Measurements (Angle Substrate Entry)

Figure 24. Resist Thickness Histogram (Angle Substrate Entry)

Figure 25. Resist Thickness Histogram (Straight Substrate Entry)

different, the positional measurements of Figures 22 and 23 show a sharp non-uniformity for position 7 on the angle-oriented scheme. As a result of the irregular thickness at position 7 and better control of edge effects afforded by increasing the resist viscosity, the angle-orientation was not continued.

Resist Thickness and Expected Line Width Deviation

The expected line width of the photoresist image is a function of the resist thickness and thickness uniformity. To achieve a line image with near zero line width deviation from the design value, requires that the resist be exposed with the proper light energy for the particular resist thickness in use. Where there are variations in the resist thickness across the substrate, there will be corresponding variations in the line widths at a fixed exposure energy. Figures 26 and 27 show the expected change in 5.0-mil (127 μm) and 3.0-mil (76.2 μm) lines for a variable resist thickness and a constant exposure energy. These figures consistently show a 0.2-mil (5.08 μm) change in line width per micrometer change in resist thickness. This is a rather significant change in line width; that is, 4 percent on the 5.0-mil line. Obviously to minimize the variation in line widths it is necessary to maintain the most uniform resist thickness possible. As previously discussed this is done by higher doctor bar pressures, higher interference levels, and by higher viscosity levels.

A second approach to line width control is to operate at a thickness level that is less sensitive to variations in the overall thickness. Figure 28 shows the required exposure energy for increasing resist thicknesses. It can be seen that at higher resist thickness, more exposure energy is required to properly expose the resist and that the required exposure range is strongly dependent upon small changes in the thickness. At lower thickness values the opposite is true; that is, the proper energy required is only limitedly dependent upon the thickness. Therefore, resist thickness variations at the lower end of the thickness-energy curve have a far less significant effect on the line width. It may be concluded from the contributions of photoresist thickness and thickness uniformity to the dimensional distribution on line widths, that a thinner resist coating will afford tighter dimensional distributions than thicker resist coatings.

Thickness Uniformity Distributions

Figures 29 and 30 show the resist coating thickness distribution on 3.75- by 4.5-inch (95 by 114 mm) gold-coated substrates for nominal thicknesses above 3.25 μm . Comparing Figures 29 and 30 to Figures 31 and 32 which have a nominal thickness of less than 2.0 μm , it can be easily seen that tighter distributions exist for the smaller overall thickness. Using the information on

Text continued on page 52.

Figure 26 . Line Width Change Versus Resist Thickness (5-Mil Lines)

Figure 27. Line Width Change Versus Resist Thickness (3-Mil Lines)

Figure 28. Resist Thickness Versus Exposure Energy

expected line width deviation for changing resist thickness, it can be reasoned that the thinner coating thicknesses would afford better process control on line dimensions.

Line Width Distributions

Figures 33 and 36 are the respective line width distributions for the resist thickness distributions shown in Figures 29 and 32. As expected, the lesser resist thickness, by virtue of its tighter thickness distribution, produced a tighter line width distribution under proper exposure energy conditions for each average thickness. It is also interesting to note the correlation between the thickness distributions and the respective line distributions (Compare Figure 29 with 33 and Figure 30 with 34).

In Figure 29 the thickness is skewed to the high side of $\bar{X}$ as is the line width distribution of Figure 33. For positive resist and exposure settings that are adjusted for proper exposure of the average resist thickness ($\bar{X}$), the higher than average resist thicknesses will be underexposed in proportion to the difference between the thickness and the $\bar{X}$ thickness. The underexposure

Figure 29. Resist Thickness Distribution Measured at 9 Positions, Run-to-Run ($\bar{X} > 3.0 \mu\text{m}$)

condition will result in a line width proportionally higher than the $\bar{X}$ line width. The opposite is true for thicknesses less than the $\bar{X}$ thickness. This type of correlation can be easily seen when comparing Figure 29 with 33 and Figure 30 with 34 on a cell-for-cell basis. This effect is masked by thickness measurement resolution in Figures 31 and 35 and 32 and 36.

Recommended Operating Procedure

Machine set-up and start-up/shut-down procedures are given in Appendix A. This section will address only the technical and parts scheduling aspects of roller coating.

Figure 30. Resist Thickness Distribution Measured at Center of Substrate, Run-to-Run ($\bar{X} > 3.0 \mu\text{m}$)

The most important contribution of photolithography to HMC fabrication is the faithful reproduction of the photomask image containing the electronic circuit with sufficient dimensional control to hold the circuits electrical characteristics within the designed tolerances. This philosophy applies principally to thin-film resistors.

To maintain a ± 10 percent control on thin-film, tantalum-nitride resistors whose sheet resistivity may vary by as much as ± 8 percent, requires a ± 2 percent control on the line width. Using a minimal 5.0-mil (127 μm) line, this implies a dimensional control of ± 0.1 mil (5.08 μm) maximum deviation from the nominal value. It is obvious that distributions like those of Figures 33

Figure 31. Resist Thickness Distribution Measured at 9 Positions, Run-to-Run ($\bar{X} < 2.0 \mu\text{m}$)

and 34 do not maintain, in all cases, the necessary tolerance. Therefore, it again becomes obvious that a thinner resist coating is required.

The following conditions are recommended to achieve the tightest line width distribution possible:

- Resist thickness should be $1.8 \pm 0.1 \mu\text{m}$;
- Roller size should be E-6;

Figure 32. Resist Thickness Distribution Measured at Center of Substrate, Run-to-Run ($\bar{X} < 2.0 \mu\text{m}$)

Figure 33. Line Width Distribution Measured at 9 Positions, Run-to-Run ($>3.25 \mu\text{m}$ Resist Thickness)

- Resist should be AZ1350J;
- Viscosity should be 35 ± 3.3 Zahn Number 2 cup seconds;
- Interference should be 25 to 30 mils (635 to 762 μm);
- Doctor bar pressure should be sufficiently high to achieve the desired thickness and to eliminate trailing edge buildup;
- Filter size should be 5.0 μm maximum (sintered silver);

Figure 34. Line Width Distribution Measured at Center of Substrate, Run-to-Run ($>3.25 \mu\text{m}$ Resist Thickness)

- Resist temperature should be 72 to 76°F (22 to 24°C); and
- Gloves should be worn at all times.

As mentioned earlier, the roller coater is the first operation in a semiautomatic, multiple HMC photolithography process. The capacity of each of seven process steps is nearly matched at ~ 400 substrates per hour. With the large capacity each

Figure 35. Line Width Distribution Measured at 9 Positions, Run-to-Run, (<2.0 μm Resist Thickness)

Figure 36. Line Width Distribution Measured at Center of Substrate, Run-to-Run ($<2.0 \mu\text{m}$ Resist Thickness)

system only needs to be operated at a fraction of its capacity to achieve production schedules. Since the capacity cannot actually be changed, each system, including the roller coater, should be operated only long enough to process the number of parts required at the given time. The rest of the time the process line will sit idle. This situation requires careful parts scheduling by Production Control for the efficient and economical use of the equipment and operating personnel. It is possible to meet present production schedules with less than half-shift operation. Therefore, scheduling should be arranged such that all parts are made ready for photolithographic processing at the beginning of each shift.

ACCOMPLISHMENTS

The roller coater has been fully characterized using Shipley AZ1350J photoresist. The roller coater is a satisfactory system for coating photoresist on 3.75- by 4.50-inch (95 by 114 mm) substrates for the production of hybrid microcircuits with ± 10 percent as-etched resistor tolerances. It is somewhat fragile in its structure and construction, but should withstand production use provided it is properly operated and maintained.

Dimensional control of HMC geometries requires a resist coating thickness less than $2.0\text{ }\mu\text{m}$ with a thickness uniformity of $\pm 0.1\text{ }\mu\text{m}$. Control of doctor bar pressure, interference, and resist viscosity are critical in obtaining the desired thickness control. Determining the optimum doctor bar pressure, interference, and resist viscosity is largely empirical and settings may vary appreciably from system-to-system or roller-to-roller.

All planned activities involving the roller coater have been accomplished and roller coating technology has been transferred to Process Engineering. The roller coating system has been implemented and is being successfully used in HMC production. Process and material limits have been established which will maintain a ± 2 percent dimensional control on the 5.0-mil ($125\text{ }\mu\text{m}$) photoresist image.

FUTURE WORK

No future work on roller coating is required under present HMC product and processing requirements. If product requirements, processing requirements, or both are changed, then additional process development efforts may be required.

A backup resist should be characterized on the roller coater in case the AZ1305J composition is changed and cannot be roller coated or becomes unavailable. A short term process development effort should be started to determine the roller coaters usefulness with respect to vias. It is believed, under certain via-hole characteristics (via corners with a smooth radius), the roller coater could be used to protect via metallization.

It is recommended that spray resist coating be investigated as an alternative to roller coating to achieve smaller HMC geometries and dimensional control. It is believed that spray coating may be more durable and economical than roller coating in the long run.

Appendix A

START UP AND SHUTDOWN PROCEDURES

Gyrex Roller Coater Start Up

1. Remove plastic bottle of MEK and let drain.
2. Install plastic bottle of Shipley AZ1350J photoresist.
3. Turn control switch on coater to PUMP position.
4. Using a squeeze bottle filled with Shipley AZ thinner, completely wet coating roller.
5. Turn the doctor bar PRESSURE dial to 8.
6. Turn PUMP SELECTOR, on front of clean bench, to RESIST.
7. Open drain valve on bottom of filter and drain solvent.
Leave open until resist begins to flow into filter.
8. Adjust the flow control valve, on top of filter, to provide adequate flow of resist, but not enough to flow over the coating roller end-seals (about one-half turn open).
9. Turn the substrate INTERFERENCE DIAL, located on top of the machine, until the substrate THICKNESS DIAL is set with (150) directly in line with (25) on the INTERFERENCE DIAL.

Substrate Loading and Coating

1. Place substrates on glass back-up plate.
2. Place back-up plate on conveyor belt.
NOTE: Do not place back-up plate on the seam of the conveyor.
3. Remove back-up plate with substrates from the other end of the conveyor.
NOTE: Avoid touching the coated surface of the substrates.

Flush Out and Shutdown Procedure

1. Turn PUMP SELECTOR, on front of clean bench, to OFF.
2. Allow resist to drain into container. Scrape resist on doctor bar down to return hole with Teflon scraper.

3. Remove the photoresist container, and install container of MEK, approximately one-half full.
4. Turn PUMP SELECTOR, on front of clean bench, to RESIST.
5. Turn flow control valve all the way counterclockwise.
6. Open drain valve on bottom of filter and drain resist. Leave open until MEK begins to flow into filter.
7. Allow the machine to clean itself for approximately 5 minutes.
8. Turn PUMP SELECTOR to OFF.
9. Remove container of MEK and replace with a container of fresh MEK.
10. Repeat steps 4 through 7 and then 8.
11. Using a squeeze bottle filled with MEK, clean photoresist from the Teflon seals and any spots on the machine.
12. Turn doctor bar control counterclockwise to the end of its travel.
13. Wet the coating roller using a squeeze bottle filled with Shipley AZ thinner. Let the machine run until the roller is dry.
14. Turn control switch off.

Appendix B

MAINTENANCE AND FACILITY REQUIREMENTS

Proper maintenance of the roller coater is important for successful operation. In particular, the system must be thoroughly cleaned after every use to assure that no residual photoresist is left on the roller, doctor bar, or in the resist supply lines. A dirty system will not produce good resist coatings, and in time will damage the roller. Major maintenance such as replacing the conveyor belt, replacing the roller, and lubricating the roller bearing should be done when necessary. The rollers should never be touched by hand, and there should never be any doctor bar pressure on the roller when the roller is not turning and wetted.

The roller coater should be in a class 100, vertical flow, exhaust hood. The cleanliness requirements are necessary to prevent foreign material from contacting the wet roller or the freshly coated substrates. The exhaust portion is required to abstract all fumes when the system is cleaned. A spill pan should be placed beneath the roller coater with a drain going to a waste solvent pan. The pan used is to catch photoresist, cleaning solvent, or both. The clean hood should have a hinged, full-face shield for air control inside the hood. The exhaust volume should be slightly less than the clean air volume during coating and more than the clean air volume during the cleaning operation. Yellow lights should be provided in the hood.

The roller coater should be arranged so that it directly feeds into the conveyor IR prebake oven either by hand or preferably by an intermediate conveyor,

The Gyrex Micro 9 roller coater is fragile and should be maintained and handled with care. The rollers will get out of alignment if mishandled.

Appendix C

MICROCOATER TROUBLESHOOTING GUIDE

The following are some possible coating deficiencies and their remedies.

Coating too thin: Increase fluid viscosity or decrease doctor bar pressure.

Note: Multiple dry passes will increase thickness by 100 percent. Multiple wet passes will increase thickness by approximately 70 percent.

Coating too thick: Decrease fluid viscosity or increase doctor bar pressure.

Fine-line skips in coating: Decrease backup to coating roller clearance (increase interference) or decrease doctor bar pressure.

Trailer edge bead or plugged holes in substrate: Increase backup to coating roller clearance (decrease interference) or increase fluid viscosity.

Bubbles in coating: Increase fluid viscosity or decrease backup to coating roller clearance (increase interference), or allow further permeation of resist to coating roller.

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