Metrology Errors in the Use of Insulating Dots for Plated Thickness Measurements

by Dr. Thomas E. Dinan,†

Plated thickness is usually greater at the edges between insulators and plated cathodes. This can cause a measurement error when using insulating dots to create a step for thickness measurements by profilometry. A mathematical model for predicting this error was written using the finite-volume method and an Excel spreadsheet. It was assumed that ohmic effects determined the current distribution. Leveling effects due to polarization or mass transfer were not included in the model. Calculated results are compared with experimental values for electroplated copper and a nickel-iron alloy.

Introduction

One method of measuring the thickness of electroplated films is to use an insulating dot to create a step that can be measured by profilometry. The dot is applied before plating and removed thereafter. The area where the dot has been applied is not plated and creates a step between the area under the dot and the area outside of the dot. An outline of the process is shown in Fig. 1.

It is well known that current accumulates at edges.[1] We can expect that the plated thickness at the edge of an insulating dot will be greater than the thickness some distance from the dot. If thickness measurements are made near the edge of a dot, they will contain some level of error as they will not be representative of the surface of the part distant from the dot.

Calculation Procedure

The current distribution surrounding an electrically insulating, circular dot was modeled. The volume of solution was 9.36 radii vertically from the surface of the dot and 9.36 radii horizontally from the center of the dot. The radius (R) used was that of the dot. It was assumed that the problem was cylindrically symmetric and that the potential gradient far away from the dot would be uniform. The potential of the cathode was set to be zero. The potential of the anode surface 10.0 radii from the dot in the vertical (z) direction was set to be 10 V. Figure 2 is an illustration of the solution volume.

Nuts & Bolts: What This Paper Means to You

In printed circuits, thickness is usually greater at the edges between insulators and plated cathodes. This can cause a measurement error when using insulating dots to create a step for thickness measurements by profilometry. Here the author develops a mathematical model for predicting this error. His calculated results are compared with real world values for copper and nickel-iron alloy.

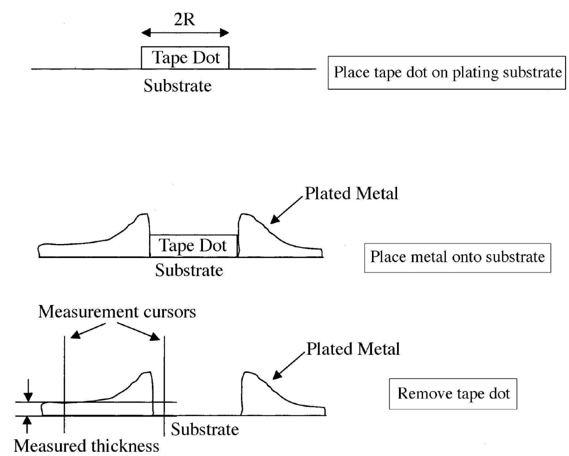

Figure 1—Process flow for the use tape dots for measuring electroplated thickness.

The finite volume method[2] was used to set up the problem. In this method a current balance is set up over a finite volume and it is assumed that Ohm's Law applies. It is further assumed that the plating bath is electrically conductive and isotropic. Therefore there will be no accumulation or depletion of charge within a given volume. Figure 3 shows a finite volume. The distance between each node (N, S, E, W and P) is set to be 1 (arbitrary units) in order to simplify calculations.

The equation for the potential at point P within the bulk of the volume is then given by

$$\varphi_P = \frac{(2\varphi_W r_{WP}) + (2\varphi_E r_{PE}) + (\varphi_N (r_{PE}^2 - r_{WP}^2)) + (\varphi_S (r_{PE}^2 - r_{WP}^2))}{((2r_{WP}) + (2r_{PE}) + (2(r_{PE}^2 - r_{WP}^2)))} \quad (1)$$

where:
φ_X = Potential at node X (where X is N, S, E, W or P),
r_{PE} = Average radius of nodes P and E, and
r_{WP} = Average radius of notes W and P.

The shape of each finite volume within the bulk of the volume will be that of a ring with a square cross-section. The shape of the finite volume at the center of the volume will be that of a circular disk. The equations for the finite

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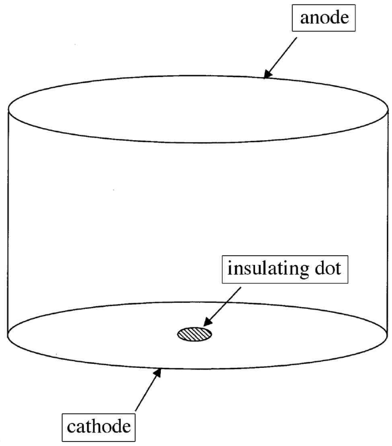

Figure 2—The solution volume showing the insulating dot on the cathode.

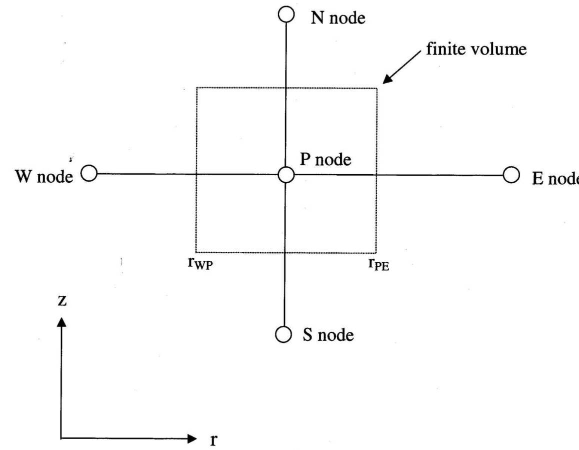

Figure 3—Diagram of the finite volume.

volumes at the surface of the volume of solution will be different from the one shown previously. They are not given here but can be easily derived from the principles of charge conservation and Ohm's Law that each finite volume must satisfy.

The % deviation of thickness was calculated from the following formula:

$$\% \ Deviation = \left(\frac{i_r - i_{avg}}{i_{avg}}\right) \times 100 \qquad (2)$$

i_{avg} was taken to be the current density perpendicular to the cathode at r = 9.36 radii. i_r was the current density at the point of interest. The calculations were done with a Microsoft Excel spreadsheet on a desktop computer.

Results and Discussion

Figure 4 shows the relationship between the % deviation from the plated thickness far away from the dot versus the distance from the dot edge expressed in dot radii. The % deviation drops to a negligibly small value at 3.0 radii from the dot. This is a worst case solution. In practice, some amount of electrode polarization will be present to improve the thickness uniformity. For comparison, two profilometer traces are also plotted in Fig. 4 for an acid copper bath with proprietary additives and for a nickel-iron alloy bath. A 3.18-mm (0.125-in.) diameter tape dot at the center of a 15.24-cm (6.0-in.) diameter wafer was used to produce the two profilometer traces. The profilometer traces indicate that these plating baths have a more uniform thickness distribution surrounding the dot than that calculated from this model. In fact, it appears that any measurement point further away from the dot edge than (r - R)/R > 0.5 will result in an accuracy on the order of 1% for these profilometer traces. Therefore, using this model as a guideline for the point to make the thickness measurement will result in an accuracy as good, or better, than that shown in Table 1 which is derived from these results.

Table 1
% Deviation Versus Normalized Radius from the Dot Edge

% Deviation	Normalized Radius from the Dot Edge [(r – R)/R]
10.0	0.41
1.0	1.63
0.1	4.07

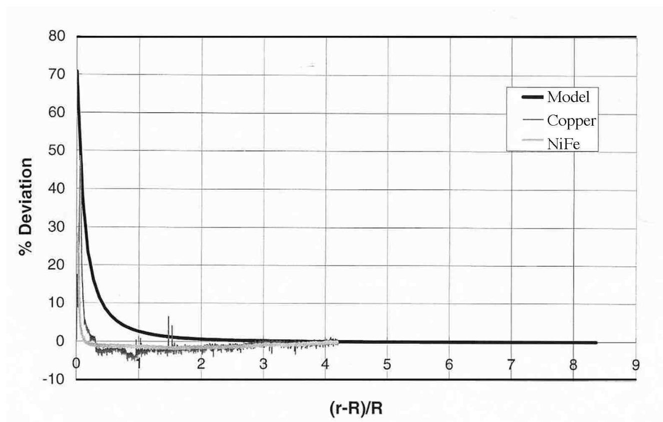

Figure 4—Thickness deviation versus distance from dot edge.

Conclusion

A model of the current distribution surrounding an insulating dot has been developed using the finite volume method. A guideline for the distance from the dot edge where thickness measurements should be made to achieve a particular level of accuracy has been presented.

Acknowledgements

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References

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2. S. V. Patankar, *Numerical Heat Transfer and Fluid Flow*, McGraw-Hill Book Co., New York, NY, 1980.

About the Author

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