IV. Multichip Module–Dielectric Package

G. E. Ponchak

The most frequently used materials for multichip module–dielectric (MCM-D) packages are polyimides and other polymers. These materials absorb moisture to varying degrees. Materials with the lowest moisture uptake have a water content of 0.5% [1] while other materials can have a water content greater than 4% [2]. Life tests on die containing Al test structures that were coated by various polymers showed failure modes attributed to Al : H_2O interactions. For polyimides, the measured median life of the Al test structure was approximately 385 and 6950 h when subjected to 121°C, 99.6% RH, and 85°C, 85% RH, 40-V bias, respectively. Further results have shown that passivation increases the median life of the test structures and that the passivation is not harmed by the polymer coating [3]. Therefore, passivation of the die is required to minimize moisture-failure mechanisms, and polymer coatings are not a substitute for hermetic packaging.

Adhesion of the polymer to the substrate is a major failure concern. Stresses are created at the polymer/substrate interface due to differences in the CTE between the two materials. These stresses can be large at room temperature due to the high processing temperature required to cure the polymers; the processing temperatures can be greater than 300°C. The amount of stress is proportional to the CTE mismatch and the polymer film thickness [4]. If the stress is greater than the adhesion strength of the polymer/substrate interface, the polymer will delaminate from the substrate. Stress cracks at the corners of via holes are another potential problem since the cracks tend to grow with thermal cycling. Optimization of the processing steps can minimize this effect [5]. Even if the polyimide does not delaminate from the substrate or base material, the stress may cause the substrate to warp. As a rule of thumb, the thickness of a ceramic base should be 20 times the thickness of the polyimide. Semiconductor substrates require an even greater thickness to avoid warpage [6].

The metal system used in the MCM-D process must be optimized. Typically, Cu is used for all of the dc and RF lines because of its good electrical conductivity and low cost. Unfortunately, it has been shown that Cu diffuses into polyimide at a rapid rate. The diffusion mechanism is temperature dependent. At low temperature ($T < 185$°C), Cu atoms diffuse through the polyimide, as shown in Figure 9-12. The rate of diffusion can be high enough that Cu will diffuse through 1 μm of polyimide in 4 months. At higher temperatures, Cu atoms are self gettering. Therefore, line widths are reduced, and the metal profile changes as shown in Figure 9-13. Finally, at the glass-transition temperature of the polyimide, Cu cluster migration has been reported [7]. Also, Cu has been shown to have poor adhesion to polyimides [5]. To minimize these failure mechanisms, Cr or Ti is required as a diffusion barrier between the Cu and the polyimide, but Cr/Cu/Cr metal pads have poor mechanical properties due to metal interdiffusion. Therefore, Ni is required as a diffusion barrier between the Cr and Cu. Ni cannot be used as a diffusion barrier between the Cu and polyimide since it also diffuses into polyimide [8]. Lastly, Cu diffusion is greater if the Cu lines are on top of the polymer surface instead of imbedded in the polyimide. The increased diffusion rate is due to surface voids in the polymer and CuO formation that has a higher diffusion rate than Cu [7]. In addition, exposed Cu lines on the surface of an MCM-D will corrode. Therefore, Cr or Au capping is required for upper level metal lines [9].

Via-hole formation is critical for MCM-D technologies since they are used in large numbers for interlevel interconnects. The via holes are made either by laser

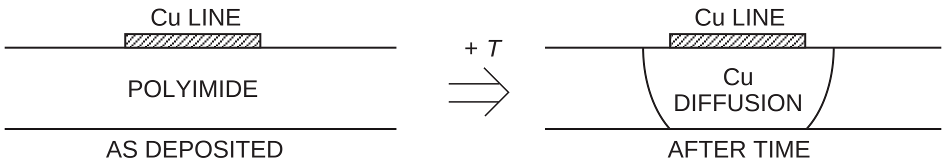

Figure 9-12. Copper diffusion in polyimide.

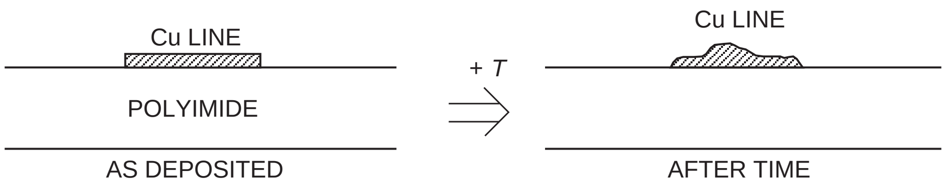

Figure 9-13. Self-gettering of Cu changes line geometry.

drilling, wet etching, or dry etching. Cleaning out the bottom of the via hole is critical. A residue of 400 Å of polymer at the bottom of the via is sufficient to create an open circuit [10]. Also, stress cracks at the corners of via holes, as shown in Figure 9-14, are a common problem.

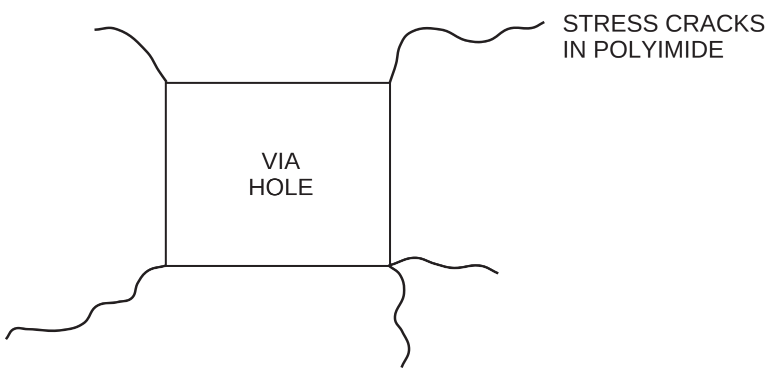

Figure 9-14. Stress cracks in polyimide at via holes.

Lastly, many of the MCM-D fabrication approaches, such as HDI [11], place polymers directly over the MMICs and other chips to be interconnected. Even though the polymers are thin relative to the die substrate and typically have permittivities of 3, they can have large effects on the microwave performance of the MMIC. Specifically, the polymer will increase the line capacitance, which decreases the guided wavelength. Therefore, distributed matching circuit elements will appear longer than the same structure without the polymer. Although the degree of circuit degradation is dependent on the transmission line type, substrate material and thickness, and characteristic impedance of the line, in general, coplanar waveguide (CPW) circuits will be effected more than microstrip circuits because of the greater field concentration at the substrate/polymer interface. If the MMIC is not designed to account for this frequency shift, the circuit performance will be degraded.

References

[1] Dupont Company product literature for Pyralin LX, data sheet # H-12287, April 1989.

[2] Dupont Company product literature for Pyralin PD, data sheet # H-32234, May 1991.

[3] Kodnani, D. Jaffe, and R. Jaccodine, "Evaluation of Polymeric Coatings for MCM Applications," *IEEE Trans. Comp., Packaging, and Manufact. Tech.–Part B*, Vol. 18, No. 4, pp. 658–665, November 1995.

[4] M. Pecht, X. Wu, K. W. Paik, and S. N. Bhandarkar, "To Cut or Not to Cut: a Thermomechanical Stress Analysis of Polyimide Thin-Film on Ceramic Structures," *IEEE Trans. Comp., Packaging, and Manufact. Tech.–Part B*, Vol. 18, No. 1, pp. 150–153, February 1995.

[5] V. Murali, T. Rucker, J. Fu, and R. Shukla, "Yield and Reliability Concerns in Polyimide Based Multi-Chip Modules," *1992 IEEE Multi-Chip Module Conf. Dig.*, pp. 98–101, March 18–20, 1992.

[6] K. P. Shambrook and P. A. Trask, "High-Density Multichip Interconnect (HDMI)," *Proc. 39th Electron. Components, Conf.*, pp. 656–662, 1989.

[7] J. H. Das and J. E. Morris, "Metal Diffusion in Polymers," *IEEE Trans. Comp., Packaging, and Manufact. Tech.–Part B*, Vol. 17, No. 4, pp. 620–625, November 1994.

[8] G. S. Frankel, S. Purushothaman, T. A. Petersen, S. Farooq, S. N. Reddy, and V. Brusic, "Corrosion and Adhesion of Multilayer Pad Structures for Packaging Applications," *IEEE Trans. Comp., Packaging, and Manufact. Tech.–Part B*, Vol. 18, No. 4, pp. 709–714, November 1995.

[9] R. S. Patel, T. A. Wassick, and C. Y. Ralston, " Metal Capping of MCM Thin Film Features Using a Laser," *IEEE Trans. Comp., Packaging, and Manufact. Tech.–Part B*, Vol. 17, No. 3, pp. 264–268, August 1994.

[10] G. White, E. Perfecto, D. McHerron, T. DeMercurio, T. Redmond, and M. Norcott, "Large Format Fabrication–a Practical Approach to Low Cost MCM-D," *IEEE Trans. Comp., Packaging, and Manufact. Tech.–Part B*, Vol. 18, No. 1, pp. 37–41, February 1995.

[11] R. A. Fillion, R. J. Wojnarowski, T. B. Gorcyzca, E. J. Wildi, and H. S. Cole, "Development of a Plastic Encapsulated Multichip Technology for High Volume, Low Cost Commercial Electronics," *IEEE Trans. Comp., Packaging, and Manufact. Tech.–Part B*, Vol. 18, No. 1, pp. 59–65, February 1995.