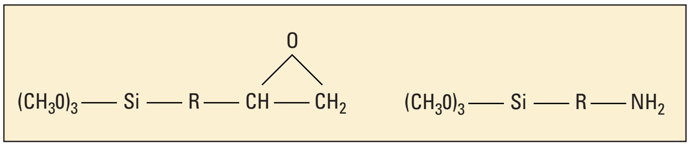

FIGURE 1. General chemical structures of epoxy silane (left) and amino silane.

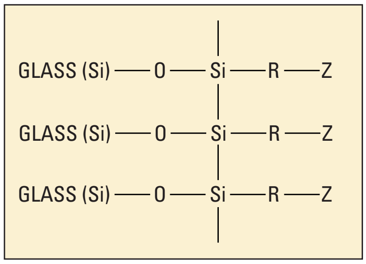

FIGURE 2. The generic chemical structure of silanes bonded to E-glass. "Z" represents either the amino or epoxy reactive group available for chemical bonding to the resin.

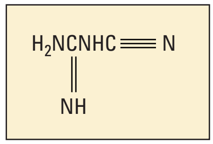

FIGURE 3. The chemical structure of dicyandiamide (dicy), the most common cross-linking agent used in FR-4.

CAF Resistance of NON-DICY FR-4

A new study shows how a novel non-dicyandiamide FR-4 stacks up under Telecordia GR-78 insulation and degradation tests. **by ERIK J. BERGUM**

Conductive anodic filamentation (CAF) occurs in PCBs when a conductive filament forms in the laminate dielectric material between two adjacent conductors under an electrical bias; the result is an electrical short. CAF is a significant and potentially dangerous source of electrical failure in the PCB and, thus, the overall system of which it is a part.

While CAF has been well-documented, until recently, the mainstream PCB industry regarded it as only a possibility, not something worth worrying about day-to-day. However, that perception has changed. As PCB designs have increased in density and, in particular, as via hole-to-hole spacing has been dramatically reduced, CAF has become an everyday concern.

Applications like telecom infrastructure, automotive electronics, and long-term data storage have focused most heavily on CAF because of reliability, safety, and cost-of-failure issues. However, concern about CAF is certainly not limited to these market segments.

Accordingly, an aggressive search has begun for solutions, specifically in terms of substrate laminate materials. Laminate materials such as bismaleimide triazine (BT) with standard woven E-glass reinforcement are sometimes used for better CAF resistance where a specific problem is identified or thought possible. BT offers better CAF performance than traditional FR-4 resin systems.[1] However, BT comes at a price when compared to FR-4 in terms of cost, ease-of-processing, and availability.

Recently, much work has been done in developing FR-4-based CAF solutions, but with the focus being on the woven E-glass reinforcement. CAF growth typically occurs along the glass fiber reinforcement-to-resin interface in the laminate substrate material.[1, 2] Woven E-glass fabrics used in FR-4 and most PCB laminate materials are treated with a chemically reactive material that enhances the glass-to-resin bond.

The conventional approach to minimizing the propensity of laminate materials to CAF has been to use specially produced glass fabrics with reduced amounts of the chemically reactive treatment on the glass. While this approach has shown positive results in reducing CAF, the basic CAF mechanism is only reduced and not eliminated.

Due to the properties of its resin system as opposed to the glass fabric, BT provides good CAF performance. So, resin system-based solutions for CAF are possible.

CAF Mechanisms

Much has been written about the technical details of what causes and influences CAF. However, the following general review is appropriate to support the technical approach taken in addressing CAF.

As a failure, either in the field or lab test-induced, CAF has many well-documented variables and contributors. Some key variables are:

- CAF formation will generally occur at the resin-to-E-glass interface, except in the case of PCB defects such as lamination voids or drill fracturing.[1]
- Different feature configurations have different probabilities and rates of CAF failure along the resin-to-glass interface, as follows in decreasing order[1]:
  - hole-to-hole.
  - hole-to-feature.
  - feature-to-feature, in plane.
  - feature-to-feature, out of plane.
- Moisture must be present for CAF to occur.[1, 2]
- The higher the electrical bias, the more likely and faster CAF will occur.
- The smaller the spacing between features under electrical bias, the more likely and faster CAF will occur.[1, 2]
- PCB quality and processing are important factors; in particular, innerlayer contamination, poor lamination, rough drilling, and poor plating can negatively affect CAF performance.[1]
- The inherent performance of the laminate cannot be exceeded; good PCB quality will not permit the CAF per-

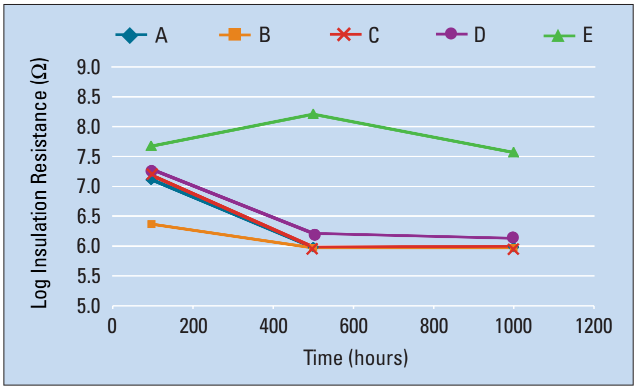

FIGURE 4. Average insulation resistance versus test time, hole-to-hole spacing of 0.010″, after 1000 hours 85°C/85RH, at 100V bias (data averaged).

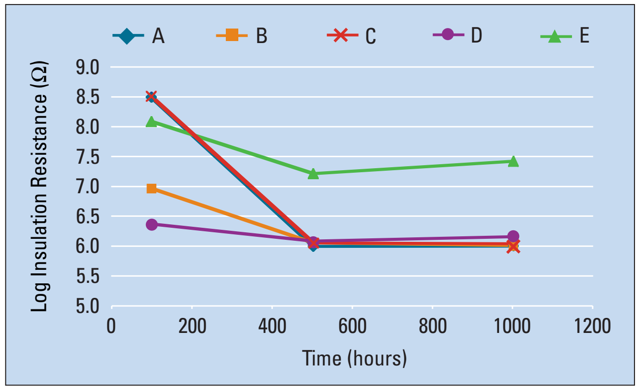

FIGURE 5. Average insulation resistance versus test time, hole-to-hole spacing of 0.015″.

formance entitlement of a laminate to be exceeded.

Because this study focuses on improving the glass-to-resin bond interface, a brief review of the chemistry at that interface is appropriate. Woven E-glass fabrics are typically treated with a chemical bonding agent to enhance the resin-to-glass bonds. The most common bonding agents are epoxy or amino silanes (Figure 1).

Bonding of these finishes to the glass occurs via a hydrolization and subsequent cross-linking reaction to the glass. In the resulting generic chemical structure (Figure 2), Z represents either the amino or epoxy reactive group available for chemical bonding to the resin. Both the surface of the glass and the finish are somewhat hydrophilic in nature.

The most common and traditional cross-linking agent used in FR-4 and many other epoxy-based systems is dicyandiamide (dicy). Dicy is hydrophilic, and its chemical structure is shown in Figure 3.

This combination of a hydrophilic surface and a hydrophilic cross-linking agent seems to be responsible for the mechanism whereby CAF occurs along the glass filaments at the resin interface. Varnell *et al* showed that non-dicy cross-linked epoxies exhibited much less tendency to CAF with standard glass finishes or even with improved, reduced glass finishes that were specifically designed for better CAF performance.[2] In fact, the data showed that both finishes' performance was roughly equal with the non-dicy cross-linked epoxy, suggesting that the dicy in some way contributed to CAF. Another supporting point is that BT laminates that show good CAF performance are not dicy cured.

While the specific mechanism and chemistry that occur between dicy and the glass finish have not been well studied or well characterized, very strong circumstantial evidence exists that this mechanism promotes CAF. This area is worthy of further research and will be considered in future studies.

Test Results

Non-dicy resin technology in FR-4 or other resin laminates is not new, even if dicy has been the preferred cross-linking agent for many resin laminates. Non-dicy FR-4 laminates have been aggressively investigated and marketed for several years due largely to their improved thermal performance.[3, 4] One family of non-dicy based FR-4 laminates, marketed by Polyclad Laminates Inc. under the trade name "TURBO," provides improved thermal reliability performance as a direct result of the FR-4 non-dicy resin.

Based on previous CAF test results, these non-dicy FR-4 laminates have demonstrated excellent CAF performance. In this study, one of these laminates (Material E)* was compared with four other commercially available laminates for CAF performance. The materials were:

- Material A: A 170°C Tg FR-4 laminate marketed as CAF-resistant based on improved glass.
- Material B: A reduced dielectric constant laminate based on an epoxy/polyphenylene oxide (PPO) blend, marketed as CAF-resistant based on improved glass finish.

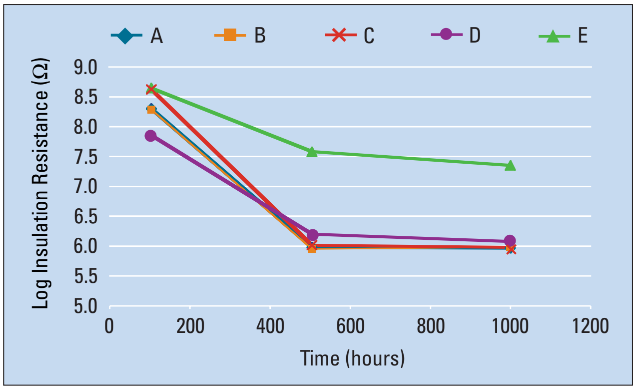

FIGURE 6. Average insulation resistance versus test time, hole-to-hole spacing of 0.020″.

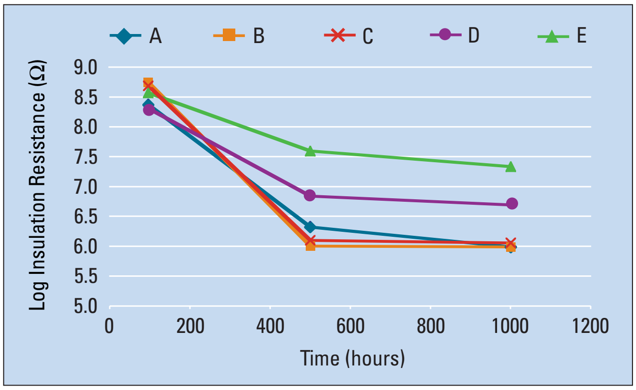

FIGURE 7. Average insulation resistance versus test time, hole-to-hole spacing of 0.025″.

- Material C: A 155°C Tg, reduced CTE FR-4 laminate, marketed as CAF-resistant based on improved glass finish.
- Material D: A 210°C Tg reduced dielectric constant laminate based on a proprietary resin system, marketed as CAF-resistant based on improved glass finish and resin.
- Material E: A 175°C Tg, non-dicy FR-4 laminate marketed as CAF-resistant based on improved resin.

All materials tested were manufactured into PCBs over the same time period using substantially identical process condition. The only differences were that certain process steps were performed as appropriate to the specific material types.

Testing was performed by an independent test laboratory at 85°C and 85% relative humidity at a bias voltage of 100V for 1000 hours, per Telecordia GR-78 requirements. Many other test regimes are used in the industry, but this regime is the most common and stringent. Testing was performed with the Sun Microsystems 10-layer CAF test vehicle.

All PCBs were built with the same construction, using all 2116 glass style single-ply cores and prepregs. The PCBs had a finished thickness of approximately 0.053″ (1.35 mm). Six PCBs of each material were tested for CAF performance.

Figures 4 to 7 show the average insulation resistance versus test time for hole-to-hole spacing 0.010″, 0.015″, 0.020″, and 0.025″ (0.25, 0.38, 0.51, and 0.64 mm, respectively) parallel to the glass fiber direction. These hole-to-hole data represent the trends observed in the other feature combinations and are generally considered the worst-case condition. The data clearly show the insulation resistance of Material E is maintained better than any of the other materials tested (Figure 8).

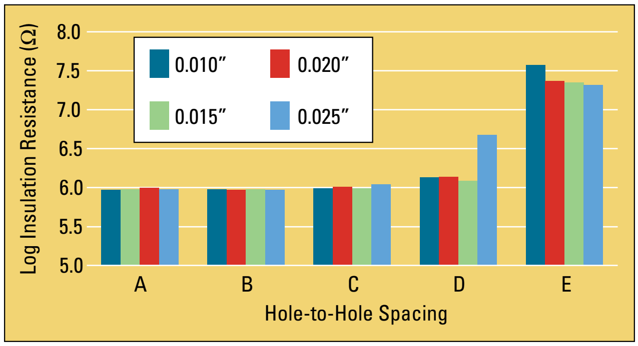

FIGURE 8. Insulation resistance after 1000 hours 85°C/85RH, at 100V bias, using various hole diameters.

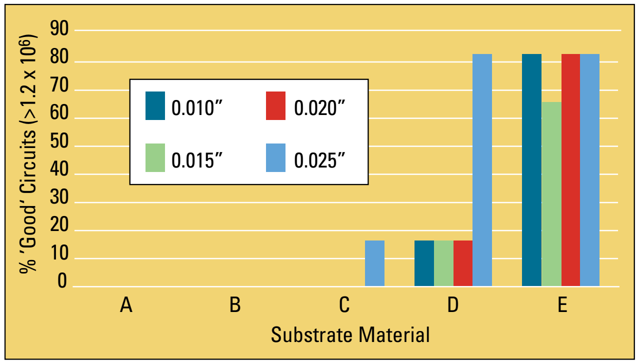

FIGURE 9. Percent of holes passing 1000 hours 85°C/85RH, at 100V bias (holes parallel to the fiber direction).

The CAF test results are also viewed from a pass/fail standpoint where a circuit passed if it showed greater than 1.2MΩ insulation resistance and the resistance does not degrade by more than one decade over the length of the test (Figure 9). Again, Material E outperformed the other types. ○

*"TURBO" is a trademark of Polyclad Laminates Inc.

ACKNOWLEDGMENTS

The author wishes to thank Dr. William D. Varnell and Helen M. Enzien for their thorough and excellent data analysis, without which this paper would not have been possible.

REFERENCES

1. Karl Sauter, "Evaluating PCB Design, Manufacturing Process, and Laminate Material Impacts on CAF Resistance," Proceedings of the IPC Printed Circuits Expo, March 2002.
2. William Varnell, et al., "Conductive Anodic Filament Resistant Resins," Proceedings of the IPC Printed Circuits Expo, March 2002.
3. Robert Demaree, "Thermal Stability of Halogen Free Laminating Materials," CircuiTree, October, 2001.
4. William Varnell, "Thermally Reliable Substrates For Lead-Free Assembly," Proceedings of Nepcon West, February 2001.

ERIK J. BERGUM is vice president of marketing, laminate products, with Polyclad Laminates Inc./Cookson Electronics PCB Materials and Chemistry (Franklin, NH). He can be reached at 603-934-5642 ext. 5226; ebergum@cooksonelectronics.com.