Conductive Anodic Filament Resistent FR-4 Substrates

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Introduction

As the trend to increased interconnection density continues, conductive printed circuit board features become closer and closer together. It is now common to see 3 mil lines and spaces on local areas of circuit boards, and via spacing of less than 10 mils. As the feature spacing gets smaller the probability for Conductive Anodic Filament (CAF) growth becomes significant. Many PWB designs now require the use of CAF resistant substrates to reduce the opportunity for CAF failures. Early solutions to CAF required use of Non FR-4 substrates such as Bismaleimide Triazine based materials. To meet the increasing requirements for CAF resistance and use the current PWB fabrication process, new FR-4 materials are needed.

CAF is the growth of a subsurface filament from an anode to cathode. This is the result of an electrochemical corrosion process that causes deposits of corrosion byproducts along the fiberglass filaments to form. The current model of CAF formation and growth involves two steps, the physical degradation of the fiber/epoxy bond followed by an electrochemical reaction responsible for conductive deposits to form. There are many factors that can contribute to CAF formation. These are summarized in Figure 1. Efforts to develop FR-4 substrates more resistant to CAF growth have focused on both improving the Epoxy-Filament bond and reducing the probability of the electro-chemical reaction occurring by modifying the FR-4 resin chemistry and the nature of the silane finish on the fiberglass reinforcement.

New more CAF resistant FR-4 products have been developed and are now available. The development of these improved FR-4 substrates demonstrates that epoxy based FR4 materials can be capable of meeting the requirements for CAF resistant high-density PWB designs. CAF test data comparing traditional FR-4 materials to new FR-4 products developed by Polyclad Laminates will be presented. These new materials have been shown to greatly improve CAF resistance.

Improved Resin Matrix Technologies

Modification of the resins used to produce FR-4 substrates to provide increased CAF resistance has been achieved by eliminating a significant amount of the amine functionality typically used in the epoxy-curing agent and by increasing the fiberglass filament wet-out through use of lower viscosity base resins. These modifications greatly reduce the rate of the electrochemical reaction associated with CAF formation. These same resin modifications also improve the thermal performance as measured by T-260, IST, thermal shock, and thermal cycle testing. Commercially produced 140 C Tg and 175 c Tg thermally stable laminates are now available from Polyclad Laminates, designated with the Turbo. This report evaluates the CAF resistance of these thermally stable laminates compared to their traditionally formulated FR-4 counterparts.

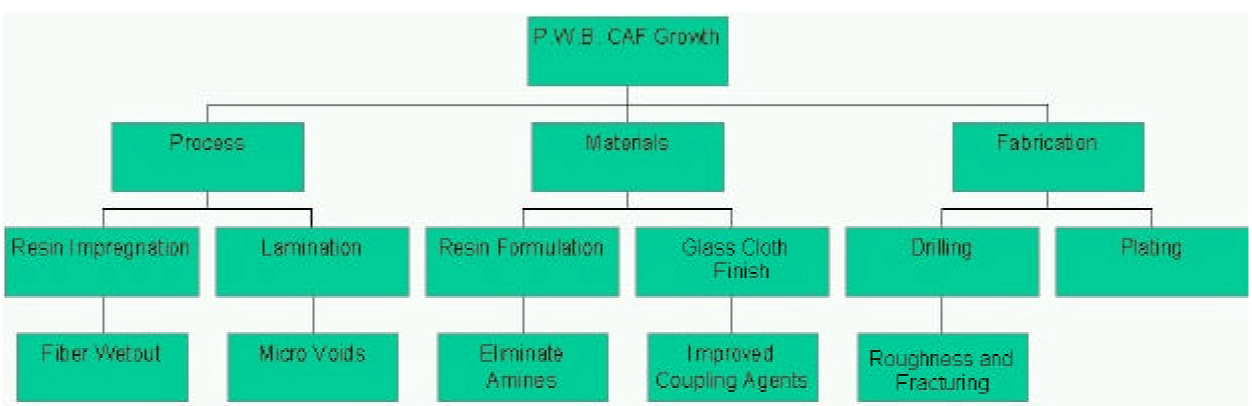

Figure 1 – CAF Factors

CAF Performance Evaluations

There are many different test conditions and test vehicles for evaluating the CAF resistance of printed circuit boards and substrate materials. The CAF performance of these new FR-4 resin technologies were measured in 4 studies using the CAF test vehicle developed by Sun Micro Systems and CAF resistance testing performed at Microtek Laboratories. For each study below the test samples were prepared at the same time in the same PWB fabrication facility. Testing was performed simultaneously at the test lab to minimize any processing or testing variations.

Study 1

This study compares the performance of traditional FR-4 140 °C Tg substrate to its thermally stable FR-4 140 C Tg counterpart. Both substrates were produced with the same traditional E-glass reinforcements commonly used in the United States. Eight samples of each type were conditioned at 65 °C, 85%RH, 50 and 100 Volts bias for 500 hours. Hole-to-hole spacing of 10 mils, 14 mils, and 26 mils were evaluated. Insulation resistance was measured at 100V DC. Results from Study 1 are reported in Table 1 and Figure 2.

At hole-to-hole spacing of 14 mils the 226 Turbo products had an average initial insulation resistance that was 30% higher than traditional FR-4 and after

500 hours an average final insulation resistance 100 times higher than the standard FR-4. One criterion for defining a "CAF Resistant" substrate is that the insulation resistance does not decrease by more than one order of magnitude after 500 hours under bias. Over the 500 hour test the insulation resistance of the thermally stable Turbo product decreased by only .7 orders of magnitude while the traditional FR-4 decreased by 2.5 orders.

Study 2

This study compares the performance of traditional FR-4 170 °C Tg substrate to its thermally stable FR-4 175 °C Tg counterpart. Both substrate types were produced with standard E-glass woven reinforcements. 10 Samples were conditioned at 65°C, 85%RH, 100 Volts Bias for 500 hours. Hole-to-hole spacing of 10 mil, 14 mil, and 26 mil were tested. Results from Study 2 are reported in Table 2 and Figure 3.

At hole-to-hole spacing of 14 mils the 370 Turbo product had an average initial insulation resistance that was 72% higher than the traditional 170 °C Tg FR-4 substrate. After 500 hours under bias the 370 Turbo product had an average insulation resistance 93% higher than the traditional 170 °C Tg FR-4. Both the traditional and the thermally stable FR-4 products insulation resistance decayed about 0.7 orders of magnitude after 500 hours.

Table 1 – Temp 65°C, Humidity, 85%RH, Test Time 500 Hours, Spacing .0144" Hole-to-Hole, Bias Voltage 50 Volts DC

Material	Tg (°C)	Initial Insulation Resistance (Mohms)	Initial Insulation Resistance Improvement (%)	Final Insulation Resistance Improvement (Mohms)	Final Insulation Resistance Improvement (%)	Insulation Resistance Decay over Test Time (orders of magnitude)	Insulation Resistance Decay Reduction over Test Time Improvement %
Traditional FR-4	140	$1.55\ E^{+9}$		$6.6\ E^{+6}$		2.5	
TURBO™ 226	140	$2.03\ E^{+9}$	30%	$6.67\ E^{+8}$	10,000%	.7	72%

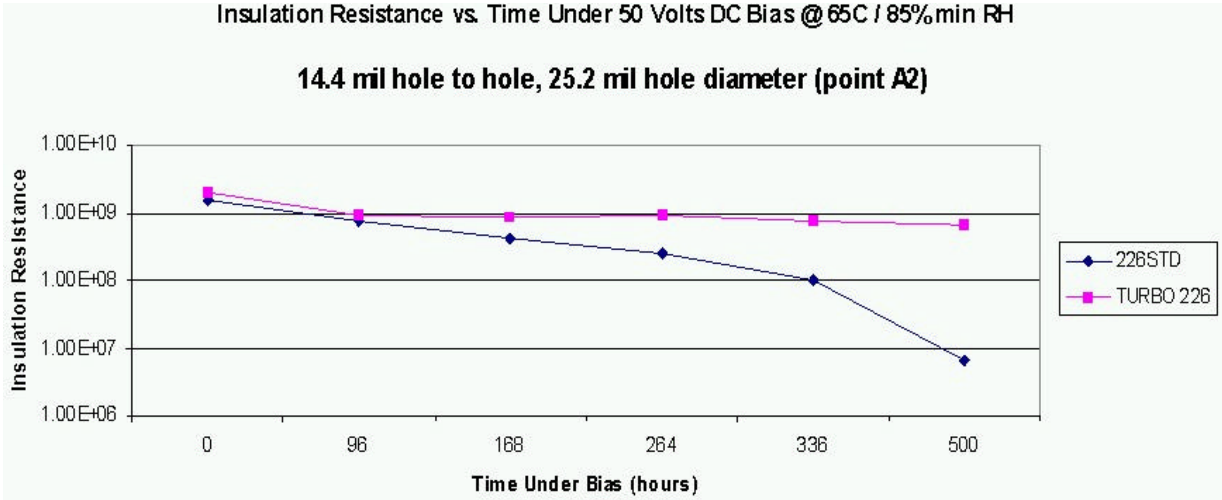

Figure 2 - Insulation Resistance vs. Time Under 50 Volts DC Bias @ 65 °C / 85% min RH

Table 2 – Temp 65 °C, Humidity, 85%RH, Test Time 500 Hours, Spacing .0143" Hole-to-Hole, Bias Voltage 100 Volts DC

Material	Tg (°C)	Initial Insulation Resistance (Mohms)	Initial Insulation Resistance Improvement (%)	Final Insulation Resistance Improvement (Mohms)	Final Insulation Resistance Improvement (%)	Insulation Resistance Decay over Test Time (orders of magnitude)	Insulation Resistance Decay Reduction over Test Time Improvement %
Traditional FR-4	175	3.92 E^{+10}		1.32 E^{+10}		.73	
TURBO™ 370	175	6.77 E^{+10}	72%	2.55 E^{+10}	93%	.69	6%

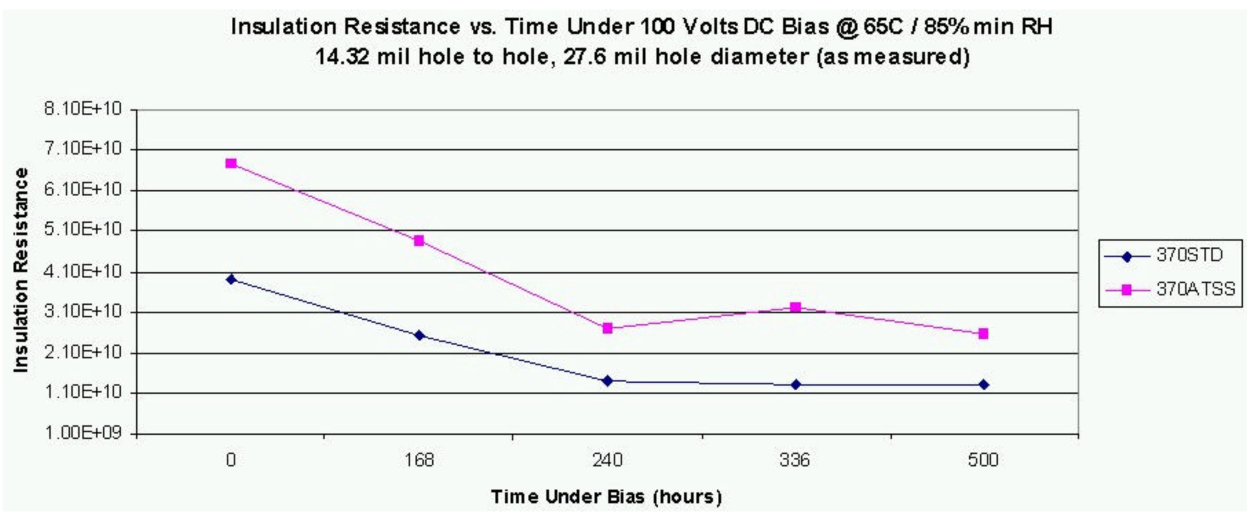

Figure 3 - Insulation Resistance vs. Time Under 100 Volts DC Bias @ 65 °C / 85% min RH

Study 3

This study compares the performance of traditional FR-4 170 °C Tg substrate to the thermally stable 175 Tg substrates with average hole to copper trace spacing of 6.8 mil. 10 samples were conditioned as reported above in Study 2. Results are reported in Table 3 and Figure 4

Again the initial and final insulation resistance of the thermally stable FR-4 was significantly higher than the traditional FR-4. The traditional FR-4 decayed 1.01 orders of magnitude after 500 hours while the thermally stable FR-4 decayed only 0.87 orders of magnitude.

Study 4

This study compares the performance of the thermally stable FR-4 175 °C Tg laminate produced with standard E-glass and traditional FR-4 silane adhesion promoters to the performance of the same thermally stable FR-4 175 C Tg material produced with standard E-glass but with an alternative “CAF Resistant” silane adhesion promoter. Twenty-five (25) samples of each type were tested at both 10 and 100 volts continuous bias for 1000 hours. Test chamber conditions were the same as used in the studies above. Data was collected at 10, 14 and 26 mil hole-to-hole spacing. Results for the 26 mil hole-to-hole spacing are presented in Table 4 and Figure 5.

Results at the various spacing and voltages were very similar. At the 26 mil hole-to-hole spacing the average initial and final insulation resistance of products were within 10% of each other. Both types of substrate decayed about 0.8 orders of magnitude over the 1000 hours of testing. No significant improvement was observed between the “CAF resistant” silane treated fiberglass and the conventional silane treated fiberglass used in the United States. In this study the chemical resistance of the Turbo resin system greatly reduced the impact of the fiberglass cloth finish.

Table 3 - Temp 65°C, Humidity, 85%RH, Test Time 500 Hours, Spacing .0068” Hole-to-Feature, Bias Voltage 100 Volts DC

Material	Tg (°C)	Initial Insulation Resistance (Mohms)	Initial Insulation Resistance Improvement (%)	Final Insulation Resistance Improvement (Mohms)	Final Insulation Resistance Improvement (%)	Insulation Resistance Decay over Test Time (orders of magnitude)	Insulation Resistance Decay Reduction over Test Time Improvement %
Traditional FR-4	175	$4.2\ E^{+10}$		$3.8\ E^{+9}$		1.01	
TURBO™ 370	175	$6.6\ E^{+10}$	57%	$1.4\ E^{+10}$	368%	.87	14%

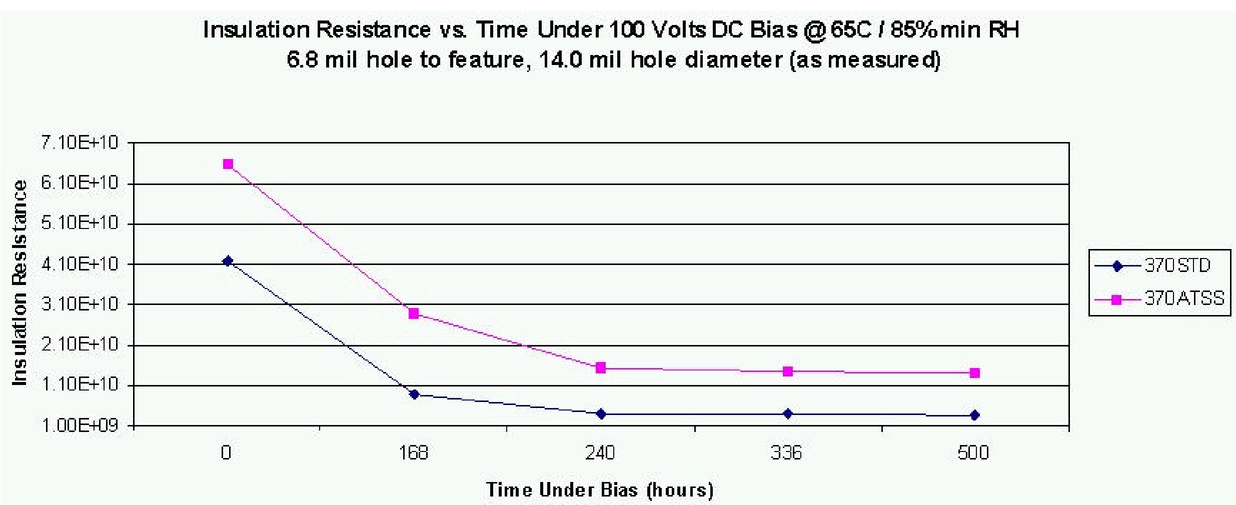

Figure 4 - Insulation Resistance vs. Time Under 100 Volts DC Bias @ 65 °C / 85% min RH

Table 4 – Temp 65°C, Humidity, 85%RH, Test Time 500 Hours, Spacing .0068" Hole-to-Feature, Bias Voltage 100 Volts

Material	Tg (°C)	Initial Insulation Resistance (Mohms)	Initial Insulation Resistance Improvement (%)	Final Insulation Resistance Improvement (Mohms)	Final Insulation Resistance Improvement (%)	Insulation Resistance Decay over Test Time (orders of magnitude)	Insulation Resistance Decay Reduction over Test Time Improvement %
TURBO™ 370 "CAF Glass"	175	1.19 E^{+10}		3.06 E^{+9}		.83	
TURBO™ 370 Std Glass	175	1.31 E^{+10}	10%	3.34 E^{+9}	9%	.82	1%

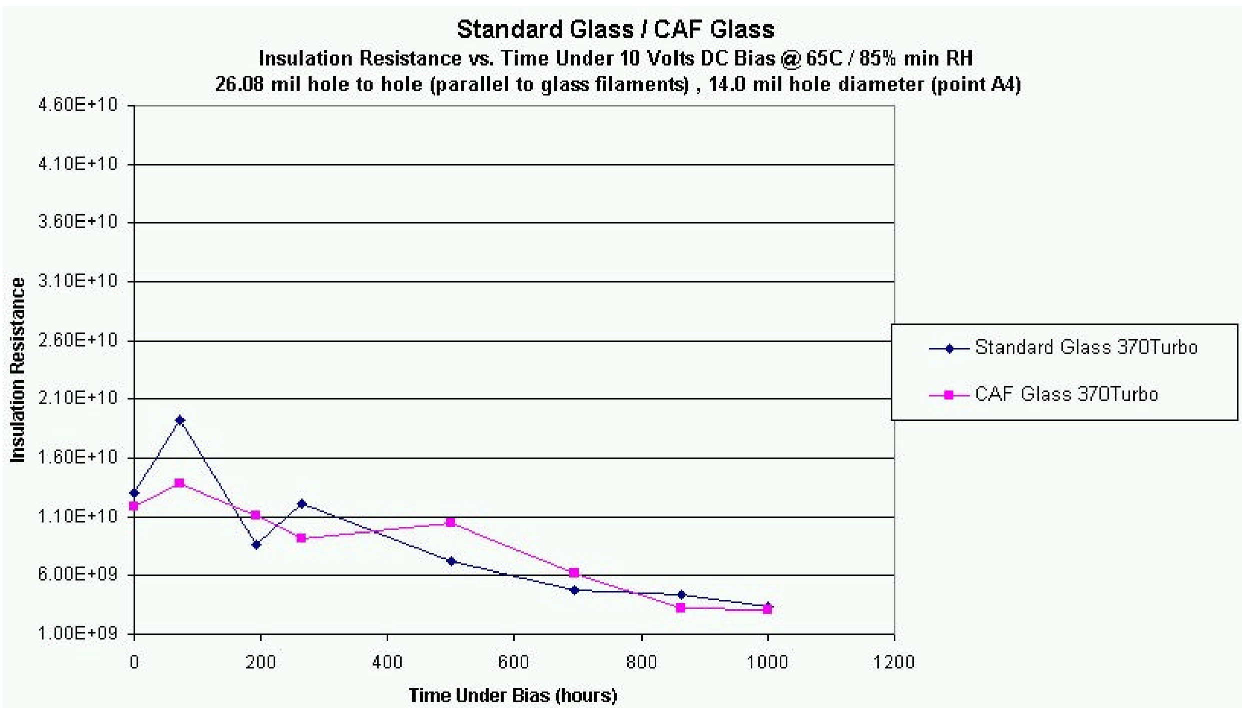

Figure 5 - Insulation Resistance vs. Time Under 10 Volts DC Bias @ 65 °C / 85% min RH

Conclusions

Newly developed thermally stable FR-4 materials can be used to significantly improve the CAF resistance of printed wiring boards. Changes in the matrix resin curing reaction can be more significant than differences between silane finishes used to improve the adhesion of the matrix resin to the fiberglass filaments. Additional studies of fiber wet out, dielectric construction, drilling quality, and other key substrate and PWB fabrication processes are needed to improve our ability to design and produce PWBs with better CAF resistance.