The Design and Fabrication of HDI Interconnects Utilizing Total Integration of Fiber-Reinforced Materials

An Overview of Fiber-Reinforced HDI Material Options

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It is now possible to produce HDI products, including high layer count backplanes and microvias, without the use of resin-coated coppers or SBU-type dielectrics. Typically, the microvia HDI world has been fueled by utilizing a resin-coated copper technology or other non-reinforced materials to comprise the outer dielectrics of the multilayer. However, fiber reinforcement in all dielectrics can provide many benefits to the HDI designer and the printed circuit fabricator.

Although the use of resin-coated copper continues to grow, the alternative of using fiber-reinforced materials provides more flexibility of resin systems and thickness in any given HDI design. As the designs become more complex, and the layer counts increase, fiber-reinforced materials offer lower Z-axis expansion, lower X-Y expansion rates, more thickness latitude, resistance to cracking, and a wide variety of resin options not possible with other approaches. This article explores the use of various fiber-reinforced material technologies for HDI as compared to resin-coated copper constructions.

Non-Reinforced Dielectrics

Resin-coated copper technology and SBU dielectrics (liquid and/or dry film) dominate the microvia HDI world with over 95% of the world market share. Resin-coated copper products have a slightly larger volume of usage than do SBU dielectrics; however, both technologies are continuing to grow and benefit from the HDI movement in technology. This non-reinforced resin technology has done an excellent job of supplying an easily lasered, plasma-drilled or photoimaged dielectric in lower layer count designs. Although these materials have higher Z-axis expansion as compared to fiber-reinforced dielectrics, there has been little impact of the use of these materials due to Z-axis problems. In layer counts of two to twelve layers, usually Z-axis expansion is not an issue because the finished multilayers are thinner and do not typically stress the via reliability. Most of the lower layer count designs go into mobile wireless products such as cell phones.

Resin-coated copper products virtually own this special application of cell phone products. Several major printed circuit fabricators throughout the world are utilizing resin-coated copper products on the outside of the multilayer board with good success. There are two generic types of coated coppers: "B"-stage products and "B/C"-stage products. In the latter, two resin-coating processes are used to manufacture the product. One of the resin coatings is partially cured; the other coating is fully cured and provides a base for the partially cured coating. The two stage systems have an excellent market share in the cell phone arena. However, the single stage products are growing quite rapidly.

Although very popular, the resin types and thickness ranges for non-reinforced products are somewhat limited. For example, most resin-coated coppers have just two generic FR-4 resin technologies: a) 130–140°C Tg and b) 150–175°C Tg. Also, thickness are somewhat limited between 0.0015" and 0.003" (35 and 75 microns, respectively). There are a few higher performance resins that have been incorporated into resin-coated copper products such as the Mitsubishi BT technology and the Asahi APPE technology. Although these products have excellent technical merit, they are not being used in wide volume applications at this point in time.

Some of the opportunities for new product offerings in the field of non-reinforced dielectrics will certainly be products that are thicker and that are more resistant to cracking (which may occur sometimes with non-fiber approaches to HDI). There are numerous material suppliers of resin-coated copper and SBU materials that are working on next generation materials. Certainly, this technology will progress over time.

The weaknesses of non-reinforced resin technology are not readily seen in lower layer count designs. However, as you move up in layer count, a number of factors give a compelling argument to consider fiber-reinforced options. Higher layer count designs require lower expansion rates due to the higher overall thickness involved and concerns over via reliability on the external circuitry. Also, with more complex designs, buried vias are often used to increase density. Buried vias often are designed as the second or third dielectric in the HDI board. Because of their location in the multilayer structure, they require more dimensional stability and better fill of the vias in the buried via structure. Sometimes this is difficult with resin-coated copper or other non-reinforced approaches.

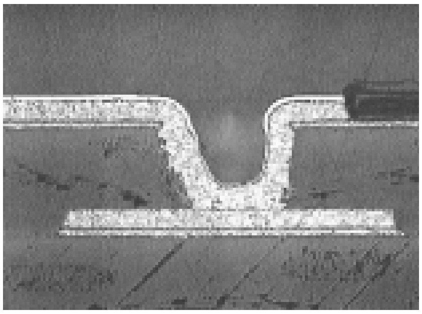


Figure 1. Fiber-Reinforced Microvia 170°Tg E-Glass 1-8-1 Structure (courtesy of Hadco Corporation).

Nonreinforced thermoset polymers are also difficult to prevent from cracking, a common phenomenon when dealing with copper-rich designs that incorporate constraining thermo-mechanical features such as buried vias. Under thermal excursion, the resin can fracture around the pads of the buried vias (that are totally encapsulated by the resin from the resin-coated copper). Also, it is difficult to maintain good thickness retention and uniformity with nonreinforced dielectrics compared to fiber-reinforced materials, especially at thicknesses above 50 microns.

Another advantage of fiber-reinforced materials is the effective peel strength at temperature. Fiber-reinforced materials typically have very good peel strengths even after thermal conditioning. Fiber-reinforced materials offer robust thermal bond strength, which is needed for a number of high I/O PBGA rework and removal procedures. In general, fiber reinforcement provides more latitude in processing, both at the material manufacturer and the interconnect fabricator.

Laser Via and Hole Formation Evolution

Within the last three years, some parallel efforts have advanced the state of the art of producing solid microvia structures in fiber-reinforced dielectrics that rival the advances in resin-coated copper approaches. In the past, laser drilling through a glass-reinforced substrate was an intriguing idea, but not very practical. The hole roughness was high on the first attempts and the microvias were difficult to clean, metallize, and plate.

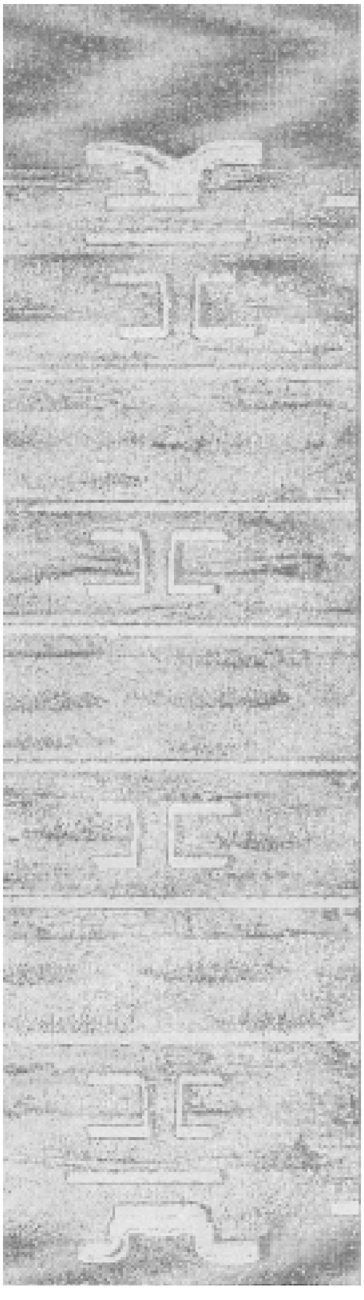


Figure 2. Fiber-reinforced HDI Interconnect: 170 Tg e-Glass 1-8-1 Structure (courtesy of Hadco Corp.).

This scenario has changed dramatically. Several manufacturers of laser drill equipment now utilize multiple frequency lasers (usually two separate laser systems with different wavelengths) that provide sequential processing during hole formation. By tailoring the frequency of one laser to remove the copper foil, the alternate laser can have a different frequency and pulse configuration that allows fast and clean removal of the glass fibers and resin, thereby forming a reliable microvia hole. These laser machines all use next-generation galvo technology for speed enhancement and provide software pro-

Figure 3. Dk vs. Resin Content: Effect of SI Technology

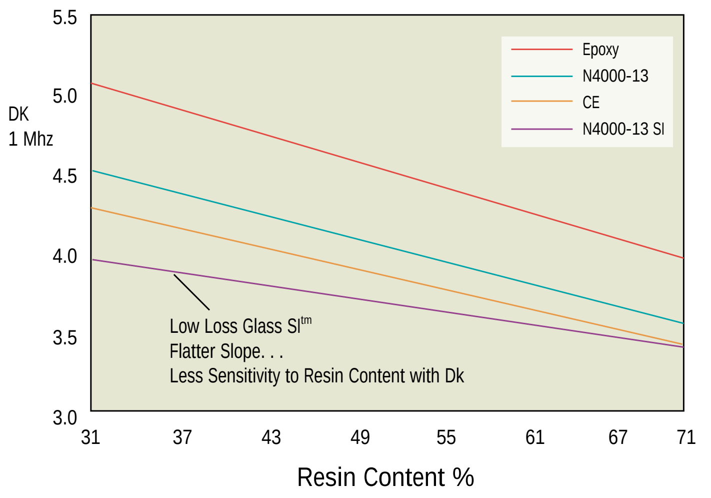
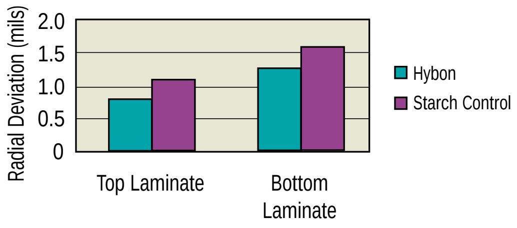


Figure 4. Drilled Hole Tolerance for Hybon Laminates.



gramming of the process to optimize the texture of the hole.

In addition to advancements in the laser drilling arena, several chemistry advancements in hole cleaning, metallization, and hole plating now make it possible to have excellent coverage and high integrity microvia structures in fiber-reinforced materials. The fibers actually provided some lock-and-key adhesion for the metallization and can provide for a well-formed microvia structure.

E-Glass Reinforced HDI Dielectrics

When E-glass was first proposed as a microvia, the approach used epoxy-based dielectrics on 106 glass. This provided a low glass content (less than 40% by weight) and a low thickness (less than 60 microns) so that the laser drilling process would be close to that of resin-coated copper. This approach worked originally, but did not satisfy a number of other design requirements. For the most part, most specifications require a minimum 0.0035" dielectric and a single ply 106 did not meet that criteria. Also, 50-ohm impedance designs usually required thicker dielectrics in order to achieve standard line width and spaces on the outside circuitry. Unless the line widths were very low for external circuitry (0.002"), an external microstrip line would not lend itself well to a single ply 106-prepreg dielectric.

As the technology of laser drilling and microvia processing progressed, thicker dielectric substrates such as 1080 and 2113 became viable candidates for blind via formation and buried via formation. Today, standard types of glass cloth styles and prepregs are now used for blind via and microvia constructions.

The options for E-glass type and the associated resin types for this type of HDI construction are extensive. Table 1 lists the various E-glass resin systems possible by resin type, including Tg and X-Y CTE. The options available are vast considering the smaller material options with non-fiber-reinforced materials. Probably the biggest advantages of utilizing fiber-reinforced materials is X-Y-Z CTE comparisons of resin-coated copper dielectrics vs. standard materials. Figures 1 and 2 illustrate some fiber-reinforced micrographs of a 1-8-1 HDI design.

SI™ and Low Loss/Low Dk Technology

One of the additional benefits of utilizing fiber-reinforced dielectrics is the potential use of low loss (Df)/low Dk glass fabrics in combination with low loss/low Dk resins for the application of wide bandwidth circuits. The use of low Dk glass fabrics is termed “SI technology,” and is based on Nittobo glass fiber technology. This SI technology allows improved signal integrity at very high digital and analog frequencies, while providing the other benefits of uniform thickness retention for impedance control in tight tolerance designs. Typically, SI technology drops the Dk and Df values 10% and 25%, respectively, compared to standard E-glass reinforcements with the same resin system. This happens because of the significant influence of the glass properties on the total dielectric properties of the laminate. The electrical properties at 10Ghz of various SI technology resins are provided in Table 2.

Because the Dk of the glass fabric more closely matches the Dk of the resin, SI technology reduces the sensitivity of Dk to resin content as shown in Figure 3.

This provides a distinct advantage of low loss fabrics in applications such as Rambus™, where the tolerance for Impedance is 28 ohms plus or minus 10%. At this low value for an impedance target, there is more sensitivity for the laminate properties than the line width for holding the correct impedance.

Thermount®RT™ Laminate and Prepreg Technology

Thermount is another good example of a fiber-based reinforcement for microvia applications that is being used in production today with HDI and MCM technology. Thermount is a mature aramid fiber-reinforced technology that allows significant benefits in ease of laser processing while retaining excellent X-Y CTE control. Thermount’s non-woven Aramid reinforcement material is coated with various resin systems with specifically controlled thickness offerings. Thermount offers the fastest laser drilling speeds of all the fiber-reinforced materials because of the organic nature of the fiber which laser drills quite easily. Dupont has released a next generation fabric technology referred to as Thermount®RT™ which has more moisture resistance for applications such as MCMs and HDI interconnects. This aramid fiber provides for excellent thickness uniformity and drillability. They are combined with X-Y CTE values in the 8–12 PPM range. Thermount also has excellent CAF resistant properties. Table 3 provides the material properties of Thermount type dielectrics.

Table 1. Advanced HDI Material Properties.

Resin Type	Fiber Type	Application	Designation	Tg°C DSC *TMA **DMA	X-Y CTE –40°C to +125°C PPM	Z CTE –50°C to +250°C %
Resin Coated Copper	None	HDI	Resin Coated Copper…Various	135–140 155–170	+16	+5.0
Epoxy	E-Glass	Broad Spectrum	N4000–2	140	12–16	4.5
Epoxy	E-Glass	Low CTE	N4000–6	170	10–14	3.75
Epoxy Low CTE	E-Glass	Low CTE	N4000–7	155	10–14	3.7
Epoxy Low CTE	SI Glass	Rambus™	N4000–7 SI	155	10–14	3.7
Epoxy Jedec	E-Glass	PBGA MCM	N4000-X1	180	10–14	3.7
Epoxy Low Loss	E-Glass SI™	1–4 Ghz Telecom Rambus	N4000–13 N4000-13 SI	200	10–14	3.5
Epoxy Aramid	Thermount®	HDI, MCM	N4500–6T	170	8–12	4.0%
BT BT JEDEC	E-Glass	Telecom PBGA, HDI	N5000 N5000-32	180	10–14	3.75
Polyimide	E-Glass	Burn-In	N7000–1	250*	12–15	1.75
Polyimide Low Loss	E-Glass	High Rel Telecom	N7000–2HT	250*	9–13	2.7
Cyanate Ester	E-Glass	High Rel Low Loss	N8000	250*	11.13	2.7
Non-Halogenated***	E-Glass	Green	EF™ Series (In Development)	140 170	12–16 10-14	4.5 3.75
Non-Lead Non-Halogenated***	E-Glass SI	Telecom No-Lead	EF™ Series (In Development)	210*	9–13	3.5
APPE	E-Glass SI	1–10 Ghz MCM, PBGA	N6000 N6000SI	210**	10–14	3.5

***In Development

ZebraLink Hybon™ Technology

A new fiber technology on the horizon is PPG's Zebralink Hybon™ product. This product involves a unique glass fiber technology that has significant mechanical and thermal advantages that facilitate HDI technology, including increased stiffness and drilled hole accuracy. The Zebralink Hybon technology starts with a glass fiber extrusion and coating technology that allows the fabric weavers to eliminate the heat cleaning and silane coating processes normally associated with glass fabrics. By incorporating an excellent fiber-to-resin enhancement technology at the extrusion step, the Zebralink Hybon results in glass fabrics that provide excellent resin-to-fiber bond, thereby potentially providing better CAF resistance and high reliability in closely spaced holes. In addition, the mechanical properties of the fabric woven from this fiber allow improved registration during drilling, which is critical for HDI alignment, especially on 1.0 MM PBGA and 0.8 MM PBGA HDI designs. Figure 4 illustrates some data of this technology compared to the standard sizing and cleaning method of manufacturing fibers and cloth. Since most HDI designs have a combination of mechanical drilling and laser/plasma drilling of the interconnect substrate, the Zebralink Technology also has the potential advantage of increased accuracy of via dimensional accuracy. Presently, the Zebralink Hybon product is in beta site testing for all fiber-reinforced microvia applications. It may offer substantial advantages as compared to the mixed dielectric approach with resin-coated copper products.

Table 2. SI™ Technology HDI Material Properties @10 Ghz.

Resin Type	**Designation**	**Application**	**Dk @ 10 Ghz**	**Df @ 10 Ghz**
Low CTE Epoxy	N4000–7 SI	Rambus™	Under Test	Under Test
Low Loss Non-Halogenated Low Lead	EF Series (In Development)	No-Lead Non-Halog	3.27	0.0147
Low Loss Epoxy SI	N4000–13 SI	1–4 Ghz Telecom Rambus™	3.20	0.0059
APPE SI	N6000 SI	1–10 Ghz Telecom	3.36	0.0036

Resin Filling and Thermal Resistance

The move to HDI is usually accompanied by designs that involve multiple internal buried via pairs in addition to the external microvias. Resin-coated copper materials can have difficulty in this technology if the buried vias have significant depth and quantity. This is difficult because a significant volume of resin is necessary to fill both the vias and the circuitry on the surface of the buried via. With resin-coated copper, a common practice in Japan is to fill the vias with a resin plug prior to the final lamination. However, this practice is costly and somewhat tricky to perform. If the vias are not sufficiently filled with resin, the thermal resistance of the structure can be lower than required. However, with standard prepreg technology, more resin can be made available for the via hole process, thereby reducing the need for via filling prior to final lamination of the board.

Heat Resistance versus CTE

Selecting the right material for a fiber-reinforced HDI design involves many factors. Some high performance resin systems have a good balance of thermal resistance and low CTE, which can provide certain designs more reliability and a wider process window, especially in the backplane arena. Figure 5 gives a matrix of Thermal Resistance (TGA) vs. CTE that is helpful in selecting the optimum fiber-reinforced material for the HDI design.

Summary

As layer counts continue to rise, fiber-reinforced dielectrics can provide many benefits to compliment resin-coated copper usage. Backplane designs are an important application from this approach because of the need for the lower Z-axis expansion afforded by fiber-reinforced dielectrics.

Figure 5. HDI and Thermal Performance.

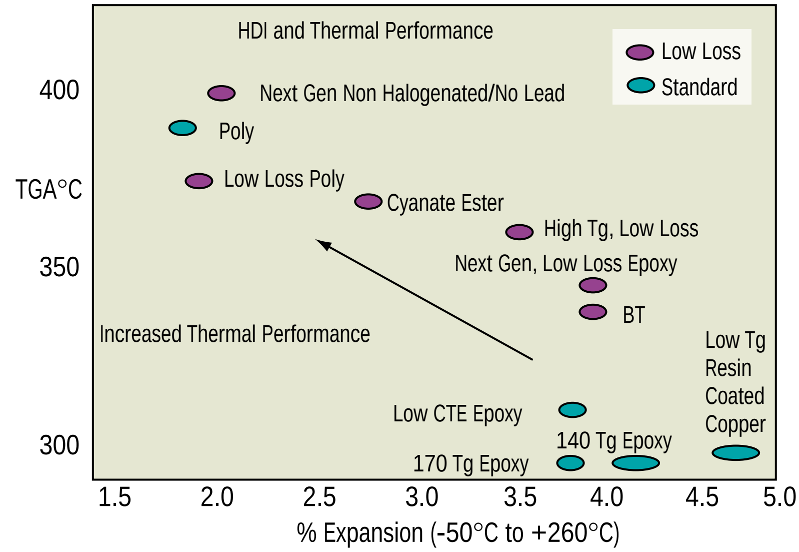


Table 3. Thermount® RT™ HDI Material Properties.

Property	2.0N710 N4000-6T	3.0N710 N4000-6T	4.0N710 N4000-6T
Thickness	1.90	2.85	3.80
Laminate Thickness	2.10	3.10	4.10
Tg°C	170	170	170
Dk @ 1Mhz	3.9	3.9	3.9
In Plane CTE PPM/C	11.0	10.5	10.5

Thermount®RT™ is a registered Trademark of the Dupont Corporation.

Table 4. Benefits of Resin-coated Copper and Fiber-reinforced HDI Materials.

Property	**Resin Coated Copper**	**Fiber Reinforced HDI**
Material Options (volume availability)	Epoxy High Tg Epoxy	Epoxy High Tg Epoxy Low Loss Epoxy Low CTE Epoxy Aramid Epoxy SI Technology APPE Polyimide Low Loss Polyimide Cyanate Ester
Z-axis Range	+5.0%	1.7%–4.5%
X–Y CTE Range PPM/°C	+16	8–16
Tg Range°C	130–170	130–250
Laser Drilling Speed	High	Moderate
Plasma Compatibility	Yes	No
Non-Halogenated	In Development	In Development
Optimum Layer Counts	2–12	2–50
Dielectric Thickness Range (microns)	35–75	35+
Minimum Copper (microns)	5	5
Low Dk Resins	Yes (introduction stages)	Yes (mature)
Chip Packaging	Yes (introduction stages)	Yes (mature)
SI Technology	Not Available	Yes
Controlled CTE	Not Available	Yes
Next Generation Possibilities	More Thickness Range, wider selection of resins	Robust, lower loss, CTE, Planarity, etc.

The multiple benefits of fiber-reinforced materials include lower thermo-mechanical expansion rates, better hole wall adhesion during the metallization process, uniformity of material in the multilayer structure, and easier UL approval of new products. Additional benefits include accessibility to new fiber technologies such as the Zebralink Hybontm Products, less moisture sensitivity, better potential fill of buried via stacks, and the ease of processing conventional materials. Fiber-reinforced HDI complements resin-coated copper technologies and provides other options to the fabricator and to the OEM end-user, including a broad spectrum of resin systems. Table 4 summarizes the benefits of fiber-reinforced materials and resin-coated copper dielectrics.

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Reference:

Hybon RCY Yarns, Dr. Bruce Novich, *Circuitree*, March 1999.