Presented at IPC Printed Circuits Expo® 2002
www.ipcprintedcircuitexpo.org

Novel Base Material for Microvias in PWBs by Using Unique Glass Fiber

Wataru Ueno, Mikiya Fujii, Yoshiharu Suzuki and Shin Kasai
Nitto Boseki Co., Ltd.
Fukushima, Japan

Abstract
The rapid developments of IT equipment are placing increased demands on printed wiring boards (PWBs) in terms of high efficiency, high-density and lightweight. Industry experience has proven that glass fiber base materials are essential for highly reliable PWBs, in particular to obtain such characteristics as heat resistance, dimensional stability, and mechanical strength and insulation reliability. There can be some difficulties in the processing of traditional PWB laminating in terms of accuracy and cost performance applications are focused on fine glass fiber fabric developments. Resin coated copper foil (RCC) is used widely as layer material for build-up (sequential) processing technology as a solution to these accuracy issues. However, in RCCs increasing use, much higher reliability such as no warp and crack and correspondingly improved dimensional stability and high cost performance are being demanded.

We are investigating new glass base materials to overcome these deficiencies in both systems by developing improved spinning and binder technology in a novel, non-woven glass fiber fabric (FF sheet). This novel base material for microvias is able to bring high reliability, good processing and also high productivity as an improved RCC alternative.

Introduction

Miniaturization of electronic devices places increasing demands on the quality and integration of PWBs. Since high accuracy of circuit line, space with excellent surface smoothness, and very small and precise microvia are demanded to these advanced PWBs for HDI, laser drilling and build-up technology, new and improved insulation layer materials have been investigated.

There are two types of glass fiber base material for insulation layer material in PWBs. The first type is cloth (woven) type material. The 1080 type cloth of 50 micrometers thickness is a major fine cloth, and 106 and 101 are super fine cloths and are beginning to be used for dielectric layers of microvias. Fairly low productivity of these ultra thin glass cloths, however, is hindering utilization. In laminating processes involving these ultra thin cloths, the difficulties of twist and warp have also occurred. Furthermore, the problems of microvia hole accuracy and wall coarseness are introduced in the laser drilling process because the glass density in the laminate is different between intersections and holes. The second type is glass paper (non-woven) material. One advantage of this material is much higher productivity than that of cloth materials. Glass paper has improved via hole processing accuracy because of the uniform dispersion of glass filaments in glass paper. Glass papers are mainly used to CEM-3 type laminate and commercially the finest glass paper is $25g/m^2$ as base material that is possible to achieve a minimum of 70 micrometers dielectric. Glass paper using conventional glass fiber is not able to obtain ultra thin dielectric and is not strong enough in tensile strength even though it has large binder adhesion.

FF sheet that we introduce in this paper obtains characteristics equal to glass cloths in addition to the advantages of high productivity, good microvia hole processing and good handling equivalent to that of glass papers (see Figure 1). We propose FF sheet as ultra thin insulation layer material for HDI, laser drilling and build-up technology of PWBs instead of RCC.

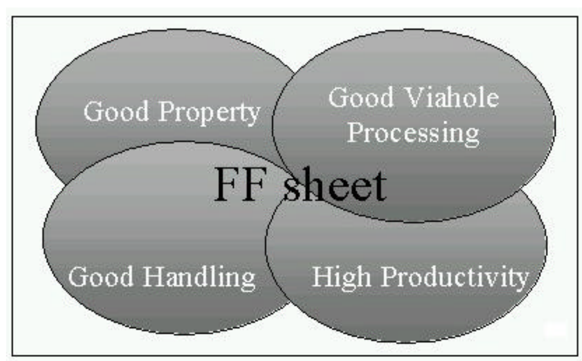

Figure 1 - Features of FF Sheet

Core Technologies of FF Sheet

FF (Flat glass fiber)

Since our company produces glass fibers (yarn) and weaves glass cloth (woven fabric) vertically for a long time, we have accumulated significant technology related to designing fiber structures and fabric styles. We have developed a deformed glass fiber that differs from conventional circle section fibers. The deformed glass fiber has an elliptical shape and we named this fiber FF.

FF has a long axis of 18 micrometers and a short axis of 4.5 micrometers. In other words, the average flat ratio is 1:4 as shown in Figure 2.

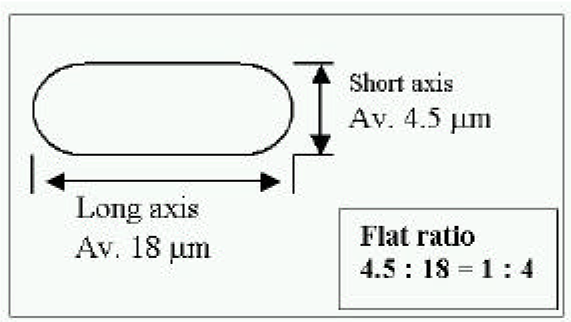

Figure 2 – Cross-Section Scheme of FF

The surface of FF is 1.3 times as large as conventional glass fiber. This larger surface of FF provides that more matrix resin surrounds FF.

Furthermore, FF has advantages in the dynamic characteristic of fiber itself and application to base material. FF has obtained high elasticity by computer analysis. It is about 2 times in long axis direction and about 1.1 times in short axis comparison with conventional fiber of same cross-section area as shown in Figure 3.

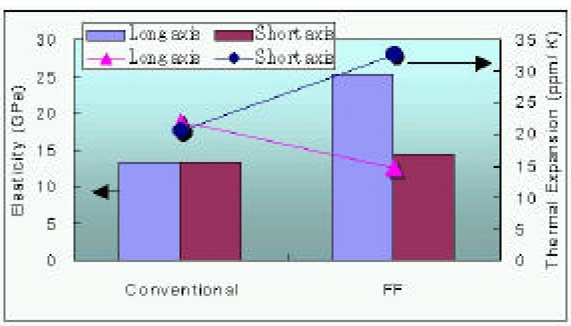

Figure 3 - Effects of Glass Fiber Shape on Laminate Elasticity and Thermal Expansion at Same Cross-Section Area Fibers

This means FF improves the reinforcement and the dimensional stability of PWBs in comparison with conventional glass fiber.

Filament Dispersion

FF sheet is formed with chopped filaments of certain length. The unique elliptical shape of FF helps to improve dispersion relative to conventional glass fiber because the flat area faces the force during the dispersion process. This phenomenon is a very important property and leads to a number of advantages for FF sheet.

Binder Technology

It is well known that the performance of glass fiber reinforced composite materials (laminates) depend on their binder and finish. We have significant experience on binder and finish of glass fiber and cloth production. It is difficult to obtain the tensile strength of non-woven material in organic solvent and good adhesive strength between glass fiber and resin matrix. We have studied a special binder that improved both the tensile strength and the adhesive strength. Recently we succeeded in obtaining an excellent binder and applied it to FF sheet.

Advantages of FF Sheet

Since FF sheet has excellent uniformity glass filament in the sheet, surface smoothness, thickness accuracy and easy laser drilling processability were demonstrated. Use of a High-performance binder has also improved the base material strength. In addition, non-woven fabrics can be used to improve the productivity relative to woven fabrics. We are sure that FF sheet offers both high reliability and high cost competitiveness for fine base material.

The following points are raised for the main characteristic of FF sheet.

1. Excellent thickness accuracy in very thin dielectric
2. Good laser drilling property of laminate
3. Good handling of FF sheet
4. Highly productivity

Evaluations and Results

Excellent Thickness Accuracy of Dielectric

It is a challenge to get transparent fabrics for PWBs. In cases of non-woven fabrics, material thickness influences not only laminate thickness but also thickness accuracy caused by matrix resin flow. Figure 4 shows the relation between base material thickness and weight of glass cloth, glass paper and FF sheet. In each base weight, FF sheet is much thinner than glass paper.

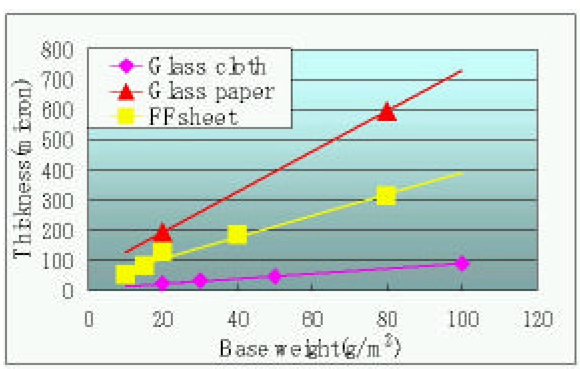

Figure 4 - Material Thickness vs. Base Weight of Glass Cloth, Glass Paper and FF Sheet

The cross-section figures of conventional glass paper and FF sheet are shown in Figure 5 and Figure 6, respectively.

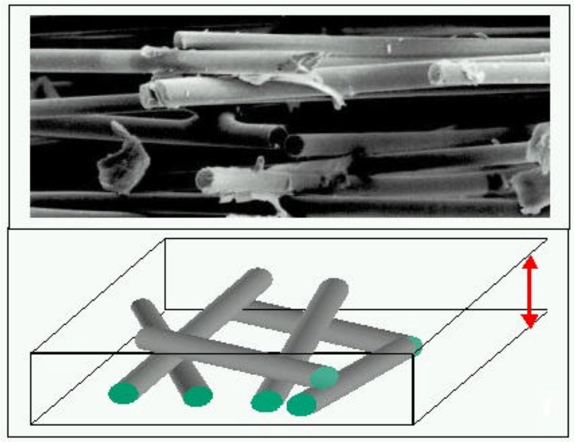

Figure 5 – Cross-Section Photo and Image Scheme of Glass Paper

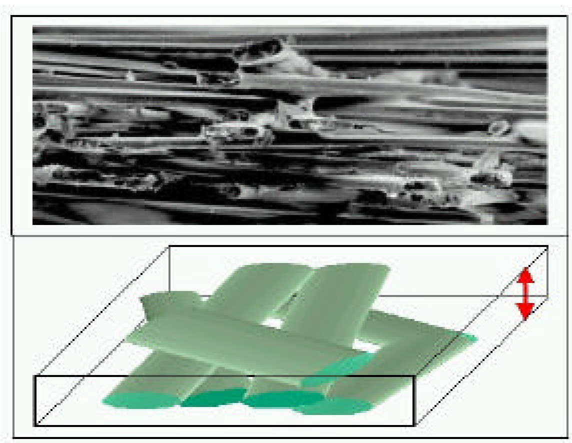

Figure 6 – Cross-Section Photo and Image Scheme of FF Sheet

There are large spaces between filaments in traditional glass paper. On the other hand, in FF sheet, there are much more glass fibers in the same thickness and its density is very high. Specifically, the bulk density has achieved over $0.2g/cm^3$ at FF sheet, while glass paper is in $0.12g/cm^3$. This results in improved uniformity and stabilized insulation layer thickness.

After laminating, FF sheet increases its glass content up to 40wt% (glass paper is 30wt% at most) and gains about $0.55g/cm^3$ as glass density (Glass paper is about $0.37g/cm^3$). FF sheet has achieved 30 micrometers as insulation thickness at $13g/m^2$ base material, which is the thinnest product at present as shown in Figure 7.

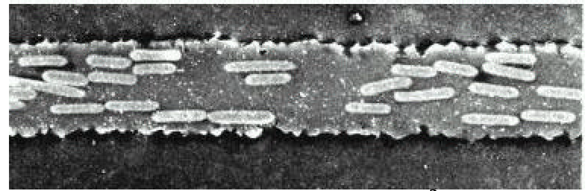

Figure 7 – Cross-Section of $13g/m^2$ FF Sheet Laminate

Figure 8 shows results of laminate thickness of each six measured points in the same laminate sample. FF sheet laminate has equal accuracy of thickness with cloth laminate.

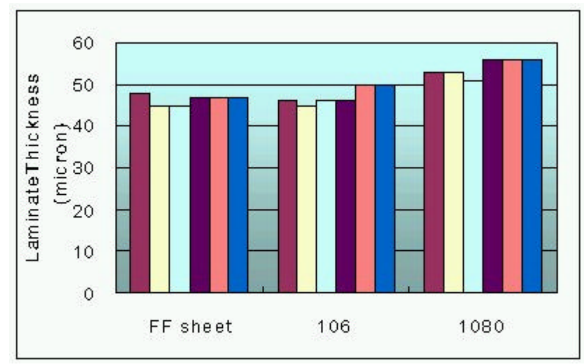

Figure 8 - Comparison of Laminate Thickness Among Six Points in A Laminate

Surface Smoothness in Very Thin Dielectric

Figures 9, 10 and 11 show the surface photograph of glass paper, FF sheet and 1080 cloth, respectively. It is observed that the image of glass fibers uniformly occupying all area in FF sheet in Figure 10, while sparse glass fiber overlaps in glass paper in Figure 9. In 1080 cloth, there is large space between strands. FF sheet improves the surface smoothness, no matter the direction tested, due to the greater uniformity of filling with this composition (Figure 12). Another big improvement is seen in reducing warp and distortion using the fine base material.

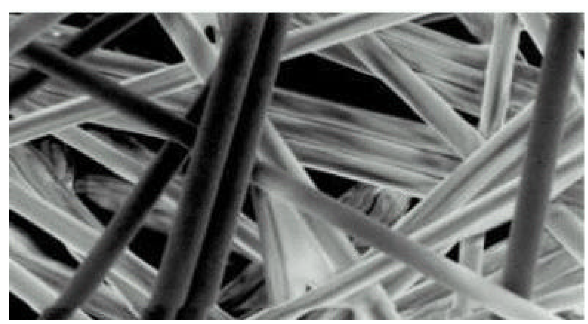

Figure 9 - Surface Photo of Glass paper

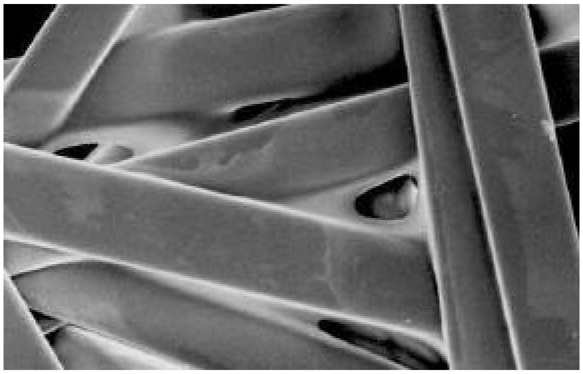

Figure 10 - Surface Photo of FF Sheet

Figure 11 - Surface Photo of 1080 Cloth

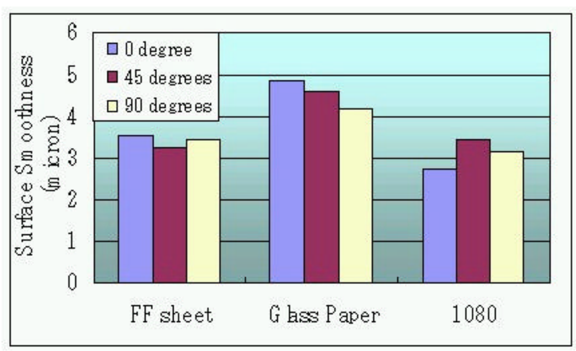

Figure 12 - Surface Smoothness Comparison of FF Sheet, Glass Paper and 1080 Type Cloth for Three

Excellent Laser Processability of Laminate

Perhaps the most improved characteristic using FF sheet is excellent microvia processing. The reduction of via size is an important element for impedance control in high frequency circuits in recent years, in addition to contributing to the improvement of wiring density[1]. For these reasons, particularly for via hole processing, laser drilling is becoming a mainstream and easy processing technique for high accuracy in PWBs.

There are many strand intersections of high glass density in conventional glass cloths and the glass density gaps are the obstacle to drilling processing. Although the recent development of ultra thin glass cloth reduced the inhomogeneous distribution of glass fiber in cloth has been paid attention to[2], it is impossible to eliminate the intersections in cloths. On the other hand, there are no strand intersections in FF sheet because of the non-woven nature of the material. Additionally, FF sheet has achieved a uniform distribution of the filaments in the matrix resin.

The actual via taper cross-section after laser and plating process is shown in Figures 13 and 14 as SEM photographs. Both of them confirm a well-finished microvia hole.

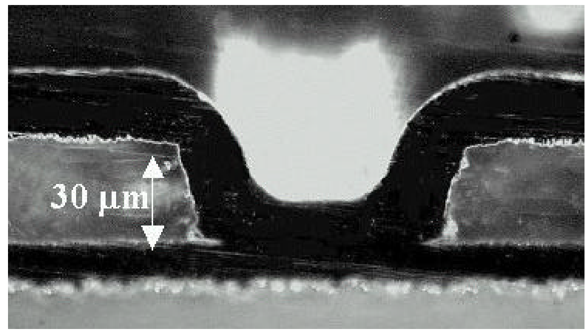

Figure 13 - Finished Condition of Laser Processing on 30 mm Type FF Sheet Laminate Laser= 10mJ – 1Shot

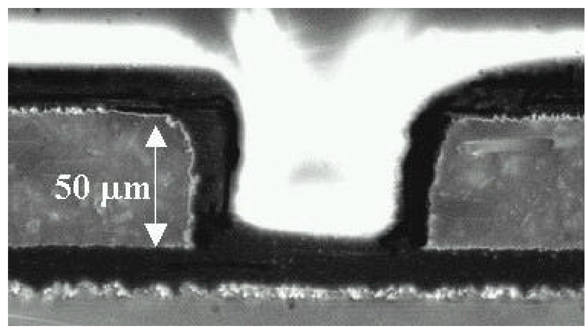

Figure 14 - Finished Condition of Laser Processing on 50 mm Type FF Sheet Laminate Laser= 10mJ – 1Shot

Good Handling and Good Character of FF sheet

Acrylic resins are generally used as a principal ingredient in conventional non-woven fabric binder. For the characteristics of acrylic resins, membrane strength and adhesion property to glass fiber are very good, and they sometimes have excellent solvent resistance to solvent and resin during prepreg treating. This means acrylic resin binders suitable for non-woven fabrics that need high base material strength and good handling. However, there are some disadvantages to laminated glass papers. In general, heat resistance in molten solder is very low, and the usage is limited such as CEM-3. We therefore have embarked to develop a new high performance binder suitable for FF sheet. It obtains both good handling equal to glass papers and much higher laminate characteristics equal to glass cloths.

Figure 15 is base material strength comparison between FF sheet and glass paper. FF sheet is achieving sufficient base material strength as shown in Figure 15. It exceeds glass paper considerably and has obtained 2 or more times in 5wt% binder adhesion degree, which is the general value for glass papers. This result indicates that FF sheet is sufficient to be treated in solvent and resin during prepreg treating.

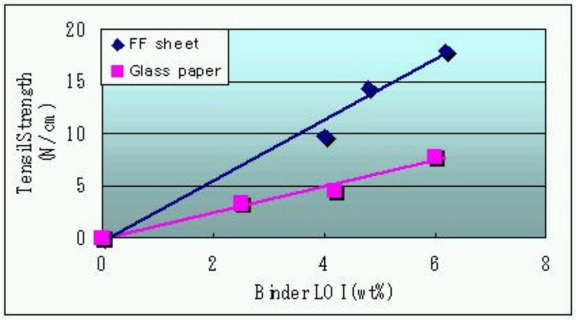

Figure 15 – Comparison of Base Material Strength Between FF Sheet and Glass Paper on 20g/m^2 Base Material

The comparison of base material tensile strength with fine cloths is shown in Table-1.

Table 1 - Comparison of Base Material Strength Among FF Sheet, 104,106 and 1080 Type Cloth

	Weight g/m^2	Fmax(warp) N/cm	Fmax(weft) N/cm
FF Sheet	20	21	16
104 type cloth	19	40	20
106 type cloth	25	40	40
1080 type cloth	47	98	78

Furthermore, refer to Table-2 and 3 for the mechanical strength and heat solder resistance of laminated materials.

Table 2 - Laminate Strength Comparison Between 1080 Type Cloth and FF Sheet

Item	Unit	Direction	1080	FF sheet
Tensile Strength	Mpa	0	300	200
		90	240	175
Tensile Modulus	GPa	0	17	11
		90	14	10
Bending Strength	Mpa	0	540	350
		90	430	310
Bending Modurulus	GPa	0	23	16
		90	20	14
Glass Fiber Content	wt%		50	40

Table 3 - Hot Solder Resistance of Laminate

Condition*	FF sheet	1080	Glass paper
30 min.	excellent	excellent	good
60 min.	excellent	excellent	good
90 min.	good	excellent	poor
Glass Fiber content (wt%)	40	50	30

*PCT 121°C / Solder 260°C 20sec dip

Other General Properties of FF sheet Laminate

We would like to introduce electrical and other characteristics of FF sheet laminate here below (Table-4 and 5) as detailed evaluation results by a treater. These characteristics vary, depending on whether epoxy resin (laminate formed is designated as EPX) or BT resin (laminate formed is designated as BTL) were used. FF sheet achieves these good laminate characteristics in addition to improving the traditional disadvantages of both handling and laser processability of fine glass cloths.

Figure 16 shows condition of IVH formation using 13g/m^2 FF sheet. It is observed that the excellent layer condition of FF sheet as well as RCC. We expect the usage of FF sheet for microvias in build-up technology in PWBs.

Table 4 - Electrical Characteristics of FF Sheet Laminate with Epoxy Resin and BT Resin

Test	Uni	Conditioning		EPX	BTL
Insulation	Ω	C-		5.0×10^{14}-10^{15}	5.0×10^{14}-10^{15}
		C-96/20/65+D-		5.0×10^{14}-10^{15}	5.0×10^{14}-10^{15}
VolumResistivi	Ω	C-		5.0×10^{14}-10^{15}	5.0×10^{14}-10^{15}
		C-		5.0×10^{14}-10^{15}	5.0×10^{14}-10^{15}
Surface	Ω	C-		5.0×10^{14}-10^{15}	5.0×10^{14}-10^{15}
		C-		5.0×10^{14}-10^{15}	5.0×10^{14}-10^{15}
Dielectric		C-	1MH	4.1	4.3
			1GH	4.0	4.0
			10GH	3.7	3.8
Dissipation		C-	1MH	0.01	0.00
			1GH	0.00	0.01
			10GH	0.00	0.01

Table 5 – Other Characteristics of FF Sheet Laminate with Epoxy Resin and BT Resin

Test	Unit	Conditioning		EPX	BTL
Glass Temperatur	℃	A	TMA	170-180	195-205
			DMA	195-205	225-235
Thermal Coefficien	ppm/℃	A	X	20-25	20-25
			Y	25-30	25-30
			Z	45-55	45-55
Het Resistanc		A		300℃/10min NoDelaminatio	300℃/10min NoDelaminatio
Cu Peel	N/cm	A	12μm	9.8-	9.8-
			18μm	12.0-	11.8-
			35μm	14.7-	13.7-
Chemical	-	23℃ 5Hrs	MEK	No	No
			20% NaOH	No	No
			20% HCl	No	No
Test	Uni	Conditioning		EPX	BTL
Water	wt	E-		0.5-	0.5-
Thermal Coefficie	Kcal mhr ℃	A		0.31	0.31
Flame (UL94)	sec	A		V-0	V-0
		E-		V-0	V-0
Specific		A		1.79	1.79
Flexural	MP	Lengthwi		127-	108-
		Crosswi		108-	88-
Flexural	MP	Lengthwi		9800	10800
		Crosswi		8800	9800
Elongati	%	Lengthwi		1.6	1.2
		Crosswi		1.5	1.1

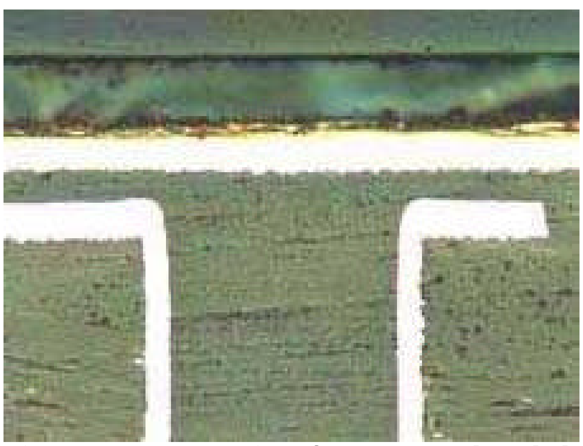

Figure 16 - Cross-section of IVH Core: Glass cloth (t=0.2 mm) Hole = 0.2mm Buildup: 13g/m^2 FF sheet (t=0.03mm)

Conclusion

Driven by the progress of high-density packaged electronics, PWB technology improvements will accelerate these trends with further improvements in thickness and microvia quality and density. This has been demonstrated by using increasingly fine fiber, but this introduces disadvantages in cost and handling issues. Using FF sheet and a novel base material can eliminate these deficiencies and trade-offs.

FF sheet, a novel base material using highly elliptical glass fiber introduced in this paper, surpasses the characteristics of glass cloth base materials in both cost competitiveness and good handling and surpasses the laminate characteristics of both RCC and glass paper. We expect that FF sheet will contribute substantially in the area of fine feature and high performance PWBs especially for microvias as an improved RCC alternative.

The characteristics of our FF sheet are summarized in following Table 6.

Table 6 – Organization of Base Material Properties

	Fine cloth	FF sheet	Glass paper
Hanndling	Poor	Good	Good
Surface smoothness	Good	Excellent	Poor
Drilling prosessability	Good	Excellent	Good
Heat resistanse	Excellent	Excellent	Poor
High productivity	Poor	Good	Good

Acknowledgment

This manuscript received Figures 13, 14 and 16 in addition to Tables 4 and 5 data as PWB characteristics by courtesy of Mitsubishi Gas Chemical Inc.

References

1. Toshihiko Nishio et.al, "Challenges in Printed Circuit Board for High Speed Applications," Journal of Japan Institute of Electronics Packaging,Vol.4,No.7,(2001).
2. Yasuyuki Kimura, "Specially Developed Glass Fabric for Ultimate Small Diameter Holes of High Density Board by Build-up Method," IPC Printed Circuits EXPO Proceedings,2000.