

Low Thermal Expansion and High Heat Dissipation Printed Wiring Boards

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Abstract

It is important to find ways to reduce the size and weight of satellite power supplies. This goal requires the development of surface mounting technology, in which the devices supply high power while using large-scale ceramic packages. The technology has been developed to make printed wiring boards (PWBs) with high heat dissipation and low thermal expansion. However, conventional glass-epoxy and aluminum core PWBs do not provide enough high heat dissipation and low thermal expansion to develop reliable PWBs. In this study, therefore we attempted to develop a new type of core PWB by utilizing CFRP (Carbon Fiber Reinforced Plastics) in order to overcome the above problems. It has been confirmed that the CFRP core PWB developed shows higher heat dissipation and lower thermal expansion than the conventional PWBs.

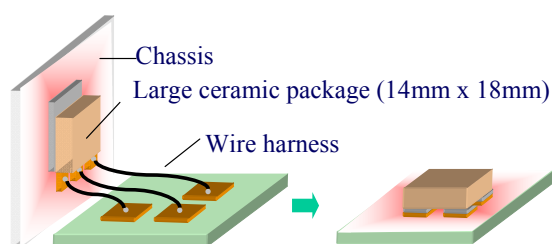
Key Words: Carbon Fiber Reinforced Plastics, Thermal Conductivity, Coefficient of Thermal Expansion

1. Introduction

A PWB (Printed Wiring Board) is used to mechanically support and electrically connect electronic components using conductive pathways. PWB technology is continually evolving towards reducing the size and weight of the PWB. These changes are often accomplished through advances in the following technologies: multilayer, surface mounting, fine-pitch, hole density, hole size, and multichip modules. Among these technologies, we focused on surface mounting to save space and allow increased component density on the printed wiring assembly effectively.

In particular, this technology will be very effective for application to satellite power supplies with high voltage power supplies (HVPS) for hall thrusters, since it is so important to reduce the size and weight of the power supply. However, no one has succeeded in the sur-

face-mounting of large ceramic packages on a PWB in the HVPS.



(a) Conventional structure (b) Proposed structure

Fig. 1. (a) Conventional and (b) proposed mounting structures for satellite power supplies.

To surface-mount the large ceramic packages, it is indispensable for the PWB to realize high heat dissipation and low thermal expansion. Generally, a glass epoxy

PWB has been used for surface mounting packages. In the PWB, however, the heat generated from the packages can not be easily dissipated since thermal conductivity of glass epoxy materials are as low as $0.3 \text{ Wm}^{-1}\text{K}^{-1}$.

A metal core PWB is known to have high heat dissipation ability. The core material is selected in aluminum alloy, copper, and copper/iron-nickel alloy/copper (CIC). The aluminum alloy has generally been used for the core material since this alloy has not only the high thermal conductivity of $170 \text{ Wm}^{-1}\text{K}^{-1}$ but also the low specific gravity of 2.7 g/cm^3 . However, an aluminum alloy (24ppm/K) has higher thermal expansion than ceramics (7ppm/K). To overcome the defects described above, Carbon Fiber Reinforced Plastics (CFRP) is a promising candidate to help develop the PWB required.¹⁻²⁾

In this paper, a novel CFRP core PWB manufacturing process is proposed.

2. Proposed manufacturing process and fabrication method

2-1. Current process

Conventional manufacturing process flow will be described first so that our proposed process for CFRP core PWB can be clearly understood. Figure 2 shows the schematic illustration of current process flow where each step is depicted in cross-sectional view. In this figure, a first through hole is drilled in the CFRP core material (step b). The core material, insulating prepregs and copper foils are laminated in vacuum conditions (step c). In the general method the prepregs used are made of glass epoxy materials. Then the first through hole formed is filled up with the epoxy resin by its re-melt and flow on lamination. A second through hole is drilled approximately coaxially with the first through hole (step d), where the second through hole has a diameter smaller than that of the first through hole. The subsequent processes are not described here since these processes are the same as the glass epoxy PWB processes.

Unfortunately this current method has some serious problems.

First, conductive carbon powder is generated from the side wall of the first through hole. Electrical reliability will be degraded by diffusion of the conductive powder into the insulating resin in the lamination (step c). When the CFRP core PWB is cut for product, a similar

problem will occur due to the emergence of the carbon fibers.

Second, barrel crack may occur since the coefficient of thermal expansion (CTE) of the conventional insulating resin is largely different from that of CFRP. The heat dissipation will also become low since the insulating resin with low thermal conductivity exists between the signal through hole and the CFRP core.

2-2. Proposed process

Figure 3 shows the schematic illustration of proposed process flow where each step is depicted in cross-sectional view.

In this figure, copper clad laminate made from CFRP prepreg is prepared (step a). A first through hole is drilled in the CFRP core material (step c) and the CFRP core is plated (step d). This method prevents the plating layer from diffusing carbon powder. However, the CFRP core becomes heavy, and CTE mismatch between the copper and the CFRP core will bring about interface delamination. Other than side wall of the first through hole, there is no need for copper plating on the surface. Therefore unnecessary copper plating is removed (step e). Carbon powder is not generated, since carbon fibers do not appear from the CFRP core surface after patterning.

The CFRP core, insulating prepregs and copper foils are laminated (step f). The Prepregs are made of epoxy resin containing alumina filler, and its hardener has thermal conductivity of $3 \text{ Wm}^{-1}\text{K}^{-1}$ and CTE of 30ppm/K. The First through hole is filled up with the epoxy resin containing alumina filler with high thermal conductivity and low thermal expansion rather than epoxy resin. As a result, the PWB has high electrical reliability and high heat dissipation.

A second through hole is formed approximately coaxially with the first through hole, where the second through hole has a diameter smaller than that of the first through hole (step h). The board is patterned (step i). It is not necessary to describe the subsequent processes here.

To prevent carbon fiber from emerging through the side wall of the PWB in the cutting process, all cutting lines for the products pass through either first or second through holes as shown in Fig.4. The side wall of the first and second through holes has been covered, so carbon fiber will not emerge in the cutting process for the product.

2-3. Fabrication method of current and proposed PWBs.

In Fig. 2 and 3, the manufacture process is shown for a two-layer board. In the practice process, a four-layer board was fabricated by laminating glass epoxy material between the two-layer boards.

The two kinds of CFRP core boards were manufactured by using the pitch carbon fibers with two different thermal conductivities. They are the carbon cloth with a thermal conductivity of $500 \text{ Wm}^{-1}\text{K}^{-1}$ and the unidirectional carbon fiber of $800 \text{ Wm}^{-1}\text{K}^{-1}$, respectively.

Thermal conductivity, CTE, and electrical reliability were estimated in the CFRP core board utilizing the carbon cloth. In the CFRP core board employing unidirectional carbon fiber, thermal conduction ability and surface mounting reliability were investigated to clarify the potential of the PWB assembly.

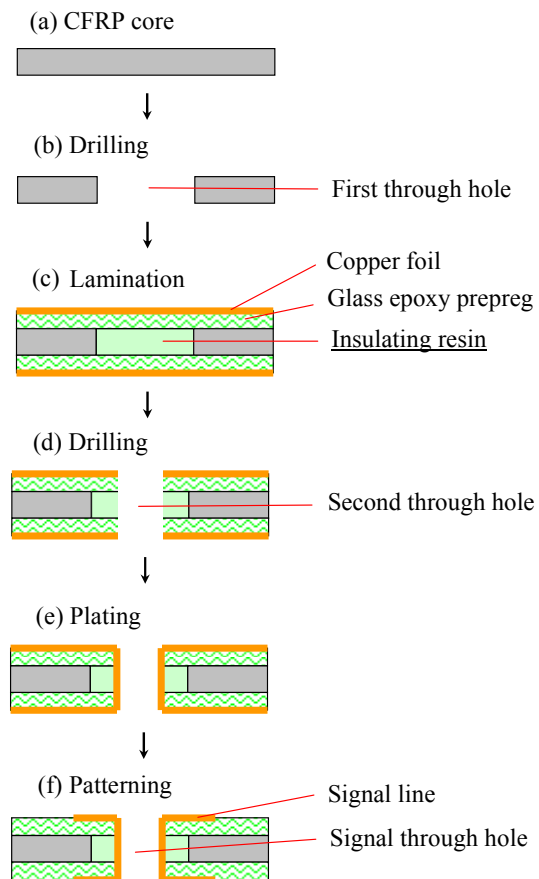


Fig. 2. Schematic illustration of current process flow. Each step is depicted in cross-sectional view.

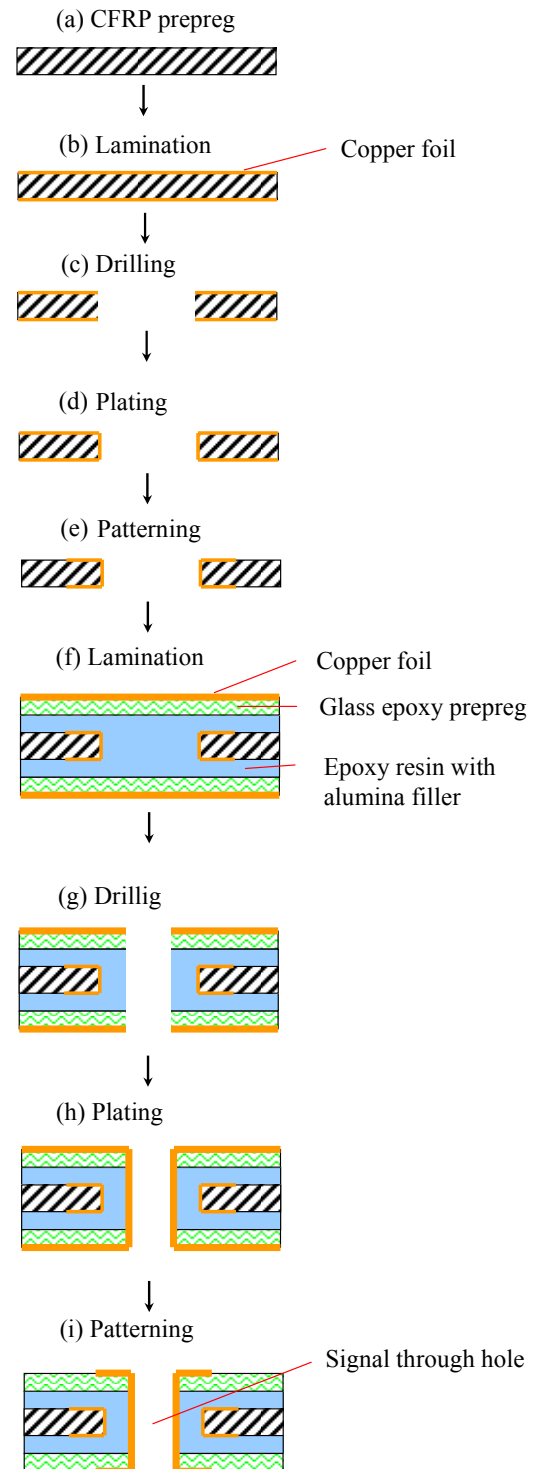


Fig. 3. Schematic representation proposed process flow. Each step is depicted in cross-sectional view.

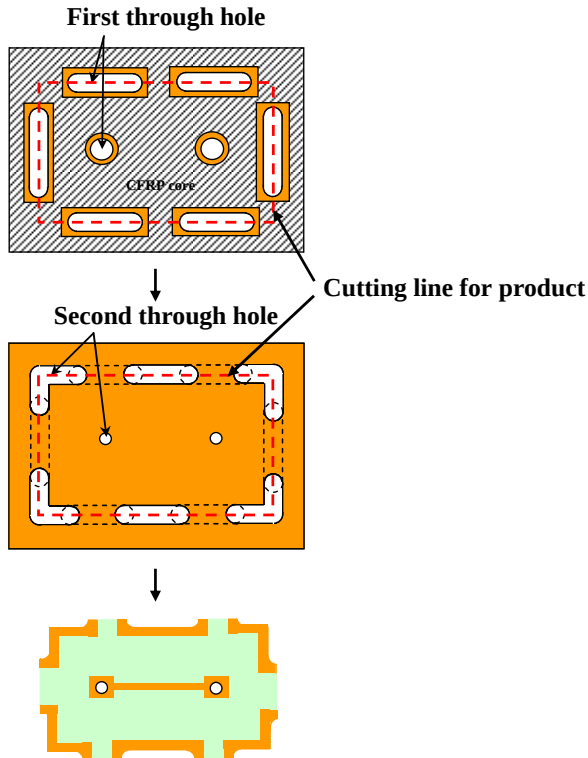


Fig. 4. Position relation of First and Second through holes.

3. Results and Discussion

3-1. Structure

Figure 5 shows the CFRP core PWB developed using $500 \text{ Wm}^{-1}\text{K}^{-1}$ carbon fiber cloth. In this board the plane size and thickness were 180mm x 130mm, and 3.3mm, respectively. The weight was evaluated to be 190g. The carbon fiber did not appear on the side wall of the board due to being covered by epoxy resin with alumina filler or copper plating.

Figure 6 shows a cross sectional view of the CFRP core PWB. The signal through hole was formed separately from these CFRP cores by the epoxy resin with alumina filler. The through hole provided a high resistance of more than $65\text{M}\Omega$ at an applied voltage of 250V, which was estimated by Flying Probe Checker.

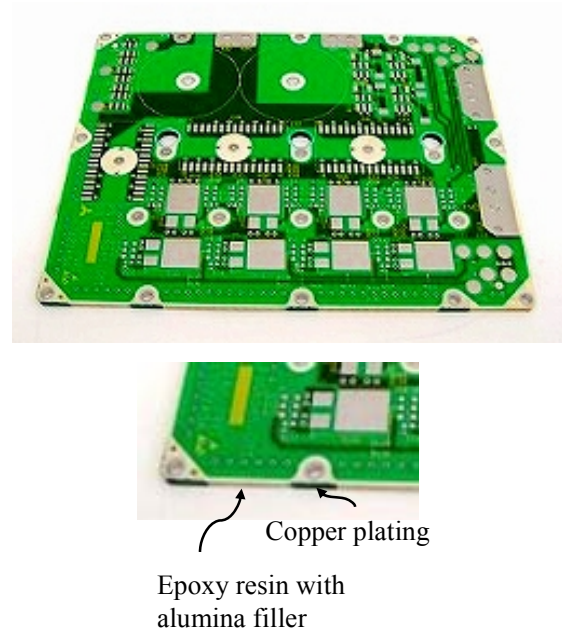


Fig. 5. CFRP core PWB developed.

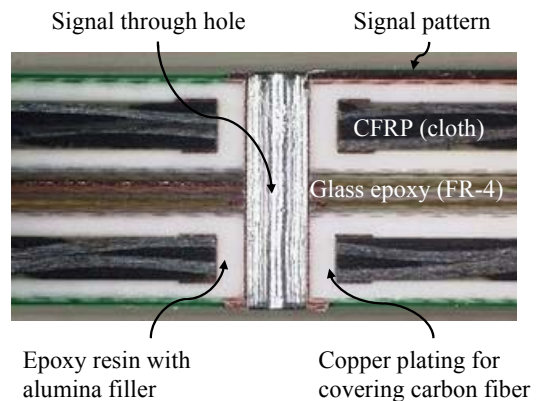


Fig. 6. Cross-sectional view of CFRP core PWB as developed.

3-2. Thermal properties

CTE and thermal conductivity of the CFRP core PWB were measured. These properties depend largely on content of residual copper in a PWB. The measurement was carried out for the CFRP core PWB both with and without copper pattern in all layers.

Table 1 lists CTE of the CFRP core PWB with and without copper pattern in the direction of in-plane and out-of-plane. The CTE's in the temperature range from 30 to 100 °C were 2.1ppm/K and 9.3 ppm/K with and without

the copper pattern, respectively, in the direction of in-plane. The CFRP core PWB possesses almost the same CTE's as the ceramic package, which will be available for suppression of solder joint cracks in this PWB.

In the direction of out-of-plane, the CTE is closely related with electrical reliability derived from through holes in the CFRP core PWB. The CFRP core PWB shows a lower CTE than the glass-epoxy PWB in achieving electrical reliability. It was proved that the resistance change is $\pm 10\%$ in this board when performing a heat cycle in the range from -65 to 125 °C with 500cyc.

Table 1. CTE of the CFRP core PWB.

CTE in the direction in-plane (ppm/K)		
Temperature range (°C)	without pattern	with pattern
30~100	2.1	9.3
100~200	6.8	14.6
CTE in the direction out-of-plane (ppm/K)		
Temperature range (°C)	without pattern	with pattern
30~100	34.3	34.9
100~200	112.1	94.0

Thermal conductivities were measured by using the system configuration as shown in Fig. 6. Figure 7 represents a panel made for measurement of thermal conductivity in the direction of in-plane. Here the CFRP core PWB was sliced in the out of plane direction. The sliced laminae were stuck together face to face to form a layered panel.

Thermal conductivity λ was calculated by using the following expression:

$$Q = \lambda \times A \times \frac{\Delta T}{\Delta x}$$

where, Q is heat quantity, A sample area, Δx sample thickness, and ΔT temperature difference in position between (1) and (2) as shown in fig.6.

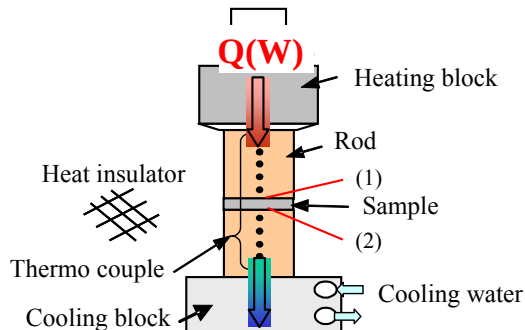
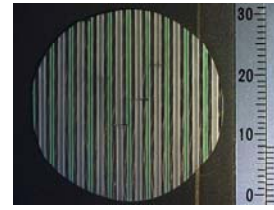


Fig. 6. System configuration for thermal conductivity measurement.



Without pattern

Fig. 7. Measurement sample for in-plane thermal conductivity. Top view

Table 2 indicates thermal conductivity of this CFRP core PWB. Thermal conductivities were $1 \text{ Wm}^{-1}\text{K}^{-1}$, and $50 \text{ Wm}^{-1}\text{K}^{-1}$ with and without the copper pattern, respectively, in the direction of in-plane.

Table 2. Thermal conductivity of the CFRP core PWB.

	Thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$)	
	In the direction in-plane	In the direction in-plane
With pattern	No data	1.1
Without pattern	48	0.8

3-3. Thermal conduction ability of the PWB assembly

Figure 8 shows configuration of the thermal test under vacuum. Thermal conduction ability of glass epoxy, aluminum core, and CFRP core PWB assemblies were compared. A chip resistance was mounted in each PWB for an electric power input of 3W. The difference in the temperature of the thermo couple (1) near source and (2) about 100mm from source was measured in each PWB.

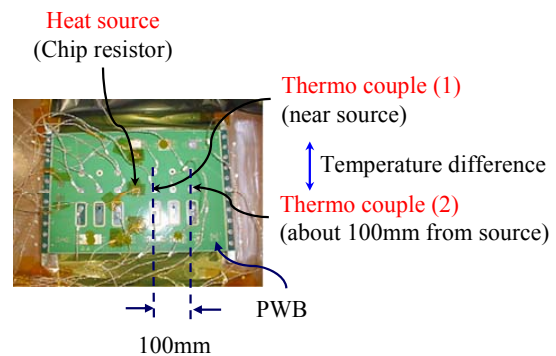


Fig.8. Configuration for thermal conduction measurement under ultimate vacuum (1×10^{-4} Torr).

Figure 9 shows the time dependence of temperature between thermo couple (1) near source and about 100mm from source in glass epoxy, aluminum core, and CFRP core PWB assemblies for electric power input of 3W. As a result, glass epoxy PWB had a temperature difference of temperature of about 30°C. Aluminum and CFRP core PWB was lower than 5°C. Thermal ability of CFRP core PWB is higher than that of aluminum core PWB when using unidirectional carbon fiber at $800 \text{ Wm}^{-1}\text{K}^{-1}$. As for carbon cloth fiber at $500 \text{ Wm}^{-1}\text{K}^{-1}$, thermal performance of CFRP core PWB will nearly equal that of the Aluminum core PWB.

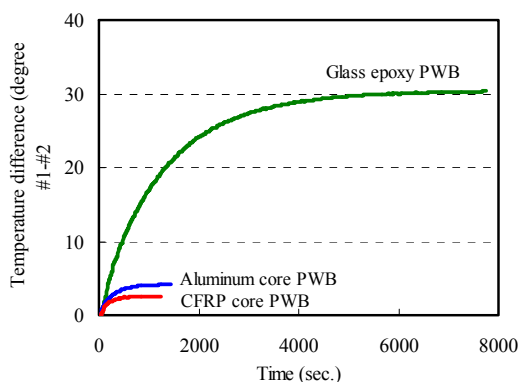


Fig. 9. Time dependence of temperature between thermo couple (1) near source and (2) about 100mm from source in glass epoxy, aluminum core, and CFRP core PWB assmblies for electric power input of 3W.

3-4. Surface mount reliability of the PWB assembly

Figure 10 shows a cross-sectional view of (a) glass epoxy, (b) aluminum core, and (c) CFRP core PWB assemblies after performing the heat cycle test in the range from 30 to 100°C with 1000cyc. The large ceramic package (MosFET:14mm×18mm) was mounted on the surface of each PWB. Solder joint cracks occurred in the aluminum core PWB.

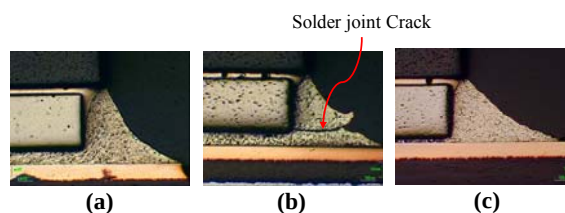


Fig. 10. Cross-sectional view of (a) glass epoxy and (b) aluminum core, CFRP core (c) PWB's after heat cycle test in the range from -30 to 100 °C with 1000cyc.

4. Conclusion

We developed the new type of CFRP core PWB utilizing high thermal conductivity carbon fiber. This PWB has high reliability with respect to insulation, high through hole, thermal conductivity, and CTE. This CFRP core PWB, having both high heat dissipation and high surface mount reliability of a large ceramic package, will be effective in reducing size and weight of satellite power supplies.

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6. References

- (1) K. Vasoya, C.Burch: "Key Benefits of Carbon Fiber in a Printed Circuit Board (PCB) and Integrated Circuit (IC) Substrate", International SAMPE Symposium and Exhibition, Conf. Proc., 26 (2006).
- (2) Y.Maeda: Carbon Fiber-New Applications and Future Prospect of Technology and Market (CMC,2000) ed. ,p.15 [in Japanese].