Fabrication of a High Heat Dissipating Double-Sided Printed Circuit Board

by Hu Wencheng, Yang Chuanren, Qiu Yan & Zhu Lin*

The technique for fabricating high heat dissipating double-sided printed circuit boards (PCB) was studied and we have developed an improved process to prepare them. Films of aluminum oxide are grown on circuit elements by anodization. Polyimide mixed with fine aluminum nitride powder is used as a binder to improve the thermal conductivity. The aluminum-base PCB is prepared after lamination, etching and subsequent steps. Thermal resistance testing of the PCB showed a value of less than 0.125 K°/W·m².

Printed circuit boards (PCB) are used in electronic devices and components over a wide range of applications.[1] At present, continuing trends in PCB technology are toward higher circuit density, higher accuracy and miniaturization.[2] Smaller spaces and higher-powered integrated circuits produce more energy that must be dissipated, which influences the thermal characteristics of the electronic package,[3] as well as its design, in order to avoid damage to the components. The traditional method is to use hardware, such as an electric fan, to lower the temperature. This in itself requires a large amount of space, which is not in accord with the trends of PCB development.

In order to meet such high heat dissipation requirements, there are available ceramic PCB bases which exhibit high thermal conductance and metal bases, such as aluminum substrates.[4] The advantages of the metal bases are ease of fabrication, no restriction on size and relatively low cost. The fragility of ceramic baseboards leads to the opposite: relatively high cost, difficulty in fabrication and restrictions on practical size. Hence, the metal-based PCBs are the primary avenue of research into high heat dissipating PCBs, which can be applied in IGBT modules, electric vehicles, switch power modules and high-power devices.

At present, the metals suitable for metal-based PCBs are aluminum, copper and Invar.[5] Aluminum exhibits low density, high heat conductivity, low cost and excellent mechanical processing characteristics. Hence, it is commonly used in metal-based PCBs. However, its expansion coefficient is relatively large. The expansion coefficient of copper is lower than that of aluminum, and its heat conductivity is excellent, but its cost is higher and copper is heavier, increasing the weight of the PCB. The expansion coefficient of Invar is very low, but its heat conduction coefficient is very small. Hence, Invar is usually used in PCBs where thermal expansion matching is the key factor. In this work, we used aluminum as the metal base.

Heat dissipation in aluminum based PCBs

Aluminum substrates are primarily used in power circuits, where the heat produced by the circuit must be fully considered in the design of the circuit. Generally, the circuit is designed according to IPC-2221 and 2222.[6] For a given circuit width, where the temperature rise is below 20°C (68°F), it can be said that such a PCB has no thermal problems. Such a metal-based PCB is shown in Fig. 1.

The primary direction of thermal flow produced by the components in a PCB is:

Components → Circuit copper layer → Binder layer → Alumina layer → Aluminum layer → Air

Nuts & Bolts: What This Paper Means to You

As the various elements on printed circuit boards get smaller and smaller, and more of them are densely packed on the board, more heat is generated which must be carried away. The venerable electric fan just cannot do it alone anymore. In this work with aluminum bases, a polymide mixed with aluminum nitride powder is added to improve the thermal conductivity of the circuitry itself.

* *Corresponding author:*
Dr. Hu Wencheng
College of Microelectronics and Solid Electronics
University of Electronic Science and Technology of China
Chengdu, Sichuan, 610054 People's Republic of China
E-mail: huwc@uestc.edu.cn

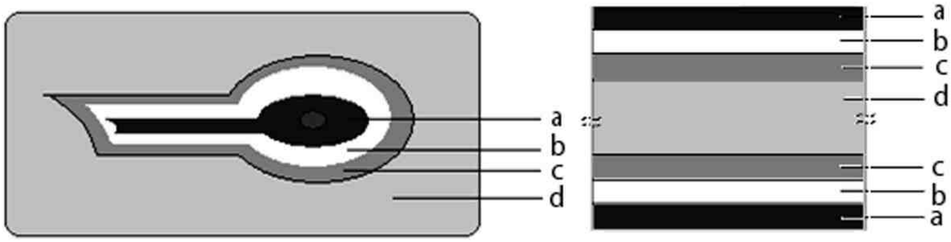

Figure 1—Portion of a high heat-dissipating printed circuit board: (a) circuit, (b) binder layer, (c) alumina layer and (d) aluminum base.

It is obvious that all steps involve heat conduction, except for the last step, which involves convective heat transfer. Conductive heat transfer can be expressed as:

$$Q = \frac{\Delta t}{\Sigma(\delta_i / \lambda_i A_i)}; R_i = \delta_i / \lambda_i A_i \quad (1)$$

where Δt = temperature difference,
δ_i = thickness of the thermal conduction layer,
λ_i = thermal conductivity,
A_i = area of the thermal conduction layer and
R = thermal resistance.

The equation of the convective heat transfer is:

$$Q = \alpha A \Delta t = \frac{\Delta t}{\frac{1}{\alpha A}}\ ;\ R = \frac{1}{\alpha A} \quad (2)$$

where α = heat transfer coefficient.

Generally, the area of heat transfer (*i.e.*, the bare aluminum area) is far greater than that for heat conduction (the area of the copper wire). From the above equations, the thermal resistance of the convective heat transfer is much smaller than that of heat conduction, and the thermal resistance is primarily concentrated in the heat conduction layers. The thermal resistance of the heat conduction layers is in a series-wound form, and is directly proportional to the thickness and inversely proportional to the thermal conductivity. Considering the thermal conductivities of the other layers, the thermal conductivity of the binder layer is small. Hence, the thermal resistance of the binder layer is at a maximum. The magnitude of the thermal conductivity and the thickness of the binder layer directly influence the heat dissipation performance of the PCB.

Preparation process

The preparation sequence for the aluminum substrate is shown in the flow diagram of Fig. 2. The goal of the first exposure and development of the photosensitive emulsion is (1) to anodize the areas of the circuit and the hole walls of the aluminum base and (2) prevent an anodized layer on the heat dissipating area from forming which would otherwise reduce the thermal resistance. The thickness of the anodized alumina layer should be limited to 50 μm (0.002 in.). We used polyimide mixed with fine aluminum nitride powder as the screen-printing binder. After the screen-printing process, the binder was coated on the circuit and hole wall areas. Raising the temperature to 190°C (374°F), the copper foil, containing pre-drilled holes, was laminated onto the aluminum base. Because of the low thermal conductivity of air, a vacuum was applied during

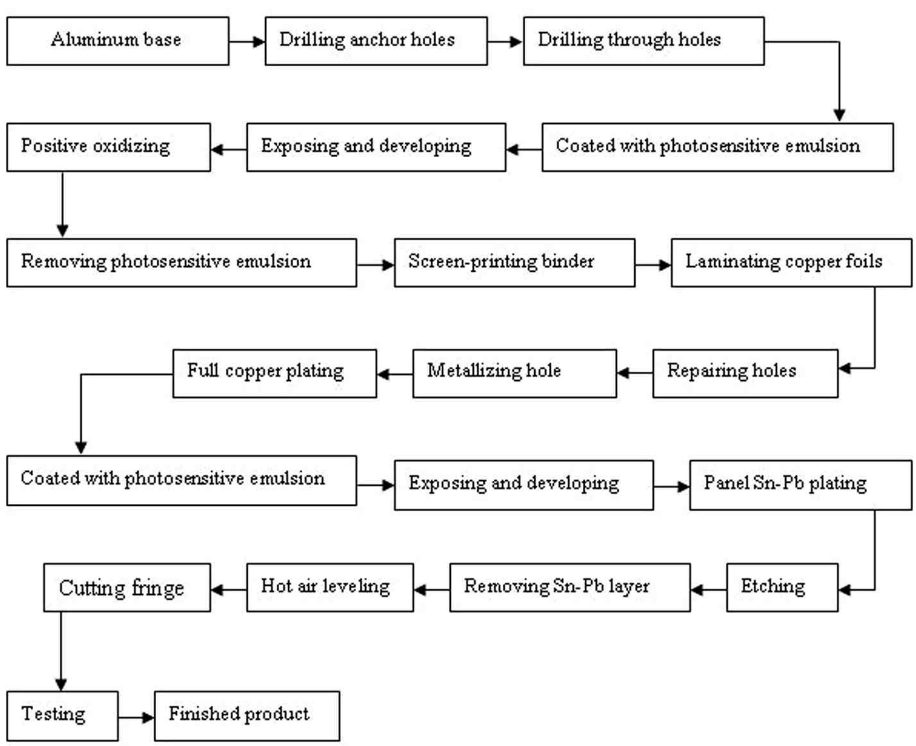

Figure 2—Technological process of preparing aluminum substrate printed circuit boards.

the lamination process in order to prevent air from remaining in the binder. The experimental pressure used here was 80 kPa (11.6 lb/in^2).

The hole repair process is intended to assure that (1) all holes in the aluminum base plate correspond to those on the copper foil and (2) the surface of alumina layer on the hole walls remain smooth. The hole metallization process was traditional electroless copper plating. The electroless copper layer thickness was about 0.5 μm (19.7 μ-in.). The copper plating process increased the thickness of the copper layer on the hole walls to about 5 μm (197 μ-in.). The second exposure and development of the photosensitive emulsion was done in order to electroplate the Sn-Pb layer on the circuit. The etching process was the traditional alkaline copper chloride process.

Thermal conductivity of polyimide mixed with fine aluminum nitride powder

The thermal conductivity values of bonding sheets typically used in the PCB industry are too low. For example, the thermal conductivity of FR-4 b-stage resin is about 0.25 W/m·°K. Hence, they cannot be directly applied to heat dissipating PCBs. Aluminum nitride exhibits high thermal conductivity and insulating resistance. Hence, we used polyimide mixed with fine aluminum nitride powder as a binder to improve its thermal conductivity.

The theoretical thermal conductivity of an aluminum nitride single crystal is estimated to be 320 W/m·°K.[7] In the present study, we determined that aluminum nitride ceramic material with a thermal conductivity as high as 260 W/m·°K could be prepared by hot-press sintering. Fine aluminum nitride powder was prepared using a self-propagating synthetic sintering method. The powder size was about 1 to 3 μm (39 to 118 μ-in.), as shown in Fig. 3. We studied the effect of the concentration of aluminum nitride powder in the binder on the thermal conductivity, and the result is shown in Fig. 4. The thermal conductivity increased with increasing aluminum nitride content. Above an aluminum nitride content of 70%, the thermal conductivity still increased rapidly, but the strength between the binder and base rapidly weakened. Hence, the optimum content of aluminum nitride in the binder was 60 to 70%, corresponding to a thermal conductivity of 5.57 to 15.16 W/m·°K. Further increases in the thermal conductivity of the binder were unnecessary, because the thermal conductivity of the anodized layer was the main thermal resistance when the thermal conductivity of the binder reached a certain value.

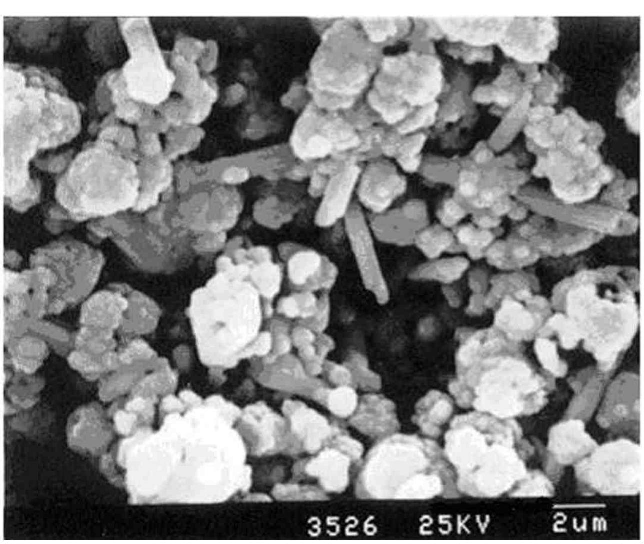

Figure 3—SEM image of fine aluminum nitride powder.

The performance of high heat dissipating double-sided PCBs

The high heat dissipating double-sided PCB was tested, and its characteristics are shown in Table 1. Compared with a conventional PCB, the high heat dissipating double-sided PCB performs favorably well, and its thermal resistance per unit area is less than 0.125 K°/W·m^2.

Summary

In conclusion, we have described a process for the preparation of high heat dissipating double-sided PCBs with improved thermal conductivity, using a polyimide mixed with fine aluminum nitride powder as a binder, prepared by a self-propagating synthetic sintering method. We also studied the effect of the ratio of aluminum nitride powder in the binder on the thermal conductivity. The high heat dissipating double-sided PCB was tested according to standard specifications, and the results showed that its thermal resistance per unit area was less than 0.125 K°/W·m^2. Other characteristics were comparable to those of conventional PCBs.

Table 1
Characteristics of the high heat dissipating double-sided printed circuit board

Performance	Experimental Value
Bonding strength of Cu foil	>1.8 kgf/cm
Thermal shock test (288°C; 550°F)	>30 sec
Dielectric breakdown strength	>30 kV
Volume resistance of resin layer	>10^{12} Ω·cm
Thermal resistance per unit area	<0.125 K°/W·m^2
Thermal cycle (Boil & freeze water cycle)	10 cycles (no change)

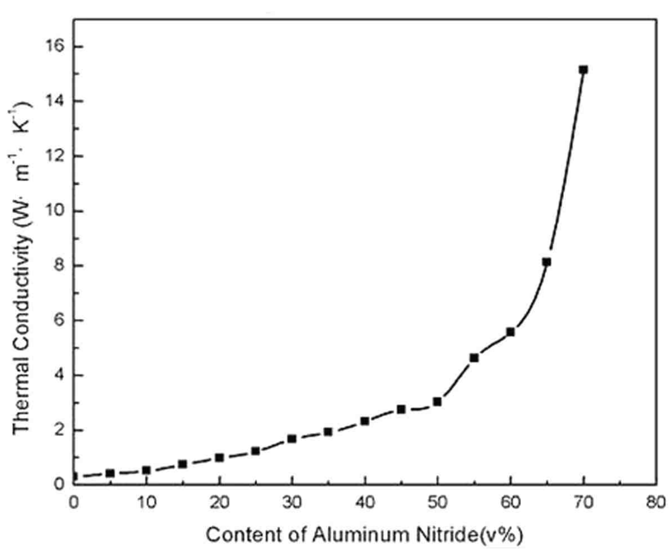

Figure 4—Relation between the thermal conductivity and the amount of fine aluminum nitride powder in binder.

References

1. C.F. Coombs, *Printed Circuit Handbook* (4th Ed.), McGraw-Hill, New York, NY, 1996.
2. L. Han & A. Voloshin, *Microelectronics Reliability,* **44**, 853 (2004).
3. Z. Zhao, *Microelectronics Reliability*, **43**, 785 (2003).
4. N. Chandler & S.G. Tyler, *Microelectronics Journal*, **26**, 393 (1995).
5. C. Jianhua, *Communication of Chemical Engineering Design*, **26**, 50 (2000)(in Chinese).
6. IPC-2221 and IPC-2222, Design Standards for Rigid Printed Boards and Rigid Printed Board Assemblies, IPC, Bannockburn, IL.
7. L. Guang-chuan, L. Jin-sheng & L. Xiu-hong, *Trans. Tianjin University*, **6**, 69 (2000).

About the Authors

Hu Wencheng is an Associate Professor at the College of Microelectronics & Solid Electronics, University of Electronic Science & Technology of China (UESTC), in Chengdu, China. He received his Masters degree in Inorganic Chemistry and Engineering from Sichuan University (SCU) in 1991.

Yang Chuanren is a Professor at the College of Microelectronics & Solid Electronics, University of Electronic Science & Technology of China (UESTC). He received his Masters degree in Electronic Materials and Components from the University of Electronic Science & Technology of China (UESTC) in 1986.

Qiu Yan is a Graduate Student at the College of Microelectronics & Solid Electronics, University of Electronic Science & Technology of China (UESTC). She received her Bachelors degree in Applied Chemistry from Sichuan Normal University (SCNU) in 2002.

Zhu Lin is a Graduate Student at the College of Microelectronics & Solid Electronics, University of Electronic Science & Technology of China (UESTC). She received her Bachelors degree in Ceramic Materials from Shandong University (SDU) in 2003.

Membership Report AESF

34 Members Celebrate Milestones

(August 2005)

55 Years
Clifford A. Peter, Milwaukee

35 Years
Joseph Z. Holody, Toronto
Robert W. Marsch II, Philadelphia

30 Years
Martin E. Galle, Garden State
Keith G. Kitchens, Southeastern
Stephen G. Szucs, Cincinnati/Dayton

25 Years
William Bitler, Susquehanna Valley

20 Years
Dr. Joseph A. Abys, Garden State
Timothy J. Lamb, Portland
Darrell Swanson, Santa Clara Valley

15 Years
Gustavo A. Battel, Orange County Metro
Erik Boye-Rasmussen, International
Steven Carter, Los Angeles
Michael D. Dattilo CEF, Seattle Puget Sound
Gary Dekermenjian, Los Angeles
Raymond Evans, New York
Satoshi Kawashima, International
Mitsuhide Maeda, International
Yeung-Kit Ming, Taipei

10 Years
Terry Burgess, Dallas/Ft. Worth
Larry Emch CEF, Cleveland
Vicente Gomez, Mexico City
Charles R. Groom, Detroit
Michelle Hoogeveen, Grand Rapids
John J. Kelley III, Providence/Attleboro
Gerry Leroux, Montreal
Keith Mallitt, Australian
Donald E. Moser CEF, Garden State
Mark Muchoney CEF, Philadelphia
Gary Null, Indianapolis
John D. Parsons, Los Angeles
Tom L. Ritzdorf, Seattle Puget Sound
Lee A. Swope, Cleveland
Kevin Wasag CEF, Chicago

23 New Members are Introduced

(August 2005)

Boston
Matthew Pearlson,
Buffalo
Molly Turner, Moog Inc.
Chicago
Cliff Spiro, Cabot Microelectronics Corp.
Cleveland
Danijela Milosevic, SIFCO ASC
Detroit
Steve Kennedy, KC Jones Plating Company
Mike Minier, KC Jones Plating Company
Mike Sigman, KC Jones Plating Company
Jie Xiao, Wayne State University
Grand Rapids
Mike Dennis, Meridian Automotive Systems
Charles Koster, Master Finish Co.
Michelle Rioux, Valley City Environmental Services
Warren Taylor, Master Finish
Los Angeles
Cindy Klinger, AnaCon Laboratories Inc.
Mexico City
Carlos Dominguez-Rios, CIMAV
New York
Charles Sexton, EIDRE Corp.
Pittsburgh
Warren Ritchey, Ritchey Metals Company
Silicon Valley
Geeta Godgul, Western Digital
Southeastern
Kieta Goolsby, Process Engineering Co., Inc.
Upper Midwest
Dennis Blaugh, C & R Plating Corp
Tim Kurcz, K.C. Jones Plating
Stephen Qualy, ADC Broadband Inc.