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DBC Technology for Low Cost Power Electronic Substrate Manufacturing

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Abstract

This paper deals with a method for low cost power electronic substrates creation, which are used for power electronic devices. Direct bond copper (DBC) technology is suitable for creating substrates with excellent thermal and electrical conductivity and good mechanical properties. Furthermore, DBC allows to create copper layers with the thickness of hundreds micrometers in one processing step. In this work, the muffle furnace is used for bonding copper to ceramic. Temperature profile, oxygen concentration during the bonding process and final treatment is described. The last part summarizes the results and presents advantages of this method.

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1. Introduction

The miniaturization is the current trend in power electronic modules, but there is a problem with cooling of these modules. The properties of the most common used substrates, such as glass-epoxy substrate, are insufficient in the field of power electronics. Ceramic and metal substrates are used, because they have high reliability, good mechanical properties and excellent heat conductivity. These substrates, based on ceramics and metals, are used in many applications, for example power LED, solar cells, automotive industry and electrical traction. [1,9]

One of the promising methods used for the production of power electronic substrates is Direct Bond Copper technology (DBC). In comparison with other deposition techniques, such as screen printing or electrochemical

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plating, DBC allows to create copper layers with the thickness of hundreds micrometers in one processing step. This process can be very cost effective mainly in the mass production. It is suitable for high currents conduction and heat transfer from power electronic components. [1,9]

The ceramic material is an insulation base of the power electronic substrate. The most commonly used ceramic is alumina Al_2O_3 . The main advantage of alumina is the low production cost and the thermal conductivity in order of tens $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$. The conductive layer is made of copper foil. The copper is a very good electrical conductor and its thermal conductivity is $395 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$. [1,7,8]

2. Direct metal to ceramic bonding

One of the most common methods for bonding metal to ceramic is the direct bonding. When the copper is used as metal material, this method is called Direct Bond Copper (DBC). [2]

During the bonding process, thin transition layers are created between metal and ceramic, which is formed by oxygen bridge between these two materials. There is no easily identifiable intermediate phase. [5]

It is necessary to have the tight contact with the ceramic over the entire area to get good adhesion required by DBC technology. To get the tight contact, the metal part can be changed into the liquid state by melting. The copper liquid surface will copy the ceramic surface and good adhesion is then obtained after cooling. Problems can arise during the melting process, when the metal part entirely loses its shape. This problem can be avoided by the use of gas metal eutectic method. [1,5]

2.1. Gas-metal eutectic method

This method is based on creation of liquid surface layer on the metallic part, which is used for bonding process. The melting point of this liquid is lower than the melting point of the metal itself. This temperature is usually $10\text{ }^\circ\text{C}$ to $50\text{ }^\circ\text{C}$ lower than the melting temperature of the metal part. When the appropriate temperature is reached, metal surface becomes soft, pliant and conforms easily to the shape of the substrate surface. It results in a very strong bond between these two materials. Predominant constituent of this liquid layer should be the same element as the rest of metallic part. Any additional constituent should be present in only very small amount. It is necessary to keep the thickness of the melted layer thin compared to the thickness of the basic metal that is being bonded. [2,5]

2.2. DBC technology

DBC technology is based on gas-metal eutectic method and it is used for bonding copper foil to ceramic insulation base. In the atmosphere which is made up of circa 0.4 % weight percentage oxygen, $\text{Cu-Cu}_2\text{O}$ is formed on the whole surface of copper foil in the form of thin layer. The melting point of this eutectic is $1065\text{ }^\circ\text{C}$, which is $18\text{ }^\circ\text{C}$ lower than melting point of pure copper ($1083\text{ }^\circ\text{C}$). In this condition the eutectic is used as a glue to bond the solid copper foil to ceramic, without copper part losing its shape. [2,3,4,5]

The formation of the liquid surface layer is not the only requirement for quality bond. Another requirement is the low ceramic-solder interfacial energy. Interfacial energy becomes rapidly low due to the small amount of oxygen, which is responsible for forming Cu_2O and subsequent eutectic. [2,4]

3. Experiments and results

3.1. Preparation

The surface treatment of copper foil and the ceramic is necessary to be done before the connection process. Cutting of the Cu foil is the first step of preparation. The flat surface of the Cu foil is very important because the foil must be fully adherent to the ceramic base.

It is necessary to treat the surface of the copper foil and Al_2O_3 before starting bonding process itself. The surface of the copper foil is cleaned by using of 10% HCl followed by the cleaning in the solution of demineralized water

and pure isopropylalcohol. Ceramic substrate is cleaned by two solutions. The first one consists of demineralized water and pure isopropylalcohol, the second one is composed of acetone and pure alcohol. Intensity of cleaning process is increased by ultrasonic cleaning device. [6]

3.2. Direct bonding of copper to ceramic

First of all the copper foil is put on the ceramic sheet and a good contact between Cu and ceramic over entire area must be ensured. The sample is put into a muffle furnace. The muffle furnace temperature is controlled by the defined temperature profile. The determination of temperature profile is important for creation of optimum contact between Cu and Al_2O_3 . Maximum temperature inside the furnace is between melting point of eutectic Cu-Cu₂O (1065 °C) and melting point of copper (1083 °C). This interval is the only possible for a proper connection of copper to ceramics. The copper cannot be melted in the entire volume but only on its surface. The parameters of the reliable connection of Cu and Al_2O_3 were determined by series of experiments. The maximal temperature is between 1072 °C and 1076 °C. The sample is exposed to this temperature for 15 minutes (Fig. 1).

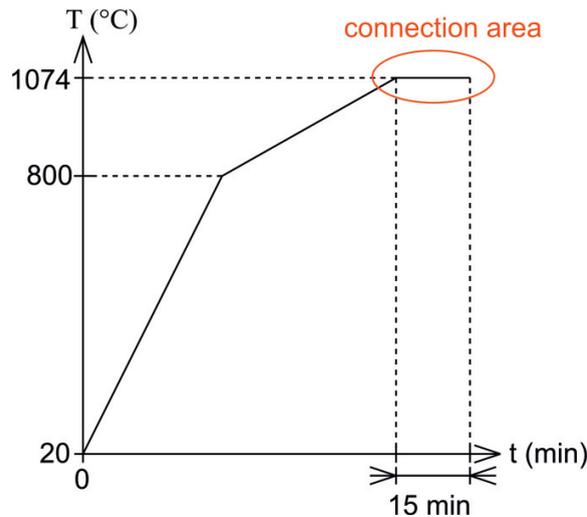


Fig. 1. Used temperature profile.

The low oxygen concentration must be kept inside the furnace during the connection process, especially in the appropriate time of the connection (marked area in Fig. 1.). The low O_2 concentration is reached by a nitrogen atmosphere inside the furnace. This atmosphere is created by flowing nitrogen. The concentration of oxygen is kept at the low level during the whole temperature profile. Due to this, the surface oxidation of copper is reduced. The oxidation of surface continues after the connection process, because the copper is still exposed to high temperature. It is caused by a slow cooling of furnace. To avoid the next oxidation of copper foil the inert atmosphere should be kept in the furnace during the cooling process as well.

3.3. Final treatment of substrates

In our experiments, the low concentration of oxygen is not kept during the whole process in order to minimize nitrogen consumption in muffle furnace and reduce the cost of DBC technology. The high temperature together with oxygen presence creates undesirable layer of oxides. These oxides must be removed before further process steps. The surface of copper is treated by chemical way. A nitric acid is diluted in ratio: one part of acid and two parts of water. The samples are put into this solution for 30 to 90 minutes. The time depends on the thickness of oxides. Samples were cleaned by demineralized water after their removing from the solution. The layer, which was exposed to this etching solution, was sanded. After these processes the substrate is ready for preparation of conductive patterns. These patterns are made by the milling and final etching. The final product, which could be used as a substrate for power LED, is shown in Fig. 2.

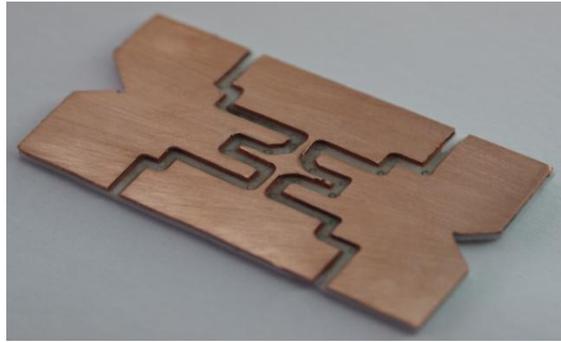


Fig. 2. DBC substrate for power LED (dimensions 31 mm x 18 mm).

4. Conclusion

The goal of our research was the modification and optimization of direct bond copper technology and its application in the field of power electronic modules where the low manufacturing cost and high thermal and electrical conductivity are strictly required. The developed technology can be used for the production of ceramic substrates with the maximum thickness of copper layer around 0.7 mm, which is very difficult to achieve by other methods. These substrates provide excellent thermal and electrical conductivity, which is necessary for effective cooling of power components such as power LED diode. Next advantages of these substrates are good mechanical properties and good thermal endurance. These substrates can operate in the temperature range from -100 °C to 250 °C. The heat conductivity of these substrates is circa 30 times higher in comparison with conventional glass-epoxy substrates.

Future research in this area will be focused on copper bonding on both sides of ceramic substrate and process optimization. It will lead to the creation of larger dimensions of power electronic substrate. Parameters such as adhesion of copper on ceramic, ceramic warpage, delamination, heat transfer, dielectric breakdown, and maximum current density will be tested.

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