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Short communication

A promising solution using CVD diamond for efficient cooling of power devices

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ABSTRACT

Diamond has several exceptional physical and chemical characteristics. This is the best material for both electrical insulators (10 MV cm^{-1}) and thermal conductors (2000 W m^{-1} K^{-1}, five times more than copper at room temperature). In this study, we analyzed and quantified the advantages of the insertion of CVD diamond layer in the innovative thermal management assemblies. We also developed a specific model to simulate the working environment of the component. In the simulation, we compared the use of a traditional substrate (AlN) with that of the diamond CVD one in order to confirm that using the diamond substrate reduced thermal resistance.

1. Introduction

1.1. Context

The heat transfer is a major obstacle that limits the generalization of the power electronics [1]. During recent years, components have higher performance and smaller size than before thanks to technological advances in electronic. However, the maximum operation temperature of silicon components has not changed for years. The maximum temperature is limited at 175 °C [2]. A lot of problems will appear due to the thermal limitation. Thus, electronic circuit design must be accompanied by a thermal study to validate the safe operation [1,2].

Diamond has outstanding properties. It has several exceptional physical and chemical characteristics. This material is very interesting in plenty of application domains, such as electronics, mechanics, optics and telecommunications [4]. This is the best material for electrical insulators (10 MV cm^{-1}) and thermal conductors (2000 W m^{-1} K^{-1}, five times more than copper at room temperature). Nevertheless, the coefficient of thermal expansion of diamond is very close to that of silicon [1,3]. These properties are particularly interesting in elaborating highly efficient thermal management systems in power electronics domain. Fig. 1 shows the thermal conductivity for different materials, which are often used in power electronics domain.

Nowadays, CVD (Chemical Vapor Deposition) technology becomes mature and offers different kinds of thermal diamond substrates with a price of 1–10 €/mm^3. And we can have large surface CVD diamond for different applications. Fig. 2 shows a piece of diamond substrate that we have used and its corresponding properties [5].

1.2. Objectives

We used the simulator COMSOL (module electrothermics) to build models and simulated the working environment of an electronic component. Using this simulation tools, we can evaluate different structures and materials to optimize the cooling system components for power electronics. We have succeeded a structure with a diamond substrate and copper micro-pillars, which has been technologically realized to validate the whole process simulation and design.

2. Investigation by simulation

2.1. Conventional structure

The conventional cooling structure with DBC (Direct Bonder Copper: Copper/AlN/Copper) substrate is shown in Fig. 3. The chip was welded onto the substrate. The substrate was directly soldered to an aluminum plate connected to a water-cooling system or

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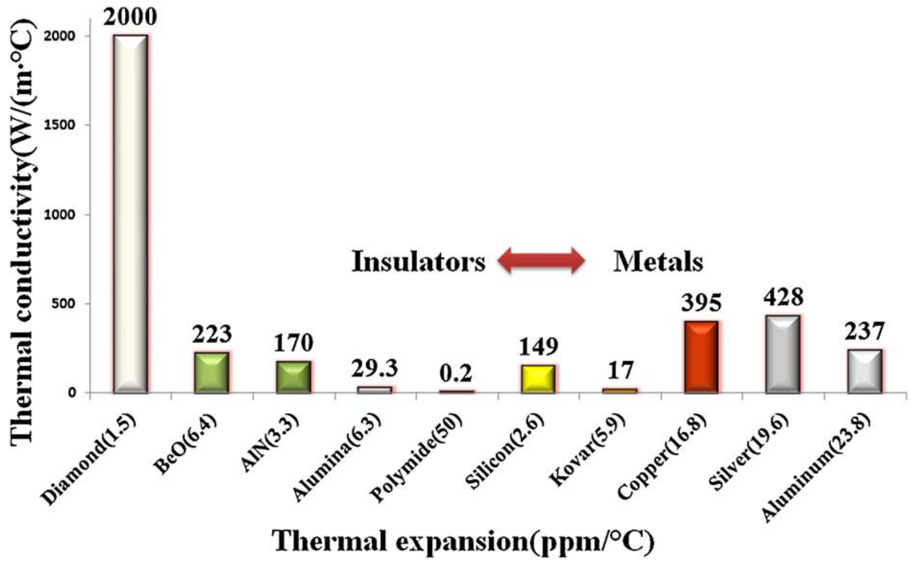

Fig. 1. Thermal conductivity of materials.

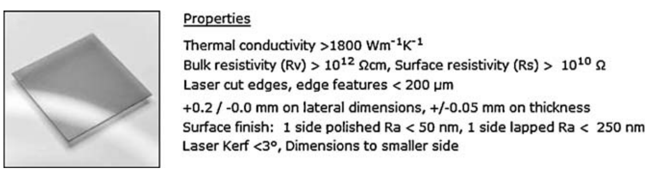

Fig. 2. Photo of polycrystalline CVD diamond thermal substrate and its properties [5].

heat sink. The cooling of the component through this structure was achieved by conduction through the different layers and convection to water-cooling or heat sink. The radiations are usually neglected in our systems. For the first try, we replace AlN with diamond in the same conditions in order to simulate in the same conventional structure.

As we can see, there is no difference in thermal distribution between diamond and AlN solutions, because the thermal convection resistance is much higher than the thermal conduction resistance in such a structure. Replacing the AlN substrate by a diamond substrate does not provide a significant improvement.

2.2. New structure

In order to benefit from the properties of diamond, we designed another cooling structure. We removed these redundant layers for reducing thermal conduction resistance. Then the substrate can be cooled directly by the water flow. Fig. 4 shows the new structure.

Fig. 4 shows the chip temperature due to power dissipation. With these conditions, when the temperature junction is 120 °C, the power density of system with AlN is 225 W/cm^2 and that with the CVD diamond is greater than 450 W/cm^2. We can obtain a factor of 2 in power dissipation comparing diamond to AlN substrate. The heat flux of the chip can be transferred more easily, because global thermal resistance has been reduced.

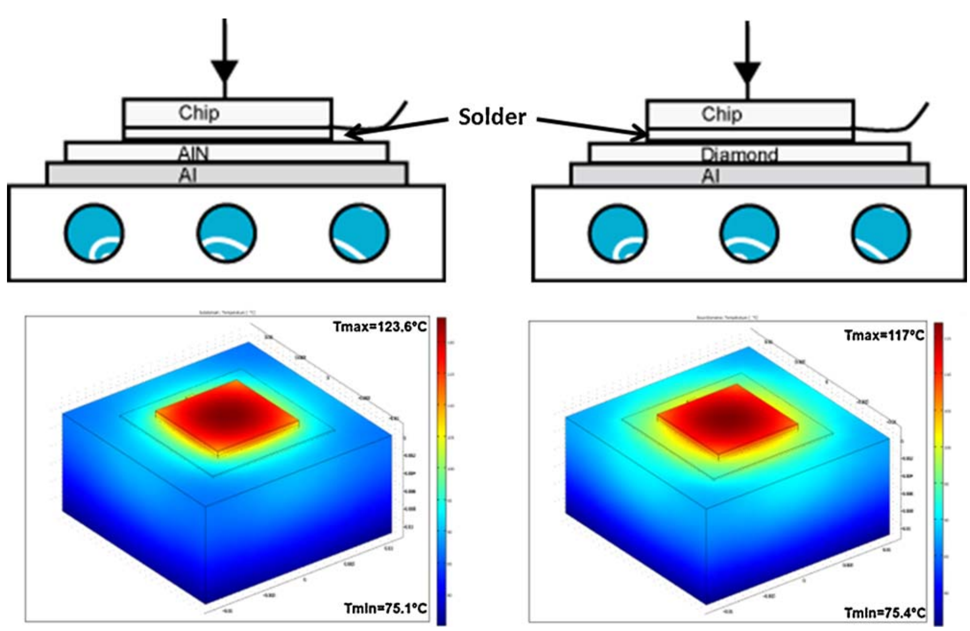

Fig. 3. Comparison between AlN and diamond structures using thermal simulations.