Chip-level bonding for microelectronic components by induction sintering of micro structured Ag particles

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***Abstract*— A new induction based sintering process for chip level bonding of power electronics components is presented in which silver particles containing pastes are used as bonding material. Using finite element methods, the bonding process was analyzed and optimized so that efficient sintering of the particles could be achieved in subsequent heating and bonding tests. Therefore, the process has great potential for application in the industrial production of electronic components.**

Keywords*— *Induction bonding, chip-level packaging, FE simulation

I. Introduction

Power electronics can be regarded as a solution for a multitude of technical challenges of the 21st century. For example, power electronic modules are primarily integrated into electric drives, power supply systems, converters for photovoltaic and wind energy plants, rail vehicles as well as hybrid and electric vehicles. Typical power electronic components are diodes, IGBTs (Insulated Gate Bipolar Transistor), MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistor), bipolar transistors or power LEDs. Figure 1 shows the schematic structure of a power electronics module.

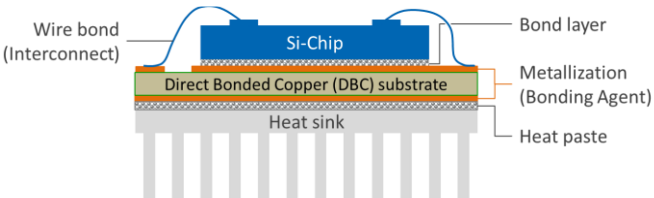

Figure 1: Schematic structure of a power electronics module in semiconductor technology.

In order to meet the rapidly increasing requirements in the electronics industry, the integration of complex and highly efficient power modules into electronic assemblies is essential. This is accompanied by the need to improve heat dissipation through thermal conductivity, temperature resistance, electrical conductivity and current carrying capacity [1]. The aforementioned properties are determined by the semiconductor-related packaging and interconnection technology, in particular the connection techniques and materials between chip and substrate. The resulting pressure to innovate has the effect that most technological improvements in power electronics are currently taking place in the area of chip bonding [2] [3]. The present work contributes to this trend.

II. Technical Background

For the bonding of silicon chips with a ceramic based substrate commonly used in power electronics (Direct Bonded Copper, DBC), several alternative bonding technologies are available in addition to lead-free soldering. Examples are thermocompression bonding, eutectic bonding, adhesive bonding, and as of late silver sintering (e.g. Ag sintering). The induction based Ag sintering technology presented here is a new promising process for realizing cohesive connections between semiconductor components and DBC.

To date, the particle sintering in chip bonding is based on thermal conduction. The heat is produced by an external ceramic hotplate and transferred through the whole bonding setup with process temperatures of up to $T_p = 280$ °C [4] at high pressure loads of up to $p = 30$ MPa [5]. Consequently, temperature sensitive power modules and bonding connections of heterogeneous materials with different thermal expansion coefficients can only be manufactured to a limited extent, since thermomechanical stresses in the bonding zone lead to the failure of the connections. Thus, the integration density and the choice of filler materials are limited. Time-intensive heating and cooling phases also cause long cycle and process times.

The induction based sintering process with rapid heating presented here allows for selective heating of the bond. In comparison to convective Ag particle sintering, the aim is to bond components onto a DBC substrate without integral heating, at low pressure and within short process times. Compared to other chip bonding processes currently used, the new inductive process offers advantages due to the formation of a highly thermally conductive Ag intermediate layer and high energy efficiency.

III. Bonding by Induction Sintering

The process sequence of the newly developed method is as follows: The micro structured silver paste layer is applied by screen printing to the DBC substrate. The silver sintering paste is then dried at moderate temperatures so the organic components of the paste can evaporate and only polymer chains of higher volatilization temperature remain in the layer. They act as an adhesive and stick the particles together. The electronic component is then placed on the sinter paste and the stack is inserted, positioned and fixed in the jig of a chip bonder. Subsequently, a single turn inductor is positioned around the chip so that the sinter layer can be heated through the inner field. A bond head that acts as a pressure stamp is placed on top of the chip to apply the bonding force. The bonding process is introduced when the electromagnetic field is applied. The electromagnetic field induces eddy currents in the metallic particles. These currents cause resistance heating, especially at the particle boundaries due to the contact resistance. As a result of the temperature increase and the applied pressure, the particles start to sinter and bond to the substrates so a firm bonding between the components is established. Depending on the bonding pressure, bonding time and the applied electromagnetic field, the densification of the sintered layer can be varied. Additionally, diffusion between sintered layer and substrate can be controlled by means of the process parameters and thus the quality of the bonding can be adjusted. Figure 2 shows the schematic experimental setup of the new inductive bonding process.

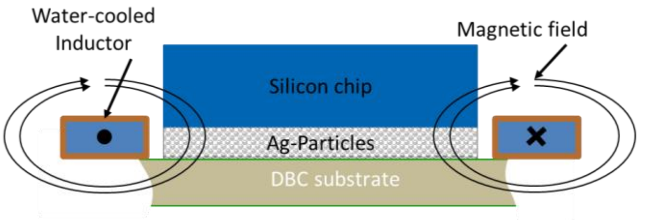

Figure 2: Schematic depiction of the experimental setup of the new inductive bonding process.

IV. Experimental and Simulation Investigations

In a first step, the process of heating both in the sintered layer and in the components was simulated using finite element methods. The software COMSOL Multiphysics and the corresponding AC/DC module were used. The planned experimental setup for bonding was modeled for this purpose. Simplifications on the model, especially with regard to temperature and pressure dependent material properties of the sintered layer, were necessary because the simulation of the sintering and melting behavior of the particles is complex. Furthermore, the thermodynamic behavior of the nano particles are not yet fully understood and depends on a large number of boundary conditions. The aim of the simulations was to map the heat generation and distribution both in the sintered layer and in the components to be bonded, depending on the electromagnetic power input, the bonding time and the inductor geometry. Furthermore, a suitable inductor geometry had be developed to facilitate an effective and homogeneous heating limited to the bonding area.

The simulation analyses were complemented by heating and bonding tests. Therefore, diodes and Si dummies (Figure 3) constituted electronic components and DBC as well as Si substrates bonding partners. The bonding surface of the components was coated by Ag or Au bonding agents. The Si substrate was Au-coated. The silver paste consisted of micro scaled Ag powder (µAg) which was applied by dispensing, aerosol-jet-printing and screen-printing and then dried at temperatures $T_d < 120$ °C. To perform and monitor heating, sintering and bonding experiments, a setup was developed. The most important features of this installation are the precise positioning of the bonding partners and the induction coil, the controlled introduction of a bonding pressure as well as the possibility to observe the components during the bonding process by means of an infrared transparent pressure stamp using a thermal camera. The test data thus generated could then be used to validate the simulation results.

V. Results

By means of simulation, a suitable inductor geometry for the bonding process could be determined. By multistage fitting of the inductor geometry to the workpiece geometry as well as the adaptation of coil contour to the chip dimensions, the heat generation in the heating process could be effectively limited to the bonding zone. In the heating experiments, the findings from the simulation could be validated to a large extent. In the bonding experiments, it was also possible to bond the DBC substrate firmly to the chip. Figure 3 shows the scanning electron microscope image of an inductively sintered silver layer obtained by focused ion beam (FIB).

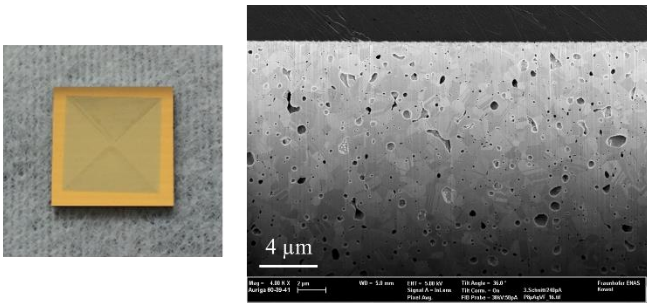

Figure 3: Sinter paste printed on Si-dummy coated with Au bonding agent (left), scanning electron microscope image of an inductively sintered silver layer (right).

VI. Conclusion

Within the scope of the investigations it could be shown that induction sintering of micro structured silver particles may be used for bonding processes on chip-level. Using simulation tools, an inductor geometry adapted to the geometry of the components to be bonded was determined for the bonding process and tested in heating and bonding experiments. Due to the very rapid heat generation by means of induction, potentially very short process times for bonding can be realized. As a result, the bonding process has great potential for application in industrial power electronics production.

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