Innovative die bonding technology for mechatronic packaging of automotive power electronics

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1. Introduction

Nowadays, the automotive industry is seeing the introduction of a wide range of new functions and applications, driven on one end by the reduction of fuel consumption and on the other hand associated pollutant emissions requirements and by the improvement of in-road car safety. This new functional perimeter goes together with the spread of power electronics implemented within more and more electric driven systems, with medium and high power capabilities. These electrically driven systems either replace previously hydro-mechanical systems for Power Steering for instance, or allow the introduction of new functionalities like "Stop & Start", or even lead to new power train architectures like hybrid vehicles. It turns out from all those systems that the demand for power electronics equipments, tailored for the automotive environment, tremendously increases the need of improved assembly technologies. Robust assembly technologies for power electronics packaging are available today, but they have been developed for railway and industrial applications. Thus, they correspond to specifications which are quite different from those of automotive electronic manufacturing in terms of volume of production, process flexibility as well as process yield and thus cost efficiency. Even though these assembly technologies – based on the use of DBC (Direct Bonded Copper) substrates – can be used for initiating the mentioned functions or applications, there is a strong need to introduce a manufacturing breakthrough for power dice assembly to answer the reliability and cost requirements of the automotive market.

2. Power packaging technologies

2.1 State of the art

The current state of the art in power module packaging technology is mostly orientated towards the use of ceramic substrates plated with Cu layers, usually referred to as DBC (Direct Bonded Copper – Figure 1). This type of packaging technology has demonstrated its reliability for die attachment in power electronics for industrial and railway applications. They correspond to ambient temperatures that are often limited around 80°C for the heatsink. This moderate case temperature can be found in some car compartments but can be far from the need of power electronics embedded in actuators, in this matter the case temperature is often far above 110°C. The intrinsic rectangular shape of DBC imposes in many occasions a rectangle power electronic module. This is well suited for standard standalone modules (separated from the actuators) but this can be a drawback for power mechatronic modules. Despite its numerous advantages for “standard” automotive applications, the spread of the DBC technology towards new automotive applications is limited by several factors like cost, capacity to handle high surge current in the tight space of power actua-
It will be appreciated from the foregoing that an alternative die bonding technology is needed for using high temperature solders with low grade plastics for the housing of an IML power mechatronic module. This is to keep the advantages of cost and reliability competitiveness of an IML power mechatronic module.

3. Die Laser Soldering of an IML power mechatronic module

3.1 Die Laser Soldering principals

The innovative approach that is proposed for manufacturing IML power mechatronic module consists in using short and localized heating to escape from the above problems. A highly focused heat source, typically a laser diode, will heat up the lead-frame from the die opposite face (Figure 5). This highly focused heat source avoids heating the metal/plastic junction over the plastic temperature limits. This heating system may be installed in a conventional automatic die bonder that can ensure high manufacturing flexibility and throughput.

3.2 Quality assessment of Die Laser Soldering

In general the quality of a solder joint is judged by its density (void content) and with the help of metallurgical analysis (distribution of the intermetallics phases, thickness of the intermetallics at the die and substrate interfaces). The following is a comparison between DLS and conventional processes.

The DLS process has been used to build test samples of an IML module. Several materials for leadframes have been tested with a combination of die sizes. To give an example of what is achievable with the association of the IML packaging technology and of the Laser Die Soldering process we will base our demonstration on the most severe conditions for manufacturing this type of power module.

The leadframe was made of nickel plated copper on which were soldered 40 mm MOSFET dice. The plastic embedding the leadframe is a standard PPS, with a melting temperature around 270°C. The plastic is close to the perimeter of the die, 1.5 mm. The die solder is a high lead content PbSnAg its liquidus temperature is around 300°C. For this test the nickel plating is chosen for its poor solderability. Moreover, the copper material has a high lateral thermal conductivity that allows a rapid lateral diffusion of the heat which favours the melting of the plastic in case of overheating.

Void content: The above test coupons were then tested using X-Ray photo imaging, Scanning Acoustic Microscopy and micro-sectioning with Scanning Electron Microscopy analysis. Conventional solder reflow processes in belt furnaces exhibit a void contents in the range of 10 to 30% of the die surface while the state of the art vacuum solder reflow process exhibits void contents of 5 to 10%. Meanwhile, the DLS process never shows a void content greater than 5% on a sample size of 4000 soldered dice. Figure 6 is a typical representation of the results.

Metallurgical analysis: A conventional solder joint initially exhibits solder phases that gathers depending on the speed of the solder cooling, a low speed cooling increases the grain sizes. A good intermetallics thickness at the interfaces is generally in the range of 3 to 4µm. Because the cooling kinetics of the DLS process is very important and mostly imposed by the thermal mass of the mechatronic package, the intermetallics are very small and evenly dispersed within the solder joint. The initial intermetallics thickness of a DLS joint is always less than 1µm. Figure 7 is an example of the SnAg intermetallics dispersion in the lead matrix for the PbSnAg solder.

3.3 Reliability assessment of Die Laser Soldering

The soldering kinetics of the Die Laser Soldering process, imposed by the short and localized heating of the IML package leadframe, is beneficial to the metallurgy of the solder joints. Some may think that this kinetics either introduces...
mechanical stress in the die and solder joint or may perturb the internal structure of the soldered dice by local overheating. This paragraph will demonstrate that this is not the case and that the dice assembled with the DLS process have a quality and reliability equal to dice assembled with a conventional process.

Power cycling: Figure 8 shows a typical IML power mechatronic test sample that was used for the power cycling tests [1]. An IML package was mounted onto an aluminium heatsink with an intermediate thermal interface. Two identical MOSFET dice were soldered with the DLS process onto the copper leadframe of the IML package. The dice were connected to operate in series and to be heated up using their body diode under a fixed and constant direct current.

The power cycling test bench is an assembly of different independent cells. Each cell hosts a single module that is cooled with a fan that forces the air onto the power module heatsink. The fan is stopped during the heat up phase. When the module reaches a preset temperature value the IML power module is bypassed and the fan is switched on to cool down the part to a lower preset temperature value. The module temperature is the temperature measured at the IML package close to the dice. During the test the voltage drop of the two diodes in series and the module on and off time are monitored. Figure 9 shows a typical record of a power cycling test.

The IML power mechatronic modules were manufactured with the DLS process and also using a vacuum reflow process. In this latter case a high grade plastic is used to manufacture the power mechatronic package. Both sets of devices are heated up under a fixed current of 50A with an initial power dissipation setting of 35 watts per die. The dice are 40mm, the solder joint thickness is 70µm and the solder type is a high lead content solder (PbSnAg). The IML power modules were cycled until catastrophic failure. Figure 10 gives the number of power cycles each module configuration withstood when 50% of the tested population failed.

Dice parametric testing: Each dice of the IML power mechatronic modules was parametrically tested after Die Laser Soldering and compared to standard devices equipped with identical dice. There was no evidence of any influence on the electrical parameters of the laser soldered dice.

4. Conclusion

Automotive power electronics is challenging nowadays as well as material science, manufacturing means, electronics and vehicles architectures. The overall target is to reduce the CO2 emission by the application of more and more electronic embedded systems. This goes from basic actuators like blowers or electronic power steering to more complex systems like micro-hybrids up to full-hybrids based on fuel-cell energy systems. All these new applications face tradeoffs between cost, performances and systems integration capability.

This paper proposes the IML power mechatronics packaging technology in association with a novel die bonding technique to the market. These two new technologies are high potential solutions to the above problems.

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7. References


8. Glossary

IML Insert Moulded Leadframe
DLS Die Laser Soldering
DBC Direct Bonded Copper