Advanced Packaging for Simultaneous Hermetic Lid Sealing and Chip Backside Heat Removal

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In the framework of the EU project Heatpack [1], we are exploring advanced packaging technologies for high power density components to improve state-of-the-art thermal management solutions. A new concept is presented here to remove the dissipated heat of a flip-chip mounted GaN chip, by physically connecting its backside to the package lid. The proposed solution utilizes a highly thermally conductive silver paste to both hermetic seal a transparent Silicon Carbide lid and connect the chip onto it. The bonding is based on a low-temperature laser diffusion bonding process (LADB) developed at CSEM [2].

The EU project Heatpack [1] aims to develop and validate critical technology building blocks for enabling transformative packages for space applications with very low thermal resistance. These thermal management solutions beyond state-of-the-art are necessary to fully exploit the potential of wide-bandgap technologies, which are now being considered as critical in numerous industrial sectors and, in particular, for space. The high thermal conductivity of the materials used for the assembly of high-power semiconductors is becoming very important, since the power per unit area of these chips is increasing considerably. Package miniaturization and increased functionality are driving the overall market of System-in-Packages (SiP) for Aerospace components. The high power per unit area results in an increase of junction temperatures. Benefits for a better thermal management solution will range from improved performance to increased components reliability and lifetime.

The cross-section of a SiP including a high-power GaN HEMT-based Solid State Power Amplifier and Electronic Power conditioner chip is shown in Figure 1. These components are assembled inside a ceramic package and sealed hermetically with a Silicon Carbide lid. The choice of the lid material and the low-temperature laser bonding are both crucial to reduce the stress to a minimum and to ensure the hermeticity of the lid and proper thermal connection to the back-side of the GaN chip, without compromising the structural integrity of the flip-chip bump interconnections.

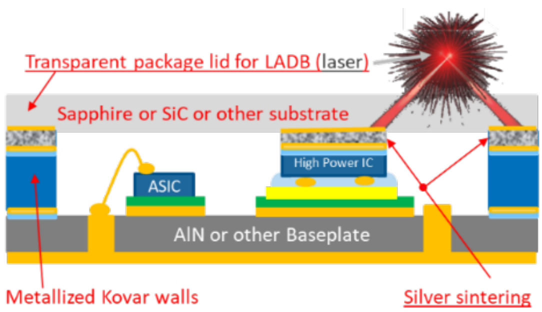

Figure 1: LADB (laser) hermetic sealing and back-side chip bonding on the lid to efficiently remove heat with silver paste sintering.

In a standard flip-chip configuration the heat is dissipated through the bumps and the underfiller. This is relatively inefficient due to the limited thermal conductivity of the underfiller materials (up to ten W/mK) and the large thickness and low surface area of the lead-free solder (~60 W/mK) bumps compared to the available chip surface. To exploit a larger surface for cooling we can employ the chip's backside and connect it to a lid with a high thermal conductivity. This improves thermal management considerably, given that the chip substrate is a good thermal conductor compared to solder. Si or SiC substrates offer up to a factor 5 better thermal conductivity than SAC lead-free solder. To obtain a quantitative assessment of the proposed solution in terms of temperature values, thermal simulations were carried out and are shown in Figure 2. On the average, the maximum junction temperature is reduced by $\Delta T_{max.}$ = (94.7-86.1°C) ~ 9°C for each chip dissipating 1 W. The effect scales linearly with dissipated heat.

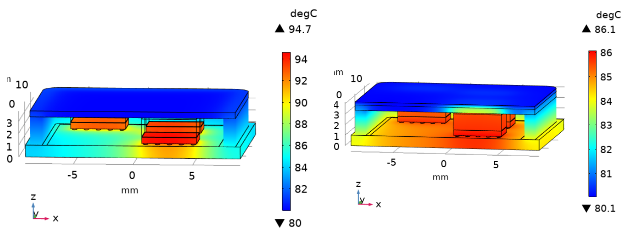

Figure 2: Temperature plot of chips dissipating 1 W each in flip-chip mount. Right: chip backside additionally connected to lid (SiC/Cu-D spacer + Ag paste).

The crucial aspect is to reduce mechanical stress by using a low-thermal expansion lid made of Silicon-Carbide and perform a low-temperature laser bonding process (LADB reached TRL 4 by ESA evaluation [2]), taking advantage of the partial transparency of SiC at the laser wavelength. SiC is preferred since it offers a very low thermal expansion (similar to GaN) and superior thermal conductivity, thereby ensuring better heat spreading. This technology has been developed and tested in the past for SiC-based MEMS pressure sensors [3].

Additional activities are carried out with the characterization of the thermal properties of silver paste as well as the thermo-optical model calibration for fine-tuning of the LADB process. Optimal parameters are needed for sintering the Silver paste according to the configuration shown in Figure 1. An independent task in the framework of this project is the development of micro-channels for removing heat from the SiC lid onto an external passive/active heat exchanger. This approach has the potential to be extended to general-purpose butterfly packages for high power optoelectronic components, where the Kovar lid could potentially be replaced by a Silicon carbide lid and connected to the component itself [4].

This work is supported in the framework of EU Project Heatpack.

[1] HEATPACK is an EU-Project Consortium developing "High thErmAl efficiency componenTs PACKages for space". http://www.heatpack.eu/

[2] R. Jose James, *et al.*, "Radiation Hard Glass and Sapphire-based Miniature Hermetic Packages for Space Applications", CSEM Scientific and Technical Report (2019) 31.

[3] A. Hoogerwerf, *et al.*, "Silicon carbide pressure sensors for harsh environments", Proceedings of Transducers Conference, Berlin (D), June 2019.

[4] G. Spinola Durante, *et al.*, "Thermal Management Modeling of High-power Chips and Calibration with Experimental Data", CSEM Scientific and Technical Report (2019) 30.