Novel packaging solutions for GaN power electronics: Silver-diamond composite packages

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Keywords: Thermal management, diamond composites, thermal modeling, thermal conductivity, GaN

Abstract

We present a new packaging solution for GaN power electronics for efficient heat extraction needed for high power devices. The benefits of using silver diamond composite as base plate in packages for GaN power bars is demonstrated. A dramatic improvement in thermal management (as high as ~50%) was obtained with respect to the existing packaging technologies based on CuW. Micro-Raman thermography measurements were carried out to determine the device temperature at a range of operating power levels. A finite element thermal model was built to assert the obtained experimental results and was found to be in good agreement.

INTRODUCTION

In GaN-based power electronics, thermal management is the key factor for both performance and reliability [1], [2]. In fact, poor reliability of GaN-based devices is very often a consequence of an excessive increase of channel temperature. An optimized thermal management of the package results in an improved device lifetime and a reduced cooling system demands, leading to improved lifetimes and cost savings at the system level.

We illustrate here to our knowledge for the first time the impact of using silver diamond composite as a base plate in packages on the self-heating of GaN devices. Silver diamond composites consisting of diamond particles in a matrix of silver alloy, feature an excellent thermal conductivity as high as 650 W/mK at room temperature and a CTE close to that of the semiconductor materials [3]. This is significantly larger than the thermal conductivity of conventional packaging materials such as CuW. These advanced composite materials are therefore capable of providing optimized thermal management solutions at the heat spreader level for many applications, however, to date have not been experimentally tested for device applications, in particular not for GaN power electronics.

CHARACTERIZATION AND SIMULATION DETAILS

Micro-Raman thermography measurements were performed on AlGaN/GaN multi-finger HEMTs (power bars, with 18 fingers) grown on SiC substrates to determine their device temperature at various power levels. More details on Raman thermography can be found in [4], [5]. It determines device temperature with submicron spatial and can even access temperature with nanosecond time resolution. The devices were attached to both silver diamond composite and CuW base plates by using standard AuSn solder, in order to assess the difference between the two materials in terms of thermal management efficiency.

Figure 1 shows the temperature results from Raman measurements in the centre finger of the devices at different power values, i.e., the peak device temperature rise with respect to the temperature at the backside of the base plate which was kept at 25ºC. Devices attached on silver diamond composite base plates exhibit peak temperatures approximately half that of the peak temperatures exhibited by devices mounted on CuW base plates, especially at high power levels which are standard for device operation. The same trend was obtained for temperatures in the outer fingers. However, due to the crosstalk effect, temperatures are higher in the centre finger. There is a clear improvement from the point of view of heat extraction, with obvious benefits for device reliability and system requirements.

A 3-D finite element model of the device was built utilizing the ANSYS software package [6] to compare to the experimental data. The outcomes from the simulations are consistent and in good agreement with the ones obtained experimentally (see Figure 1). Figure 2, illustrates the temperature distribution across the whole device on silver diamond compared to the one on CuW base plate. Again it is apparent that temperature is significantly lower in devices brazed onto the silver diamond composite.

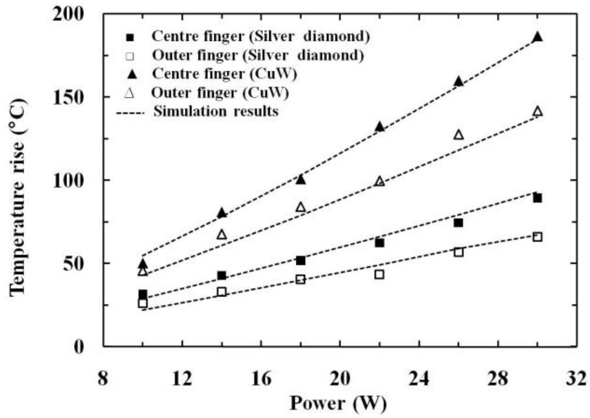

Figure 1: Peak temperature rise in the centre finger of AlGaN/GaN HEMTs devices (18 fingers power bar) brazed to silver diamond composite and CuW base plates as a function of the dissipated power, obtained by Raman thermography. 3-D finite element thermal modeling results are shown for comparison.

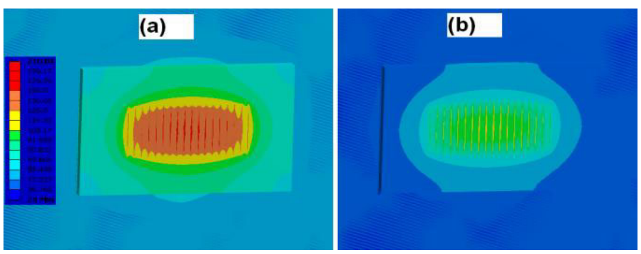

Figure 2: Temperature distribution in AlGaN/GaN HEMT (18 fingers power bar) for a dissipated power level of 30W obtained from 3-D finite element simulation for (a) device brazed onto CuW base plate, and (b) onto diamond composite base plate.

The superior thermal management obtained with base plates that are made of silver diamond composite, can be ascribed to the big difference in thermal conductivity between silver diamond composite and CuW. Figure 3 shows the thermal conductivity of silver diamond composite and CuW as a function of temperature.

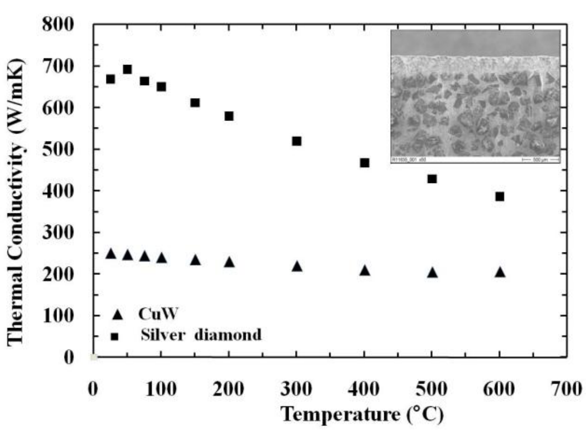

Figure 3: Thermal conductivity as a function of temperature for silver diamond composite and CuW materials. In the inset a SIM image of silver diamond is shown.

CONCLUSIONS

Micro-Raman thermography measurements and finite element thermal modeling were performed in order to compare the thermal management performance of silver diamond composite and CuW, when used as base plates for GaN power electronics. The results show a large improvement in terms of heat extraction with silver diamond composite, by up to a factor of two. This unprecedented packaging solution will allow the achievement of longer lifetime and more reliable GaN power electronics.

ACKNOWLEDGEMENTS

This work was carried out in the framework of the European Framework 7 project AGAPAC (Advanced GaN Packaging). The authors would like to thank Dr. A. Sarua and Dr. J. Pomeroy for their support during measurements and for fruitful discussions.

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[6] *ANSYS Workbench 2.0 Framework*, ANSYS, Inc.

ACRONYMS

(Al)GaN: (Aluminum) Gallium Nitride
HEMT: High Electron Mobility Transistors
SiC: Silicon Carbide
CTE: Coefficient of Thermal Expansion
CuW: Copper Tungsten