DETERMINATION OF ON CHIP TEMPERATURE DISTRIBUTION OF DEVICES UNDER OPERATION BY USING RAMAN MICROSCOPY

J. Kováč jr.[1,2], R. Szobolovszký[1], M. Florovič[1], J. Kováč[1], A. Chvála[1], T. Vincze[1]

[1] Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, Ilkovičova 3, 81219 Bratislava
[2] International Laser Centre, Ilkovičova 3, 84104 Bratislava
e-mail: jaroslav_kovac@stuba.sk

Abstract *Thermal management in high-power HEMTs and SiC diodes is one of the most crucial aspects for device reliability and performance while efficient heat extraction from the active device region is a key task. In this paper Raman spectroscopy method suitable for real time on-chip temperature measurements on power AlGaN/GaN based high-electron mobility transistor (HEMT) grown on SiC substrate and SiC high-power diode is presented. The method is verified by measurements with micro thermistor. The results show that this method have a potential for device analysis in thermal management. The features and limitations of the proposed method are discussed. The analysis of thermal behavior can help during design and optimization of power HEMTs for microwave applications and SiC diodes for power applications.*

Keywords GaN, HEMT, SiC, temperature, Raman microscopy

1. INTRODUCTION

Recent progress in GaN-based high-electron mobility transistors (HEMTs) has confirmed them to be the leading transistor technology for future high-power devices at high-frequency operation utilizing their excellent electronic properties, high electron saturation velocity, and high breakdown voltage [1]. In fact, a high potential of these devices is deteriorated by self-heating caused by the dissipated power during the HEMT operation. This has influence on the electrical characteristics as well as device reliability [2]. High-power AlGaN/GaN devices experience significant temperature rises during operation within very small device dimensions. From this point of view the thermal management in high-power AlGaN/GaN HEMTs devices is one of the most crucial aspects for device reliability and performance [3,4]. Power devices prepared on SiC and Si substrates have better power dissipation than the ones grown on sapphire substrate [5]. Various experimental methods were employed to determine channel temperature of power GaN-based HEMTs, e.g. Raman spectroscopy, interferometric mapping, static and pulse I-V characterization method and IR camera image to determine the channel temperature of power HEMTs. These techniques are widely applied but require advanced setup to obtain accurate results and, in some cases, special test structures. In many cases, they are needed to compare with results of different measurement methods. In this paper the electrothermal measurement results of power AlGaN/GaN HEMT for microwave applications and SiC power diodes using Raman microscopy are shown.

2. EXPERIMENTAL

The first structure under investigation is active 2-gate fingers HEMT with Gate dimensions of 150x0.15μm^2 and Source Drain distance of 4 μm consisting of GaN-cap/$Al_{0.29}Ga_{0.71}N$-barrier/GaN-spacer/GaN-doped layers grown on 4H-SiC substrate as shown in Fig. 1b). The second 8-gate fingers HEMT on the same die is used as Schottky diode sensor using one of the gates. The backside Au substrate contact is soldered to CuMo lead frame using AuSn solder. Top ohmic Drain/Source/Gate contacts are created by Au-based metallization layers. The second structure under investigation is diode structure consisting of thick natural n+ substrate, 100 μm of isotopic n+ buffer layer, 100 μm of isotopic n- drift layer and top natural p+ layer as shown on Fig. 1b). Both structures are mounted in package with open cover for possible inspection and the package was placed on a heat sink. The chip carrier and heat sink were found as substantial factors for more accurate and defined temperature measurements. Driving circuits and temperature controller were employed to stabilize the heat sink plate at certain temperature using Peltier element for device in package measurement.

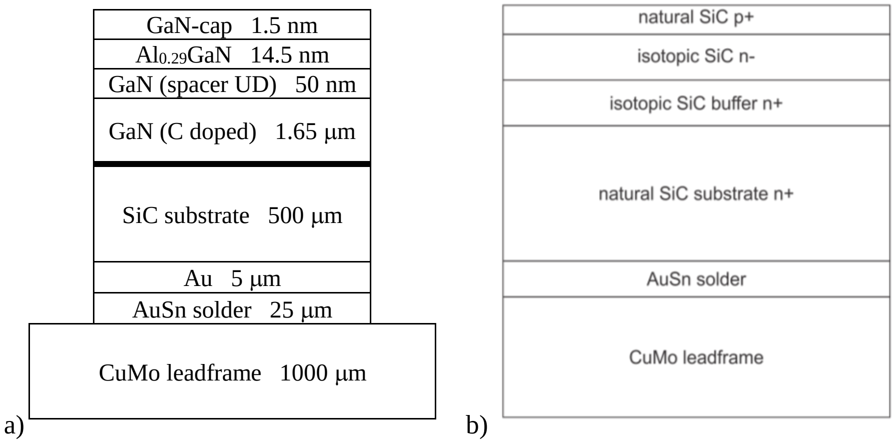
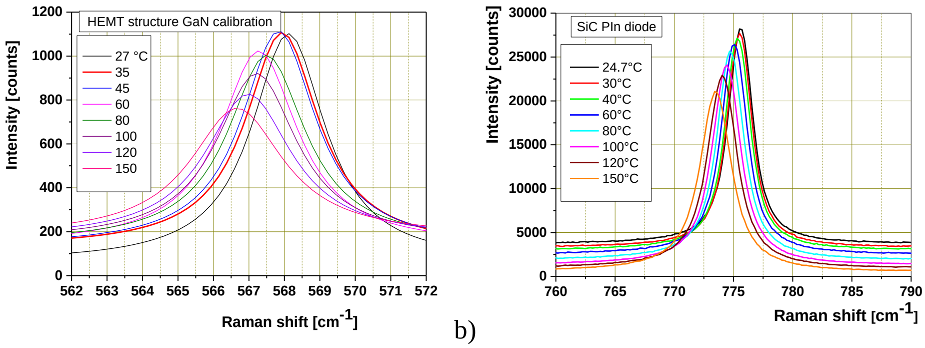


Fig. 1 2D cross section of the analysed structures a) AlGaN/GaN HEMT on SiC substrate and b) SiC PIN diode.

Before the measurement under operation, calibration measurements were performed on the bare chips placed on a stabilized temperature-controlled plate. After that the measurements under operation were performed. The measurement setup consists also of driving system for high power electro thermal properties measurements. To provide a direct experimental insight into the temperature distribution of AlGaN/GaN HEMT and SiC diode under operation a confocal micro-Raman thermography of the device surface was applied. The MonoVista 750 CRS system with laser excitation wavelength of 514 nm was used for Micro- Raman spectra recording (focused spot ~1μm). The shift of a Raman peak is confirmed to be directly proportional to the change of temperature. The measurement of temperature using Raman method is verified with thermistor placed on the contact surface of SiC PIN diode.

3. RESULTS AND DISCUSSION

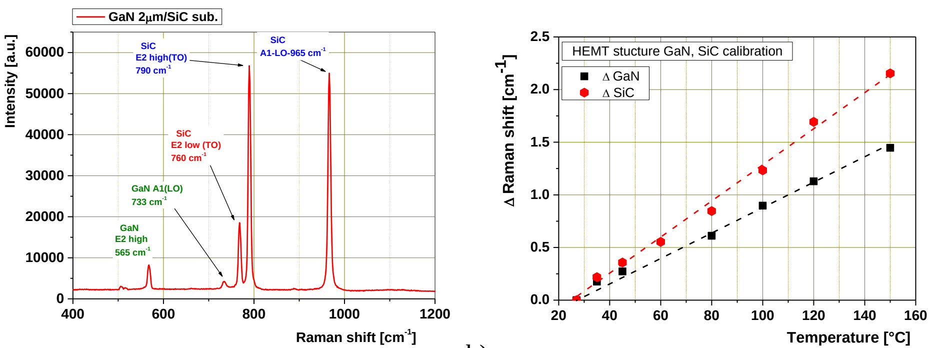
The change of Raman line position and its FWHM at different temperature of the structure is clearly obvious on Fig. 2. On Fig 2a) there are shown results from calibration measurement of AlGaN/GaN HEMT where GaN E_2 high Raman line was analyzed and on Fig. 2b) the results of SiC PIN diode where SiC E_2 high Raman line was analyzed. From these measurements a calibration line for Raman line shift with temperature has been obtained. The whole Raman spectrum with calibration results is shown on Fig. 3.



a) b)

Fig. 2 Raman line change with temperature of a) GaN E_2 high from AlGaN/GaN HEMT and b) SiC E_2 high from SiC diode.

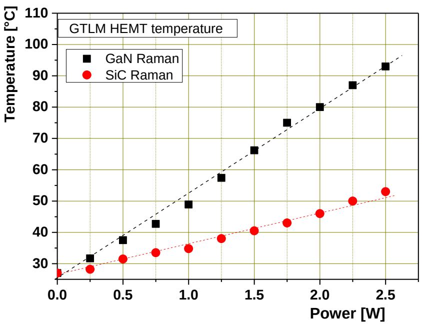
The complete summary of measured values of one HEMT device and one SiC diode under operation for various dissipated powers is shown in Fig. 4. The comparison of determined temperature from GaN and SiC peak shift in HEMT device (Fig. 4a) shows that the temperature decreases also through the volume of the device as the top GaN layer shows ~93°C and SiC substrate only ~53°C for 2.5 W of dissipated power. For an additional information a micro thermistor was used for direct temperature evaluation of the SiC PIN diode. The thermistor has a very high accuracy (~3 %). However, the thermistor dimension is large compared to the diode dimensions and therefore, only one thermistor (ThR1) was attached directly on the Al contact pad using thermal glue. This thermistor



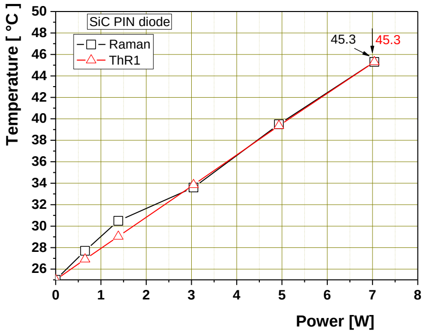
a) b)

Fig. 3 a) Raman spectrum of AlGaN/GaN HEMT on SiC substrate at room temperature and b) results of Raman line shift from calibration measurement.

was used to validate the above described method and determine the temperature of the top contact. A perfect match of the temperatures measured by Raman method and Thermistor for various dissipated powers visible on Fig. 4b) confirms the accuracy of the method.



a)



b)

Fig. 4 Measured temperature values of a) HEMT device and b) SiC diode under operation for various dissipated powers.

4. CONCLUSIONS

In this paper the temperature distribution through the power GaN-based HEMT and at surface of SiC PIN diode have been investigated. Micro Raman spectroscopy was successfully applied to determine the channel temperature with maximum temperature of ~93°C on the surface and 53°C at the SiC substrate for applied power of 2.5W. A perfect match of the temperatures measured by Raman method and Thermistor for various dissipated powers of SiC PIN diode confirms the accuracy of the method.

Acknowledgement

The research leading to these results has received from the ECSEL Joint Undertaking (JU) under grant agreement No 783274, project 5G_GaN2. The JU receives support from the European Union’s Horizon 2020 research and innovation program and France, Germany, Slovakia, Netherlands, Sweden, Italy, Luxembourg, Ireland. This publication reflects only the author's view and the JU is not responsible for any use that may be made of the information it contains. The work was also supported by Grant VEGA 1/0739/16 through the Ministry of Education, Science, Research and Sport of Slovakia.

References

[1] N. Miura, T. Nanjo, M. Suita, T. Oishi, Y. Abe, T. Ozeki, H. Ishikawa, T. Egawa, T. Jimbo, *Solid-State Electronics* 48, 5, 689, May (2004).

[2] O. Ambacher, J. Smart, J. R. Shealy, N. G. Weimann, K. Chu, M. Murphy, W. J. Schaff, and L. F. Eastman, *Journal of Appl. Phys.* 85, 6, 3222-3233, (1999).

[3] Y. Liyuan, A. Shan, Ch. Yonghe, C. Mengyi, Z. Kai, M. Xiaohua, H. Yue, *Journal of Semiconductors* 34, 7, 074005-1, Jun. (2013).

[4] Q. Hao, H. Zhao, Y. Xiao, M. B. Kronenfeld, *International Journal of Heat and Mass Transfer* 116, 496–506, January (2018).

[5] S. Chowdhury, *Phys. Stat. Sol. (A)* 212, 5, 1066-1074, (2015).