Influence of Temperature Variation on Electrical and Photon Emission AlGaN/GaN High Mobility Electron Transistors Characterization.

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Introduction.

Wide-bandgap AlGaN/GaN high electron mobility transistors (HEMTs), through their high breakdown field and excellent electron transport properties found a significant recognition in high power microwave applications. Additionally, such advantages as high operation voltage, high cut-off frequency or high impedance for power matching, place them in the spearhead of the most up to date and likely devices.

Despite of all the advantages of HEMTs, some of the aspects still need to be enhanced. Due to high power density, self-heating effect can not be neglected. Furthermore temperature variation has a significant influence on the electrical parameters and Photon Emission characterization, which is proved to be very useful tool in both design and debug processes.

Firstly devices and setup will be presented, secondly electrical and PE characterization will be introduced and finally the following abstract will be summarized.

Test Structure and Experimental Setup.

The high power, high gain $Al_{0.25}Ga_{0.75}N$/GaN-HEMT structures were designed and fabricated in Ferdinand Braun Institut für Höchstfrequenztechnik, Berlin, using MOCVD technique for epitaxial growth. The transistors are fabricated using i-line stepper lithography in combination with electron-beam lithography for the T-gate structures (0.4 µm gate length). A cross sectional view of those devices is shown in **Fig.1**. The layer sequence on top of a 400µm thick semi insulating SiC substrate consist of a nucleation layer, following a 2µm GaN buffer layer and a 25nm AlGaN (25 % Al content) barrier layer. A 2-dimensional electron gas (2DEG) quantum well is formed under the AlGaN barrier layer which acts as transistor channel. A Ti/Al/Ti/Au metallization scheme covered with WSiN/Au overlay metal is employed for the fabrication of the source/drain ohmic contacts in such a way that pattern delineation during rapid thermal annealing at 830°C is preserved [1,2]. In order to optimize power density and gain, the transistor gate is designed as T-shape with a gate foot length of 0.4µm. The distance between the source and drain edge and the gate foot is 1µm and 6µm, respectively. The Gate contacts are made using Pt/Au metallization in order to create the Schottky barrier.

The electrical measurements have been carried out using a semiconductor parameter analyzer and the photon emission measurements have been performed on the Hamamatsu Photon

Emission Microscope Phemos1000. Additionally for thermal measurements, a hot-chuck was assembled into chamber of Phemos 1000.

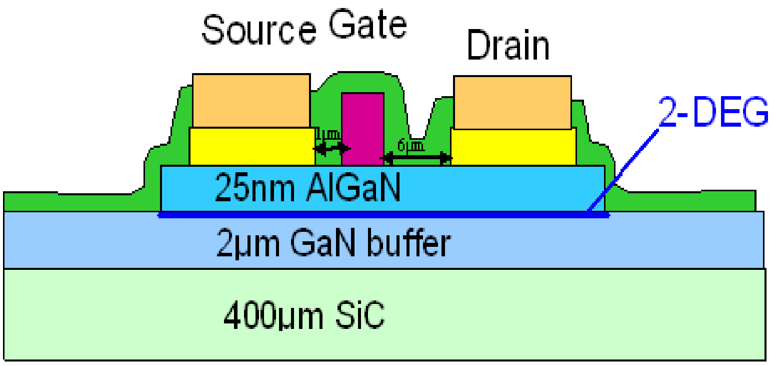

Fig.1. Cross sectional view of Al0.25Ga0.75N/GaN-HEMT.

Electrical Characterization.

Optimum drain and gate voltage ranges had to be found. Electroluminescence is strictly related to the electrical parameters of the device. Therefore initial electrical analysis needed to be conducted to estimate the most appropriate parameters for further research.
The device has been placed on the hot-chuck. Drain voltage was permanently set to 15V and gate voltage has been varied from -5,5V (pinch-off region) up to -2,5V. For the first set of measurements, 3 different temperatures were chosen (25^{0}C, 55^{0}C and 85^{0}C). Drain and gate currents have been monitored in parallel. Drain current versus gate voltage dependence is presented in **Fig.2.** For the best sensitivity to current change, a semi-logarithmic scale has been chosen.

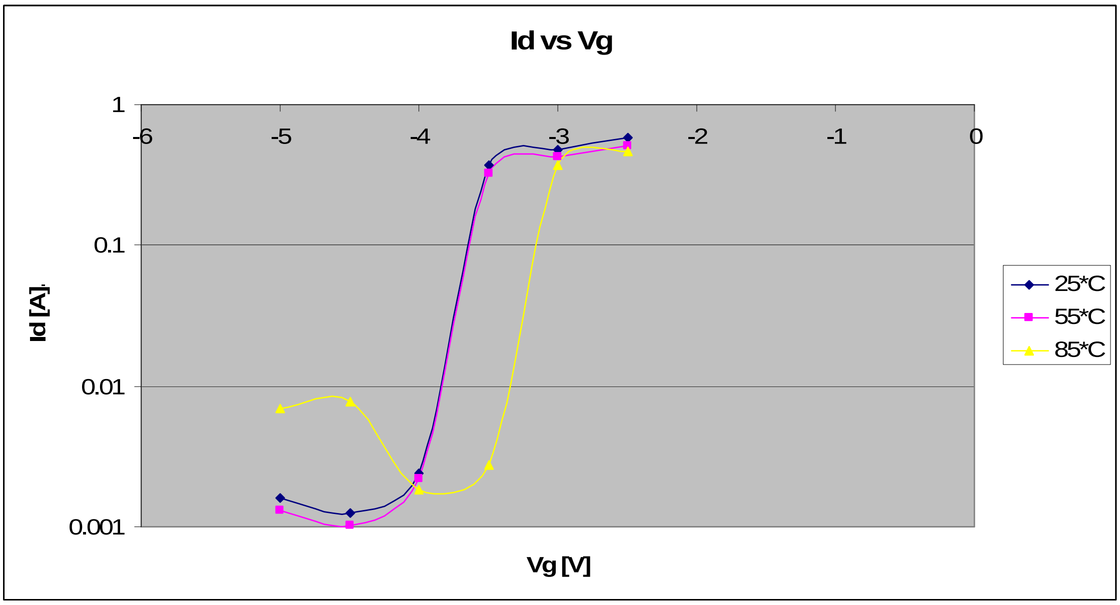

Fig.2. Drain current versus gate voltage in semi-log scaly for 3 different temperatures.

Curves for 25^{0}C and 55^{0}C show similar shapes in the full gate voltage range, only the curve measured for 85^{0}C represents a different behavior. Drain current for the gate voltages enclosed in (-5,-4) interval is located in the mA regime therefore, is more sensitive for any temperature changes. The following phenomena will be more detail analyzed and discussed in the final presentation.

A similar observation has been made for the gate current characteristic (**Fig.3.**). For higher temperatures, and gate voltages higher then -4V gate current increases exponentially.

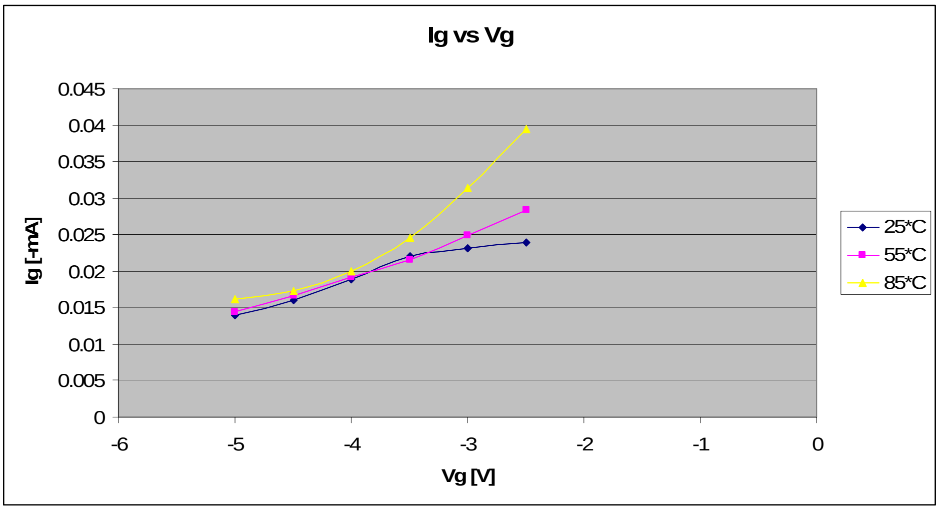

Fig.3. Gate current versus gate voltage for 3 different temperatures.

The second set of measurements was performed for 3 different gate voltages (-5V, -4V, -3V) and the temperature was varied from 25^{0}C to 85^{0}C. The drain current decreases almost linearly for the each of 3 gate voltages (**Fig.4.**) (for I_d curve related to V_g=3V, much weaker temperature dependence was observed), however for the gate current situation is more complex (**Fig.5.**). For temperatures above 50^{0}C, gate current starts to increase more rapidly and for the curve related to V_g=3V (almost fully opened channel) it increases already exponentially.

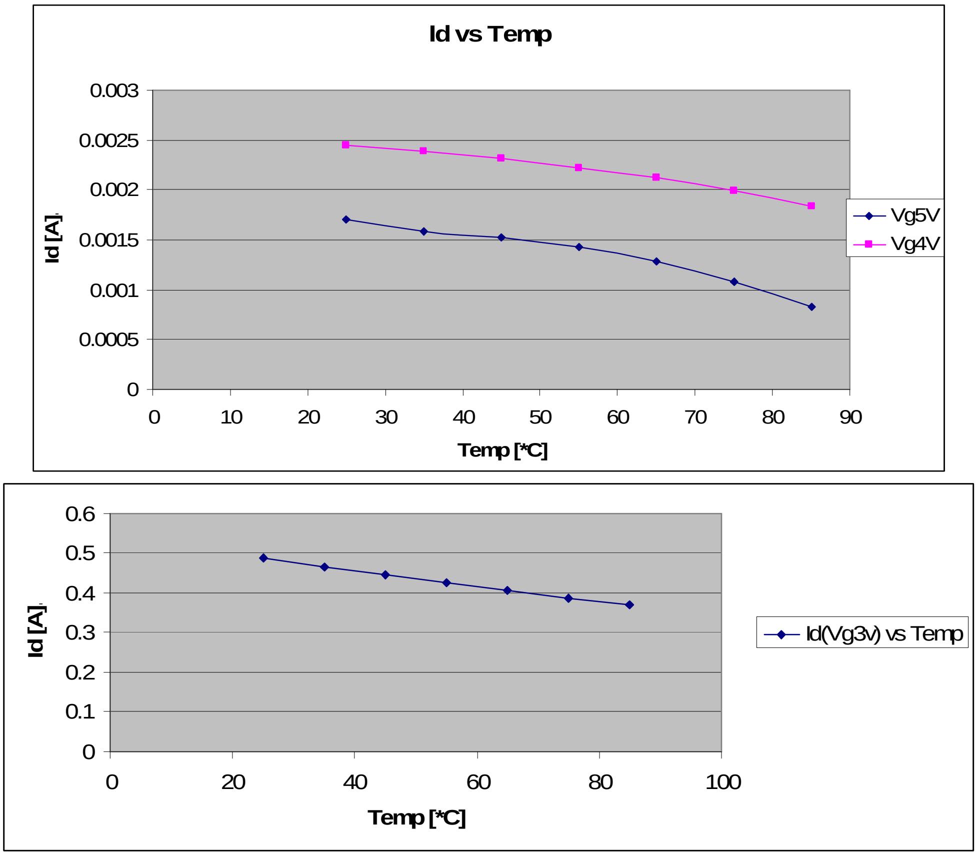

Fig.4. Drain current versus temperature for 3 different gate voltages.

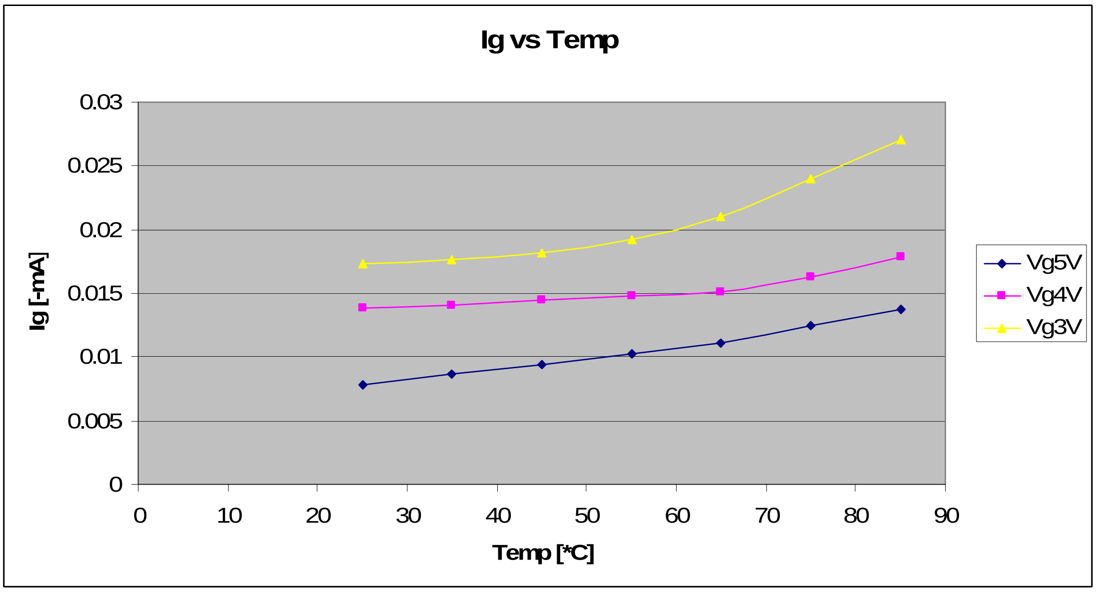

Fig.5. Gate current versus temperature for 3 different gate voltages.

PE Characterization.

PE measurements were conducted by means of Phemos 1000. Device was placed on the hot-chuck, mounted in the main chamber of the system. As in case of electrical measurements two different sets of thermo-electrical conditions were defined. First, gate voltage was varied from -5 up to -2,5V and 3 different temperatures were selected (**Fig.6).**

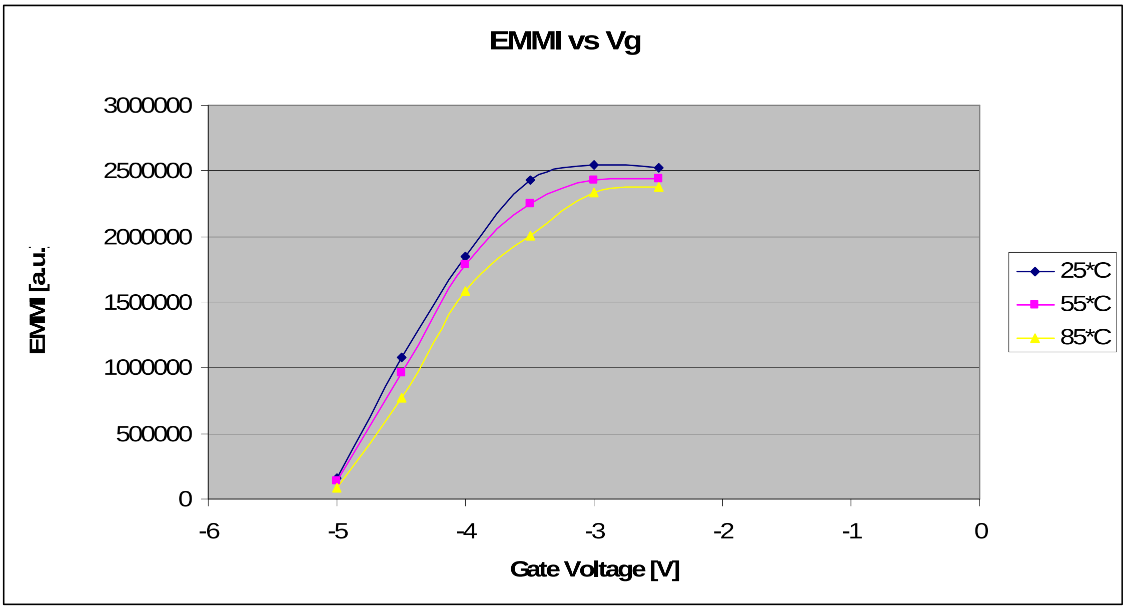

Fig.6. Photon Emission versus gate voltage for 3 different temperatures.

PE curve is more flat for the higher temperatures. Additionally for lower gate voltages (-3, -2.5) characteristics related to higher temperatures remain unchanged (device temperature stabilization), while PE curve related to 25^0C decreases.

Subsequently, as for the electrical measurements, second set of the experimental conditions has been adjusted. PE has been measured for 3 different gate voltages and temperature was varied from 25^0C up to 85^0C. The strongest emission occurred for the lowest gate voltage. All the curves have the same comparable shape and for each gate voltage PE decreases linearly with temperature increase (**Fig.7.**).

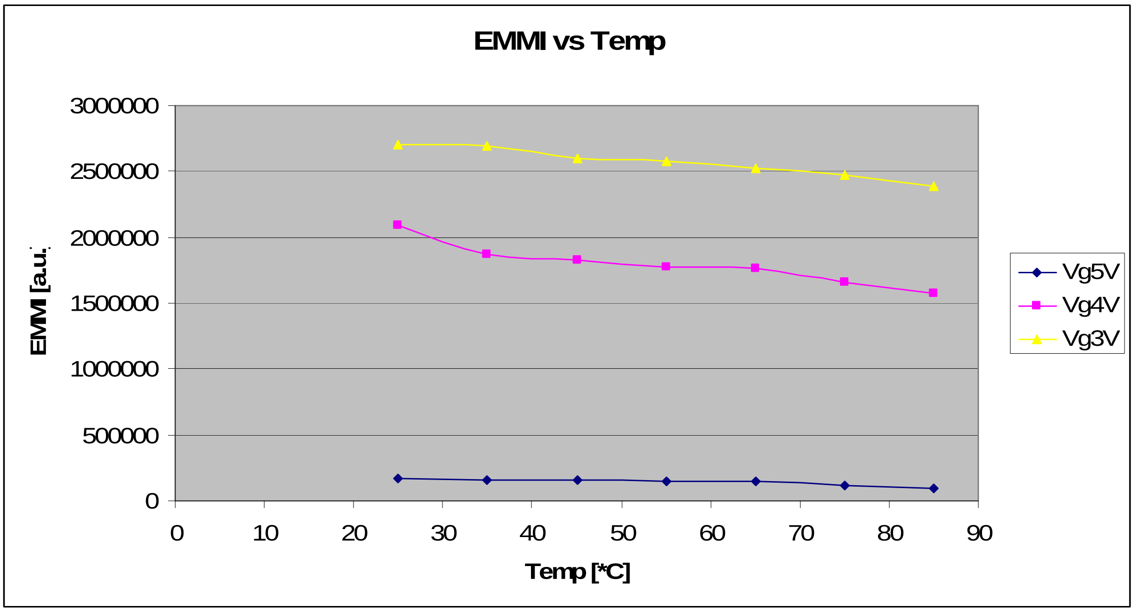

Fig.7. Photo Emission versus temperature for 3 different gate voltages.

Summary and conclusion.

Electrical characterization of HEMTs has been performed in two different sets of measurements. Significant influence of the temperature increase, especially for the lower gate voltages, was observed. Drain current dependence to temperature variation remained much lower sensitive then the gate current dependence.

Photon emission showed a decrease for higher temperatures. The similar phenomena was observed for each of the 3 gate voltage values (-3V, -4V, -5V). Additionally, PE curve inclination for 85^0C in (-3, -2.5) gate voltage range remained unchanged, while for 25^0C decreased rapidly.