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Temperature extraction in Normally-Off AlGaN/GaN HEMTs using Transient Interferometric Mapping

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ABSTRACT

The transient interferometric method (TIM) is used to quantify self-heating effects in normally-off AlGaN/GaN high electron mobility transistors (HEMT) with p-GaN gate. By means of thermal-optical simulations for different positions of heat sources in space and time, the best fit for the temperature distribution corresponding to the TIM signal is found.

1. INTRODUCTION

Normally-off AlGaN/GaN high electron mobility transistors (HEMTs) with p-GaN gate are currently developed for power switching applications [1].

The self-heating effect is one of the main limiting factors for the performance and reliability of these devices. Liquid crystal thermography [2], micro-Raman thermography [3] or scanning thermal microscopy [4], have been used to map the temperature distribution in GaN-based devices.

Recently we have presented a qualitative analysis of power dissipation in normally-off AlGaN/GaN devices using the transient interferometric method (TIM) [5].

Using TIM, the extraction of the power sources is possible by integration of the heat equation along the probe beam path in the active device area [6, 7]. However, when the active area has low reflectivity or the multiple reflections effect causes nonlinear phase distortions, the quantitative TIM analysis in this region is problematic.

In this work we present a new post-processing method for TIM data evaluation, enabling temperature extraction in the whole heated region from the limited TIM data outside the active region utilizing the 2D nature of the power dissipation source located in the two-dimensional electron gas (2DEG).

2. EXPERIMENTS

2.1. Devices under study

The devices under study are two-fingered p-GaN gate HEMTs (gate width W= 2x125 µm), with a gate to drain distance L_{DG}= 10 µm. The $Al_{0.23}Ga_{0.77}N$ barrier is 14 nm thick, and the carbon-doped GaN buffer layer with 3.2 µm thickness is grown on an n-type SiC substrate [8].

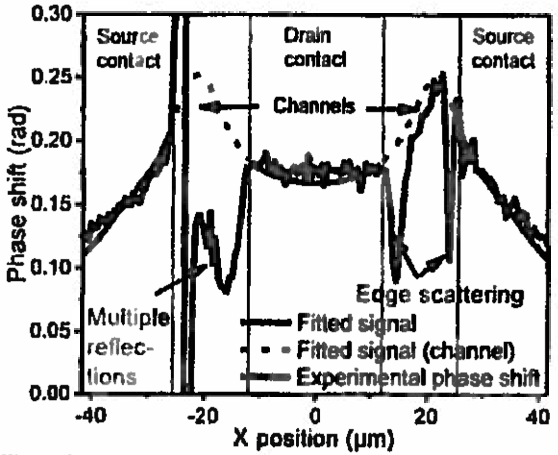

Figure 1: Experimental TIM signal (black line), fitted model in the area under the metallizations (solid red) and in the channels (dashed red) at t=10 µs (end of the pulse).

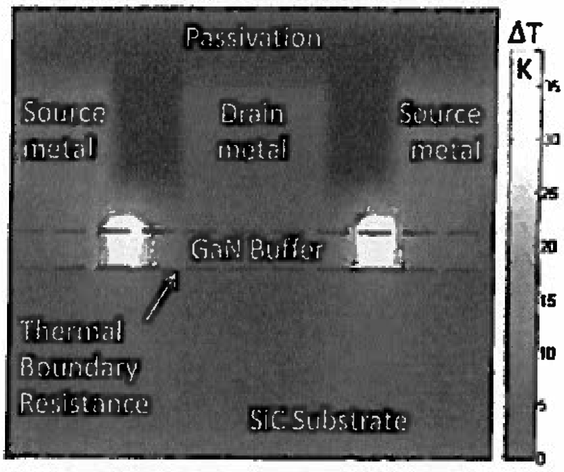

Figure 2: Distribution of temperature increase in the device at t= 10 µs (end of the pulse) obtained from the fitting procedure.

2.1. TIM analysis

The devices have been biased with a constant drain voltage of 25V (e.g. representing a short-circuit load condition) and the gate voltage is pulsed from -5 V to 5 V for 10 µs. The drain current was 80 mA, giving a constant dissipated power of 2 W during the pulse.
The TIM signal was recorded and extracted during the pulse but also during the cooling phase. The scan path includes both the active region and the metallization area.

3. POST-PROCESSING

The method is based on the solution of the inverse heat conduction problem. We consider a series of spatially distributed heat sources located in the channel. Simulating the transient temperature distribution for each independent source in the thermal finite elements model of the transistor, we create a basis of temperature distributions. By introducing different time-delays for each of these sources, we create a basis of spatiotemporal temperature distributions. We compute subsequently a basis of TIM phase-shift distributions corresponding to each source for each delay.
A linear least square algorithm then finds a solution for the time-dependent temperature distribution by fitting the TIM measurements with a linear combination of the simulated phase shift distributions of the basis.

4. RESULTS AND DISCUSSIONS

The temperature can be extracted at any point in space and time. For example, in a double finger device with L_{SG}=1µm, W_G=2x125µm and L_{DG}=12µm, the maximum temperature rise during the 2W, 10-µs-long pulse is about 38 K at the gate position, see figure 2.
The used post-processing technique has several advantages over a direct integration. First of all, out of all possibilities for phase shift distributions, the simulator gives only those that are allowed by the heat equation applied to the model. The consequence is that, since most of the artefacts cannot be fitted by a distribution of heat sources with positive power values, they can be distinguished from real power dissipation. As a consequence, temperature can be extracted in areas suffering from artefacts. Of course the spatial resolution is limited by the distance of the heat source from the measurement position, due to the damping in the heat propagation. It is seen in figure 1 that the experimental phase shift in the channel differs from the simulation except in the middle of the right channel area, which features a high reflectivity and does not suffer from artefacts.
A possible uncertainty in other parameters such as thermo-optical parameters can be compensated too, since the phase is considered linearly weighted by them, and another condition to fulfill is the matching of the total power. The method could also potentially allow the extraction of thermal parameters like lateral heat diffusivity or thermal boundary resistance, since the experimental and simulated diffusivities can be directly compared from the shape of the phase distribution as a function of time.
The secondary optimization outputs, such as the residuals, give therefore hints for the reliability of the solution.

5. CONCLUSION

A new robust data post processing method of the transient interferometric method has been demonstrated with a TIM scan on normally-off AlGaN/GaN high electron mobility transistors with p-GaN gate for which the signal in the active area shows high optical artefacts.

ACKNOWLEDGMENT

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13:10-16:00	**LUNCH & BREAK**	
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Chair: J. Kuzmik		
16:00	**Semiconductor Transport Properties and Power Devices Using III-Nitrides (invited)**	**Enrico Bellotti**
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17:00	Temperature extraction in Normally-Off AlGaN/GaN HEMTs using Transient Interferometric Mapping	C. Fleury
17:12	AlN/GaN HEMTs with thin GaN/AlN buffer layers on sapphire (0001) substrates	Ch. Zervos
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18:00	**Polaritonic Devices (invited)**	**Pavlos Savvidis**
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