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Thermoreflectance Measurement: Effect of GaN Cap Layer and Carbon Doped Buffer Layer on Thermal Resistance of HEMTs

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GaN-based High Electron Mobility Transistors (HEMTs) are widely used for high-frequency and high-power applications due to the wide band gap, high saturation velocity, and high mobility of electrons [1]. In order to make the GaN HEMT devices cost-effective, InAlN/GaN heterostructures are grown on foreign substrates, like Si, sapphire, and SiC. GaN grown on Si substrate suffers from strain due to lattice mismatch between GaN and Si. To reduce the stress on GaN, graded AlGaIn stress release layers are used. To prevent unwanted oxidation of the InAlN barrier layer, sometimes a thin GaN cap layer is used. To confine the channel electrons, carbon doping is incorporated into the buffer layer [2]. Figure 1 shows the schematic layer structure of the wafers. The wafers were procured from Veeco Instrument Incorporation, USA. Schottky gate HEMTs were fabricated on these wafers at Microelectronics and MEMS laboratory, IIT Madras. The fabrication process flow is explained in detail elsewhere [3]. In this paper, we studied the effect of the GaN cap and carbon-doped buffer layers on the self-heating of Schottky gate HEMTs.

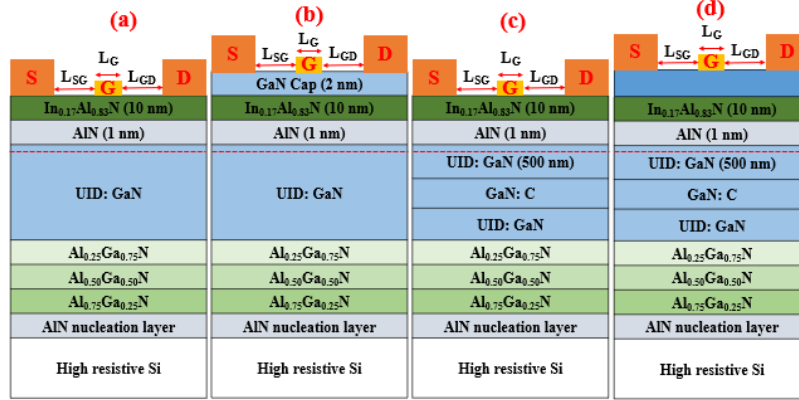


Figure 1: Schematic layer structure of the wafer; (a) without GaN cap and no carbon doping, (b) with GaN cap but no carbon doping, (c) without GaN cap but with carbon doping, (d) with GaN cap and carbon doping in the GaN buffer layer.

The thermoreflectance measurement was carried out at the XLIM laboratory, University of Limoges, France. Thermoreflectance measurement is based on the fact that the reflectivity of materials is a function of the material temperature [4]. The dependence of the relative change in the surface reflectance on the surface temperature can be expressed by the following equation [5].

$$\frac{\Delta R}{R_0} = C_{th} \cdot \Delta T$$

Where, C_{th} is the thermal coefficient of the material which depends on the material properties and the wavelength of the excitation LED. It is important to choose the optimal wavelength that gives the highest C_{th} value for a better measurement sensitivity. The thermal resistance (R_{th}) is measured in two steps; (i) calibration step and (ii) measurement step. In the calibration step, the value of the thermal coefficient of the material is obtained by measuring the change in relative reflectivity ($\Delta R/R_0$) at two different temperatures; 20 °C for the cold condition and 75 °C for the hot condition. From the measured value of $\Delta R/R_0$ and ΔT , the value of C_{th} is calculated using a signal with a wavelength of 365nm, this wavelength is suitable for

measurement on the GaN surface and allows more accurate measurements. Figure 2a and b show the CCD image in the calibration step and in the measurement step, respectively.

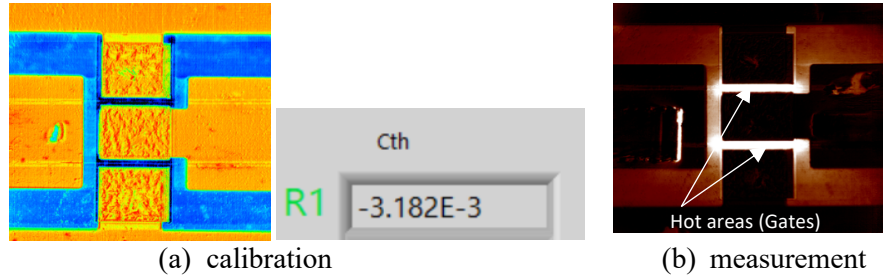


Figure 2: (a) CCD image in (a) calibration step and (b) measurement step.

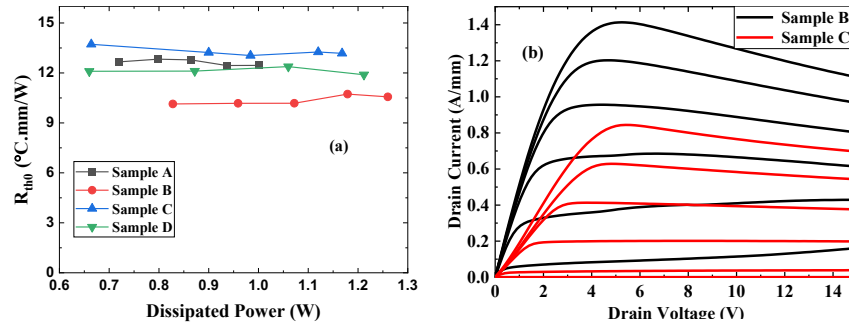


Figure 3: (a) R_{th0} versus dissipated power of Samples A, B, C, and D. (b) Output characteristics of Samples B and C.

In the measurement step, a dissipated power is applied to the transistor, $\Delta R/R_0$ is measured by the CCD camera and the temperature rise is extracted using the value of C_{th} calculated in the previous step. The value of thermal resistance is calculated by dividing ΔT by the value of P_{diss} , i.e.,

$$R_{th} = \frac{\Delta T}{P_{diss}}$$

The measurement is carried out for several dissipated powers in order to observe the evolution of the thermal resistance according to the dissipated power. The results demonstrate that the thermal resistance of the transistors studied is constant for the dissipated powers applied.

Figure 3a plots R_{th0} (normalized R_{th}) in $^{\circ}\text{C}\cdot\text{mm}/\text{W}$, respectively, for samples A, B, C, and D. From the figure, we can see that the thermal resistance is highest in the case where there is no GaN cap layer but the buffer layer is doped with carbon. On the other hand, the thermal resistance is lowest in the case where there is a GaN cap layer, but the buffer is not doped with carbon. Both the GaN cap layer and carbon doping in the buffer layer play a significant role in changing the thermal properties of the material. The thermal conductivity of GaN is more than that of InAlN. As a result, the GaN cap layer helps in dissipating heat and reduces thermal resistance. On the other hand, carbon doping reduces the thermal conductivity of GaN and increases the thermal resistance. Figure 3b plots the output characteristics of Sample B and C, for which the values of R_{th0} are extreme. Our study shows that the reduction in current in Sample C compared to B is not only due to carbon doping but also due to increased self-heating.

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