

Effect of interface traps on the different conduction mechanisms of MISHEMT from 200 K to 450 K

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Abstract— In this work, the effect of the interface traps on the different conduction mechanisms of a Metal Insulator Semiconductor High Electron Mobility Transistor (MISHEMT) operating in multiple temperatures (from 200 K to 450 K) is evaluated through High Electron Mobility Transistor (HEMT) and Metal Insulator Semiconductor Field Effect Transistor (MISFET) numerical simulations. The interface traps of the MISFET poses barely any effect on the threshold voltage. For the HEMT, however, the behavior with traps enabled is basically the opposite when the traps are disabled. Combining the opposite behaviors of the threshold voltage curves of the MISFET and HEMT as a function of temperature, gives a possible explanation of the threshold voltage rebound effect observed in MISHEMT.

Keywords— MISHEMT, multiple conduction, temperature, GaN, threshold voltage

I. INTRODUCTION

The High Electron Mobility Transistor (HEMT) can be used in simple designs for power switch applications, RF and microwave circuits [1, 2], and has been commercially used in the field of power electronics and high frequency operation since 1983 [3]. It also operates in harsh environments [4]. This device is based on the two-dimensional electron gas (2DEG) which forms a region of high mobility and high density of carriers at the interface of the heterostructure, usually AlGaIn/GaN, being the main mechanism of the HEMT [5].

However, at scaled dimensions the HEMT presents a high gate leakage current and current collapse due to electrons capture by traps at the passivation layer. By introducing an insulator between the gate metal and the semiconductor, a better immunity against the gate leakage current while mitigating the current collapse, giving birth to the Metal Insulator Semiconductor High Electron Mobility Transistor [6, 7, 8]. For applications requiring high frequency or high power operations, the MISHEMT is considered one of the most promising candidates in the future [8, 9].

While many studies strive to acquire a more stabilized threshold voltage (V_{TH}) for normally-off operation, through the research of new materials and process steps [1-2, 5-11], another important point is to understand the working principle of the device. These devices present multiple conduction mechanisms, composed of HEMT and MISFET, which impacts the device's behavior [12-16]. When operating under different temperatures the device presents a rebound effect on the threshold voltage [15, 16]. This work focuses on studying the influence of interface traps on threshold voltage of

simulated HEMT and MISFET in order to understand the rebound effect in the threshold voltage of a MISHEMT.

II. DEVICE CHARACTERISTICS

The rebound effect was observed on a MISHEMT [13, 15] fabricated at imec – Belgium – with channel width of 5 μm , gate length of 600 nm, 2 nm gate insulator of Si_3N_4 , 15 nm barrier layer of AlGaIn, 1 nm spacer of AlN, and 2.5 μm GaN grown on a silicon platform, as presented in figure 1A. The simulated MISFET, figure 1B, and simulated HEMT, figure 1C, were designed with the same materials and dimensions.

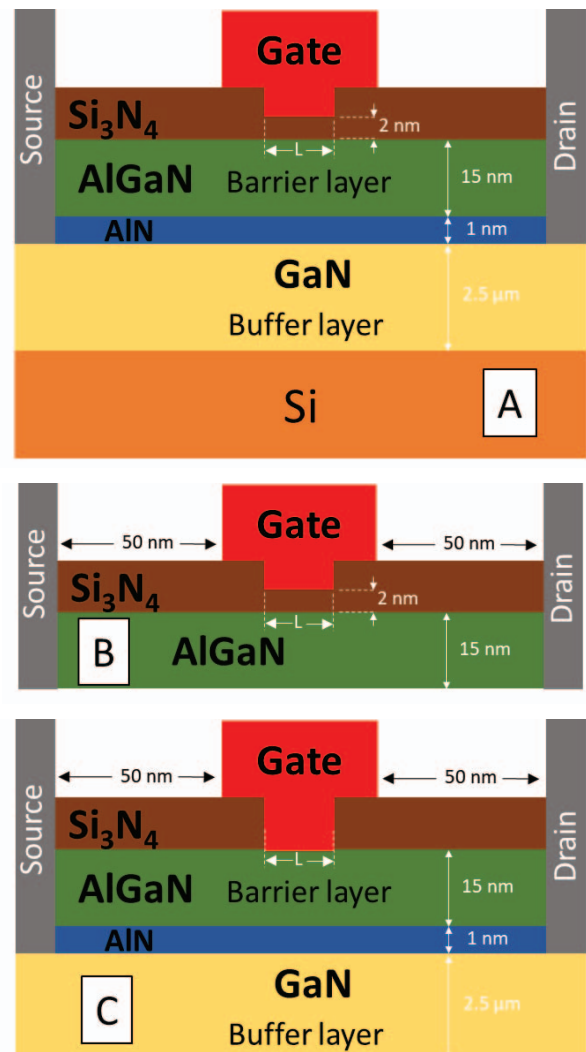


Fig. 1. Cross section structure of the MISHEMT (A), simulated MISFET (B) and simulated HEMT (C) used in this work.

The MISFET was evaluated using Sentaurus Synopsys TCAD simulations. The device has a channel width of 1 μm , gate length of 600 nm, 2 nm gate insulator of Si_3N_4 , a 15 nm barrier layer of AlGaIn. The distance between gate and drain (LGD), and between gate and source (LGS) were kept at 50 nm.

The HEMT was evaluated using Sentaurus Synopsys TCAD simulations. The device has a channel width of 1 μm , gate length of 600 nm, 5 nm of Si_3N_4 for passivation, 15 nm layer of AlGaIn, 1 nm spacer of AlN, and 2.5 μm GaN. The distance between gate and drain (LGD), and between gate and source (LGS) were kept at 50 nm.

III. RESULTS AND ANALYSIS

Figure 2 presents the drain current as a function of gate voltage for a MISFET with traps, disabled (top) and enabled (bottom), at the $\text{Si}_3\text{N}_4/\text{AlGaIn}$ interface, at different temperatures. For increasing temperature, it is possible to see the decrease on the current for high V_{GS} , due to mobility degradation, and the shift of the V_{TH} to the left due to the reduction of the Fermi potential. The acceptor-type trap was used thus inducing a capture of electrons reducing the current drive. Also, there is a slight shift in the threshold voltage, which will be thoroughly approached in figure 3. The second derivative was the method used for the V_{TH} extraction [17, 18].

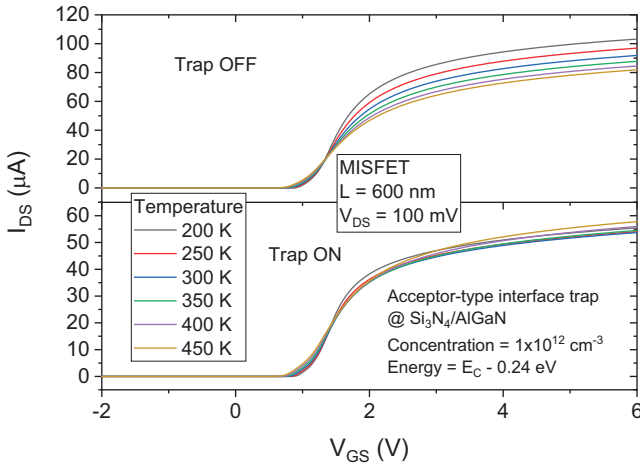


Fig. 2. Drain current as a function of gate voltage for different temperatures, for a MISFET with interface traps at $\text{Si}_3\text{N}_4/\text{AlGaIn}$ disabled (top) and enabled (bottom).

The V_{TH} behavior of the MISFET as a function of temperature follows the usual trend of decreasing with increasing temperature. The presence of the traps does not change the behavior significantly, possibly because the charges accumulated at the traps are not enough to affect the high mobility channel.

Figure 4 presents the drain current as a function of gate voltage for a HEMT at different temperatures, with traps enabled (bottom) and disabled (top). The energy which usually the traps are found are in the range of $E_C - 0.5$ eV [18, 19] with a density concentration above 10^{12} cm^{-3} [20, 21]. When the traps are disabled, it is possible to observe an increase of the drain current for increasing temperature, at

high V_{GS} . However, when the traps are considered, the drain current decreases for increasing temperature due to the mobility degradation.

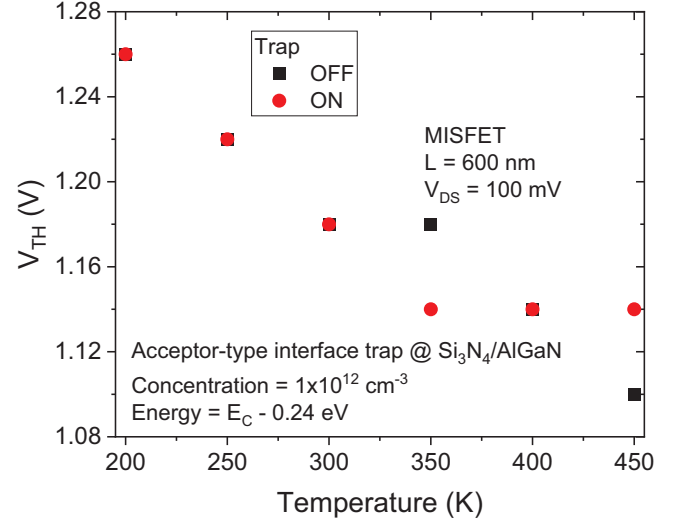


Fig. 3. Threshold voltage as a function of temperature for a MISFET with interface traps at $\text{Si}_3\text{N}_4/\text{AlGaIn}$ disabled (top) and enabled (bottom).

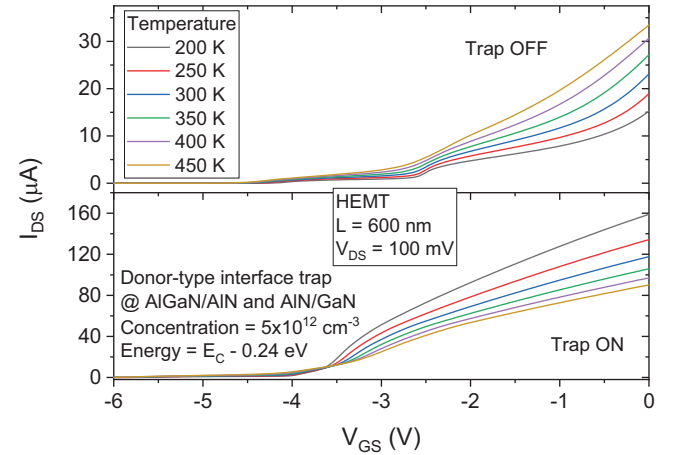


Fig. 4. Drain current as a function of gate voltage for different temperatures, for a HEMT with interface traps at the $\text{Si}_3\text{N}_4/\text{AlGaIn}$, AlGaIn/AlN and AlN/GaN, disabled (top) and enabled (bottom).

The threshold voltage as a function of temperature of the HEMT is presented in figure 5, for traps disabled and enabled. For increasing temperature, it is possible to see a slight decrease of the V_{TH} when the traps are disabled due to depletion depth reduction. However, when traps are enabled, the behavior changes since the increasing temperature increase the energy and numbers of ionized donor-like traps, increasing the capture of electrons thus reducing the positive charge resulting in the increase of V_{TH} [22, 23].

Figure 6 presents the threshold as a function of temperature of the HEMT and MISFET. For increasing temperature, the MISFET fermi potential reduces thus decreasing the V_{TH} , the behavior of the HEMT however is the opposite, since the traps at the 2DEG interfaces (AlGaIn/AlN and AlN/GaN) plays a major role and are thermally assisted.

With further improvement, the devices should have approximate values of V_{TH} while maintaining the same behavior. Combining both the trend of MOS and HEMT V_{TH} curves, should give the approximate behavior of the MISHEMT rebound effect, where there was a decrease of V_{TH} temperature from 200 K to 350 K and a great increase from 350 K to 450 K [15,16].

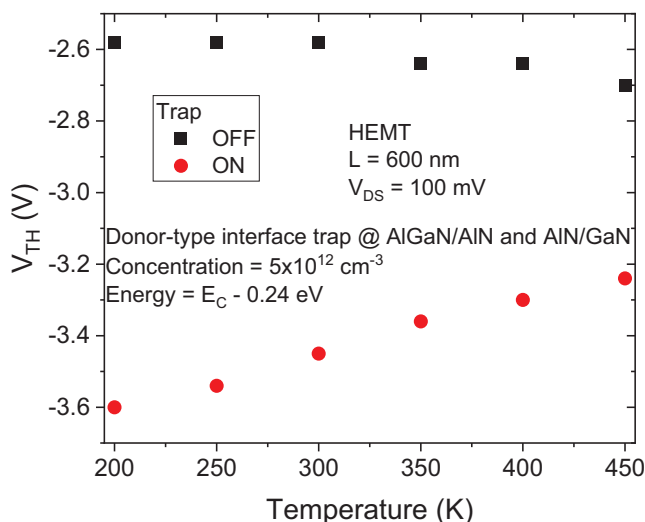


Fig. 5. Threshold voltage as a function of temperature for a HEMT with interface traps at the $\text{Si}_3\text{N}_4/\text{AlGaIn}$, AlGaIn/AlN and AlN , disabled (top) and enabled (bottom).

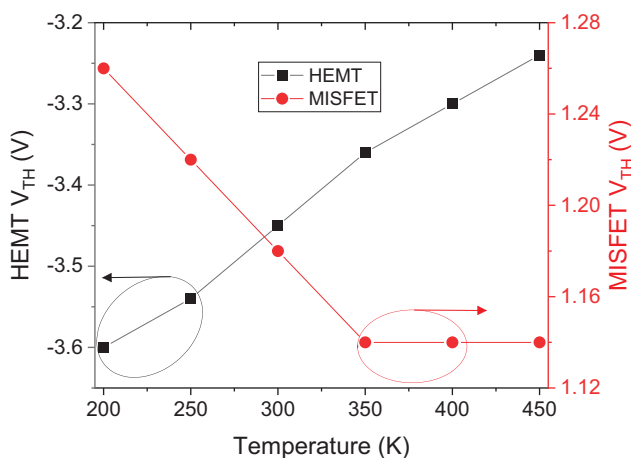


Fig. 6. Threshold voltage as a function of temperature of MISFET and HEMT with traps enabled.

IV. CONCLUSIONS

In this work the effect of interface traps on different conduction mechanism measured by the threshold voltage of simulated HEMT and MISFET was studied in a large range of temperature (from 200 K to 450K) in order to explain these effects on MISHEMTs. Through the threshold voltages curves of MISFET, it was possible to observe that the interface traps barely affect the device's behavior. The HEMT, however presented a completely different behavior when the traps are considered. When comparing the results of the threshold voltages of both simulated devices, with traps enabled, is possible to infer that, if the conduction mechanisms was adjusted properly for experimental MISHEMT, the MOS conduction (MIS channel) should

dominate the behavior until 350 K, while for higher temperatures the HEMT (2DEG) should be the dominating mechanism, resulting in the threshold voltage rebound effect.

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