Edited by H. Ryssel, P. Pichler - September 1995

Two-Dimensional Simulation of Deep-Trap Effects in GaAs MESFETs with Different Types of Surface States

K. Horio, K. Satoh and T. Yamada

Faculty of Systems Engineering, Shibaura Institute of Technology
307 Fukasaku, Omiya 330, JAPAN

Abstract

Effects of surface states on I-V curves and turn-on characteristics in GaAs MESFETs are studied by 2-D simulation. These characteristics are essentially determined by deep-acceptor-like state. Depending on whether it acts as an electron trap or a hole trap, the turn-on characteristics change drastically. Physical mechanism of slow transients due to surface states is discussed.

1. Introduction

Many performance instabilities such as drain-current drifts, hysteresis in I-V curves, sidegating effects, and frequency-dependence of small-signal parameters have been reported experimentally in GaAs MESFETs. These were supposed to occur due to deep levels in the semi-insulating substrate or surface states on the active layer. However, the detailed mechanisms were not well clarified. As to the effects of semi-insulating substrate, many theoretical works have been made since a numerical model including deep levels was proposed [1], and clarified to some extent how the deep levels affect device characteristics. As to the effects of device surface conditions, only a few theoretical works were recently reported [2],[3]. So, in this work, we have systematically simulated GaAs MESFETs considering surface states, and found that drastic change of device characteristics arises depending on the nature of surface states.

2. Physical Model

We consider a GaAs MESFET where the active-layer thickness is 0.2 μm and its doping density is 10^{17} cm^{-3}. The gate lenght is typically 0.3 μm. For a substrate, we consider undoped semi-insulating LEC GaAs where deep donors "EL2" (N_{EL2}) compensate shallow acceptors (N_{Ai}) [1]. For the surface-state model, we assume that the surface states consist of a pair of deep donor and deep acceptor [4], and the following two cases are considered for GaAs surface [4],[5].

a) Sample 1: $E_{SD} = 0.925$ eV, $E_{SA} = 0.8$ eV [3],[4]
b) Sample 2: $E_{SD} = 0.87$ eV, $E_{SA} = 0.7$ eV [2],[5]

where E_{SD} is energy difference between the bottom of conduction band and deep donor's energy level, and E_{SA} is energy difference between deep acceptor's energy level and the top of valence band. The surface states are assumed to distribute uniformly within 5 Å from the surface. Their density and capture cross-section for carriers are typically set to 10^{13} cm^{-2} and 10^{-15} cm^2, respectively. Basic equations are the Poisson's equation, continuity equations for electrons and holes, and three rate equations for the deep levels. These are solved numerically in two dimension.

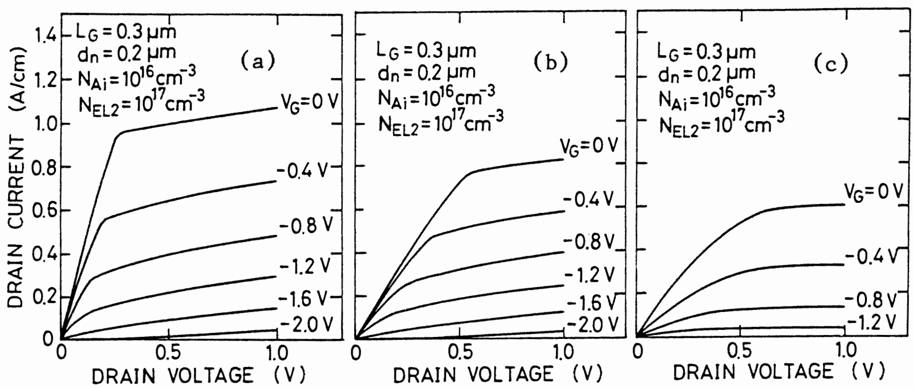

Figure 1: Comparison of calculated drain characteristics of GaAs MESFETs with and without surface states. (a) Without surface states, (b) Sample 1, (c) Sample 2.

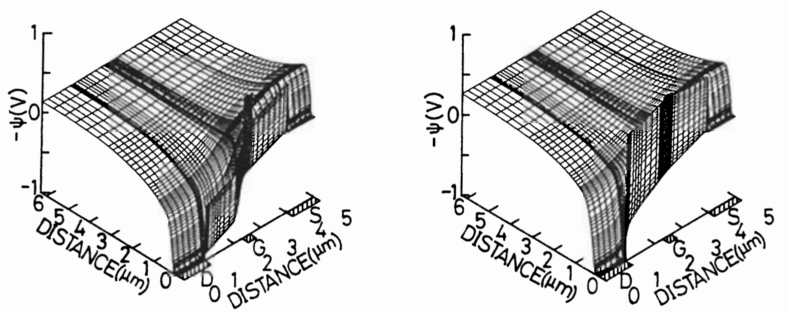

Figure 2: Comparison of potential profiles with different surface states. $V_G = 0$ V and $V_D = 1$ V. (a) Sample 1, (b) Sample 2.

3. I-V Characteristics

Figure 1 shows an example of calculated drain characteristics. When considering surface states, drain currents are estimated lower because the Fermi level is pinned around the mid-gap and the depletion layer is formed (Figure 2). It is also seen that the drain currents are lower for the case of Sample 2. This is because the dominant surface state is the deep acceptor in these cases and its energy level for Sample 2 is nearer to the valence band. In Figure 2, it should be noted that in Sample 1, the drain voltage is applied along surface-state layer, but in Sample 2, the drain voltage is entirely applied along the interface between drain electrode and surface-state layer. This is because in Sample 1 the deep acceptor acts as an "electron trap", while in Sample 2 the deep acceptor acts as a "hole trap". This difference of trap nature does not strongly affect I-V characteristics, but leads to dramatic difference in transient characteristics as described in the next section.

4. Turn-on Characteristics

Figure 3 shows comparison of turn-on characteristics with and without surface states when the gate voltage changes abruptly. Without surface states, the drain current becomes a steady-state value around $t = 10^{-11}$ s. For Sample 1 (with electron trap), the drain current shows fast response, too, and becomes constant temporarily around $t = 10^{-11}$ s, but decreases slightly during $t = 10^{-5}$ to 10^{-1} s. This current decrease starts when the deep acceptor (electron trap) begins to capture electrons. However, the difference of ionized-trap density between OFF and ON states is small in this electron-trap case, so the surface state does not strongly affect the characteristics. A dramatic feature arises in the case of Sample 2 (with hole trap). The drain current remains a low value for some period and begins to increase slowly around $t = 10^{-2}$ s. (This sort of slow transient is sometimes observed experimentally and called "gate-lag".) This slow transient is due to slow response of the deep acceptor (hole trap). In this case, as seen in Figure 4(a), the depletion layer exists along the entire region from source to drain. So, even if the gate voltage is changed, the drain current remains low (Figures 4(b),(c)) until the deep acceptors capture or emit carriers to change their ionized density much. The ionized deep-acceptor density should decrease when the deep acceptors (hole traps) begin to capture holes, which can be supplied from the Schottky contact, as is understood from the potential profiles in Figures 4(b)-(e). Thus the width of depletion region under the surface-state layer begins to decrease, leading to the slow increase in drain current.

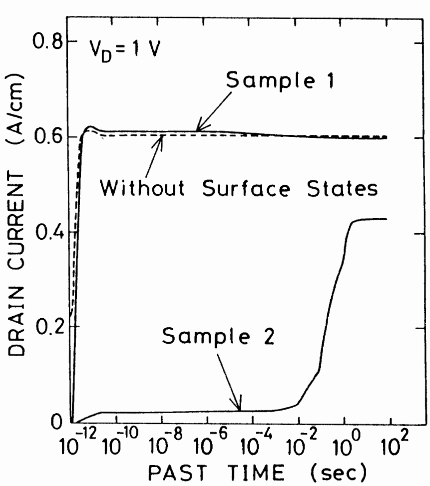

Figure 3: Comparison of turn-on characteristics of GaAs MESFETs with and without surface states. $V_D = 1$ V.

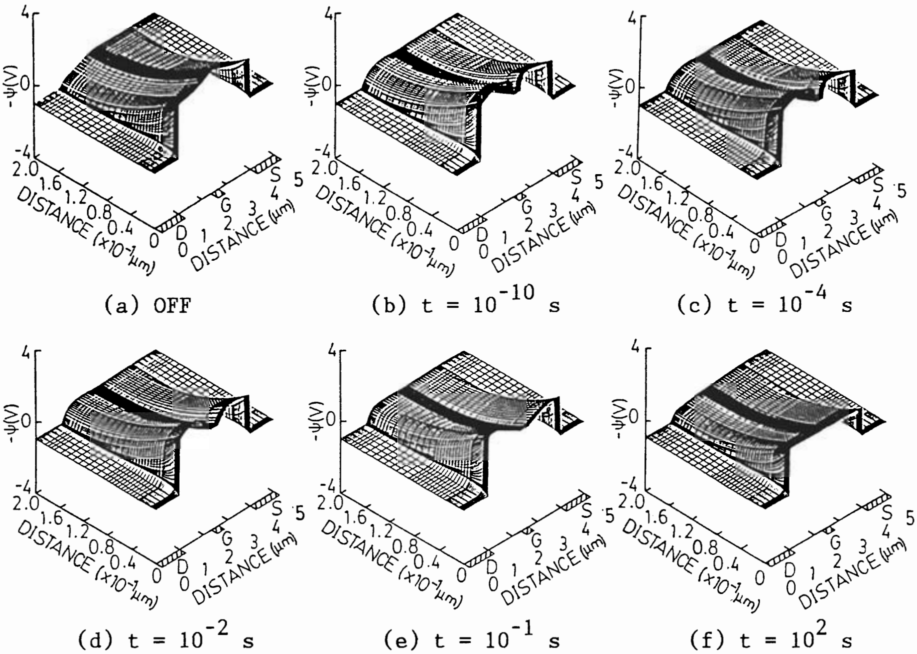

Figure 4: Potential profiles for the case of Sample 2. (b) to (f) are profiles during the turn-on process. t is the past time after the gate voltage is changed abruptly.

5. Conclusion

2-D simulation of surface-state effects in GaAs MESFETs has been made. The characteristics are essentially determined by the deep-acceptor-like state. Depending on whether it acts as an electron trap or a hole trap, the turn-on characteristics can change drastically. Physical mechanism of the slow transients due to surface states has been discussed and clarified.

References

[1] K. Horio, H. Yanai and T. Ikoma, "Numerical simulation of GaAs MESFET's on the semi-insulating substrate compensated by deep traps", *IEEE Trans. Electron Devices*, vol.35, pp.1778-1785, 1988.

[2] C. L. Li, T. M. Barton and R. E. Miles, "Avalanche breakdown and surface deep-level trap effects in GaAs MESFET's", *IEEE Trans. Electron Devices*, vol.40, pp.811-816, 1993.

[3] S. H. Lo and C. P. Lee, "Analysis of surface state effect on gate lag phenomena in GaAs MESFET's", *IEEE Trans. Electron Devices*, vol.41, pp.1504-1512, 1994.

[4] W. E. Spicer *et al.*, "New and unified model for Schottky barrier and III-V insulator interface states formation", *J. Vac. Sci. Technol.*, vol.16, pp.1422-1433, 1979.

[5] H. H. Wieder, "Surface Fermi level of III-V compound semiconductor-dielectric interfaces", *Surface Sci.*, vol.132, pp.390-405, 1983.