Analysis of Small Signal Behaviour of Transparent Gate Recessed Channel (TGRC) MOSFET for High Frequency/RF Applications

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ABSTRACT

In this paper, small signal behavior have been investigated for Transparent Gate Recessed Channel (TGRC) MOSFET in terms of Y-parameters and Z-parameters, the results are compared with Conventional Recessed Channel (CRC) MOSFET at THz frequency range, using ATLAS device simulator. Small-signal Y-parameters and Z-parameters are commonly employed for those networks which are operating at RF and microwave frequencies, where admittances are more easily computed in compared to voltages and currents. Since, at high frequency it is very difficult to estimate current and voltages.

Keywords: CRC-MOSFET, cut-off frequency, ITO, RF, TGRC-MOSFET, Y-parameter, Z-parameter.

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1. INTRODUCTION

In the era of sub –100 nm dimensions, continuing scaling of conventional MOSFETs is done to advance opportunities for further high speed and low power applications. Highly scaled MOSFETs achieved cut-off frequencies in several THz range making CMOS technology appropriate for RF application and wireless communications [1-4]. In the conventional MOSFET, as the channel length reduces, the gate control over the channel gets reduced due to the increased source/drain capacitances [5]. However, with scaling down the device dimensions, the so-called SCEs arises such as mobility degradation, hot carrier effects, drain induced barrier lowering, parasitic capacitances etc. making the scaled devices inapt for RF/ wireless applications [6].

In TGRC-MOSFET, the metal gate is replaced by a transparent conducting oxide [7-8] called indium tin oxide (ITO). ITO is a solid solution of indium oxide (In_2O_3) and tin oxide (SnO_2). It is transparent and colourless in thin layers. Moreover, due to the increased demand for high-speed electronics products, the accurate modeling of the small signal behaviour at high frequencies (HF) is necessary in microwave circuits and systems [9].

All simulations have been performed using ATLAS and DEVEDIT 3D device simulator [10]. For the simulations authors adopted physical models accounting for the electric field-dependent and concentration-dependent carrier mobilities, Shockley–Read–Hall recombination/generation with doping dependent carrier lifetime, inversion layer Lombardi CVT mobility model, wherein concentration-dependent mobility, high field saturation model are all included [10]. To incorporate all non-local effects, we have adopted the hydrodynamic energy transport model and are more accurate than drift-diffusion method.

2. DEVICE STRUCTURE AND METHODOLOGY

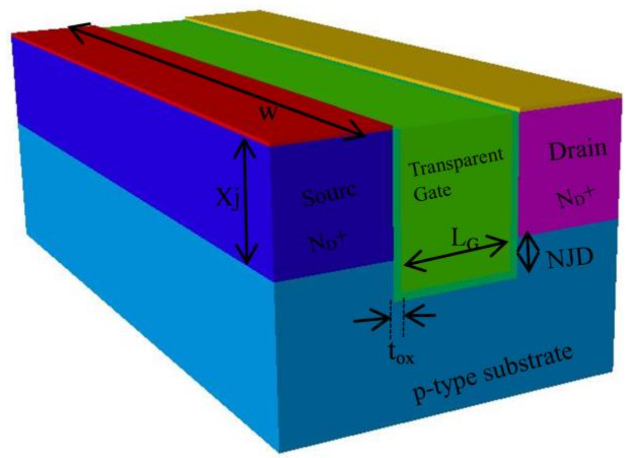

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Fig.1(a) Schematic structure of TGRC-MOSFET.

Fig. 1(a-b) shows the simulated 3D device structure of TGRC-MOSFET and 2-D meshed structure of TGRC-MOSFET respectively. All simulations have been performed using ATLAS and DEVEDIT 3D device simulator. The Source/Drain region is highly doped with n-type impurity of 1×10^{19} cm^{-3}. While substrate is doped with a p-type impurity of 1×10^{17} cm^{-3} and t_{ox} thick oxide layer of 2.0 nm is embodied in it as shown in Fig.1.In order to fairly analyze the device performances, both the devices are optimized to have the same threshold voltage, i.e., 0.4V. In this simulation all the junctions of the structure are assumed as abrupt and the biasing

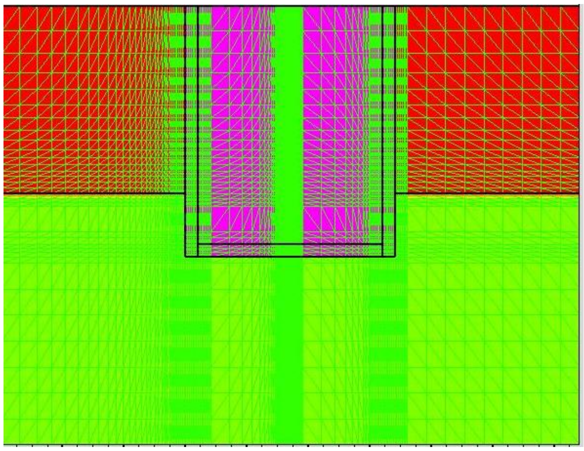

Fig.1(b) 2-D Meshed structure of TGRC-MOSFET.

conditions are considered at room temperature (T=300K) and the doping profiles are uniform. Further, two numerical techniques Gummel and Newton have been considered to obtain the solutions [10]. Negative Junction Depth (NJD) is taken 10 nm. Gate bias (V_{gs}) is applied 0.7 V and drain bias (V_{ds}) is applied 0.5V. Gate workfunction of TRC-MOSFET (Φ_{ITO}) is 4.7 eV and 4.4 for CRC-MOSFET.

3. RESULTS AND DISCUSSIONS

Fig. 2 (a-d) compares the real components of Y-parameters and Z-parameters of CRC-MOSFET with TGRC-MOSFET. Without any additional appropriate parameters, the Y-parameters and Z-parameters characteristics are well reproduced up to the cutoff frequency. Correct calculation of Y-parameters and Z-parameters promises the applicability for RF and very fast switching [11]. Z_{11} is higher (lower Y_{22}) at low frequency and decreases gradually as frequency is

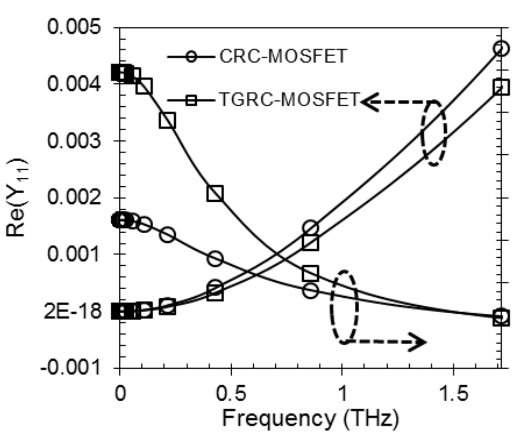

Fig. 2(a): Y-parameters Re (Y_{11}) and Z-parameters Re(Z_{11}) at V_{gs}=0.7 V and V_{ds}=0.5 V.

increases while Z_{22} is higher (lower Y_{11}) at low frequency and deceases gradually w.r.t. frequency in TGRC-MOSFET as compared to CRC-MOSFET i.e. input impedance is high and output impedance is less as shown in Fig. 2(a) and 2(d) respectively. If the input impedance of the device is high, it means the device is useful for RF application of MOSFETs [5]. Z_{12} and Z_{21} (open circuit transfer impedance) parameters are also high in TGRC-MOSFET and reduce gradually when frequency is increases as shown in Fig. 2(b) and 2(c) respectively. Similarly Y_{12} and Y_{21} (short circuit transfer admittance) are enhanced in TGRC-MOSFET which leads to high input impedance as evident from Fig. 2(b) and 2(c) respectively.

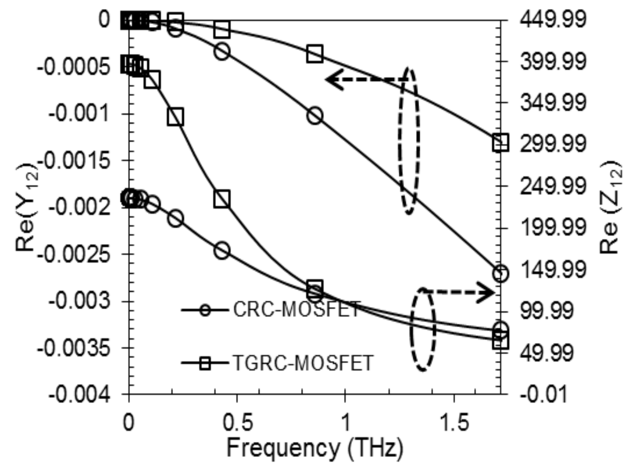

Fig. 2(b): Y-parameters Re (Y_{12}) and Z-parameters Re(Z_{12}) at V_{gs}=0.7 V and V_{ds}=0.5 V.

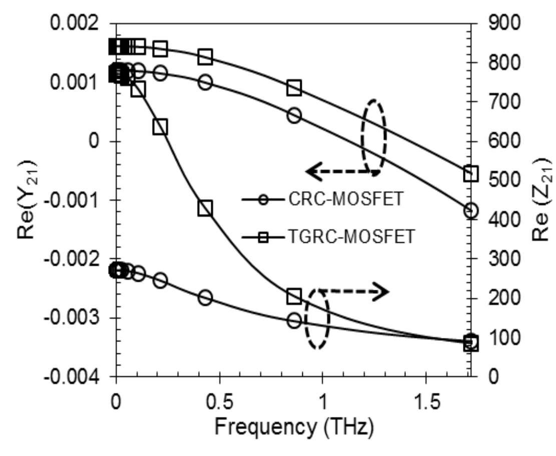

Fig. 2(c): Y-parameters Re(Y_{21}) and Z-parameters Re(Z_{21}) at V_{gs}=0.7 V and V_{ds}=0.5 V.

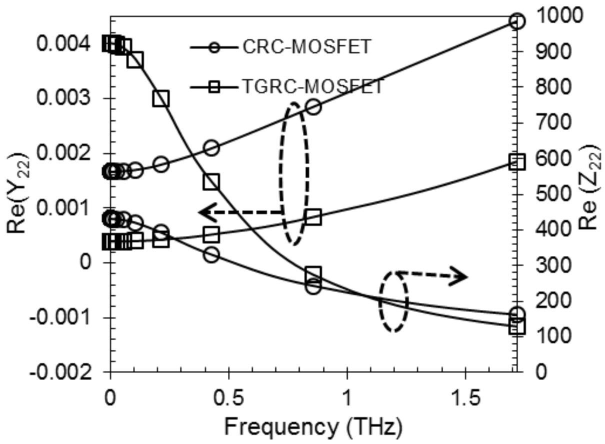

Fig. 2(d): Y-parameters Re(Y_{22}) and Z-parameters Re(Z_{22}) at V_{gs}=0.7 V and V_{ds}=0.5 V.

CONCLUSION

In this paper, small signal behavior has been investigated for Transparent Gate Recessed Channel (TGRC) MOSFET in terms of Y-parameters and Z-parameters. All the results have been compared with conventional one. All Y-parameters (Y_{11}, Y_{12}, Y_{21}, Y_{22}) and Z-parameters (Z_{11}, Z_{12}, Z_{21}, Z_{22}) shows the improved performance when a transparent conducting oxide incorporate in place of metal oxide. Here a transparent conducting oxide known as ITO is used. All simulations have been performed using ATLAS and DEVEDIT 3D device simulator. . Scaling of MOSFETs achieved cut-off frequencies in several THz range making CMOS technology suitable for RF application and wireless communications.

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