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CONFERENCE ABSTRACT BOOKLET

Single Trap and Low Frequency 1/*f* Noise Modeling in MOSFETs with Dirac Materials or 2D Semiconductor Channel

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Low frequency noise models for transistors based on 2D materials are prospective tools for assessing the impact of traps on device performance and reliability. However, until now scarce data are available mostly due to limited sample reproducibility. Furthermore, analysis is also limited to using compact analytical formulas since only recently TCAD tools have been extended to properly manage 2D materials. This work aims to expand physics-based noise modeling in the realm of devices featuring 2D material channels. It presents a model of trapping-detrapping noise (TDN) based on carrier number fluctuation (CNF) theory in single gate (SG) MOSFETs with graphene (Gr) or MoS_2 as channel materials. The model is validated with results from a calibrated, technology computer-aided design (TCAD) tool and with available experiments. The CNF model has been proposed to be adequate in 2D materials [1]. For a single trap in the gate dielectric, it provides a drain current noise spectral density [2] as $S_{ID} = S_{\Delta f_t}.\, q^2.[(dI_D/dQ_{ch}).(dQ_{ch}/dQ_{tr})]^2$ (1), where, $S_{\Delta f_t} = 4f_t(1-f_t)\tau/(1+(2\pi f\tau)^2)$, f_t is the trap occupation probability, f is the frequency, and τ is the trapping time. With the help of Fig. 1 (a), we propose $dQ_{ch}/dQ_{tr} = [1-(z_0/T_{ox})][C_{DoS}/(C_{DoS}+C_{ox})]$ for the transfer function between the change in trap charge (trap located at $z = z_0$) and the change in channel charge. Generalization of the term $[1-(z_0/T_{ox})]$ to composite gate stacks has been given in [2]. This expression is validated against TCAD simulations in Figs. 1 (b) and (c) where the DoS capacitance, C_{DoS}, is evaluated either from the DoS of graphene or of a 2D material. We also write $dI_D/dQ_{ch} = (dI_D/dV_{GS}).(dV_{GS}/dQ_{ch}) = g_m/(WL_GC_{eq})$, where, $C_{eq} = C_{DoS}C_{ox}/(C_{DoS}+C_{ox})$, and g_m, W and L_G have usual meanings. By replacing the expressions above in (1), the input-referred gate voltage noise spectral density can be expressed as $S_{VG} = S_{ID}/g_m^2 = S_{\Delta f_t}.\, q^2/(WL_GC_{ox})^2.[1-(z_0/T_{ox})]^2$(2)

Figures 2 and 3 compare the models in (1) and (2) with TCAD simulations of the trapping noise [3, 4]. The relative position of the trap energy level with reference to the Fermi level, $E_T - E_F$, is carefully optimized to ensure that simulations with the non-local tunneling model converge to have observable noise output. For inelastic tunneling to traps, the Huang Rhys factor and phonon energy have been considered in accordance with [2]. The model shows consistent match with TCAD simulation for both graphene and MoS_2 considering both elastic and inelastic tunneling. The terms, τ and f_t, have been extracted directly from the TCAD simulations.

Subsequently, the CNF model for a single trap is extended to low frequency $1/f$ noise by integrating (1) for multiple traps distributed in energy and space in the gate dielectric. The low frequency model $1/f$ noise model is validated by comparing it with the experiments in [1] as shown in Fig. 4 and found to exhibit an excellent match. Consistently with [1], the model predicts different effective trap concentrations at the Fermi level corresponding to the different biases and proves as an effective starting tool to aid noise data interpretation in MOSFETs with 2D material channels.

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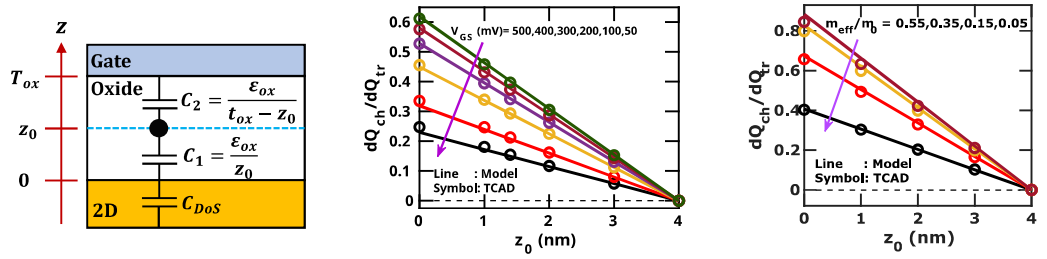
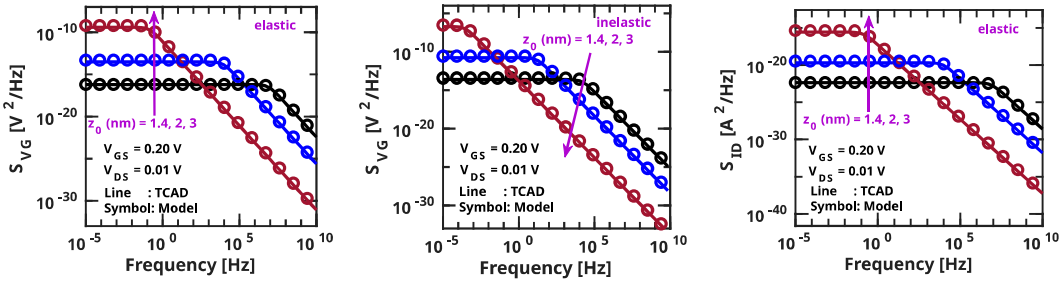


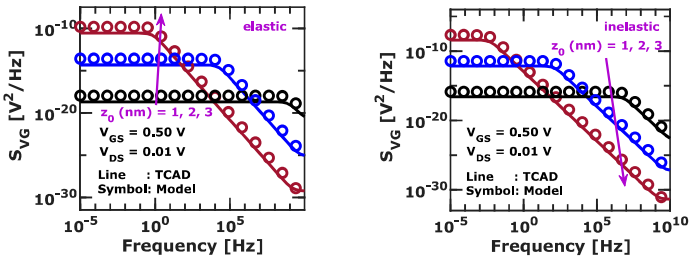
(a) (b) (c)

Figure 1. (a) Schematic showing the capacitance divider leading to the expression of dQ_{ch}/dQ_{tr} for a single trap at z_0 in gate dielectric; **(b)** dQ_{ch}/dQ_{tr} vs z_0 at different V_{GS} (i.e., different DoS at the Fermi level) for a single trap in SG Gr MOSFET; **(c)** dQ_{ch}/dQ_{tr} vs z_0 for a single trap in SG MOSFET with 2D semiconductor channel. m_{eff}/m_0 is changed to check the DoS dependences. $T_{ox} = 4nm, \varepsilon_{ox} = 22\varepsilon_0, L_G = 30\ nm, W = 1\ \mu m, V_{DS} = 10\ mV, q\chi_{Gr} = q\Phi_{M,GrFET} = 4.6\ eV, q\chi_{MoS2} = q\Phi_{M,MoS2FET} = 4.3\ eV$



(a) (b) (c)

Figure 2. S_{VG} at a few different z_0 considering **(a)** elastic transitions, **(b)** inelastic transitions for a single trap in a SG Gr MOSFET; **(c)** same as (a) but for S_{ID}. Note the Lorentzian shape (flat and then going as $1/f^2$)



(a) (b)

Figure 3. S_{VG} as a function of frequency at different z_0 considering **(a)** elastic, **(b)** inelastic transition for a single trap in a SG MoS_2 MOSFET

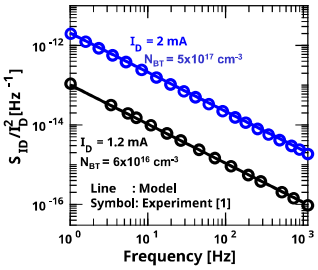


Figure 4. Comparison of $1/f$ noise model with experiment in [1] for Gr MOSFETs.

References

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