Electrically Doped 2D Material Tunnel Transistors

H. Ilatikhameneh, F. W. Chen, J. Appenzeller, R. Rahman, and G. Klimeck
Department of Electrical and Computer Engineering, Purdue University, West Lafayette, IN, 47907 USA
e-mail: hesam.ilati2@gmail.com.

INTRODUCTION

Tunnel field effect transistors (TFETs) have attracted a lot of attention as promising candidates for low power transistors [1, 2]. It is recently shown that 2D material TFETs such as transition metal dichalcogenide (TMD) based TFETs can provide a high ON-current while keeping the subthreshold swing (SS) less than conventional Boltzmann limit of 60 mV/dec at room temperature [3]. These high ON-current values in 2D TFETs are due to the tight gate control which translates into a high electric field at the tunnel junction. Despite the fact that a high chemical doping of the source contact is crucial for having a high performance TFET [3], this doping method has several drawbacks such as introducing the defect states in the bandgap which can degrade device OFF-state performance [4]. Electrical doping on the other hand, avoiding these problems, is currently the predominant method in the realization of 2D TFETs. It is critical for device designers to understand how different parameters affect the performance of electrically doped junctions. Equivalent oxide thickness (EOT) has been generally accepted as the key performance factor in these devices. However, in this work, it is shown through atomistic simulations that in electrically gated junctions the thickness of the oxide rather than EOT plays the main role. Two small band gap 2D materials Bilayer graphene (BLG) and monolayer WTe_2 are studied for high ON-current TFET application.

MODEL

Two different tight-binding (TB) models are employed here; WTe_2 Hamiltonian is represented by a sp^3d^5 2nd nearest neighbor with spin-orbit coupling while BLG Hamiltonian considers only p_z orbital. The atomistic quantum transport simulations use a self-consistent Poisson-NEGF method. The structures of electrically doped WTe_2 and BLG TFETs are shown in Figs. 1 and 2, respectively. The total thickness of the device is shown as T_{tot} in Fig. 1. All of the transport simulations have been performed with our simulation tool NEMO5 [5, 6].

RESULTS

Contradictory to the *chemically* doped devices where electric field (E) at the tunnel junction depends on EOT [7], in *electrically* doped BLG and WTe_2 TFETs, electric field depends on the oxide thickness as shown in Figs. 3 and 4.

$$E \approx \frac{\pi}{2}\frac{V_1 - V_2}{T_{tot}} \quad (1)$$

Here V_1 and V_2 are the potential levels at two sides of the tunnel junction. This finding shows that the new analytic model for electrically doped devices [8] can be applied to small band gap materials too.

Figures 5 and 6 show that the impact of oxide thickness is much larger on the transfer characteristics of the electrically doped TFETs compared to the impact of their dielectric constant.

CONCLUSION

In summary, atomistic transport simulations unveil that in the novel class of *electrically* doped TFETs (even those made of small band gap materials) the key parameter for transistor performance is oxide thickness instead of EOT.

ACKNOWLEDGMENT

This work was supported in part by the Center for Low Energy Systems Technology (LEAST), one of six centers of STARnet, a Semiconductor Research Corporation program sponsored by MARCO and DARPA.

REFERENCES

[1] J. Appenzeller et al., Phys. Rev. Lett. 93, 196805 (2004).
[2] A. M. Ionescu et al., Nature 479, 329337 (2011).
[3] H. Ilatikhameneh et al., "Tunnel Field-Effect Transistors in 2D Transition Metal Dichalcogenide Materials," accepted for publication in IEEE JxCDC (2015) DOI: 10.1109/JXCDC.2015.2423096, arXiv:1502.01760.
[4] S. Agarwal et al., IEEE tran. on elec. dev. 61, 1488 (2014).
[5] S. Steiger et al., IEEE tran. on nano. 10, 6, 1464 (2011).
[6] J. E. Fonseca et al., Journal of Comp. Elec. 12, 592 (2013).
[7] K. Suzuki et al., IEEE tran. on elec. dev., 40, 2326 (1993).
[8] H. Ilatikhameneh et al., "Scaling Theory of Electrically Doped 2D Transistors," http://arxiv.org/abs/1504.03387.

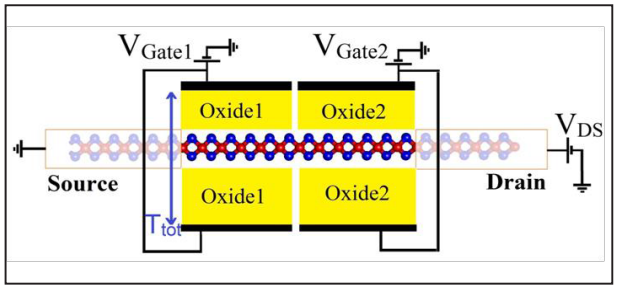

Fig. 1. Physical structure of an electrically doped WTe2 TFET with the oxide lengths of 13nm.

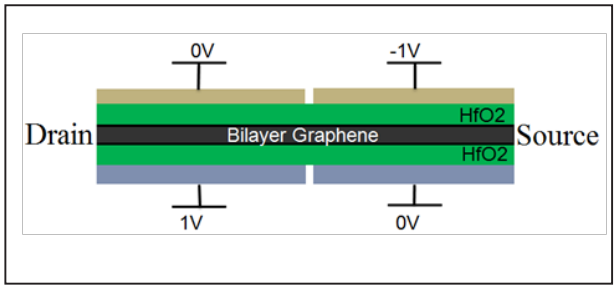

Fig. 2. Physical structure of an electrically doped BLG pn junction with the oxide lengths of 20nm.

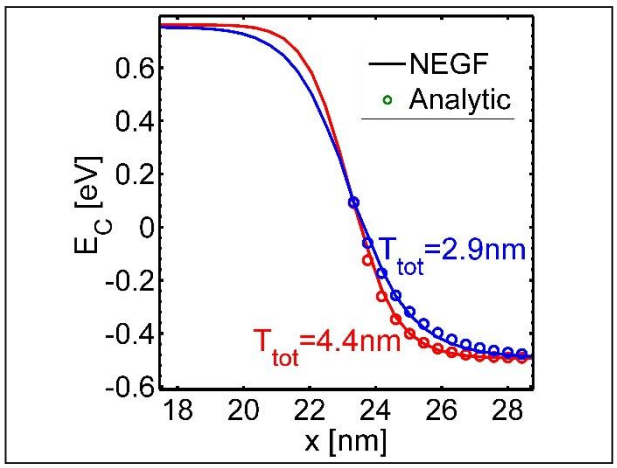

Fig. 3. Conduction band profiles of WTe_2 TFET with different oxide thicknesses while EOT is fixed. Analytic results are obtained following the new scaling theory [8].

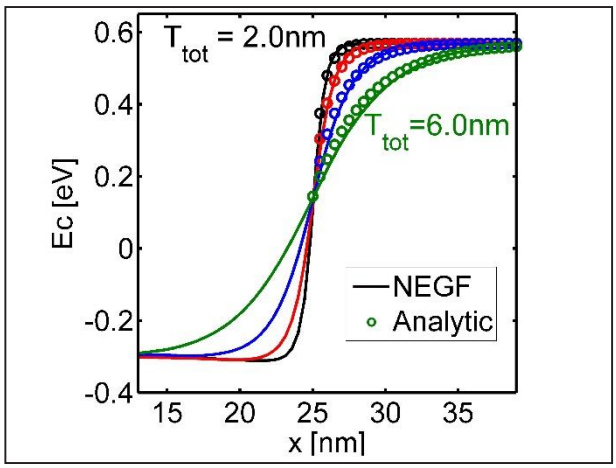

Fig. 4. Conduction band profiles of BLG pn junction with different oxide thicknesses while EOT is fixed. Analytic results are obtained following the new scaling theory [8].

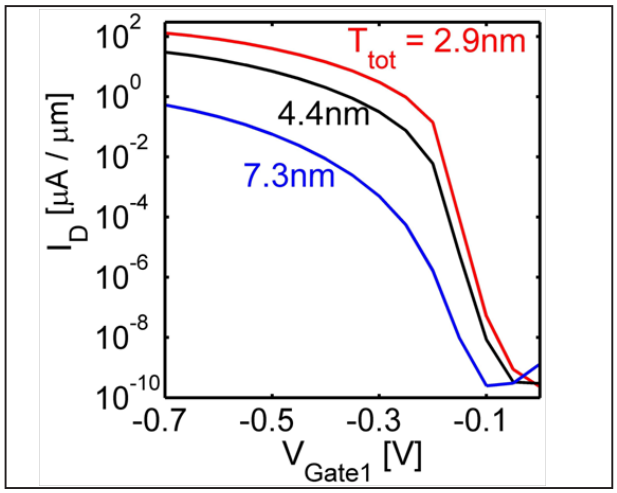

Fig. 5. Transfer characteristics of WTe_2 TFET with different oxide thickness (ϵ=20).

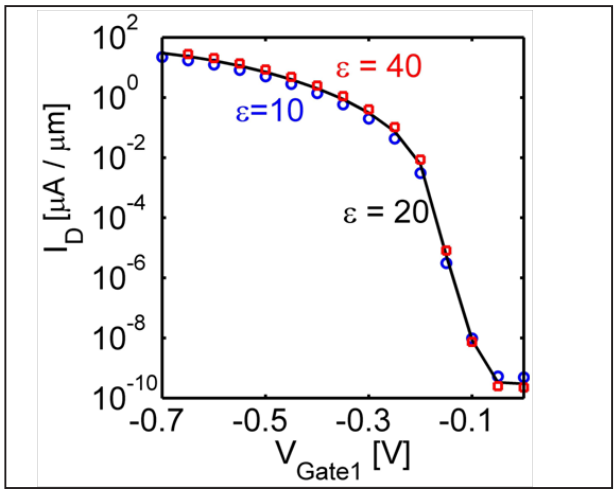

Fig. 6. Transfer characteristics of WTe_2 TFET with different oxide dielectric constants. ($T_{tot} = 4.4nm$).