Electronics with 2D Semiconductors and their Heterostructures

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Two dimensional layered materials such as metal dichalcogenides are currently being investigated extensively due to their potential application in next generation electronics. One of the main reasons for 2D materials to be of interest is their inherent advantage in terms of electrostatics. As the channel length of the transistor is downscaled, there is a need to reduce the 'effective' body thickness as well to make sure that 2-D electrostatic effects are reduced [2].To understand why this is the case, one may define an *effective screening length* λ, which is the characteristic length within which potential variations along the length of the channel are screened out [3]. This means that, beyond a length of λ, the channel can effectively screen out the electric field coming from the drain, thereby maintaining a 1-D electrostatic profile. For ultra-scaled MOSFETs it is then desirable to have λ as small as possible. While the exact form of λ depends on the details of the device structure, for single and double gate geometries it can be approximated by [3] –

$$\lambda = \sqrt{\frac{\varepsilon_s d_s d_{ox}}{\varepsilon_{ox}}} \quad \text{(single-gate)} \qquad (1)$$

$$\lambda = \sqrt{\frac{\varepsilon_s d_s d_{ox}}{2\varepsilon_{ox}}} \quad \text{(double-gate)} \qquad (2)$$

Here, ε_s and d_s denote the dielectric constant and thickness of the semiconductor respectively and ε_{ox} and d_{ox} are the respective quantities for the oxide. From (1) and (2), it is clear that to have λ as small as possible, d_s needs to be small (thin films). Surely, in this context the 2D materials represent the best possible scenario that nature has to offer. We have recently shown using atomistic simulations [4] that it transistors that use these 2D materials as channel could potentially be highly attractive for low power applications (see Fig. 1.).

Nonetheless, 2D semiconductor di chalcogenides could be particularly interesting for developing new heterostructures. The 2D nature and compensated surface indicate that such heterostructures could be made to be abrupt and defect free. Additionally the possible configurations in which such heterojunctions could be extremely large. For example, one could make these vertically or horizontally. Going beyond just 2D-2D heterostructures it is possible to make them from 3D-2D, 1D-2D interfaces as well. Here, we shall discuss some of our recent work on heterostructures comprised of MoS_2 and amorphous Si. When 3D amorphous Si is combined with 2D MoS_2, a van der Waals diode can be formed that then leads to significantly higher performance for photo detection in terms of sensitivity and speed compared to state of the art. Experimentally such junctions can be formed by simply depositing amorphous Silicon layers on top of mechanically exfoliated MoS_2 layers. If large scale growth for 2D di-chalcogenides could be perfected, such heterotstructures could have a significant impact on future large area electronics applications.

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REFERENCES

[1] B. Radisavljevic et al. Nature Nanotech. 6, 147–150 (2011).
[2J. Knoch, et al (IEDM) Tech. Dig., 173, 2008.
[3] J. Knoch, et al, IEEE Elect. Dev. Lett. 29, 372 (2008).
[4] Yoon et al, Nanoletters, vol. 11, no. 9, pp. 3768-3773, 2011.

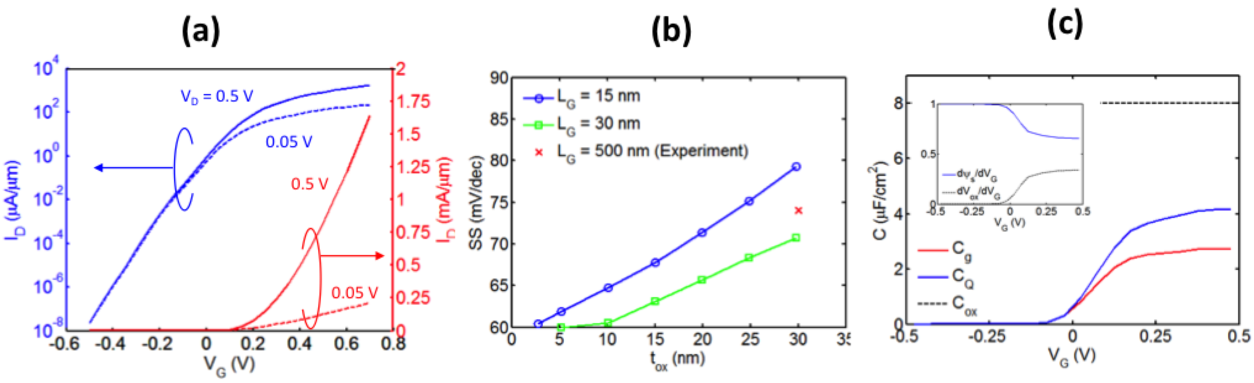

Fig. 1. (a) Transfer characteristic of a monolayer MoS_2 transistor in both log and linear scales. (b) The subthreshold swing as a function of gate oxide thickness for two different gate lengths. (c) Capacitance vs Voltage characteristics. Inset shows the change in surface potential ψ_s with gate voltage V_g . Results adopted from[4]).