Transport properties of 2D material transistors

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INTRODUCTION

Two dimensional materials have unique features which make them good candidates for future integrated circuits: good electrostatic control of gate on the channel, small short channel effects, and easier fabrication and lithography. Among 2D materials, bilayer graphene and transition metal dichalcogenides (TMDC), such as MoS2, have attracted more attention. The band gap of these materials can be tuned dynamically with an external field. In this work, we investigated the transport properties of the 2D devices with and without the dynamic band gap (DBG) tuning.

THEORY

The band gap of bilayer graphene [1] and TMDC materials [2] depends on the vertical electric field. To provide such fields, the top and bottom gates of a FET need to have different voltages. The minimum sub threshold swing (SS) of DBG FET (n-i-n doping) can be proved to be

$$SS_{min} = \left(\frac{60}{1 - \frac{C_{Tot}}{C_{TG}} + \frac{(\alpha-1)}{2}\frac{C_{Tot}}{C_{Ch}}} \right) [\frac{mV}{dec}], \quad (1)$$

where C_{TG}, C_{Ch}, and C_{Tot} are the top gate, channel, and total capacitance, respectively. α is the DBG modulation factor defined as,

$$\alpha = \frac{1}{q}\frac{dE_g}{dV}, \quad (2)$$

where E_g and V are the band gap, and voltage difference between the top and bottom layers of channel, respectively. In Fig. 2, the band gap and DBG modulation factor for bilayer graphene and MoS2 have been shown. SS_{min} can be smaller than $60mV/dec$ only if α be larger than 1, which is not the case for both bilayer graphene and MoS2. In the conventional dual gate FETs, the top and bottom gates are shorted, without any vertical field and DBG effect. SS_{min} for 2D material based FETs without DBG effect is $60mV/dec$.

SIMULATION

In this work, the self-consistent Poisson-QTBM (Quantum Transmitting Boundary Method [4]) methodology has been used within the tight binding (TB) description. Simulations have been done by our nanodevice simulation tool NEMO5 [3] in parallel with about 300 cpus. The TB model uses an $sp^3d^5s^*$ basis with nearest-neighbor interaction. The model captures the precise band structure of MoS2. All simulated bilayer MoS2 devices have the channel and source/drain length of 15nm and 10nm, respectively. The physical structure of simulated bilayer MoS2 transistors is shown in Fig. 1.

RESULTS

Fig. 3 shows the output characteristics of bilayer MoS2 FET (n-i-n doping) with DBG for different back gate biases. In this case, the back gate can change the threshold voltage. The output characteristics of bilayer MoS2 tunnel FET (p-i-n doping) with and without DBG are plotted in Figs. 4 and 5, respectively. There is an unwanted threshold voltage shift due to drain voltage in the DBG case which is absent without DBG. Even though the on-current of DBG bilayer MoS2 FET is 2 orders of magnitude larger than TFETs, and the threshold voltage can be controlled by back gate, it can not provide SS smaller than $60mV/dec$. In case of TFETs, the DBG bilayer MoS2 TFET underperforms conventional bilayer MoS2 TFET.

ACKNOWLEDGMENT

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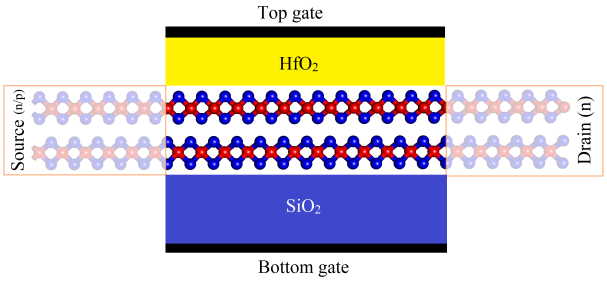

Fig. 1. Physical structure of simulated bilayer MoS2 transistors: p-i-n doping for tunnel FETs and n-i-n doping for FETs.

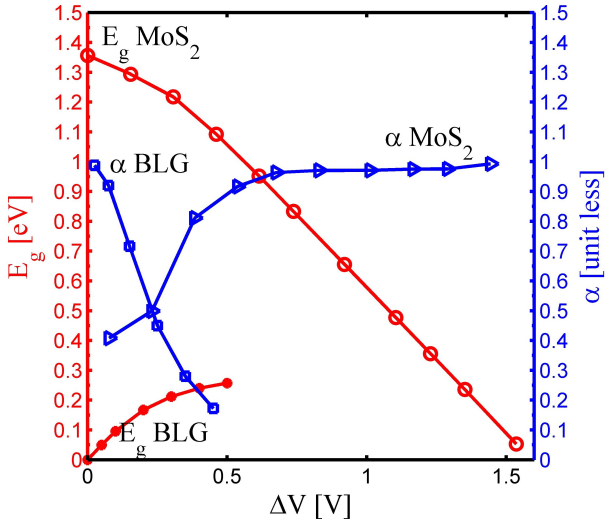

Fig. 2. Band gap (E_g) and DBG modulation factor (α) of bilayer MoS2 and bilayer graphene (BLG) as function of voltage difference between top and bottom layer (ΔV).

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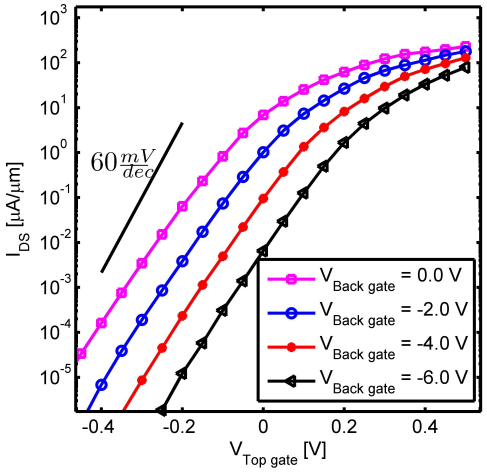

Fig. 3. Output characteristics of bilayer MoS2 FET with DBG.

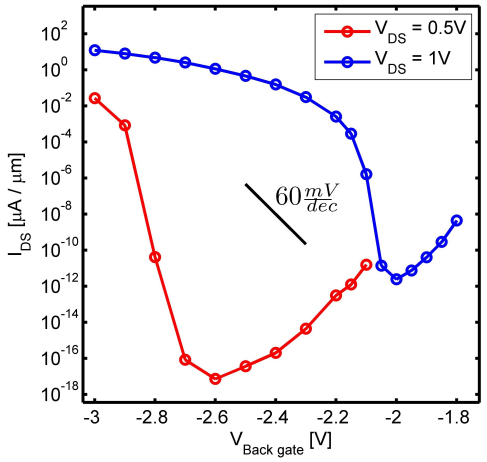

Fig. 4. Output characteristics of bilayer MoS2 tunnel FET (p-i-n doping) with DBG.

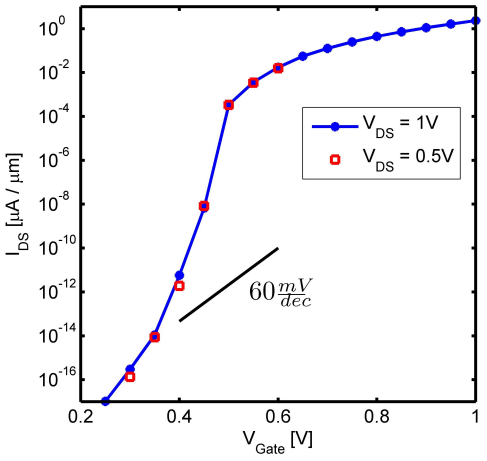

Fig. 5. Output characteristics of bilayer MoS2 tunnel FET (p-i-n doping) without DBG.