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A generalized model for nanoscale ultrathin field-effect transistors featuring 2-D materials as conducting channels with a wide range of carrier mobility

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Mineral molybdenum disulfide (MoS_2) and graphene are among novel two-dimensional materials, abundant in nature and considered as potential candidates for conducting channels in a new generation of nanoscale ultrathin field-effect transistor (FET). The miniaturization of conventional FETs becomes simpler without the drain/source diffusion which can be replaced by MoS_2 or graphene conducting channel. Not only graphene FET (GFET) can retain nearly all operational characteristics of conventional ones but can also achieve better performance parameters like cut-off frequency, carrier mobility and switching speed, whereas MoS_2 FET has lower carrier mobility but better saturation characteristics. However, recent research should be extended further before one can understand precisely the control mechanisms or parameters that allow the devices to perform or exhibit a certain desired output or characteristic. Here, a semi-analytical model is introduced so that it could be served as a tool to predict device characteristics and to explain further the physics behind those observable phenomena as well. GFET shares the same physical structure with MoS_2 FET. The crucial difference is due to hexagonal lattice of carbon atoms in graphene layer compared to intertwined three-atomic layer of MoS_2 that amounts to all differences (other than that of bandgap opening) in characteristics of these two devices. The model shows that it can faithfully reproduce different features of the current voltage characteristics in both nanoscale GFET and MoS_2 FET. Matching modeled results with experimental data were obtained on four different GFET devices with effective carrier mobility μ ranging from 1,000 to 24,000 cm^2/V.s., and on three experimental MoS_2 FETs with μ ranging from 0.6 to 750 cm^2/V.s. Moreover, this model shows that variations in contact resistance observed in experiments can be successfully calculated.

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