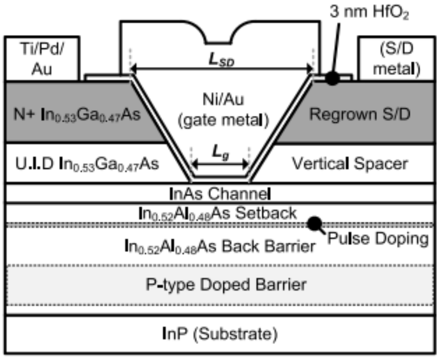
Nanoscale MOSFETs 2017 – Excercise 4

1. Graphene has a linear dispersion relation near the Dirac point, with

$$E(k) = \pm\hbar v_F \left|k_x^2 + k_y^2\right|$$

   a. Evaluate $n_s = 4\sum_{k_x,k_y} f_0$ and show that $n_s \propto F_1(\eta_F)$ and that graphene has a DOS which increases linearly with energy. The factor 4 originates from spin and valley degeneracy.
   b. Evaluate $J^+ = 4q\sum_{k_x,k_y} v_x f_0$ and show that $J^+ \propto F_1(\eta_F)$.
   c. Numerically evaluate the minimum achievable current density for a ballistic graphene FET at T=300 K, which occurs when E_F is at the Dirac point (k_x=k_y=0). v_F=10^6 m/s.

2. A high performance MOSFETs have demonstrated g_m~3.0 mS/µm at V_{DS}=0.5 V, V_{GS}-V_T=0.4 V (*Lee et. Al, IEEE EDL pp.621, 2014*). The device consists of a 5-nm-thick InAs quantum well, and a 3-nm-thick HfO_2 oxide.



   How close does this transistor operate to the ballistic limit ($g_{m,exp}/g_{m,bal}$)? Numerically calculate the drain current (assuming a single subband), and obtain the transconductance. Use $\varepsilon_{r,ox}$=25 and m^*=0.03 m_0.

3. One of the reasons for lower g_m for a III-V MOSFETs are traps inside the high-k oxide (D_{it}). This leads to extra stored charge, changing the relationship between potential and applied voltages: $\psi_s = V_G - \frac{qn_s(\psi_s)}{C_{ox}} - \frac{qD_{it}(\psi_s)}{C_{ox}}$. Assuming a FET operating in the saturated regime with T=0K, derive a relation for $g_m \propto \frac{\delta\psi_s}{\delta V_{GS}}$. For the trapped charge, you can assume $n_{trapped} = qD_{it}\delta\psi_s$, where D_{it} is the concentration of traps. For the FET from 2, how much is the g_m degraded if D_{it}=10^{13}cm^{-2}eV^{-1}.

For numerical evaluation of the Fermi-Dirac integrals, you can use FD_int_approx.m from the homepage.