Instability of two-dimensional electron transport in ungated semiconductors

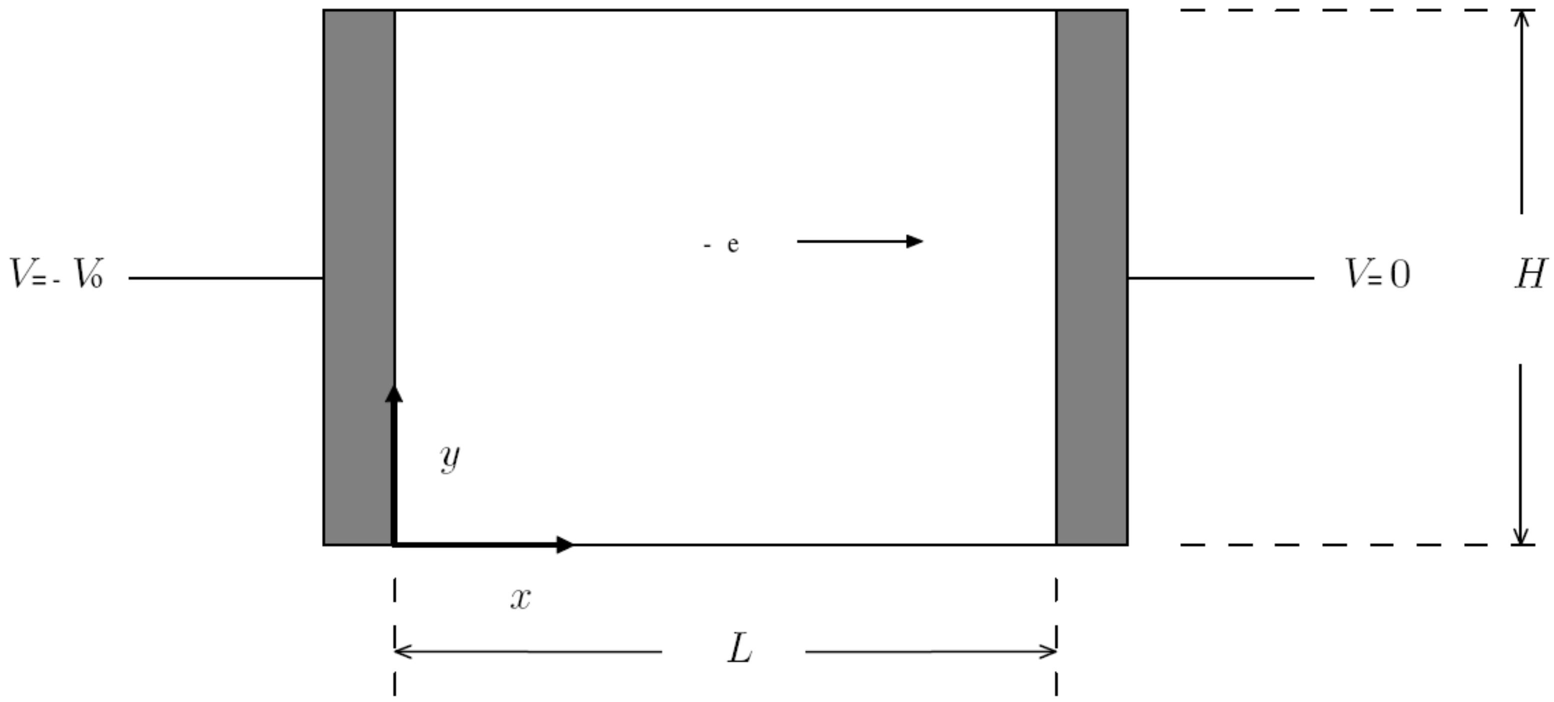
Williams Calderon-Munoz

Previous works

- Dyakonov and Shur (1993,2005) have used capacitor approximation and zero ac voltage at the source and zero ac current at the drain

- Instead consider Poisson, continuity and momentum equations and just the semiconductor

Schematic of device



Mathematical model

$$\frac{\partial V}{\partial x} + E_x = 0,$$
$$\frac{\partial V}{\partial y} + E_y = 0,$$
$$\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{e}{\epsilon_s}(n - N_D) = 0,$$
$$\frac{\partial n}{\partial t} + \frac{\partial (un)}{\partial x} + \frac{\partial (vn)}{\partial y} = 0,$$
$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - \frac{e}{m}\frac{\partial V}{\partial x} + \frac{u}{\tau} = 0,$$
$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} - \frac{e}{m}\frac{\partial V}{\partial y} + \frac{v}{\tau} = 0.$$

$$V(0, y, t) = -V_0,$$
$$V(L, y, t) = 0,$$
$$n(0, y, t) = n_0,$$
$$v(x, 0, t) = 0,$$
$$v(x, H, t) = 0,$$
$$\frac{\partial V}{\partial y}(x, 0, t) = 0,$$
$$\frac{\partial V}{\partial y}(x, H, t) = 0,$$

$$\int_0^L \int_0^H n(x, y, t)\; dxdy = N_D L H.$$

Non-dimensional model

$$
\begin{aligned}
\frac{\partial V}{\partial x} + E_x &= 0,\\
\frac{\partial V}{\partial y} + E_y &= 0,\\
\frac{\partial E_x}{\partial x} + \frac{1}{R^2}\frac{\partial E_y}{\partial y} + \alpha\,(n-\beta) &= 0,\\
\frac{\partial n}{\partial t} + \frac{\partial (un)}{\partial x} + \frac{1}{R}\frac{\partial (vn)}{\partial y} &= 0,\\
\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \frac{1}{R}v\frac{\partial u}{\partial y} - \frac{\partial V}{\partial x} + \frac{\sqrt{\alpha}}{\gamma}u &= 0,\\
\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + \frac{1}{R}v\frac{\partial v}{\partial y} - \frac{1}{R}\frac{\partial V}{\partial y} + \frac{\sqrt{\alpha}}{\gamma}v &= 0,
\end{aligned}
$$

$$
\begin{aligned}
V(0,y,t) &= -1,\\
V(1,y,t) &= 0,\\
n(0,y,t) &= 1,\\
v(x,0,t) &= 0,\\
v(x,1,t) &= 0,\\
\frac{\partial V}{\partial y}(x,0,t) &= 0,\\
\frac{\partial V}{\partial y}(x,1,t) &= 0,\\
\int_0^1\int_0^1 n(x,y,t)\,dx\,dy &= \beta,
\end{aligned}
$$

Steady-state solution

$$
\begin{aligned}
\alpha &= \frac{e n_0 L^2}{V_0 \epsilon_s}, \\
\beta &= \frac{N_D}{n_0}, \\
\gamma &= \sqrt{\frac{\tau^2 e^2 n_0}{\epsilon_s m}}
\end{aligned}
$$

$$
\begin{aligned}
\overline{E}_x(x,y) &= -1, \\
\overline{E}_y(x,y) &= 0, \\
\overline{V}(x,y) &= x-1, \\
\overline{n}(x,y) &= \beta, \\
\overline{u}(x,y) &= \gamma/\sqrt{\alpha}, \\
\overline{v}(x,y) &= 0.
\end{aligned}
$$

$$
\begin{aligned}
E_x(x,y,t) &= \overline{E}_x(x,y) + E'_x(x,y,t), \\
E_y(x,y,t) &= \overline{E}_y(x,y) + E'_y(x,y,t), \\
V(x,y,t) &= \overline{V}(x,y) + V'(x,y,t), \\
n(x,y,t) &= \overline{n}(x,y) + n'(x,y,t), \\
u(x,y,t) &= \overline{u}(x,y) + u'(x,y,t), \\
v(x,y,t) &= \overline{v}(x,y) + v'(x,y,t),
\end{aligned}
$$