MIT Virtual Source Model 2.0.0

Model By Prof. Shaloo Rakheja and Dimitri Antoniadis

By

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Acknowledgements

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- Nanohub-U course on "Fundamentals of Nanotransistors" by prof. Mark Lundstrom is an excellently designed course. It was a great course and did help me to understand the physics involved in the transistor at this scale.
- Wikipedia has been the fastest source to get information on any terminology or other doubts.

HEMT Devices

High Electron Mobility Transistors

- HEMT is a heterojunction device which has high current carrying capacity
- 2 different materials with dissimilar energy band gaps form a junction
- Due to heterojunction we have abrupt change in Energy band at the junction and it goes even below the fermi level hence it has large number of available electrons

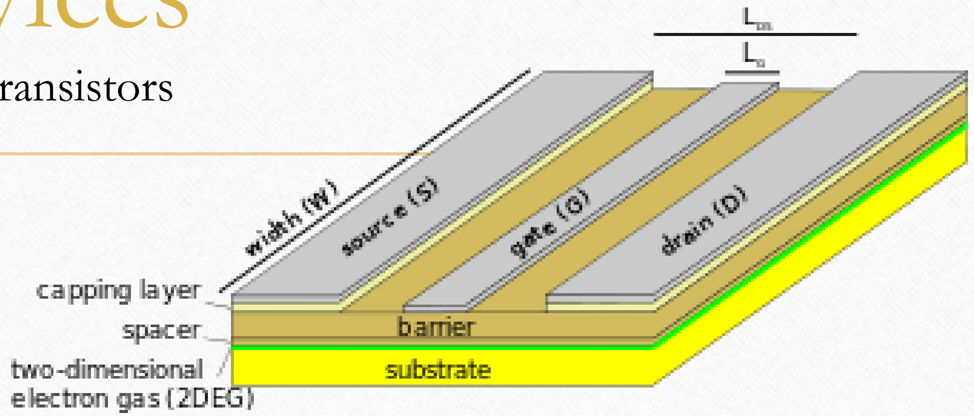
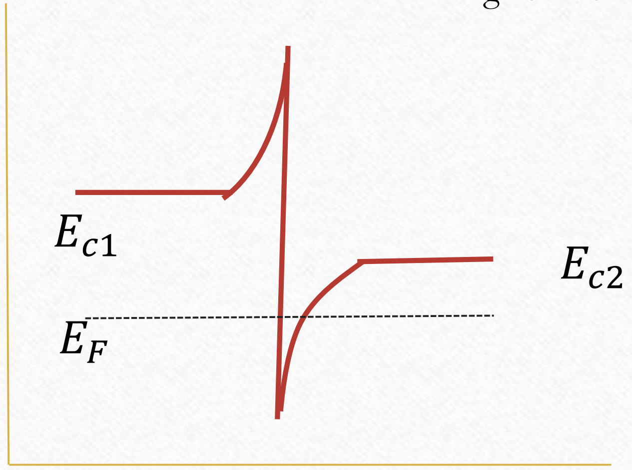
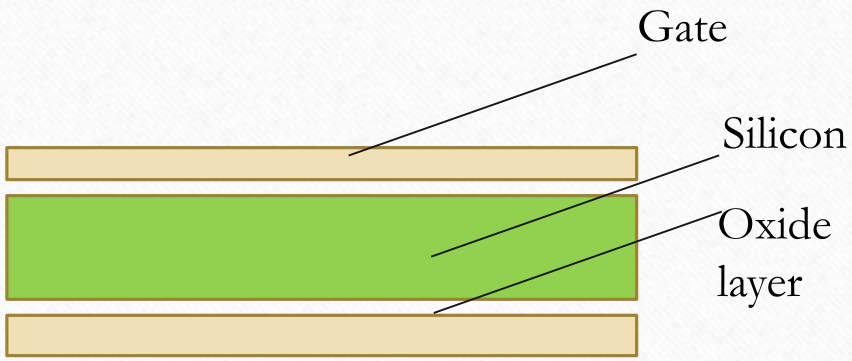


Image source-Wikipedia.org



ETSOI Devices

- Extremely thin silicon on insulator devices have extremely thin channel length and has 2 gates
- Due to small size we have to consider the sub-bands too as electrons can exists only in quantum states which can be calculated with quantum mechanics if we know the potential well



- It is a secondary capacitance felt when at quantum level the shift of electrons from an energy state to other alters the capacitance of the device
- It is related to density of states as $C = q^2 \times D_{2D}$

- The channel length charge is linearly dependent on Gate voltage if $V_g \gg V_T$ and exponentially dependent if $V_g \ll V_T$
- ETSOI has implementations on CMOS amplifier due to its size

Parameters on which MIT VS model depends

- $C_{ox}, V_T, \delta, v_{sat}, \mu, L$ are physical parameters which are pretty much known although μ_n is not very well defined so we use apparent mobility and v_{sat} is also replaced by v_{inj} in this model and hence little tweaking is done by parameters like β which is used for velocity tweaking due to V_{DS} and α which is introduce to account for the variation of V_T in subthreshold and above threshold as bands changes a little bit in both the regimes
- We have Resistances too between extrinsic and intrinsic terminals and that too is included in this model

Description of Charge model of MVS

- When the size of the channel decreases to the order where 1D electrostatics can't be easily applied there we use can this model with few parameters(most of them are physical) and we can model that problem too using familiar 1D electrostatics although with few tweaks
- When size of transistor is reduced then $I = WQv$ here I changes due to Q being given by $Q = -C_{ox}(V_{GS} - V_T)$ and as V_T is given by $V_T = V_{T0} - \delta V_{DS}$ where δ is DIBL. Velocity doesn't depends on the size of the channel although it depends on V_{DS} in this model which is semi-empirical relation with β parameter

Description of Charge model of MVS

- As metal contacts at the terminals introduce resistances hence the values of V_{DS} is less than extrinsic applied voltage. This correction is included in this model. This tends to reduce the charges(as current or flux is reduced) although as no current is drawn by gate terminal so it doesn't requires any correction
- VS model is based on identifying the top of the barrier and there we are applying 1D electrostatics to determine the charge
- Dependency of Q_{in} with V_{GS} is exponential at low voltage($V_{GS} \ll V_T$) and converts to linear at high voltage($V_{GS} \gg V_T$) so an empirical relation can be formed

MVS Model 2.0.0

- In this model we assume that Resistances aren't constants and depend on I_{DS} with a function given by $Fsat = \frac{1}{\left(1-\left(\frac{Id}{Idsat}\right)^{\beta}\right)^{1/\beta}}$. This relation introduces the decrease of g_m as seen at high current.
- In this model we also account for the sub bands and we subtract ϵ_{10} from fermi level along with applied surface potential(to calculate the band gap) which is the first energy sub band in the conduction band.
- We consider non parabolicity of conduction band in this model and account the DOS accordingly

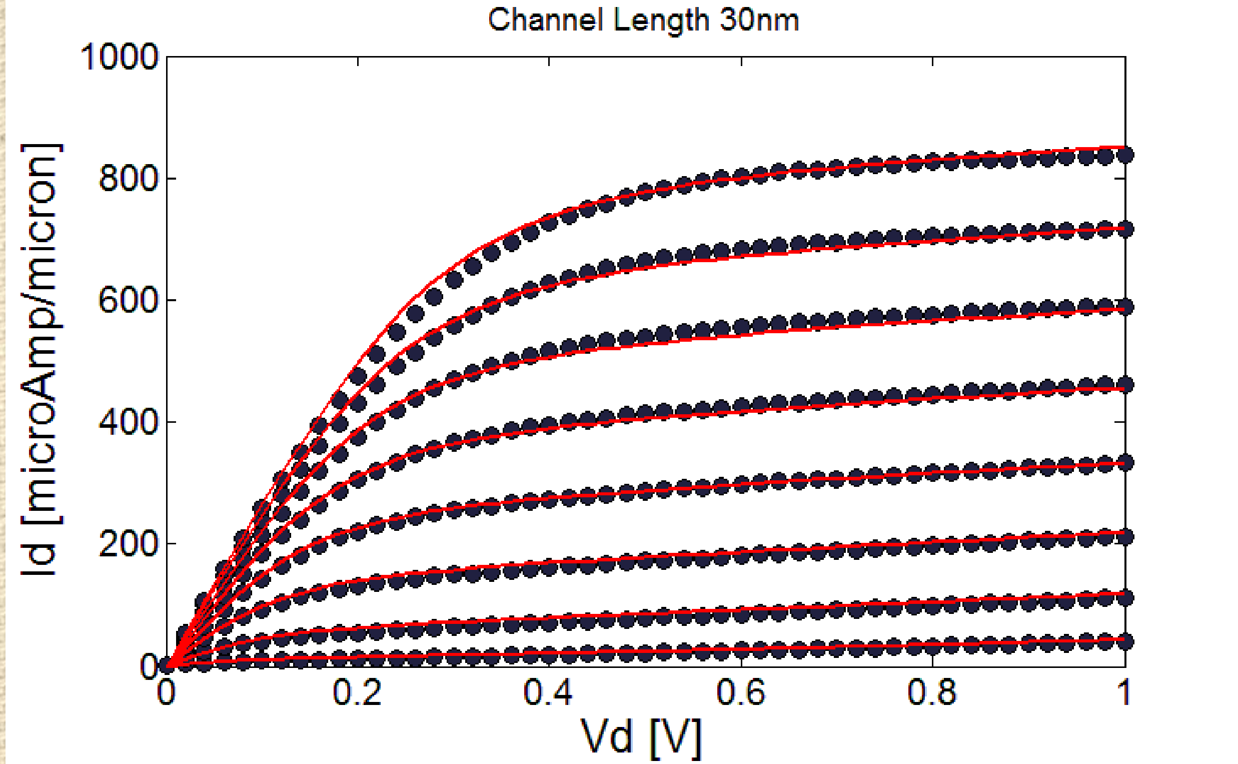
MVS Model 2.0.0

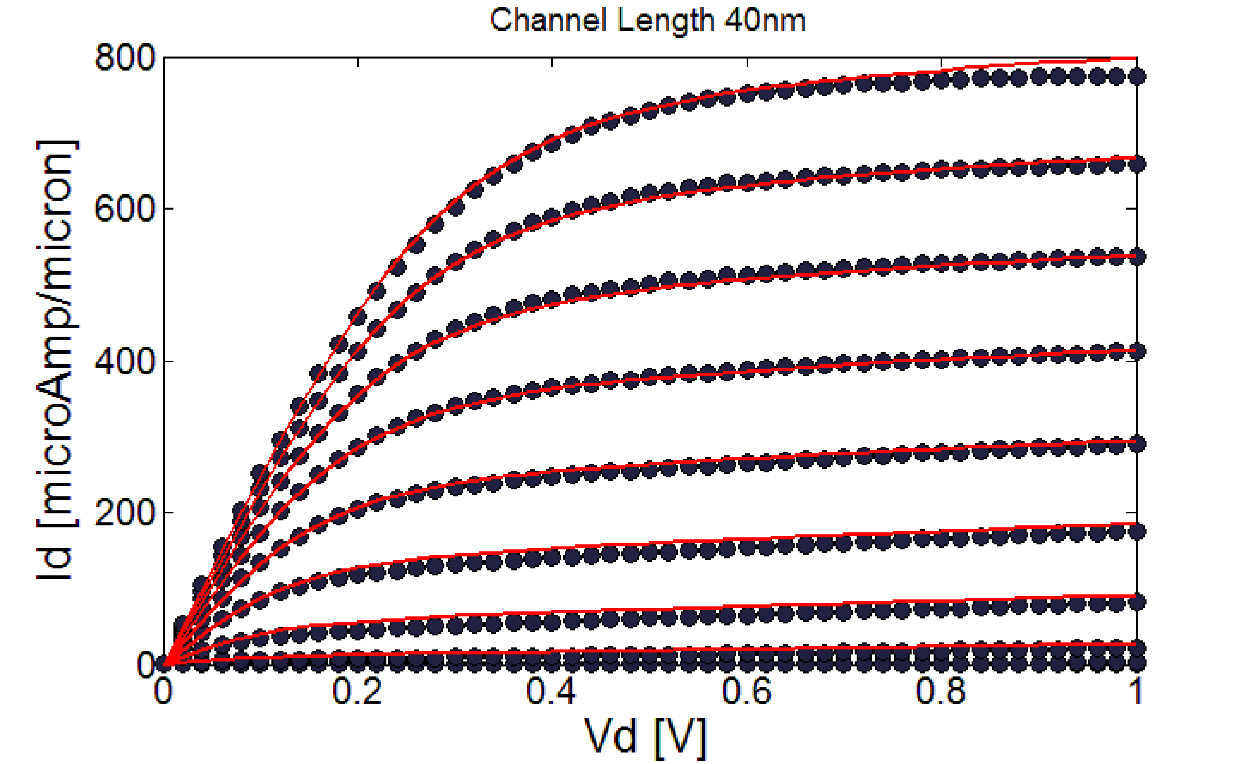
- The charge Q_{x0} is calculated by integrating DOS*fermi-dirac function from $\epsilon_{10} - q\psi$ to ∞(entire conduction band)
- For small channel we have to consider quantum capacitance too while calculating Gate channel capacitance $\frac{1}{C_{gc}} = \frac{1}{C_{ins}} + \frac{1}{C_{QM}(x_{av})}$
- $C_{ins} = \epsilon/t_{ins}$ and $C_{QM}(x_{av}) = \epsilon/x_{av}$ here x_{av} is the separation between channel charge centroid and semiconductor-insulator interface
- x_{av} is given by empirical parameters and due to the above relations the surface potential is defined at centroid of the charge not at the interface as C_{gc} value is now reduced due to quantum capacitance and to account for it we assume that the length is increased

MVS Model 2.0.0

- The charge Q_{x0} is given by $-\frac{q}{v_t}((2-T)Fs + TFd)$ here T is transmission, Fs is flux or current entering from source and Fd is flux from drain. These flux are dependent on η_{fs} and η_{fd} which accounts energy gaps at source and drain respectively
- If we include 2D electrostatics then ψ_s is dependent on C_{g-VS}(which is equal to C_{gc}), C_{d-VS}, C_{s-VS} and Q_{x0}

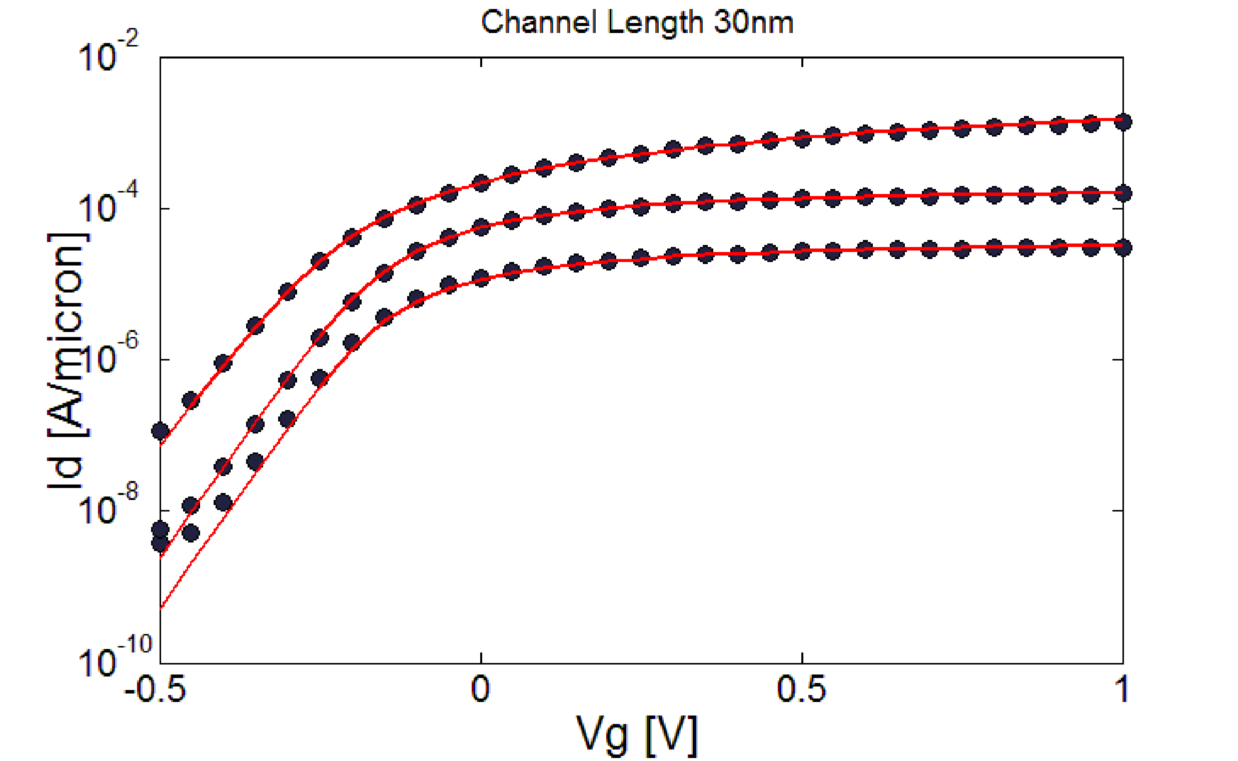
ET-SOI Plots of Id vs Vd

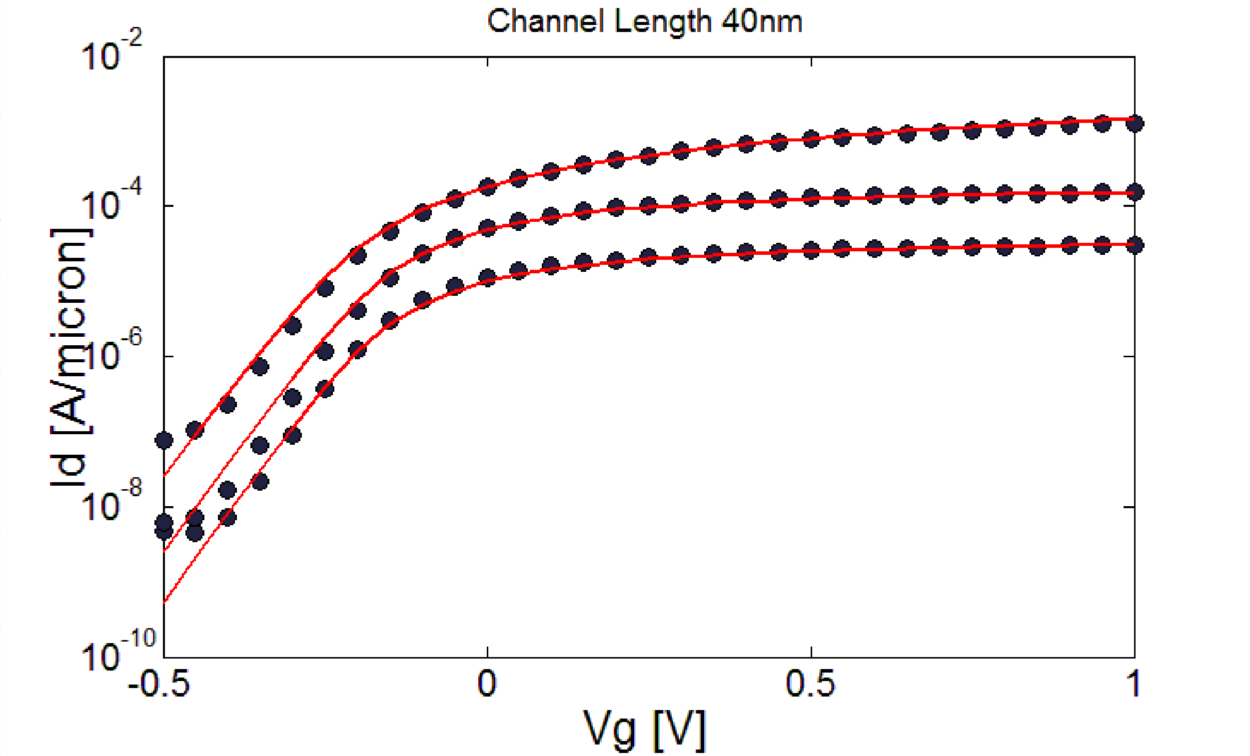




Increase in channel length results in decrease in current for same Vds and Vgs due to decrease in transmission but saturation current isn't much dependent on Vd

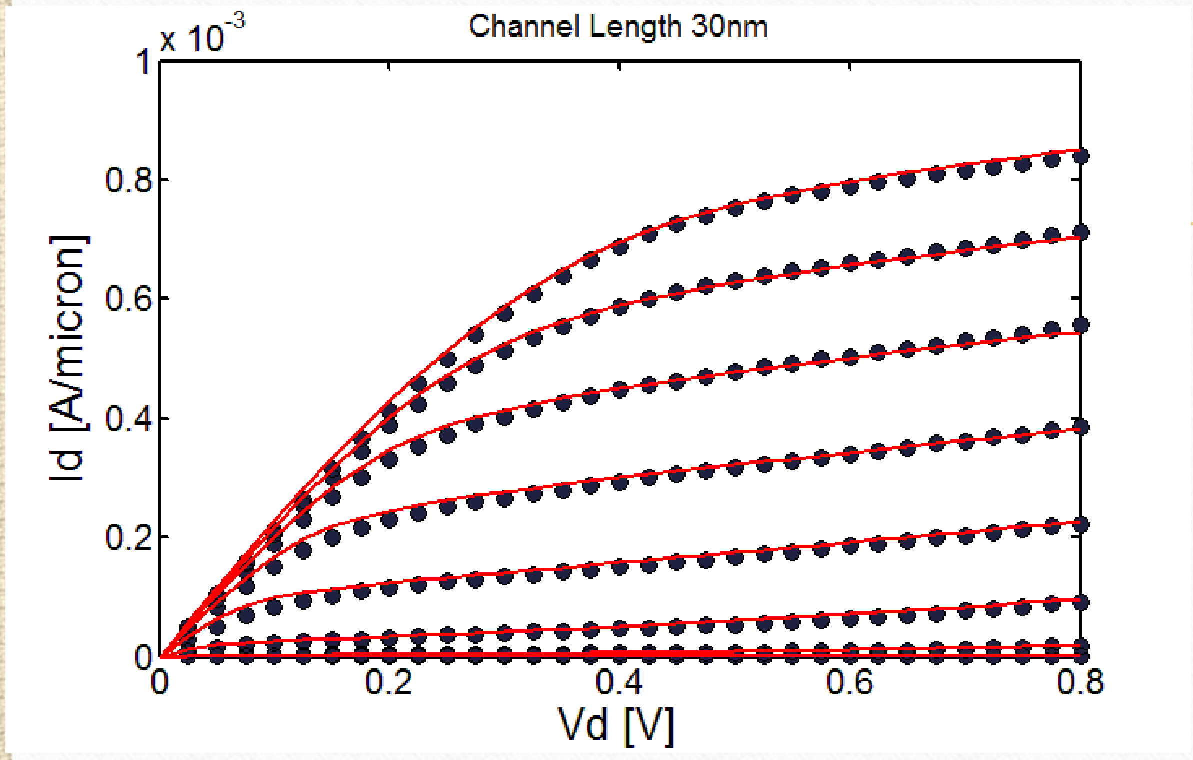
ET-SOI Plots of Id vs Vg

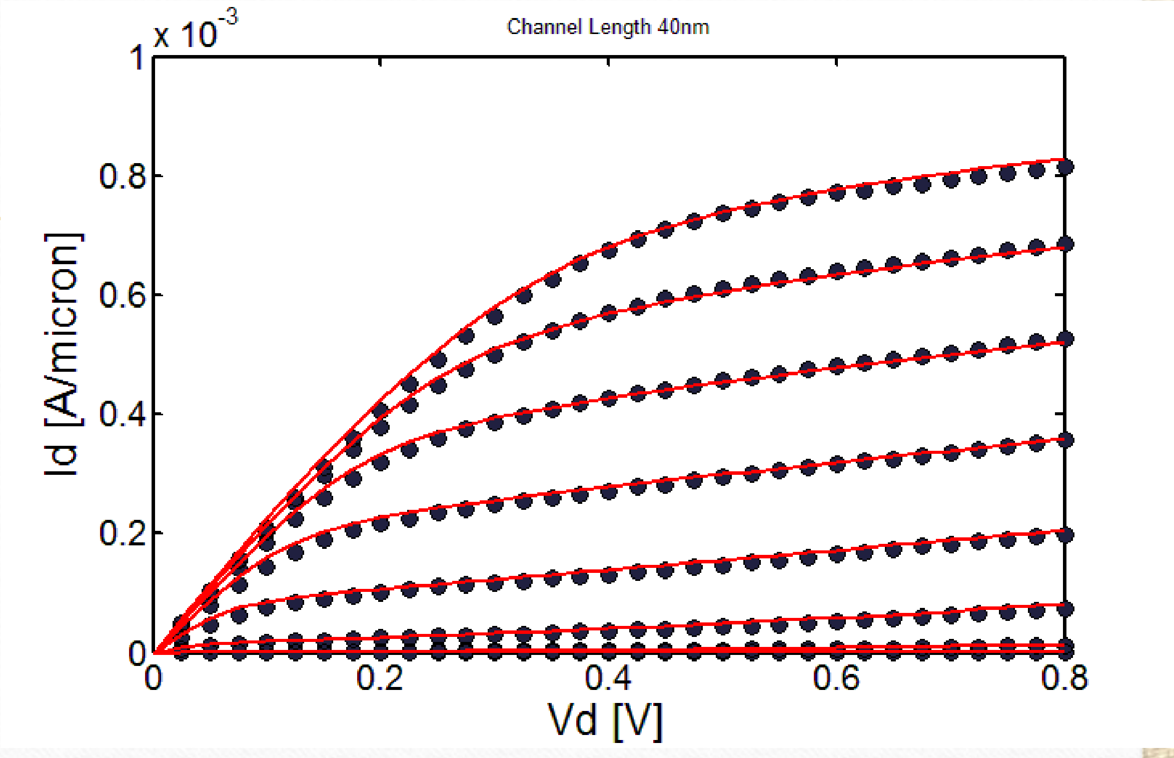




DIBL and subthreshold swing is lowered at higher channel length

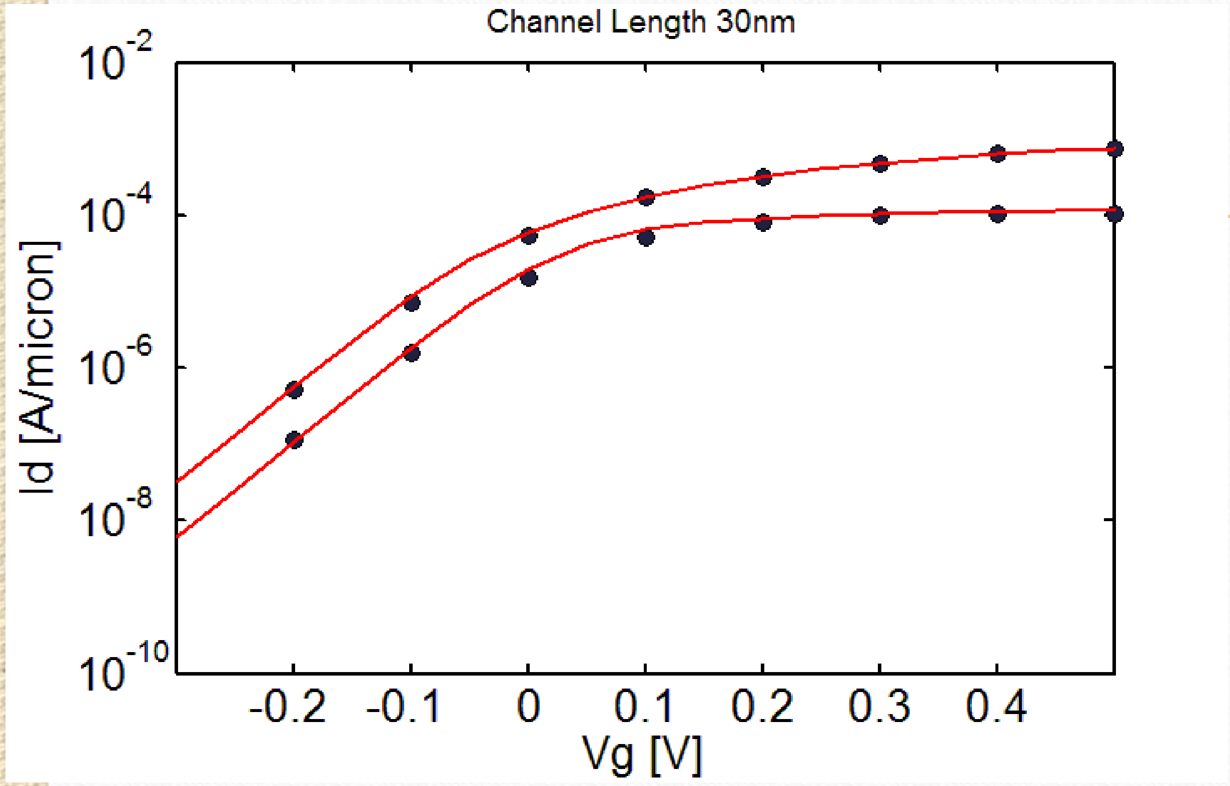
HEMT Plots of Vd vs Id

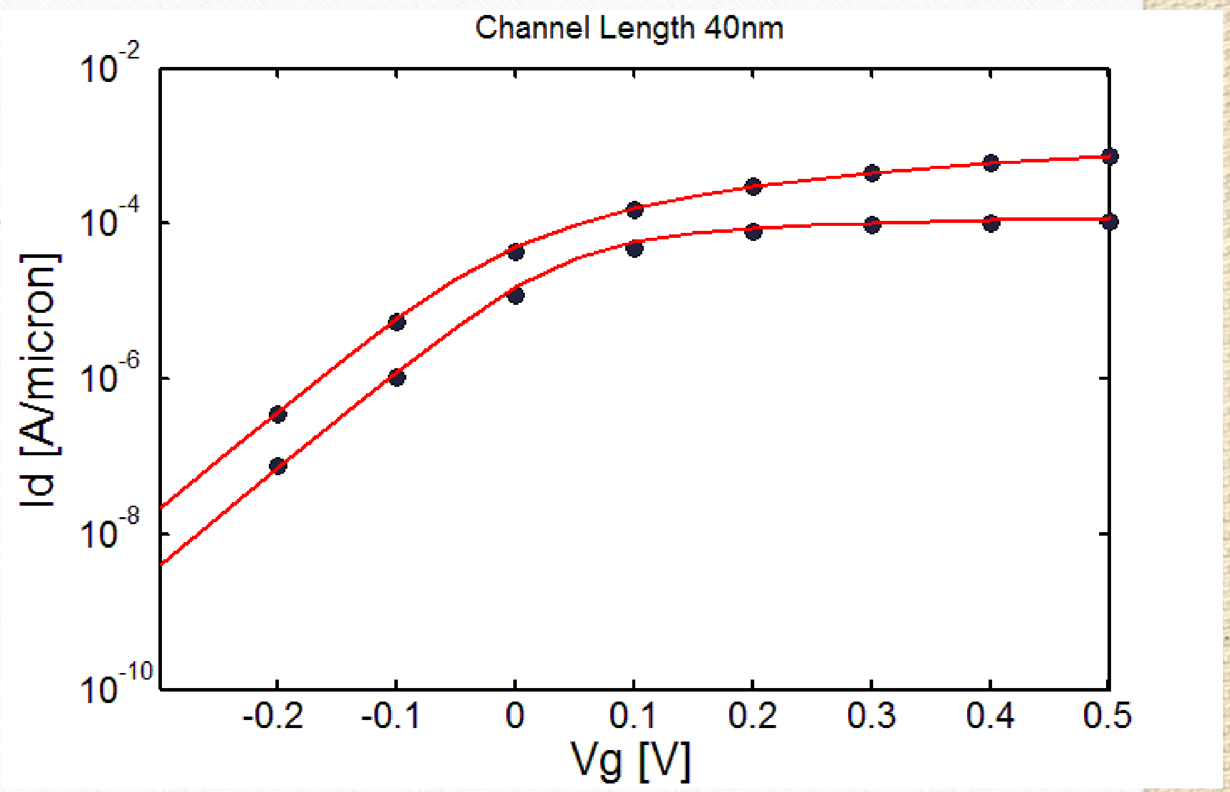




Increase in channel length results in decrease in current for same Vds and Vgs due to decrease in transmission and saturation current is dependent on Vd although this effect too decreases with increase in channel length

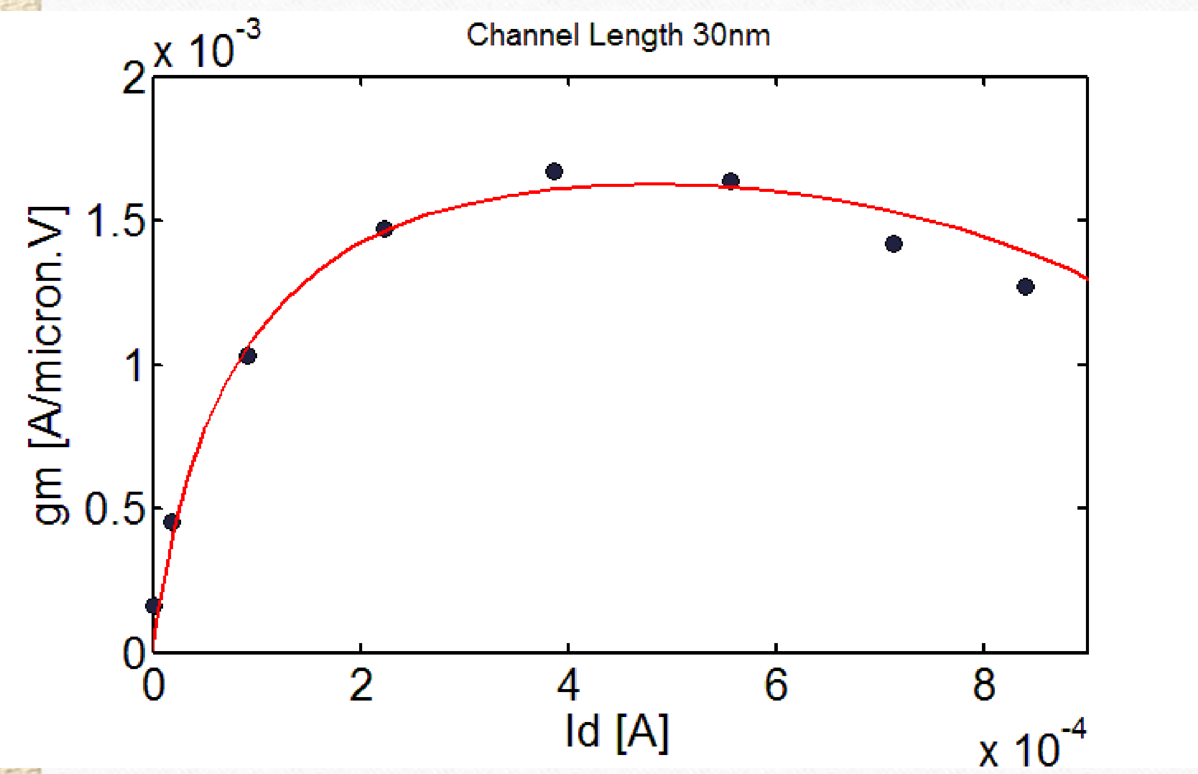
HEMT Plots of Vg vs Id

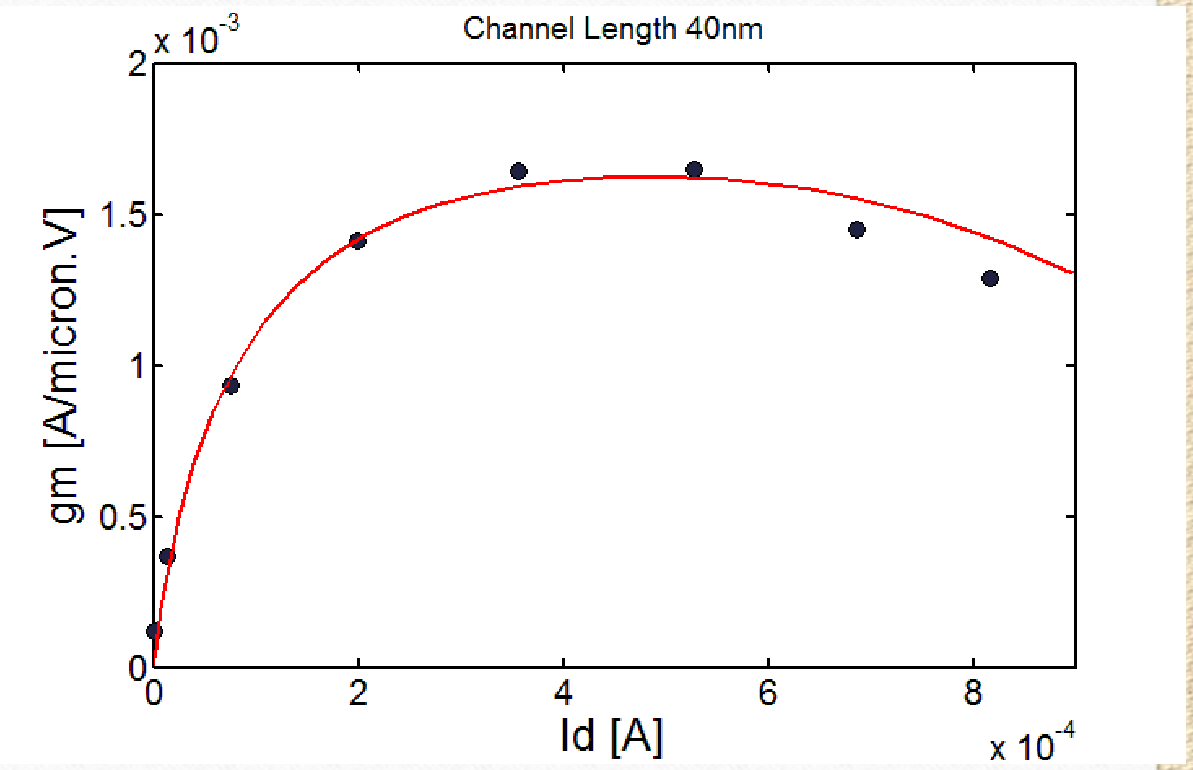




Decrease in DIBL can be observed

HEMT Plots of Gm vs Id





- First the conductivity increases as the current increases before reaching saturation
- We see a drop after the saturation of mobility as we have considered series resistances to be current dependent which increases with it and hence at higher current we see this unusual drop

THANK YOU