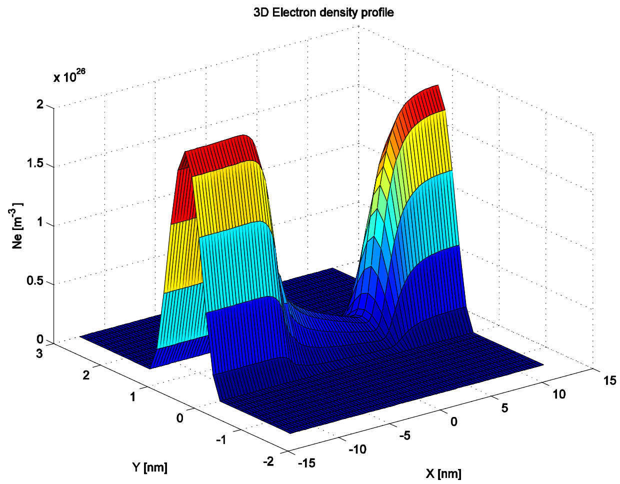
nanoMOS lab-I
Semi-Classical Ballistic Transport



Summary

- Semi-Classical ballistic model (clbte model)
- Subband occupancy of thin and thick layers double-gate MOSFETS.
- Id vs. Vgs and Id vs. Vds plots of devices with different work functions.
- Getting familiar with the output files…

Getting Started

- Open a browser and go to nanohub.purdue.edu
- Login by clicking in nanoMOS 2.0 in the nanotools list.
- Click on Modify/Create input file
- Go to examples folder, select the appropriate exercise: lab-1…etc and copy it to the working folder.
- Go back to the working folder

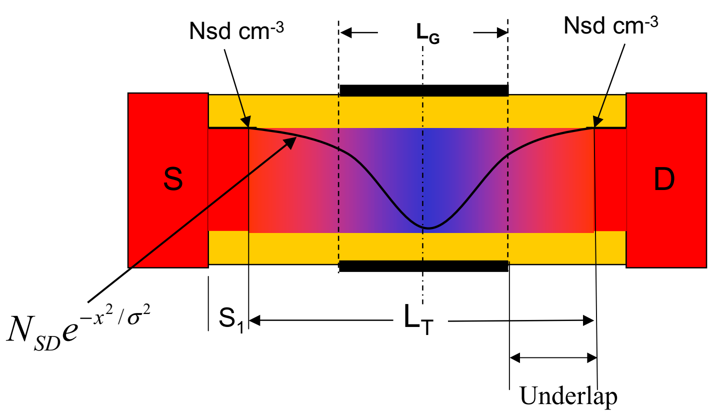
Getting Started

- On top of the page go to "Step 2: Execute"
- Select your input deck from the pull-down button.
- Choose a name for the output folder and output file.
- Run the simulation by clicking on the "Run nanoMOS" button.
- Once simulation is done, go to "Step 3: output", select an output file and open it….
- Congratulations you ran a nanoMOS simulation through the nanoHUB !!!!

Output files

- Convergence.dat : date and nanomos version plus outer error at each iteration for each bias point
- .dat: data file of each quantity chosen in the ploting capabilities of the input file
- .ps: postscript image of the corresponding .dat file
- .mat: mat file containing all matlab variables.
- Output file that you chose contains matlab output at runtime.
- PUNCH log file

Simulated structure



Exercise 1

- Equilibrium thin body (1.5 nm) simulation, unprimed and prime ladder.
- Check subband occupancy.
- The simulation will take 1 minute
- The input deck is in the example folder: uiuc-1.1
- Check your results with the one in the output folder /uiuc-1.1

Ex-1 input deck

```
$ DEVICE DIRECTIVE
device  nsd=1e20, nbody=0, lgtop=10, lgbot=10, lsd=7.5,
+         overlap_s=0, overlap_d=0,
+         dopslope_s=0, dopslope_d=0,
+       tsi=1.5, tox_top=1.5, tox_bot=1.5, temp=300
...
$ TRANSPORT DIRECTIVE
transport model=clbte, mu_low=500, beta=2, vsat=1e7,
+         ELE_TAUW=1e-13, ELE_CQ=1
...
$ OPTIONS DIRECTIVE
options valleys=all, num_subbands=1, dg=true, fermi=true,
+       ox_penetrate=false
...
$ PLOTTING CAPABILITES
plots I_V=n, Ec3d=y, Ne3d=y, Ec_sub=y, Ne_sub=y, Te=n,
+         Ec_IV=y, Ne_IV=y
end
```

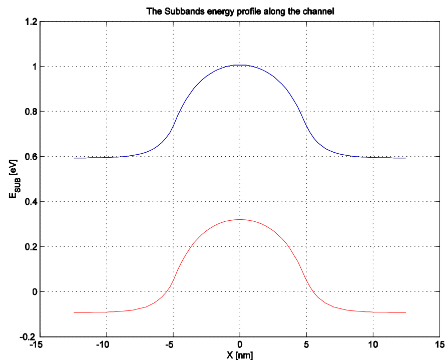
Thin body

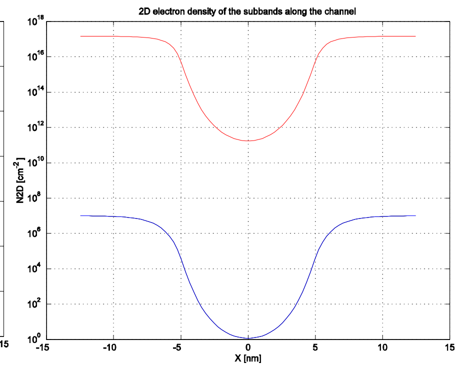
Classical

All valleys

Ec and Ne for all valleys

Outputs, uiuc-1.1





What are these plots ? Check the other output files…

Remarks

- In thin bodies DG MOSFETs only the lowest subband is occupied.
- You can do a simulation using only the unprimed ladder.
- This also reduces the computation time.
- A classical ballistic simulation gives you a good idea of the subband occupancy

Exercise 2

- Equilibrium thick body (3 nm) simulation, unprimed and primed ladder.
- Check subband occupancy.
- The simulation will take 1 minute
- The input deck is in the example folder: uiuc-1.2
- Check your results with the one in the output folder /uiuc-1.2

Ex-2 input deck

```
$ DEVICE DIRECTIVE
device  nsd=1e20, nbody=0, lgtop=10, lgbot=10, lsd=7.5,
+         overlap_s=0, overlap_d=0,
+       dopslope_s=0, dopslope_d=0,
+       tsi=3.0, tox_top=1.5, tox_bot=1.5, temp=300

$ TRANSPORT DIRECTIVE
transport model=clbte, mu_low=500, beta=2, vsat=1e7
+         ELE_TAUW=1e-13, ELE_CQ=1

$ OPTIONS DIRECTIVE
options valleys=all, num_subbands=1, dg=true, fermi=true,
+       ox_penetrate=false

$ PLOTTING CAPABILITES
plots I_V=y, Ec3d=y, Ne3d=y, Ec_sub=y, Ne_sub=y, Te=n,
+         Ec_IV=y, Ne_IV=y
```

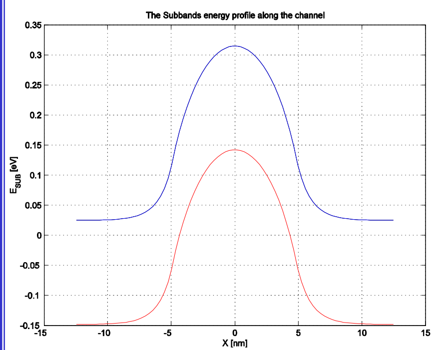
Thick body

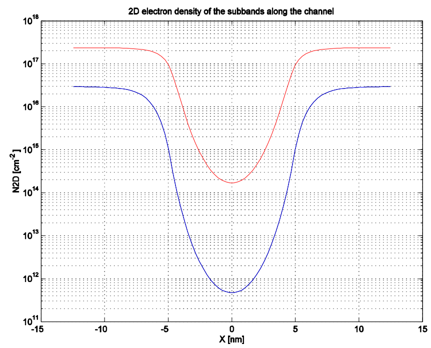
Classical

All valleys

Ec and Ne for all valleys

Outputs, uiuc 1.2





What are these plots ? Check the other output files…

Remarks

- In thick bodies DG MOSFETs several subbands can be occupied.
- You have to do a simulation using both the unprimed and primed ladder.
- This increases the computation time.
- A classical ballistic simulation gives you a good idea of the subband occupancy

Exercise 3

- Non equilibrium thin body (1.5 nm) simulation, abrupt junction, Id vs. Vgs and Id vs. Vds simulation
- The simulation will take 8 minutes for Id vs. Vgs and 4 minutes for Id vs. Vds
- The input deck is in the example folder: uiuc-1.3.1 for Id vs Vgs, and uiuc-1.3.2 for Id vs. Vds.
- Check your results with the one in the output folder /uiuc-1.3.1 and /uiuc-1.3.2

Ex-3 input deck

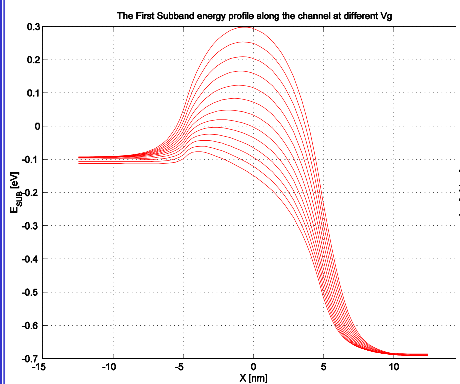
```
$ DEVICE DIRECTIVE
device  nsd=1e20, nbody=0, lgtop=10, lgbot=10, lsd=7.5,
+          overlap_s=0, overlap_d=0,
+        dopslope_s=0, dopslope_d=0,
+        tsi=1.5, tox_top=1.5, tox_bot=1.5, temp=300

$ BIAS DIRECTIVE
bias vgtop=0.0, vgbot=0.0, vs=0.0, vd=0.6, vgstep=0.05, vdstep=0,
+     ngstep=12, ndstep=0, vd_initial=0.0

$ PLOTTING CAPABILITES
plots I_V=y, Ec3d=y, Ne3d=y, Ec_sub=n, Ne_sub=n, Te=n,
+          Ec_IV=y, Ne_IV=y
```

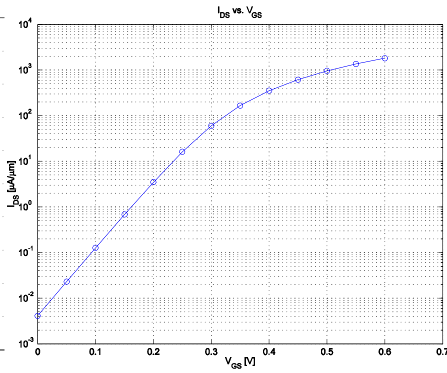
Thin body

Id vs. Vgs simulation

Plot I-V characteristics

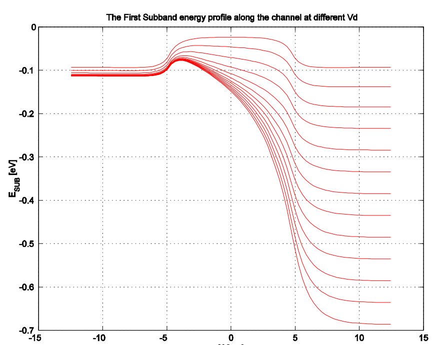
Outputs, uiuc-1.3.1

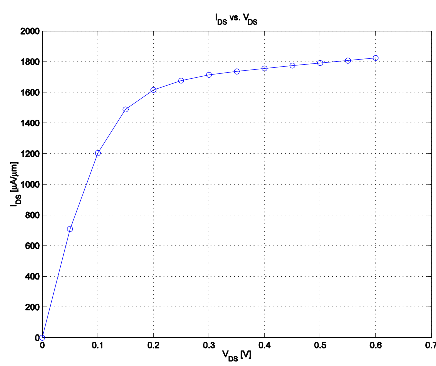




What are these plots ? Check the other output files…

Outputs, uiuc-1.3.2





What are these plots ? Check the other output files…

Remarks

- Top of the barrier is pulled down as gate voltage is increased.
- Drain side of conduction band is pulled down as drain voltage is increased.
- Sub-threshold slope.
- Device turns on and off.

Exercise 4

- Non equilibrium thick body (3.0 nm) simulation, abrupt junction, Id vs. Vgs and Id vs. Vds simulation.
- Work function ajusted to match off-current of exercise 3.
- Compare on current and sub-threshold slope with results from exercise 3.
- The simulation will take 8 minutes and 4 minutes for Id vs. Vgs and Id vs. Vds simulation respectively
- The input deck is in the example folder: uiuc-1.4.1 for Id vs Vgs, and uiuc-1.4.2 for Id vs. Vds.
- Check your results with the one in the output folder /uiuc-1.4.1 and /uiuc-1.4.2

Ex-4 input deck

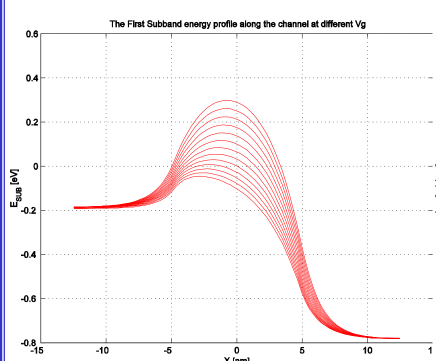
```
$ DEVICE DIRECTIVE
device  nsd=1e20, nbody=0, lgtop=10, lgbot=10, lsd=7.5,
+          overlap_s=0, overlap_d=0,
+        dopslope_s=0, dopslope_d=0,
+        tsi=3.0, tox_top=1.5, tox_bot=1.5, temp=300

$ BIAS DIRECTIVE
bias vgtop=0.0, vgbot=0.0, vs=0.0, vd=0.6, vgstep=0.05, vdstep=0,
+    ngstep=12, ndstep=0, vd_initial=0.0

$ MATERIAL DIRECTIVE
material wfunc_top=4.55, wfunc_bot=4.55, mlong=0.91, mtran=0.19, kox_top=3.9,
+        kox_bot=3.9, dec_top=3.34, dec_bot=3.34, ksi=11.7
```

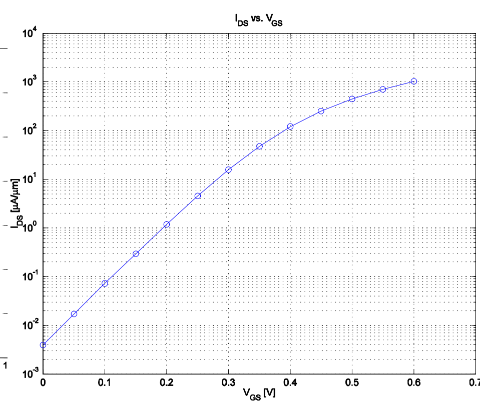
Thick body

Id vs. Vgs simulation

Work function calibrated

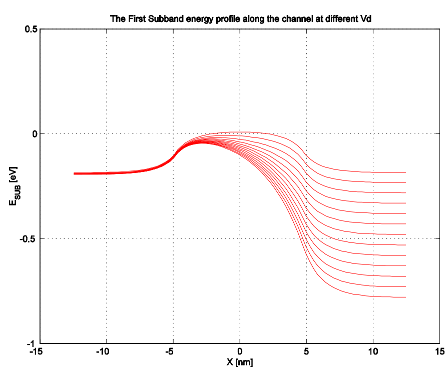
Outputs, uiuc-1.4.1

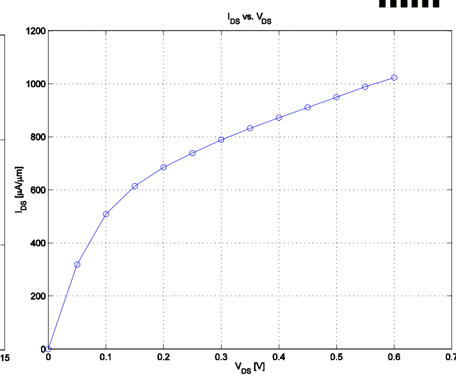




What are these plots ? Check the other output files…

Outputs, uiuc-1.4.2





What are these plots ? Check the other output files…

Remarks

- By comparison with exercise 3, We see that thin body DG have better electrostatics
- Therefore, by adjusting the work function to get the same off current, the thin body DG gives better on current.
- The Subthreshold slope is consequently better in thin body DG.