Special Topics on Basic EECS I Design Technology Co-Optimization
Lecture 17

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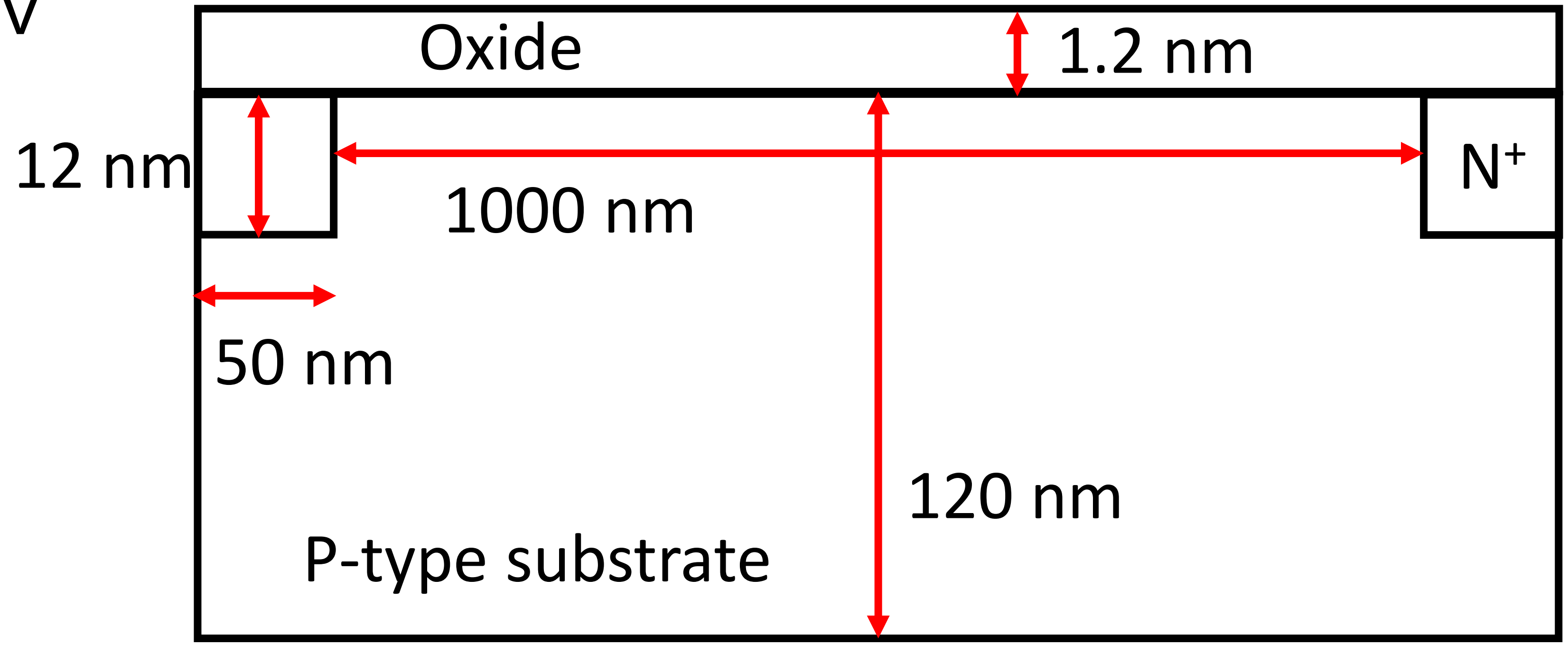
L17

Simulation of a long-channel MOSFET

- Effective oxide thickness of 1.2 nm
  - Gate workfunction of 4.3 eV
  - Substrate doping of 1.5X10^{18} cm^{-3}
  - V_{DD} of 1.2 V

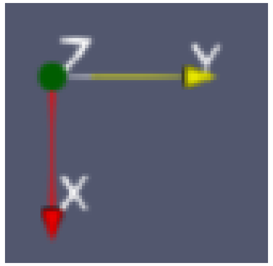


Structure generation

- Spacing along the vertical direction: 1.2 nm
  - Spacing along the lateral direction: 5 nm
  - How many points? 102 X 221 = 22542
  - Too many points for such a simple structure…
- Source/drain doping profile
  - Gaussian profile is usually used.
  - In this example, abrupt junctions are assumed.

Mapmaker

- Input file
  - x: Depth
  - y: Channel
  - z: Width




```
thing (type="mapmaker",name="structure") {
   mapmaker (type="3d",cgns="long.cgns") {
      cuboid (x0=-1.2nm,y0=-550nm,x1=120nm,y1=550nm,z0=0.0,z1=1.0um,nx=102,ny=221,nz=2)
      region (name="semiconductor",material="silicon",ix0=1,ix1=101,iy0=0,iy1=220,iz0=0,iz1=1)
      region (name="insulator",    material="oxide",  ix0=0,ix1=1,  iy0=0,iy1=220,iz0=0,iz1=1)
      doping (region="semiconductor",ix0=1,ix1=101,iy0=0,  iy1=220,iz0=0,iz1=1,density=-1.5e18/cm3)
      doping (region="semiconductor",ix0=1,ix1=11, iy0=0,  iy1=10, iz0=0,iz1=1,density=2e20/cm3)
      doping (region="semiconductor",ix0=1,ix1=11, iy0=210,iy1=220,iz0=0,iz1=1,density=2e20/cm3)
      contact (name="source",ix0=1,  ix1=6,  iy0=0,  iy1=0,  iz0=0,iz1=1)
      contact (name="gate",  ix0=0,  ix1=0,  iy0=10, iy1=210,iz0=0,iz1=1)
      contact (name="drain", ix0=1,  ix1=6,  iy0=220,iy1=220,iz0=0,iz1=1)
      contact (name="body",  ix0=101,ix1=101,iy0=0,  iy1=220,iz0=0,iz1=1)
   }
}
```

Long-channel device structure

- It is not very realistic.
  - Abrupt source/drain doping
  - Constant substrate doping
  - Spacer
  - Source/drain contact

Loading the sturcture

- In a MOSFET, we have a gate contact.
  - The workfunction must be specified.
  - Do not forget to specify the bandgap narrowing model.

```
thing (type="device",name="mosfet") {
   device (type="3d",areafactor=1.0) {
      load (cgns="long.cgns",dbpath="/                                  ")
      electrode (name="gate",workfunction=4.3)
   }
}

property (thing="mosfet",model="effectiveintrinsicdensity",nobandgapnarrowing)
```

Here goes your dbpath.

Building a circuit

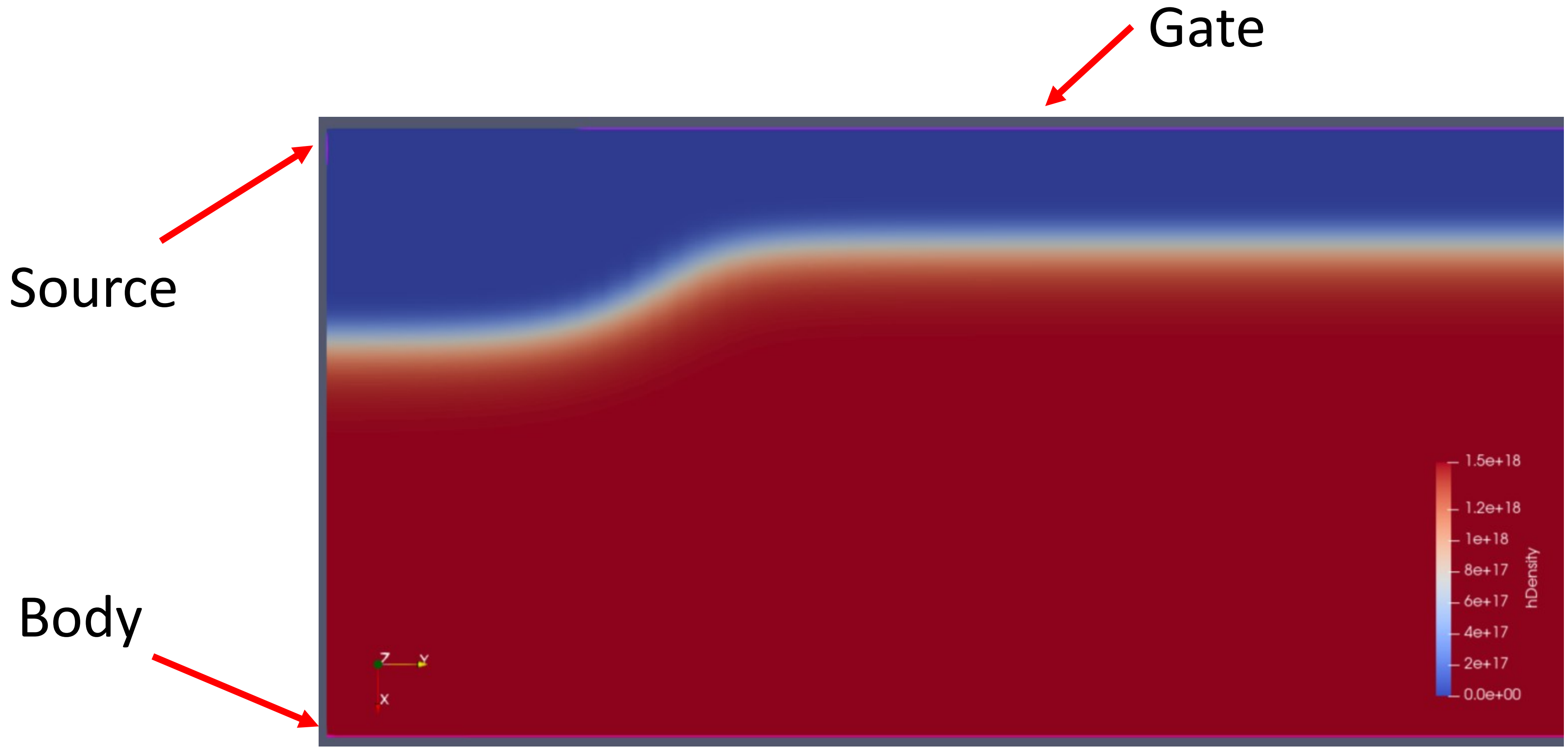
- We need (at least) two voltage sources.
  - Prepare them (`vg` and `vd` in this example) and build a circuit.

```
thing (type="lumped",name="vg") {
   lumped (type="v",value=0.0)
}

thing (type="lumped",name="vd") {
   lumped (type="v",value=0.0)
}

thing (type="circuit",name="circuit") {
   circuit {
      node (thing="gnd",name="GND")
      node (thing="mosfet", contact="source",name="GND")
      node (thing="mosfet", contact="gate"   ,name="IN")
      node (thing="mosfet", contact="drain"  ,name="OUT")
      node (thing="mosfet", contact="body"   ,name="GND")
      node (thing="vg", contact="0", name="GND")
      node (thing="vg", contact="1", name="IN")
      node (thing="vd", contact="0", name="GND")
      node (thing="vd", contact="1", name="OUT")
   }
}
```

Equilibrium

```
law (name="eqlaw") {
    equation (type="poisson",thing="mosfet")
}

solve (law="eqlaw",initialstep=1.0,plot,plotprefix="long_eq",cgns)
```

- Depletion of holes



Setting a law and a book

- Drift-diffusion simulation and IV curves
  - There are two voltage sources. Therefore, we need to specify the “virlc” equation twice.

```
law (name="dclaw",iteration=12) {
   equation (type="poisson"     ,thing="mosfet")
   equation (type="econtinuity",thing="mosfet")
   equation (type="hcontinuity",thing="mosfet")
   equation (type="contact"     ,thing="mosfet")
   equation (type="virlc"       ,thing="vg")
   equation (type="virlc"       ,thing="vd")
   equation (type="kirchhoff"   ,thing="circuit")
}

book (name="input_iv", csv="input_iv.csv") {
   event (thing="mosfet", contact="gate")
   event (thing="mosfet", contact="drain")
}
```

Bias ramping

- Usually, we consider two drain voltages.
  - A voltage close to zero, $V_D \approx 0$ V & a voltage equal to V_{DD}
  - In the following example, we take 0.05 V.

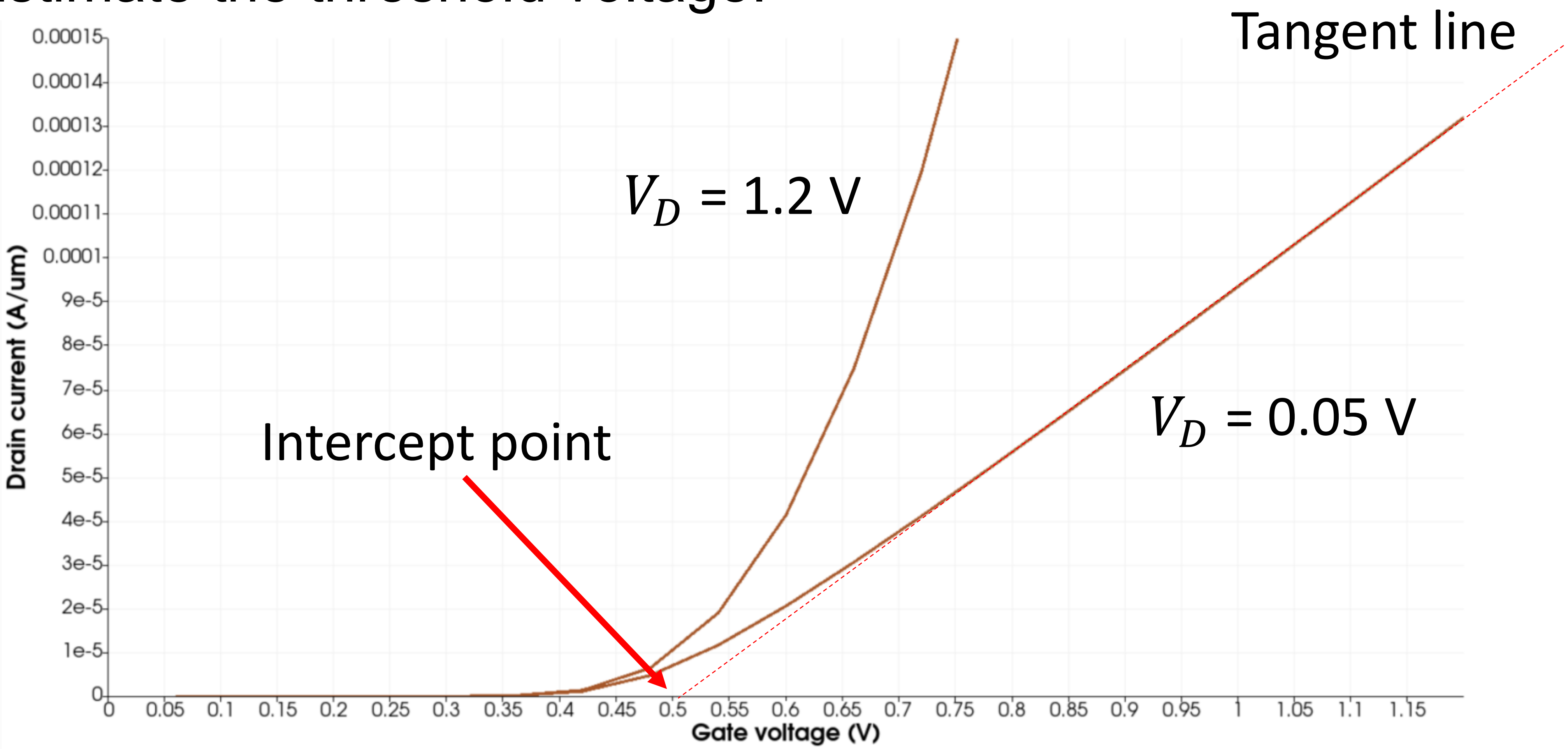
```
solve (law="dclaw",initialstep=1.0) {
   goal (thing="vd", quantity="voltage", value=0.05)
}
```

  - After running this `solve` statement, we have a solution at V_G = 0 V and V_D = 0.05 V.
  - Then,

```
solve (law="dclaw",initialstep=0.01,maxstep=0.01,minstep=0.01,plot,plotprefix="long_dc",cgns,book="input_iv") {
   goal (thing="vg", quantity="voltage", value=1.2)
}
```

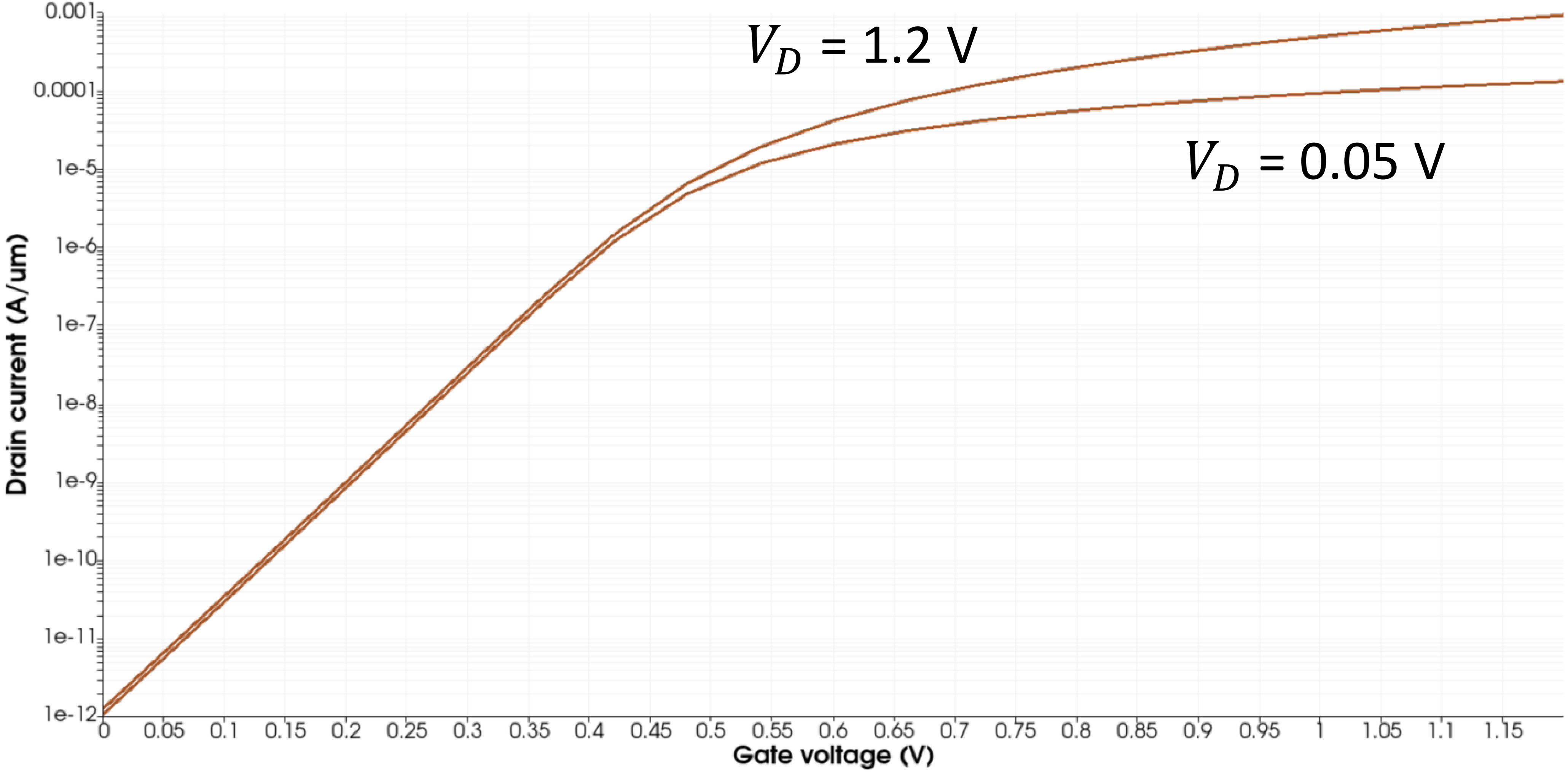
Ramping the gate voltage up

- Results WITHOUT any physical model, from 0 V to 1.2 V
  - Estimate the threshold voltage.



Semi-logarithmic graph

- Estimate the subthreshold slope, the DIBL, I_{ON}, and I_{OFF}.



Physical models

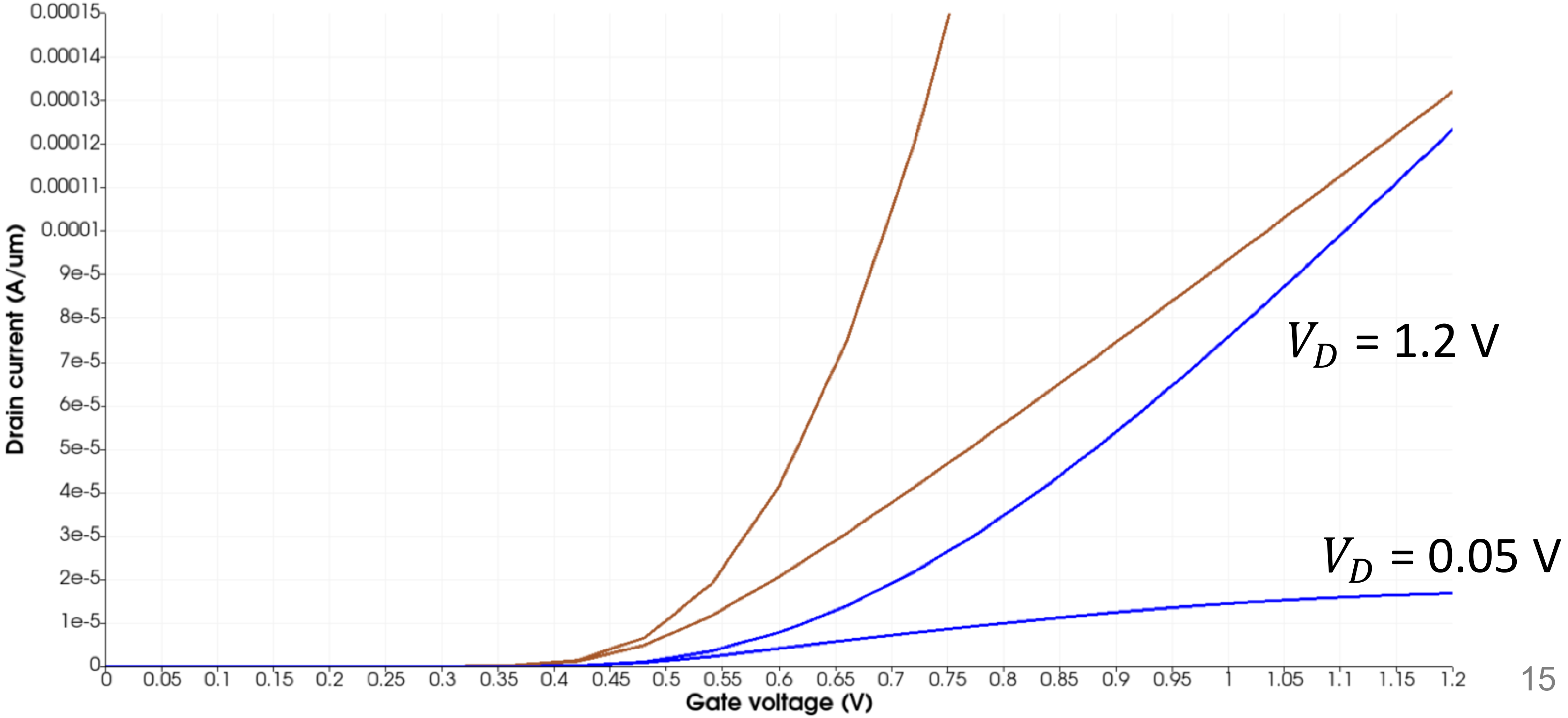
- Of course, we must include physical models.
  - Add the following lines.

```
property (thing="mosfet",model="mobility",mujtaba,canali)
property (thing="mosfet",model="recombination",srh)
```

  - Observe their effects.

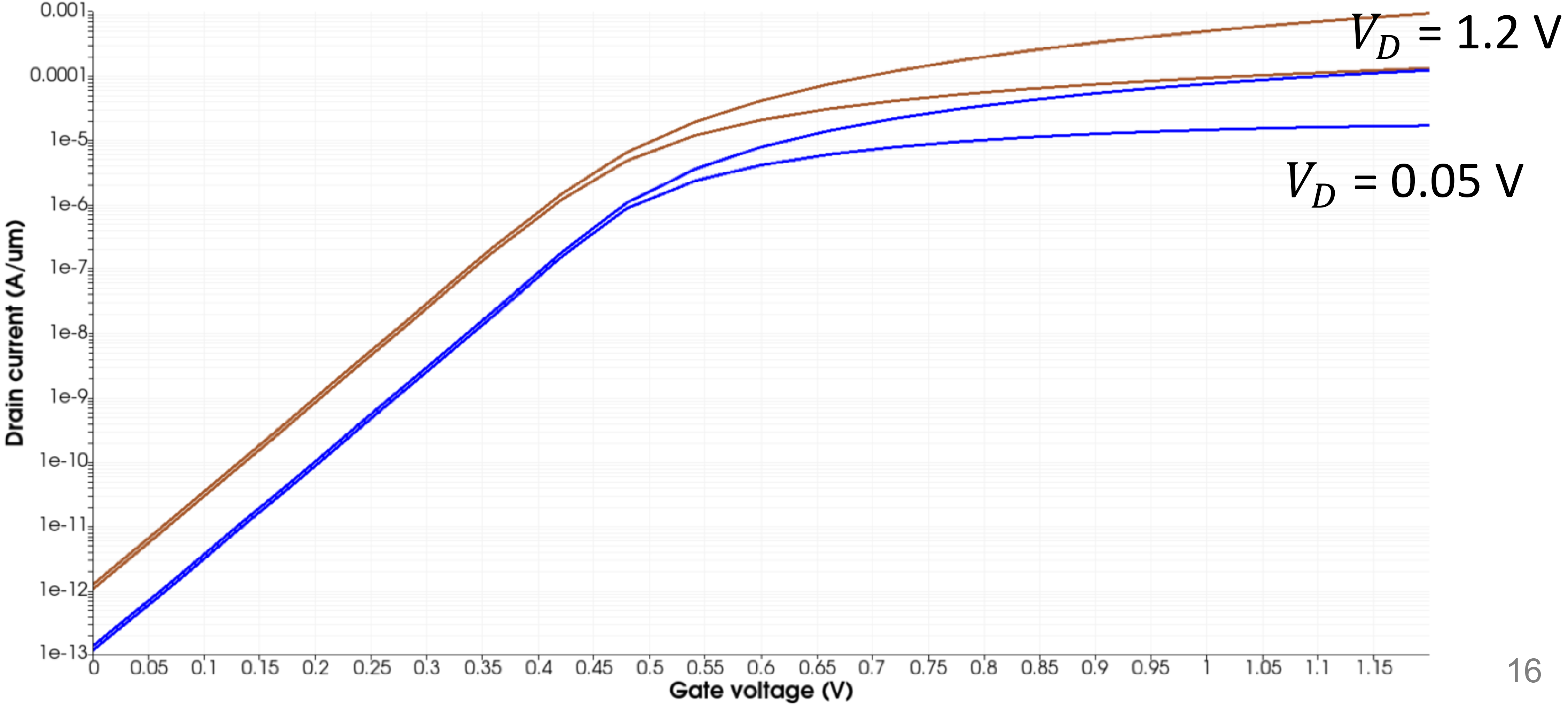
Linear curve

- Significantly reduced current (Blue curves)



Semi-logarithmic curve

- Significantly reduced current (Blue curves)



Ramping the drain voltage up

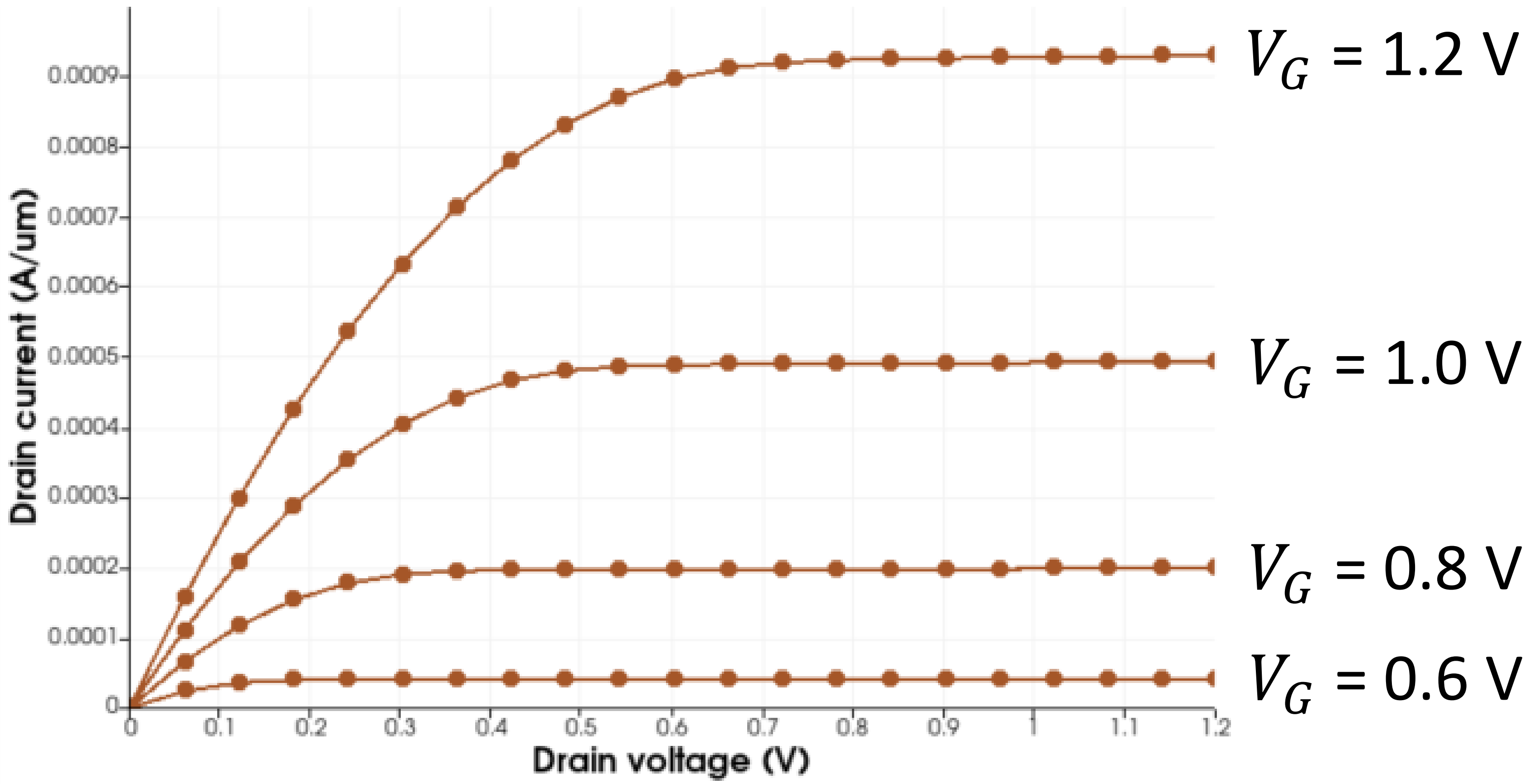
- We need several gate voltages.
  - Select a value and ramp up the gate voltage.
- Increase the drain voltage from 0 V to V_{DD}.

```
solve (law="dclaw",initialstep=0.05,maxstep=0.05,minstep=0.01,dozero,
       plot,plotprefix="long_dc",cgns,book="output_iv") {
  goal (thing="vd", quantity="voltage", value=1.2)
}
```

- Repeat it with other V_G values.

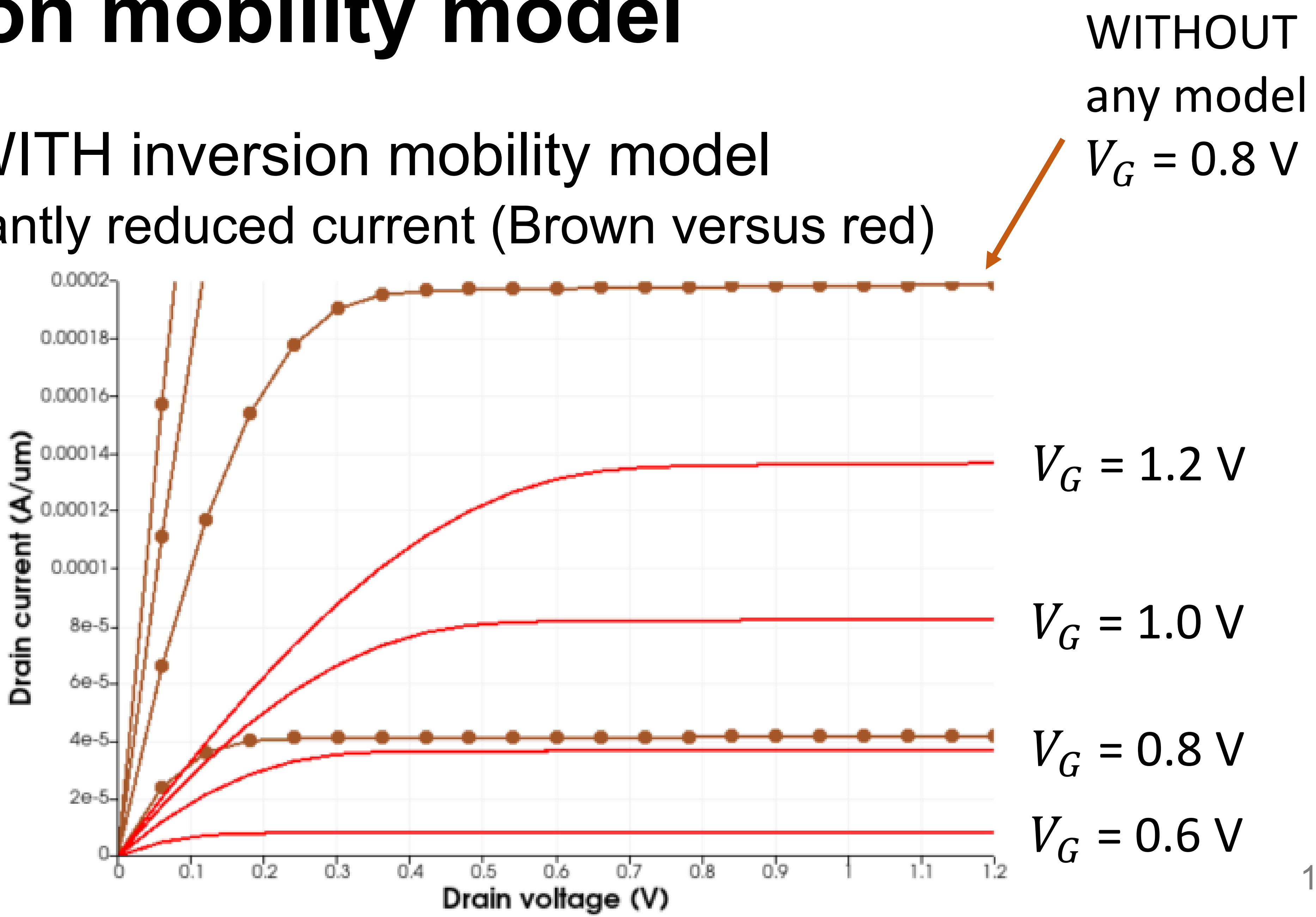
Without physical models

- Results WITHOUT any physical model from V_G = 0.6 V to 1.2 V (0.2 V step)



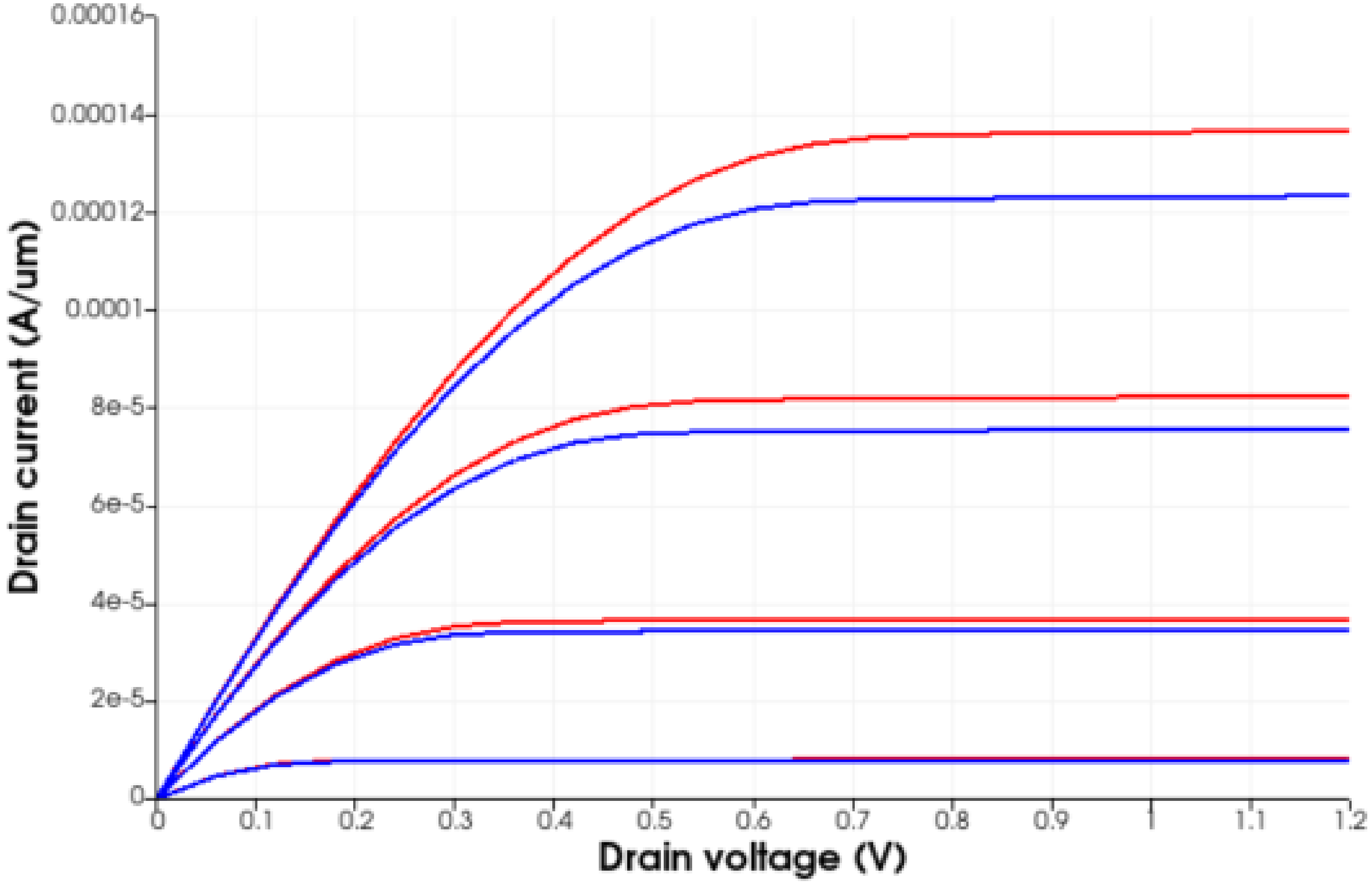
Inversion mobility model

- Results WITH inversion mobility model
  - Significantly reduced current (Brown versus red)



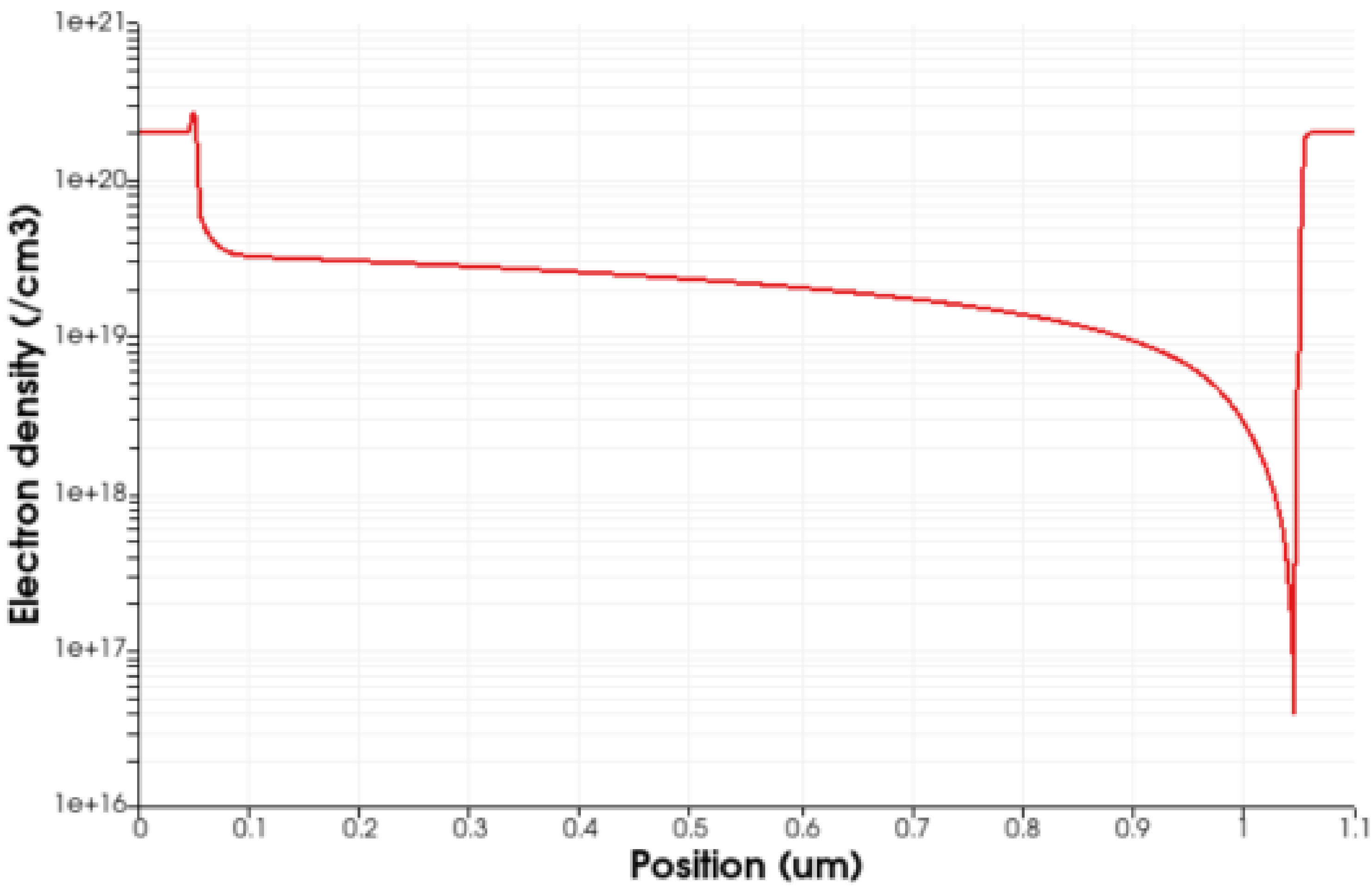
Velocity saturation

- Results WITH inversion mobility model + velocity saturation



Electron density

- Interface carrier density at $V_G = V_D = V_{DD}$



Homework#17

- Due: 08:00 on Nov. 17
- Submit a report through the GIST LMS system.
  - From the input IV characteristics of our long-channel MOSFET, estimate the DIBL. (Of course, you must consider physical models.)

Thank you!