Advanced MOSFETs and Novel Devices

Dr.-Ing. Josef Biba

7. Tutorial & Excercise

Device Simulation

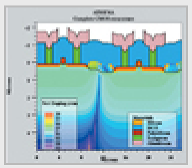
SILVACO ENGINEERED EXCELLENCE

TCAD http://www.silvaco.com/products/tcad/index.html

Silvaco provides different **T**echnology **C**omputer **A**ided **D**esign (TCAD)
software packages for modeling semiconductor processes, devices and circuit.

ATHENA

Process Simulation Framework. Integrates several process simulation modules in a user-friendly environment provided by Silvaco TCAD interactive tools.

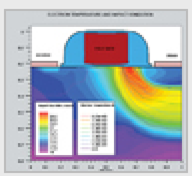


More...

- **Athena** is the process simulator
  - Simulates all processes e. g. implantation, oxidation, diffusion, etching etc.

ATLAS

Device simulation framework that enables simulation of the electrical, optical, and thermal behavior of semiconductor devices.



More...

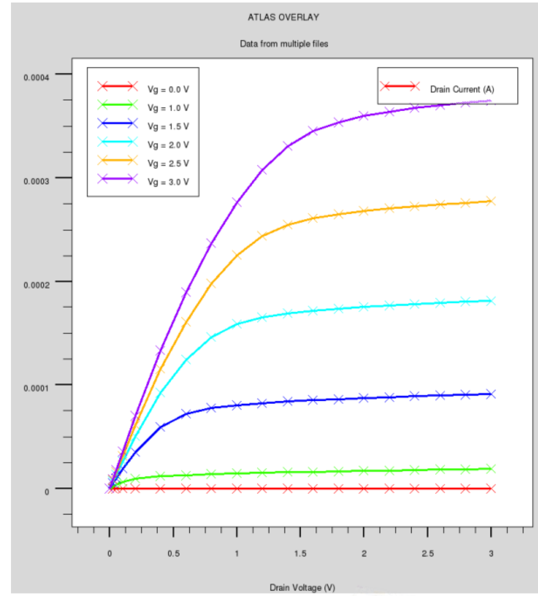
- **Atlas** is the device simulator
  - Simulates electrical characteristics e. g. IV, CV of devices

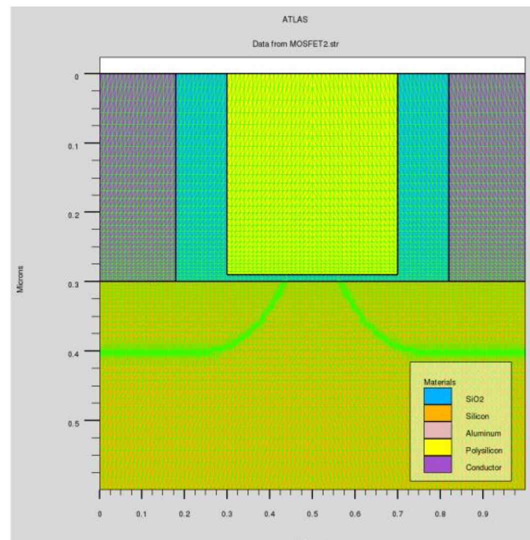
Generating Atlas Input File:

- **Initial Definitions**
  - Mesh
  - Structure
  - Electrodes
  - Doping
  - Regridding
- **Models**
- **Solutions**
  - Initial Guess
  - Bias steps
  - Bias sweeps

Results:

- **1D Plots**
  - IV Characteristic
  - Profiles
- **2D Plots**
  - Structure
  - Contour Plots





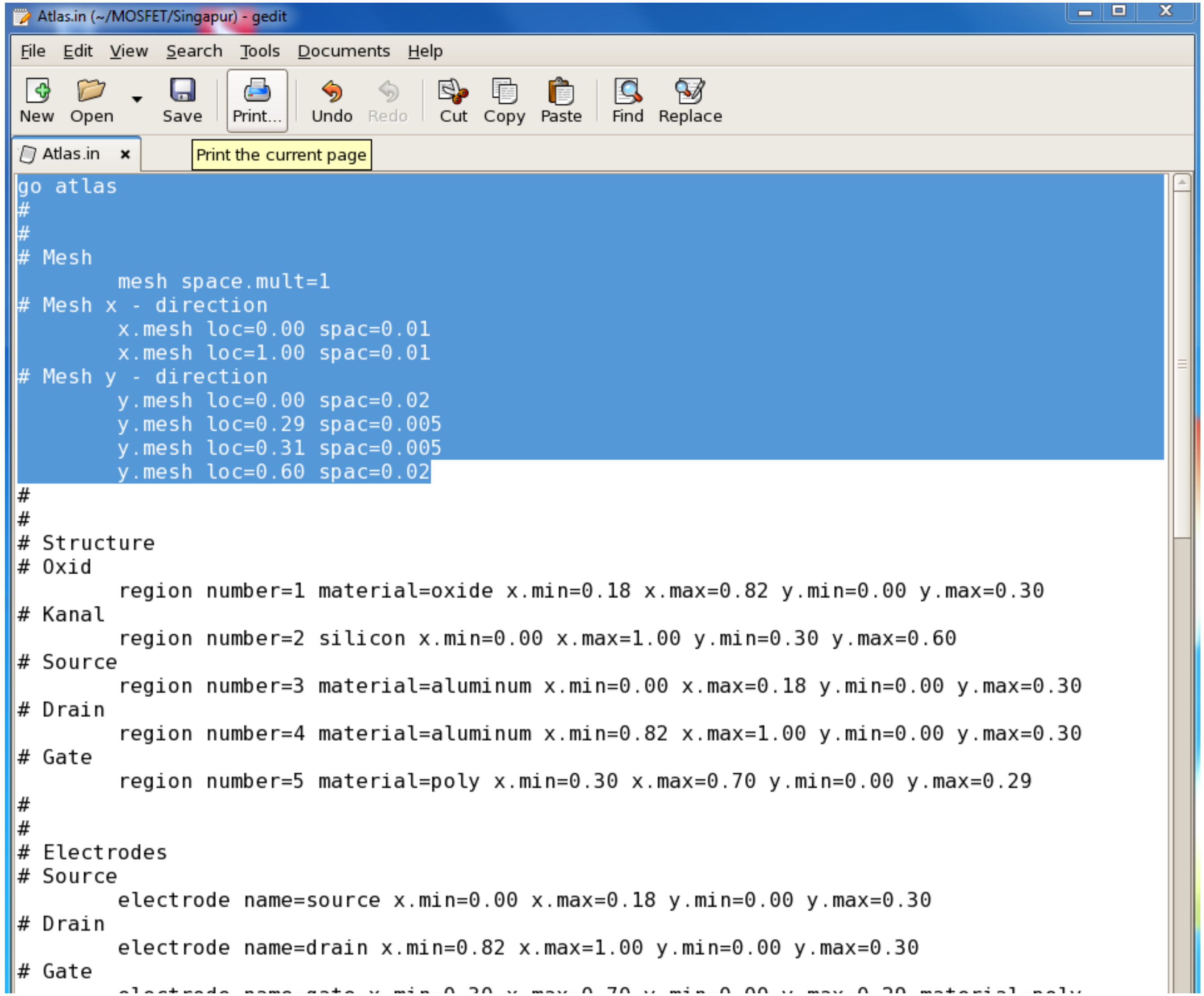
The input file has the following structure:

- The **physical structure** to be simulated
  - Structure from the process simulator
  - Self defined structure
- The **physical models** to be used
  - Choose models for e. g. recombination, tunneling breakdown etc.
- The **numerical methods** for the simulation
- The **bias conditions** for the electrical characteristics
  - IV characteristic, e. g. transfer characteristic
  - CV characteristic

Device Simulation – Mesh

Defining a mesh for Atlas:

- **Go Atlas** says to use Atlas simulator
- **Mesh space** is a scaling factor for the mesh
- **X.Mesh** defines the mesh in x – direction
- **Y.Mesh** defines the mesh in y - direction

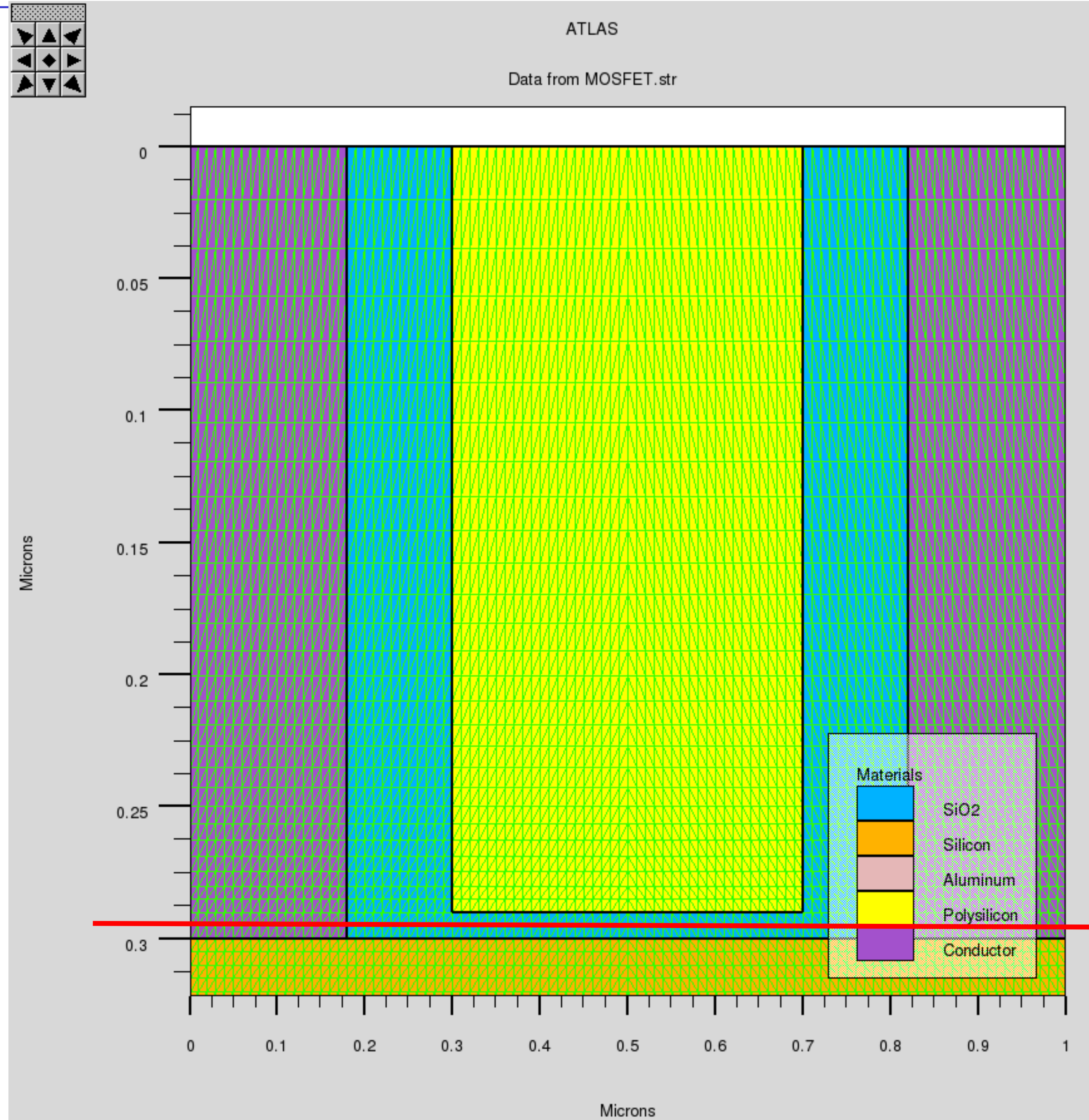



```
go atlas
#
#
# Mesh
        mesh space.mult=1
# Mesh x - direction
        x.mesh loc=0.00 spac=0.01
        x.mesh loc=1.00 spac=0.01
# Mesh y - direction
        y.mesh loc=0.00 spac=0.02
        y.mesh loc=0.29 spac=0.005
        y.mesh loc=0.31 spac=0.005
        y.mesh loc=0.60 spac=0.02
#
#
# Structure
# Oxid
        region number=1 material=oxide x.min=0.18 x.max=0.82 y.min=0.00 y.max=0.30
# Kanal
        region number=2 silicon x.min=0.00 x.max=1.00 y.min=0.30 y.max=0.60
# Source
        region number=3 material=aluminum x.min=0.00 x.max=0.18 y.min=0.00 y.max=0.30
# Drain
        region number=4 material=aluminum x.min=0.82 x.max=1.00 y.min=0.00 y.max=0.30
# Gate
        region number=5 material=poly x.min=0.30 x.max=0.70 y.min=0.00 y.max=0.29
#
#
# Electrodes
# Source
        electrode name=source x.min=0.00 x.max=0.18 y.min=0.00 y.max=0.30
# Drain
        electrode name=drain x.min=0.82 x.max=1.00 y.min=0.00 y.max=0.30
# Gate
```

Device Simulation – Mesh

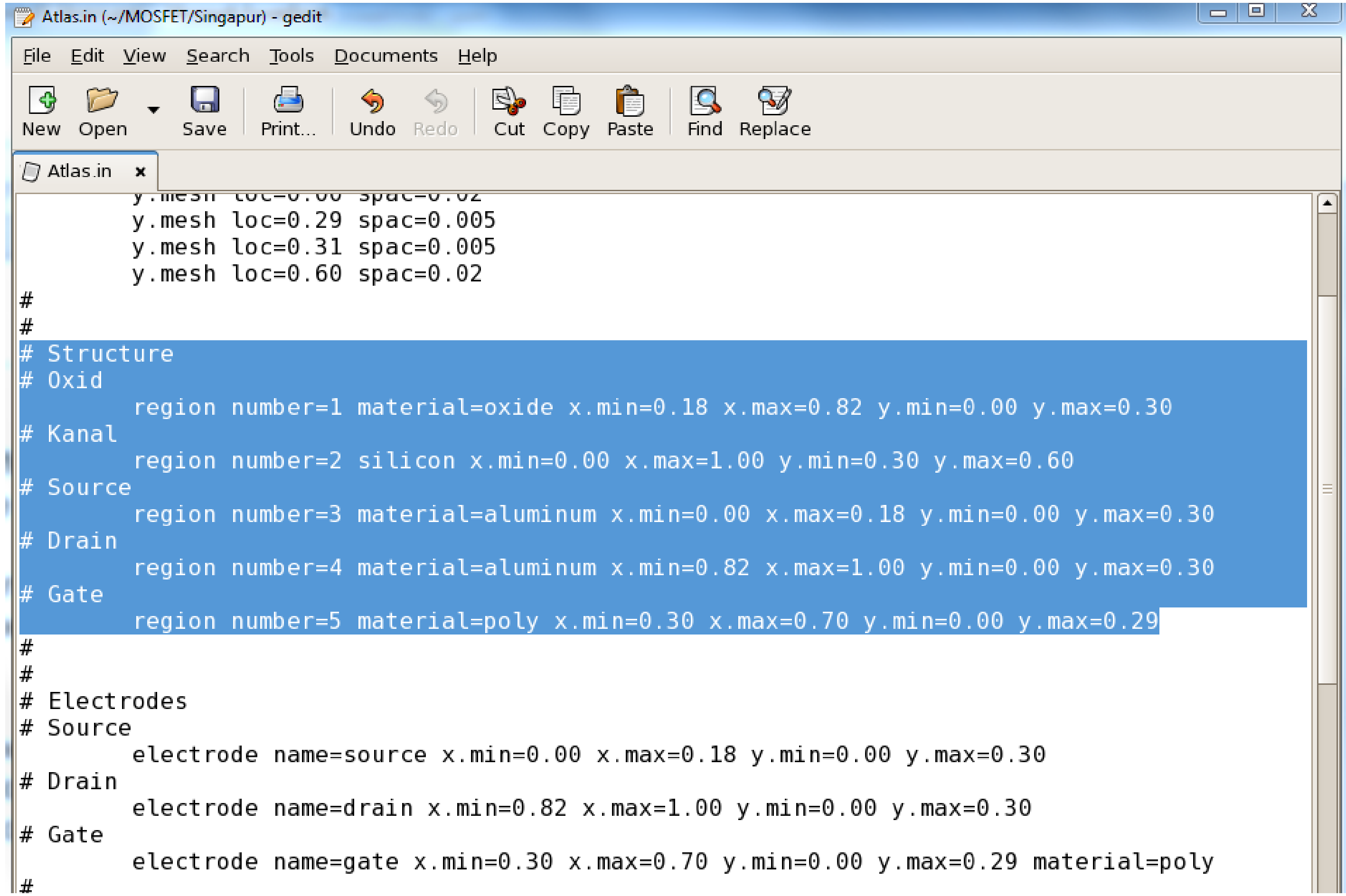
Defining a mesh for Atlas:

- **Loc** defines the position for a mesh line
- **Spac** defines the space between two mesh lines.
- If different line spacing's were defined, ATLAS adjusts the spacing step by step.
- Use fine mesh where quantities (e. g. doping) changes
- Use coarser mesh where quantities stay constant (e. g. substrate)



Defining a structure:

- **Region** defines different layers of the device
- **Number** assigns an identification number to the region
- **Material** defines the material of the region (e. g. silicon, poly, oxide, aluminum etc.)
- **X.min X.max** defines start and end point of the region in x - direction
- **Y.min Y.max** defines start and end point of the region in y - direction



Defining a structure:

- **Region** defines different layers of the device
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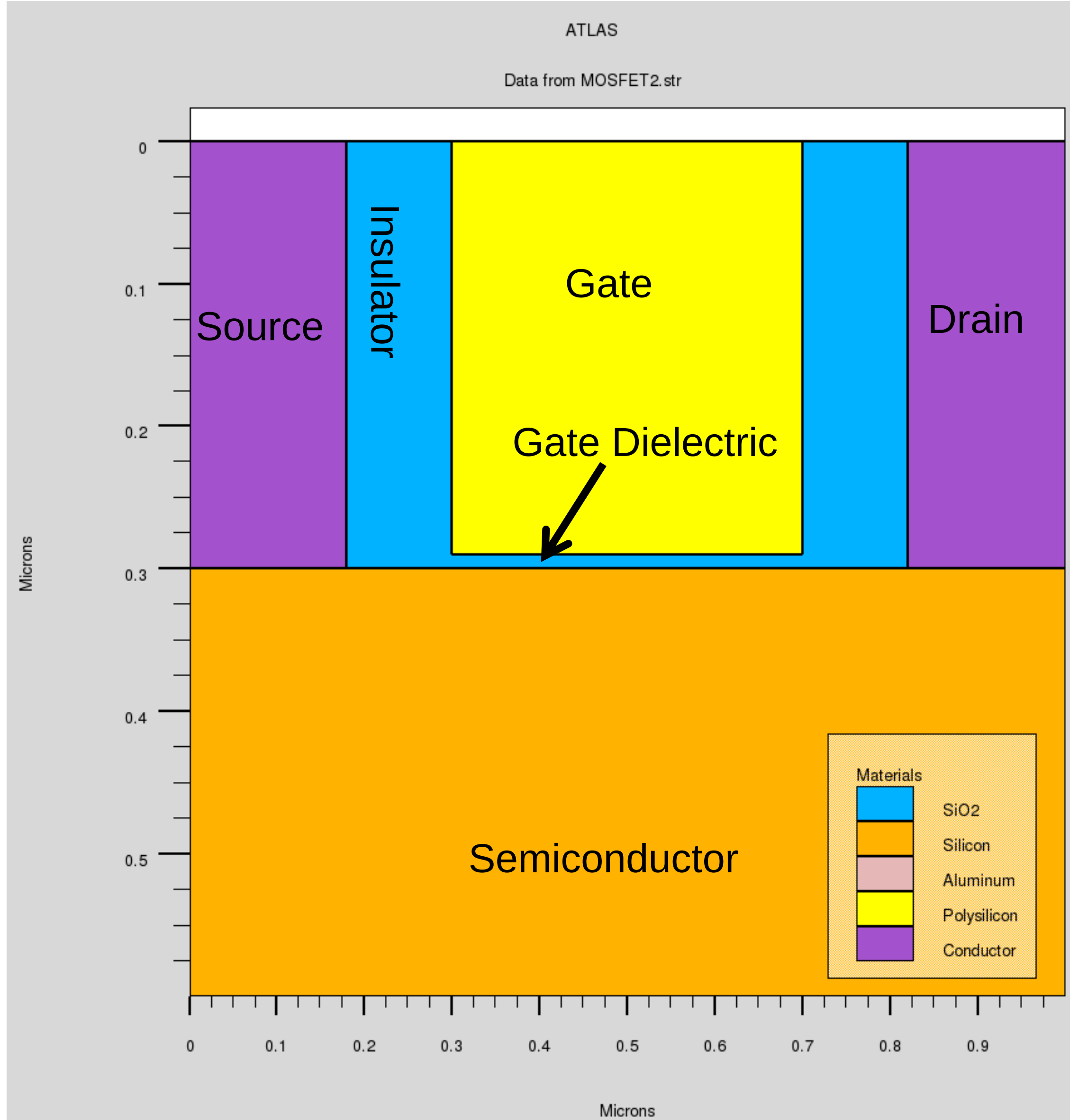
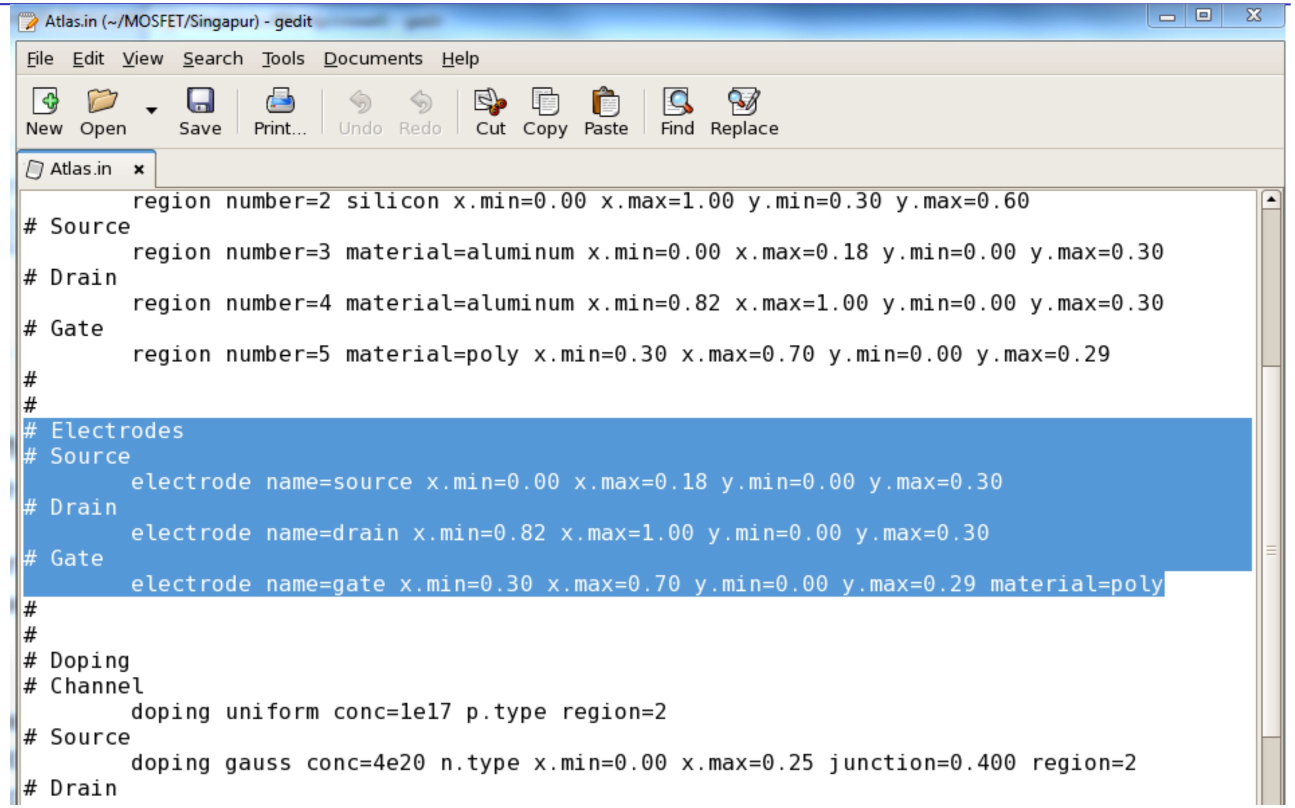


Defining electrodes:

- **Electrode** defines an electrode for setting bias or current conditions
- **Name** assigns a name to the electrode
- **Material** defines the material of the electrode
- **X.min X.max Y.min Y.max** see region
- All electrical properties are defined in the **contact** statement

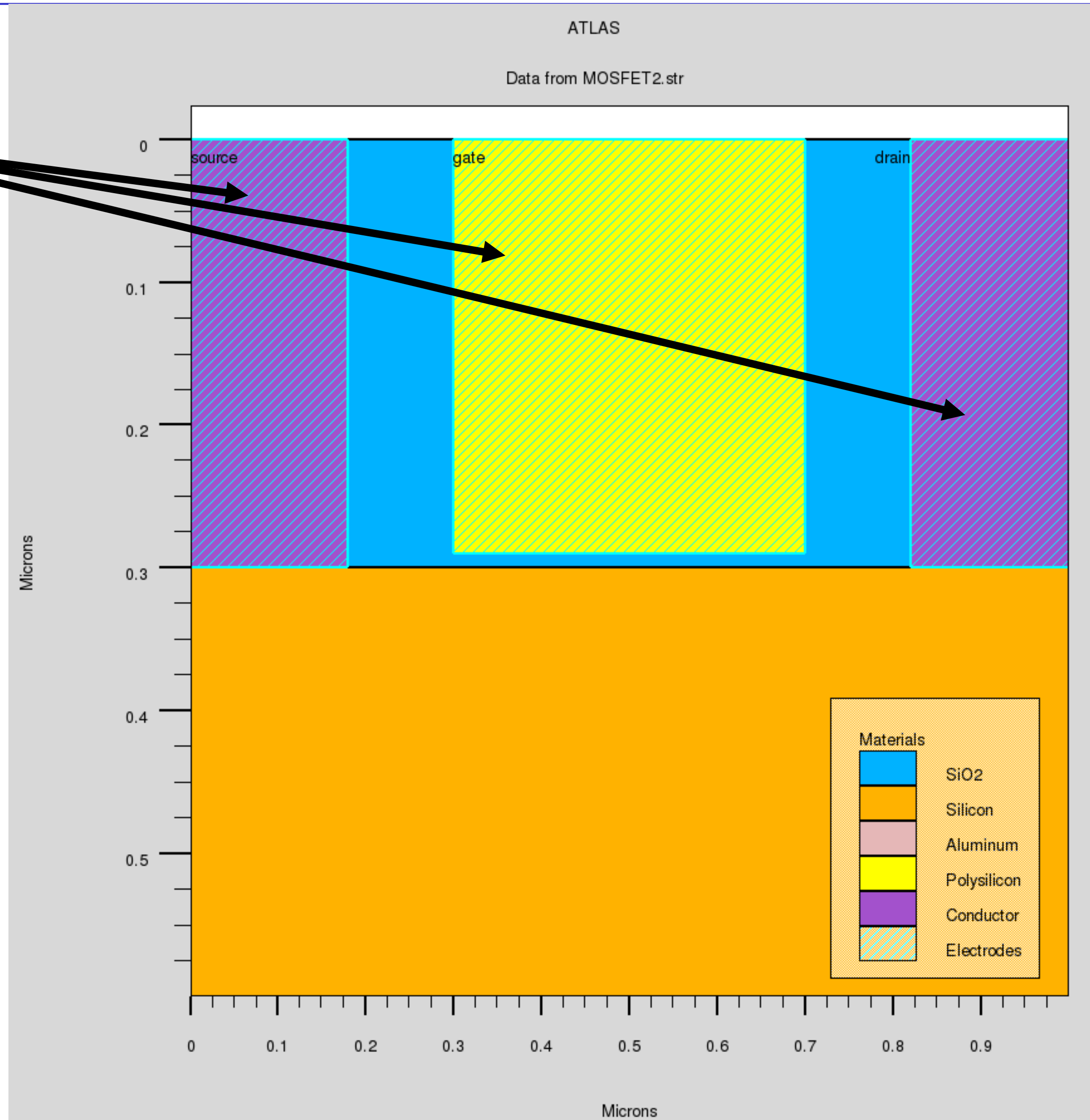



```
        region number=2 silicon x.min=0.00 x.max=1.00 y.min=0.30 y.max=0.60
# Source
        region number=3 material=aluminum x.min=0.00 x.max=0.18 y.min=0.00 y.max=0.30
# Drain
        region number=4 material=aluminum x.min=0.82 x.max=1.00 y.min=0.00 y.max=0.30
# Gate
        region number=5 material=poly x.min=0.30 x.max=0.70 y.min=0.00 y.max=0.29
#
#
# Electrodes
# Source
        electrode name=source x.min=0.00 x.max=0.18 y.min=0.00 y.max=0.30
# Drain
        electrode name=drain x.min=0.82 x.max=1.00 y.min=0.00 y.max=0.30
# Gate
        electrode name=gate x.min=0.30 x.max=0.70 y.min=0.00 y.max=0.29 material=poly
#
#
# Doping
# Channel
        doping uniform conc=1e17 p.type region=2
# Source
        doping gauss conc=4e20 n.type x.min=0.00 x.max=0.25 junction=0.400 region=2
# Drain
```

Device Simulation – Electrodes

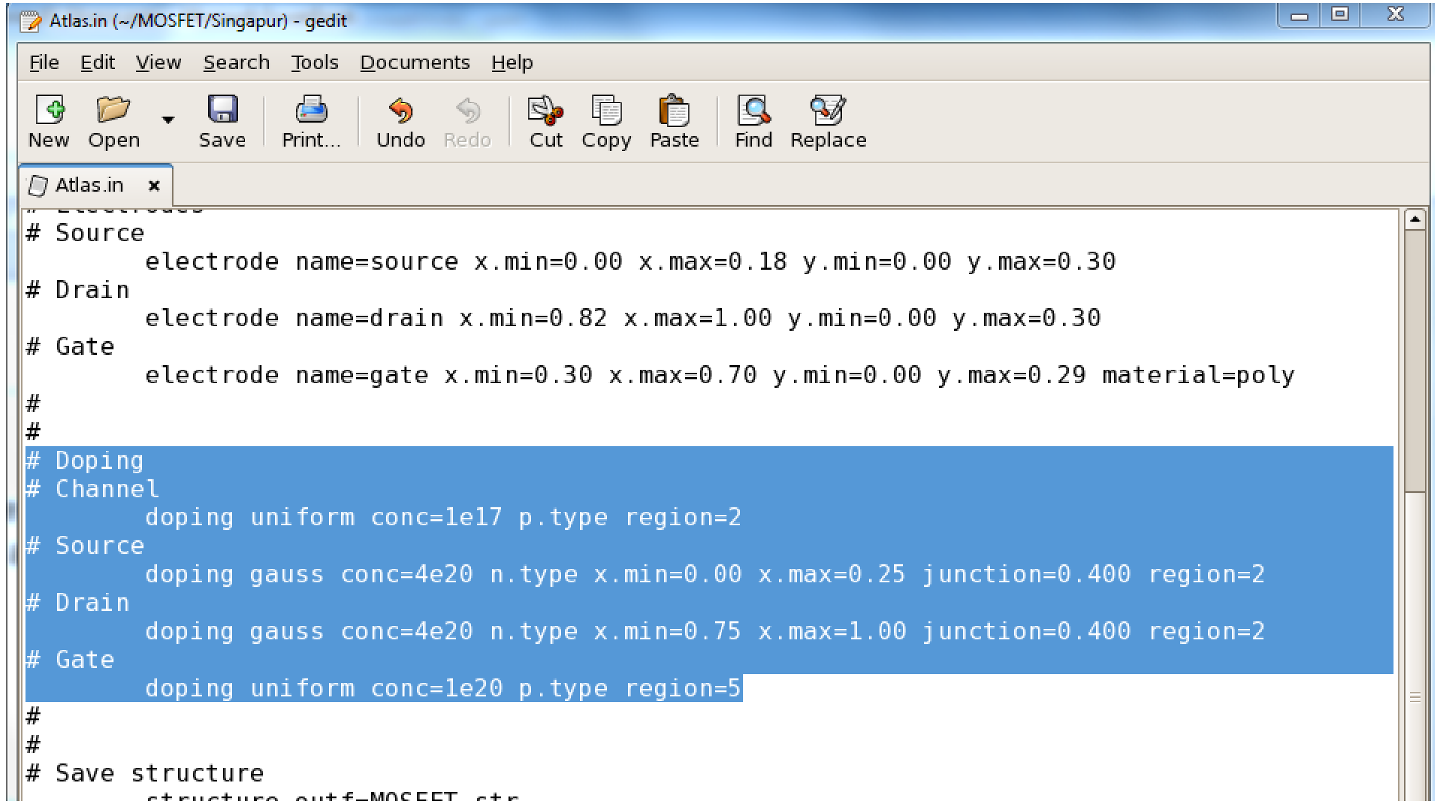
Defining electrodes:

- **Electrode** defines an electrode for setting bias or current conditions
- **Name** assigns a name to the electrode
- **Material** defines the material of the electrode
- **X.min X.max Y.min Y.max** see region
- All electrical properties are defined in the **contact** statement



Defining Doping:

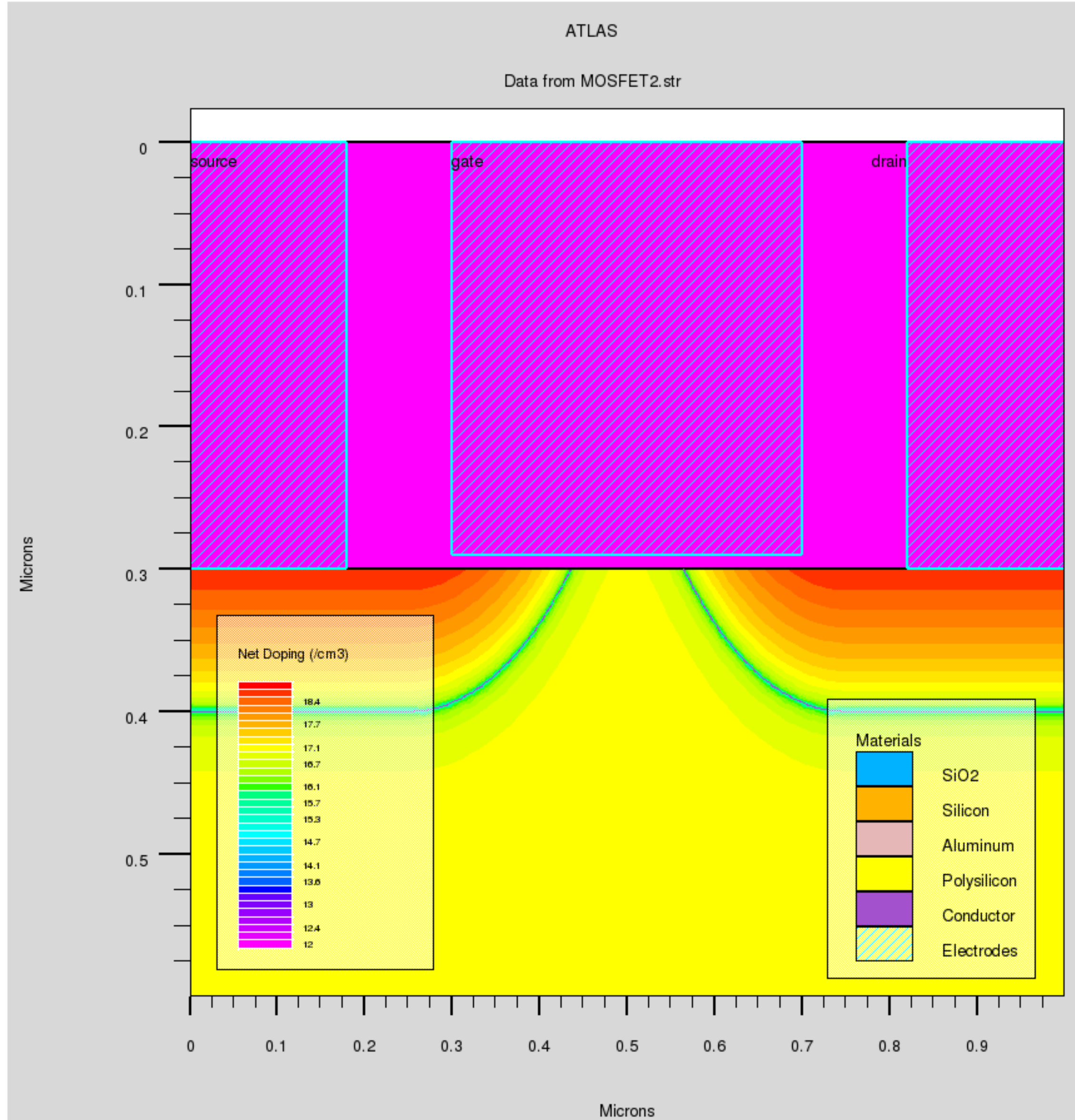
- **Doping** defines the doping of different areas of the device
- **Uniform** makes a constant doping
- **Gauss** defines a doping with Gaussian shape
- **Junction** defines the depth of a Gaussian doping
- **Region** assigns the doping to the previous defined region.




```
# Source
        electrode name=source x.min=0.00 x.max=0.18 y.min=0.00 y.max=0.30
# Drain
        electrode name=drain x.min=0.82 x.max=1.00 y.min=0.00 y.max=0.30
# Gate
        electrode name=gate x.min=0.30 x.max=0.70 y.min=0.00 y.max=0.29 material=poly
#
#
# Doping
# Channel
        doping uniform conc=1e17 p.type region=2
# Source
        doping gauss conc=4e20 n.type x.min=0.00 x.max=0.25 junction=0.400 region=2
# Drain
        doping gauss conc=4e20 n.type x.min=0.75 x.max=1.00 junction=0.400 region=2
# Gate
        doping uniform conc=1e20 p.type region=5
#
#
# Save structure
```

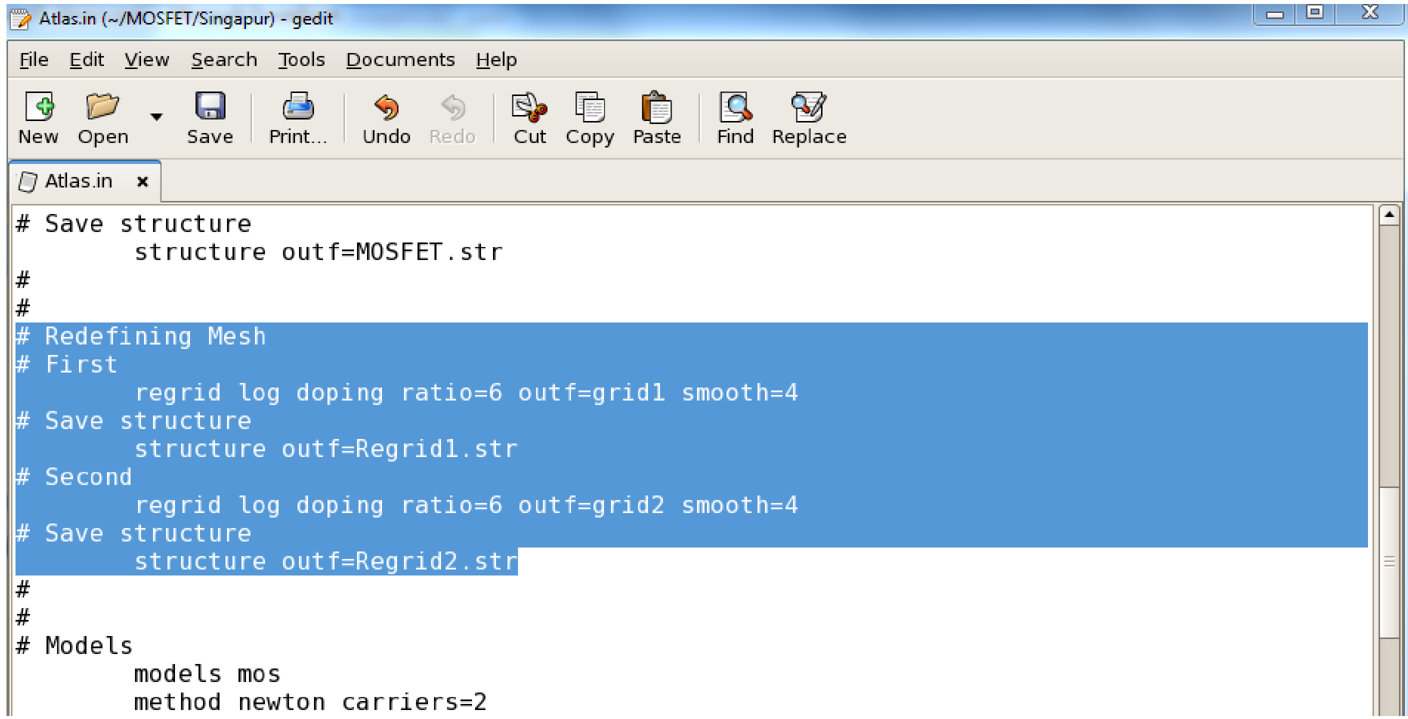
Defining Doping:

- **Doping** defines the doping of different areas of the device
- **Uniform** makes a constant doping
- **Gauss** defines a doping with Gaussian shape
- **Junction** defines the depth of a Gaussian doping
- **Region** assigns the doping to the previous defined region.

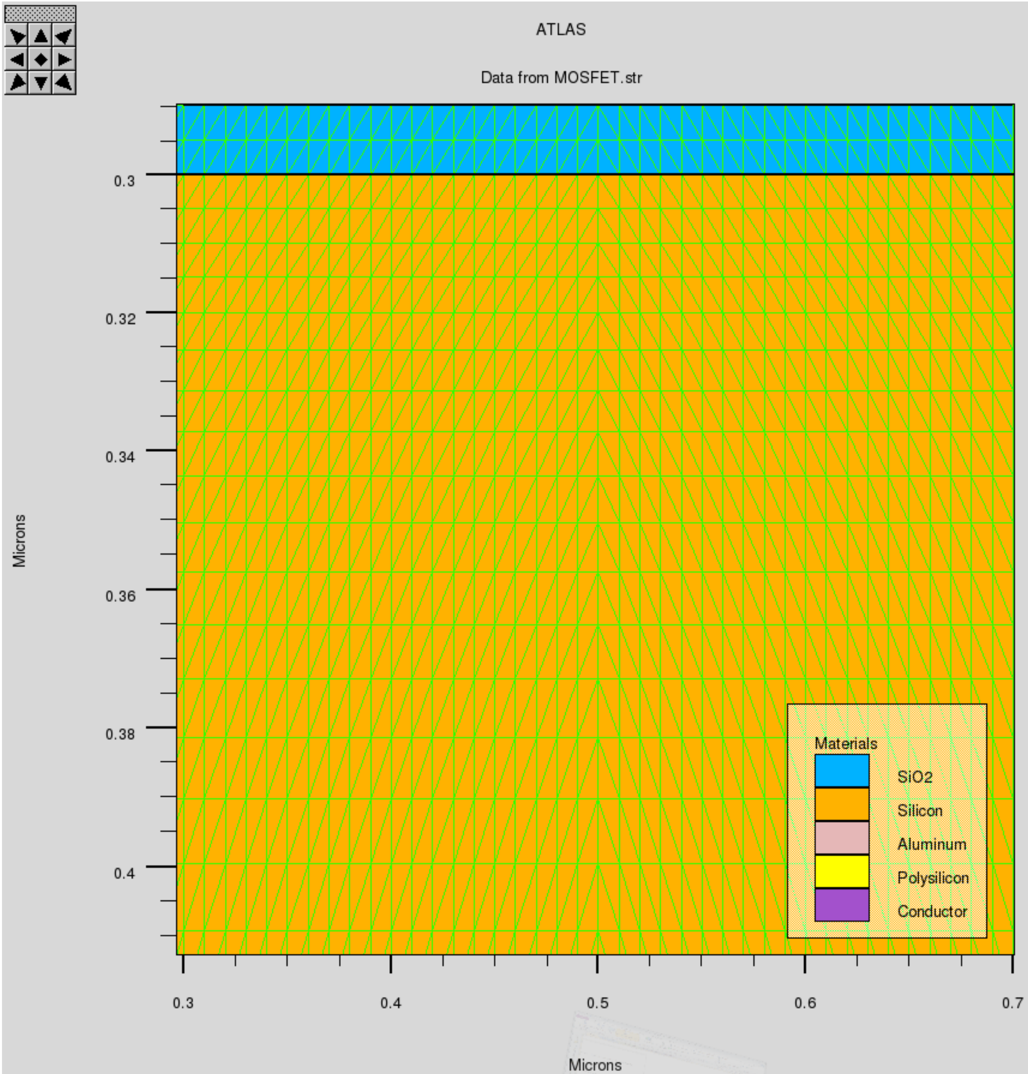


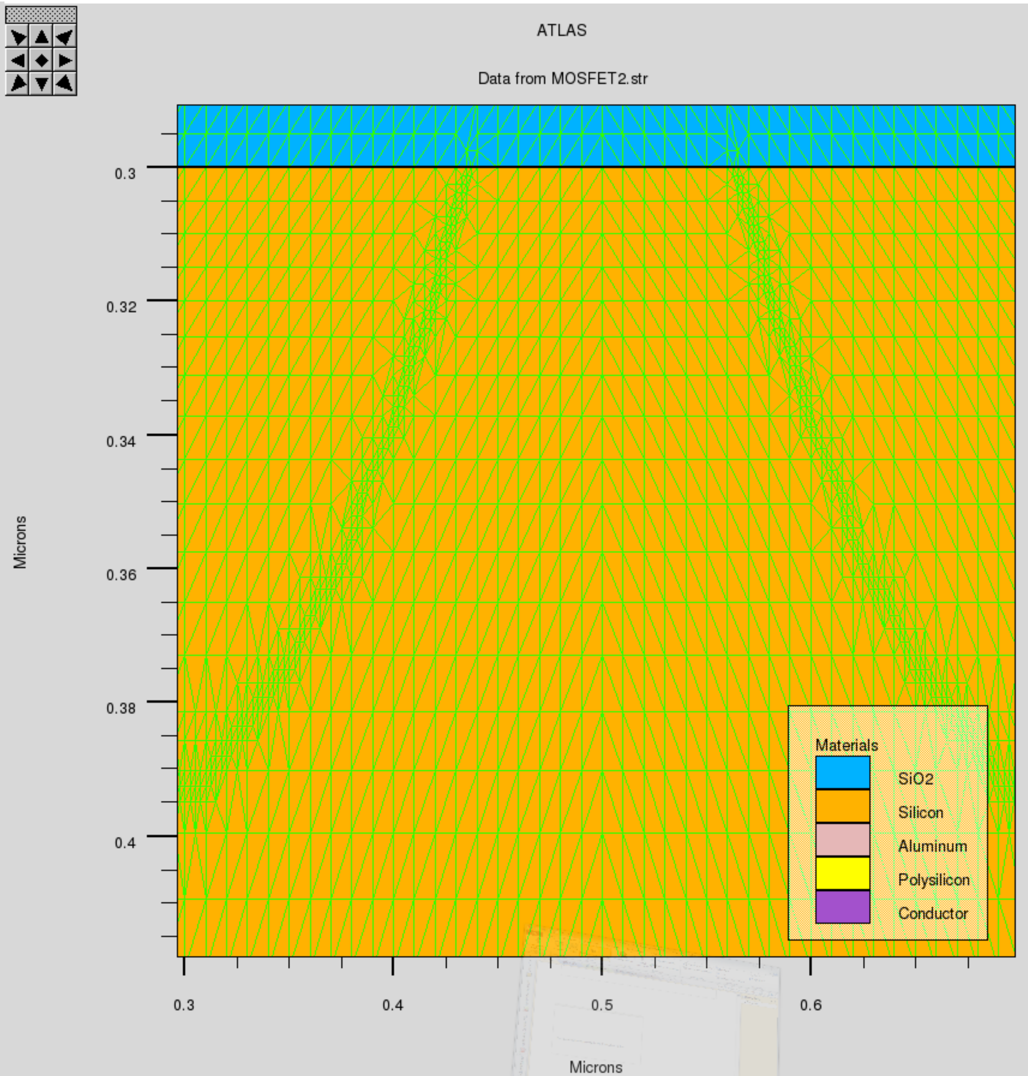
Defining Doping:

- **Regrid** redefines the mesh according to a specific quantity
- **Log** uses a logarithmic refinement scale
- **Doping** sets doping as refinement quantity
- **Ratio** defines the maximum allowed variance across one element
- **Smooth** reduces number of obtuse triangles

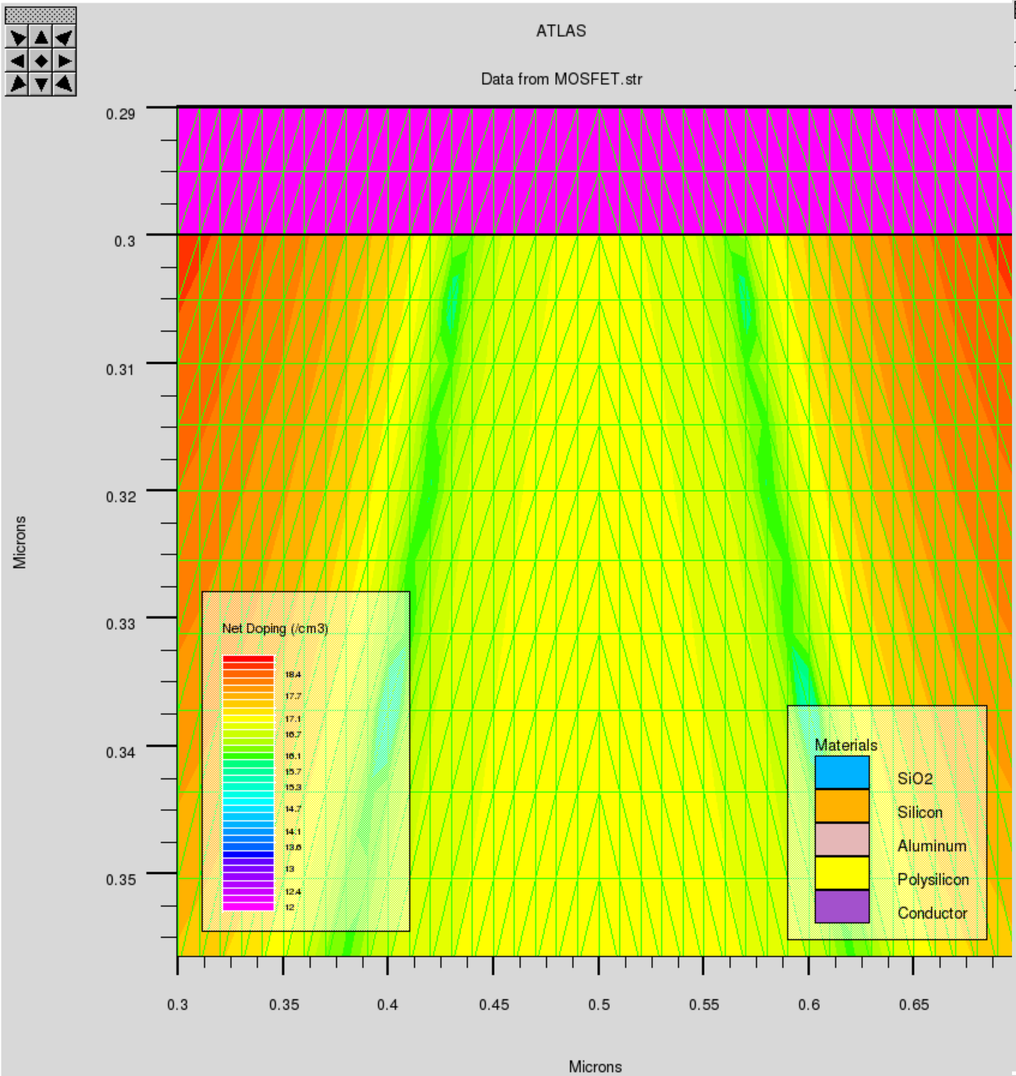


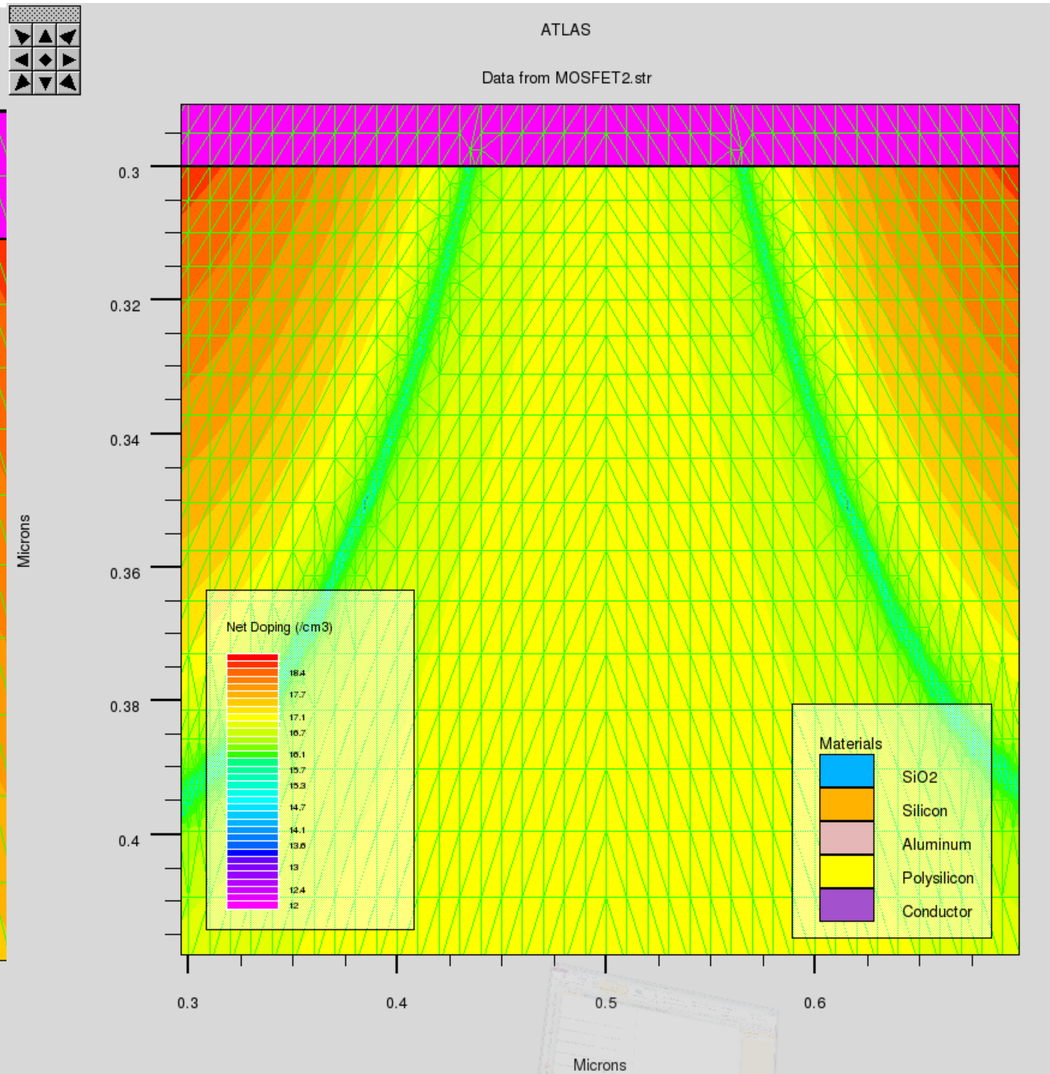
Device Simulation – Regrid





Device Simulation – Regrid





Device Simulation – Models / Methods

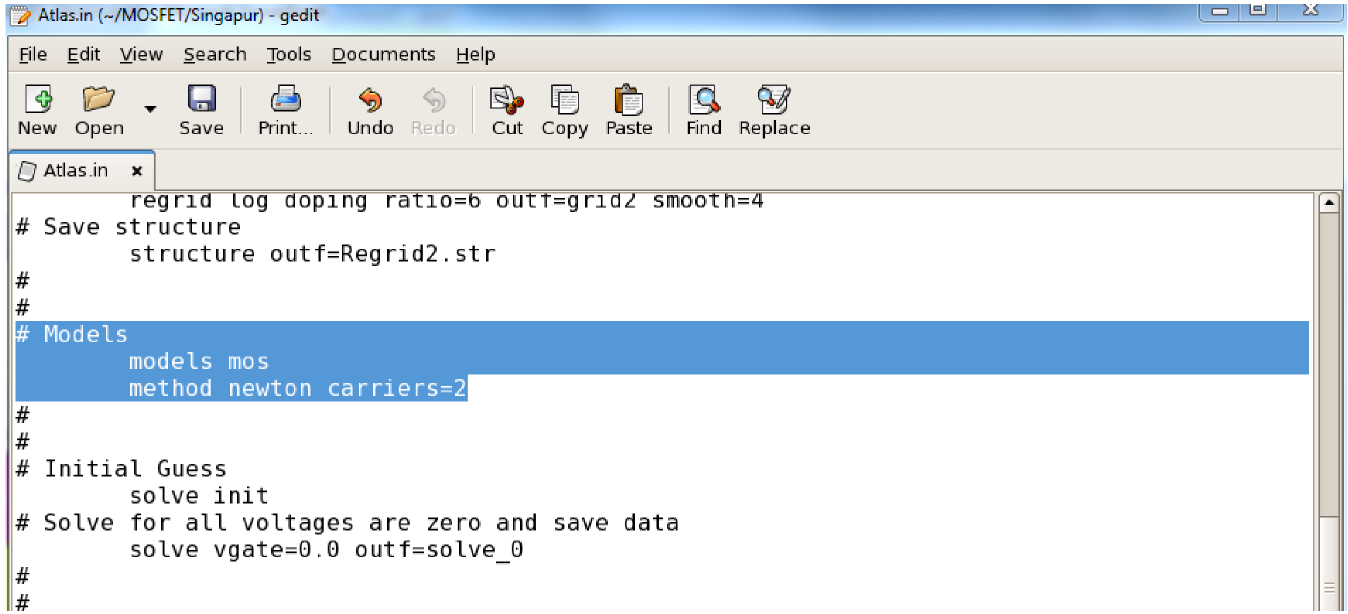
Selecting Models / Method:

- **Models** selecting physical models for carrier statistics, mobility, recombination, impact ionization, tunneling

- **Mos** selects a group of predefined models for a special case

- **Method** selects the numerical technique for calculating solutions

- **Carriers** defines if electrons holes, both or none are considered



Device Simulation – Initial Guess / Save Structure

Initial Guess and save structure:

- **Solve** performs a solution for a given bias point
- **Init** sets all electrodes to 0 V
- **Vgate** defines bias for the former defined electrode “gate”
- **Outf** saves data to file
- **Output** specifies data stored in a structure file
- **Structure** writes mesh and solution informations

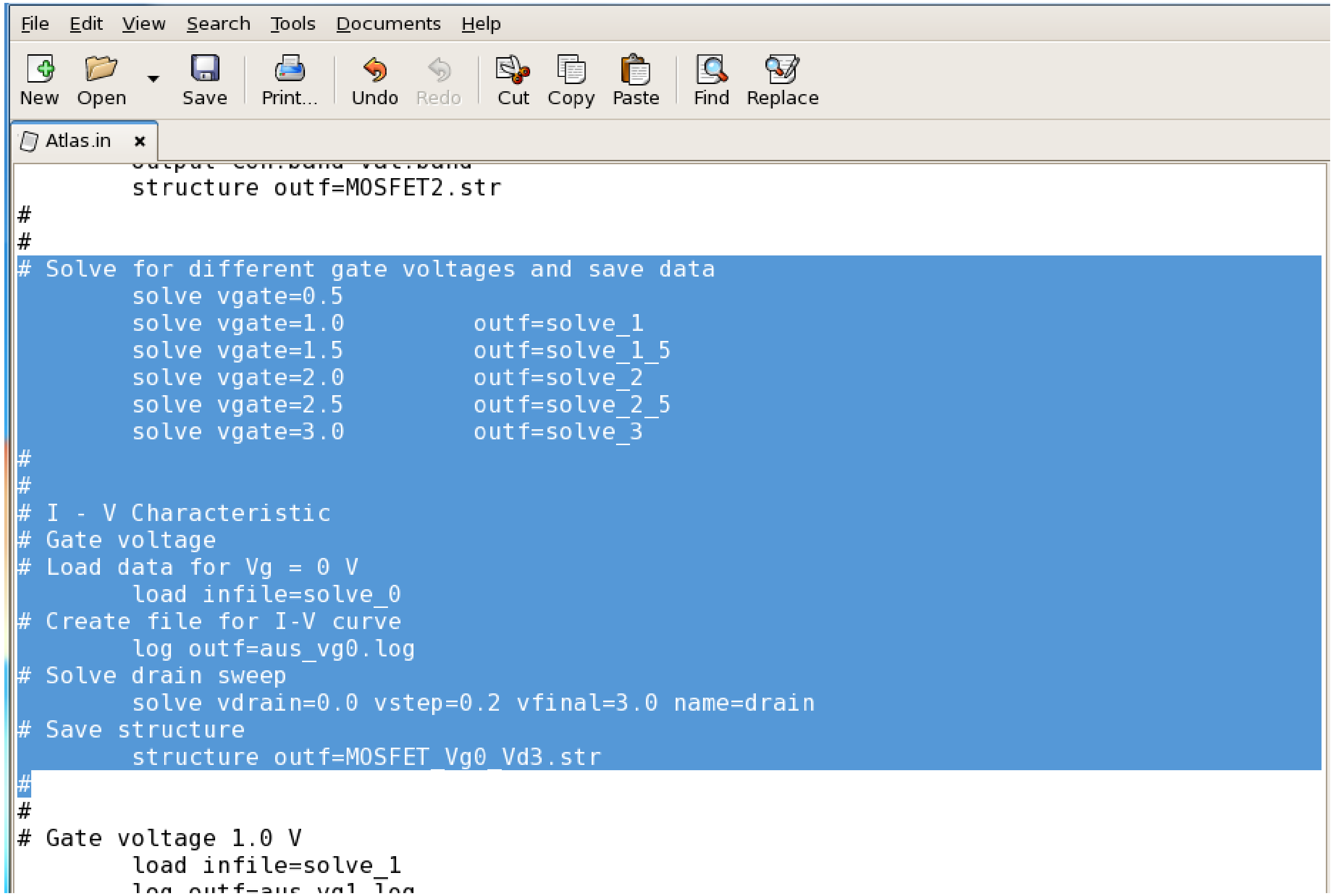
Atlas.in

```
#
# Models
        models mos
        method newton carriers=2
#
#
# Initial Guess
        solve init
# Solve for all voltages are zero and save data
        solve vgate=0.0 outf=solve_0
#
#
# Save with energy bands
        output con.band val.band
        structure outf=MOSFET2.str
#
#
# Solve for different gate voltages and save data
        solve vgate=0.5
        solve vgate=1.0         outf=solve_1
        solve vgate=1.5         outf=solve_1_5
        solve vgate=2.0         outf=solve_2
        solve vgate=2.5         outf=solve_2_5
        solve vgate=3.0         outf=solve_3
#
#
# I - V Characteristic
# Gate voltage
```

Device Simulation – Bias step / sweep

Bias step / sweep:

- Solve for different gate voltages and save result
- **Load** loads previous saved data specified by **Infile**
- **Log** saves all electrode characteristics to a file
- **Vdrain** sets drain voltage to zero
- **Vstep** defines steps for the voltage sweep
- **Vfinal** sets the final voltage for the sweep



- **Name** is the name of the sweeped electrode

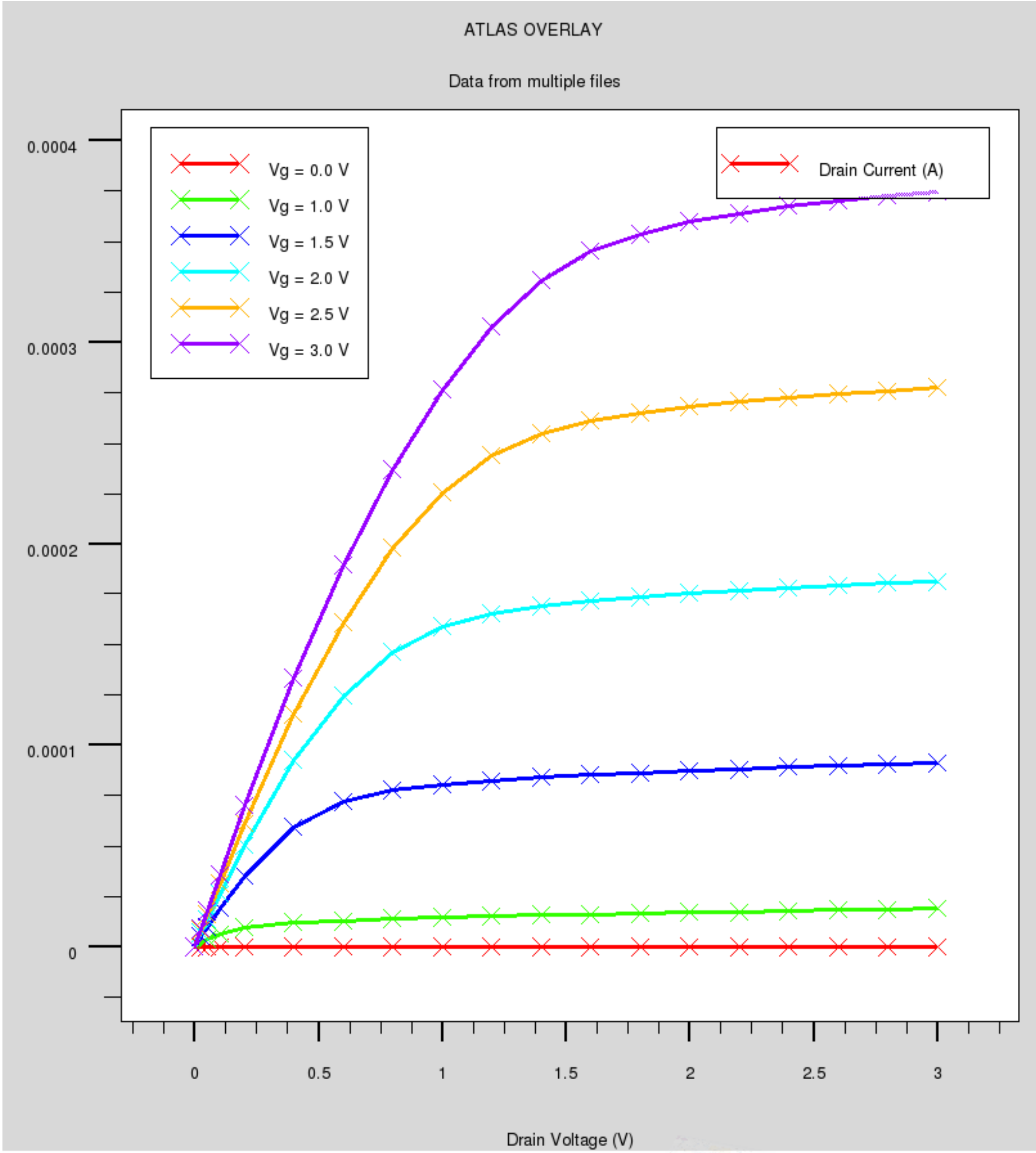
Device Simulation – 1D Plots

1D Plots:

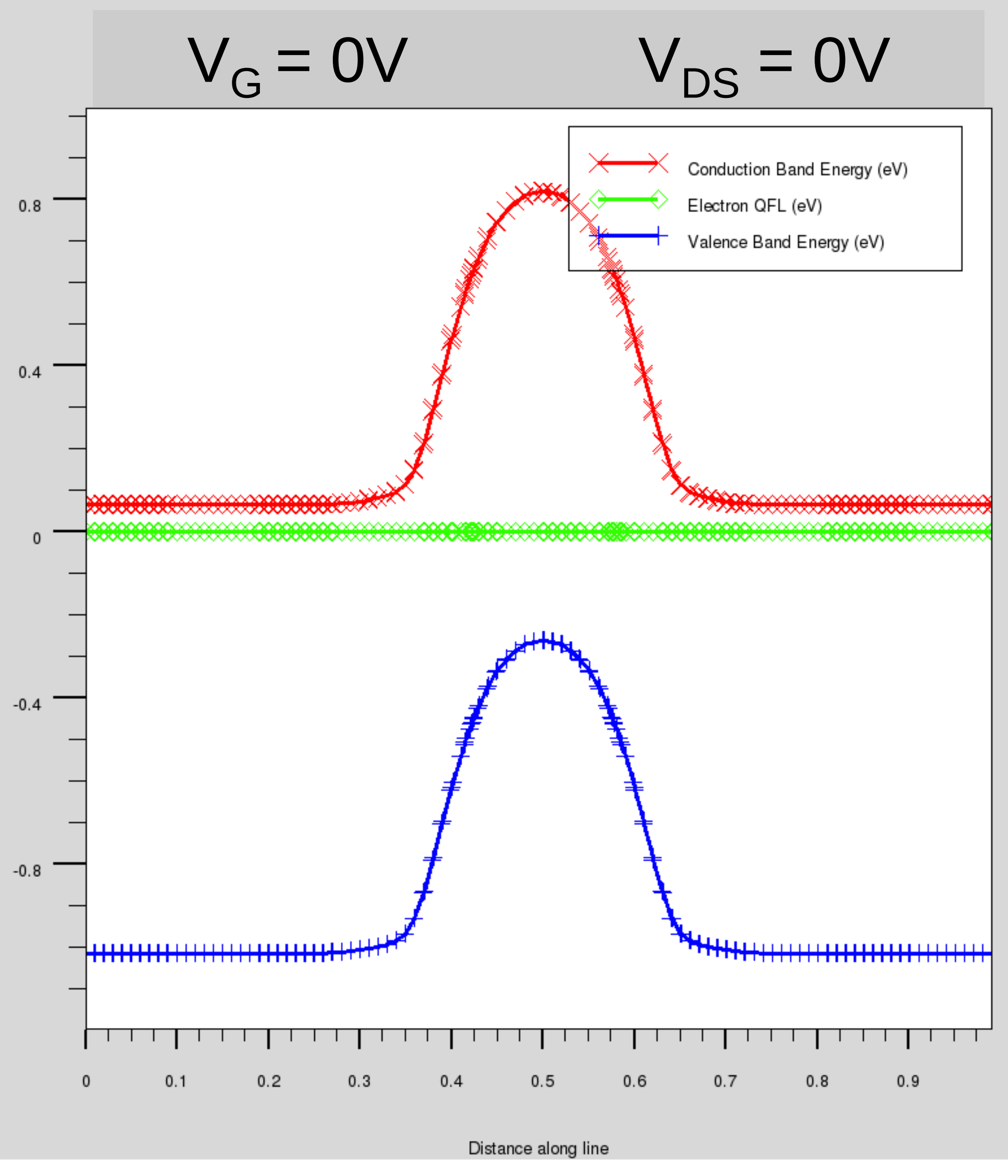
- Simulated output characteristic for different applied gate voltages

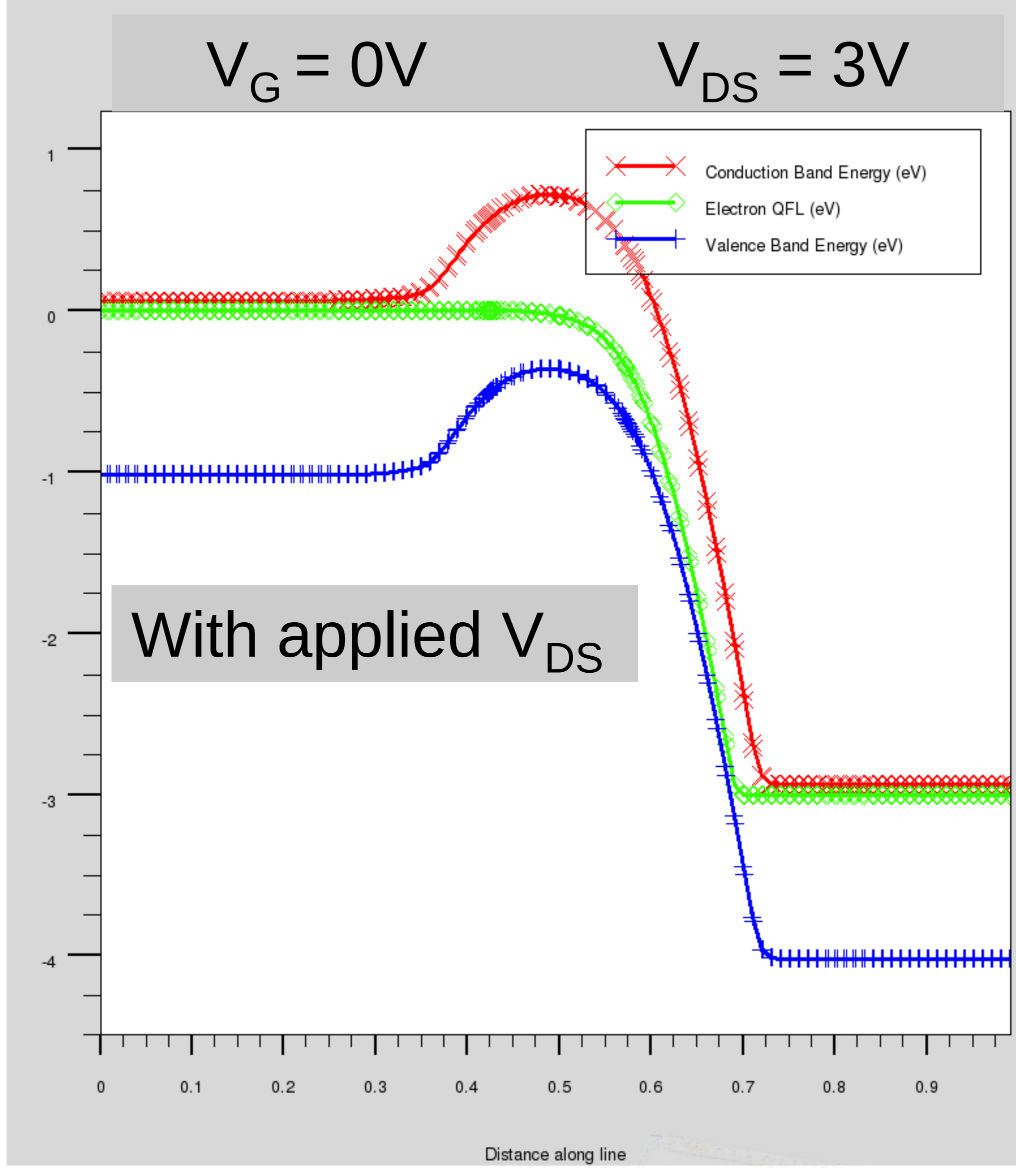
- In this case the current is not A! It is A / µm!

- Other 1D plots:
  - Doping
  - Acceptor / Donor concentrations
  - Currents
  - Quasi Fermi Levels
  - Conduction / Valance Bands
  - Electric field

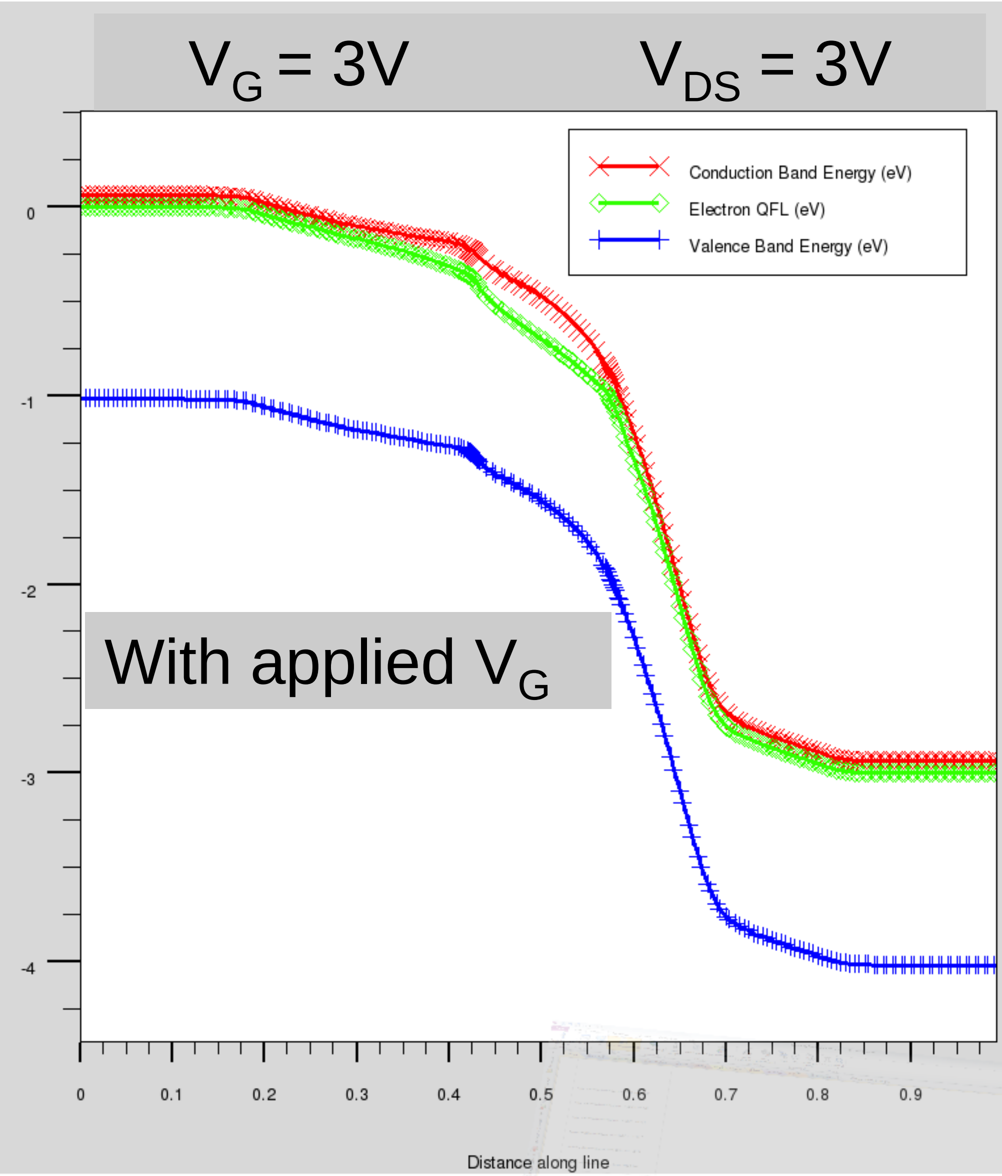


Device Simulation – 1D Plots MOSFET Band Diagram





Device Simulation – 1D Plots MOSFET Band Diagram

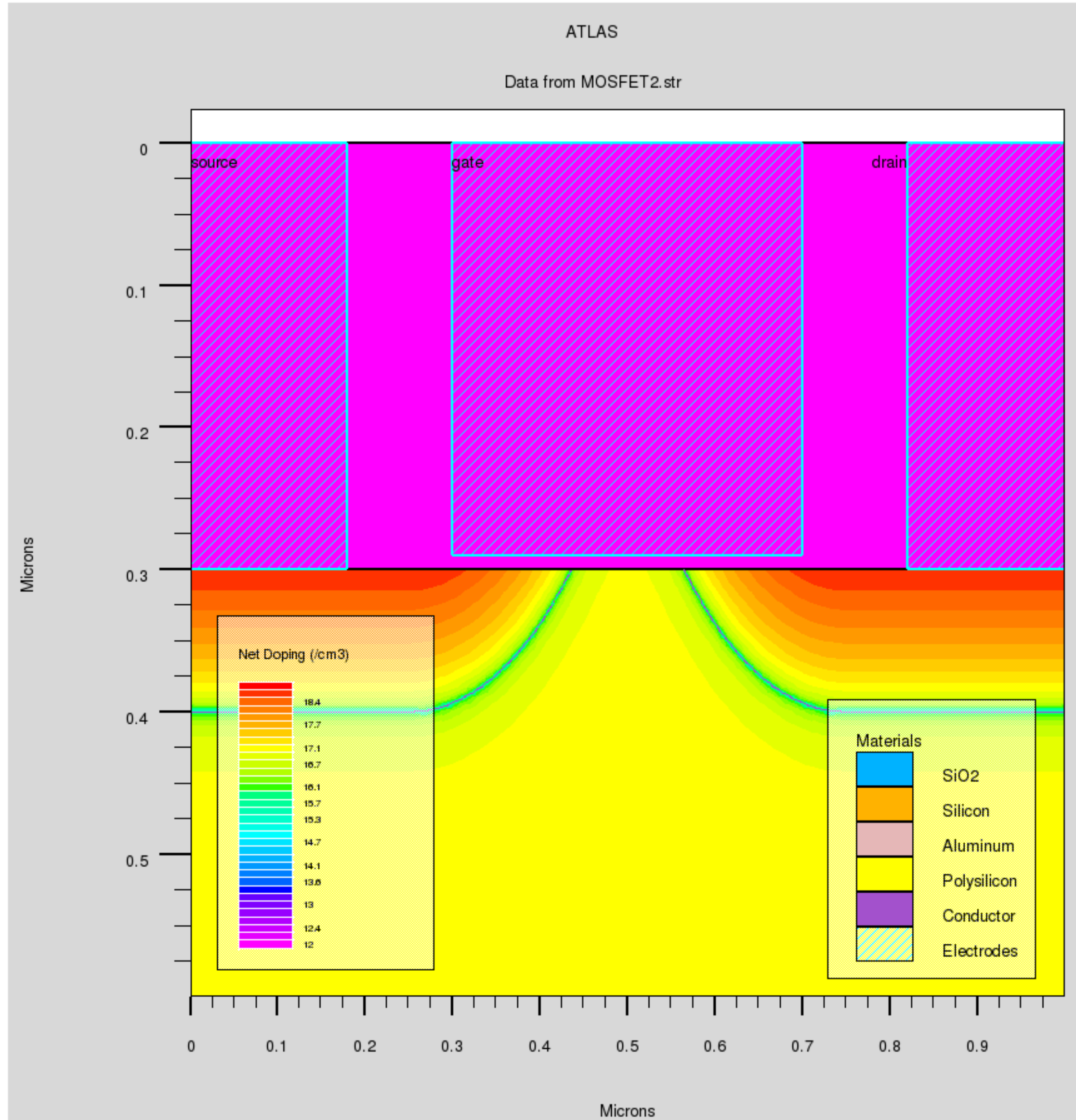


1D Plots:

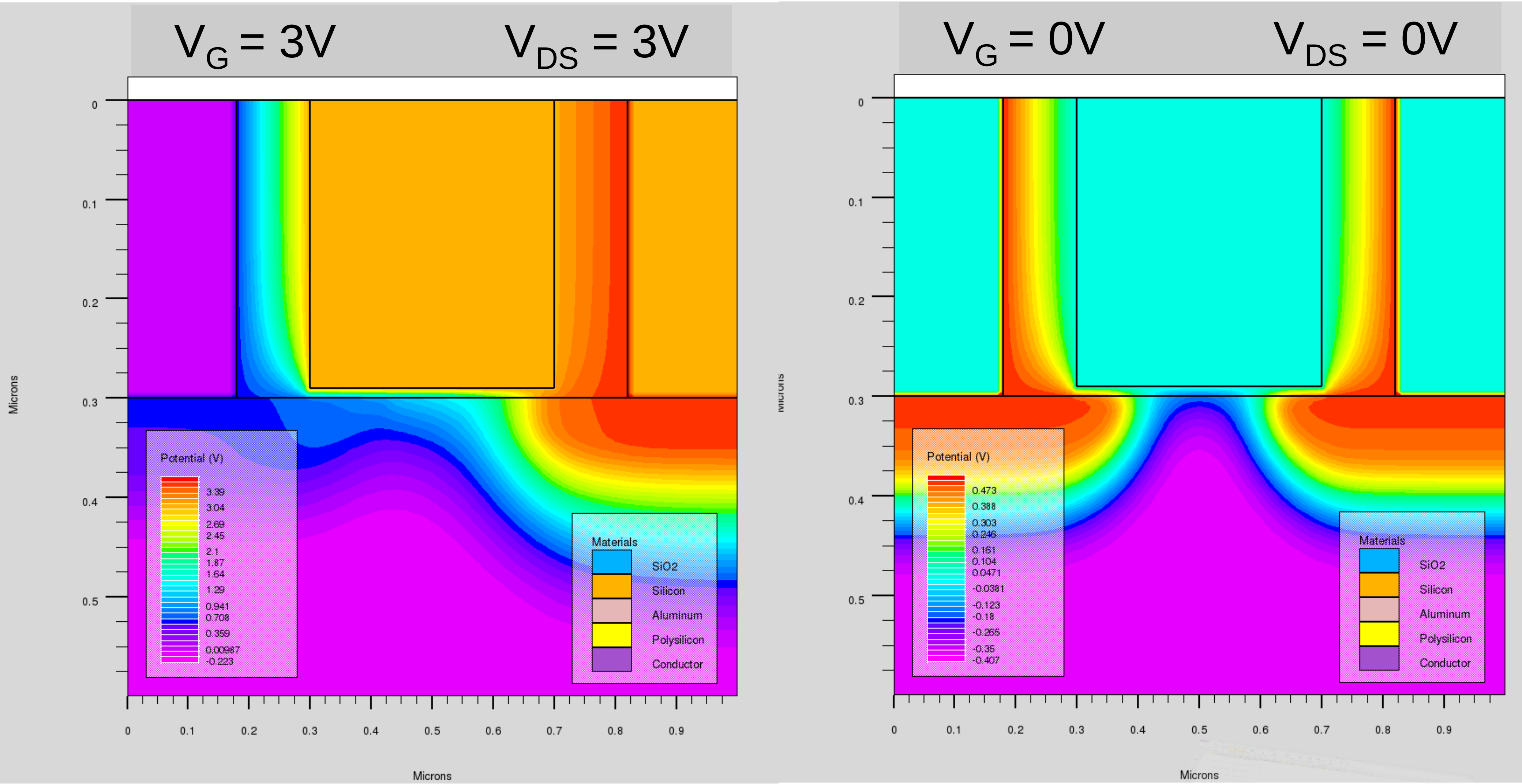
- Simulated band diagrams
- Barrier height reduced
- Compare to second Tutorial

2D Plots:

- Simulated doping profile
- Other 2D plots:
  - Doping
  - Acceptor / Donor concentrations
  - Currents
  - Quasi Fermi Levels
  - Conduction / Valance Bands
  - Electric field

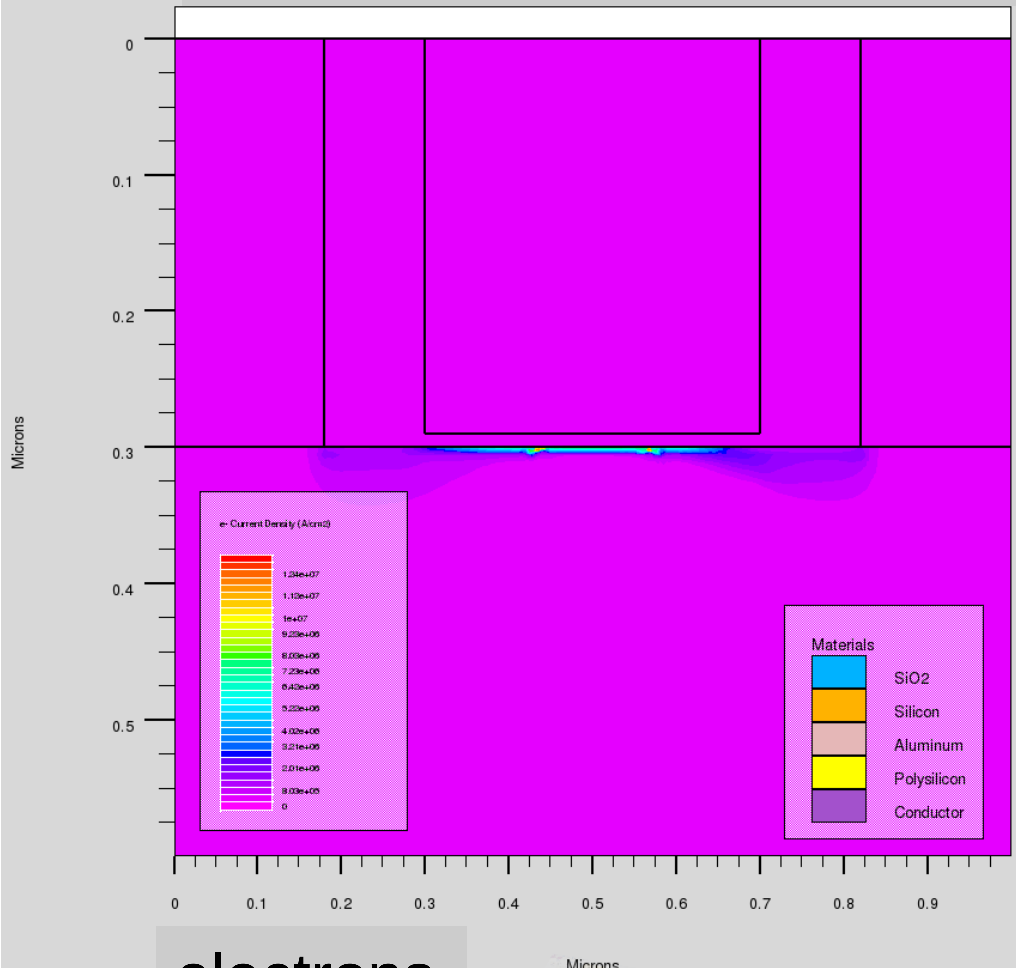


Device Simulation – 2D Plots Potential



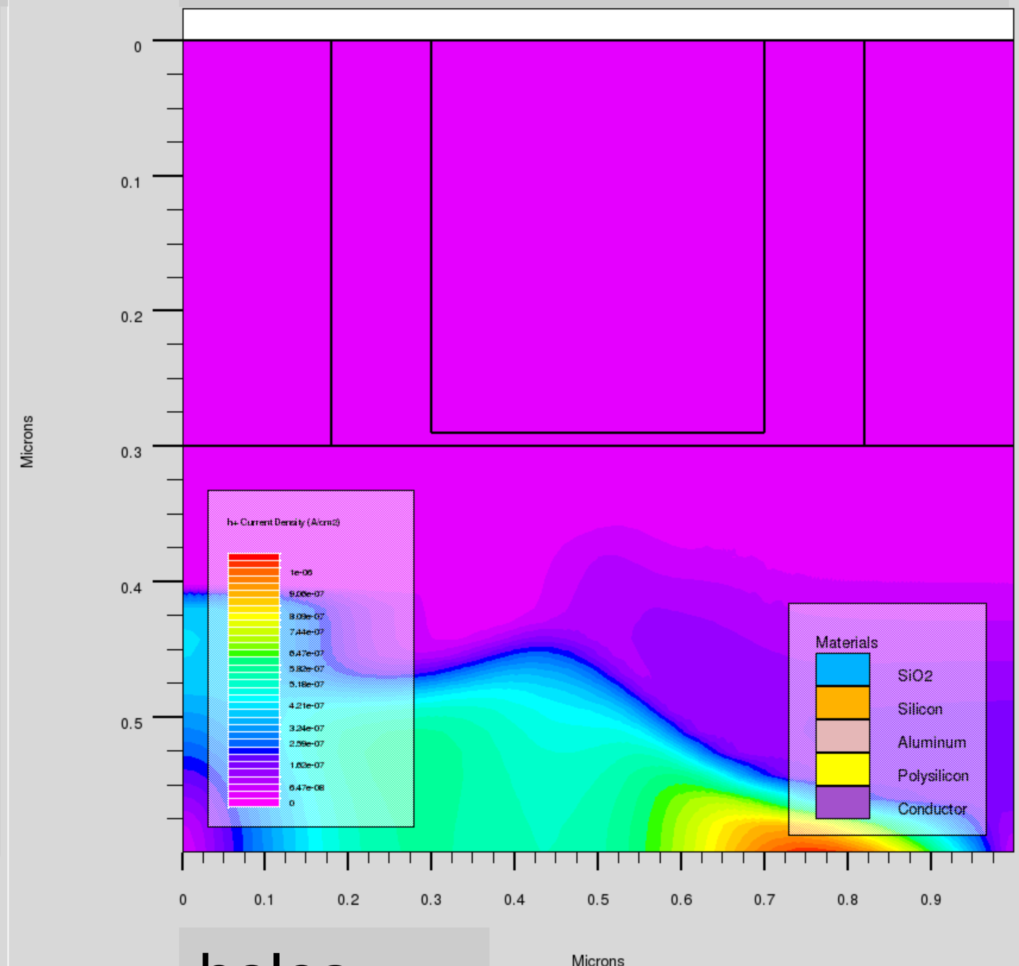
Device Simulation – 2D Plots Current Density

$V_G = 3V$ $V_{DS} = 3V$



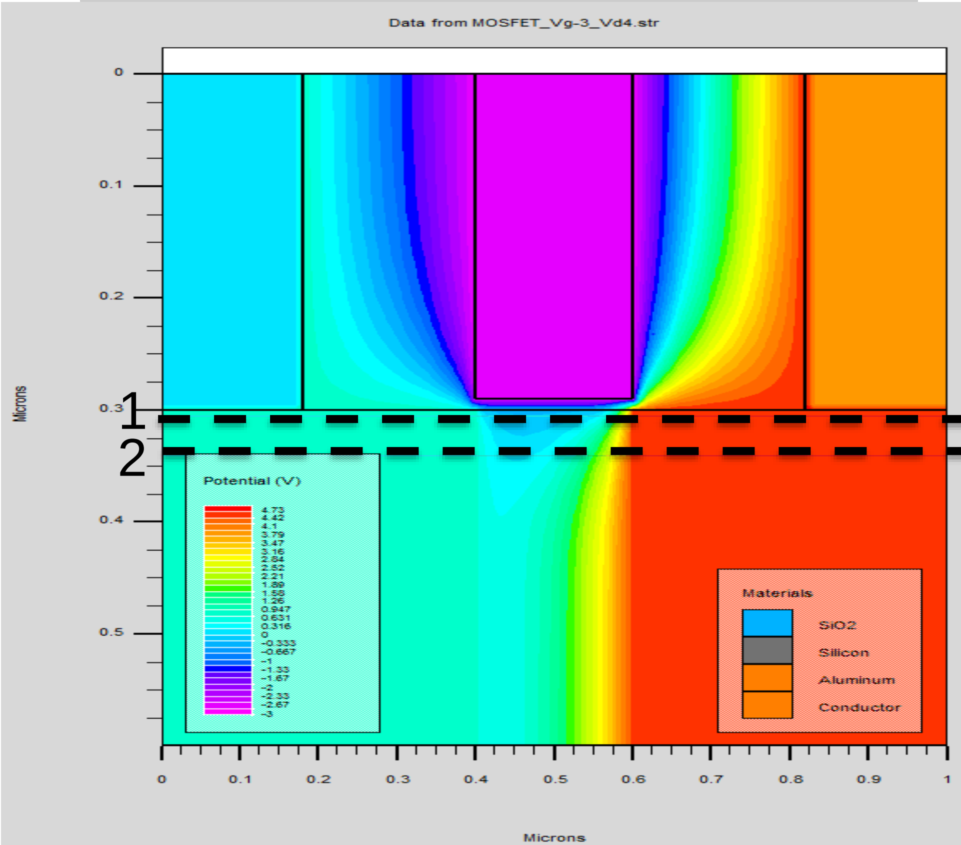
electrons

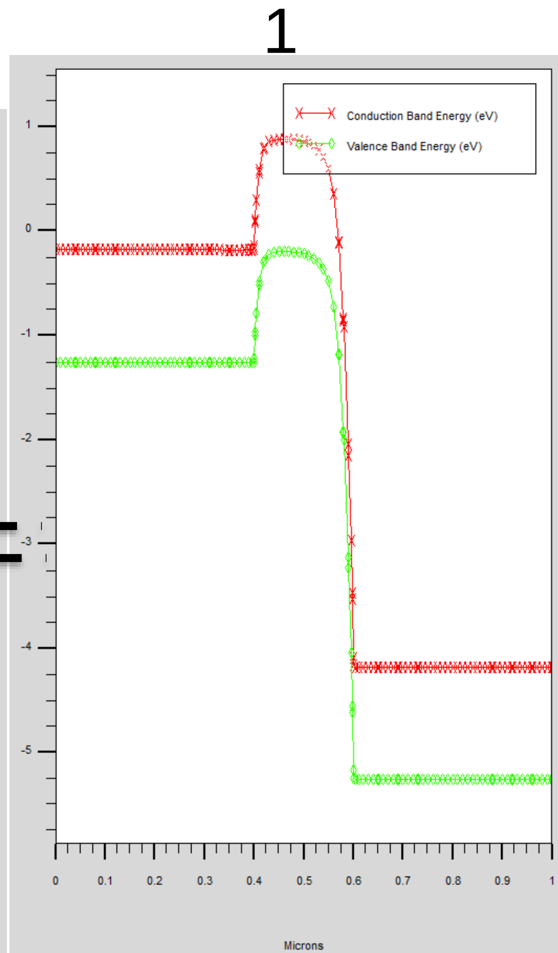
$V_G = 3V$ $V_{DS} = 3V$

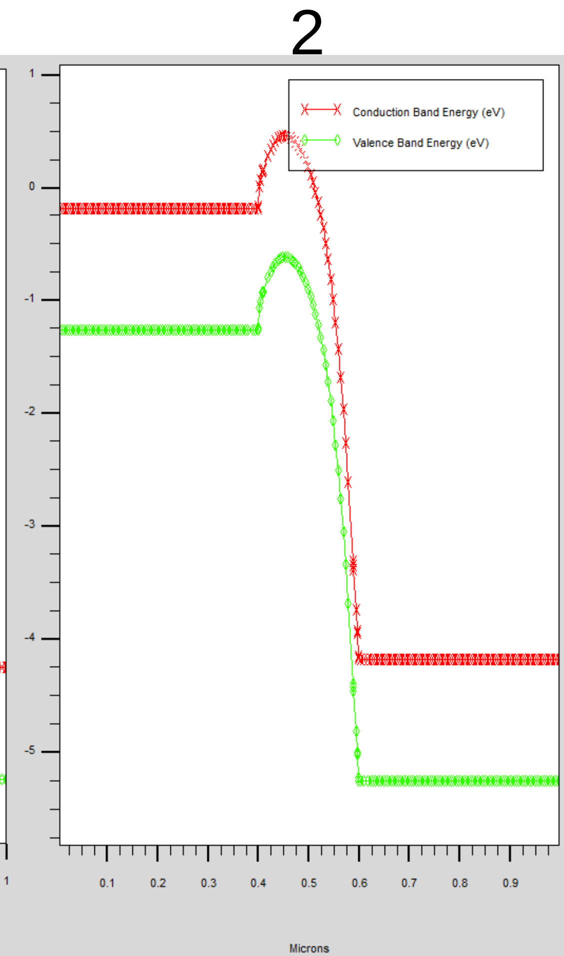


holes

$V_G = -3V$ $V_{DS} = 3V$







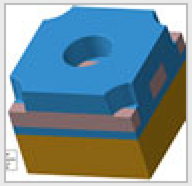
Transistor switched off

SILVACO ENGINEERED EXCELLENCE

TCAD http://www.silvaco.com/products/tcad/index.html

Victory Process

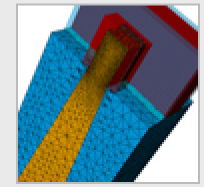
3D Process Simulator. Includes complete process flow core simulator and three advanced simulation modules: Monte Carlo Implant, Advanced Diffusion and Oxidation, and Physical Etch and Deposit.



More...

Victory Device

General-purpose 3D device simulator using a tetrahedral meshing engine for fast and accurate simulation of complex 3D geometries.



More...

- **Victory** is the process and device simulator in 3D
  - Simulates all processes e. g. implantation, oxidation, diffusion, etching etc.
  - Simulates electrical characteristics e. g. IV, CV of devices
  - Useful for FinFET calculations

- **Important:** Always choose the right models