

# NUMERICAL SIMULATION OF SEMICONDUCTOR DEVICES WITH TCAD SENTAURUS

**DESSIS**



**Integrated Systems Engineering**

Development, Modeling and Optimization of Microelectronic  
Processors, Devices, Circuits, and Systems

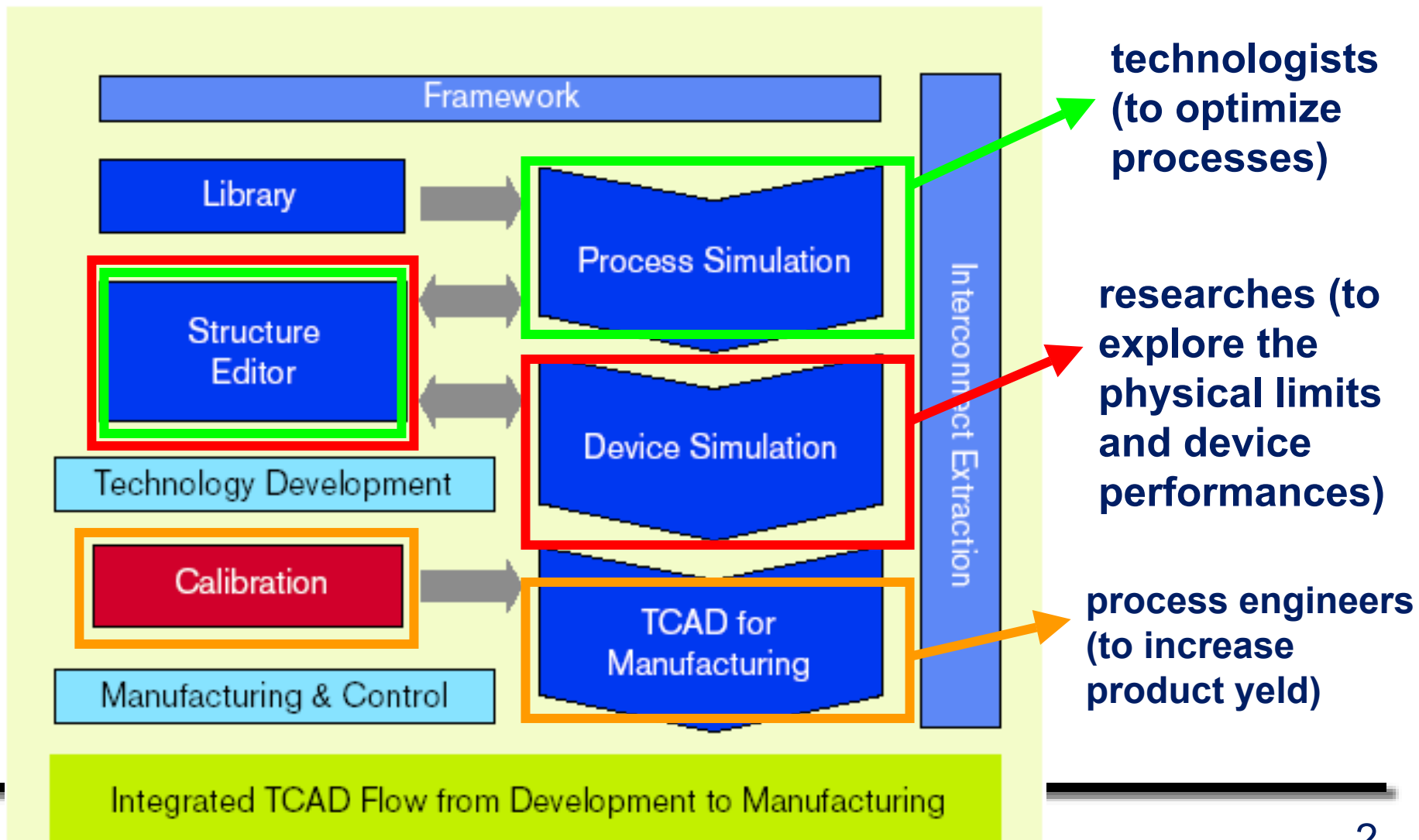
**TCAD Sentaurus**

**SYNOPSYS®**

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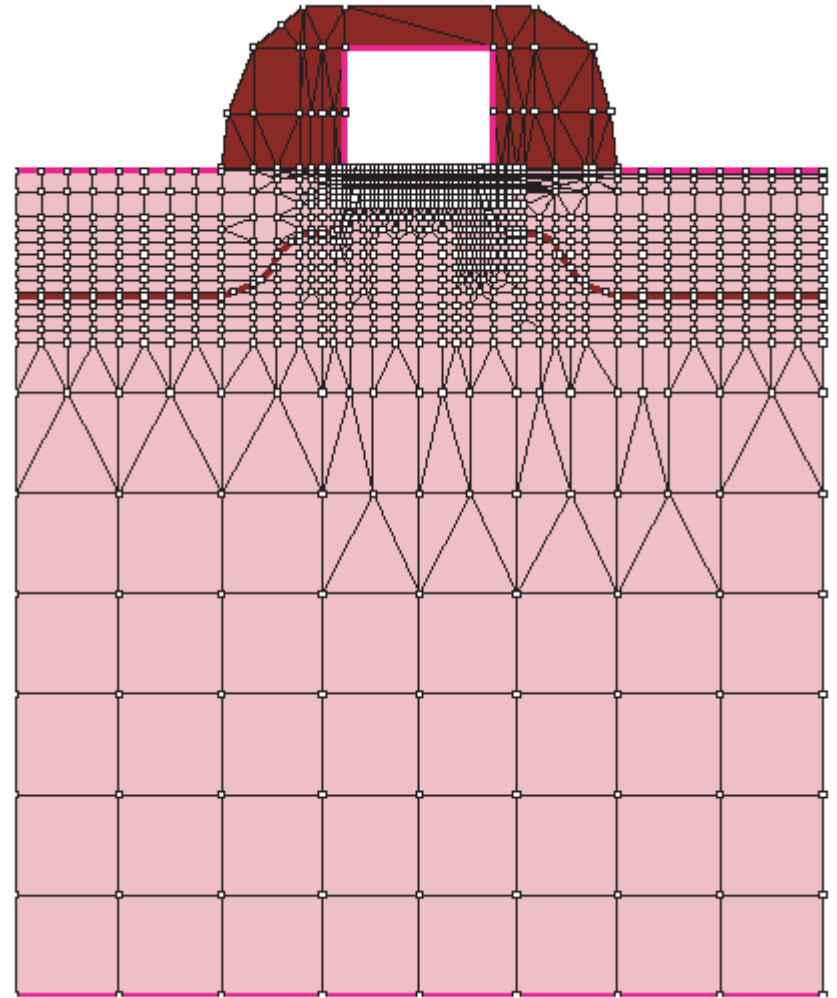
## What is TCAD?

Technology Computer Aided Design refers to using computer simulations to develop and optimize semiconductor processing technologies and devices.



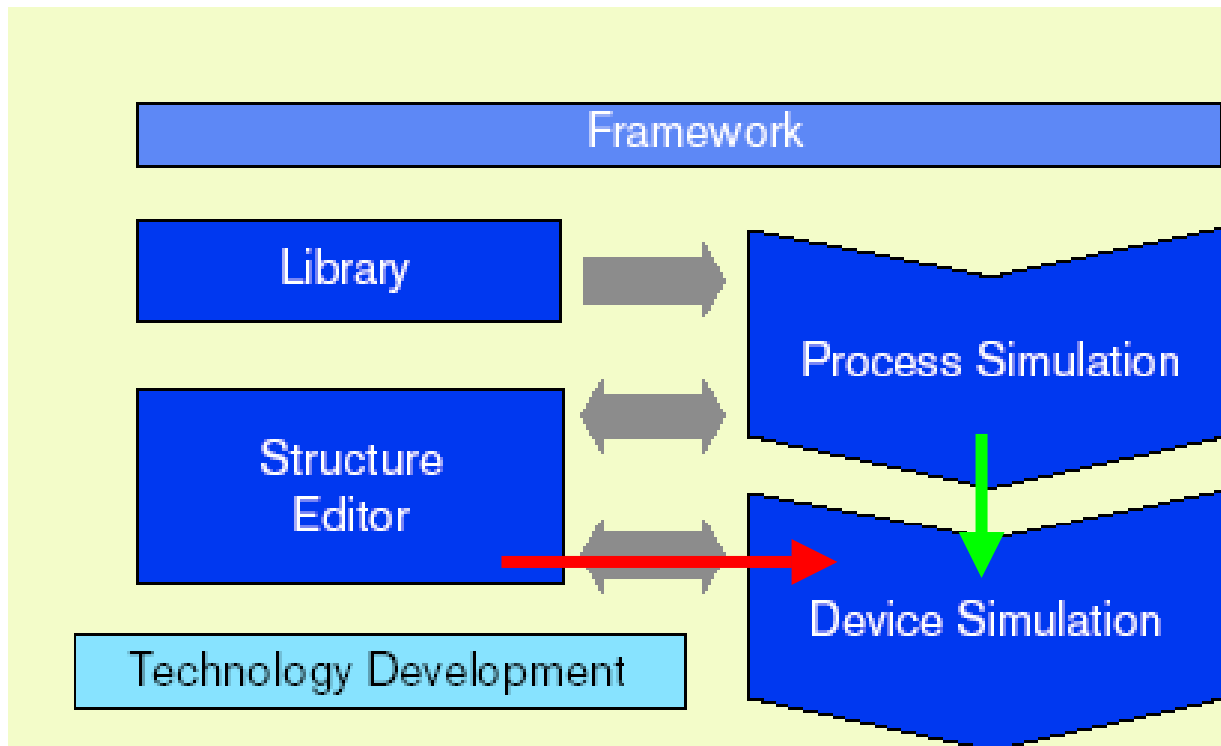
# Device Simulation

- Sentaurus simulates numerically the electrical behavior of a semiconductor device. It can be thought as a virtual measurement: terminal currents, voltages and charges are computed based on a set of physical device equations that describe the carrier distribution and the conduction mechanisms.
- The device is represented as a meshed finite element structure.

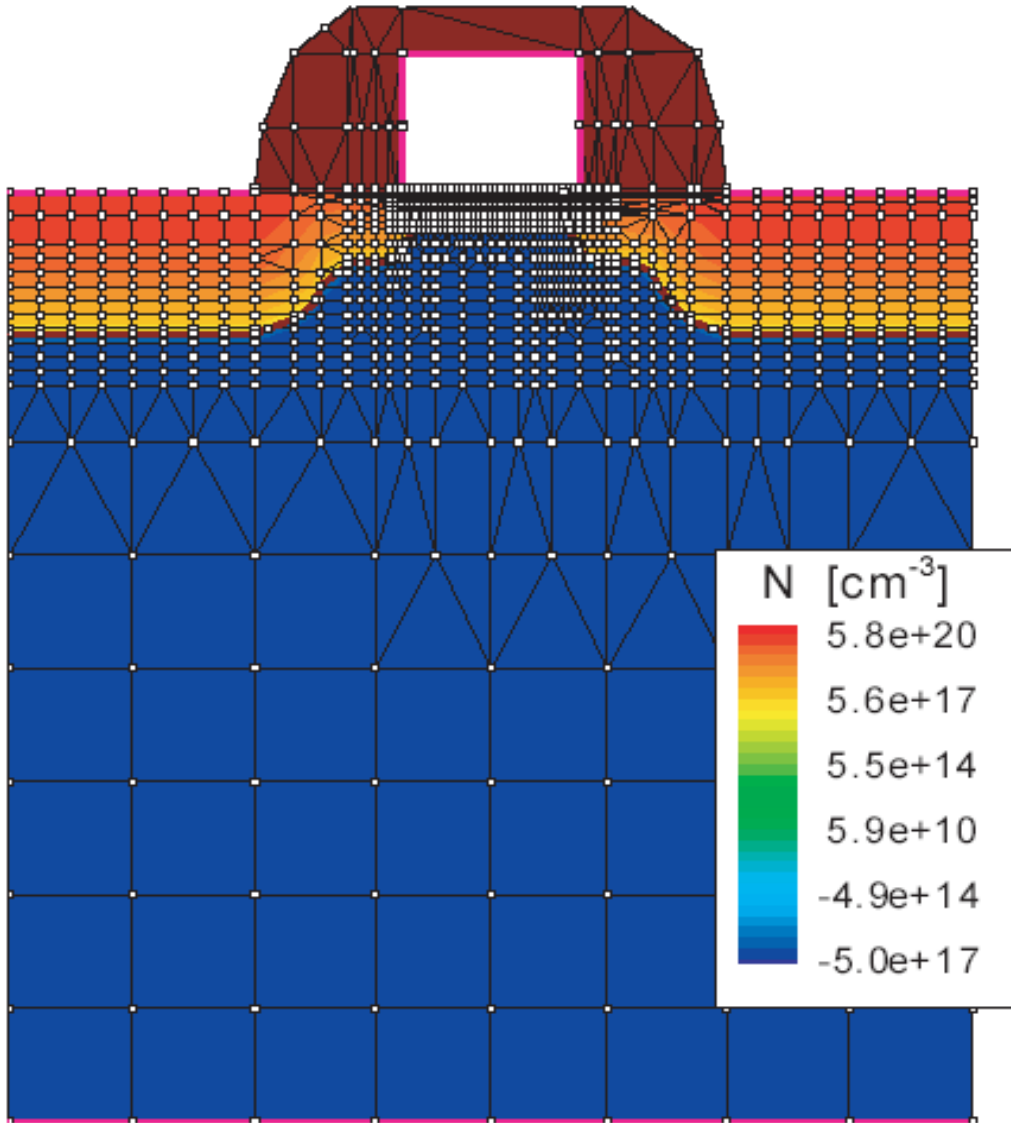


# Tool flow: from device creation and meshing to device simulation

## PHASE 1: device creation and meshing



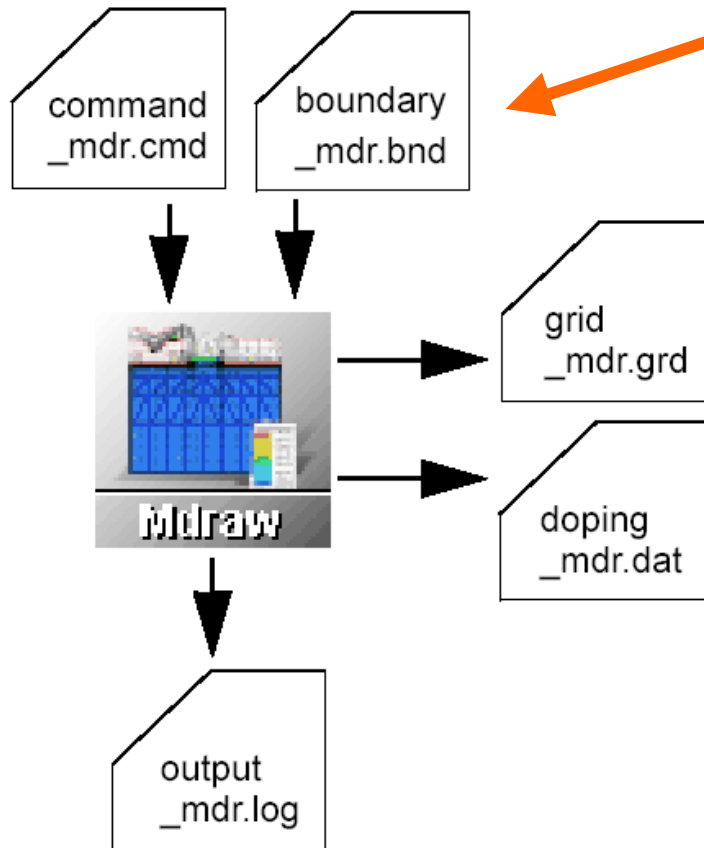
Device structures can be created by **process simulation** or by the **structure editor**.



Each device structure is described by two files:

- the **grid** (or geometry) file contains a description of the regions, boundaries, material types, location of the electrical contacts.
- the **data** (or doping) file contains the doping profiles.

## Creating and meshing device structures using the structure editor Mdraw:



- By using the graphical user interface
- By editing the command\_mdr.cmd and boundary\_mdr.bnd files

**the grid and doping files are generated by running the Mdraw mesher**

The **boundary\_mdr.cmd** file contains the definition of the regions, boundaries, material types, and location of the electrical contacts.

The **command\_mdr.bnd** file contains the definition of the doping masks, doping profile functions, and the meshing strategies.

For maximum efficiency of a simulation, a mesh must be created with a minimum number of vertices to achieve the required level of accuracy.

It is recommended that to create the most suitable mesh, the mesh must be densest in those regions of the device where the following are expected: high current density, high electric fields, high charge generation.

Generally, a total node count of 2000 to 4000 is reasonable for most 2D simulations.

## Example: 2D DIODE

### diode.bnd

```
Silicon { rectangle[ (40,0) (74,7.5)]}  
Contact "katode" { line[ (40,7.5) (74,7.5)] }  
Contact "anode" {line[ (43.25,0) (43.85,0)]  
line[ (44.65,0) (45.45,0)] line[ (46.05,0) (46.65,0)]  
line[ (68.45,0) (69.05,0)] line[ (69.85,0) (70.45,0)]  
line[ (71.25,0) (71.85,0)]}
```





# diode.cmd

```
Title "2D DIODE"
```

```
Profiles
```

```
{  
    constFunction "substrate"{  
        constValue = 1.0e+15  
        species = P  
        line = {(-150 0) (150 0)}  
        lateralFactor = 0  
        maxDistance = 8  
    }  
    gaussFunction "buried-up"{  
        species = P  
        line = {(84 7.5) (30 7.5)}  
        peakValAndJunc =  
        (peakvalue = 1.0e19 depth = 3.3  
        valueAtDepth = 1.0e+15)  
        lateralerf  
    }  
}
```

## diode.cmd

```
####  
### p-well  
####  
    gaussFunction "p-well"{  
        species = B  
        line = {(43 0) (72 0)}  
        peakValAndStdDev =  
            (peakvalue = 1.0e18 stddev = 0.3)  
        lateralerf  
    }  
    gaussFunction "contact"{  
        species = B  
        line = {(42.95 0) (47.65 0)}  
        line = {(67.45 0) (72.15 0)}  
        peakValAndStdDev =  
            (peakvalue = 2.0e20 stddev = 0.08)  
        lateralerf  
    }  
}
```

## diode.cmd

Refinement

```
{
  {top = -10
   left = -150
   bottom = 15
   right = 150
   MaxElementSize = 3
   MinElementSize = 2}
##### active area refinement
#buried layer
  {top = 0
   left = 30
   bottom = 13
   right = 84
   MaxElementWidth = 1
   MaxElementHeight = 0.5
   MinElementWidth = 0.8
   MinElementHeight = 0.1}
```

## diode.cmd

```
# P-well lateral
{top = 0
 left = 40
 bottom = 4
 right = 48
 MaxElementWidth = 0.5
 MaxElementHeight = 0.25
 MinElementWidth = 0.04
 MinElementHeight = 0.1}
{top = 0
 left = 67
 bottom = 4
 right = 74
 MaxElementWidth = 0.5
 MaxElementHeight = 0.25
 MinElementWidth = 0.04
 MinElementHeight = 0.1}
```

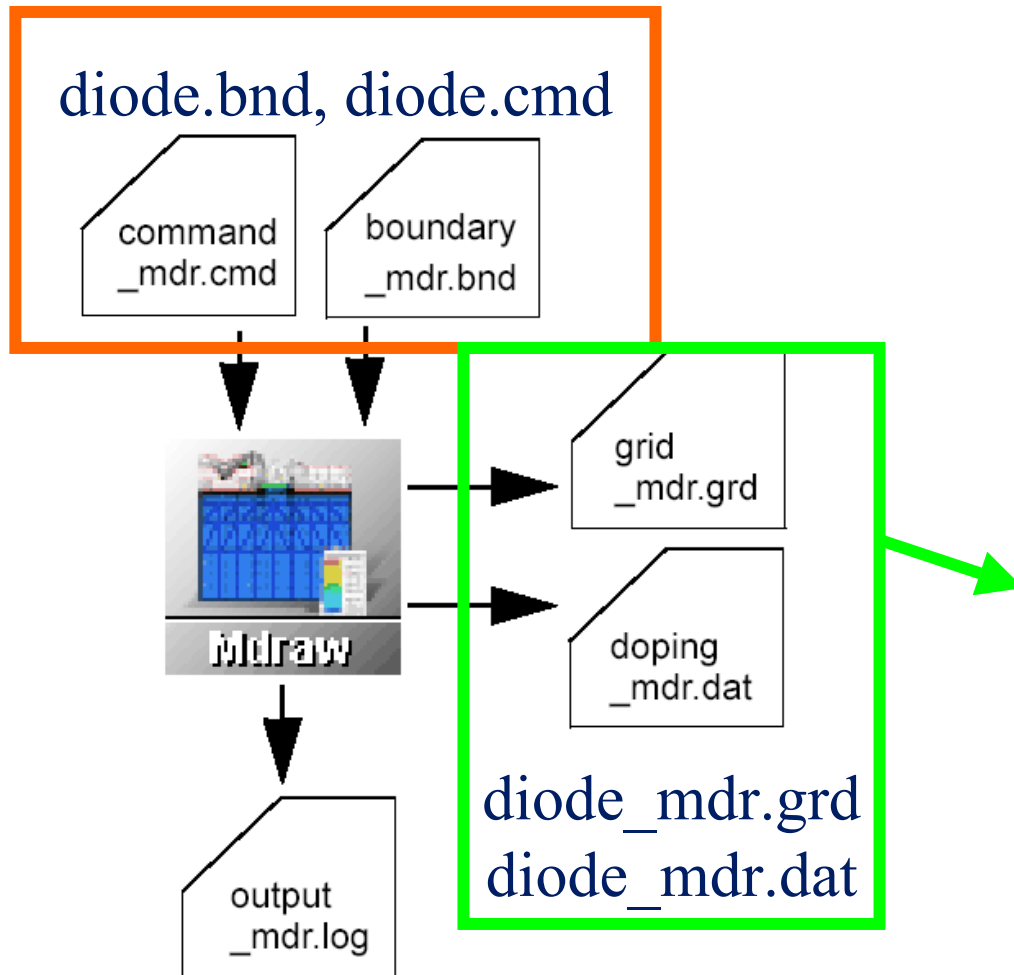
## diode.cmd

```
# p-well active region
{top = 0
  left = 40
  bottom = 4
  right = 74
  MaxElementWidth = 2
  MaxElementHeight = 0.25
  MinElementWidth = 0.2
  MinElementHeight = 0.1}

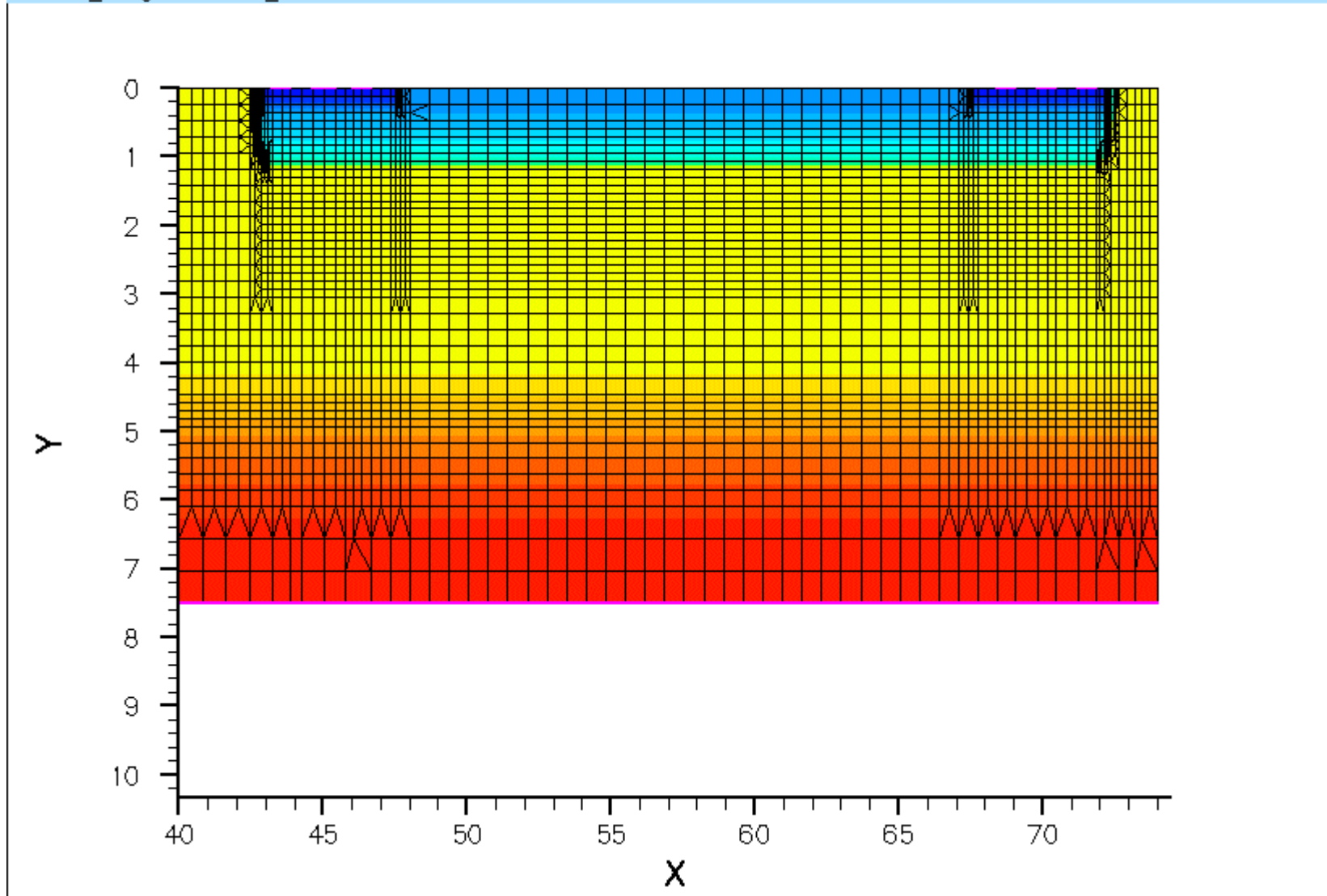
# p-n active region
{top = 0.8
  left = 43
  bottom = 3
  right = 72
  MaxElementHeight = 0.1
  MinElementHeight = 0.08}

}
```

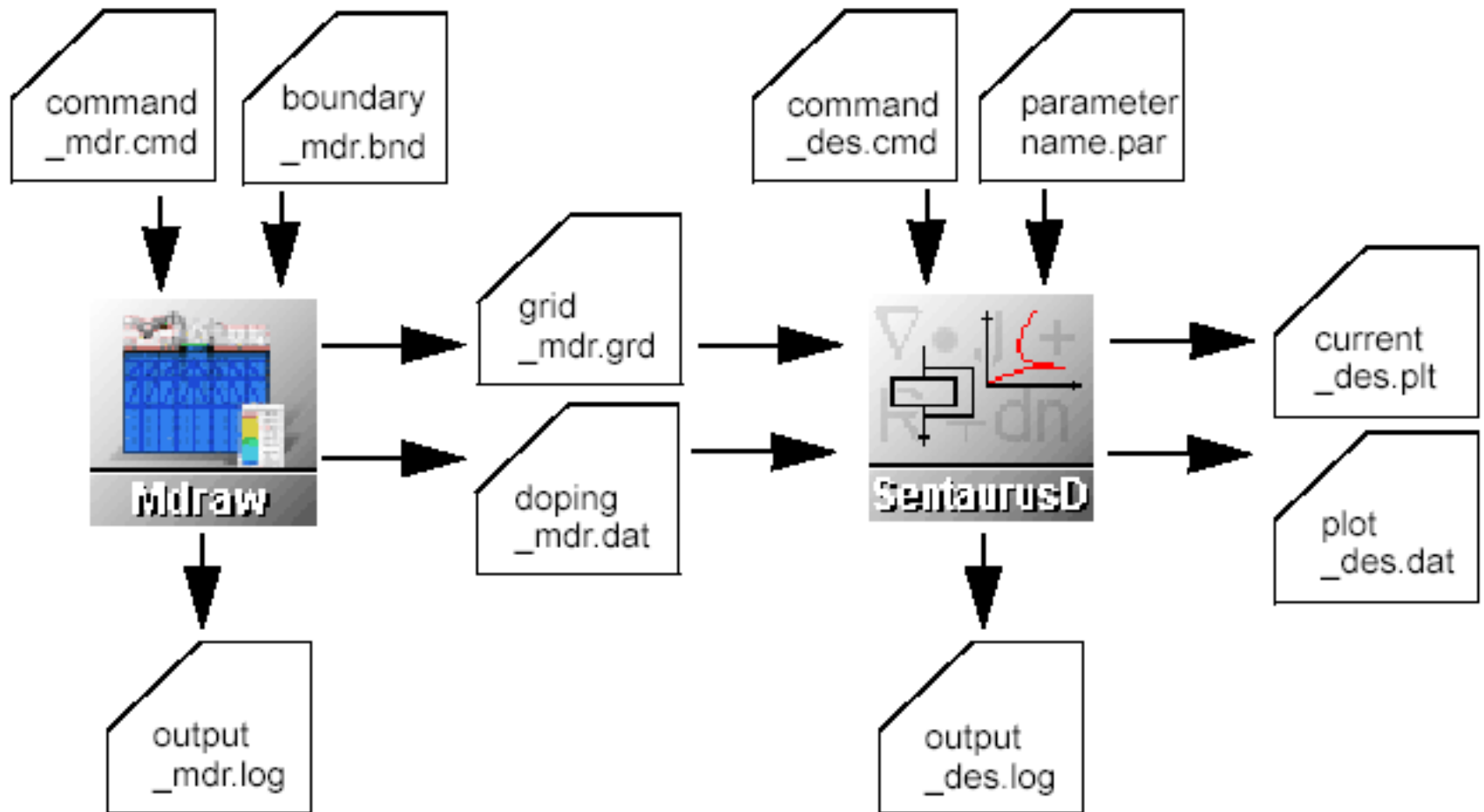
## Creating and meshing device structures using the structure editor Mdraw:



For visualizing the device structure and doping: **Tecplot** is a plotting software with extensive 2D and 3D capabilities. It is used to explore and analyze data, to create informative 2D and 3D views, to create plots and animations.

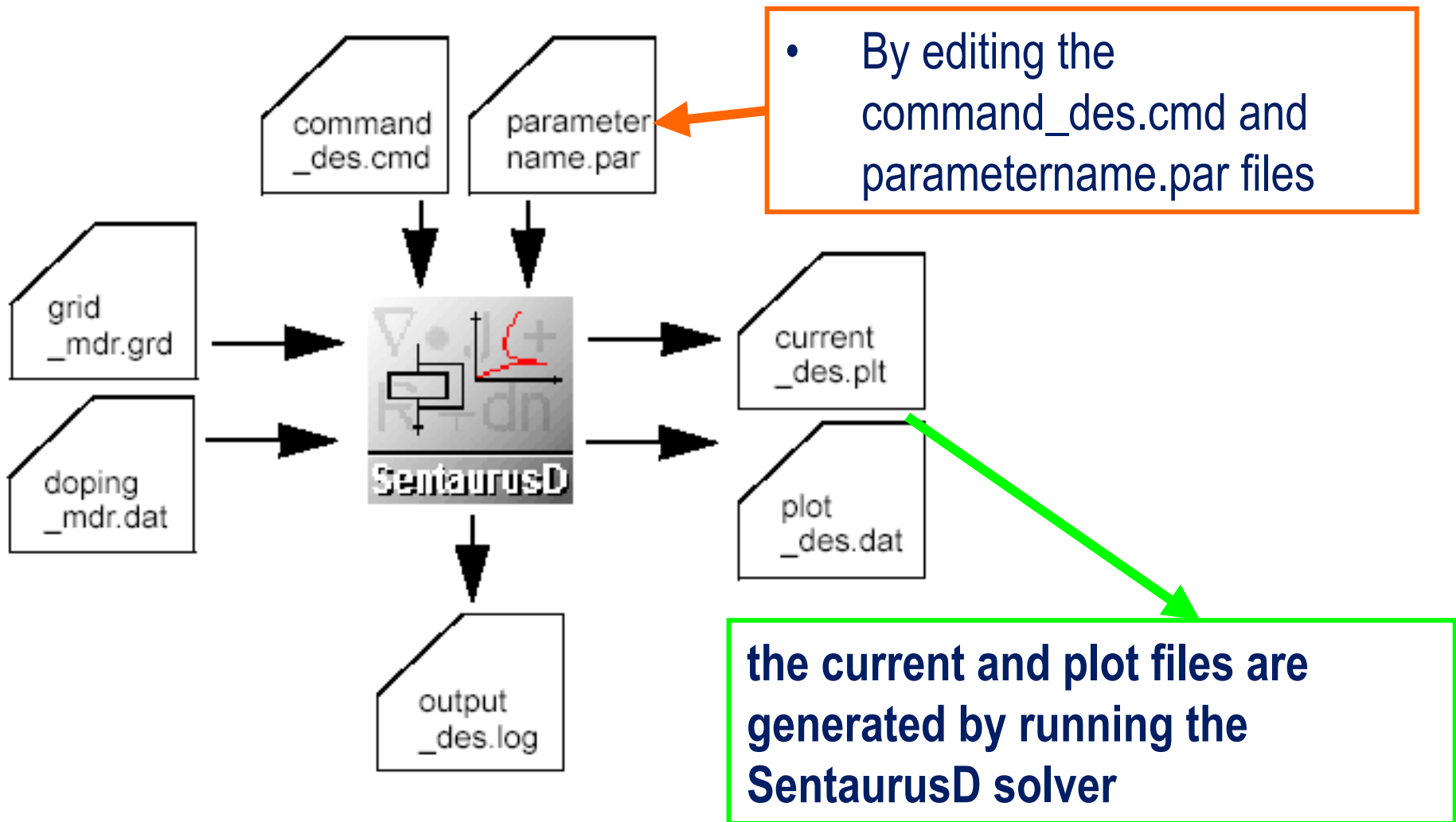


## PHASE 2: device simulation





## Simulation of the device using SentaurusD:



The **command\_des.cmd** file is organized in command or statement sections. It contains commands for input/output files, electrodes, physics, plots, math, equations to be solved.

The **parametername.par** file contains user-defined values for model parameters (coefficients). The parameters in this file replace the default values.

### Features:

different device geometries: 1D, 2D, 3D, and 2D cylindrical

different equations to be solved: Poisson, drift-diffusion, thermodynamic and hydrodynamic models

an extensive set of models for device physics and effects in smc

mixed-mode support of netlists with mesh-based devices and SPICE circuit models.

## simulation.cmd

```
Electrode {{name="anode"    voltage=0.0}  
            {name="katode"   voltage=0.0 resistance=1e4}}}
```

```
File {grid="diode_mdr.grd"  
       doping="diode_mdr.dat"  
       current="output"  
       output="output"  
       plot="output"  
#       save="output"  
#       Param="parameters.par"  
       }
```

## simulation.cmd

```
physics {EffectiveIntrinsicDensity(Slotboom)
    Recombination( SRH(DopingDependence)
        auger(withGeneration)
        Avalanche(Lackner)
    )
    Mobility( DopingDependence
        HighFieldSaturation
    )
    Temperature=300
}

Math {
    Extrapolate *Used for the quasistationary solution.
    Derivatives *Turns on Mobility analyt. derivatives.
    AvalDerivatives *Turns on Avalanche analyt. deriv.

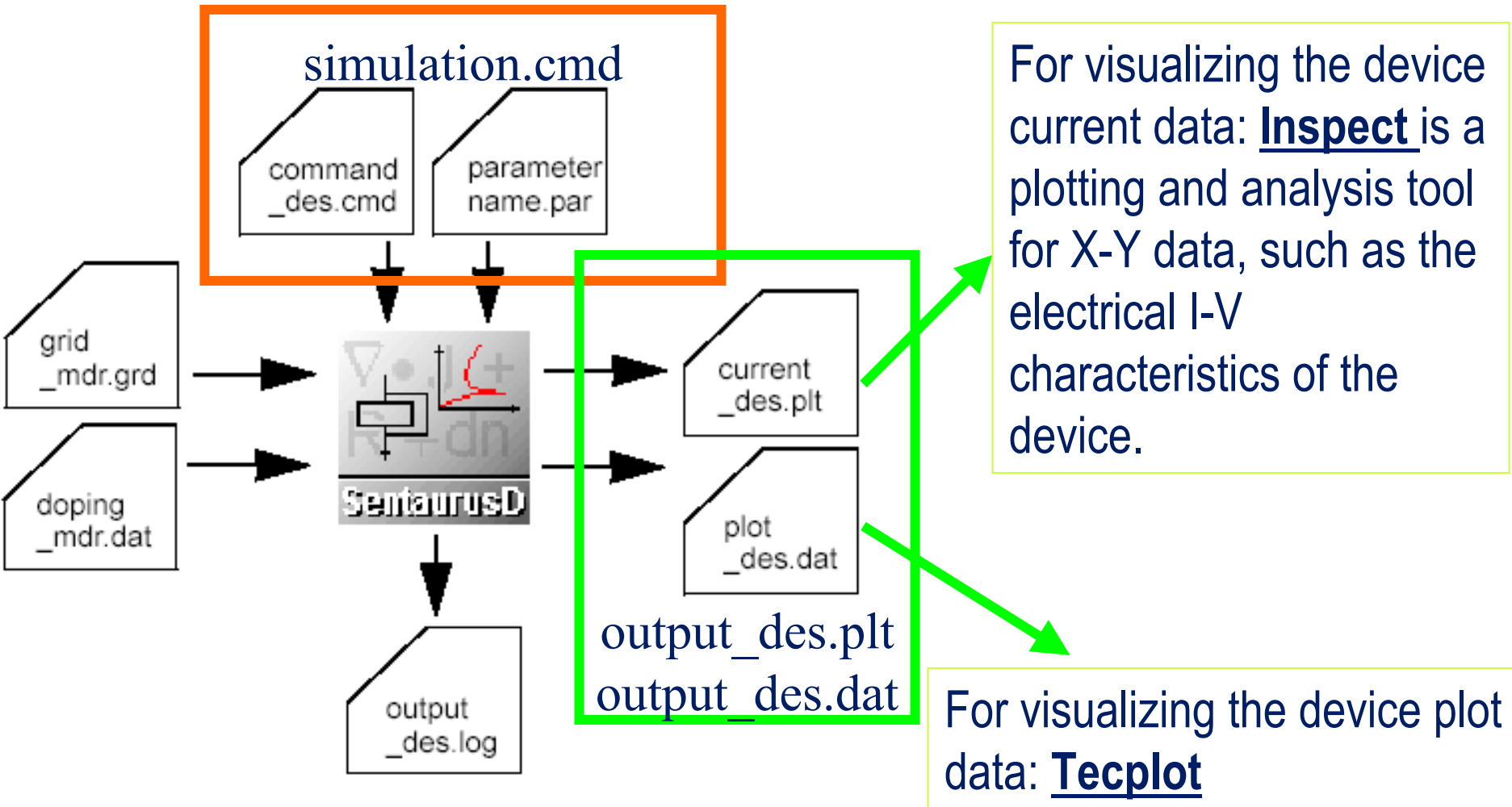
    Iterations=100
        *Max. number of steps without solution.
}
```

## simulation.cmd

```
Plot { eDensity hDensity
        ElectricField/Vector
        ElectricField
        Potential
        Doping
        SpaceCharge
        AvalancheGeneration
        DonorConcentration AcceptorConcentration
        SRH Auger Avalanche
    }

Solve {
    Poisson
    QuasiStationary
    (InitialStep=0.001 Maxstep=0.1 Minstep=1e-10
      Goal {name=katode voltage=70.0}
      Plot { range=(0 1) intervals=2 }
    )
    { coupled (iterations=5) { Poisson electron hole}}
}
```

## Simulation of the device using SentaurusD:



# PHASE 3: output analysis

## Visualization of the output data: I-V curves with INSPECT

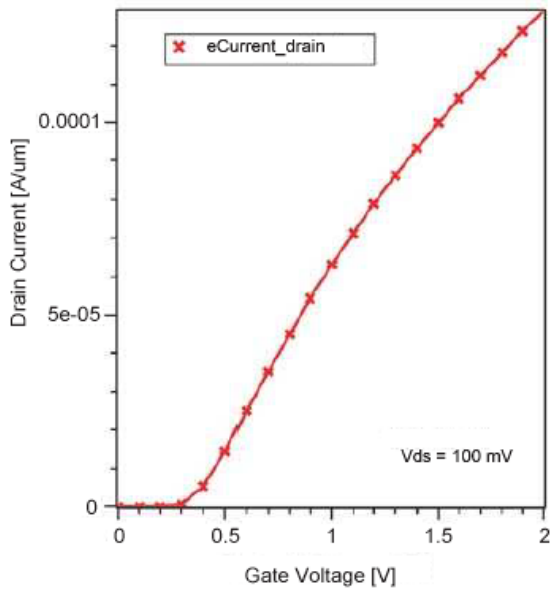


Figure 5 Id-Vgs characteristic of 0.18 μm n-channel MOSFET

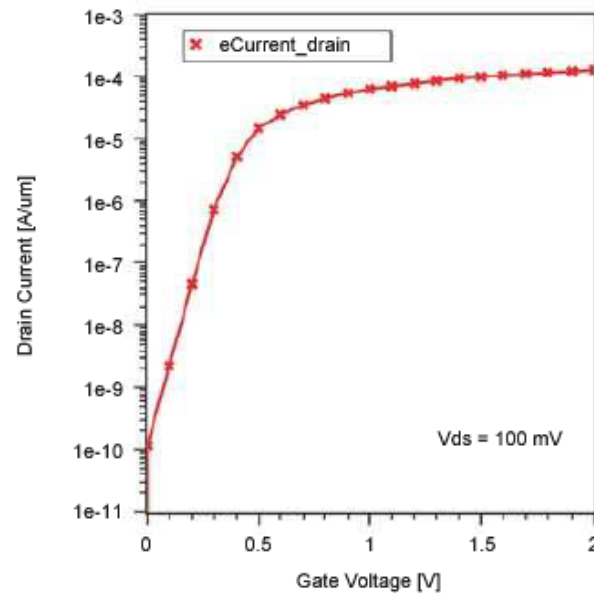


Figure 6 Id-Vgs characteristic of 0.18 μm n-channel MOSFET replotted on semi-log scale

# PHASE 3: output analysis

## Visualization of the output data: 2D output data with TECPLOT

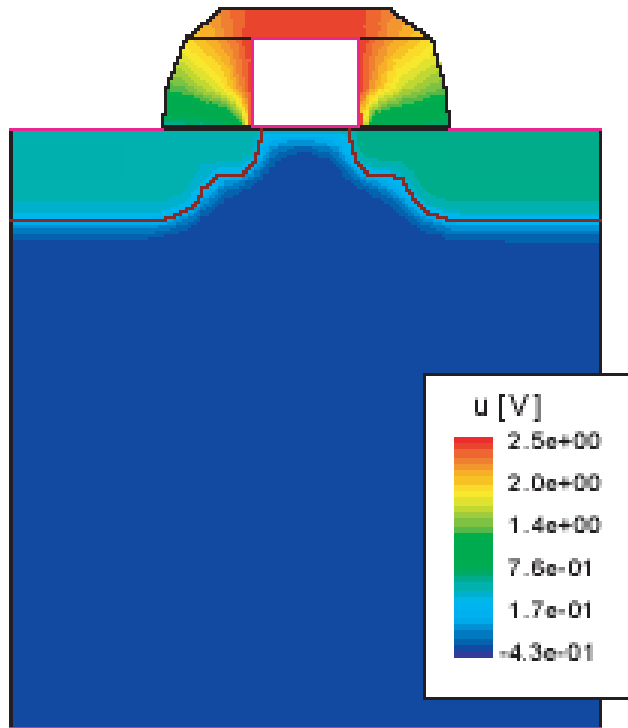


Figure 7 Default display of electrostatic potential and junctions



# PHASE 3: output analysis

## Visualization of the output data: 2D output data with TECPLOT

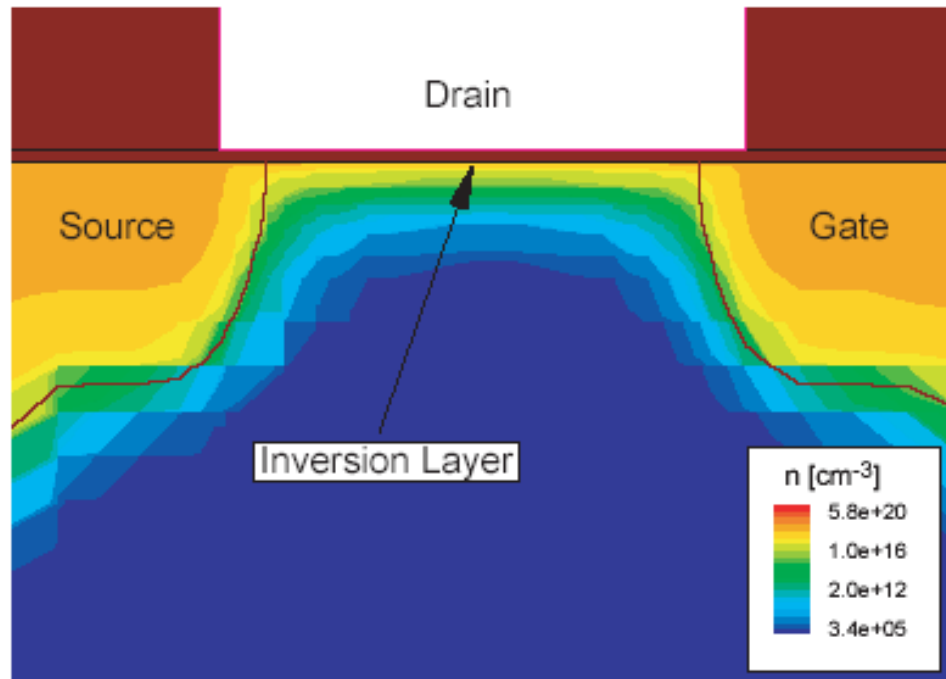


Figure 8 Magnification of channel region showing contours of electron concentration

# PHASE 3: output analysis

## Visualization of the output data: 2D output data with TECPLOT

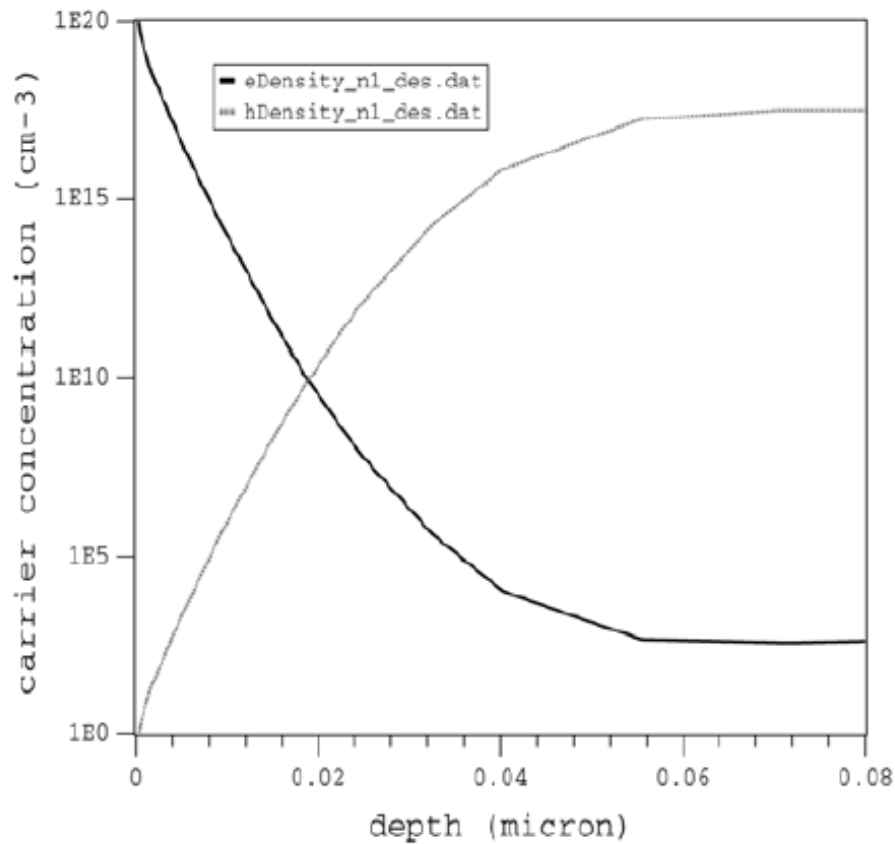


Figure 9 Vertical electron and hole profiles at center of channel

# Flow diagram

