TCAD for electronic devices part 2

Microelectronics devices, sensors and MEMS

Academic Year 2023/2024

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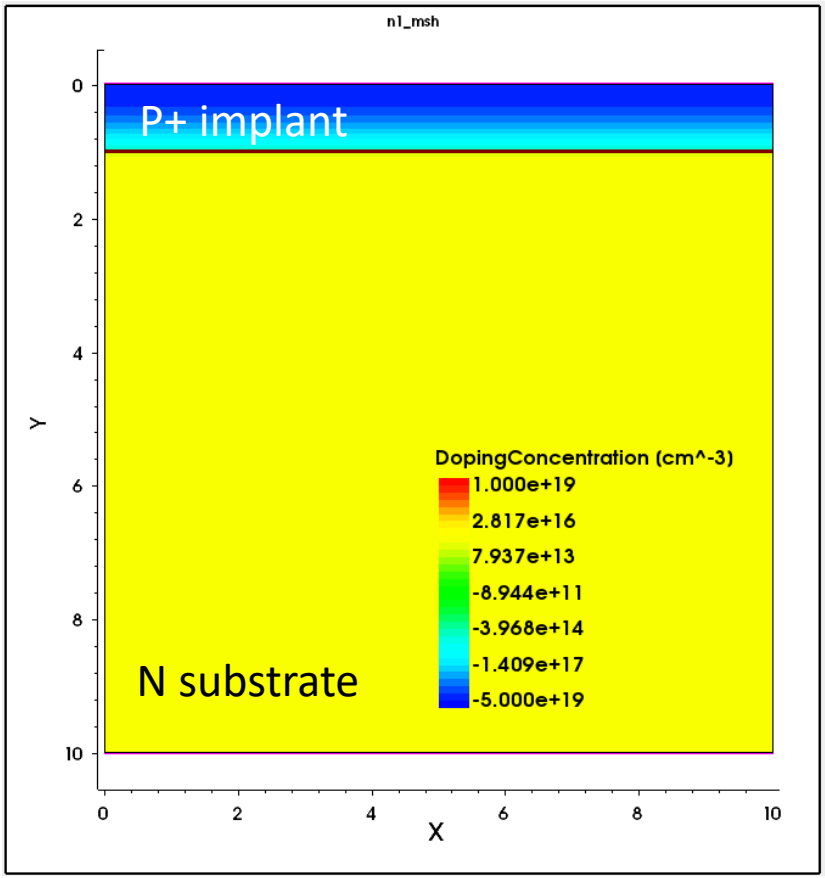
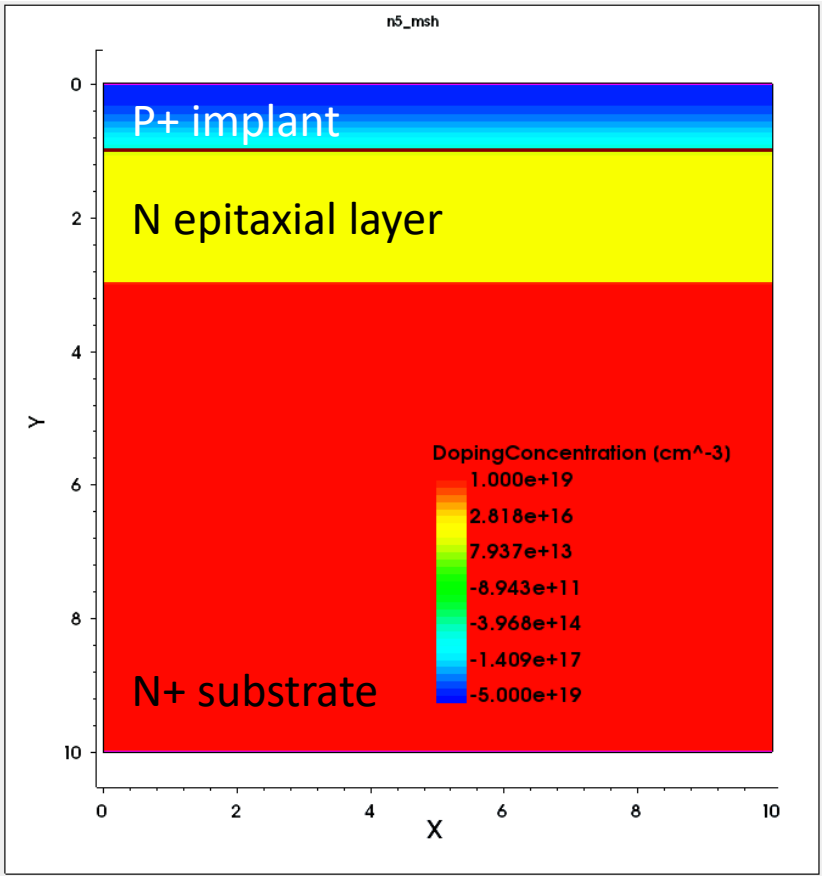
P-N junction – 1D simulation domains

Structure 2a

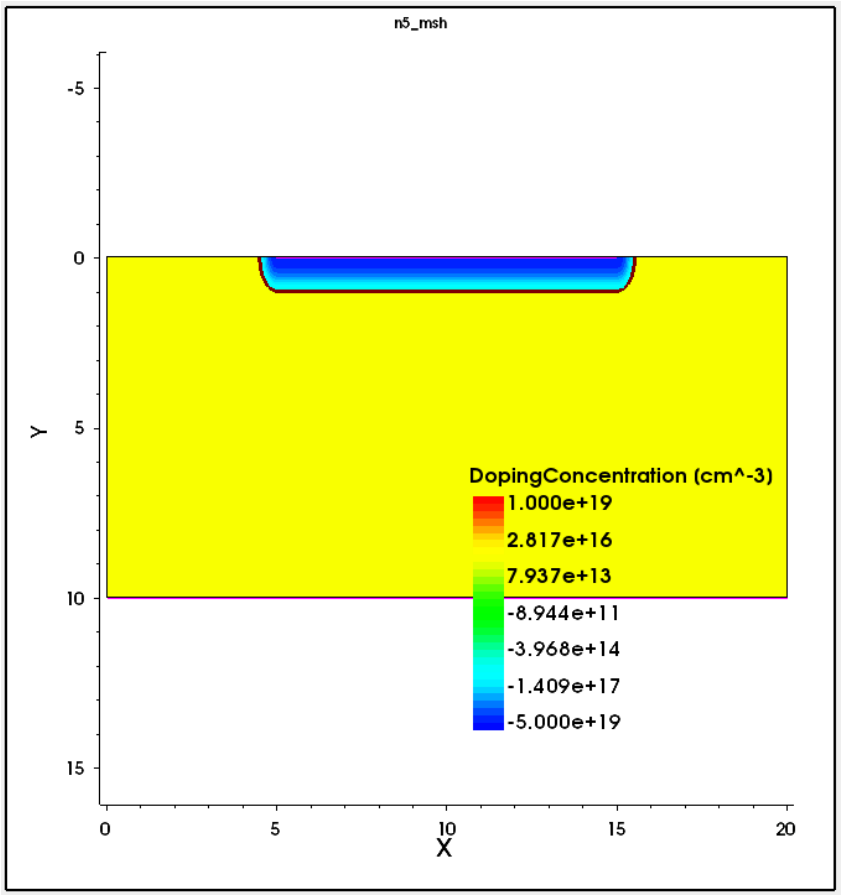


Structure 2b

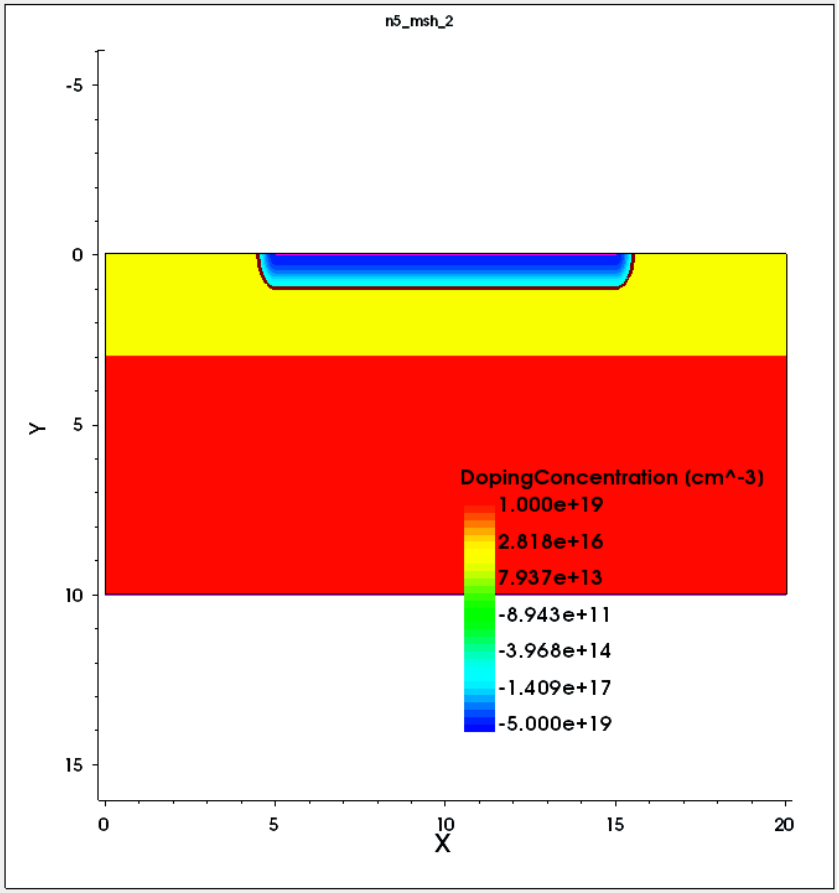


P-N junction – 2D simulation domains

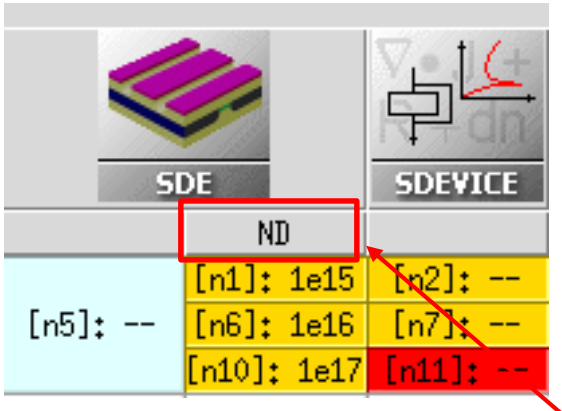
Structure 2c



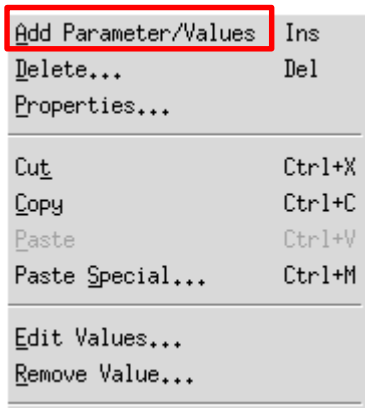
Structure 2d



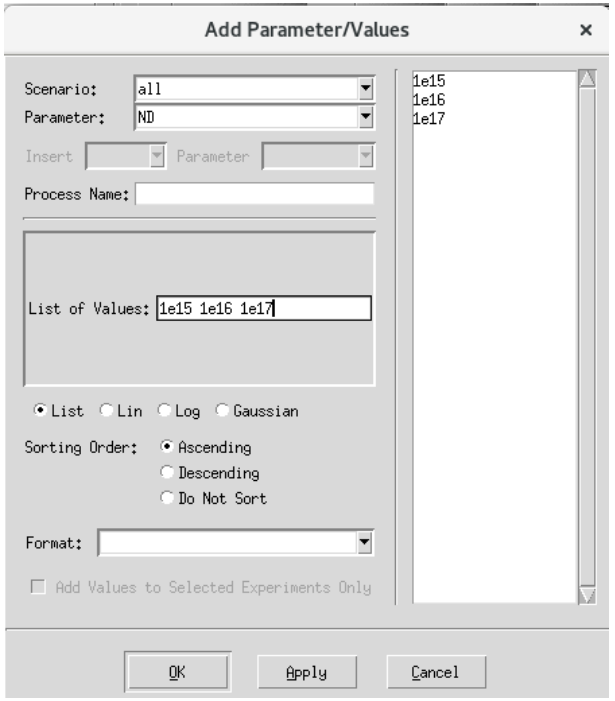
Structure 2a: simulation setup



Right-click in gray area below the SDE tool



Dialog box



Parameter: substrate doping concentration ND

```
;; Defines the doping profiles

(sedr:define-constant-profile "substrate" "PhosphorusActiveConcentration" @ND@)
(sedr:define-constant-profile-material "substrate" "substrate" "Silicon")

(sedr:define-gaussian-profile "Ptop_prof" "BoronActiveConcentration" "PeakPos" 0  "PeakVal"
5e19 "ValueAtDepth" 1e15 "Depth" 1 "Gauss" "Factor" 0.5)
(sedr:define-refinement-window "Ptop_refwin" "Line"  (position 0 0 0)  (position 10 0 0) )
(sedr:define-analytical-profile-placement "Ptop_plac" "Ptop_prof" "Ptop_refwin" "Positive"
"NoReplace" "Eval")
```

IV curves in reverse bias

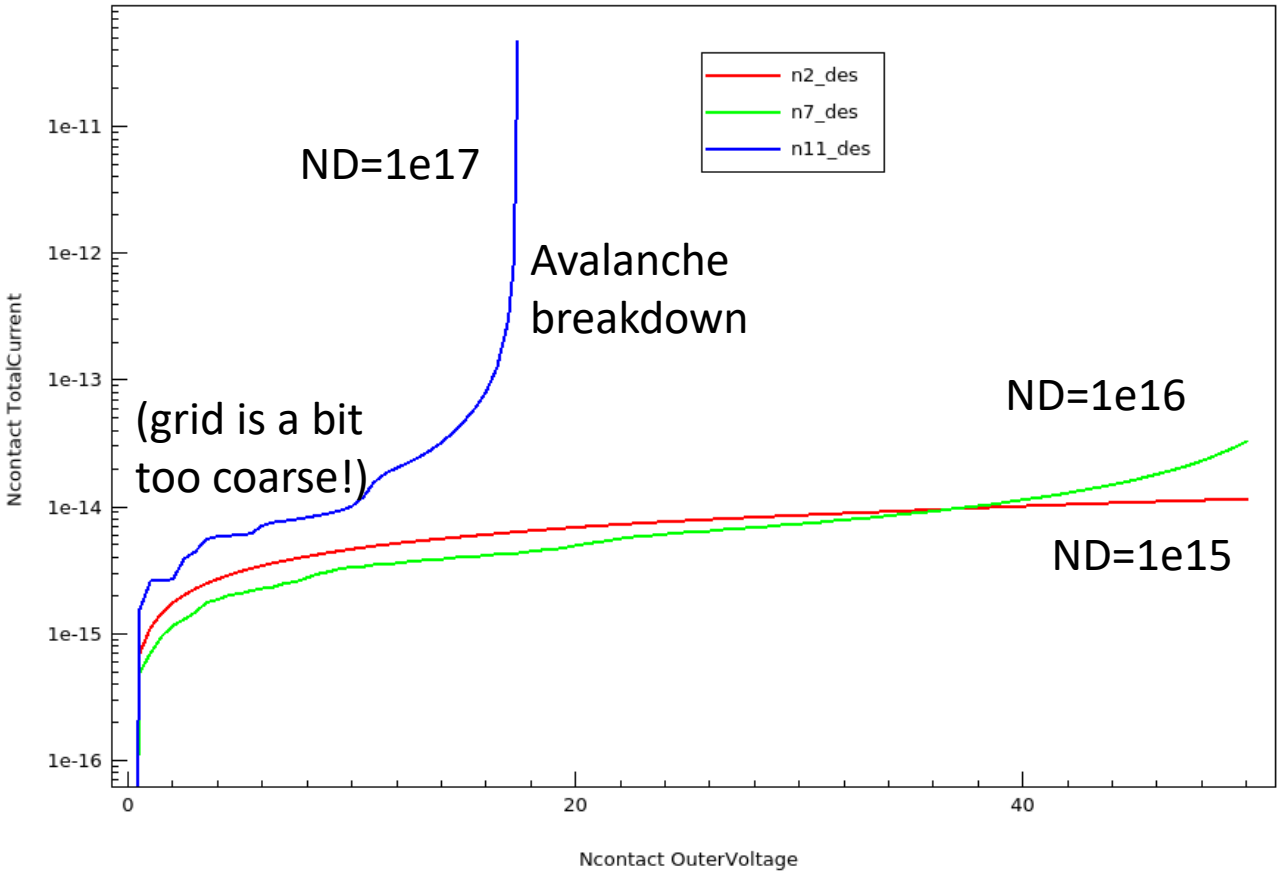
```
Physics{
        Temperature = 300
        Recombination(SRH( DopingDep ) Avalanche)
}
```

Turns on avalanche multiplication
By impact ionization

```
Solve {
        Poisson
        Coupled{ Poisson Electron Hole }
        Quasistationary(
                InitialStep=0.01 MinStep=1e-6 MaxStep=0.01
                Goal{ Name="Ncontact" Voltage=50 }
                Plot { Range = (0 1) Intervals =5}
        ) { Coupled { Poisson Electron Hole} }
}
```

Target voltage

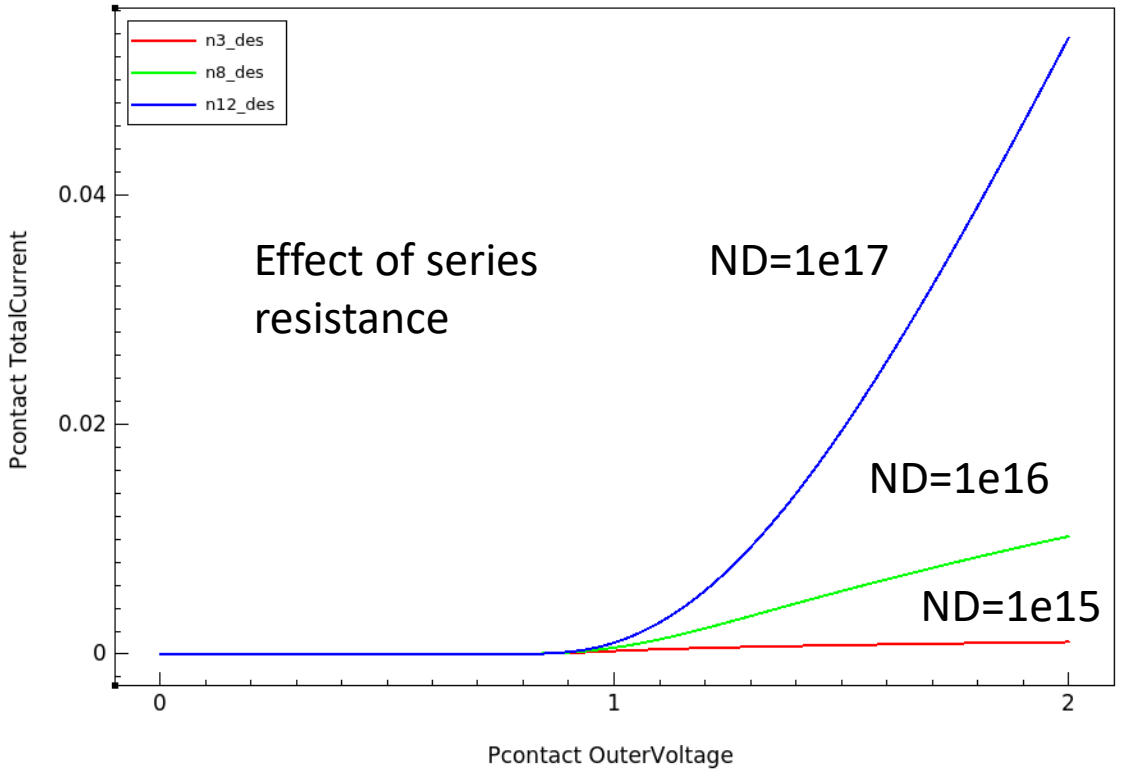
IV curves in reverse bias



IV curves in forward bias

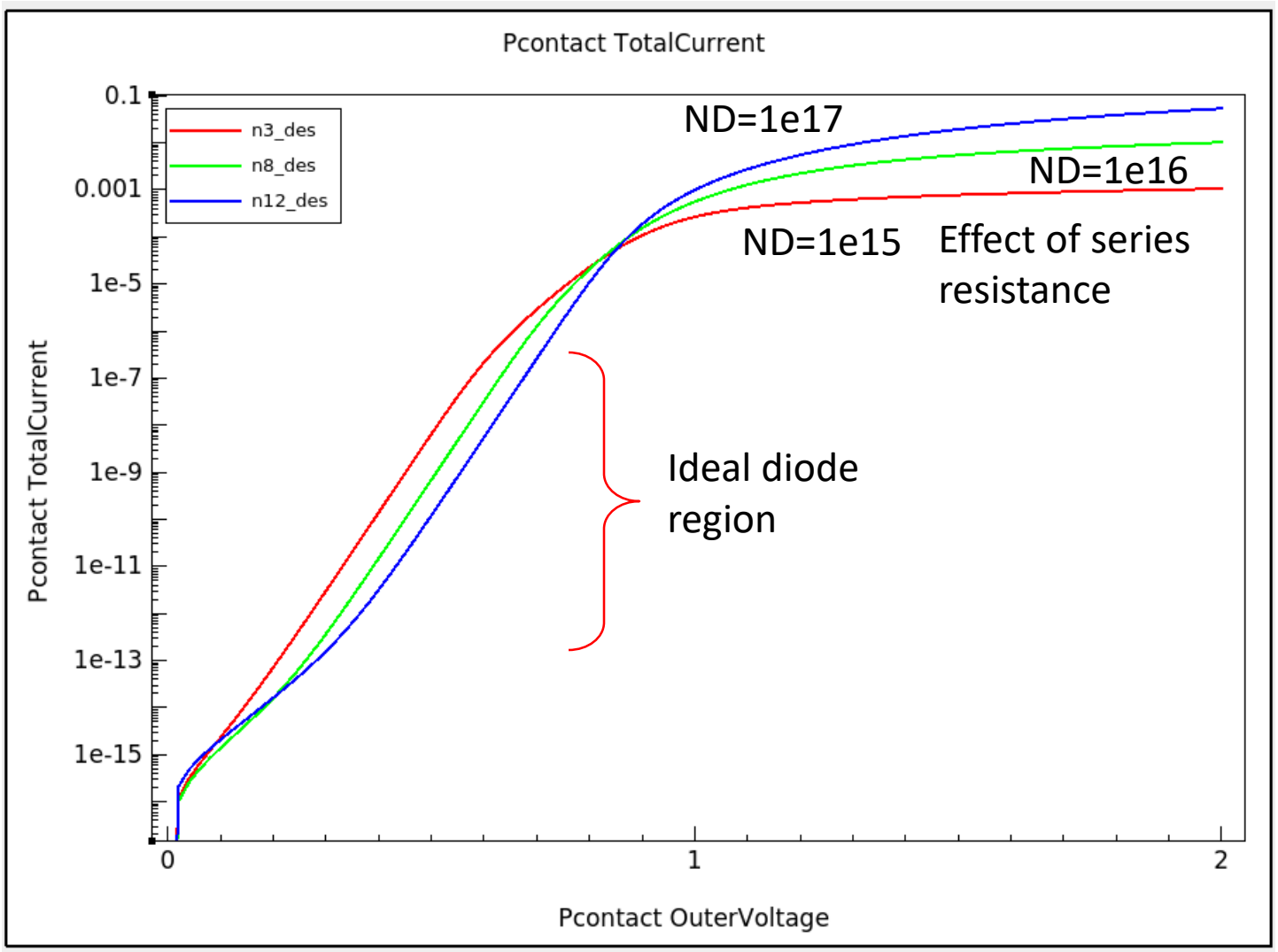
```
Solve {
        Poisson
        Coupled{ Poisson Electron Hole }
        Quasistationary(
                InitialStep=0.01 MinStep=1e-6 MaxStep=0.01
                Goal{ Name="Pcontact" Voltage=2 }
                Plot { Range = (0 1) Intervals =5}
        ) { Coupled { Poisson Electron Hole} }
}
```

Target voltage



IV curves in forward bias

Log-lin graph



Capacitance-Voltage (CV) curves

Device block

```
Device DIODE {


Electrode {
        { Name="Ncontact" Voltage=0}
        { Name="Pcontact" Voltage=0}
}


File    {
        grid    = "@tdr@"
        current = "@plot@"
        plot    = "@tdrdat@"
}


Physics{
        Temperature = 300
        Recombination(SRH( DopingDep ) )
}


Plot    {
        eDensity hDensity
        TotalCurrent/Vector eCurrent/Vector
        hCurrent/Vector
        ElectricField/Vector Potential
        SpaceCharge
        Doping
}


} # device
```

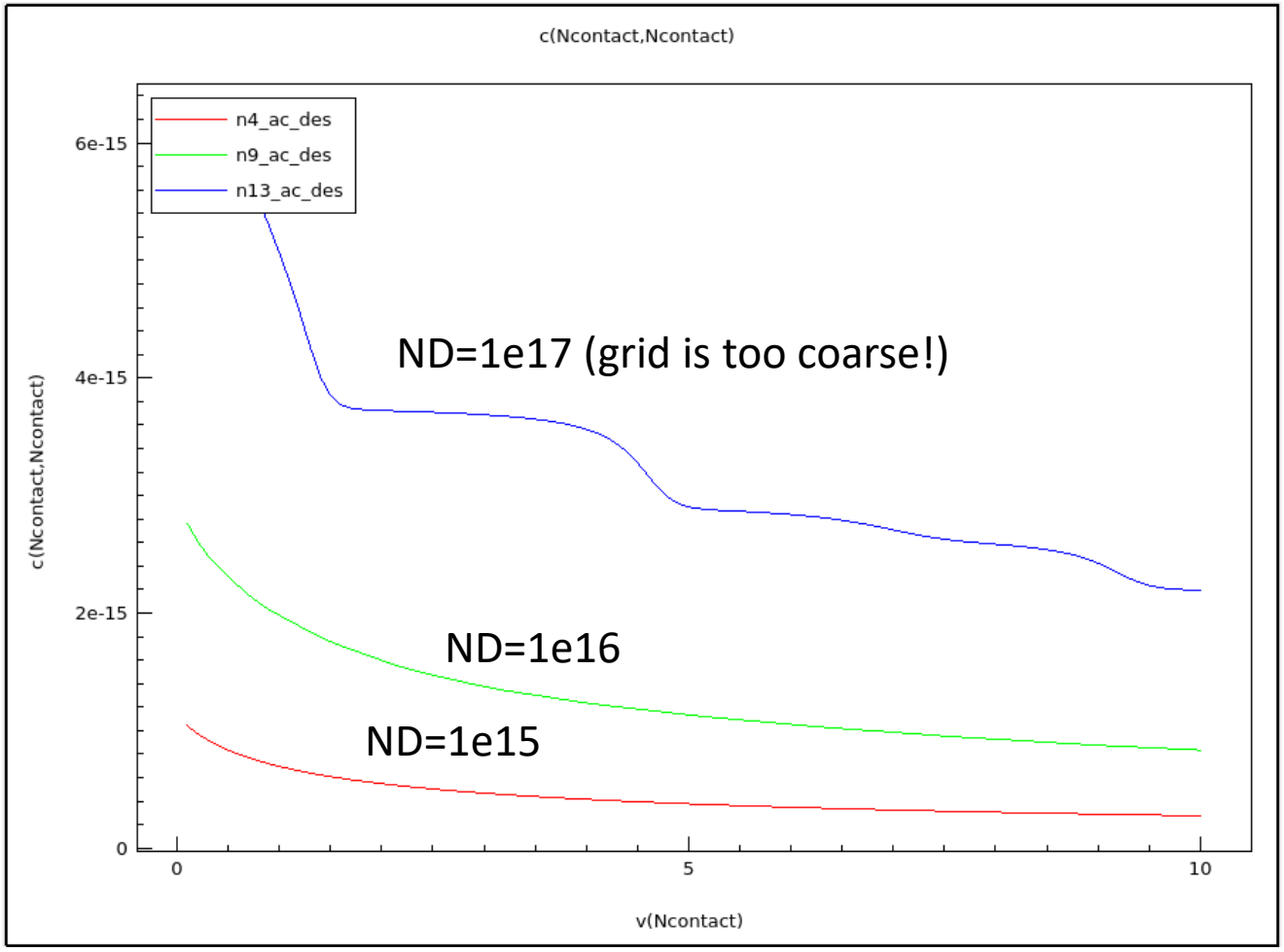
```
File {
        Output = "@log@"
        ACExtract = "@acplot@"
}

System {
        DIODE d (Ncontact Pcontact)
        Vsource_pset  vn (Ncontact  0) {dc=0}
        Vsource_pset  vp (Pcontact  0) {dc=0}
}


Solve {
        Poisson
        Coupled{ Poisson Electron Hole }
        Quasistationary (
                InitialStep=0.01 MaxStep=0.01 MinStep=1e-5
                Goal { Parameter=vn.dc Voltage=10 }
            ) { ACCoupled (
                StartFrequency=10e3 EndFrequency=10e3
                NumberOfPoints=1 Decade
                Node(Ncontact Pcontact) Exclude(vn vp)
        ) { Poisson Electron Hole }
        }

}
```

System block

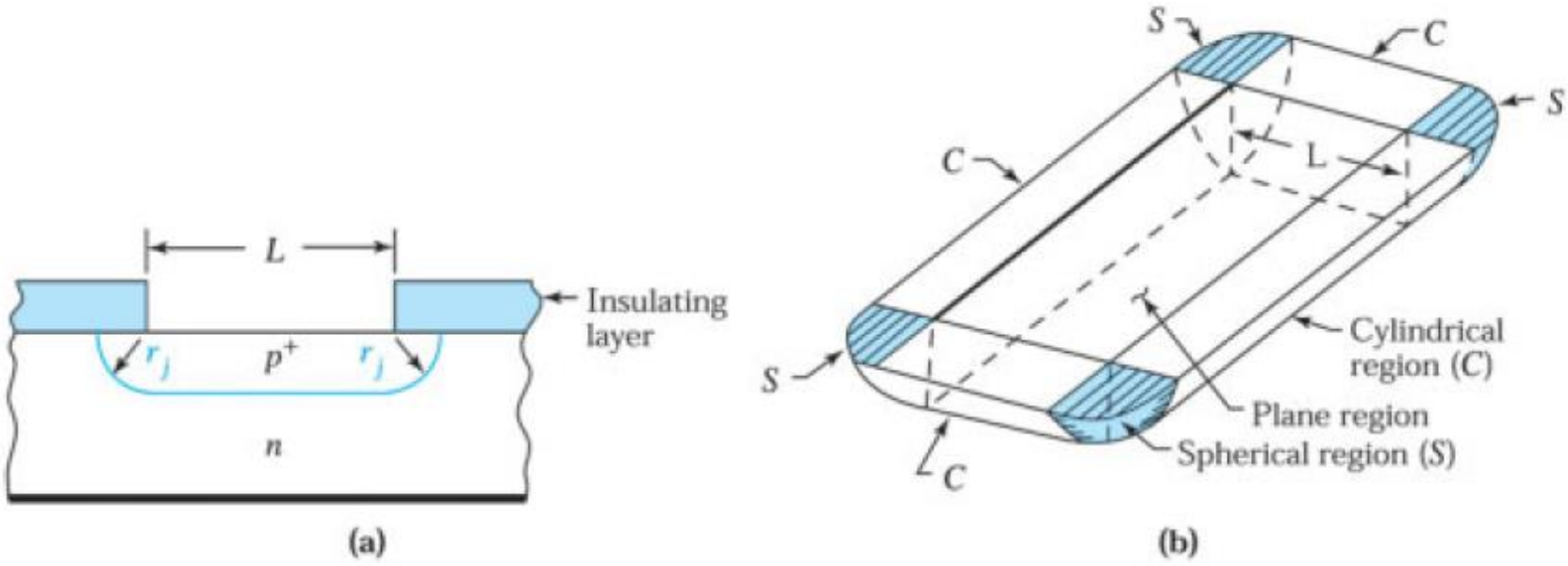
Target voltage

Frequency: 10kHz

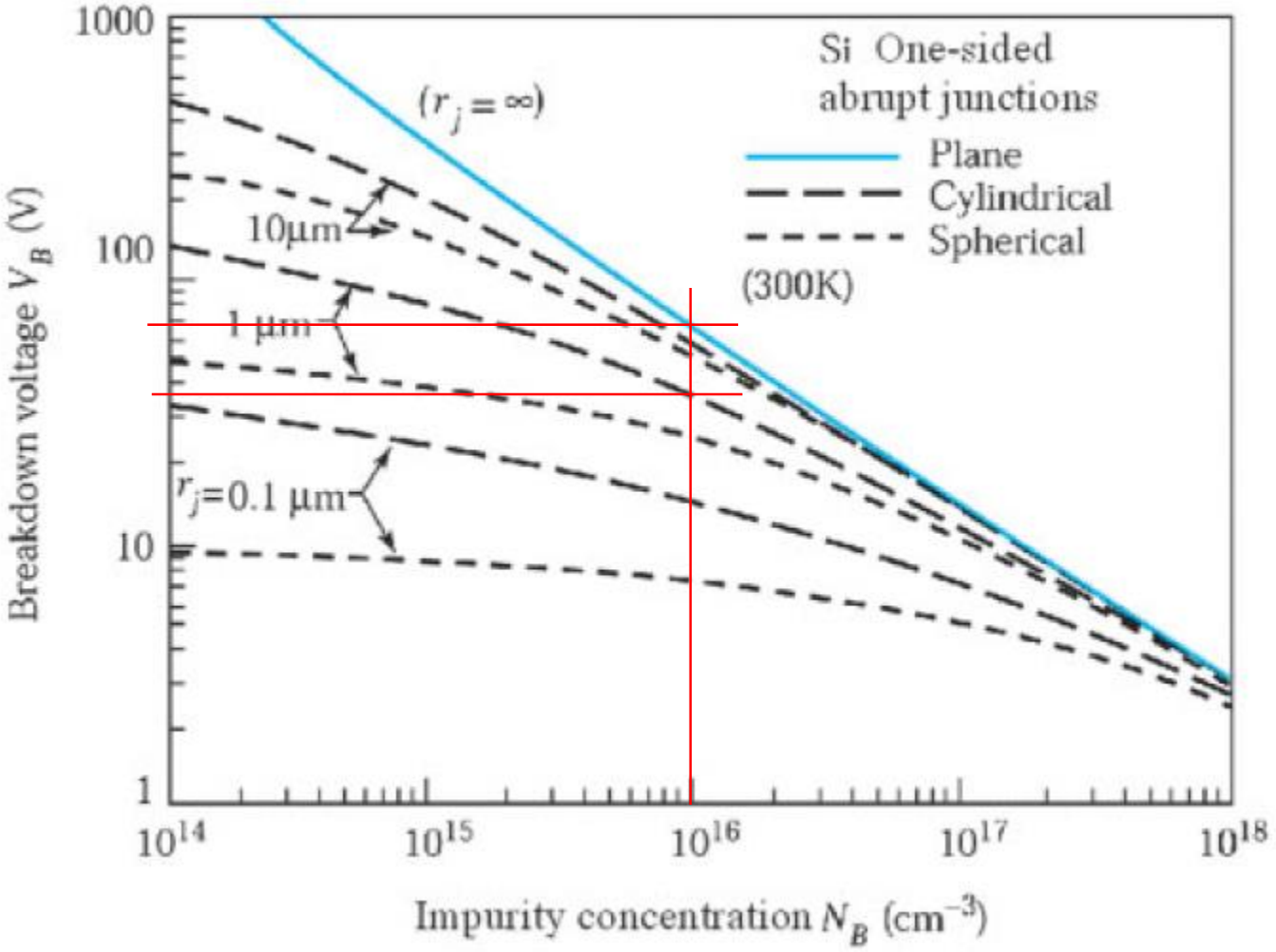
CV curves


c(Ncontact,Ncontact)
n4_ac_des
n9_ac_des
n13_ac_des
6e-15
4e-15
2e-15
0
c(Ncontact,Ncontact)
ND=1e17 (grid is too coarse!)
ND=1e16
ND=1e15
0
5
10
v(Ncontact)

Planar p+/n junction

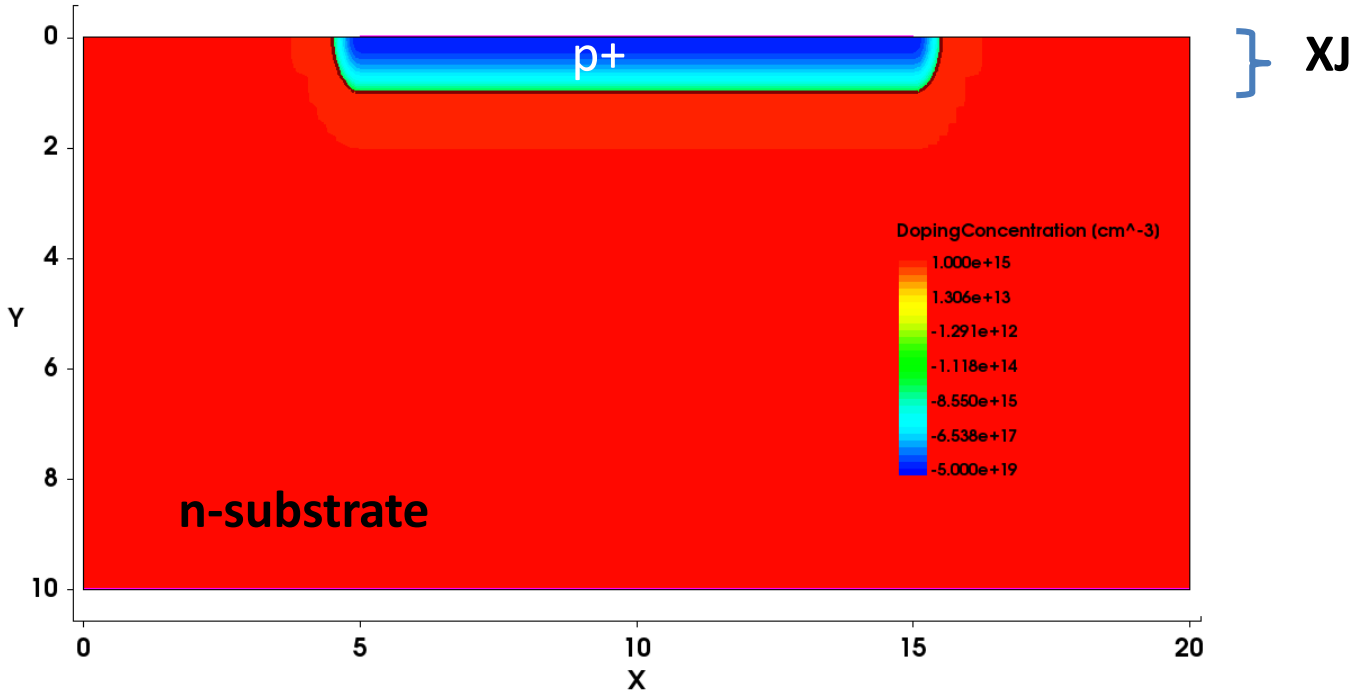


P+/n junction breakdown



Assignment 1.

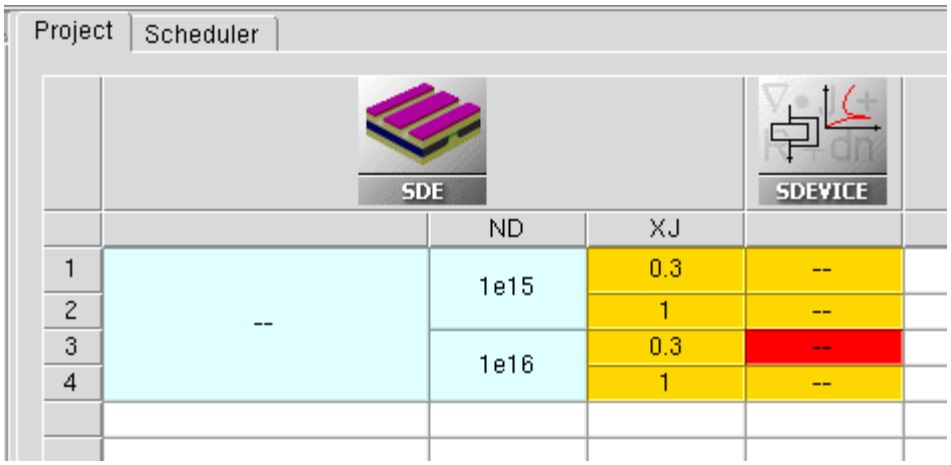
p+/n diode



Simulate I-V curves in reverse bias, including avalanche breakdown and in forward bias.

Parameters: junction depth (XJ) and substrate doping (N_D)

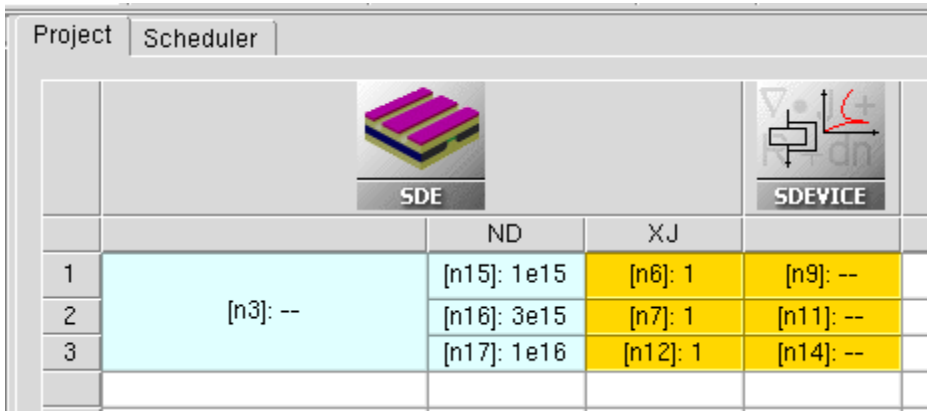
Assignment 1. Reverse bias



Parameters: junction depth (XJ) and substrate doping (N_D)

Tasks: plot the IV curves together and compare the reverse current and breakdown voltage in the different cases. How do the parameters affect the simulated characteristics?

Assignment 1. Forward bias

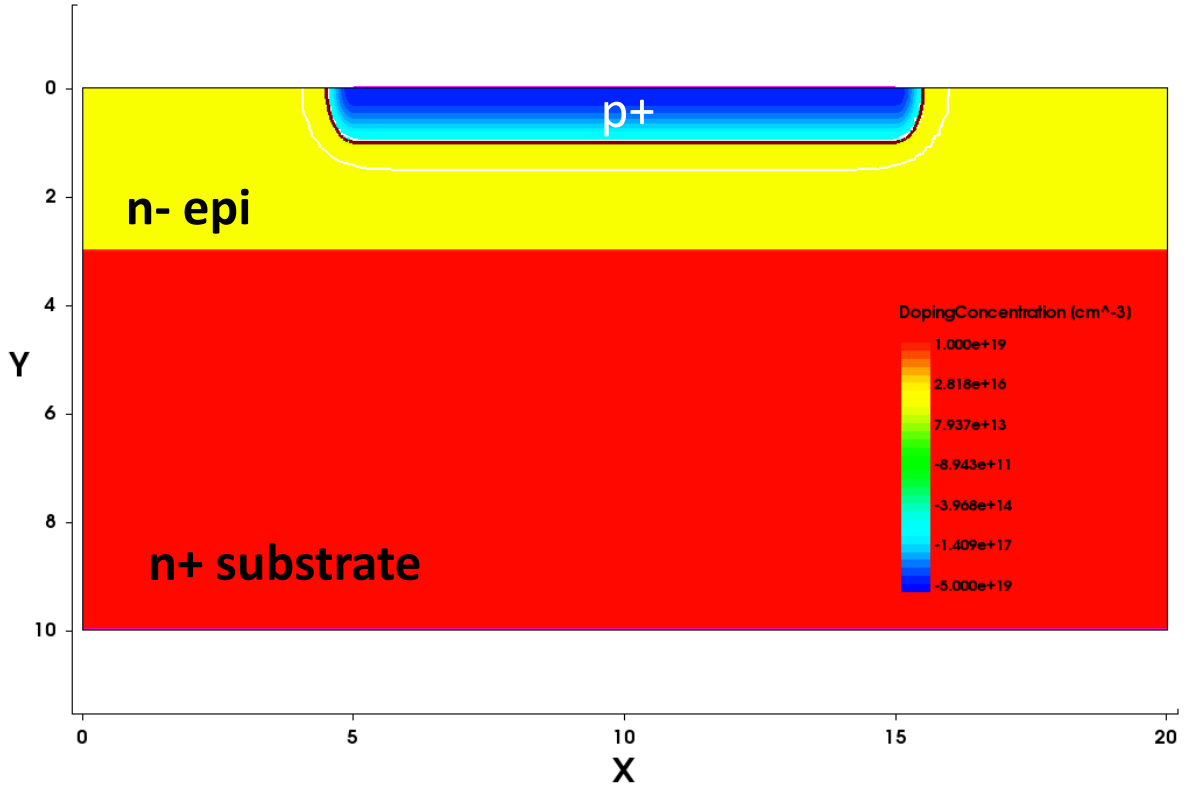


Parameters: substrate doping (N_D), XJ=1

Tasks: plot the IV curves together in lin-lin and log-lin scale and compare the forward current in the different operation regions. How do the parameters affect the simulated characteristics?

Assignment 2.

p+/n/n+ diode



Perform the same simulations of Example 1.

Differences between p+/n diode and p+/n/n+ diode:

- Shape of the electric field (vertical cross section)
- Breakdown voltage
- Series resistance