Homework on Transient Behavior of Junctions (Due Feb23rd, 1:00pm, needs to be turned in for grading)

Construct a p+n junction, check Jn >> Jp. Simulate transient turn-on and turn-off behavior (it can be in two separate cmd files). Turn off recombination.

Examine:

1) Spatial n, p, Jn, Jp profiles, use linear and log scale, guided by theoretical analysis, discuss results. You can plot out negative Jn/Jp values – there is option to do so when saving plot data (Plot section of your cmd file) if you wish to. Choose your time points “wisely” so that you can observe the kind of transition details we showed in class (also shown below – not perfect but quite good, improvements are welcome)

Transient Jn, Jp, Jtotal at both contacts versus time. Plot your data differently to show hole charge build up and electron charge build up, total current.

Guidelines to transient simulation:

The transient current plot needs to show

1. Jp(pcontact)
2. Jp(ncontact)
3. Jn(pcontact)
4. Jn(ncontact)
5. Jtotal(pcontact)
6. Jtotal(ncontact)

Also the junction was not exactly design to have hole current dominate over electron current, so the resulting plots are not exactly like what we analyzed in class with analytical theory.

You should make p+ doping much higher than n-base, also make the two sides have about equal widths.

I have made some sample plots of Jp / Jn for your reference.

Do not panic if you do not see plots like this initially – likely it is just a matter of changing the axis settings, like we experienced before.

Jp at two contacts waveforms

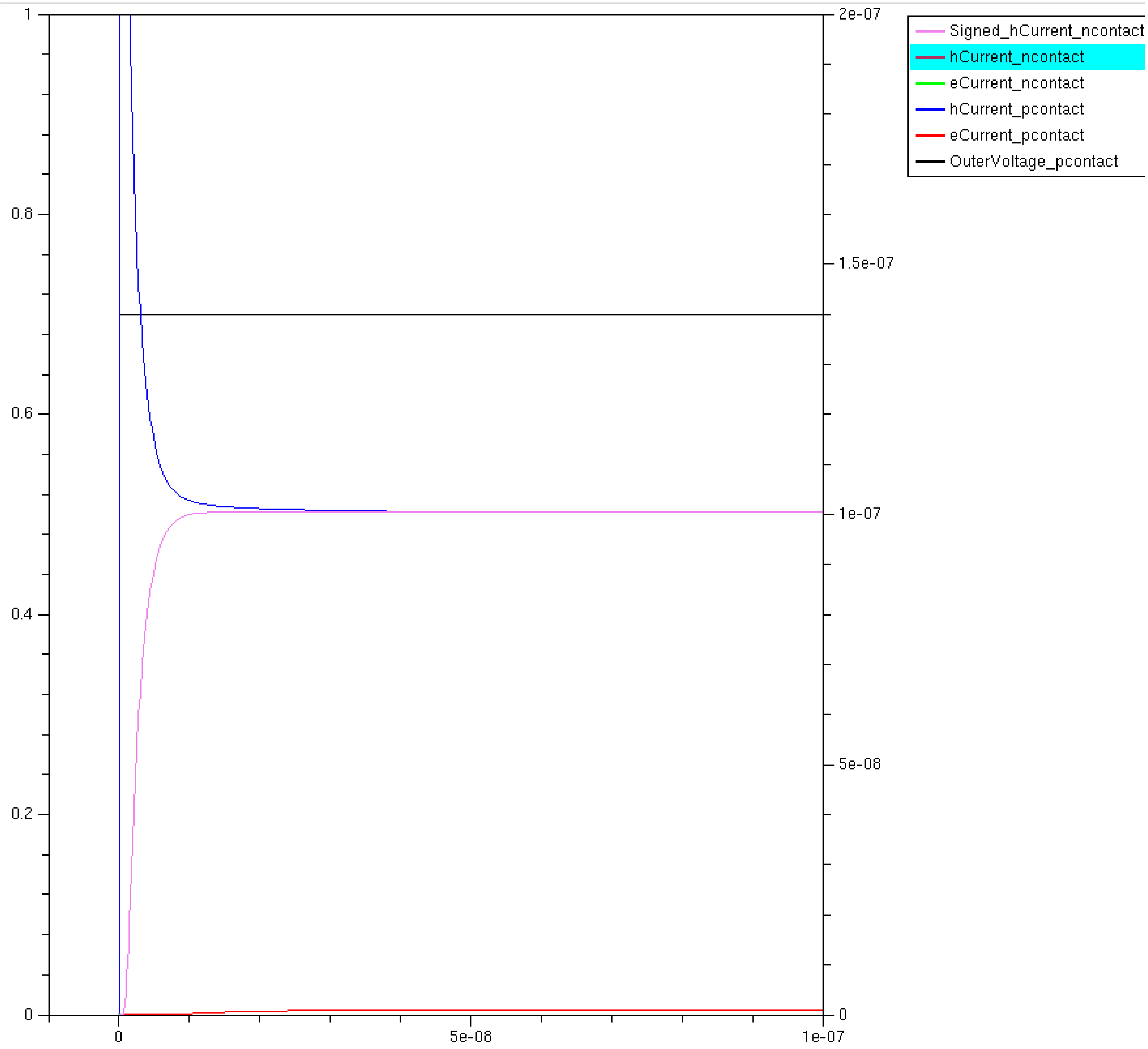

Figure 1 This is what your Jp at both contact should look like with turn-on.

Adding Jn at n-contact waveform

(note that you need to “New” curve in Inspect because going into a contact is defined as positive for currents – just multiply -1 in inspect)

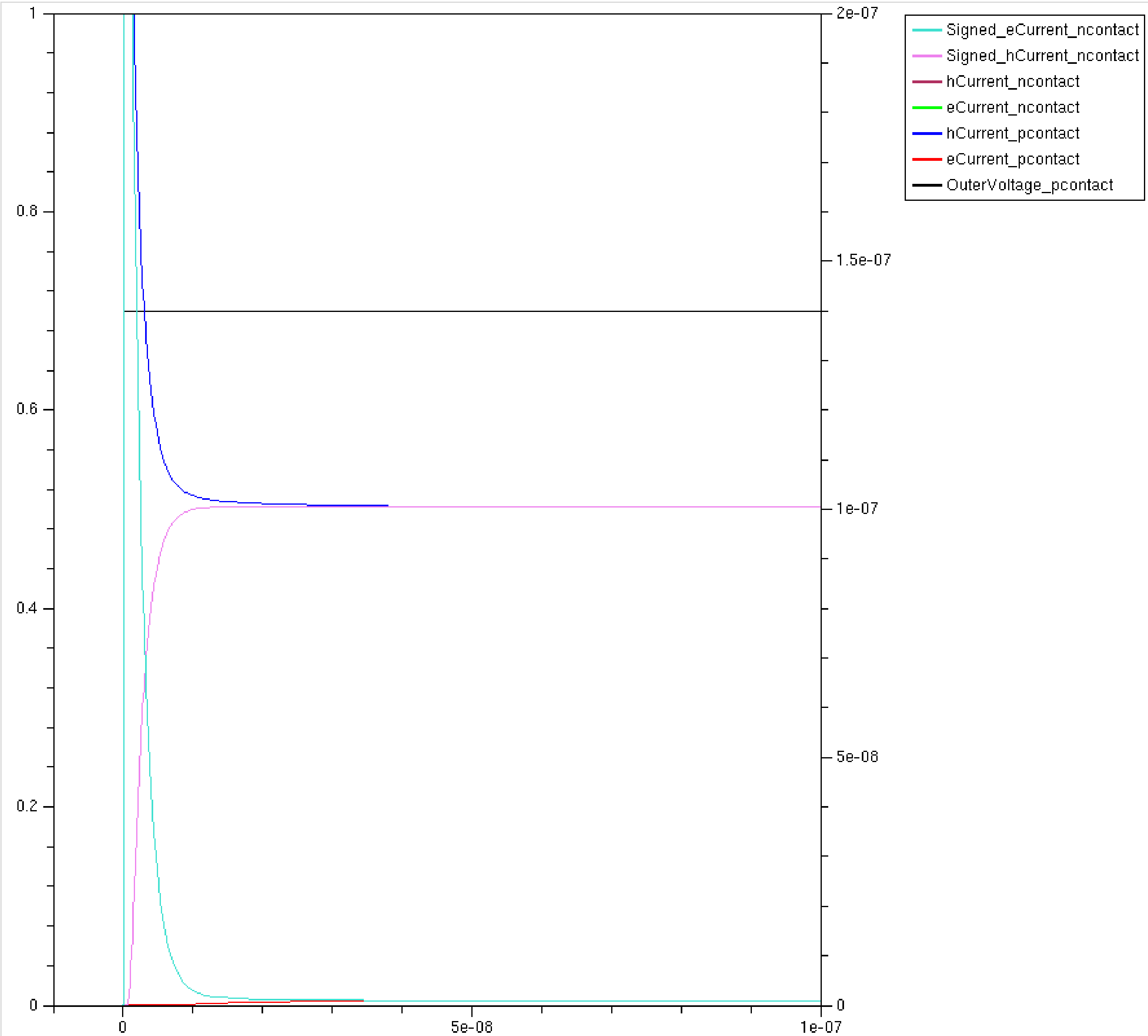

Figure 2 This also adds the Jn at the n-contact, showing initially as Jp(p-contact) is large, electrons are supplied from the n-contact.

Sample CMD File for Transient

```
#---------------------------------------------------#

#- Transient analysis

#---------------------------------------------------#

Device PNjunction {


  Electrode {

    { Name="pcontact"    Voltage=0.0 }

    { Name="ncontact"     Voltage=0.0 }


  }


  File {

      Grid    = "n1_msh"

      Doping = "n1_msh"

      Current = "pn1d"

      Plot    = "pn1d"

      Param   = "pn1d"

  }


  Physics {

      Mobility( DopingDependence)

      EffectiveIntrinsicDensity(oldSlotboom )

    *  Recombination(SRH)
```

```
 }


 Plot {
    eDensity hDensity eCurrent hCurrent
    ElectricField  eQuasiFermi hQuasiFermi
    Potential Doping SpaceCharge
    DonorConcentration AcceptorConcentration
    ValenceBandEnergy ConductionBandEnergy
    SRHRecombination
 }
}


Math {
    Extrapolate
    RelErrControl
    Notdamped=50
    Iterations=20
    NoCheckTransientError
}
# step on simulation
System {
    PNjunction PN1 (pcontact=positive ncontact=negative)
    Vsource_pset vp (positive 0) { pwl = (0.0e+00 0.0
                                   3.0e-11 0.0
                                   3.1e-11 0.7
                                   1.0e-7 0.7)}
```

```
    Vsource_pset vn (negative 0) {dc=0}

    Plot "pn_tran" (time() positive negative)

}

File {
    Output  = "pntran"
    Current = "pntran"
}

Solve {
    Coupled {Poisson Electron Hole}
    Transient (
            InitialTime=0 FinalTime=1.0e-7
            InitialStep=1e-12 MaxStep=1e-6 MinStep=1e-15
            Increment=1.1
    )
    {Coupled{poisson electron hole}
     Plot(Time = (3e-11; 9e-11;  1e-7) NoOverwrite) #plot result at different time point – choose your own points following the guidelines discussed in class today
     }
}
```

Below are some n/p/Jn/Jp profile plots taken from Xin Jin's Elec6700 Final Project Report for illustration.

6. Transient Simulation:

Illustration: Turn on and Turn off are simulated in two different cmd files.

Turn on at Time = 0.031ns, voltage step on from 0V to 0.7V

Turn off at Time = 0.031ns, voltage step down from 0.7V to 0V

6.1 Turn on condition

6.1 .1a Hole Density – log scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

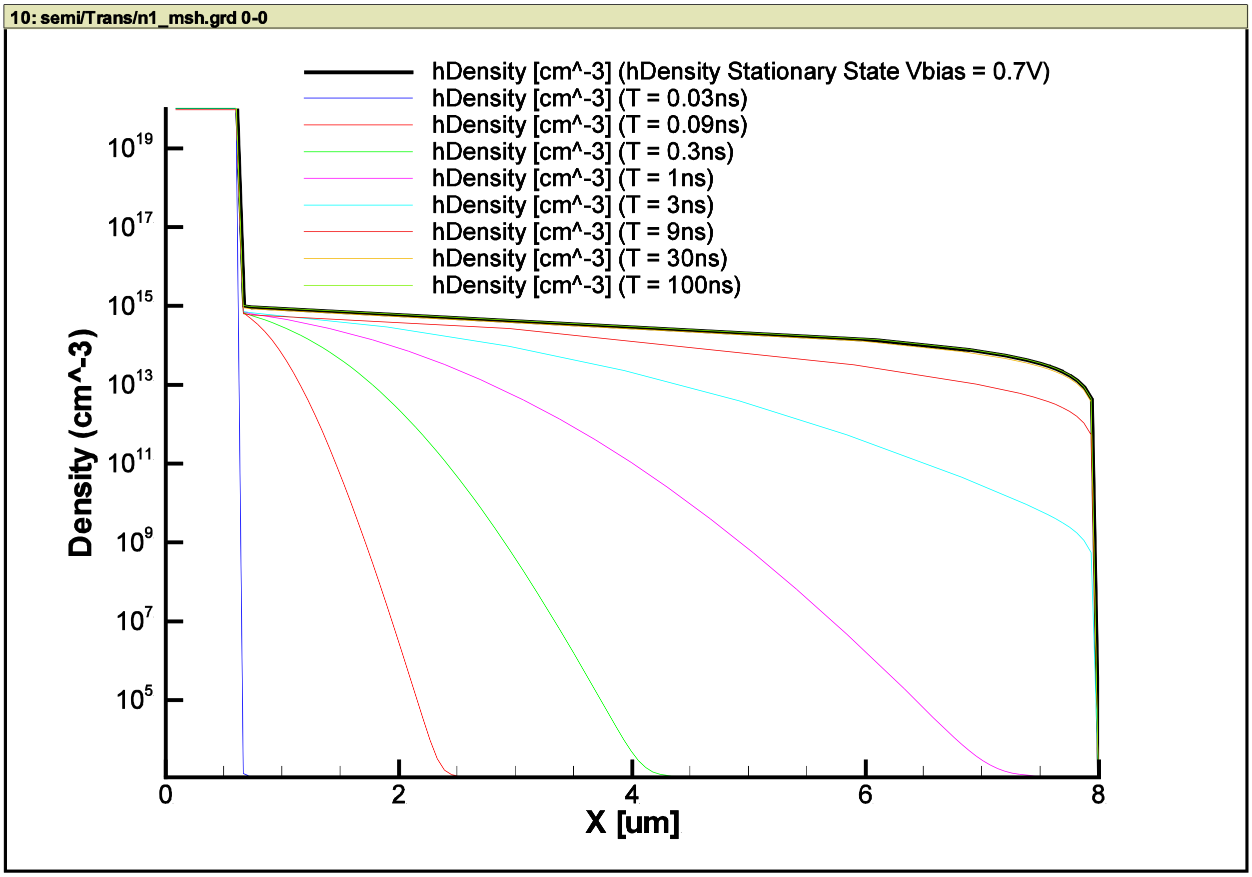

Fig.34 Hole Density – log scale (turn on)

Comment: see linear scale in the next figure.

6.1 .1b Hole Density – linear scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

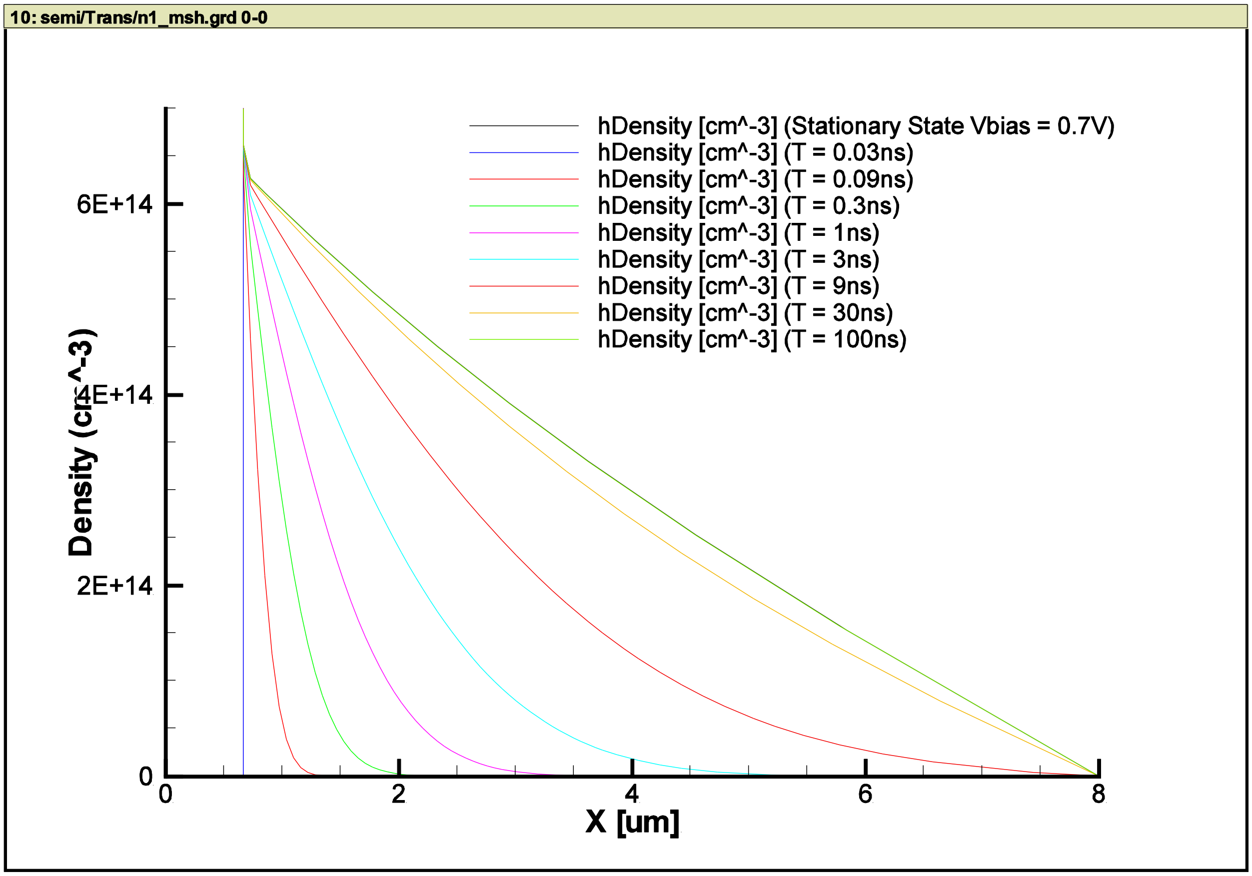

Fig.35 Hole Density – linear scale (turn on)

Comment: Consider applied a forward bias voltage on pn junction, it will build up of excess hole.

At the first moment, holes have not yet arrived at the ohmic contact from the injection point. The electron current at the ohmic (x=8) contact makes up the difference between the two hole currents at the two boundaries. The number of holes which entered the n-region through the injection point but did not arrive at the ohmic contact comprises Qs.

6.1.2a Electron Density – log scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

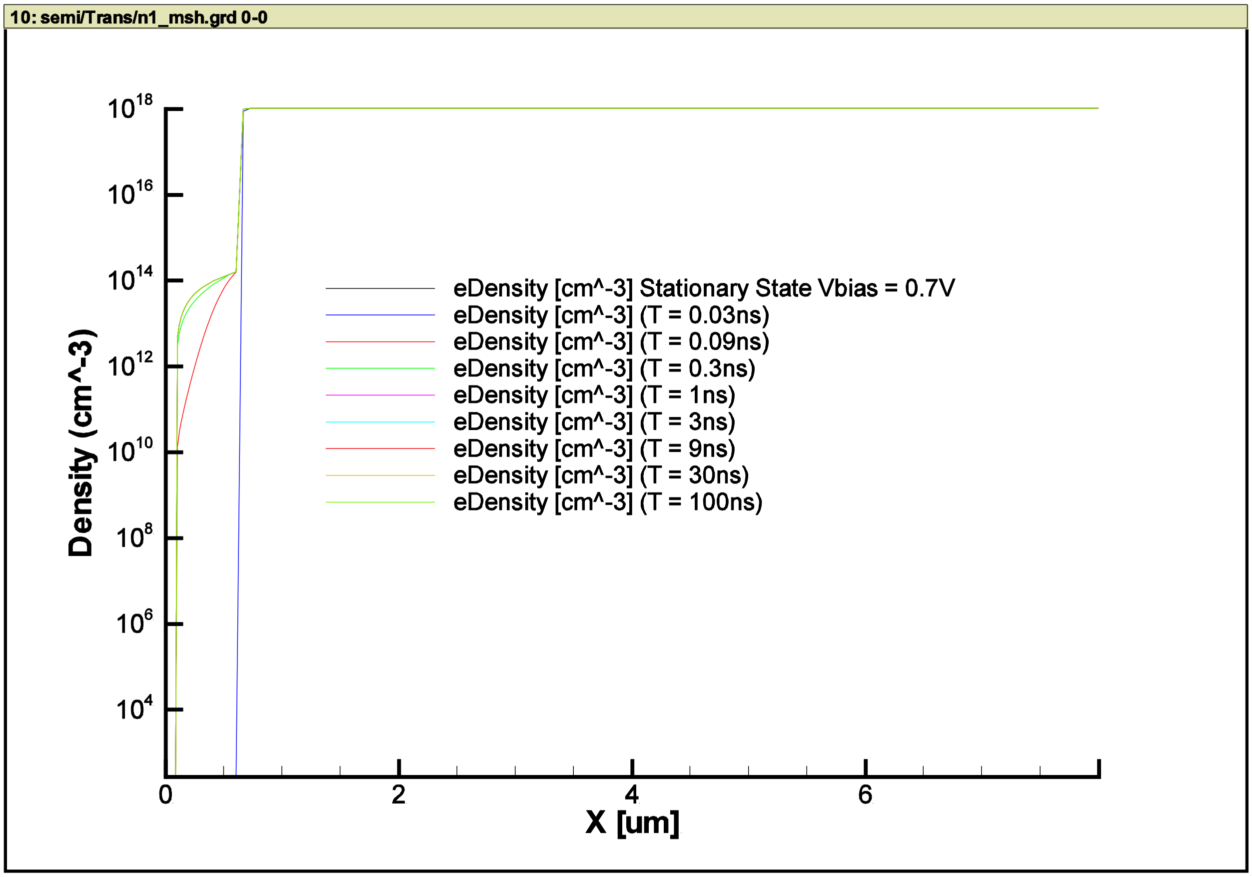

Fig.36 Electron Density – log scale (turn on)

Comment: see linear scale in the next figure.

6.1.2b Electron Density – linear scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

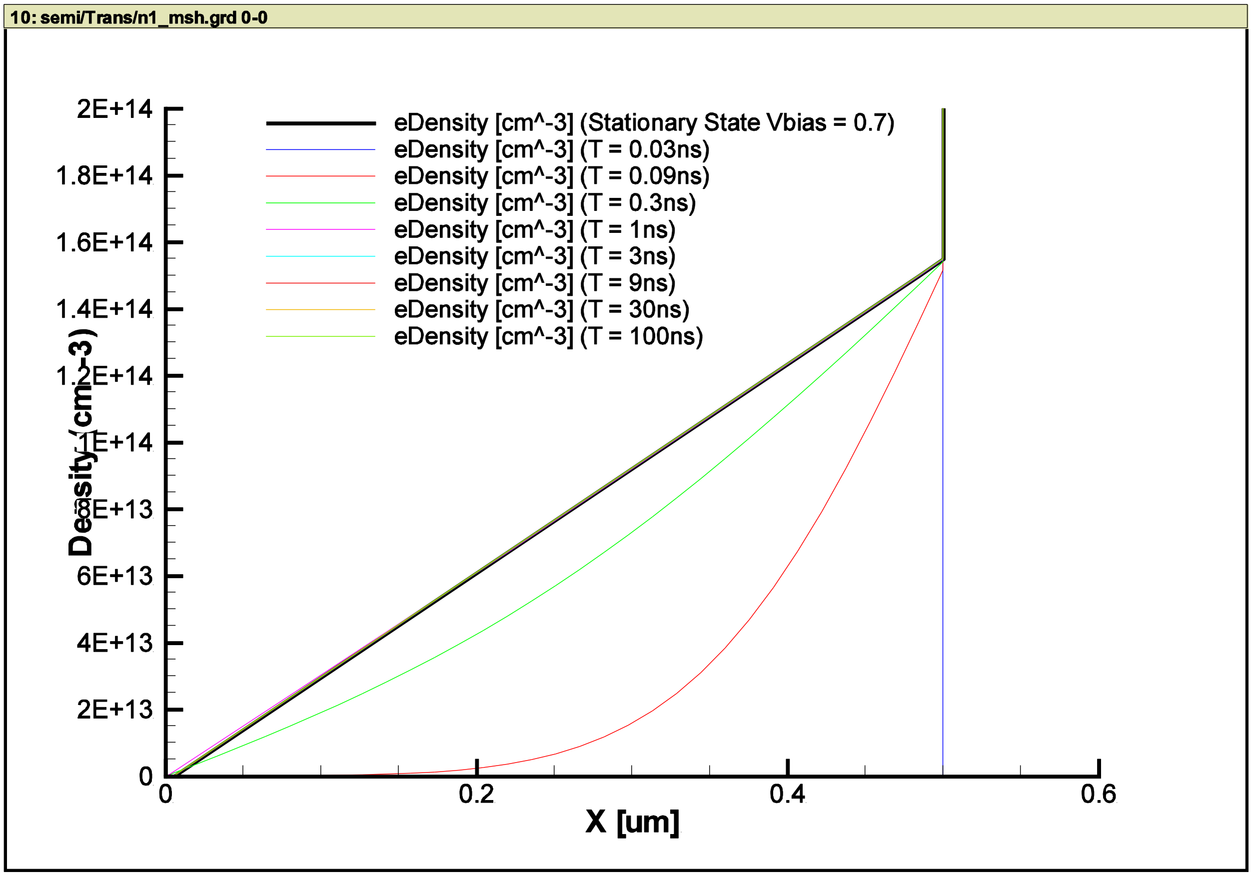

Fig.37 Electron Density – linear scale (turn on)

Comment: Electrons enter from the ohmic contact to the p-region at the same rate as the holes crossing the junction. Electrons entered from the n-side ohmic contact, supplying –Qs to set up charge neutrality.

6.1.3a Hole Current Density – log scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

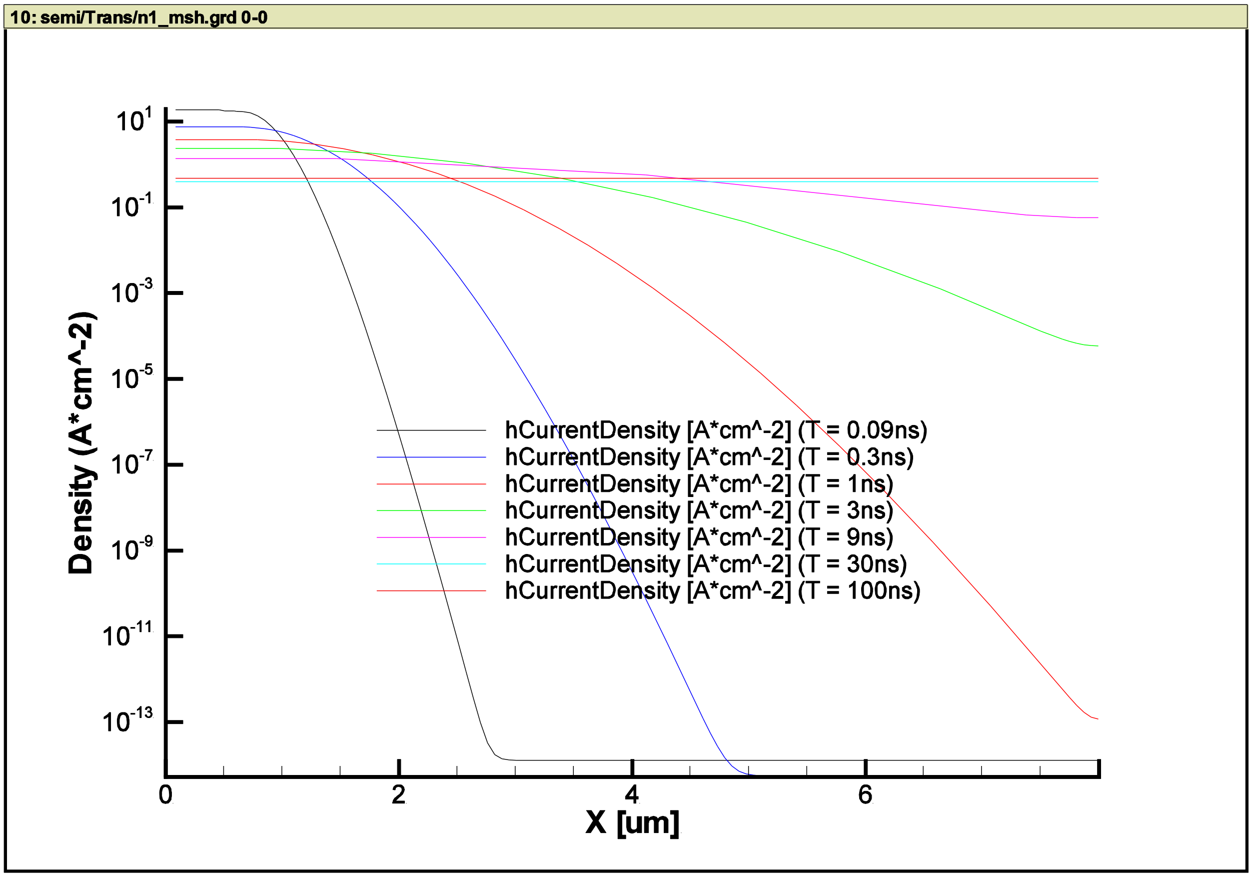

Fig.38 Hole Current Density – log scale (turn on)

Comment: see linear scale in the next figure.

6.1.3b Hole Current Density – linear scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

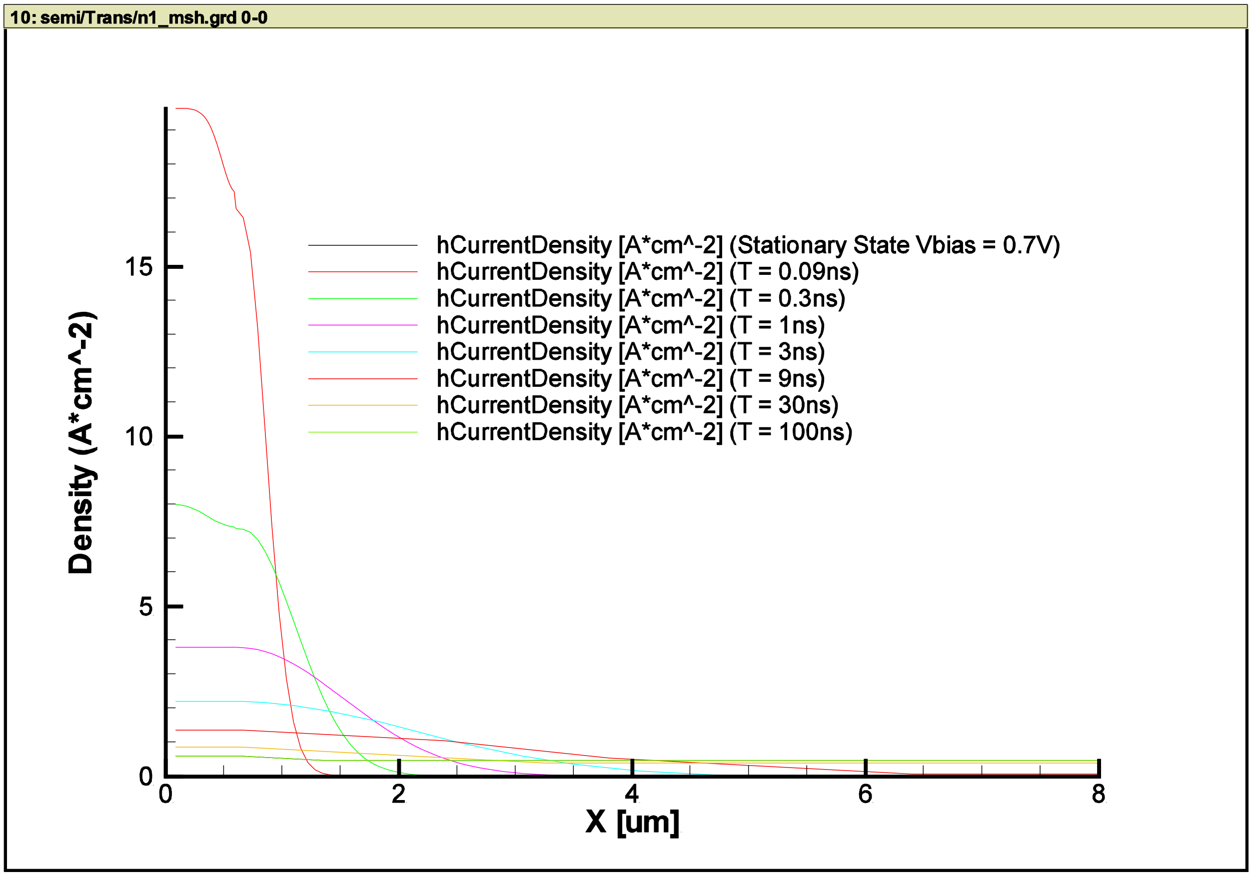

Fig.39 Hole Current Density – linear scale (turn on)

Comment: Hole current density is the slope of hole density at the injection point in n-region (if we neglect recombination).

6.1.4a Electron Current Density – log scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

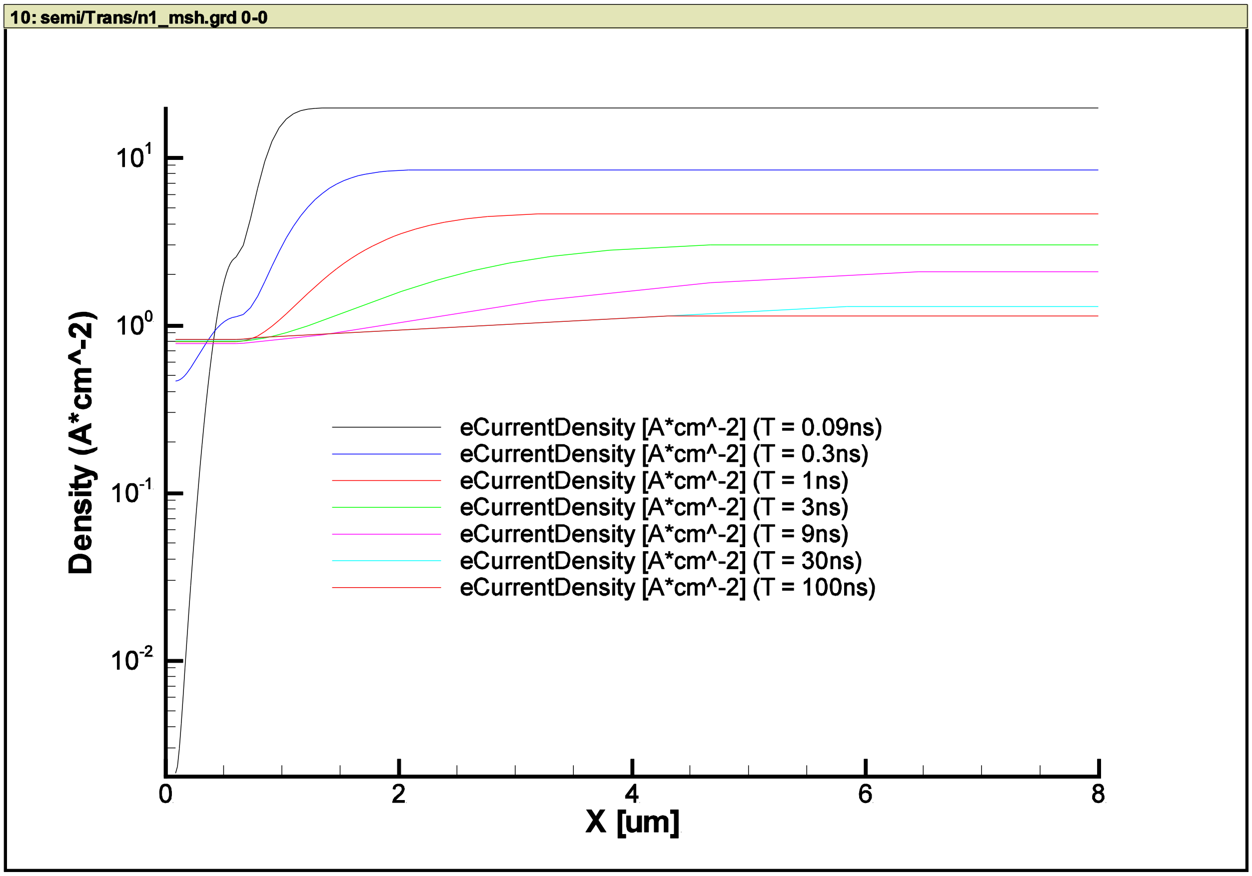

Fig.40 Electron Current Density – log scale (turn on)

Comment: see linear scale in the next figure.

6.1.4b Electron Current Density – linear scale (Vbias = 0Vat T = 0.03ns, Vbias = 0.7V at T = 0.031ns)

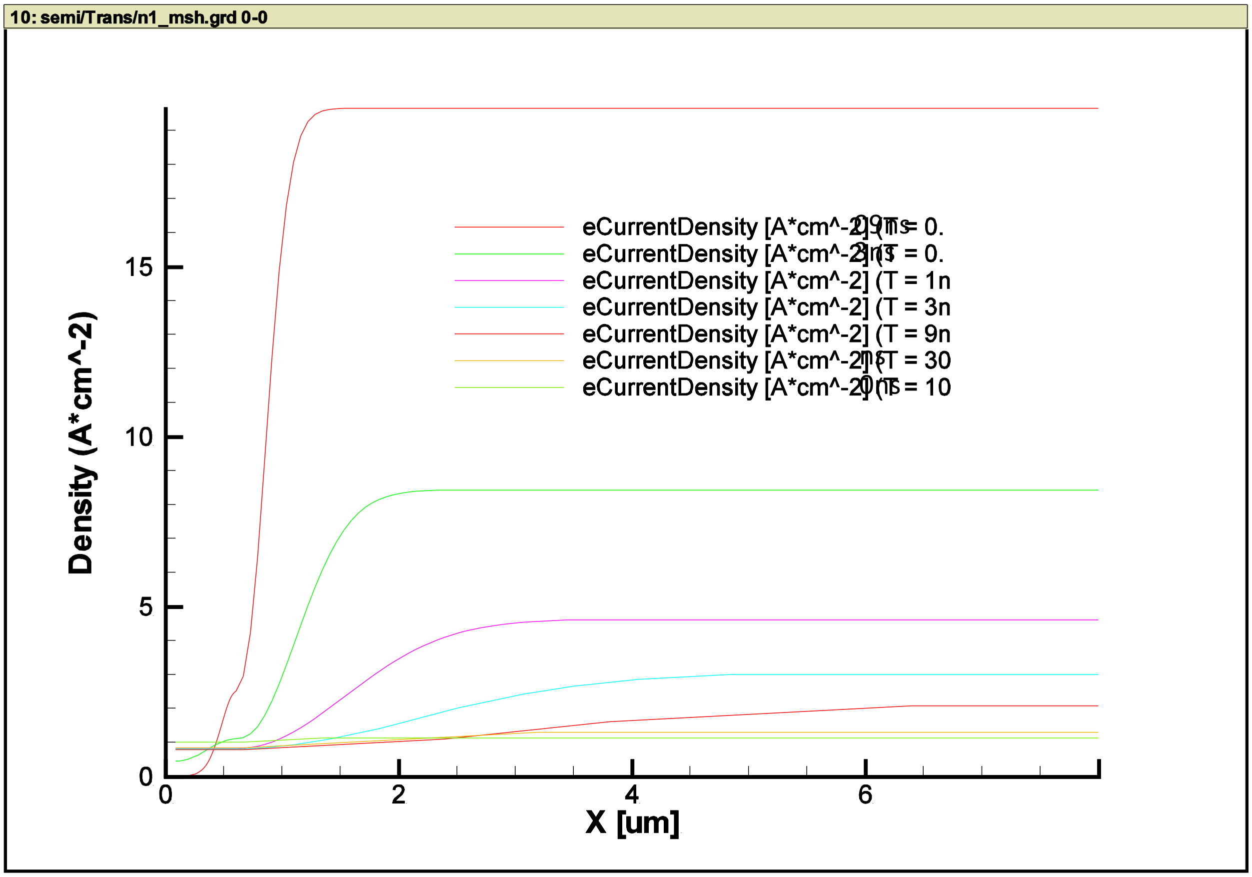

Fig.41 Electron Current Density – linear scale (turn on)

Comment: Electron current density is the slope of electron density at injection point in n-region (if we neglect recombination).

6.2 Turn off condition

6.1.1a Hole Density – log scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

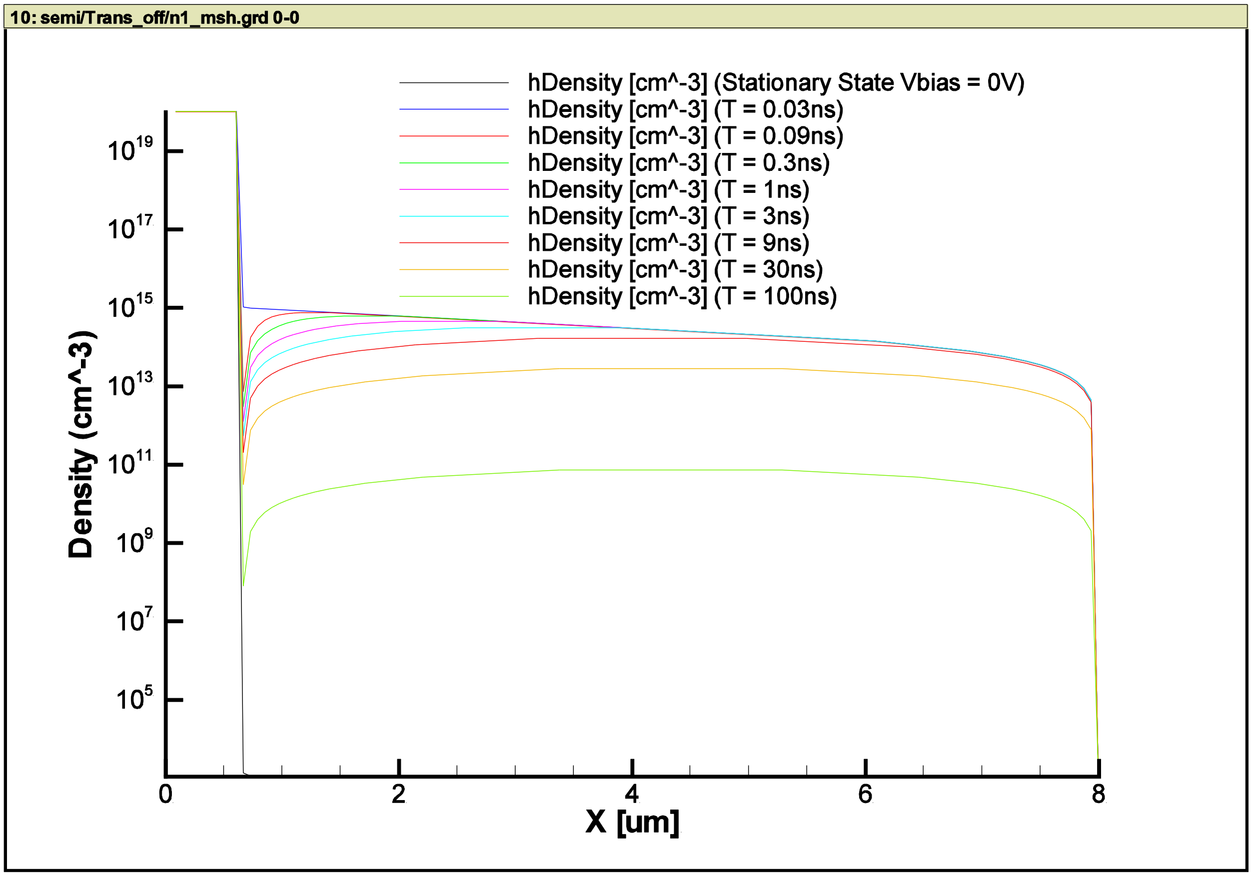

Fig.43 Hole Density – log scale (turn off)

Comment: see linear scale in the next figure.

6.1.1b Hole Density – linear scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

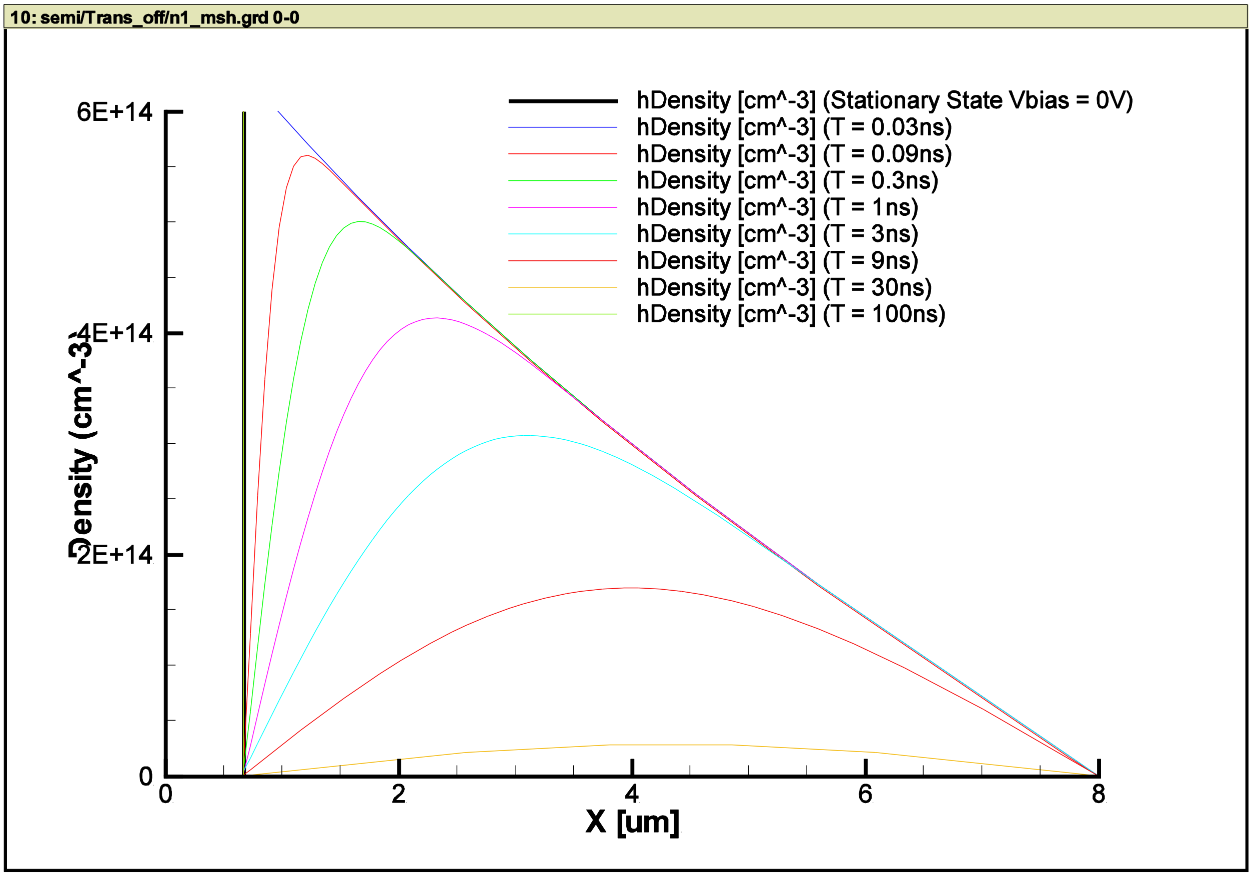

Fig.44 Hole Density – linear scale (turn off)

Comment: 2/3 of the stored hole charge is reclaimed through the junction. (for short base)

6.1.2a Electron Density – log scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

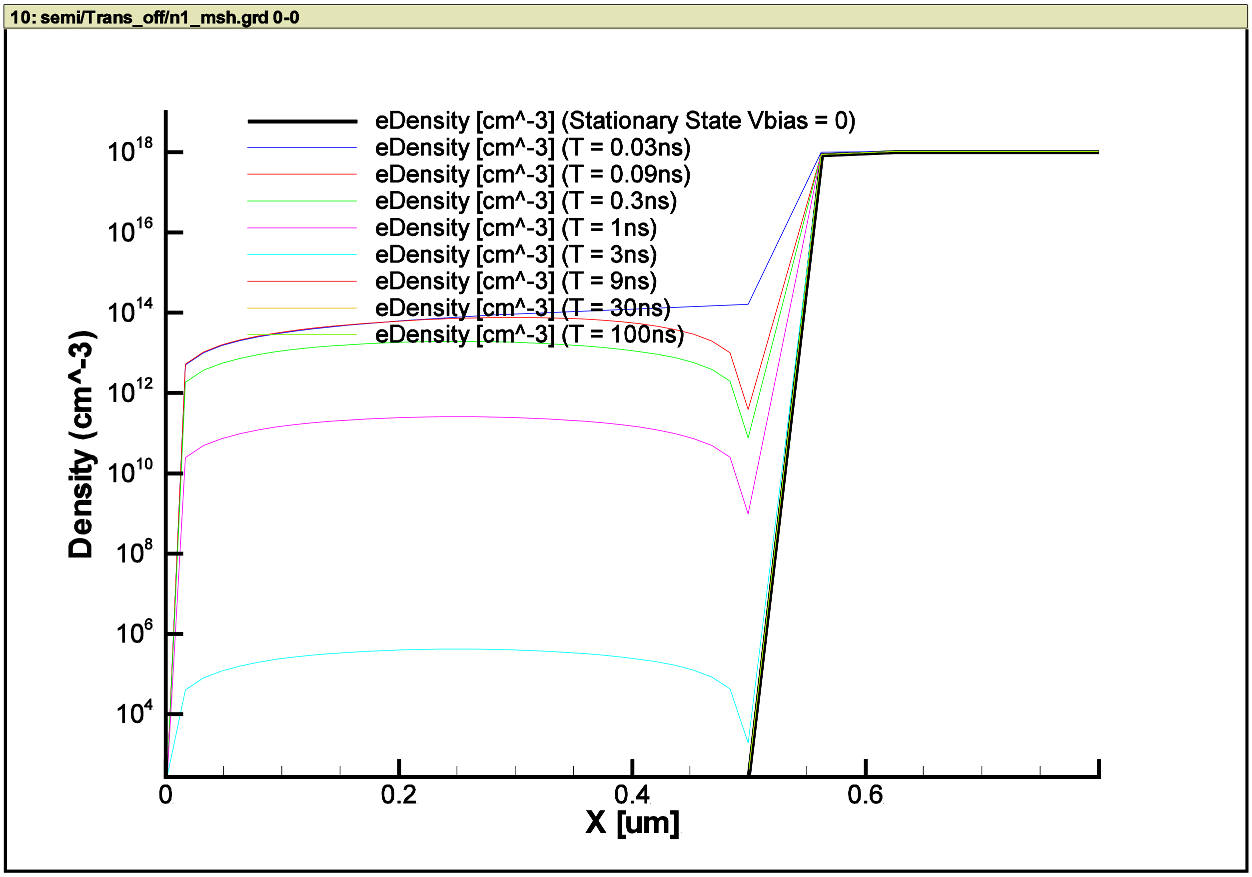

Fig.45 Electron Density – log scale (turn off)

Comment: see linear scale in the next figure.

6.1.2b Electron Density – linear scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

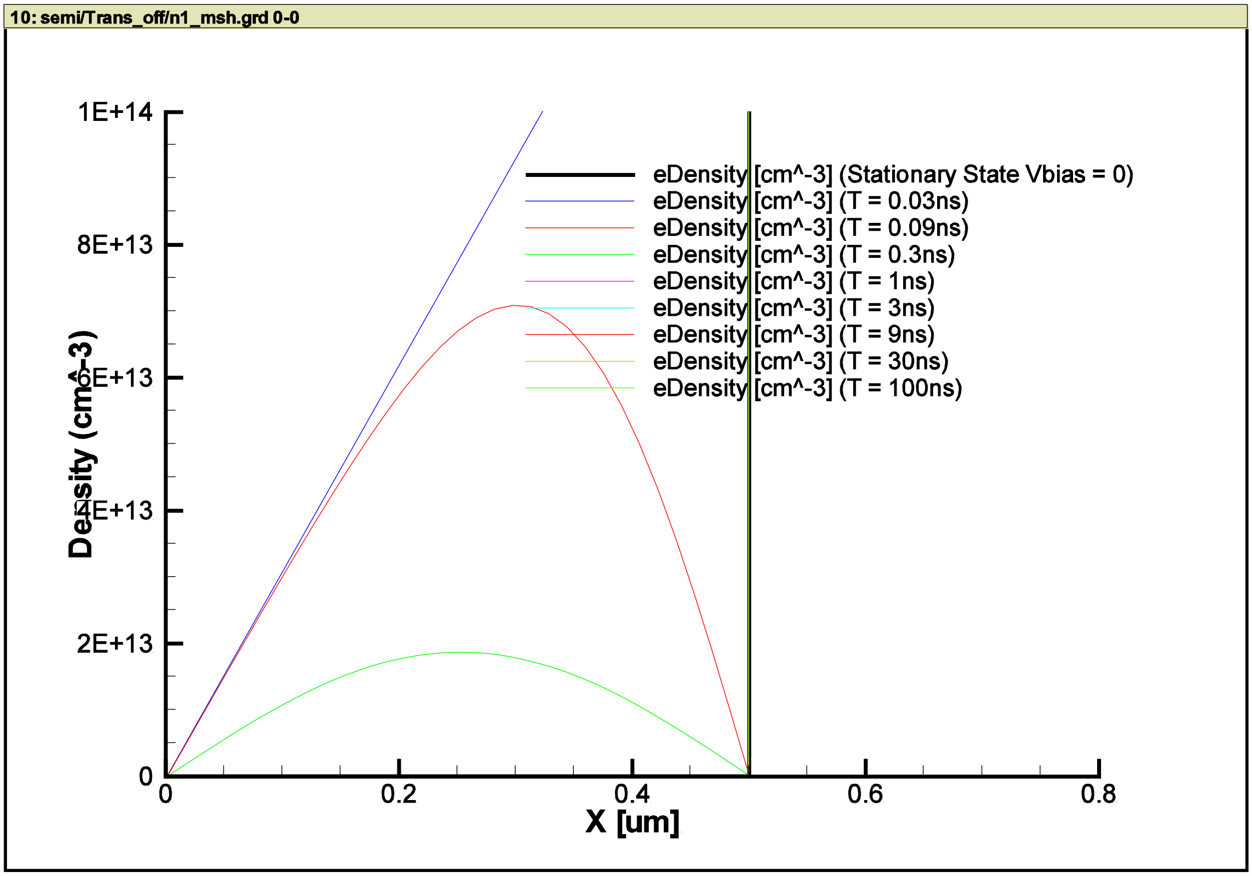

Fig.46 Electron Density – linear scale (turn off)

Comment: 2/3 of the stored electron charge is reclaimed through the junction. (for short base)

6.1.3a Hole Current Density – log scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

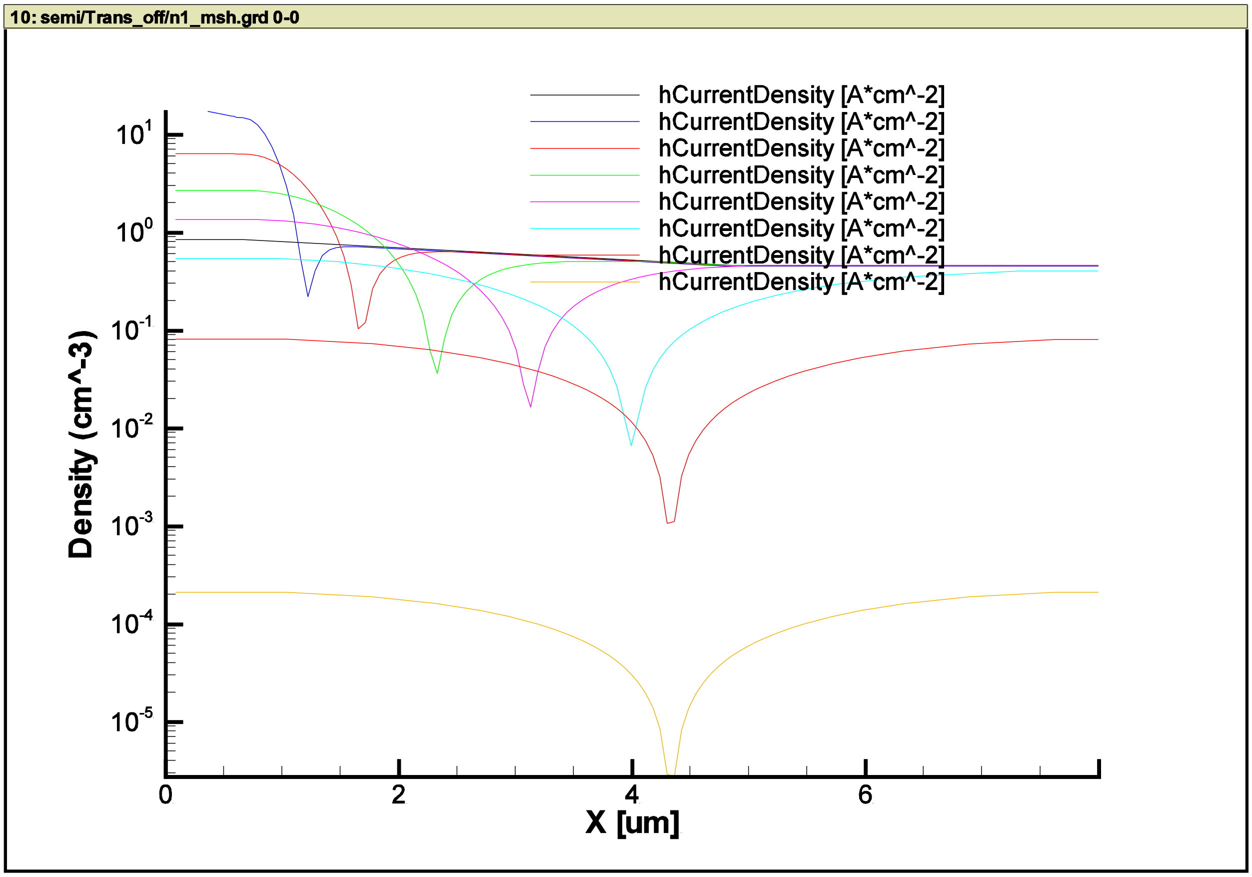

Fig.47 Hole Current Density – log scale (turn off)

6.1.3b Hole Current Density – linear scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

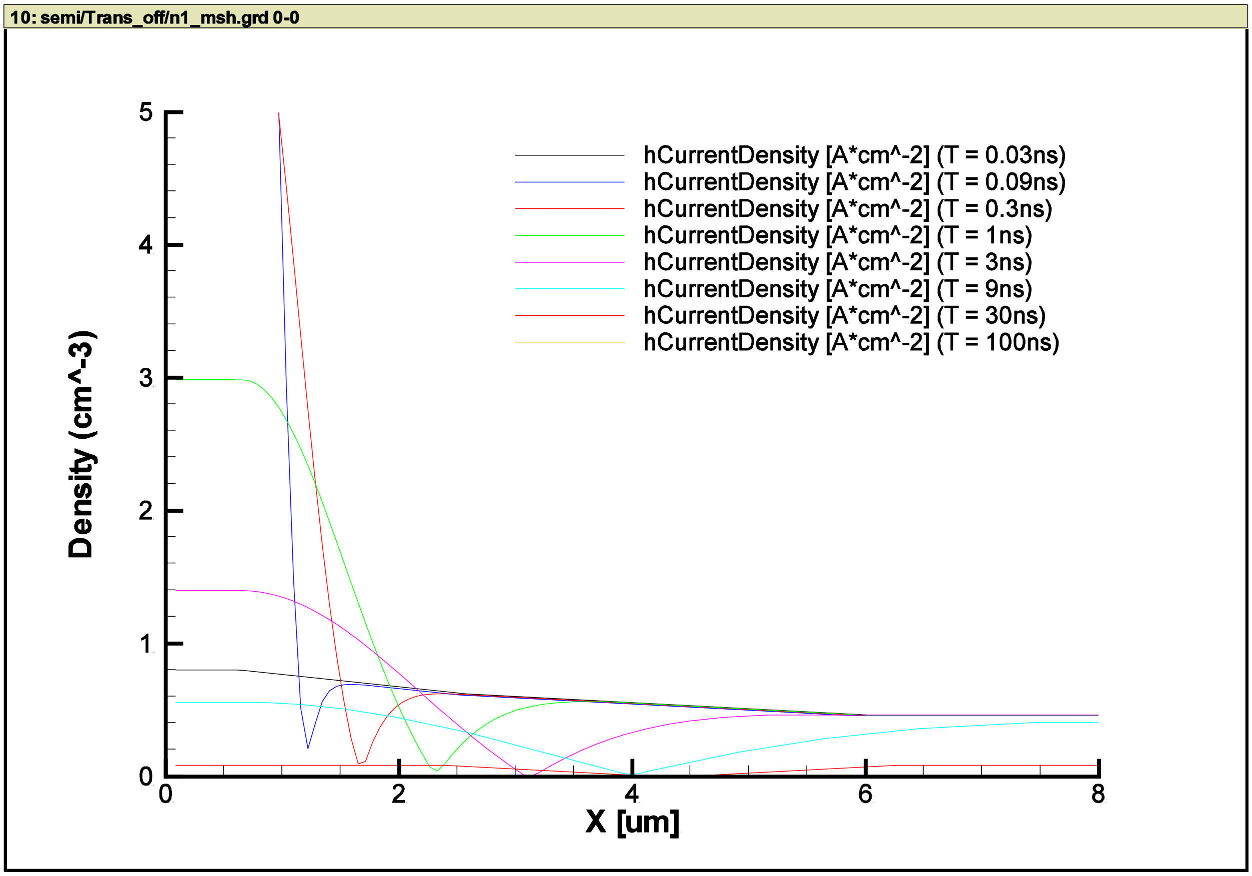

Fig.48 Hole Current Density – linear scale (turn off)

6.1.4a Electron Current Density – log scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

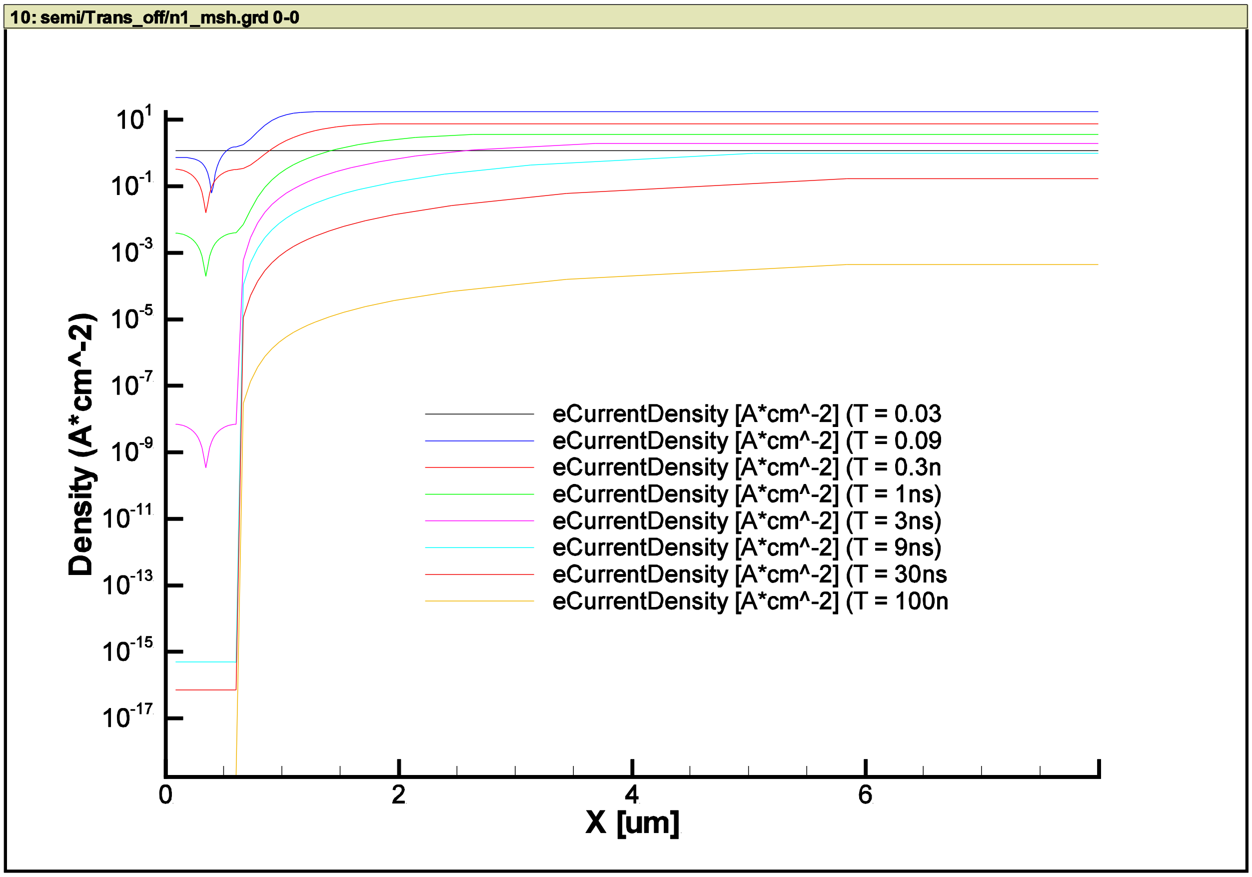

Fig.49 Electron Current Density – log scale (turn off)

6.1.4b Electron Current Density – linear scale (Vbias = 0.7Vat T = 0.03ns, Vbias = 0 V at T = 0.031ns)

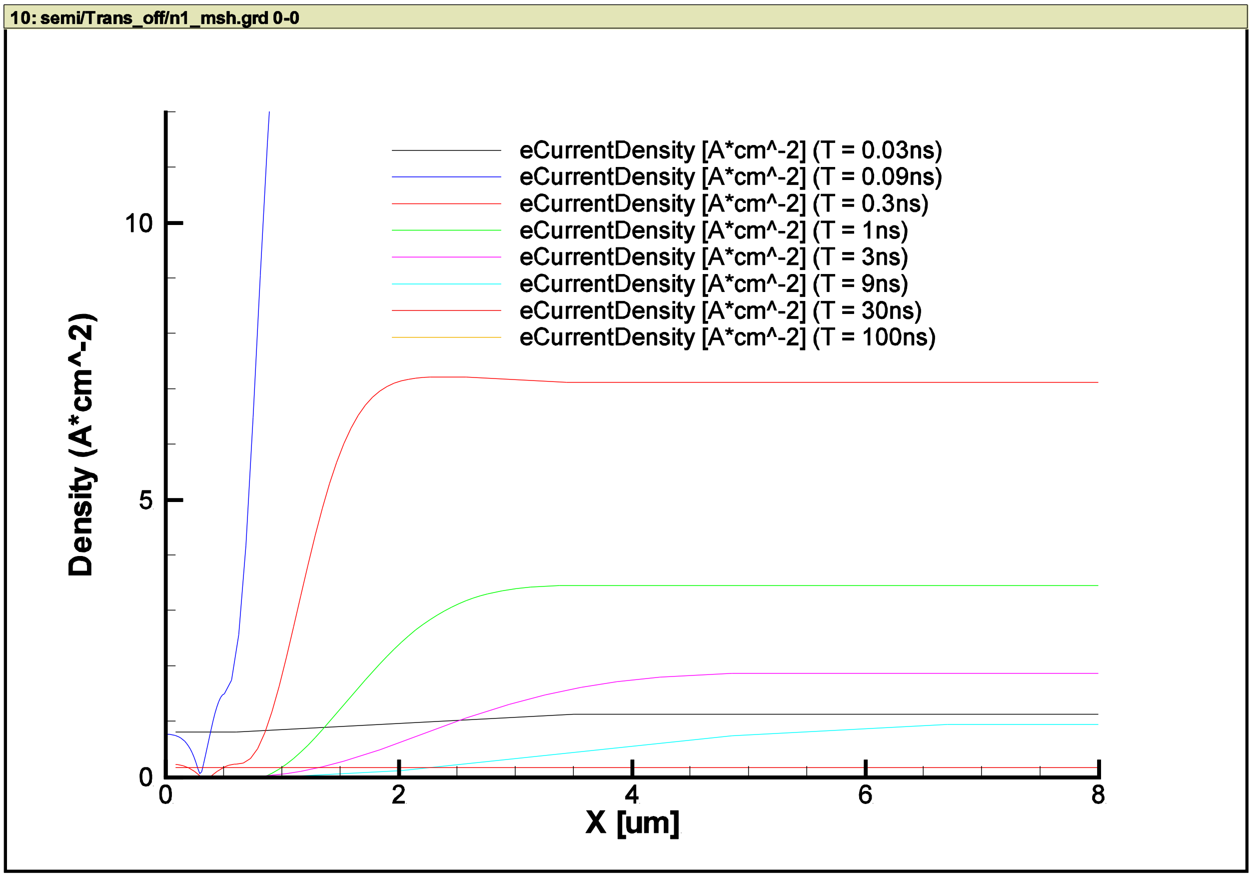

Fig.50 Electron Current Density – linear scale (turn off)

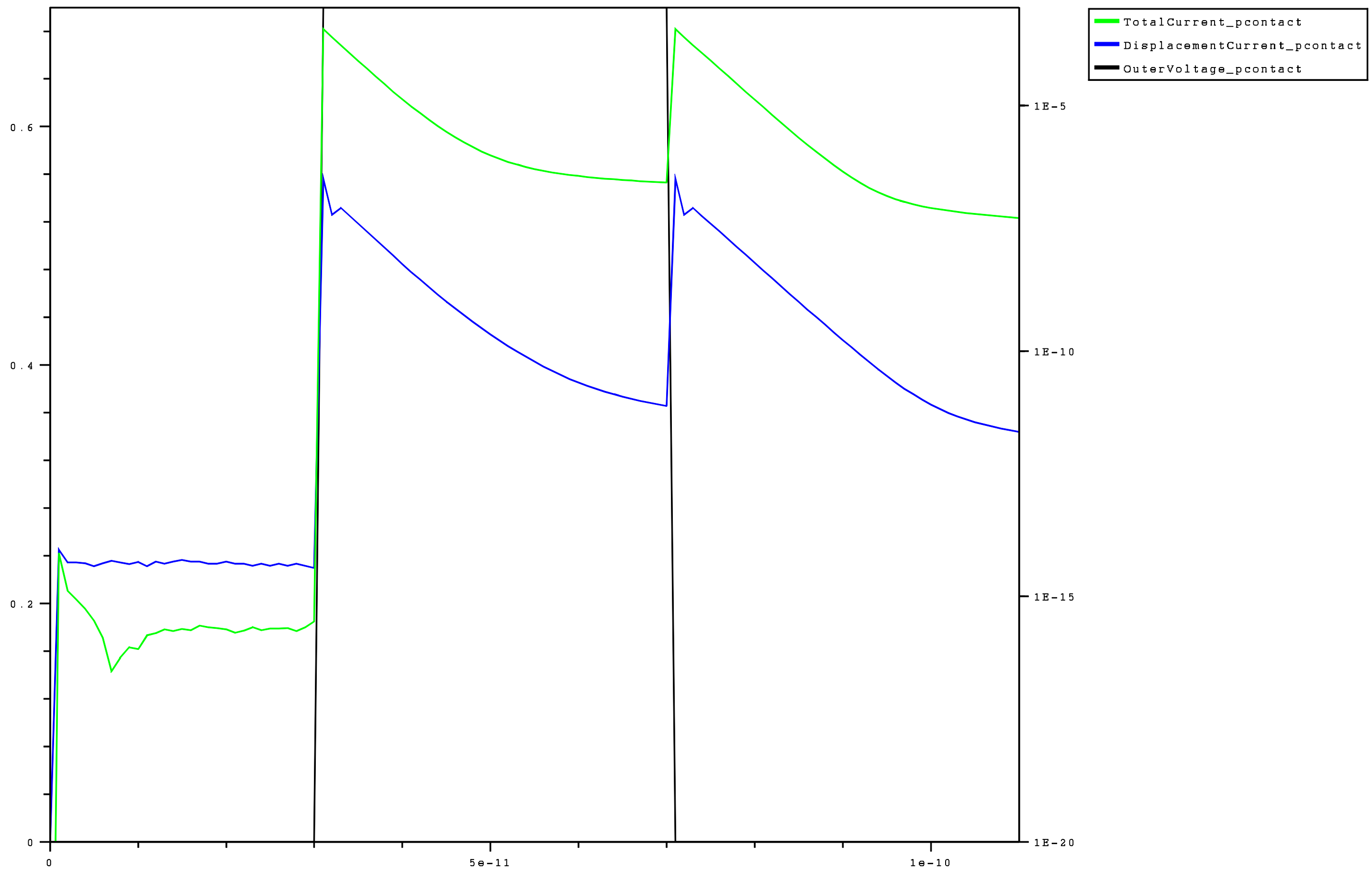

Fig.52 Displacement Current and Total Current (turn on and turn off)