Appendix A
Sentaurus Related Code

The code used in the work described in Chap. 5 is presented in this appendix. The code used for constructing the 3D NMOS transistor provides detailed information about the physical properties of the NMOS transistor.

A.1 Code for 3D NMOS Device Creation Using Sentaurus-Structure Editor Tool

The code that was used to construct the 3D NMOS transistor using Sentaurus-Structure editor tool is as follows.

```
    ; Setting parameters
; - lateral
(define Lg 0.036) ; [um] Gate length
(define subzmin -4.88); [um] Max. frontside extension in the z-direction
(define subzmax 5.12); [um] Max. backside extension in the z-direction
(define subxmin -5.42); [um] Max. leftside extension in the x-direction
(define subxmax 5.253); [um] Max. rightside extension in the x-direction
(define wn 1); [um] width of the nmos device
(define Lpreox 0.002) ; Poly rexox thickness
(define Lspacer 0.03) ; Spacer length

; Layers
(define Ysub 4) ; [um] Substrate thickness
(define Tox 12e-4) ; [um] Gate oxide thickness
(define Ypol -0.12) ; [um] Poly gate thickness

; Substrate doping level
(define Dop 1e16) ; [1/cm3]
```

```
; Derived quantities
(define Xg (/ Lg 2.0))
(define Ygox (* Tox -1.0))

;————————————————————————————————————
; Overlap resolution: New replaces Old
(isegeo:set-default-boolean "ABA")
;————————————————————————————————————

; CREATE REGIONS
; SUBSTRATE REGION
(isegeo:create-cuboid (position subxmin 0 subzmin) (position subxmax Ysub subz-
max) "Silicon" "region_1" )

; GATE OXIDE REGION - Main
(isegeo:create-cuboid (position (* Xg -1.0) 0 0) (position Xg Ygox wn) "SiO2"
"region_2")

; PolySi GATE - Main
(isegeo:create-cuboid (position (* Xg -1.0) Ygox 0) (position Xg Ypol wn) "PolySi"
"region_3")

; STI REGION - I ("behind" S/D, till the left edge of the gate extension)
(isegeo:create-cuboid (position subxmin 0 wn) (position 0.18 0.4 subzmax) "Oxide"
"STI1" )

; STI REGION - III ("to the right" of S/D)
(isegeo:create-cuboid (position 0.18 0 subzmin) (position 0.93 0.40 subzmax) "Ox-
ide" "STI3" )

; STI REGION - IV ("in front of" of S/D, till the left edge of the gate extension)
(isegeo:create-cuboid (position subxmin 0 0) (position 0.28 0.40 subzmin) "Oxide"
"STI4" )

; STI REGION - VI ("to the left of" of S/D)
(isegeo:create-cuboid (position subxmin 0 0) (position -0.18 0.40 wn) "Oxide"
"STI6" )

; STI REGION - VII ("to the right of p-well contact" of S/D)
(isegeo:create-cuboid (position 1.06 0 subzmin) (position subxmax 0.4 subzmax)
"Oxide" "STI7" )

;Poly Reoxidation
(isegeo:set-default-boolean "BAB")
(isegeo:create-cuboid (position (* (+ Xg Lpreox) -1.0) Ygox 0) (position (+ Xg
```

```
Lpreox) Ypol wn) “Oxide” “PolyReOxide1”)
(isegeo:create-cuboid (position (* (+ Xg (+ Lspacer Lpreox)) -1.0) 0 0) (position
(+ Xg (+ Lspacer Lpreox)) -0.005 wn) “Oxide” “PolyReOxide2”)

;Spacer
(isegeo:create-cuboid (position (* (+ Xg (+ Lspacer Lpreox)) -1.0) 0 0) (position
(+ Xg (+ Lspacer Lpreox)) Ypol wn) “Si3N4” “NiSpacer”)
(ise:define-parameter “fillet-radius” 0.01 0.0 0.0 )
(isegeo:fillet-edges (list (car (find-edge-id (position (* (+ Xg (+ Lspacer Lpreox))
-1.0) Ypol (/ wn 2)))) (car (find-edge-id (position (+ Xg (+ Lspacer Lpreox)) Ypol
(/ wn 2)))) ) fillet-radius)

;————————————————————————————————————————
; DEFINING AND PLACING CONTACTS

; SUBSTRATE CONTACT
(isegeo:define-contact-set “substrate” 4.0 (color:rgb 0.0 1.0 1.0 ) “##”)
(isegeo:define-3d-contact (find-face-id (position 0.01 Ysub 0.01)) “substrate”)

; GATE CONTACT
(isegeo:define-contact-set “gate” 4.0 (color:rgb 0.0 0.0 1.0 ) “——”)
(isegeo:define-3d-contact (find-face-id (position 0 Ypol (/ wn 2))) “gate”)

; DRAIN CONTACT
(isegeo:create-cuboid (position -0.066 0 0.02) (position -0.164 -0.2 (- wn 0.02))
“Metal” “Drainmetal”)
(isegeo:define-contact-set “drain_nmos” 4.0 (color:rgb 0.0 0.0 1.0 ) “##”)
(isegeo:define-3d-contact (find-face-id (position -0.1 0 (/ wn 2))) “drain_nmos”)
(isegeo:delete-region (find-body-id (position -0.1 -0.1 (/ wn 2))))

; SOURCE CONTACT
(isegeo:create-cuboid (position 0.066 0 0.02) (position 0.164 -0.2 (- wn 0.02))
“Metal” ”Sourcemetal”)
(isegeo:define-contact-set “source_nmos” 4.0 (color:rgb 0.0 0.0 1.0 ) “##”)
(isegeo:define-3d-contact (find-face-id (position 0.1 0 (/ wn 2))) “source_nmos”)
(isegeo:delete-region (find-body-id (position 0.1 -0.1 (/ wn 2))))

; p-WELL CONTACT (this would be connected to ground, along with the source)
(isegeo:create-cuboid (position 0.946 0 (+ subzmin 0.02)) (position 1.044 -0.2
(- subzmax 0.02)) “Metal” “pwell”)
(isegeo:define-contact-set “pwell” 4.0 (color:rgb 0.0 0.0 1.0 ) “##”)
(isegeo:define-3d-contact (find-face-id (position 0.98 0 0.12)) “pwell”)
(isegeo:delete-region (find-body-id (position 0.98 -0.1 0.12)))
```

;———————————————————————————————————————
; Saving BND file
;(define SOI (part:entities (filter:type "solid?"))) (iseio:save-dfise-bnd SOI "nmos65jon.bnd")
;———————————————————————————————————————

; SET DOPING REGIONS AND PROFILES
; CONSTANT DOPING PROFILES
; SUBSTRATE REGION AND PROFILE
(isedr:define-constant-profile "region_1" "BoronActiveConcentration" Dop)
(isedr:define-constant-profile-region "region_1" "region_1" "region_1")

; PolySi GATE REGION AND PROFILE - Main
(isedr:define-constant-profile "region_3" "ArsenicActiveConcentration" 2e20)
(isedr:define-constant-profile-region "region_3" "region_3" "region_3")

; ANALYTICAL DOPING PROFILES
; SUBSTRATE (LATCHUP) PROFILE (IN BETWEEN THE p-WELL AND THE SUBSTRATE)
(isedr:define-refinement-window "Latchup.Profile.Region" "Rectangle" (position subxmin 1.25 subzmin) (position subxmax 1.25 subzmax))
(isedr:define-gaussian-profile "Latchup.Profile" "BoronActiveConcentration" "PeakPos" 0 "PeakVal" 5e18 "ValueAtDepth" 1e16 "Depth" 0.4 "Gauss" "Factor" 0.0001)
(isedr:define-analytical-profile-placement "Latchup.Profile.Place" "Latchup.Profile" "Latchup.Profile.Region" "Symm" "NoReplace" "Eval")

; p-WELL PROFILE OF THE NMOS DEVICE
(isedr:define-refinement-window "pwell.Profile.Region" "Rectangle" (position subxmin 0.65 subzmin) (position subxmax 0.65 subzmax))
(isedr:define-gaussian-profile "pwell.Profile" "BoronActiveConcentration" "PeakPos" 0 "PeakVal" 2e18 "ValueAtDepth" 1e17 "Depth" 0.35 "Gauss" "Factor" 0.0001)
(isedr:define-analytical-profile-placement "pwell.Profile.Place" "pwell.Profile" "pwell.Profile.Region" "Symm" "NoReplace" "Eval")

; p-WELL CONTACT PROFILE (DEGENRATE DOPING FOR p-WELL CONTACT)
(isedr:define-refinement-window "pwelltap.Profile.Region" "Rectangle" (position 0.93 0 subzmin) (position 1.06 0 subzmax))
(isedr:define-gaussian-profile "pwelltap.Profile" "BoronActiveConcentration" "PeakPos" 0 "PeakVal" 2e20 "ValueAtDepth" 1e17 "Depth" 0.06 "Gauss" "Factor" 0.0001)

(isedr:define-analytical-profile-placement "pwelltap. Profile.Place" "pwelltap.Profile" "pwelltap.Profile.Region" "Symm" "NoReplace" "Eval")

; SOURCE
(isedr:define-refinement-window "source.Profile.Region" "Rectangle" (position 0.05 0 0) (position 0.18 0 wn))
(isedr:define-gaussian-profile "source.Profile" "ArsenicActiveConcentration" "PeakPos" 0 "PeakVal" 2e20 "ValueAtDepth" 1e17 "Depth" 0.024 "Gauss" "Factor" 0.1)
(isedr:define-analytical-profile-placement "source.Profile.Place" "source.Profile" "source.Profile.Region" "Symm" "NoReplace" "Eval")

; SOURCE HALO
(isedr:define-refinement-window "HSimplant.Profile.Region" "Rectangle" (position 0.012 0.014 0) (position 0.017 0.014 wn))
(isedr:define-gaussian-profile "HSimplant.Profile" "BoronActiveConcentration" "PeakPos" 0 "PeakVal" 2e19 "ValueAtDepth" 1e16 "Depth" 0.014 "Gauss" "Factor" 0.0001)
(isedr:define-analytical-profile-placement "HSimplant.Profile.Place" "HSimplant.Profile" "HSimplant.Profile.Region" "Symm" "NoReplace" "Eval")

; DRAIN
(isedr:define-refinement-window "drain.Profile.Region" "Rectangle" (position -0.05 0 0) (position -0.18 0 wn))
(isedr:define-gaussian-profile "drain.Profile" "ArsenicActiveConcentration" "PeakPos" 0 "PeakVal" 2e20 "ValueAtDepth" 1e17 "Depth" 0.024 "Gauss" "Factor" 0.1)
(isedr:define-analytical-profile-placement "drain.Profile.Place" "drain.Profile" "drain.Profile.Region" "Symm" "NoReplace" "Eval")

; DRAIN HALO
(isedr:define-refinement-window "HDimplant.Profile.Region" "Rectangle" (position -0.012 0.014 0) (position -0.017 0.014 wn))
(isedr:define-gaussian-profile "HDimplant.Profile" "BoronActiveConcentration" "PeakPos" 0 "PeakVal" 2e19 "ValueAtDepth" 1e16 "Depth" 0.014 "Gauss" "Factor" 0.0001)
(isedr:define-analytical-profile-placement "HDimplant.Profile.Place" "HDimplant.Profile" "HDimplant.Profile.Region" "Symm" "NoReplace" "Eval")

; LDD - SOURCE
(isedr:define-refinement-window "sourceldd.Profile.Region" "Rectangle" (position 0.016 0.0 0) (position 0.08 0 wn))
(isedr:define-gaussian-profile "sourceldd.Profile" "ArsenicActiveConcentration" "PeakPos" 0 "PeakVal" 8e18 "ValueAtDepth" 1e17 "Depth" 0.014 "Gauss" "Factor" 0.1)

(isedr:define-analytical-profile-placement "sourceldd.Profile.Place" "sourceldd.Profile" "sourceldd.Profile.Region" "Symm" "NoReplace" "Eval")

; LDD - DRAIN
(isedr:define-refinement-window "drainldd.Profile.Region" "Rectangle" (position -0.016 0.0 0) (position -0.08 0 wn))
(isedr:define-gaussian-profile "drainldd.Profile" "ArsenicActiveConcentration" "PeakPos" 0 "PeakVal" 8e18 "ValueAtDepth" 1e17 "Depth" 0.014 "Gauss" "Factor" 0.1)
(isedr:define-analytical-profile-placement "drainldd.Profile.Place" "drainldd.Profile" "drainldd.Profile.Region" "Symm" "NoReplace" "Eval")

; Vt IMPLANT
(isedr:define-refinement-window "implant.Profile.Region" "Rectangle" (position -0.015 0.002 0) (position 0.015 0.002 wn))
(isedr:define-gaussian-profile "implant.Profile" "BoronActiveConcentration" "PeakPos" 0 "PeakVal" 8e18 "ValueAtDepth" 1e17 "Depth" 0.01 "Gauss" "Factor" 0.0001)
(isedr:define-analytical-profile-placement "implant.Profile.Place" "implant.Profile" "implant.Profile.Region" "Symm" "NoReplace" "Eval")

; IMPLANT TO MITIGATE LEAKAGE (BELOW Vt IMPLANT)
(isedr:define-refinement-window "limplant.Profile.Region" "Rectangle" (position -0.015 0.014 0) (position 0.015 0.014 wn))
(isedr:define-gaussian-profile "limplant.Profile" "BoronActiveConcentration" "PeakPos" 0 "PeakVal" 7e18 "ValueAtDepth" 2e17 "Depth" 0.005 "Gauss" "Factor" 0.0001)
(isedr:define-analytical-profile-placement "limplant.Profile.Place" "limplant.Profile" "limplant.Profile.Region" "Symm" "NoReplace" "Eval")

; STI Implant - Front & Back Extensions
(isedr:define-refinement-window "Window.FrontB" "Rectangle" (position -0.018 0 -0.001) (position 0.018 0.36 -0.001))
(isedr:define-refinement-window "Window.BackB" "Rectangle" (position -0.018 0 (+ wn 0.001)) (position 0.018 0.36 (+ wn 0.001)))
(isedr:define-constant-profile "Profile.ImplantB" "BoronActiveConcentration" 5e19)

(isedr:define-constant-profile-placement "Place.Implant.FrontB" "Profile.ImplantB" "Window.FrontB")
(isedr:define-constant-profile-placement "Place.Implant.BackB" "Profile.ImplantB" "Window.BackB")

;——————————————————————————————

; DEFINE MESHING REGIONS AND MAX-MIN MESH SPACINGS

; UPPER SUBSTRATE REGION
(isedr:define-refinement-size “region_1” 0.5 0.5 0.5 0.2 0.2 0.2)
(isedr:define-refinement-window “region_1” “Cuboid” (position subxmin 0.1 subzmin) (position subxmax 2 subzmax))
(isedr:define-refinement-function “region_1” “DopingConcentration” “MaxTransDiff” 0.1)
(isedr:define-refinement-placement “region_1” “region_1” “region_1”)

; STI IMPLANT
(isedr:define-refinement-size “sti” 0.01 0.025 0.001 0.005 0.005 0.0005)
(isedr:define-refinement-window “sti” “Cuboid” (position -0.018 0 0) (position 0.018 0.36 0.002))
(isedr:define-refinement-function “sti” “DopingConcentration” “MaxTransDiff” 0.1)
(isedr:define-refinement-placement “sti” “sti” “sti”)

; STI IMPLANT-I
(isedr:define-refinement-size “sti1” 0.01 0.025 0.001 0.005 0.005 0.0005)
(isedr:define-refinement-window “sti1” “Cuboid” (position -0.018 0 0.998) (position 0.018 0.36 1))
(isedr:define-refinement-function “sti1” “DopingConcentration” “MaxTransDiff” 0.1)
(isedr:define-refinement-placement “sti1” “sti1” “sti1”)

; LOWER SUBSTRATE REGION
(isedr:define-refinement-size “region_12” 0.75 0.75 0.75 0.5 0.5 0.5)
(isedr:define-refinement-window “region_12” “Cuboid” (position subxmin 2 subzmin) (position subxmax Ysub subzmax))
(isedr:define-refinement-function “region_12” “DopingConcentration” “MaxTransDiff” 0.1)
(isedr:define-refinement-placement “region_12” “region_12” “region_12”)

; CHANNEL REGION
;(isedr:define-refinement-size “R.Channel” 0.01 0.01 0.1 0.002 0.002 0.1)
(isedr:define-refinement-size “R.Channel” 0.005 0.005 0.05 0.002 0.002 0.1)
(isedr:define-refinement-window “R.Channel” “Cuboid” (position (* Xg -1.0) 0 0) (position Xg 0.05 wn))
(isedr:define-refinement-function “R.Channel” “DopingConcentration” “MaxTransDiff” 0.1)
(isedr:define-refinement-placement “R.Channel” “R.Channel” “R.Channel”)

; SOURCE/DRAIN REGION
(isedr:define-refinement-size “sourcedrain” 0.02 0.02 0.1 0.02 0.02 0.1)
(isedr:define-refinement-window “sourcedrain” “Cuboid” (position -0.18 0 0) (position 0.18 0.1 wn))

```
(isedr:define-refinement-function "sourcedrain" "DopingConcentration" "MaxTransDiff" 0.1)
(isedr:define-refinement-placement "sourcedrain" "sourcedrain" "sourcedrain")

; Vt & LEAKAGE IMPLANT REGIONS
(isedr:define-refinement-size "implant" 0.01 0.01 0.1 0.002 0.002 0.1)
(isedr:define-refinement-window "implant" "Cuboid" (position -0.018 0 0) (position 0.018 0.07 wn))
(isedr:define-refinement-function "implant" "DopingConcentration" "MaxTransDiff" 0.1)
(isedr:define-refinement-placement "implant" "implant" "implant" )
; p-WELL CONTACT REGION
(isedr:define-refinement-size "ptap" 0.1 0.1 0.2 0.05 0.05 0.2)
(isedr:define-refinement-window "ptap" "Cuboid" (position 0.93 0 subzmin) (position 1.06 0.1 subzmax))
(isedr:define-refinement-function "ptap" "DopingConcentration" "MaxTransDiff" 0.1)
(isedr:define-refinement-placement "ptap" "ptap" "ptap" )

; p-WELL CONTACT REGION-I
(isedr:define-refinement-size "ptap1" 0.02 0.02 0.1 0.005 0.005 0.05)
(isedr:define-refinement-window "ptap1" "Cuboid" (position 0.93 0 0) (position 1.06 0.1 wn))
(isedr:define-refinement-function "ptap1" "DopingConcentration" "MaxTransDiff" 0.1) (isedr:define-refinement-placement "ptap1" "ptap1" "ptap1" )

; ION TRACK
(isedr:define-refinement-size "itrack" 0.01 0.5 0.01 0.005 0.5 0.005)
(isedr:define-refinement-window "itrack" "Cuboid" (position -0.07 0 (- (/ wn 2) 0.06)) (position -0.15 Ysub (+ (/ wn 2) 0.06)))
(isedr:define-refinement-function "itrack" "DopingConcentration" "MaxTransDiff" 0.1)
(isedr:define-refinement-placement "itrack" "itrack" "itrack" )

;——————————————————————-
; Save CMD file
(sdedr:write-cmd-file "nmos_msh.cmd")

;——————————————————————-
; Meshing structure
(ise:build-mesh "mesh" "-P" "nmos_msh")
```

The above code generates the 3D NMOS device shown in Fig. 5.2. This code generates two files (nmos_msh.grd and nmos_msh.dat) for the 3D NMOS transistor. Both these files are used with Sentaurus-DEVICE for mixed-level simulations.

A.1.1 Code for Mixed-Level Simulation of a Radiation Particle Strike Using Sentaurus-DEVICE

To simulate a radiation particle strike at the drain of the NMOS transistor of the INV shown in Fig. 5.1, the following code was used with Sentaurus-DEVICE simulator.

```
# define the n-channel MOSFET;
Device NMOS {
Electrode {
{ Name="source_nmos" Voltage=0 }
{ Name="drain_nmos" Voltage=0 }
{ Name="gate" Voltage=0}
{ Name="pwell" Voltage=0 }
{ Name="substrate" Voltage=0}

}
# Define input and output files for simulation
File {
Grid = "nmos_msh.grd" #NMOS transistor file
Doping = "nmos_msh.dat" #NMOS transistor file
Plot = "nmos"
Current = "nmos"
Param = "mos"
}

# Physical models to be applied in the simulation
Physics {
Mobility( PhuMob ( Arsenic ) HighFieldsat Enormal )
Fermi
EffectiveIntrinsicDensity( OldSlotboom )
Recombination ( SRH Auger )
Hydrodynamic( eTemperature )
#Heavy ion strike
HeavyIon (
PicoCoulomb
Direction=(0,1,0)
Location=(-0.11,0,0.5)
Length=2
Time=1e-9
LET_f=0.1 #0.1pC corresponds to 10MeV-cm2/mg
wt_hi=0.03
Gaussian
)

}
}
```

```
File{
Plot = “nmosparticlestrike_n@node@.dat”
SPICEPath = “.”
Current = “nmoslet10mm_n@node@.plt”
}

#Define the electric circuit which is to be simulated
System{
NMOS nmos(“source_nmos” = 0 “pwell”=0 “gate”=n1 “drain_nmos” = n2 “sub-
strate”=0)
pmos m0 (n2 n1 n3 n3) {w=4e-6 l=0.065e-6 as=0.52e-12 ad=0.52e-12 ps=4.26e-6
pd=4.26e-6}
Vsource_pset v1(n3 0){pwl = (0 0 100p @vdd@ 10e-9 @vdd@)}
Vsource_pset vin(n1 0){pwl = (0 0 150e-12 0 5e-9 0)}
Capacitor_pset c1 (n2 0) {capacitance=25e-15}
Plot “nmosstrike_n@node@.plt” (time() n2 i(nmos n2) i(m0 n2) i(c1 n2))
}

#Specify solution variables to be saved in the output plot files
Plot {
eDensity hDensity eCurrent hCurrent
equasiFermi hquasiFermi
eTemperature
ElectricField eEparallel hEparallel
Potential SpaceCharge
SRHRecombination Auger AvalancheGeneration
eMobility hMobility eVelocity hVelocity
Doping DonorConcentration AcceptorConcentration
ConductionBandEnergy ValenceBandEnergy
HeavyIonChargeDensity
}

#Define few settings for the numeric solver
Math { Extrapolate
Derivatives
Newdiscretization
RecBoxIntegr
Method=ILS
RelErrControl
Iterations=20
notdamped=100
Number_of_Threads = 4
Wallclock
}
```

```
#Define a sequence of solutions to be obtained by the solver
Solve {
Coupled (Iterations=100) {Circuit}
Coupled (Iterations=100) {Poisson}
Coupled (Iterations=100) {Poisson Circuit}
Coupled (Iterations=100) {Poisson Contact Circuit}
Coupled (Iterations=100) {Poisson Hole Contact Circuit}
Coupled (Iterations=100) {Poisson Hole Electron Contact Circuit}


NewCurrentFile="transient_n@node@"
#Define transient simulation parameters
Transient (
InitialTime=0 FinalTime=0.99e-9 InitialStep=1e-12 MaxStep=1e-10
Increment=1.3)
{
Coupled {nmos.poisson nmos.electron nmos.hole nmos.contact circuit }
}
Transient ( # Take very small time step during the heavy ion strike
InitialTime=0.99e-9 FinalTime=1.1e-9 InitialStep=1e-13 MaxStep=1e-12
Increment=1.3)
{
Coupled {nmos.poisson nmos.electron nmos.hole nmos.contact circuit }
Plot (FilePrefix="invconstdmm_n@node@_10" Time=(1.0e-9; 1.01e-9; 1.02e-9;
1.035e-9; 1.05e-9;
1.07e-9; 1.09e-9) NoOverwrite)
}
Transient (
InitialTime=1.1e-9 FinalTime=4e-9 InitialStep=1e-12 MaxStep=1e-10
Increment=1.3)
{
Coupled {nmos.poisson nmos.electron nmos.hole nmos.contact circuit }
Plot (FilePrefix="invconstdmm_n@node@_10_1" Time=(1.11e-9; 1.13e-9; 1.15e-
9) NoOverwrite)
}

}
```

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