Annotated TCAD Command Code

Portfolio-ready annotated version of SDE, SDevice, GIDL, LDD/Halo, and SONOS Program/Erase command scripts

Source: user-provided TCAD_COMMANDCODE.docx. This annotated document is intended for portfolio explanation and code review. Keep the original command files as the executable source.

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1. LONG SDE CODE

- Builds the long-channel reference MOSFET structure.
- Defines substrate/gate regions, source/drain doping, contacts, mesh refinement, and mirror symmetry.

Annotated Code

```
; Clear any previously defined SDE geometry, doping, mesh, and contacts.
(sde:clear)
; Define the process-up direction so vertical coordinates are interpreted consistently.
(sde:set-process-up-direction "+z")

; Select doping species and carrier models based on whether the device is nMOS or pMOS.
(if (string=? "@Type@" "nMOS")
   (begin
; Define the substrate dopant species.
      (define DopSub "BoronActiveConcentration")
; Define the source/drain and gate dopant species.
      (define DopSD "ArsenicActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18 )
)
(begin
; Define the substrate dopant species.
   (define DopSub "ArsenicActiveConcentration")
; Define the source/drain and gate dopant species.
   (define DopSD "BoronActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18)
)
)

; Gate length parameter imported from Sentaurus Workbench.
(define Lg @lgate@)
; Total simulated lateral length, including gate and source/drain extension region.
(define Ltot (+ Lg (* 2 0.01) 0.8) )

; Substrate thickness used for the 2D device cross-section.
(define Hsub 1.0)
; Gate oxide thickness parameter imported from Workbench.
(define Tox @Toxide@)
; Polysilicon gate height.
(define Hpol 0.2)


; Minimum mesh size control used near critical regions.
(define Gpn 0.005)

; Approximate junction depth used for source/drain implants.
(define Xj 0.1 )


; Derived dimensions are computed from the primary process/device parameters.
;Derived quantities
; Half-device lateral boundary for building a symmetric structure.
(define Xmax (/ Ltot 2.0))
; Half gate length.
(define Xg (/ Lg 2.0))

; Bottom substrate coordinate.
(define Ysub Hsub)
; Gate oxide top/bottom coordinate based on oxide thickness.
(define Ygox (* Tox -1.0))
```

```
; Top polysilicon coordinate.
(define Ypol (- Ygox Hpol))

(define Lcont Xmax)

; Set the default Boolean operation for overlapping SDE geometry creation.
(sdegeo:set-default-boolean "ABA")

; Create a 2D rectangular material region such as silicon, oxide, spacer, or polysilicon.
(sdegeo:create-rectangle
   (position 0.0 Ysub 0.0 )
   (position Xmax 0.0 0.0 )
; Name the silicon body/substrate region.
   "Silicon" "R.Substrate"
)

(sdegeo:create-rectangle
   (position 0.0 0.0  0.0 )
   (position Xg Ygox 0.0 )
; Name the gate oxide region.
   "Oxide" "R.Gateox"
)

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xg Ypol 0.0 )
; Define the re-oxidized oxide region around the polysilicon gate.
   "Oxide" "R.PolyReox"
)

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xg Ypol 0.0 )
; Define the polysilicon gate region.
   "PolySi" "R.Polygate"
)

; Assign electrical contacts to selected geometry edges.
(sdegeo:set-contact
   (find-edge-id (position (* (+ Xmax Xg) 0.5) 0.0 0.0))
; Label this contact as the drain.
   "drain")
(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ypol 0.0))
; Label this contact as the gate.
   "gate")
(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ysub 0.0))
; Label this contact as the substrate/body.
   "substrate")


; Define uniform doping profiles for substrate and gate regions.
(sdedr:define-constant-profile "Const.Substrate"
DopSub SubDop )
(sdedr:define-constant-profile-region "PlaceCD.Substrate" "Const.Substrate" "R.Substrate" )

(sdedr:define-constant-profile "Const.Gate"
DopSD 1e20 )
(sdedr:define-constant-profile-region "PlaceCD.Gate" "Const.Gate" "R.Polygate" )



; Define a geometric window or baseline used for implant placement or mesh refinement.
(sdedr:define-refeval-window "BaseLine.Drain" "Line"
   (position (+ Xg 0.035) 0.0 0.0 )
```

```
   (position (* Xmax 2.0) 0.0 0.0 ) )

; Define Gaussian implant profiles for source/drain, LDD extension, or halo regions.
(sdedr:define-gaussian-profile "Impl.SDprof"
DopSD
; Set a very high implant peak concentration.
"PeakPos" 0 "PeakVal" 1e20
"ValueAtDepth" SubDop "Depth" Xj
"Gauss" "Factor" 0.4
)

; Source/drain implant profile: high peak concentration for heavily doped drain/source.
(sdedr:define-analytical-profile-placement "Impl.Drain" "Impl.SDprof" "BaseLine.Drain" "Symm" "NoReplace" "Eval")




; Define mesh refinement sizes for important regions.
(sdedr:define-refinement-size "Ref.Substrate"
(/ Ltot 4.0) (/ Hsub 8.0)
Gpn           Gpn )
; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.Substrate" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-region "RefPlace.Substrate" "Ref.Substrate" "R.Substrate" )

(sdedr:define-refeval-window "RWin.Act" "Rectangle"
   (position 0.0 0.0 0.0)
   (position Xmax (* Xj 1.2) 0.0 ) )
(sdedr:define-refinement-size "Ref.SiAct"
   (/ Lcont 4.0) (/ Xj 8.0)
   Gpn            Gpn )




; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.SiAct" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-placement "RefPlace.SiAct" "Ref.SiAct" "RWin.Act" )

(sdedr:define-refinement-size "Ref.GOX"
   (/ Ltot 4.0) (/ Tox 4.0)
   Gpn         (/ Tox 8.0) )
(sdedr:define-refinement-region "RefPlace.GOX" "Ref.GOX" "R.Gateox" )

(sdedr:define-refeval-window "MBWindow.Gate" "Rectangle"
   (position (* Xg -1.0) Ypol 0.0)
   (position (* Xg 1.0) Ygox 0.0))

; Use multibox refinement to create a fine mesh near the gate/channel and a coarser mesh away from it.
(sdedr:define-multibox-size "MBSize.Gate"
   (/ Lg 8.0) (/ Hpol 8.0)
   (/ Lg 10.0) 2e-4
   1.0 -1.35)
(sdedr:define-multibox-placement "MBPlace.Gate" "MBSize.Gate" "MBWindow.Gate")



(sdedr:define-refeval-window "MBWindow.Channel" "Rectangle"
   (position 0.0 0.0 0.0)
   (position (* Xg 1.2) (* 0.5 Xj) 0.0) )
(sdedr:define-multibox-size "MBSize.Channel"
   (/ Lg 8.0) (/ Xj 8.0)
   (/ Lg 10.0) 1e-4
   1.0 1.35)
(sdedr:define-multibox-placement "MBPlace.Channel" "MBSize.Channel" "MBWindow.Channel")
```

```
(sedr:define-refinement-size "Ref.J"
   (/ 0.016 6.0) 99
   (/ 0.016 7.0) 66)

(sedr:define-refeval-window "RWin.GD" "Rectangle"
   (position (- Xg 0.01) 0.0
```

2. LONG SDEVICE transfer_curve CODE

- Builds the long-channel reference MOSFET structure.
- Defines substrate/gate regions, source/drain doping, contacts, mesh refinement, and mirror symmetry.

Annotated Code

```
!(
; Switch simulation settings between nMOS and pMOS cases.
if { "@Type@" == "nMOS" } {
; SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN 1.0
; Select density-gradient quantum correction for electrons or holes.
set DG "eQuantumPotential"
; Select carrier temperature variable for hydrodynamic transport.
set cTemp "eTemperature"
; Set the gate work function used by the gate electrode.
set WF 4.2
; Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson eQuantumPotential Electron "
; Define the full coupled equation set for the final device solution.
set EQNS "Poisson eQuantumPotential Electron Hole eTemperature"
} else {
; SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN -1.0
; Select density-gradient quantum correction for electrons or holes.
set DG "hQuantumPotential"
; Select carrier temperature variable for hydrodynamic transport.
set cTemp "hTemperature"
; Set the gate work function used by the gate electrode.
set WF 4.8
; Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson hQuantumPotential Hole"
; Define the full coupled equation set for the final device solution.
set EQNS "Poisson hQuantumPotential Electron Hole hTemperature"
}
)!


; File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
*input files:
; Input mesh generated from SDE/SProcess.
Grid= "@tdr@"
; Input mechanical/strain file, if available.
Piezo= "@tdr@"
; Parameter file passed from Sentaurus Workbench.
Parameter= "@parameter@"
*output files:
; TDR output file for spatial physical quantities.
Plot= "@tdrdat@"
; Output file for terminal currents.
Current= "@plot@"
; Log/output file for solver messages.
Output= "@log@"
}

; Define terminal boundary conditions and contact properties.
Electrode {
; Source terminal is grounded.
{ Name= "source" Voltage= 0.0 Resistor = 40 }
; Drain terminal bias is initialized, then later ramped/swept.
{ Name= "drain" Voltage= 0.0 Resistor = 40 }
```

```
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
{ Name= "gate" Voltage= 0.0 Workfunction = !(puts $WF)! }
; Body/substrate terminal is grounded.
{ Name= "substrate" Voltage= 0.0}
}

; Enable global physical models used by SDevice.
Physics {
; Use Fermi-Dirac carrier statistics for highly doped regions.
Fermi
; Enable hydrodynamic transport to account for carrier heating/high-field effects.
Hydrodynamic( !(puts $cTemp)! )
}
#include "Plot_Math_des.cmd"

; Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
* =Creating initial guess:
NewCurrentFile="n@node@_init"
; Solve Poisson and transport equations self-consistently.
Coupled(Iterations= 1000 LineSearchDamping = 1e-4){ Poisson !(puts $DG)!}
Coupled { !(puts $EQN0)! }
Coupled { !(puts $EQNS)! }

*-ramp to gate to negative
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
; Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
; Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
Goal { Name="gate" Voltage = -2.0}
; Solve Poisson and transport equations self-consistently.
)  { Coupled { Poisson !(puts $DG)! }}

*-ramp to drain to Vd
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
; Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
; Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
; Drain terminal bias is initialized, then later ramped/swept.
Goal { Name="drain" Voltage = !(puts [expr $SIGN*@Vd@])!}
){ Coupled { !(puts $EQNS)! }}

; Save spatial solution snapshots for visualization.
Plot ( FilePrefix = "n@node@_GIDL_" )

*-Vg sweep
; Set current-output file prefix for this sweep.
NewCurrentPrefix=""
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
doZero
; Control numerical step size for convergence and resolution.
InitialStep= 1e-3 Increment = 1.5
; Control numerical step size for convergence and resolution.
MinStep = 1e-7 MaxStep = 0.04
; Bias target for the current ramp or sweep.
Goal { Name = "gate" Voltage = !(puts [expr $SIGN*@Vg@])!}
){ Coupled { !(puts $EQNS)! }
; Sample terminal currents during the sweep.
CurrentPlot( Time=(Range=(0 1) Intervals = 30) )
}
```

```
}
```

3. LONG SDEVICE output_CURVE CODE

- Builds the long-channel reference MOSFET structure.
- Defines substrate/gate regions, source/drain doping, contacts, mesh refinement, and mirror symmetry.

Annotated Code

```
!(
; Switch simulation settings between nMOS and pMOS cases.
if { "@Type@" == "nMOS" } {
; SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN 1.0
; Select density-gradient quantum correction for electrons or holes.
set DG "eQuantumPotential"
; Select carrier temperature variable for hydrodynamic transport.
set cTemp "eTemperature"
; Set the gate work function used by the gate electrode.
set WF 4.2
; Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson eQuantumPotential Electron "
; Define the full coupled equation set for the final device solution.
set EQNS "Poisson eQuantumPotential Electron Hole eTemperature"
} else {
; SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN -1.0
; Select density-gradient quantum correction for electrons or holes.
set DG "hQuantumPotential"
; Select carrier temperature variable for hydrodynamic transport.
set cTemp "hTemperature"
; Set the gate work function used by the gate electrode.
set WF 4.8
; Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson hQuantumPotential Hole"
; Define the full coupled equation set for the final device solution.
set EQNS "Poisson hQuantumPotential Electron Hole hTemperature"
}
)!


; File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
*input files:
; Input mesh generated from SDE/SProcess.
Grid= "@tdr@"
; Input mechanical/strain file, if available.
Piezo= "@tdr@"
; Parameter file passed from Sentaurus Workbench.
Parameter= "@parameter@"
*output files:
; TDR output file for spatial physical quantities.
Plot= "@tdrdat@"
; Output file for terminal currents.
Current= "@plot@"
; Log/output file for solver messages.
Output= "@log@"
}

; Define terminal boundary conditions and contact properties.
Electrode {
; Source terminal is grounded.
{ Name= "source" Voltage= 0.0 Resistor = 40 }
; Drain terminal bias is initialized, then later ramped/swept.
{ Name= "drain" Voltage= 0.0 Resistor = 40 }
```

```
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
{ Name= "gate" Voltage= 0.0 Workfunction = !(puts $WF)! }
; Body/substrate terminal is grounded.
{ Name= "substrate" Voltage= 0.0}
}

; Enable global physical models used by SDevice.
Physics {
; Use Fermi-Dirac carrier statistics for highly doped regions.
Fermi
; Enable hydrodynamic transport to account for carrier heating/high-field effects.
Hydrodynamic( !(puts $cTemp)! )
}
#include "Plot_Math_des.cmd"

; Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
* =Creating initial guess:
NewCurrentFile="n@node@_init"
; Solve Poisson and transport equations self-consistently.
Coupled(Iterations= 1000 LineSearchDamping = 1e-4){ Poisson !(puts $DG)!}
Coupled { !(puts $EQN0)! }
Coupled { !(puts $EQNS)! }


*-ramp to drain to Vd
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
; Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
; Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
Goal { Name="gate" Voltage = !(puts [expr $SIGN*@Vgg@])!}
){ Coupled { !(puts $EQNS)! }}

; Save spatial solution snapshots for visualization.
Plot ( FilePrefix = "n@node@_@Vgg@Vg_" )

*-Vg sweep
; Set current-output file prefix for this sweep.
NewCurrentPrefix="IdVd_"
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
doZero
; Control numerical step size for convergence and resolution.
InitialStep= 1e-3 Increment = 1.5
; Control numerical step size for convergence and resolution.
MinStep = 1e-7 MaxStep = 0.04
; Bias target for the current ramp or sweep.
Goal { Name = "drain" Voltage = !(puts [expr $SIGN*@Vdd@])!}
){ Coupled { !(puts $EQNS)! }
; Sample terminal currents during the sweep.
CurrentPlot( Time=(Range=(0 1) Intervals = 30) )
}
```

4. LONG GIDL SDE CODE

- Builds a MOSFET structure for GIDL analysis.
- Uses a sharper drain implant profile to increase the high-field region near the drain edge.

Annotated Code

```
; Clear any previously defined SDE geometry, doping, mesh, and contacts.
(sde:clear)
; Define the process-up direction so vertical coordinates are interpreted consistently.
(sde:set-process-up-direction "+z")

; Select doping species and carrier models based on whether the device is nMOS or pMOS.
(if (string=? "@Type@" "nMOS")
   (begin
; Define the substrate dopant species.
      (define DopSub "BoronActiveConcentration")
; Define the source/drain and gate dopant species.
      (define DopSD "ArsenicActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18 )
)
(begin
; Define the substrate dopant species.
   (define DopSub "ArsenicActiveConcentration")
; Define the source/drain and gate dopant species.
   (define DopSD "BoronActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18)
)
)

; Gate length parameter imported from Sentaurus Workbench.
(define Lg @lgate@)
; Total simulated lateral length, including gate and source/drain extension region.
(define Ltot (+ Lg (* 2 0.01) 0.8) )

; Substrate thickness used for the 2D device cross-section.
(define Hsub 1.0)
; Gate oxide thickness parameter imported from Workbench.
(define Tox @Toxide@)
; Polysilicon gate height.
(define Hpol 0.2)


; Minimum mesh size control used near critical regions.
(define Gpn 0.005)

; Approximate junction depth used for source/drain implants.
(define Xj 0.1 )


; Derived dimensions are computed from the primary process/device parameters.
;Derived quantities
; Half-device lateral boundary for building a symmetric structure.
(define Xmax (/ Ltot 2.0))
; Half gate length.
(define Xg (/ Lg 2.0))

; Bottom substrate coordinate.
(define Ysub Hsub)
; Gate oxide top/bottom coordinate based on oxide thickness.
(define Ygox (* Tox -1.0))
```

```
; Top polysilicon coordinate.
(define Ypol (- Ygox Hpol))

(define Lcont Xmax)

; Set the default Boolean operation for overlapping SDE geometry creation.
(sdegeo:set-default-boolean "ABA")

; Create a 2D rectangular material region such as silicon, oxide, spacer, or polysilicon.
(sdegeo:create-rectangle
   (position 0.0 Ysub 0.0 )
   (position Xmax 0.0 0.0 )
; Name the silicon body/substrate region.
   "Silicon" "R.Substrate"
)

(sdegeo:create-rectangle
   (position 0.0 0.0  0.0 )
   (position Xg Ygox 0.0 )
; Name the gate oxide region.
   "Oxide" "R.Gateox"
)

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xg Ypol 0.0 )
; Define the re-oxidized oxide region around the polysilicon gate.
   "Oxide" "R.PolyReox"
)

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xg Ypol 0.0 )
; Define the polysilicon gate region.
   "PolySi" "R.Polygate"
)

; Assign electrical contacts to selected geometry edges.
(sdegeo:set-contact
   (find-edge-id (position (* (+ Xmax Xg) 0.5) 0.0 0.0))
; Label this contact as the drain.
   "drain")
(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ypol 0.0))
; Label this contact as the gate.
   "gate")
(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ysub 0.0))
; Label this contact as the substrate/body.
   "substrate")


; Define uniform doping profiles for substrate and gate regions.
(sdedr:define-constant-profile "Const.Substrate"
DopSub SubDop )
(sdedr:define-constant-profile-region "PlaceCD.Substrate" "Const.Substrate" "R.Substrate" )

(sdedr:define-constant-profile "Const.Gate"
DopSD 1e20 )
(sdedr:define-constant-profile-region "PlaceCD.Gate" "Const.Gate" "R.Polygate" )



; Define a geometric window or baseline used for implant placement or mesh refinement.
(sdedr:define-refeval-window "BaseLine.Drain" "Line"
   (position (+ Xg 0.035) 0.0 0.0 )
```

```
   (position (* Xmax 2.0) 0.0 0.0 ) )

; Define Gaussian implant profiles for source/drain, LDD extension, or halo regions.
(sdedr:define-gaussian-profile "Impl.SDprof"
DopSD
; Set a very high implant peak concentration.
"PeakPos" 0 "PeakVal" 1e20
"ValueAtDepth" SubDop "Depth" Xj
"Gauss" "Factor" 0.9
)

; Source/drain implant profile: high peak concentration for heavily doped drain/source.
(sdedr:define-analytical-profile-placement "Impl.Drain" "Impl.SDprof" "BaseLine.Drain" "Symm" "NoReplace" "Eval")




; Define mesh refinement sizes for important regions.
(sdedr:define-refinement-size "Ref.Substrate"
(/ Ltot 4.0) (/ Hsub 8.0)
Gpn           Gpn )
; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.Substrate" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-region "RefPlace.Substrate" "Ref.Substrate" "R.Substrate" )

(sdedr:define-refeval-window "RWin.Act" "Rectangle"
   (position 0.0 0.0 0.0)
   (position Xmax (* Xj 1.2) 0.0 ) )
(sdedr:define-refinement-size "Ref.SiAct"
   (/ Lcont 4.0) (/ Xj 8.0)
   Gpn            Gpn )




; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.SiAct" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-placement "RefPlace.SiAct" "Ref.SiAct" "RWin.Act" )

(sdedr:define-refinement-size "Ref.GOX"
   (/ Ltot 4.0) (/ Tox 4.0)
   Gpn         (/ Tox 8.0) )
(sdedr:define-refinement-region "RefPlace.GOX" "Ref.GOX" "R.Gateox" )

(sdedr:define-refeval-window "MBWindow.Gate" "Rectangle"
   (position (* Xg -1.0) Ypol 0.0)
   (position (* Xg 1.0) Ygox 0.0))

; Use multibox refinement to create a fine mesh near the gate/channel and a coarser mesh away from it.
(sdedr:define-multibox-size "MBSize.Gate"
   (/ Lg 8.0) (/ Hpol 8.0)
   (/ Lg 10.0) 2e-4
   1.0 -1.35)
(sdedr:define-multibox-placement "MBPlace.Gate" "MBSize.Gate" "MBWindow.Gate")



(sdedr:define-refeval-window "MBWindow.Channel" "Rectangle"
   (position 0.0 0.0 0.0)
   (position (* Xg 1.2) (* 0.5 Xj) 0.0) )
(sdedr:define-multibox-size "MBSize.Channel"
   (/ Lg 8.0) (/ Xj 8.0)
   (/ Lg 10.0) 1e-4
   1.0 1.35)
(sdedr:define-multibox-placement "MBPlace.Channel" "MBSize.Channel" "MBWindow.Channel")
```

```
(sedr:define-refinement-size "Ref.J"
   (/ 0.016 6.0) 99
   (/ 0.016 7.0) 66)

(sedr:define-refeval-window "RWin.GD" "Rectangle"
   (position (- Xg 0.01) 0.0 0.0)
   (position (+ Xg 0) (* Xj 0.2) 0.0) )
(sedr:define-refinement-placement "RefPlace.GJ" "Ref.J" "RWin.GD" )


; Generate the half-device mesh file.
(sde:build-mesh "n@node@_half_msh")

; Reflect the half-device structure to build the full symmetric MOSFET and rename the mirrored contact as source.
(system:command "tdx -mtt -x -M 0 -S 0 -ren drain=source n@node@_half_msh n@node@_msh")
```

5. LONG GIDL SDEVICE TRANSFERCURVE CODE

- Builds a MOSFET structure for GIDL analysis.
- Uses a sharper drain implant profile to increase the high-field region near the drain edge.

Annotated Code

```
!(
; Switch simulation settings between nMOS and pMOS cases.
if { "@Type@" == "nMOS" } {
; SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN 1.0
; Select density-gradient quantum correction for electrons or holes.
set DG "eQuantumPotential"
; Select carrier temperature variable for hydrodynamic transport.
set cTemp "eTemperature"
; Set the gate work function used by the gate electrode.
set WF 4.2
; Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson eQuantumPotential Electron "
; Define the full coupled equation set for the final device solution.
set EQNS "Poisson eQuantumPotential Electron Hole eTemperature"
} else {
; SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN -1.0
; Select density-gradient quantum correction for electrons or holes.
set DG "hQuantumPotential"
; Select carrier temperature variable for hydrodynamic transport.
set cTemp "hTemperature"
; Set the gate work function used by the gate electrode.
set WF 4.8
; Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson hQuantumPotential Hole"
; Define the full coupled equation set for the final device solution.
set EQNS "Poisson hQuantumPotential Electron Hole hTemperature"
}
)!


; File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
*input files:
; Input mesh generated from SDE/SProcess.
Grid= "@tdr@"
; Input mechanical/strain file, if available.
Piezo= "@tdr@"
; Parameter file passed from Sentaurus Workbench.
Parameter= "@parameter@"
*output files:
; TDR output file for spatial physical quantities.
Plot= "@tdrdat@"
; Output file for terminal currents.
Current= "@plot@"
; Log/output file for solver messages.
Output= "@log@"
}

; Define terminal boundary conditions and contact properties.
Electrode {
; Source terminal is grounded.
{ Name= "source" Voltage= 0.0 Resistor = 40 }
; Drain terminal bias is initialized, then later ramped/swept.
{ Name= "drain" Voltage= 0.0 Resistor = 40 }
```

```
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
{ Name= "gate" Voltage= 0.0 Workfunction = !(puts $WF)! }
; Body/substrate terminal is grounded.
{ Name= "substrate" Voltage= 0.0}
}

; Enable global physical models used by SDevice.
Physics {
; Use Fermi-Dirac carrier statistics for highly doped regions.
Fermi
; Enable hydrodynamic transport to account for carrier heating/high-field effects.
Hydrodynamic( !(puts $cTemp)! )

Recombination (
; Enable nonlocal band-to-band tunneling model for GIDL simulation.
   Band2Band(Model=NonlocalPath)
)
}
#include "Plot_Math_des.cmd"

; Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
* =Creating initial guess:
NewCurrentFile="n@node@_init"
; Solve Poisson and transport equations self-consistently.
Coupled(Iterations= 1000 LineSearchDamping = 1e-4){ Poisson !(puts $DG)!}
Coupled { !(puts $EQN0)! }
Coupled { !(puts $EQNS)! }

*-ramp to gate to negative
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
; Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
; Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
Goal { Name="gate" Voltage = -2.0}
; Solve Poisson and transport equations self-consistently.
)  { Coupled { Poisson !(puts $DG)! }}

*-ramp to drain to Vd
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
; Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
; Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
; Drain terminal bias is initialized, then later ramped/swept.
Goal { Name="drain" Voltage = !(puts [expr $SIGN*@Vd@])!}
){ Coupled { !(puts $EQNS)! }}

; Save spatial solution snapshots for visualization.
Plot ( FilePrefix = "n@node@_GIDL_" )

*-Vg sweep
; Set current-output file prefix for this sweep.
NewCurrentPrefix=""
; Perform a DC bias ramp with adaptive step control.
Quasistationary(
doZero
; Control numerical step size for convergence and resolution.
InitialStep= 1e-3 Increment = 1.5
; Control numerical step size for convergence and resolution.
MinStep = 1e-7 MaxStep = 0.04
; Bias target for the current ramp or sweep.
```

```
Goal { Name = "gate" Voltage = !(puts [expr $SIGN*@Vg@])!}
){ Coupled { !(puts $EQNS)! }
; Sample terminal currents during the sweep.
CurrentPlot( Time=(Range=(0 1) Intervals = 30) )
}
}
```

6. LONG GIDL OUTPUTCURVE CODE

- Runs an output-curve sweep for the GIDL structure.
- Used to compare current response under fixed gate bias and varying drain bias.

Annotated Code

```
!(
* Switch simulation settings between nMOS and pMOS cases.
if { "@Type@" == "nMOS" } {
* SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN 1.0
* Select density-gradient quantum correction for electrons or holes.
set DG "eQuantumPotential"
* Select carrier temperature variable for hydrodynamic transport.
set cTemp "eTemperature"
* Set the gate work function used by the gate electrode.
set WF 4.2
* Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson eQuantumPotential Electron "
* Define the full coupled equation set for the final device solution.
set EQNS "Poisson eQuantumPotential Electron Hole eTemperature"
} else {
* SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN -1.0
* Select density-gradient quantum correction for electrons or holes.
set DG "hQuantumPotential"
* Select carrier temperature variable for hydrodynamic transport.
set cTemp "hTemperature"
* Set the gate work function used by the gate electrode.
set WF 4.8
* Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson hQuantumPotential Hole"
* Define the full coupled equation set for the final device solution.
set EQNS "Poisson hQuantumPotential Electron Hole hTemperature"
}
)!


* File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
*input files:
* Input mesh generated from SDE/SProcess.
Grid= "@tdr@"
* Input mechanical/strain file, if available.
Piezo= "@tdr@"
* Parameter file passed from Sentaurus Workbench.
Parameter= "@parameter@"
*output files:
* TDR output file for spatial physical quantities.
Plot= "@tdrdat@"
* Output file for terminal currents.
Current= "@plot@"
* Log/output file for solver messages.
Output= "@log@"
}

* Define terminal boundary conditions and contact properties.
Electrode {
* Source terminal is grounded.
{ Name= "source" Voltage= 0.0 Resistor = 40 }
* Drain terminal bias is initialized, then later ramped/swept.
{ Name= "drain" Voltage= 0.0 Resistor = 40 }
```

```
* Gate terminal is initialized and assigned polysilicon/work-function behavior.
{ Name= "gate" Voltage= 0.0 Workfunction = !(puts $WF)! }
* Body/substrate terminal is grounded.
{ Name= "substrate" Voltage= 0.0}
}

* Enable global physical models used by SDevice.
Physics {
* Use Fermi-Dirac carrier statistics for highly doped regions.
Fermi
* Enable hydrodynamic transport to account for carrier heating/high-field effects.
Hydrodynamic( !(puts $cTemp)! )
}
#include "Plot_Math_des.cmd"

* Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
* =Creating initial guess:
NewCurrentFile="n@node@_init"
* Solve Poisson and transport equations self-consistently.
Coupled(Iterations= 1000 LineSearchDamping = 1e-4){ Poisson !(puts $DG)!}
Coupled { !(puts $EQN0)! }
Coupled { !(puts $EQNS)! }


*-ramp to drain to Vd
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
* Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
* Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
* Gate terminal is initialized and assigned polysilicon/work-function behavior.
Goal { Name="gate" Voltage = !(puts [expr $SIGN*@Vgg@])!}
){ Coupled { !(puts $EQNS)! }}

* Save spatial solution snapshots for visualization.
Plot ( FilePrefix = "n@node@_@Vgg@Vg_" )

*-Vg sweep
* Set current-output file prefix for this sweep.
NewCurrentPrefix="IdVd_"
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
doZero
* Control numerical step size for convergence and resolution.
InitialStep= 1e-3 Increment = 1.5
* Control numerical step size for convergence and resolution.
MinStep = 1e-7 MaxStep = 0.04
* Bias target for the current ramp or sweep.
Goal { Name = "drain" Voltage = !(puts [expr $SIGN*@Vdd@])!}
){ Coupled { !(puts $EQNS)! }
* Sample terminal currents during the sweep.
CurrentPlot( Time=(Range=(0 1) Intervals = 30) )
}
}
```

7. SHORT SDE CODE

- Builds the short-channel MOSFET structure.
- This structure is used to observe short-channel effects such as Vth roll-off, DIBL, and leakage increase.

Annotated Code

```
; Clear any previously defined SDE geometry, doping, mesh, and contacts.
(sde:clear)
; Define the process-up direction so vertical coordinates are interpreted consistently.
(sde:set-process-up-direction "+z")

; Select doping species and carrier models based on whether the device is nMOS or pMOS.
(if (string=? "@Type@" "nMOS")
   (begin
; Define the substrate dopant species.
      (define DopSub "BoronActiveConcentration")
; Define the source/drain and gate dopant species.
      (define DopSD "ArsenicActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18 )
)
(begin
; Define the substrate dopant species.
   (define DopSub "ArsenicActiveConcentration")
; Define the source/drain and gate dopant species.
   (define DopSD "BoronActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18)
)
)

; Gate length parameter imported from Sentaurus Workbench.
(define Lg @lgate@)
; Total simulated lateral length, including gate and source/drain extension region.
(define Ltot (+ Lg (* 2 0.01) 0.8) )

; Substrate thickness used for the 2D device cross-section.
(define Hsub 1.0)
; Gate oxide thickness parameter imported from Workbench.
(define Tox @Toxide@)
; Polysilicon gate height.
(define Hpol 0.2)


; Minimum mesh size control used near critical regions.
(define Gpn 0.005)

; Approximate junction depth used for source/drain implants.
(define Xj 0.1 )


; Derived dimensions are computed from the primary process/device parameters.
;Derived quantities
; Half-device lateral boundary for building a symmetric structure.
(define Xmax (/ Ltot 2.0))
; Half gate length.
(define Xg (/ Lg 2.0))

; Bottom substrate coordinate.
(define Ysub Hsub)
; Gate oxide top/bottom coordinate based on oxide thickness.
(define Ygox (* Tox -1.0))
```

```
; Top polysilicon coordinate.
(define Ypol (- Ygox Hpol))

(define Lcont Xmax)

; Set the default Boolean operation for overlapping SDE geometry creation.
(sdegeo:set-default-boolean "ABA")

; Create a 2D rectangular material region such as silicon, oxide, spacer, or polysilicon.
(sdegeo:create-rectangle
   (position 0.0 Ysub 0.0 )
   (position Xmax 0.0 0.0 )
; Name the silicon body/substrate region.
   "Silicon" "R.Substrate"
)

(sdegeo:create-rectangle
   (position 0.0 0.0  0.0 )
   (position Xg Ygox 0.0 )
; Name the gate oxide region.
   "Oxide" "R.Gateox"
)

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xg Ypol 0.0 )
; Define the re-oxidized oxide region around the polysilicon gate.
   "Oxide" "R.PolyReox"
)

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xg Ypol 0.0 )
; Define the polysilicon gate region.
   "PolySi" "R.Polygate"
)

; Assign electrical contacts to selected geometry edges.
(sdegeo:set-contact
   (find-edge-id (position (* (+ Xmax Xg) 0.5) 0.0 0.0))
; Label this contact as the drain.
   "drain")
(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ypol 0.0))
; Label this contact as the gate.
   "gate")
(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ysub 0.0))
; Label this contact as the substrate/body.
   "substrate")


; Define uniform doping profiles for substrate and gate regions.
(sdedr:define-constant-profile "Const.Substrate"
DopSub SubDop )
(sdedr:define-constant-profile-region "PlaceCD.Substrate" "Const.Substrate" "R.Substrate" )

(sdedr:define-constant-profile "Const.Gate"
DopSD 1e20 )
(sdedr:define-constant-profile-region "PlaceCD.Gate" "Const.Gate" "R.Polygate" )



; Define a geometric window or baseline used for implant placement or mesh refinement.
(sdedr:define-refeval-window "BaseLine.Drain" "Line"
   (position (+ Xg 0.035) 0.0 0.0 )
```

```
   (position (* Xmax 2.0) 0.0 0.0 ) )

; Define Gaussian implant profiles for source/drain, LDD extension, or halo regions.
(sdedr:define-gaussian-profile "Impl.SDprof"
DopSD
; Set a very high implant peak concentration.
"PeakPos" 0 "PeakVal" 1e20
"ValueAtDepth" SubDop "Depth" Xj
"Gauss" "Factor" 0.4
)

; Source/drain implant profile: high peak concentration for heavily doped drain/source.
(sdedr:define-analytical-profile-placement "Impl.Drain" "Impl.SDprof" "BaseLine.Drain" "Symm" "NoReplace" "Eval")




; Define mesh refinement sizes for important regions.
(sdedr:define-refinement-size "Ref.Substrate"
(/ Ltot 4.0) (/ Hsub 8.0)
Gpn           Gpn )
; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.Substrate" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-region "RefPlace.Substrate" "Ref.Substrate" "R.Substrate" )

(sdedr:define-refeval-window "RWin.Act" "Rectangle"
   (position 0.0 0.0 0.0)
   (position Xmax (* Xj 1.2) 0.0 ) )
(sdedr:define-refinement-size "Ref.SiAct"
   (/ Lcont 4.0) (/ Xj 8.0)
   Gpn            Gpn )




; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.SiAct" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-placement "RefPlace.SiAct" "Ref.SiAct" "RWin.Act" )

(sdedr:define-refinement-size "Ref.GOX"
   (/ Ltot 4.0) (/ Tox 4.0)
   Gpn         (/ Tox 8.0) )
(sdedr:define-refinement-region "RefPlace.GOX" "Ref.GOX" "R.Gateox" )

(sdedr:define-refeval-window "MBWindow.Gate" "Rectangle"
   (position (* Xg -1.0) Ypol 0.0)
   (position (* Xg 1.0) Ygox 0.0))

; Use multibox refinement to create a fine mesh near the gate/channel and a coarser mesh away from it.
(sdedr:define-multibox-size "MBSize.Gate"
   (/ Lg 8.0) (/ Hpol 8.0)
   (/ Lg 10.0) 2e-4
   1.0 -1.35)
(sdedr:define-multibox-placement "MBPlace.Gate" "MBSize.Gate" "MBWindow.Gate")



(sdedr:define-refeval-window "MBWindow.Channel" "Rectangle"
   (position 0.0 0.0 0.0)
   (position (* Xg 1.2) (* 0.5 Xj) 0.0) )
(sdedr:define-multibox-size "MBSize.Channel"
   (/ Lg 8.0) (/ Xj 8.0)
   (/ Lg 10.0) 1e-4
   1.0 1.35)
(sdedr:define-multibox-placement "MBPlace.Channel" "MBSize.Channel" "MBWindow.Channel")
```

```
(sedr:define-refinement-size "Ref.J"
   (/ 0.016 6.0) 99
   (/ 0.016 7.0) 66)

(sedr:define-refeval-window "RWin.GD" "Rectangle"
   (position (- Xg 0.01) 0.0 0.0)
   (position (+ Xg 0) (* Xj 0.2) 0.0) )
(sedr:define-refinement-placement "RefPlace.GJ" "Ref.J" "RWin.GD" )


; Generate the half-device mesh file.
(sde:build-mesh "n@node@_half_msh")

; Reflect the half-device structure to build the full symmetric MOSFET and rename the mirrored contact as source.
(system:command "tdx -mtt -x -M 0 -S 0 -ren drain=source n@node@_half_msh n@node@_msh")
```

8. SHORT TRANSFER CODE

- Runs the short-channel Id-Vg transfer simulation.
- The result is compared with long-channel behavior to analyze subthreshold degradation.

Annotated Code

```
!(
* Switch simulation settings between nMOS and pMOS cases.
if { "@Type@" == "nMOS" } {
* SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN 1.0
* Select density-gradient quantum correction for electrons or holes.
set DG "eQuantumPotential"
* Select carrier temperature variable for hydrodynamic transport.
set cTemp "eTemperature"
* Set the gate work function used by the gate electrode.
set WF 4.2
* Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson eQuantumPotential Electron "
* Define the full coupled equation set for the final device solution.
set EQNS "Poisson eQuantumPotential Electron Hole eTemperature"
} else {
* SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN -1.0
* Select density-gradient quantum correction for electrons or holes.
set DG "hQuantumPotential"
* Select carrier temperature variable for hydrodynamic transport.
set cTemp "hTemperature"
* Set the gate work function used by the gate electrode.
set WF 4.8
* Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson hQuantumPotential Hole"
* Define the full coupled equation set for the final device solution.
set EQNS "Poisson hQuantumPotential Electron Hole hTemperature"
}
)!


* File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
*input files:
* Input mesh generated from SDE/SProcess.
Grid= "@tdr@"
* Input mechanical/strain file, if available.
Piezo= "@tdr@"
* Parameter file passed from Sentaurus Workbench.
Parameter= "@parameter@"
*output files:
* TDR output file for spatial physical quantities.
Plot= "@tdrdat@"
* Output file for terminal currents.
Current= "@plot@"
* Log/output file for solver messages.
Output= "@log@"
}

* Define terminal boundary conditions and contact properties.
Electrode {
* Source terminal is grounded.
{ Name= "source" Voltage= 0.0 Resistor = 40 }
* Drain terminal bias is initialized, then later ramped/swept.
{ Name= "drain" Voltage= 0.0 Resistor = 40 }
```

```
* Gate terminal is initialized and assigned polysilicon/work-function behavior.
{ Name= "gate" Voltage= 0.0 Workfunction = !(puts $WF)! }
* Body/substrate terminal is grounded.
{ Name= "substrate" Voltage= 0.0}
}

* Enable global physical models used by SDevice.
Physics {
* Use Fermi-Dirac carrier statistics for highly doped regions.
Fermi
* Enable hydrodynamic transport to account for carrier heating/high-field effects.
Hydrodynamic( !(puts $cTemp)! )
}
#include "Plot_Math_des.cmd"

* Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
* =Creating initial guess:
NewCurrentFile="n@node@_init"
* Solve Poisson and transport equations self-consistently.
Coupled(Iterations= 1000 LineSearchDamping = 1e-4){ Poisson !(puts $DG)!}
Coupled { !(puts $EQN0)! }
Coupled { !(puts $EQNS)! }

*-ramp to gate to negative
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
* Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
* Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
* Gate terminal is initialized and assigned polysilicon/work-function behavior.
Goal { Name="gate" Voltage = -2.0}
* Solve Poisson and transport equations self-consistently.
)  { Coupled { Poisson !(puts $DG)! }}

*-ramp to drain to Vd
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
* Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
* Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
* Drain terminal bias is initialized, then later ramped/swept.
Goal { Name="drain" Voltage = !(puts [expr $SIGN*@Vd@])!}
){ Coupled { !(puts $EQNS)! }}

* Save spatial solution snapshots for visualization.
Plot ( FilePrefix = "n@node@_GIDL_" )

*-Vg sweep
* Set current-output file prefix for this sweep.
NewCurrentPrefix=""
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
doZero
* Control numerical step size for convergence and resolution.
InitialStep= 1e-3 Increment = 1.5
* Control numerical step size for convergence and resolution.
MinStep = 1e-7 MaxStep = 0.04
* Bias target for the current ramp or sweep.
Goal { Name = "gate" Voltage = !(puts [expr $SIGN*@Vg@])!}
){ Coupled { !(puts $EQNS)! }
* Sample terminal currents during the sweep.
CurrentPlot( Time=(Range=(0 1) Intervals = 30) )
}
```

```
}
```

9. Device Setup & Physical Models

- Annotated explanation of the repeated SDevice control block.
- This block selects nMOS/pMOS physics settings and performs a staged bias sweep.

Annotated Code

```
* Switch simulation settings between nMOS and pMOS cases.
if { "@Type@" == "nMOS" } {
* SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN 1.0
* Select density-gradient quantum correction for electrons or holes.
set DG "eQuantumPotential"
* Select carrier temperature variable for hydrodynamic transport.
set cTemp "eTemperature"
* Set the gate work function used by the gate electrode.
set WF 4.2
* Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson eQuantumPotential Electron "
* Define the full coupled equation set for the final device solution.
set EQNS "Poisson eQuantumPotential Electron Hole eTemperature"
} else {
* SIGN controls voltage polarity so the same template can run nMOS and pMOS simulations.
set SIGN -1.0
* Select density-gradient quantum correction for electrons or holes.
set DG "hQuantumPotential"
* Select carrier temperature variable for hydrodynamic transport.
set cTemp "hTemperature"
* Set the gate work function used by the gate electrode.
set WF 4.8
* Define the reduced equation set used after the initial Poisson solve.
set EQN0 "Poisson hQuantumPotential Hole"
* Define the full coupled equation set for the final device solution.
set EQNS "Poisson hQuantumPotential Electron Hole hTemperature"
}
)!


* File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
*input files:
* Input mesh generated from SDE/SProcess.
Grid= "@tdr@"
* Input mechanical/strain file, if available.
Piezo= "@tdr@"
* Parameter file passed from Sentaurus Workbench.
Parameter= "@parameter@"
*output files:
* TDR output file for spatial physical quantities.
Plot= "@tdrdat@"
* Output file for terminal currents.
Current= "@plot@"
* Log/output file for solver messages.
Output= "@log@"
}

* Define terminal boundary conditions and contact properties.
Electrode {
* Source terminal is grounded.
{ Name= "source" Voltage= 0.0 Resistor = 40 }
* Drain terminal bias is initialized, then later ramped/swept.
```

```
{ Name= "drain" Voltage= 0.0 Resistor = 40 }
* Gate terminal is initialized and assigned polysilicon/work-function behavior.
{ Name= "gate" Voltage= 0.0 Workfunction = !(puts $WF)! }
* Body/substrate terminal is grounded.
{ Name= "substrate" Voltage= 0.0}
}

* Enable global physical models used by SDevice.
Physics {
* Use Fermi-Dirac carrier statistics for highly doped regions.
Fermi
* Enable hydrodynamic transport to account for carrier heating/high-field effects.
Hydrodynamic( !(puts $cTemp)! )
}
#include "Plot_Math_des.cmd"

* Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
* =Creating initial guess:
NewCurrentFile="n@node@_init"
* Solve Poisson and transport equations self-consistently.
Coupled(Iterations= 1000 LineSearchDamping = 1e-4){ Poisson !(puts $DG)!}
Coupled { !(puts $EQN0)! }
Coupled { !(puts $EQNS)! }

*-ramp to gate to negative
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
* Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
* Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
* Gate terminal is initialized and assigned polysilicon/work-function behavior.
Goal { Name="gate" Voltage = @Vg@}
* Solve Poisson and transport equations self-consistently.
)  { Coupled { Poisson !(puts $DG)! }}

*-ramp to drain to Vd
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
* Control numerical step size for convergence and resolution.
InitialStep= 1e-2 Increment = 1.35
* Control numerical step size for convergence and resolution.
MinStep= 1e-7 MaxStep = 0.2
* Drain terminal bias is initialized, then later ramped/swept.
Goal { Name="drain" Voltage = !(puts [expr $SIGN*@Vd@])!}
){ Coupled { !(puts $EQNS)! }}

* Save spatial solution snapshots for visualization.
Plot ( FilePrefix = "n@node@_GIDL_" )

*-Vg sweep
* Set current-output file prefix for this sweep.
NewCurrentPrefix=""
* Perform a DC bias ramp with adaptive step control.
Quasistationary(
doZero
* Control numerical step size for convergence and resolution.
InitialStep= 1e-3 Increment = 1.5
* Control numerical step size for convergence and resolution.
MinStep = 1e-7 MaxStep = 0.04
* Bias target for the current ramp or sweep.
Goal { Name = "gate" Voltage = !(puts [expr $SIGN*@Vg@])!}
){ Coupled { !(puts $EQNS)! }
* Sample terminal currents during the sweep.
CurrentPlot( Time=(Range=(0 1) Intervals = 30) )
```

```
}
```

10. LDD+HALO SDE CODE

- Builds an LDD + Halo MOSFET structure.
- Adds nitride spacer, lightly doped drain extension, and halo implant to suppress short-channel effects.

Annotated Code

```
; Clear any previously defined SDE geometry, doping, mesh, and contacts.
(sde:clear)
; Define the process-up direction so vertical coordinates are interpreted consistently.
(sde:set-process-up-direction "+z")

; Select doping species and carrier models based on whether the device is nMOS or pMOS.
(if (string=? "@Type@" "nMOS")
   (begin
; Define the substrate dopant species.
      (define DopSub "BoronActiveConcentration")
; Define the source/drain and gate dopant species.
      (define DopSD "ArsenicActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18 )
)
(begin
; Define the substrate dopant species.
   (define DopSub "ArsenicActiveConcentration")
; Define the source/drain and gate dopant species.
   (define DopSD "BoronActiveConcentration")
; Set the background substrate doping concentration.
(define SubDop 1e18)
)
)

; Gate length parameter imported from Sentaurus Workbench.
(define Lg @lgate@)
; Spacer length used to separate the gate edge from the heavily doped drain implant.
(define Lsp 0.1) ;
; Re-oxidation offset used to place the spacer relative to the gate edge.
(define Lreox 0.01) ;
; Total simulated lateral length, including gate and source/drain extension region.
(define Ltot (+ Lg (* 2 0.01) 0.8) )

; Substrate thickness used for the 2D device cross-section.
(define Hsub 1.0)
; Gate oxide thickness parameter imported from Workbench.
(define Tox @Toxide@)
; Polysilicon gate height.
(define Hpol 0.2)

; Radius used to round the spacer corner for a more realistic geometry.
(define fillet-radius 0.08) ;


; Minimum mesh size control used near critical regions.
(define Gpn 0.005)

; Approximate junction depth used for source/drain implants.
(define Xj 0.1 )


; Derived dimensions are computed from the primary process/device parameters.
;Derived quantities
; Half-device lateral boundary for building a symmetric structure.
(define Xmax (/ Ltot 2.0))
```

```
; Half gate length.
(define Xg (/ Lg 2.0))
; Spacer edge location measured from the channel center.
(define Xsp (+ Xg Lsp)) ;

; Bottom substrate coordinate.
(define Ysub Hsub)
; Gate oxide top/bottom coordinate based on oxide thickness.
(define Ygox (* Tox -1.0))
; Top polysilicon coordinate.
(define Ypol (- Ygox Hpol))

(define Lcont (- Xmax Xsp)) ;

(define Lcont Xmax)

; Set the default Boolean operation for overlapping SDE geometry creation.
(sdegeo:set-default-boolean "ABA")

; Create a 2D rectangular material region such as silicon, oxide, spacer, or polysilicon.
(sdegeo:create-rectangle
   (position 0.0 Ysub 0.0 )
   (position Xmax 0.0 0.0 )
; Name the silicon body/substrate region.
   "Silicon" "R.Substrate"
)

(sdegeo:create-rectangle
   (position 0.0 0.0  0.0 )
   (position Xsp Ygox 0.0 ) ;
; Name the gate oxide region.
   "Oxide" "R.Gateox"
)

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xsp Ypol 0.0 ) ;
; Define the re-oxidized oxide region around the polysilicon gate.
   "Oxide" "R.PolyReox"
)

(sdegeo:create-rectangle
   (position (+ Xg Lreox) Ygox 0.0 )
   (position Xsp Ypol 0.0 )
; Define the nitride spacer region for LDD/Halo process emulation.
   "Nitride" "R.Spacer"
) ;

(sdegeo:create-rectangle
   (position 0.0 Ygox 0.0 )
   (position Xg Ypol 0.0 )
; Define the polysilicon gate region.
   "PolySi" "R.Polygate"
)


; -rounding spacer

; Round the spacer corner to avoid an unrealistically sharp geometry.
(sdegeo:fillet-2d
 (find-vertex-id (position Xsp Ypol 0.0))
fillet-radius) ;


; Assign electrical contacts to selected geometry edges.
(sdegeo:set-contact
```

```
   (find-edge-id (position (* (+ Xmax Xsp) 0.5) 0.0 0.0))
   "drain") ;

(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ypol 0.0))
; Label this contact as the gate.
   "gate")
(sdegeo:set-contact
   (find-edge-id (position 5e-4 Ysub 0.0))
; Label this contact as the substrate/body.
   "substrate")


; Define uniform doping profiles for substrate and gate regions.
(sdedr:define-constant-profile "Const.Substrate"
DopSub SubDop )
(sdedr:define-constant-profile-region "PlaceCD.Substrate" "Const.Substrate" "R.Substrate" )

(sdedr:define-constant-profile "Const.Gate"
DopSD 1e20 )
(sdedr:define-constant-profile-region "PlaceCD.Gate" "Const.Gate" "R.Polygate" )

;-----------------------------------------------------------------------------------------------

; Define a geometric window or baseline used for implant placement or mesh refinement.
(sdedr:define-refeval-window "BaseLine.Drain" "Line"
   (position Xsp 0.0 0.0 )
   (position (* Xmax 2.0) 0.0 0.0 ) )

; Define Gaussian implant profiles for source/drain, LDD extension, or halo regions.
(sdedr:define-gaussian-profile "Impl.SDprof"
DopSD
; Set a very high implant peak concentration.
"PeakPos" 0 "PeakVal" 1e20
"ValueAtDepth" SubDop "Depth" Xj
"Gauss" "Factor" 0.4
)

; Source/drain implant profile: high peak concentration for heavily doped drain/source.
(sdedr:define-analytical-profile-placement "Impl.Drain" "Impl.SDprof" "BaseLine.Drain" "Symm" "NoReplace" "Eval")

;-----------------------------------------------------------------------------------------------------
;Source/Drain extentions base line definitions
(sdedr:define-refeval-window "BaseLine.DrainExt" "Line"
   (position Xg 0.0 0.0 )
   (position (* Xmax 2.0) 0.0 0.0 ) )

;Source/Drain implant definition
(sdedr:define-gaussian-profile "Impl.SDextprof"
DopSD
; Set a lighter LDD extension peak concentration.
"PeakPos" 0 "PeakVal" 5e18
"ValueAtDepth" SubDop "Depth" (/ Xj 3.0)
"Gauss" "Factor" 0.25
)

;Source/Drain implants
; LDD extension implant profile: lower concentration and shallower junction than the main drain implant.
(sdedr:define-analytical-profile-placement "Impl.DrainExt" "Impl.SDextprof" "BaseLine.DrainExt" "Symm" "NoReplace" "Eval")

;-------------------------------------------------------------------------------------------------------------------
;Source/Drain base line definitions HALO
(sdedr:define-refeval-window "BaseLine.Halo" "Line"
(position Xg 0.025 0.0)
(position (/ Xj 3.0) 0.025 0.0) )
```

```
;Source/Drain Implant Definition HALO
(sdedr:define-gaussian-profile "Impl.Haloprof"
DopSub
; Set a very high implant peak concentration.
"PeakPos" 0 "PeakVal" 1e20
"ValueAtDepth" 1e18 "Depth" 0.05
"Gauss" "Factor" 0
)

;Source/Drain implants HALO
; Halo implant profile: local body doping near the junction to suppress punch-through and DIBL.
(sdedr:define-analytical-profile-placement "Impl.Halo" "Impl.Haloprof" "BaseLine.Halo" "Positive" "NoReplace" "Eval")

;-----------------------------------------------------------------------------------------------------------------------------------------


; Define mesh refinement sizes for important regions.
(sdedr:define-refinement-size "Ref.Substrate"
(/ Ltot 4.0) (/ Hsub 8.0)
Gpn           Gpn )
; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.Substrate" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-region "RefPlace.Substrate" "Ref.Substrate" "R.Substrate" )

(sdedr:define-refeval-window "RWin.Act" "Rectangle"
   (position 0.0 0.0 0.0)
   (position Xmax (* Xj 1.2) 0.0 ) )
(sdedr:define-refinement-size "Ref.SiAct"
   (/ Lcont 4.0) (/ Xj 8.0)
   Gpn            Gpn )
;-----------------------------------------------------------------------------------------------------------------------------------------



; Refine mesh where doping changes rapidly.
(sdedr:define-refinement-function "Ref.SiAct" "DopingConcentration" "MaxTransDiff" 1)
(sdedr:define-refinement-placement "RefPlace.SiAct" "Ref.SiAct" "RWin.Act" )

(sdedr:define-refinement-size "Ref.GOX"
   (/ Ltot 4.0) (/ Tox 4.0)
   Gpn         (/ Tox 8.0) )
(sdedr:define-refinement-region "RefPlace.GOX" "Ref.GOX" "R.Gateox" )

(sdedr:define-refeval-window "MBWindow.Gate" "Rectangle"
   (position (* Xg -1.0) Ypol 0.0)
   (position (* Xg 1.0) Ygox 0.0))

; Use multibox refinement to create a fine mesh near the gate/channel and a coarser mesh away from it.
(sdedr:define-multibox-size "MBSize.Gate"
   (/ Lg 8.0) (/ Hpol 8.0)
   (/ Lg 10.0) 2e-4
   1.0 -1.35)
(sdedr:define-multibox-placement "MBPlace.Gate" "MBSize.Gate" "MBWindow.Gate")



(sdedr:define-refeval-window "MBWindow.Channel" "Rectangle"
   (position 0.0 0.0 0.0)
   (position (* Xg 1.2) (* 0.5 Xj) 0.0) )
(sdedr:define-multibox-size "MBSize.Channel"
   (/ Lg 8.0) (/ Xj 8.0)
   (/ Lg 10.0) 1e-4
   1.0 1.35)
(sdedr:define-multibox-placement "MBPlace.Channel" "MBSize.Channel" "MBWindow.Channel")

(sdedr:define-refinement-size "Ref.J"
```

```
   (/ 0.016 6.0) 99
   (/ 0.016 7.0) 66)

;Gate-Drain Junction

(sdedr:define-refeval-window "RWin.GD" "Rectangle"
   (position (- Xg 0.01) 0.0 0.0)
   (position (+ Xg Lreox) (* Xj 0.2) 0.0) )
(sdedr:define-refinement-placement "RefPlace.GJ" "Ref.J" "RWin.GD" )

;Build Mesh
; Generate the half-device mesh file.
(sde:build-mesh "n@node@_half_msh")


;Reflect the device
; Reflect the half-device structure to build the full symmetric MOSFET and rename the mirrored contact as source.
(system:command "tdx -mtt -x -M 0 -S 0 -ren drain=source n@node@_half_msh n@node@_msh")


;-----------------------------------------------------------------
```

11. PROGRAM/ERASE SDEVICE CODE

- Runs transient SONOS program/erase operation.
- Applies pulse waveforms to the gate and models charge trapping in the nitride storage layer.

Annotated Code

```
; File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
; Input mesh generated from SDE/SProcess.
   Grid=      "@tdr@"
; Parameter file passed from Sentaurus Workbench.
   Parameter= "@parameter@"
; Output file for terminal currents.
   Current=   "@plot@"
; TDR output file for spatial physical quantities.
   Plot=      "@tdrdat@"
; Log/output file for solver messages.
   Output=    "@log@"
}

; Define terminal boundary conditions and contact properties.
Electrode {
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
   {Name="gate"    Voltage= 0 Material= "PolySi"

; Define a time-dependent voltage waveform at this electrode.
   Voltage=(
   !(
    set t1p 0
; Loop over program/erase cycles specified in Workbench.
    for { set i 1 } { $i <= @cycles@ } { incr i } {
      set t2p [expr $t1p + 1e-6]
      set t3p [expr $t1p + (@dtp@*1e-3)]
      set t4p [expr $t2p + (@dtp@*1e-3)]

      set t1e [expr $t3p + 2.5e-3]
      set t2e [expr $t1e + 1e-6]
      set t3e [expr $t1e + (@dte@*1e-3)]
      set t4e [expr $t2e + (@dte@*1e-3)]

; Generate the program voltage pulse sequence.
       puts "      0 at [format %0.6e $t1p], @Vgp@ at [format %0.6e $t2p], @Vgp@ at [format %0.6e $t3p], 0 at [format %0.6e $t4p],"
; Generate the erase voltage pulse sequence.
         puts "   0 at [format %0.6e $t1e], @Vge@ at [format %0.6e $t2e], @Vge@ at [format %0.6e $t3e], 0 at [format %0.6e $t4e],"
      set t1p [expr $t3e + 5e-3]
    }

    )!
    )}

; Body/substrate terminal is grounded.
   {Name="substrate" Voltage= 0}
; Drain terminal bias is initialized, then later ramped/swept.
   {Name="drain"   Voltage= 0}
; Source terminal is grounded.
   {Name="source"   Voltage= 0}
}

; Enable global physical models used by SDevice.
Physics {
; Enable electron/hole barrier tunneling through the oxide interfaces.
   eBarrierTunneling "Gateoxb_Substrate"
```

```
; Enable electron/hole barrier tunneling through the oxide interfaces.
   hBarrierTunneling "Gateoxb_Substrate"
; Enable electron/hole barrier tunneling through the oxide interfaces.
   eBarrierTunneling "Gateoxt_Polygate"
; Enable electron/hole barrier tunneling through the oxide interfaces.
   hBarrierTunneling "Gateoxt_Polygate"
}

; Apply silicon-specific recombination and mobility models.
Physics(Material="Silicon") {
; Include Shockley-Read-Hall recombination with doping dependence.
   Recombination(SRH(DopingDependence))
; Include doping-dependent mobility and high-field velocity saturation.
   Mobility(DopingDependence HighFieldSaturation)
}

; Define trap physics inside the SONOS nitride charge-storage layer.
Physics(Material="NitrideAsSemiconductor") {
; Start definition of donor/acceptor trap levels in the nitride.
   Traps(
; Donor-like trap state used to model charge storage.
       (Donor Level EnergyMid= 2.5 FromConductionBand
       Conc= 1e19
       eXSection= 1e-13 hXSection= 1e-13
; Enable electron/hole barrier tunneling through the oxide interfaces.
       eBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Enable electron/hole barrier tunneling through the oxide interfaces.
      hBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Include field-enhanced emission from traps.
       PooleFrenkel
        TrapVolume= 1e-15
      )
; Acceptor-like trap state used to model charge storage.
      (Acceptor Level EnergyMid= 1.0 FromConductionBand
       Conc= 1e19
       eXSection= 1e-13 hXSection= 1e-13
; Enable electron/hole barrier tunneling through the oxide interfaces.
       eBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Enable electron/hole barrier tunneling through the oxide interfaces.
      hBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Include field-enhanced emission from traps.
       PooleFrenkel
        TrapVolume= 1e-15
        )
   )
}

; Define averaged quantities to record during transient/program/erase simulations.
CurrentPlot {
   SpaceCharge(Average(Material="NitrideAsSemiconductor"))
   eDensity(Average(Material="NitrideAsSemiconductor"))
   hDensity(Average(Material="NitrideAsSemiconductor"))
   eTrappedCharge(Average(Material="NitrideAsSemiconductor"))
   hTrappedCharge(Average(Material="NitrideAsSemiconductor"))
}

; Select spatial quantities to save for visualization in Sentaurus Visual.
Plot {
   eCurrent/Vector hCurrent/Vector
    ElectricField
    eQuasiFermi hQuasiFermi EffectiveBandgap
   ConductionBandEnergy ValenceBandEnergy
    Doping SpaceCharge DonorConcentration AcceptorConcentration
   SRH Auger
   eMobility hMobility
    eVelocity hVelocity
```

```
   eEparallel hEparallel
   eDirectTunnel hDirectTunnel
; Enable electron/hole barrier tunneling through the oxide interfaces.
   eBarrierTunneling hBarrierTunneling
   eTrappedCharge hTrappedCharge
   NonLocal
}

; Configure numerical methods and nonlocal tunneling paths.
Math    {
; Define a nonlocal tunneling path across an oxide interface.
   NonLocal "Gateoxb_Substrate" (
; Specify the material interface used for nonlocal tunneling calculation.
      RegionInterface="R.Gateoxb/R.Substrate"
      Length= 9e-7
      Digits= 4
      EnergyResolution= 1e-4
      )
; Define a nonlocal tunneling path across an oxide interface.
   NonLocal "Gateoxt_Polygate" (
; Specify the material interface used for nonlocal tunneling calculation.
      RegionInterface="R.Gateoxt/R.Polygate"
      Length= 5e-7
      Digits= 4
      EnergyResolution= 1e-4
      )
*     CNormPrint
     Iterations= 25
; Use Backward Euler transient integration for numerical stability.
   Transient= BE

}

; Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
# initial solution
; Initialize nitride traps as empty before program/erase transient simulation.
   Set(TrapFilling= Empty)
; Solve Poisson and transport equations self-consistently.
    Coupled (Iterations= 100) { Poisson }
; Solve Poisson and transport equations self-consistently.
    Coupled (Iterations= 100) { Poisson Electron}
; Solve Poisson and transport equations self-consistently.
    Coupled (Iterations= 100 Digits= 8) { Poisson Electron Hole }

; Save spatial solution snapshots for visualization.
   Plot(FilePrefix="n@node@_Zero")

; Allow traps to dynamically fill/empty during the transient simulation.
    UnSet(TrapFilling)

; Perform time-dependent simulation for program/erase pulse or Id-Vg measurement.
   Transient(
       InitialTime= 0 FinalTime= !(puts [expr $t1p])!
; Control numerical step size for convergence and resolution.
       InitialStep= 1e-5 Minstep= 1.e-10 MaxStep= 5e-3
; Solve Poisson and transport equations self-consistently.
   ){ Coupled { Poisson Electron Hole }

      !(
; Save spatial solution snapshots for visualization.
   puts "Plot(FilePrefix=\"n@node@_programmed\" Time=([format %0.6e [expr $t3p]]))"
; Save spatial solution snapshots for visualization.
   puts "Plot(FilePrefix=\"n@node@_programmed_no_bias\" Time=([format %0.6e [expr $t1e]]))"
; Save the programmed/erased state for later electrical characterization.
   puts "Save(FilePrefix=\"n@node@_programmed\" Time=([format %0.6e [expr $t1e]]))"
```

```
; Save spatial solution snapshots for visualization.
   puts "Plot(FilePrefix=\"n@node@_erased\" Time=([format %0.6e [expr $t3e]]))"
; Save spatial solution snapshots for visualization.
   puts "Plot(FilePrefix=\"n@node@_erased_no_bias\" Time=([format %0.6e [expr $t1p]]))"
; Save the programmed/erased state for later electrical characterization.
   puts "Save(FilePrefix=\"n@node@_erased\" Time=([format %0.6e [expr $t1p]]))"
        )!

   }
}
```

12. SPROCESS IV sdevice

- Runs SONOS Id-Vg characterization after loading a saved memory state.
- Extracts electrical behavior after programmed or erased charge states.

Annotated Code

```
; File block maps Workbench input/output files for mesh, parameters, plots, currents, and logs.
File {
; Input mesh generated from SDE/SProcess.
   Grid=      "@tdr@"
; Parameter file passed from Sentaurus Workbench.
   Parameter= "@parameter@"
; Output file for terminal currents.
   Current=   "@plot@"
; TDR output file for spatial physical quantities.
   Plot=      "@tdrdat@"
; Log/output file for solver messages.
   Output=    "@log@"
}

; Define terminal boundary conditions and contact properties.
Electrode {
; Gate terminal is initialized and assigned polysilicon/work-function behavior.
   {Name="gate"    Voltage= 0  Material = "PolySi"
; Define a time-dependent voltage waveform at this electrode.
   Voltage=(0 at 0, -1.25 at 1e-6, -1.25 at 2e-6, 3.25 at 1)
   }
; Body/substrate terminal is grounded.
   {Name="substrate" Voltage= 0}
; Drain terminal bias is initialized, then later ramped/swept.
   {Name="drain"   Voltage= 0  Voltage=(0 at 0, 1 at 1e-6)}
; Source terminal is grounded.
   {Name="source"   Voltage= 0}
}

; Enable global physical models used by SDevice.
Physics {
; Enable electron/hole barrier tunneling through the oxide interfaces.
   eBarrierTunneling "Gateoxb_Substrate"
; Enable electron/hole barrier tunneling through the oxide interfaces.
   hBarrierTunneling "Gateoxb_Substrate"
; Enable electron/hole barrier tunneling through the oxide interfaces.
   eBarrierTunneling "Gateoxt_Polygate"
; Enable electron/hole barrier tunneling through the oxide interfaces.
   hBarrierTunneling "Gateoxt_Polygate"
}

; Apply silicon-specific recombination and mobility models.
Physics(Material="Silicon") {
; Include Shockley-Read-Hall recombination with doping dependence.
   Recombination(SRH(DopingDependence))
; Include doping-dependent mobility and high-field velocity saturation.
   Mobility(DopingDependence HighFieldSaturation)
}

; Define trap physics inside the SONOS nitride charge-storage layer.
Physics(Material="NitrideAsSemiconductor") {
; Start definition of donor/acceptor trap levels in the nitride.
   Traps(
; Donor-like trap state used to model charge storage.
       (Donor Level EnergyMid= 2.5 FromConductionBand
       Conc= 1e19
```

```
       eXSection= 1e-13 hXSection= 1e-13
; Enable electron/hole barrier tunneling through the oxide interfaces.
       eBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Enable electron/hole barrier tunneling through the oxide interfaces.
      hBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Include field-enhanced emission from traps.
       PooleFrenkel
        TrapVolume= 1e-15
      )
; Acceptor-like trap state used to model charge storage.
      (Acceptor Level EnergyMid= 1.0 FromConductionBand
       Conc= 1e19
       eXSection= 1e-13 hXSection= 1e-13
; Enable electron/hole barrier tunneling through the oxide interfaces.
       eBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Enable electron/hole barrier tunneling through the oxide interfaces.
      hBarrierTunneling(NonLocal= "Gateoxb_Substrate" NonLocal= "Gateoxt_Polygate")
; Include field-enhanced emission from traps.
       PooleFrenkel
        TrapVolume= 1e-15
        )
   )
}

; Define averaged quantities to record during transient/program/erase simulations.
CurrentPlot {
   SpaceCharge(Average(Material="NitrideAsSemiconductor"))
   eDensity(Average(Material="NitrideAsSemiconductor"))
   hDensity(Average(Material="NitrideAsSemiconductor"))
   eTrappedCharge(Average(Material="NitrideAsSemiconductor"))
   hTrappedCharge(Average(Material="NitrideAsSemiconductor"))
}

; Select spatial quantities to save for visualization in Sentaurus Visual.
Plot {
   eCurrent hCurrent
    ElectricField
    eQuasiFermi hQuasiFermi EffectiveBandgap
   ConductionBandEnergy ValenceBandEnergy
    Doping SpaceCharge DonorConcentration AcceptorConcentration
   SRH Auger
   eMobility hMobility
    eVelocity hVelocity
   eEparallel hEparallel
   eDirectTunnel hDirectTunnel
; Enable electron/hole barrier tunneling through the oxide interfaces.
   eBarrierTunneling hBarrierTunneling
   eTrappedCharge hTrappedCharge
   NonLocal
}

; Configure numerical methods and nonlocal tunneling paths.
Math {
; Define a nonlocal tunneling path across an oxide interface.
   NonLocal "Gateoxb_Substrate" (
; Specify the material interface used for nonlocal tunneling calculation.
      RegionInterface="R.Gateoxb/R.Substrate"
      Length= 9e-7
      Digits= 4
      EnergyResolution= 1e-4
      )
; Define a nonlocal tunneling path across an oxide interface.
   NonLocal "Gateoxt_Polygate" (
; Specify the material interface used for nonlocal tunneling calculation.
      RegionInterface="R.Gateoxt/R.Polygate"
      Length= 5e-7
```

```
      Digits= 4
      EnergyResolution= 1e-4
      )
*   CNormPrint
     Iterations= 25
; Use Backward Euler transient integration for numerical stability.
   Transient= BE
}

; Solver sequence: first build a stable equilibrium solution, then apply bias ramps/sweeps.
Solve {
   Transient (
      InitialTime= 0 FinalTime= 1e-6
; Control numerical step size for convergence and resolution.
         InitialStep= 1e-8 MaxStep= 5e-7 Minstep= 1.e-10
; Solve Poisson and transport equations self-consistently.
   ){ Coupled {Poisson Electron Hole}
; Load a previously saved SONOS programmed or erased state.
          Load(FilePrefix="n@previous|-1@_@SONOSstate@" Time=(0))
         }

; Set current-output file prefix for this sweep.
   NewCurrentPrefix="n@node@_IdVg_"
   Transient (
      InitialTime= 1e-6 FinalTime= 1
; Control numerical step size for convergence and resolution.
      InitialStep= 1e-6 MaxStep= 3.125e-02 Minstep= 1.e-7
; Solve Poisson and transport equations self-consistently.
   ){ Coupled {Poisson Electron Hole}
; Sample terminal currents during the sweep.
          CurrentPlot( Time=(Range=(0 1) Intervals= 32) )
   }
}
```