Blaze2D/Blaze3D

Device Simulator for Advanced Materials

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Contents

- Introduction: What is Blaze?
- Purpose: Why use Blaze?
- Features
- Application examples
- Conclusions

Introduction

- Blaze/Blaze3D simulates devices fabricated using advanced materials
- A library of compound semiconductors, including ternary and quaternary materials are included within Blaze
- Blaze can simulate devices of arbitrary complexity
- Blaze can easily be used with other Silvaco modules to take into account different physical effects

Key Benefits

- Built-in materials library that contains parameters for more than forty materials, selected materials include:
    - GaAs
    - AlGaAs
    - InGaAs
    - SiGe
    - GaN
    - SiC
    - Custom materials

Key Benefits (con’t)

- Blaze/Blaze3D can accommodate graded and abrupt heterojunctions
- Band gap discontinuities across a heterojunction can be easily adjusted
- Measurable DC, AC, and transient device characteristics can be simulated
- Calculated DC characteristics include threshold voltage, gain, leakage, punchthrough voltage, and breakdown behavior

Key Benefits (con't)

- Calculated RF characteristics include cut-off frequency, s-, y-, h-, and z-parameters, maximum available gain, maximum stable gain, maximum frequency of oscillation, and stability factor
- Intrinsic switching times and Fourier analysis of periodic large-signal outputs can also be calculated

Key Benefits (con’t)

- Device structure may be specified by the user within ATLAS, or by the output of a process simulator, such as ATHENA, or through Silvaco’s device editor, DevEdit
- Boltzmann and Fermi-Dirac statistics with band gap narrowing due to heavy doping can be chosen.
- Thermionic emission at abrupt junctions can easily be accounted for
- Seemless interface to other Silvaco modules, e.g. Quantum for quantum mechanical confinement effects, Luminous for optical generation effect

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Key Benefits (con’t)

- Drift-diffusion and energy balance transport models with advanced mobility models
- Trap dynamics for DC, transient, and AC
- Models for Schottky-Read-Hall, optical, and Auger recombination, impact ionization, band-to-band and Fowler-Nordheim tunneling, hot carrier injection, Ohmic and Schottkly contacts, and floating gates
- C-Interpreter interface allows user-defined model and material parameters

Applications

- Advanced material devices
- Heterostructure devices
  - APDs, HBTs, MESFET, HEMT, PHEMT
- Gaining insight into physical behavior
- Temperature behavior of advanced devices
- Device design for optimum performance reducing costly experimental investigations
- Identifying critical elements to the performance of the device

Typical ‘input deck’ within DeckBuild

```
go atlas
mesh
x.mesh loc=0.0 spac=0.05
x.mesh loc=0.3 spac=0.05
x.mesh loc=0.6 spac=0.05
x.mesh loc=1.0 spac=0.05

y.mesh loc=0.0 spac=0.02
y.mesh loc=0.15 spac=0.01
y.mesh loc=0.22 spac=0.005
y.mesh loc=0.3 spac=0.05
y.mesh loc=1.0 spac=0.07

region num=1  material=oxide
region num=2  material=InGaAs x.min=0.0 x.max=0.3 y.min=0.0 y.max=0.15
x.comp=0.47
region num=3  material=InP x.min=0.0 x.max=0.3 y.min=0.15 y.max=0.22
region num=4  material=InGaAs x.min=0.0 x.max=0.6 y.min=0.22 y.max=0.3
x.comp=0.47
region num=5  material=InP x.min=0.0 x.max=1.0 y.min=0.3 y.max=1.0

electrode num=1 name=emitter x.min=0.0 x.max=0.3 y.min=0.0 y.max=0.0
electrode num=2 name=base x.min=0.45 x.max=0.6 y.min=0.22 y.max=0.22
electrode num=3 name=collector bottom
doping x.min=0.0 x.max=1.0 y.min=0.0 y.max=1.0 n.type ascii
infile=hbtex08_n
doping x.min=0.0 x.max=1.0 y.min=0.0 y.max=1.0 p.type ascii
infile=hbtex08_p
```

```
material material=InP align=0.65material material=InGaAs
mun0=10000 mup0=400
material  taun0=1e-9 taup0=1e-9
model fermi  auger print
method climit=1e-4
output band.param con.band val.band
solve init
solve previous
save outf=hbtex08.str
tonyplot hbtex08.str –set hbtex08_doping.set
solve v3=0.0001
solve v3=0.001
solve v3=0.01
solve v3=0.1
solve v3=2
solve v2=0.0001
solve v2=0.001
solve v2=0.01
solve v2=0.1

log outf=hbtex08_IV.log
solve v2=0.05 vstep=0.2 vfinal=1.5 electrode=2
quit
```

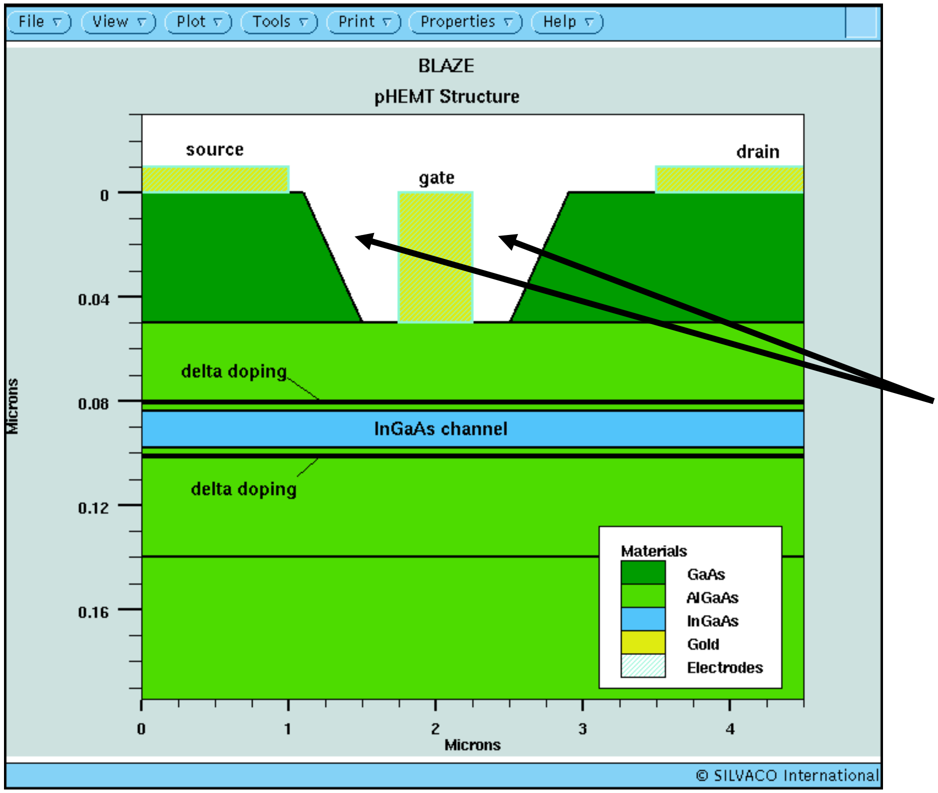
Typical Frequency Analysis ‘input deck’

```
# Frequency analysis
go atlas
mesh infile=hbtex08.str
material material=InP align=0.65
material material=InGaAs mun0=10000 mup0=400
material  taun0=1e-9 taup0=1e-9model fermi auger print
method climit=1e-4
output band.param con.band val.band
load infile=hbtex08.str master
solve previous
solve v3=0.0001   ac freq=1e6
solve v3=0.1      ac freq=1e6
solve v3=1.0      ac freq=1e6
solve v2=0.0001   ac freq=1e6
solve v2=0.1      ac freq=1e6
solve v2=1.0      ac freq=1e6

log outf=hbtex08_freq.log gains inport=base outport=collector
width=50
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=1 fstep=10 nfstep=7
mult.freq
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=2e7
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=4e7
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=6e7
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=1e8
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=2e8
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=4e8
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=1e9
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=2.5e9
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=3.5e9
solve  v2=1.0 v3=1.0 vstep=0.025 electrode=23 ac freq=2.2e10
quit
```

Readily Accessible Material Parameters

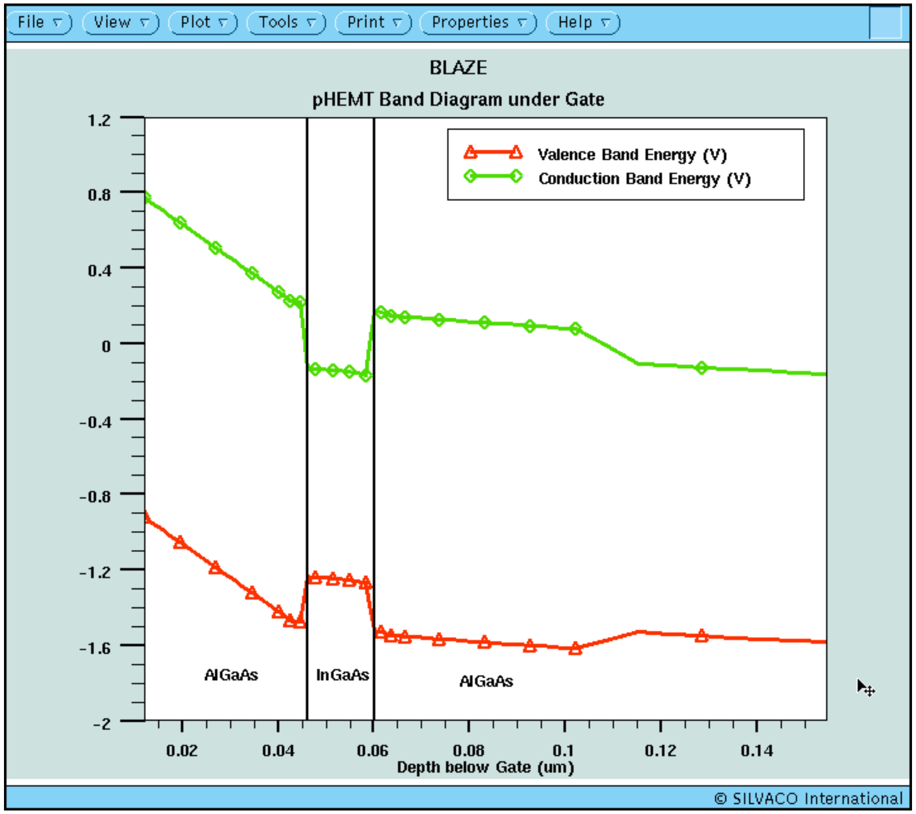
```
ATLAS> model fermi  auger print
ATLAS> method climit=1e-4
CONSTANTS: Boltzmann's constant  = 1.38066e-23 J/K
Elementary charge     = 1.6023e-19 C
Permittivity in vacuum = 8.85418e-14 F/cm
Temperature           = 300 K
Thermal voltage       = 0.0258502 V

REGIONAL MATERIAL PARAMETERS: Region : 1         2         3         4         5         6         7         8
Material     :                       Oxide    InGaAs       InP    InGaAs       InP Conductor Conductor Conductor
Type         :                     insulator semicond. semicond. semicond. semicond.   metal     metal     metal
Epsilon      :                        3.9      13.9      12.5      13.9      12.5
Band Parameters Eg (eV)      :      0.734      1.35     0.734      1.35
Chi (eV)     :                       4.13      3.73      4.13      3.73
Nc (per cc)  :                   1.52e+17   5.6e+17  1.52e+17   5.6e+17
Nv (per cc)  :                   8.12e+18  1.16e+19  8.12e+18  1.16e+19
ni (per cc)  :                   7.61e+11  1.16e+07  7.61e+11  1.16e+07
.
.
.
```

Complete HEMT and PHEMT Characterization



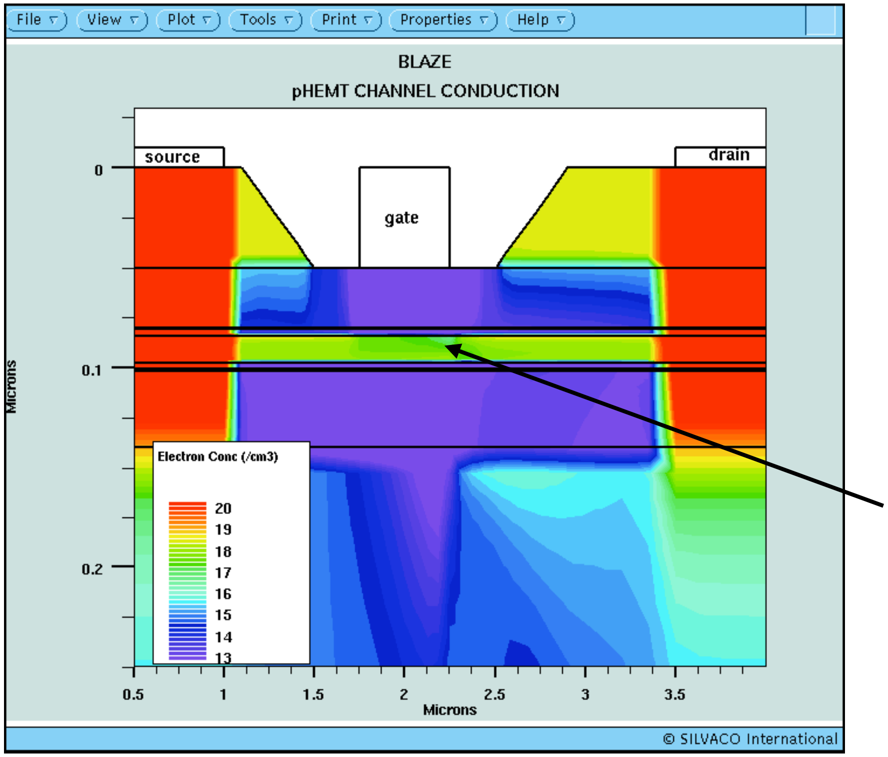
- A HEMT with an AlGaAs/ InGaAs/GaAs layer structure has been defined using the graphical structure editor DevEdit
- Angled sidewalls of the GaAs layer have been created via DevEdit
- A recessed gate has been included in the design, as well as several buffer layers and delta doped regions

Complete HEMT and PHEMT Characterization



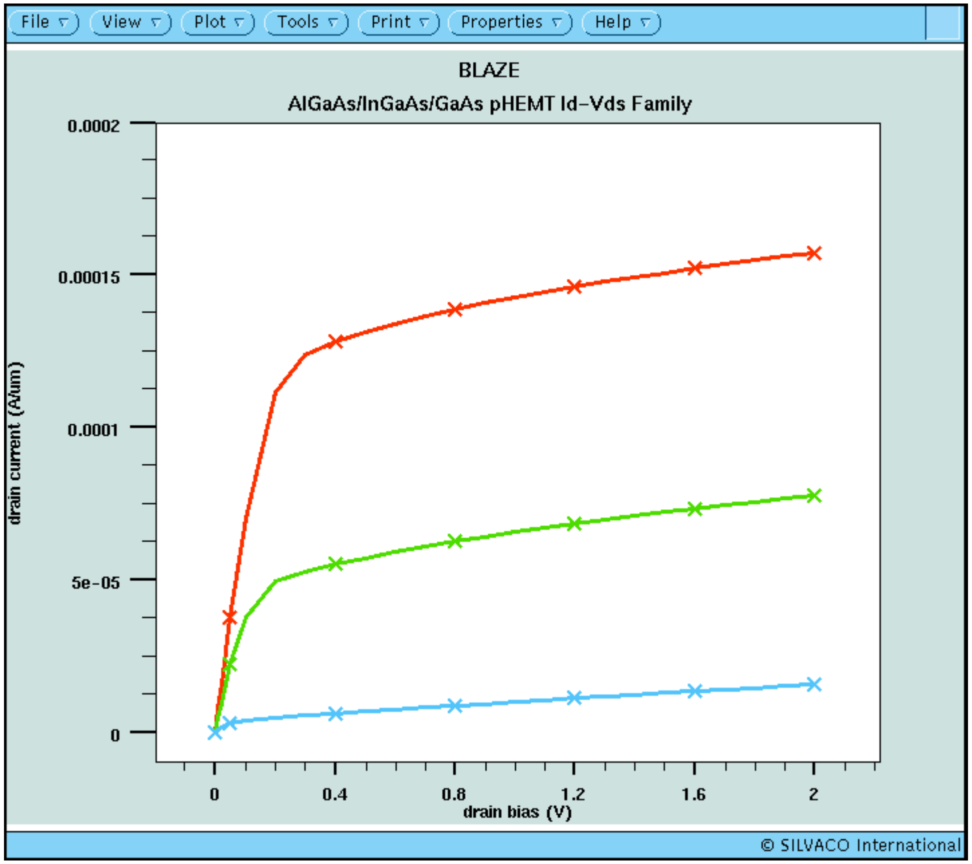
- One dimensional cutline can be taken anywhere through the structure using TonyPlot
- Band diagram taken through the gate of the HEMT
- Discontinuities in potential are seen at the heterojunctions
- These discontinuities can easily be adjusted

Application Example: HEMT and PHEMT Simulation



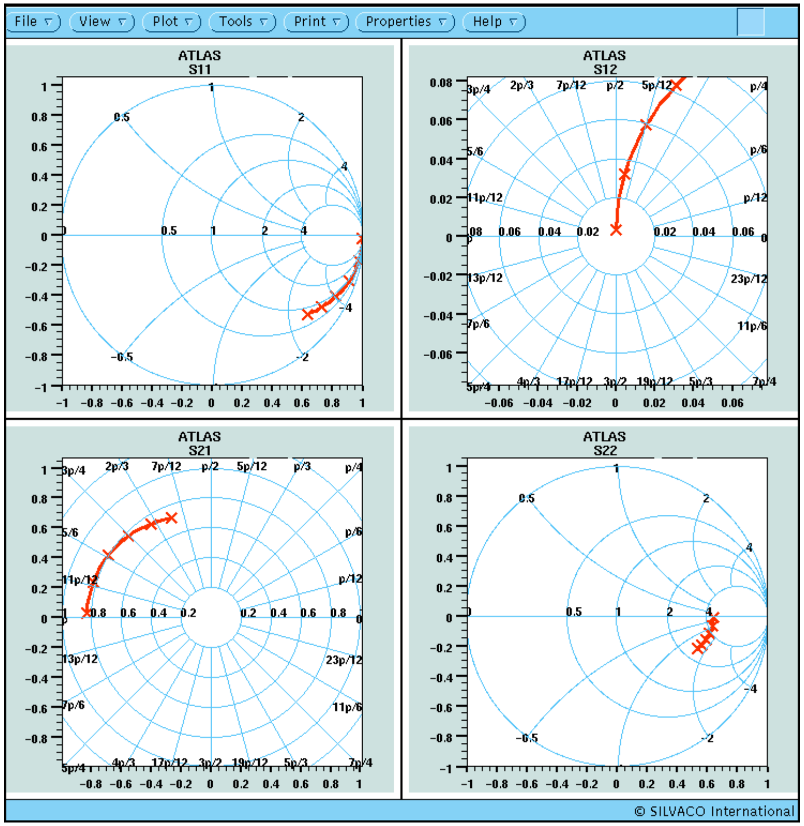
- Solution files produced by Blaze contain internal device variables, such as electron concentration
- The Schottky barrier creates a depletion layer below the gate. Electrons accumulate in the narrow band-gap materials in the channel

Complete HEMT and PHEMT Characterization



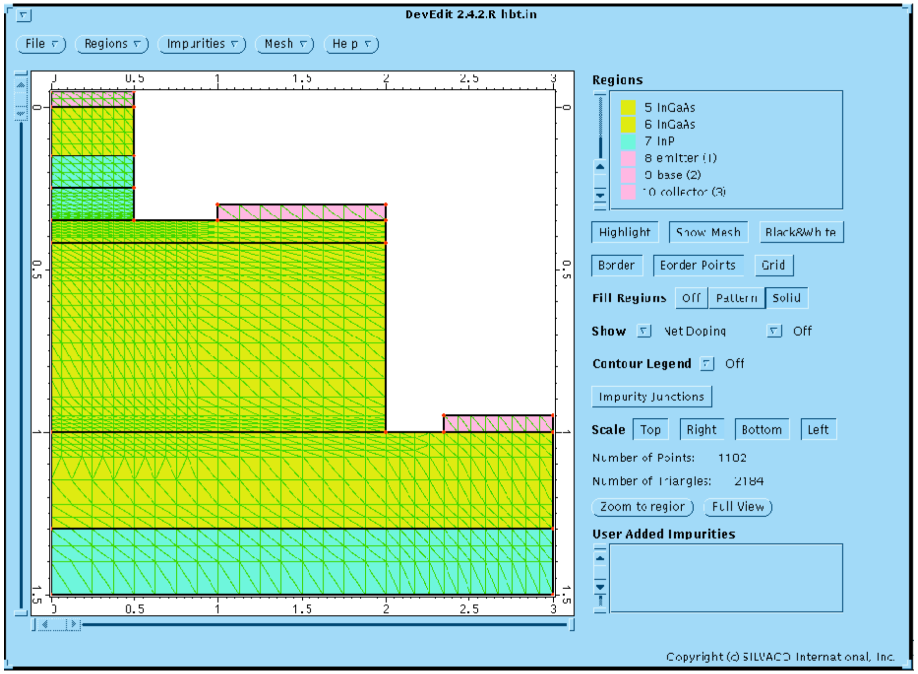
- Log file outputs from Blaze contain electrical behavior information.
- An Id/Vds plot is shown for several Vgs values
- Extraction of device parameters can be performed on these curves

Complete HEMT and PHEMT Characterization (con't)



- AC analysis can be performed and s-parameters extracted from the results
- s-parameters are displayed for this device for frequencies up to 50 GHz
- Simulation well over 100GHz also possible

Complete HBT Analysis

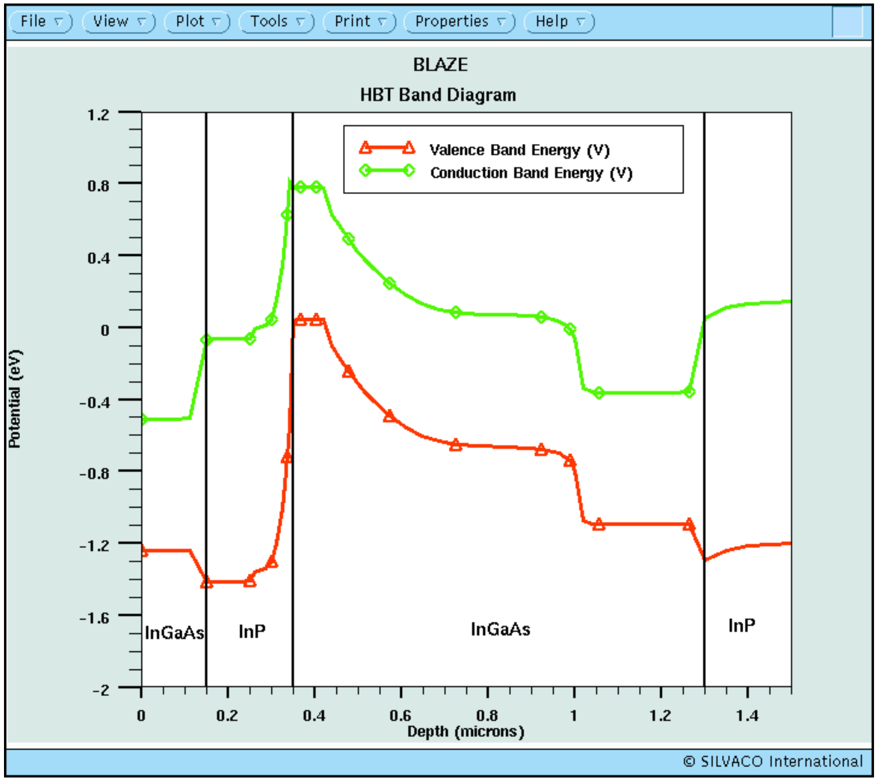


Number of Points: 1102

Number of Triangles: 2184

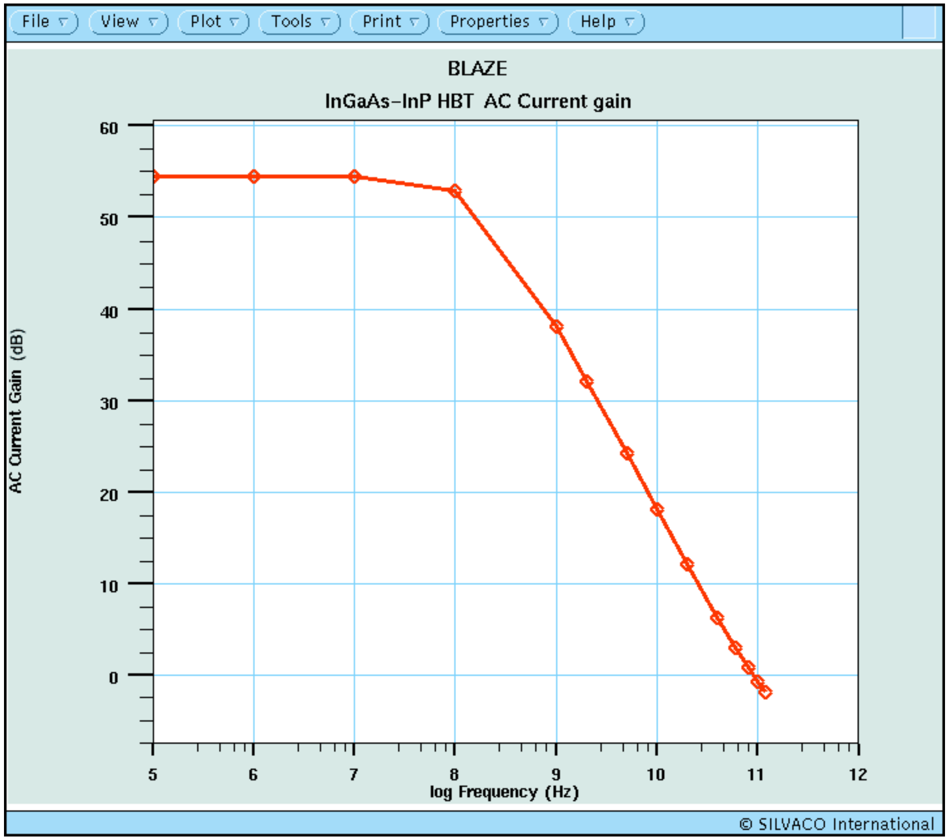
- Using DevEdit/ DevEdit3D a non-planar HBT structure can be created for simulation by Blaze/Blaze3D
- An InGaAs/InP HBT structure is illustrated here. DevEdit performs automatic meshing for use in Blaze/Blaze3D

Complete HBT Analysis (con’t)



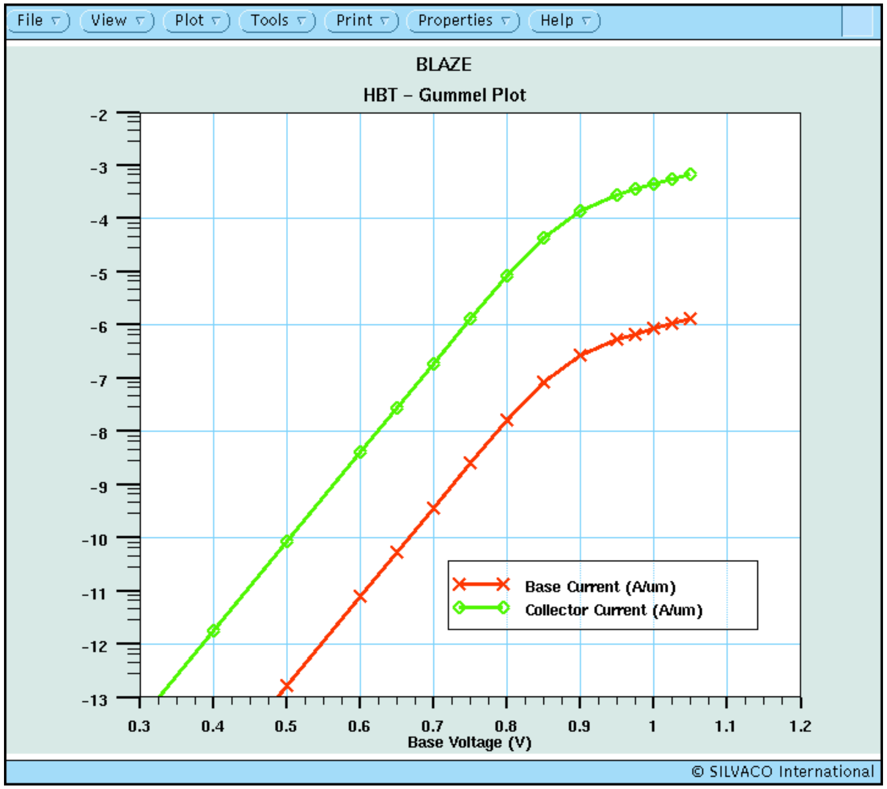
- Tools within TonyPlot allow easy manipulation of the output data
- Band diagram of an HBT through the intrinsic region

Complete HBT Analysis (con’t)



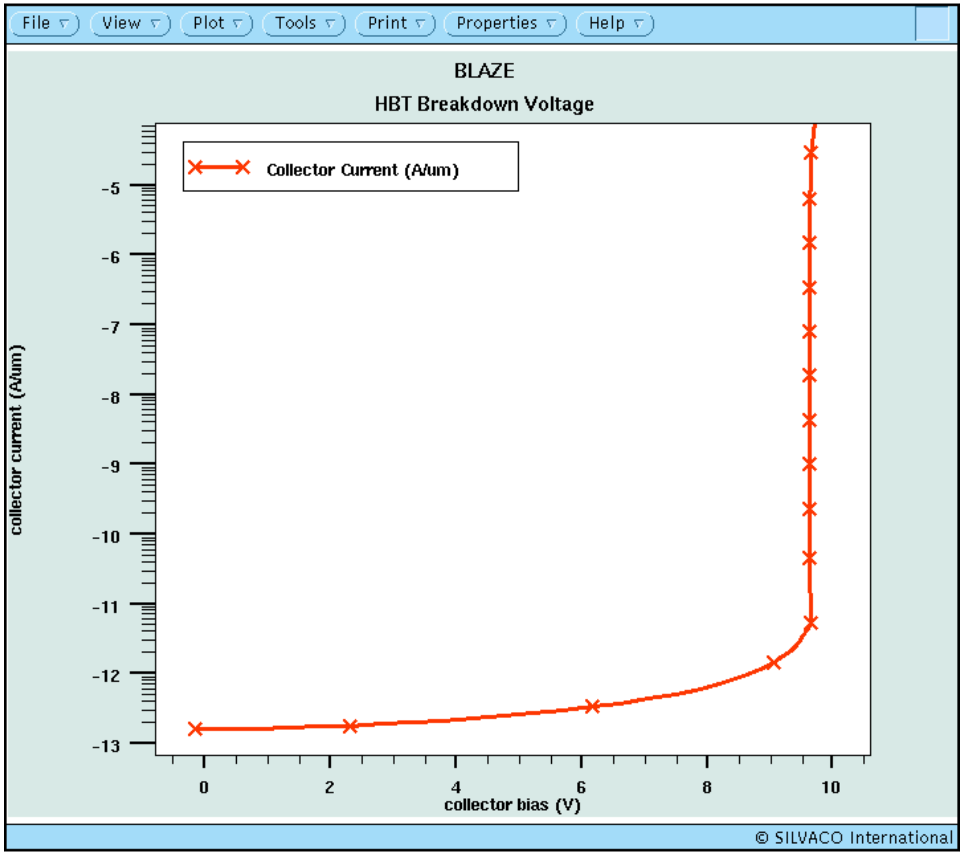
- AC analysis of the HBT provides gain vs. frequency plots, s-parameter extraction, and can predict the gain roll off with frequency

Complete HBT Analysis (con't)



- Blaze/Blaze3D is used to generate Gummel plots for HBTs
- Additional quantities, such as device gain can also be displayed

Complete HBT Analysis (con’t)

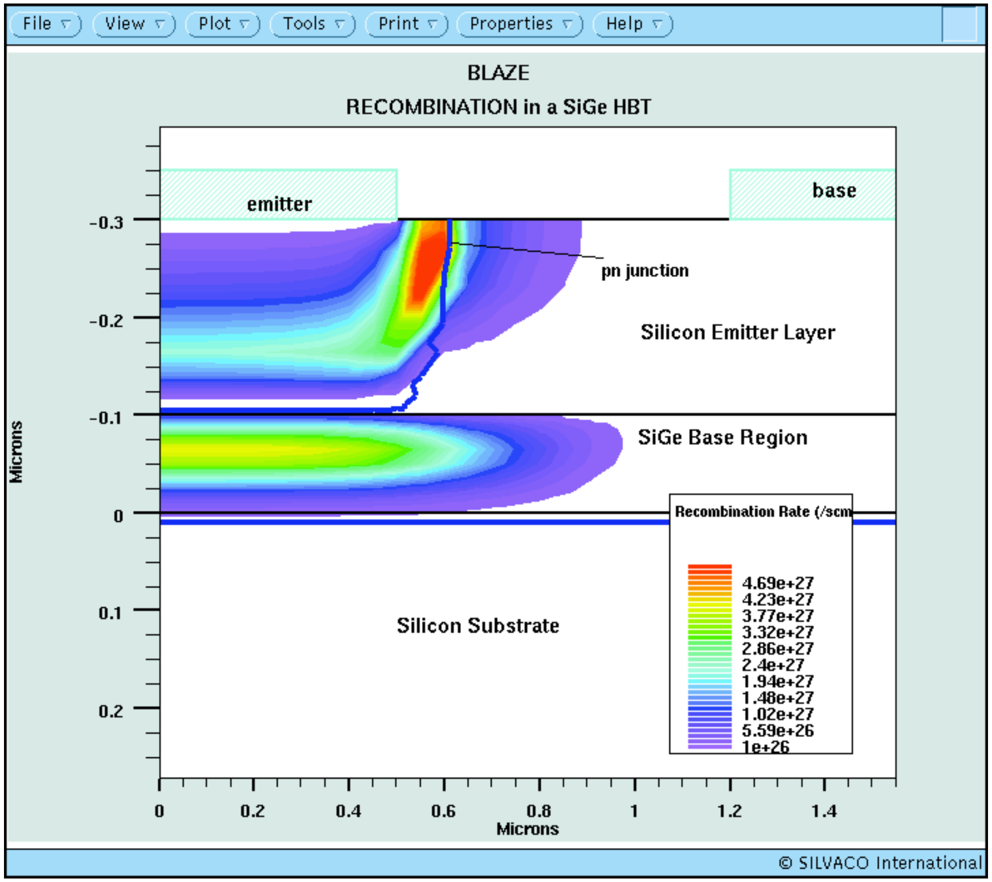


- BVCEO of an HBT
- Impact ionization models allow simulation of breakdown voltages

SiGe Technologies

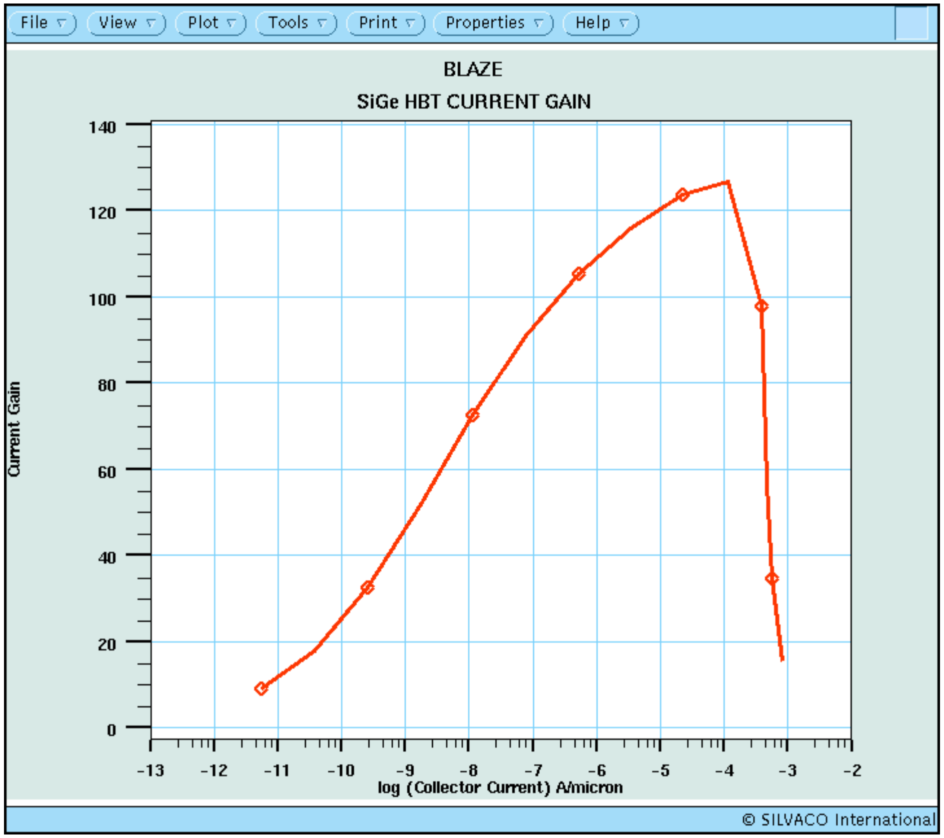
- In addition to III-V based devices, Blaze/Blaze3D can simulate any compound or elemental semiconductor materials
- Users can also easily enter their own custom materials with associated parameter values

SiGe Technologies (con’t)



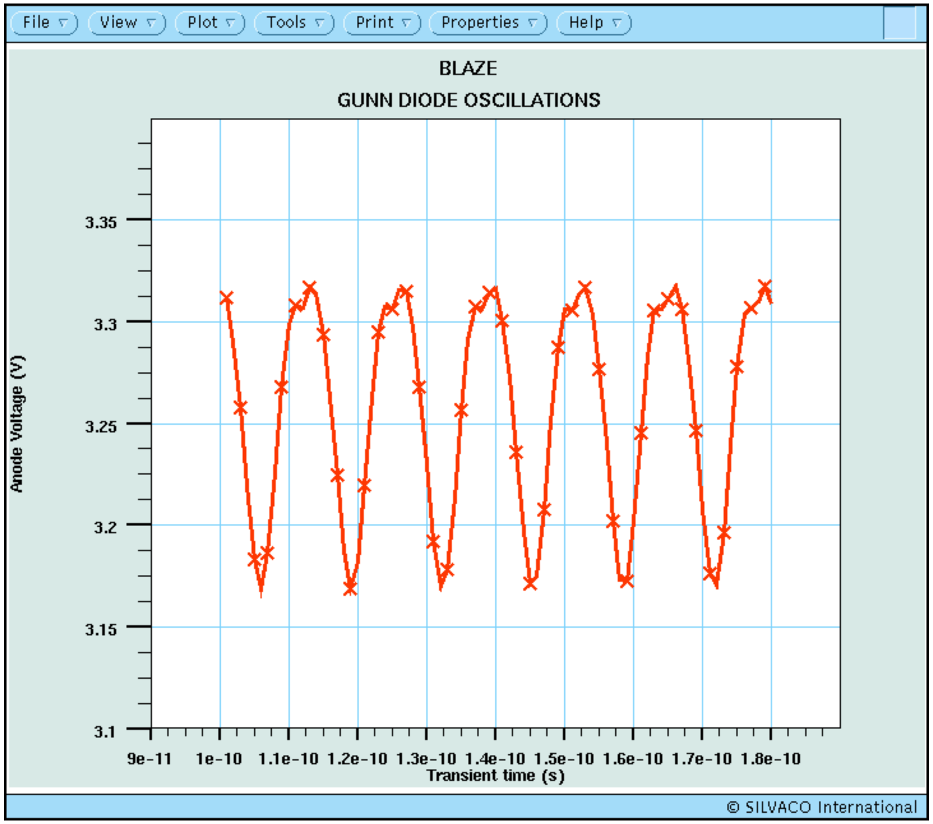
- SiGe HBT
- Recombination in the base of a SiGe HBT

SiGe Technologies (con’t)



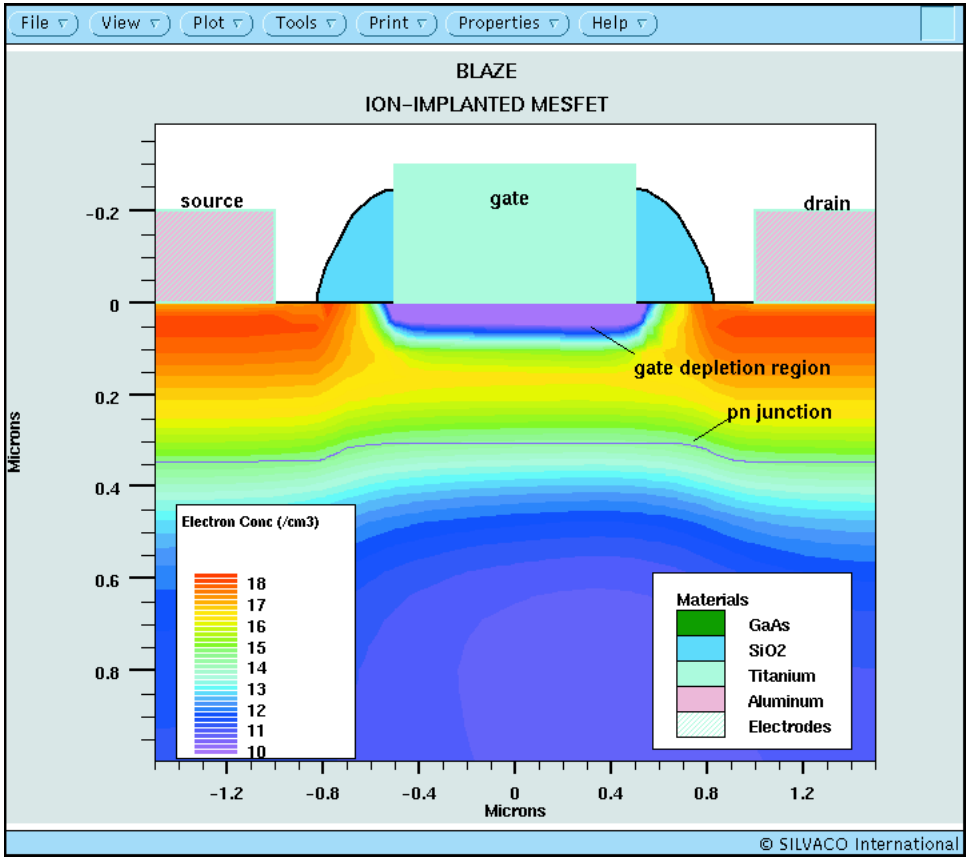
- Examples of results from a Si/SiGe HBT simulation
- Gain of the SiGe HBT

Negative-Differential Mobility



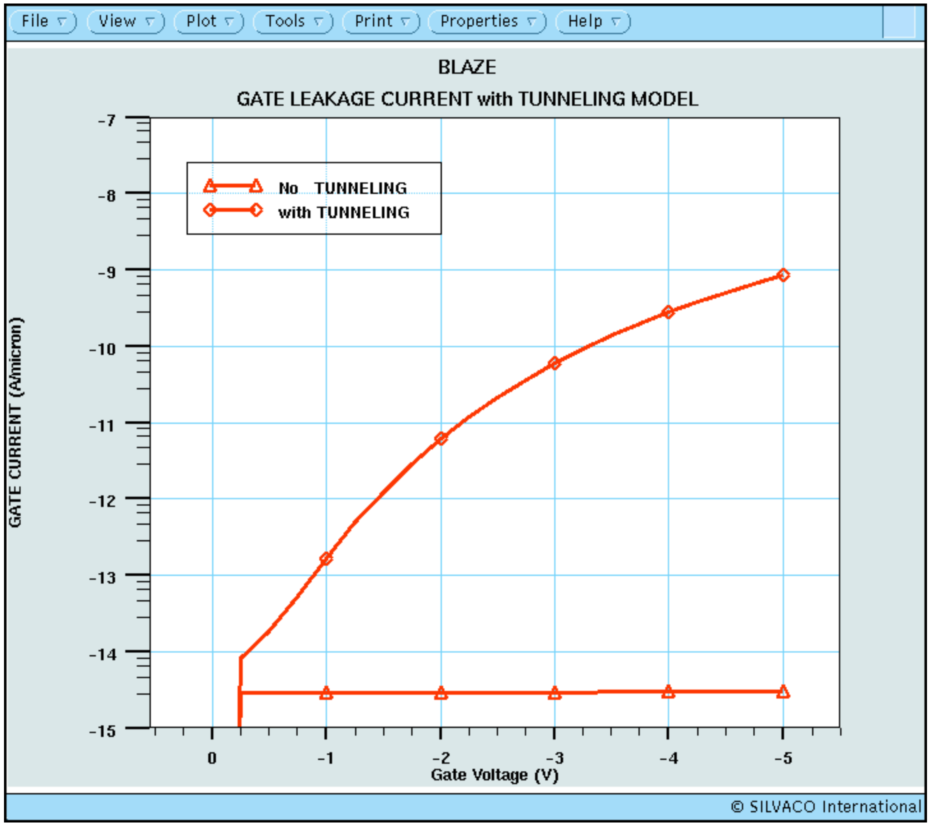
- III-V materials have a negative differential mobility
- Blaze/Blaze3D simulates this effect as illustrated by the output oscillations of a GaAs Gunn diode

GaAs MESFET



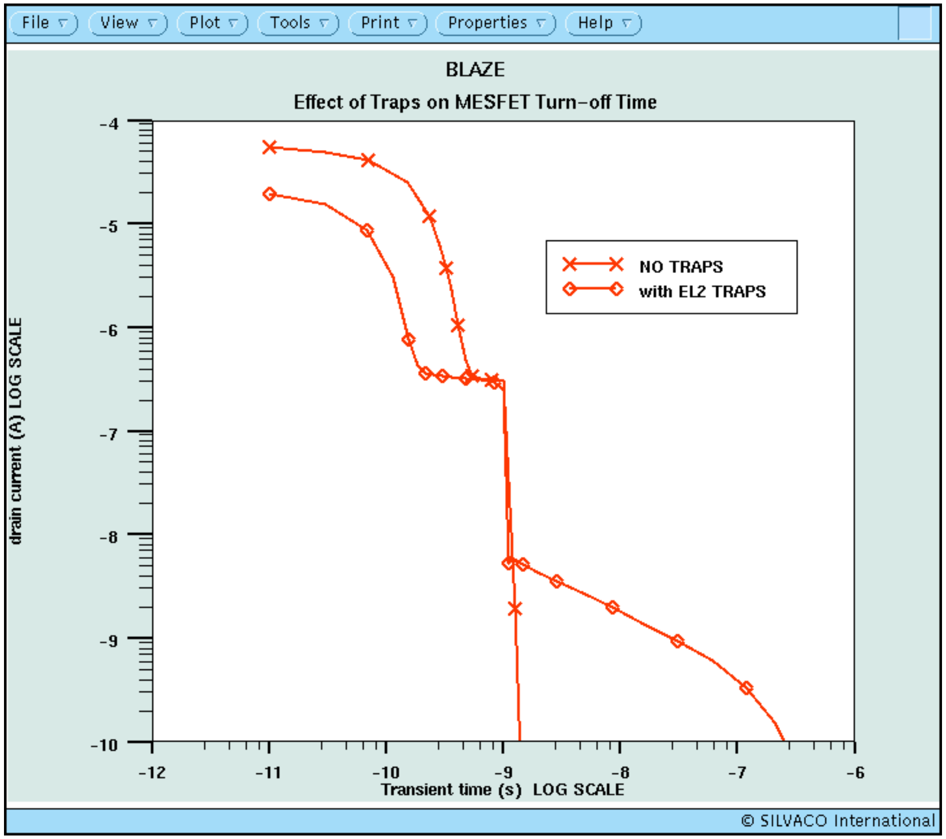
- Ion implanted MESFET structure generated using ATHENA and Flash
- Electron concentration can easily be displayed

GaAs MESFET (con’t)



- In gate current analysis and MESFET breakdown, tunneling at Schottky contacts is an important mechanism
- Thermionic emission and tunneling may also be included

GaAs MESFET (con't)



- Blaze/Blaze3D allows definition of arbitrary trap levels
- Traps can dominate the DC, switching, and RF performance of III-V devices
- Effect of EL2 traps on MESFET turn-off

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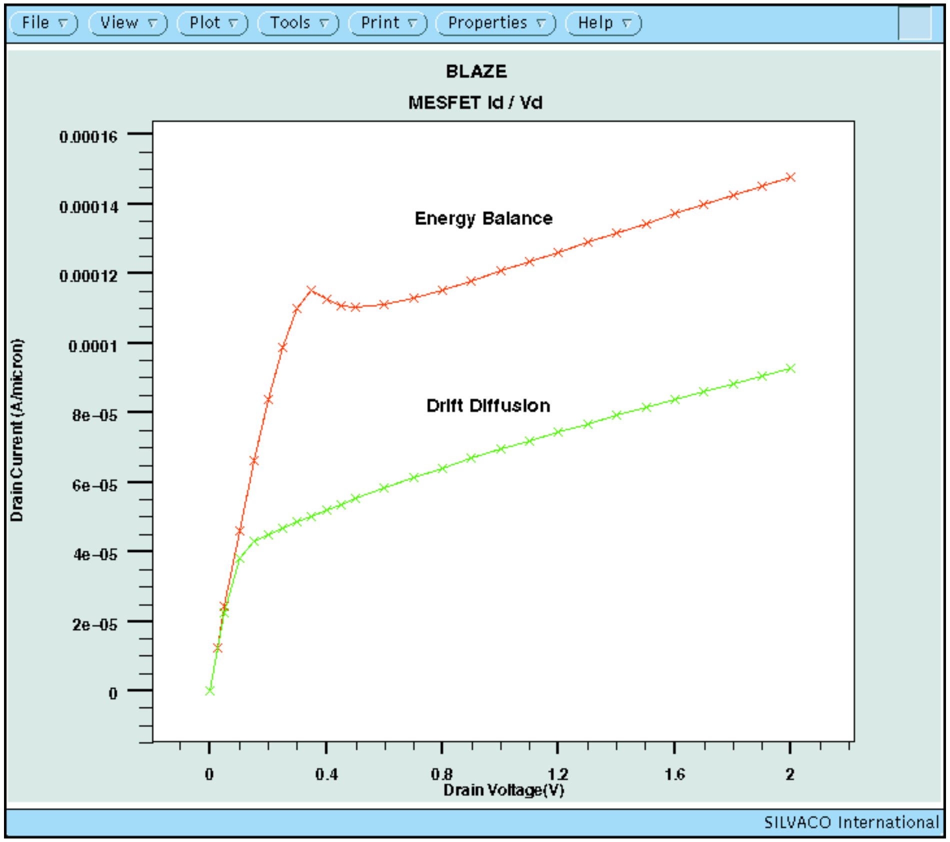
GaAs MESFET (con’t)



- Difference between a standard drift diffusion and energy balance simulation
- Blaze/Blaze3D includes energy balance models to simulate the effects of non-local carrier behavior

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Conclusion

- Silvaco’s advanced material device simulator Blaze has been discussed
- Any arbitrary semiconductor device can be simulated
- Comprehensive built in material parameter database for over 40 materials
- Runs seamlessly with Silvaco’s other TCAD tools
- C-Interpreter interface allows user-defined model and material parameters
- Ease of use within the DeckBuild environment