Introduction to SILVACO ATLAS TCAD Tool

Course ECE 445

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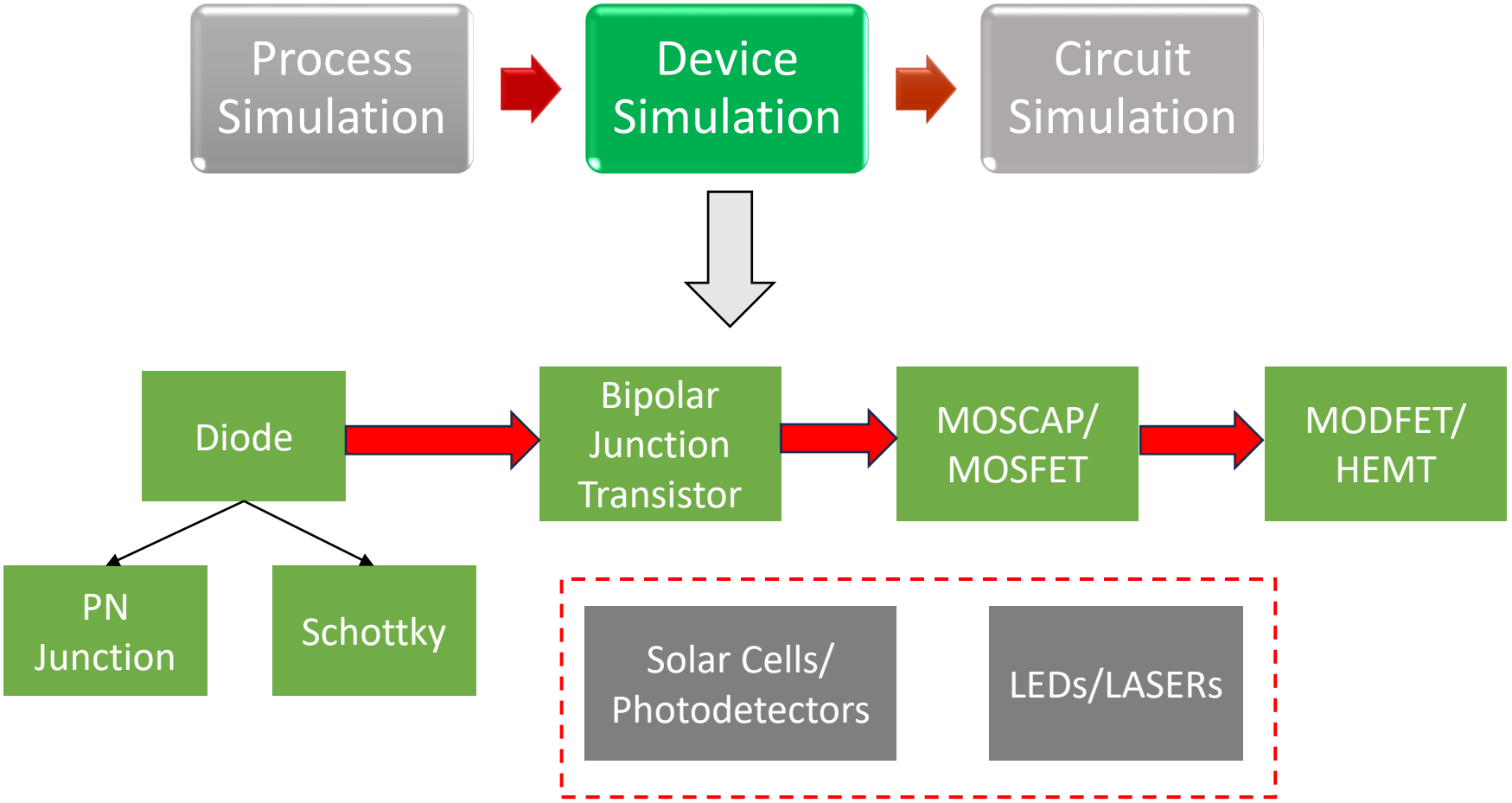
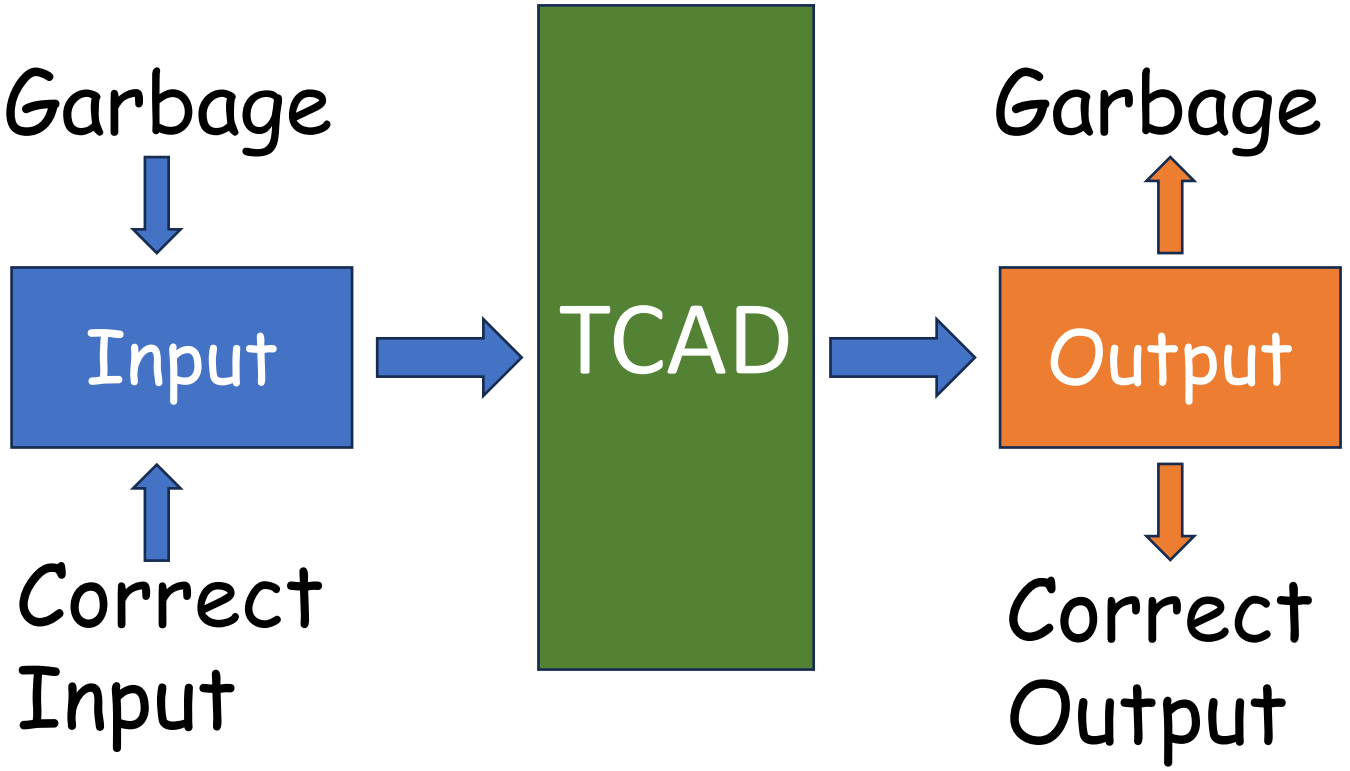
What is TCAD??

Technology Computer-Aided Design



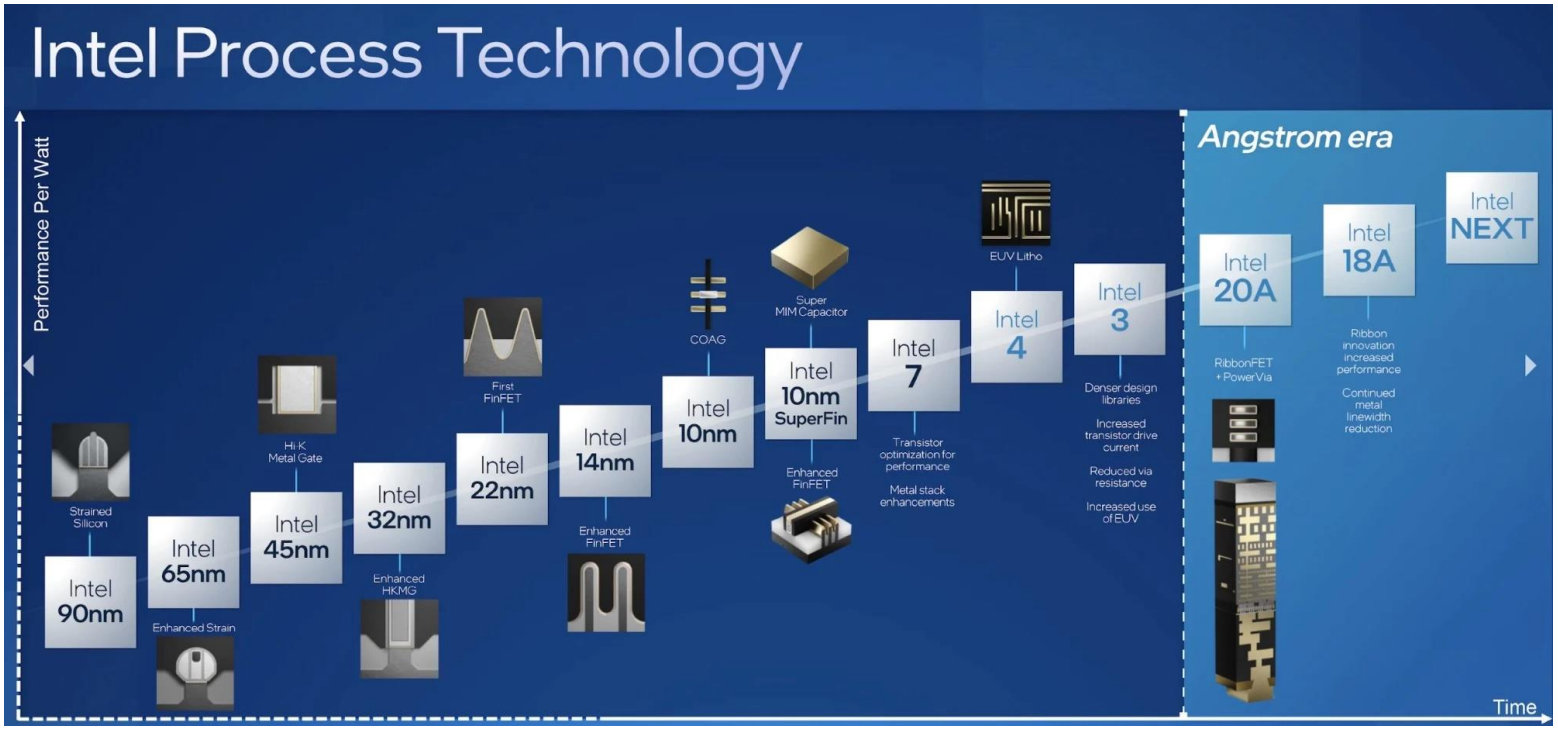
Do We Trust TCAD??

NO!! Always Verify Twice!



What Can we do with TCAD?

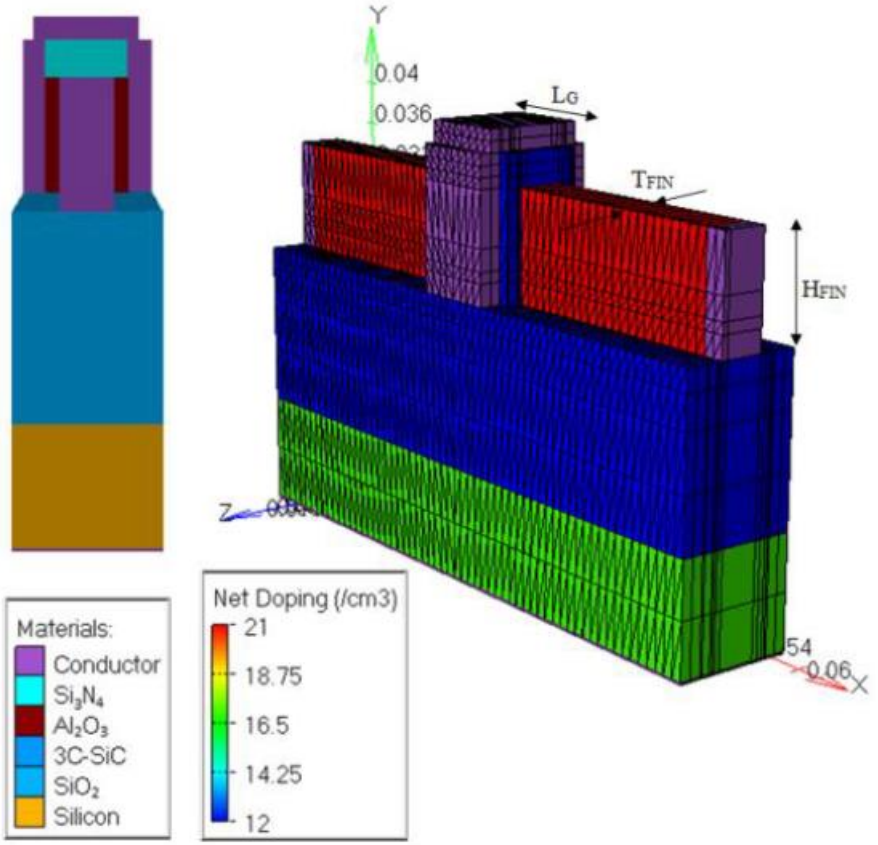
SIMULATE ANY DEVICE!



Let's Get Started with TCAD!

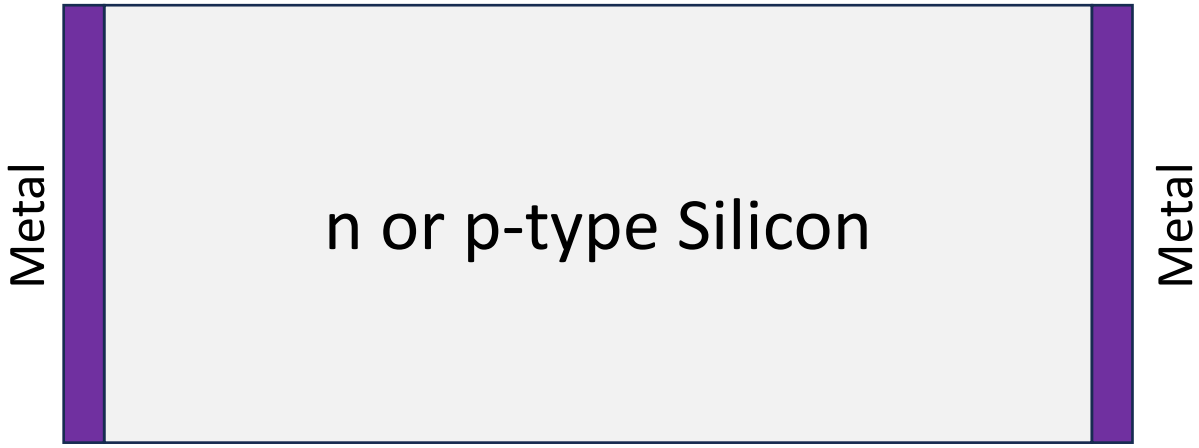
Basics of TCAD

Group	*Statements*
1. Structure Specification	MESH REGION ELECTRODE DOPING
2. Material Models Specification	MATERIAL MODELS CONTACT INTERFACE
3. Numerical Method Selection	METHOD
4. Solution Specification	LOG SOLVE LOAD SAVE
5. Results Analysis	EXTRACT TONYPLOT



Defining the Structure

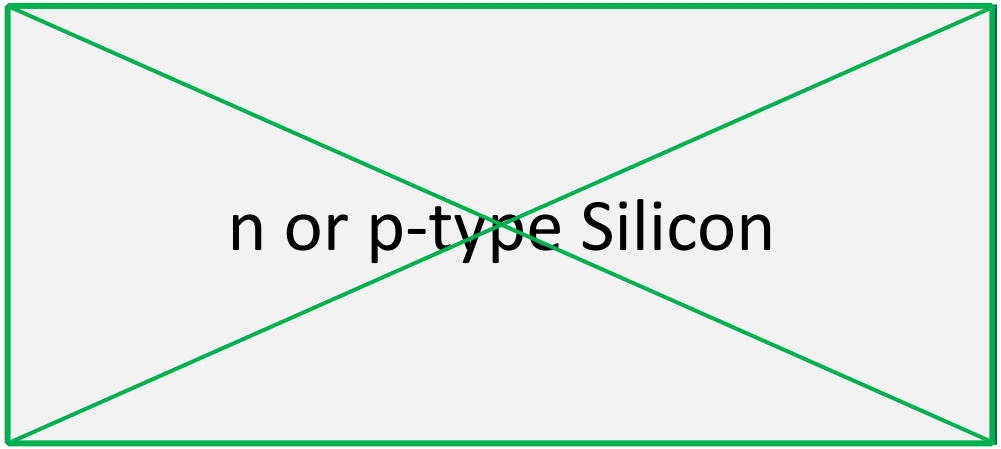
Mesh Design/ Digitization of the simulation area

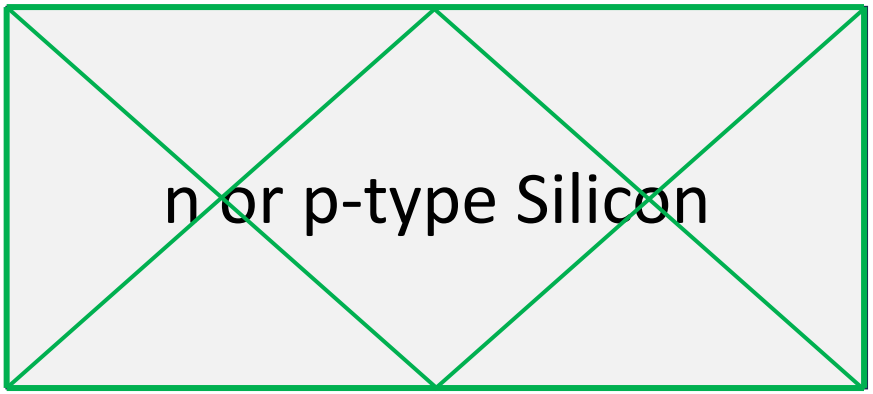


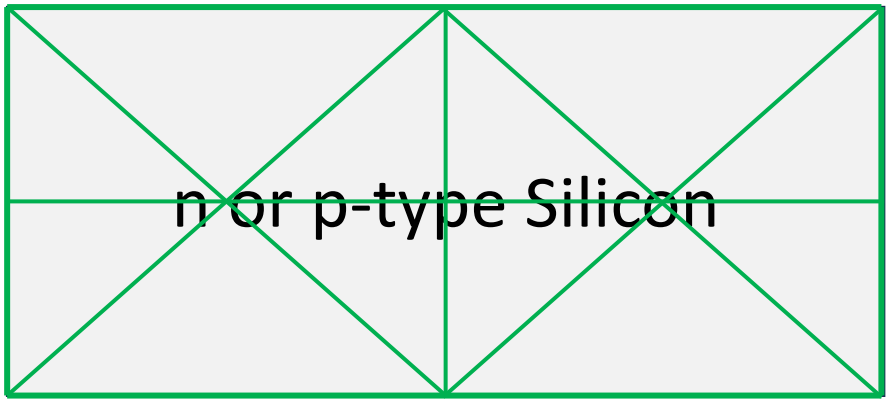
We want to simulate different properties (Current densities, Electric field, doping profile, band diagram etc.) of this resistor

How to digitize the device?

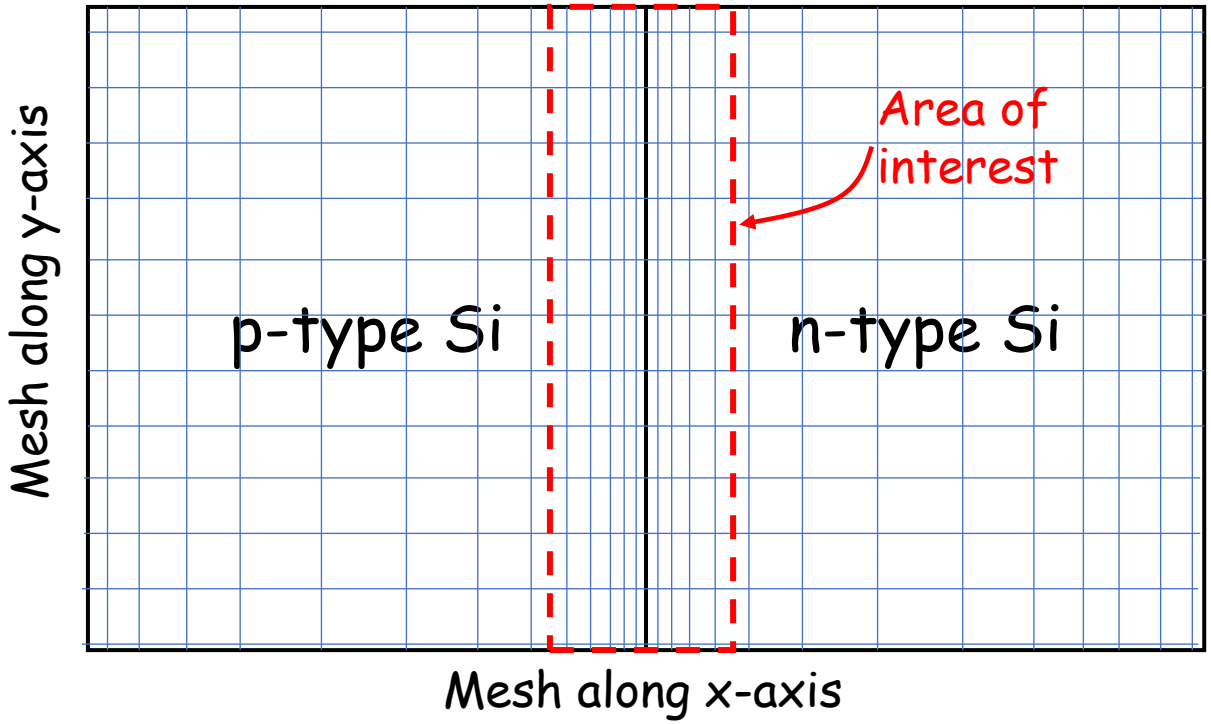
We can create different densities of meshing







How to design a mesh?



Denser at the junction (Where electric-field changes) and coarse at the middle

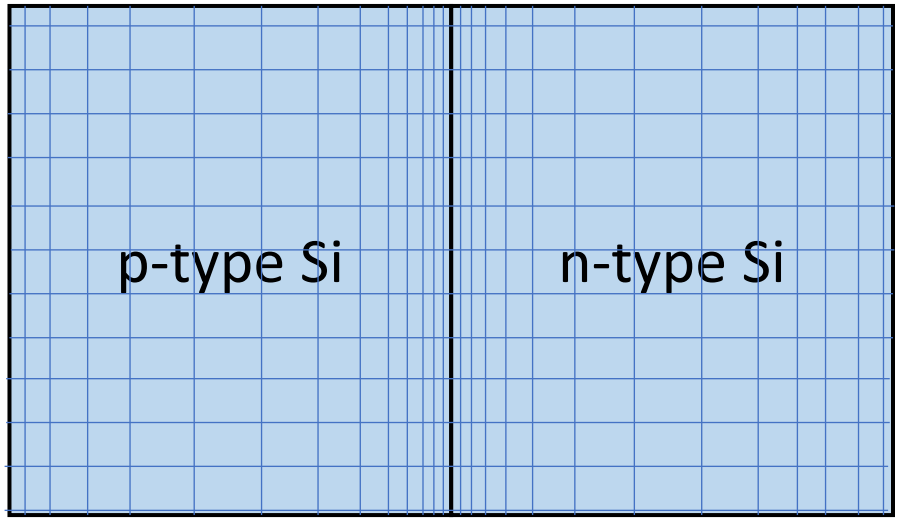
```
MESH SPACE.MULT=<VALUE>
```

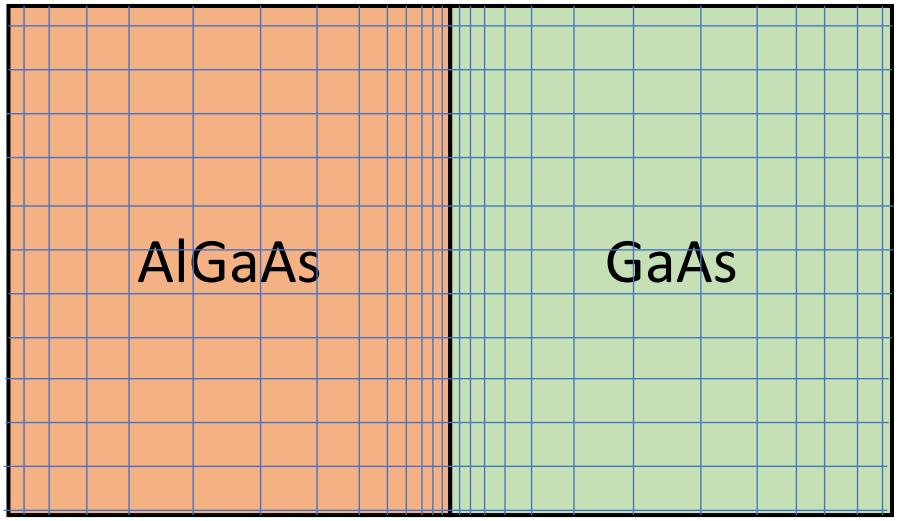
This is followed by a series of `X.MESH` and `Y.MESH` statements.

```
X.MESH LOCATION=<VALUE> SPACING=<VALUE>
.
Y.MESH LOCATION=<VALUE> SPACING=<VALUE>
```

Some useful features:
Auto mesh, Regrid etc.

Defining a Region





You can define different materials in different regions.
Regions can't exceed the area of the mesh.

```
REGION number=<integer> <material_type> <position parameters>
```

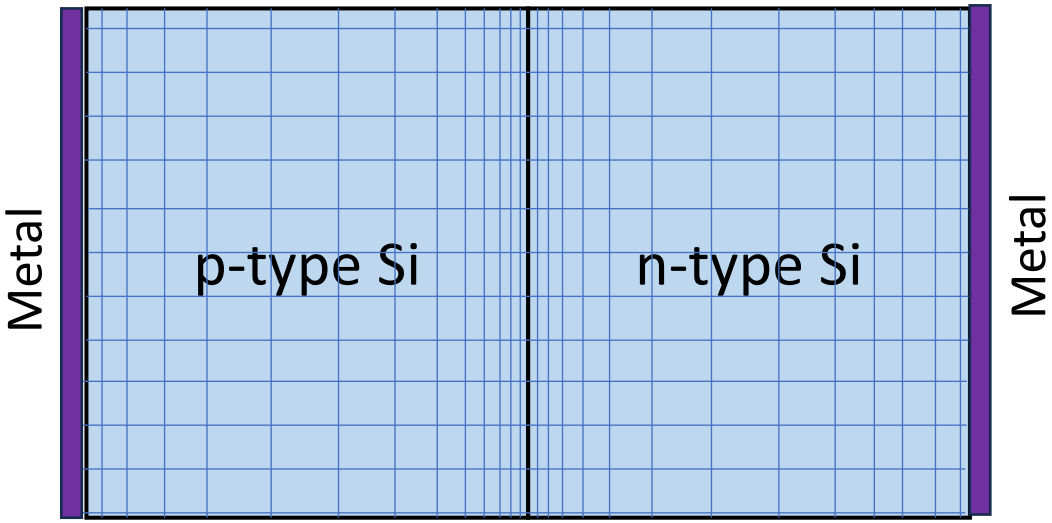
Position parameter: x.min=, x.max=, y.min=, y.max=

```
REGION NUM=1 Y.MAX=0 MATERIAL=OXIDE

REGION NUM=2 Y.MIN=0 MATERIAL=SILICON
```

For defining composition of a material use x.comp= , y.comp=

Defining a Electrode/Contact



You can define different materials in different regions.
Regions can't exceed the area of the mesh.

```
ELECTRODE NAME=ANODE X.MIN=0.5 X.MAX=1.0
```

By default the contacts are ohmic in nature

For ohmic contact there would be no electric field present between metal and semiconductor

Defining a Doping

Uniform Doping profile of x/cm^3

Doping density

Gaussian Doping of x/cm^3

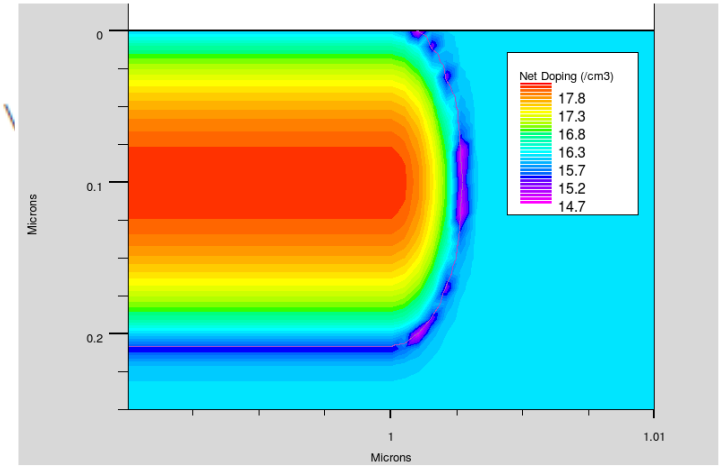
Doping density

Gaussian Doping of x/cm^3

Doping of specific type, concentration, profile, position can be defined

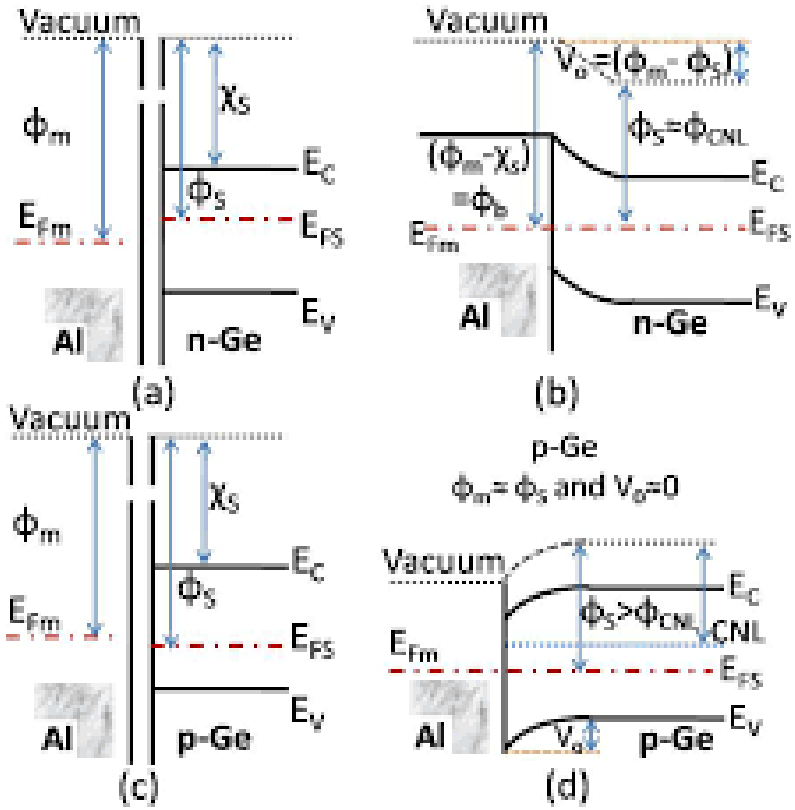
DOPING <distribution type> <dopant type> <position parameters>

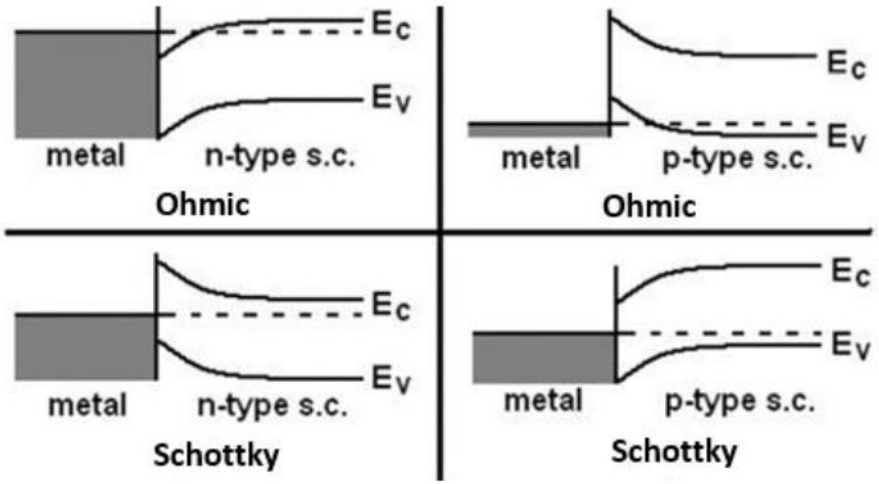
```
DOPING UNIFORM CONCENTRATION=1E16 N.TYPE REGION=1
DOPING GAUSSIAN CONCENTRATION=1E18 CHARACTERISTIC=0.05 P.TYPE \
        X.LEFT=0.0 X.RIGHT=1.0 PEAK=0.1
```



Commonly used doping profiles uniform and gaussian

Defining a Contact Property





Defining a metal workfunction changes its property from ohmic to schottky

```
CONTACT NAME=gate WORKFUNCTION=4.8
```

By default the contacts are voltage controlled, you can change it to current controlled if you want to

```
CONTACT NAME=drain CURRENT
```

How to define material properties?

For Defining basic material properties:

1. Name of material
2. Type of material: Semiconductor, Insulator, Conductor
3. Bandgap
4. Band offsets between two materials
5. Affinity
6. Permittivity
7. Density of states
8. Mobility and/or effective mass
9. Ionization property (E_C-E_D) or (E_A-E_V)
10. Thermal property
11. Transport property
12. Optical property

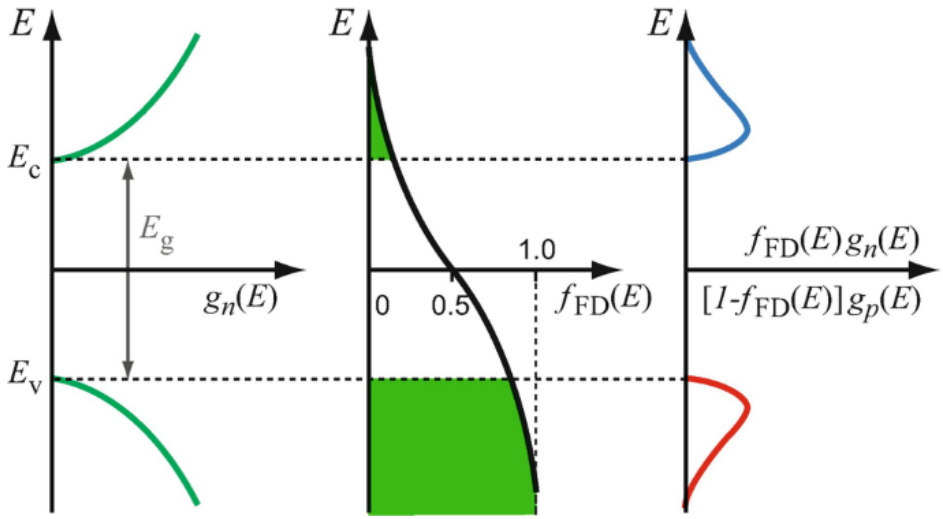
https://www.ioffe.ru/SVA/NSM/Semicond/
https://www.tf.unikiel.de/matwis/amat/semitech_en/index.html

What are different models?

Models are basically different physical phenomena that we want to use for obtaining certain output after the simulation

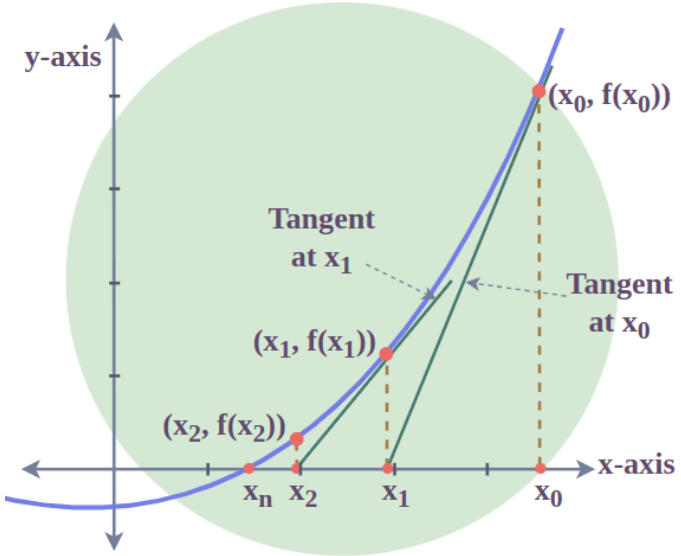
Physical Models:

1. **Carrier Statistics**
   - I. Fermi-Dirac
   - II. Boltzmann
   - III. Schrodinger
   - IV. K.P
2. **Transport properties**
   - I. Drift-diffusion
   - II. Thermionic emission
   - III. Field Emission
   - IV. Tunneling
3. **Mobility Models**
4. **Recombination models**
5. **Impact Ionization models**
6. **Tunneling models**



Numerical methods for solving the simulation

Newton-Raphson (mostly used)



You need an initial guess, generally taken at equilibrium condition

Other two methods: Gummel and Block (Used for specific kind of simulations)

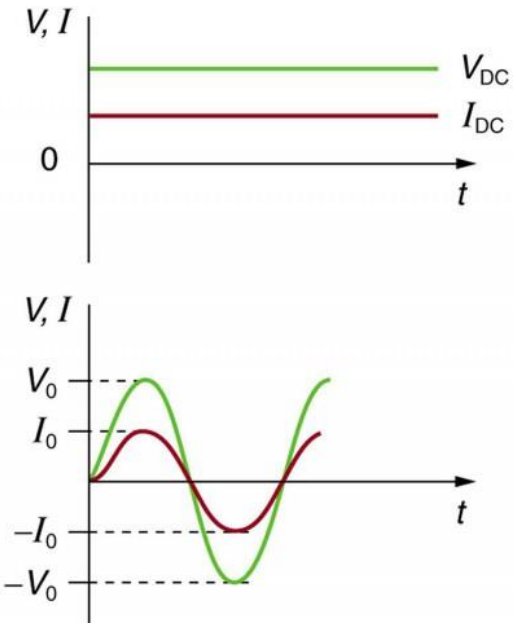
$$x_n = x_{n-1} - f(x_{n-1})/f'(x_{n-1})$$

Where,

- x_{n-1} *is the estimated* $(n-1)^{th}$ *root of the function,*
- $f(x_{n-1})$ *is the value of the equation at* $(n-1)^{th}$ *estimated root, and*
- $f'(x_{n-1})$ *is the value of the first order derivative of the equation or function at* x_{n-1}.

Different Kind of solutions

- DC : Where the applied bias is constant (Amplitude) and frequency is 0 with respect to time
- AC : Where the applied bias has a constant amplitude and frequency with respect to time
  - Single frequency (Change of voltage/amplitude)
  - Frequency response (Constant voltage/amplitude)
- Transient: The applied bias changes with respect to time



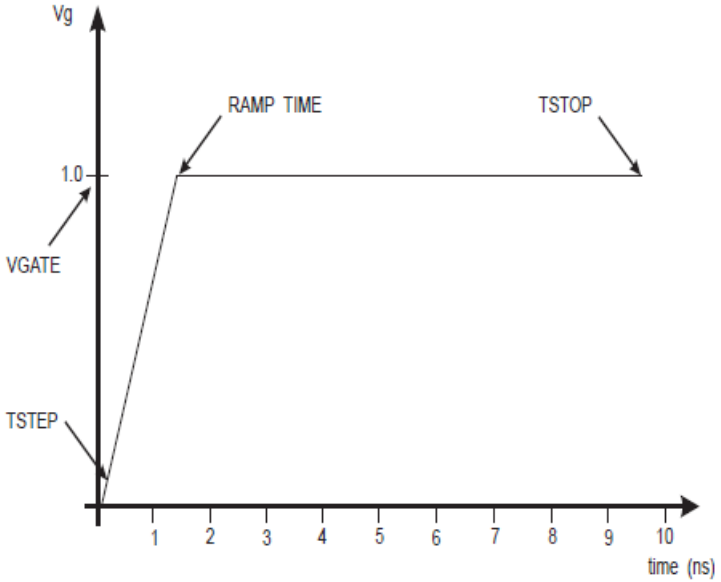


Figure 2-16 Diagram showing syntax of Transient Voltage Ramp in Atlas