# Quick Start Micro Training LLC, Dr. Ted Dellin
## *Semi Devices I: Semiconductors and Junction*

*Quick Start Micro Training LLC*
***Device Physics I: Semiconductors & Junctions***

# SAMPLE SLIDES


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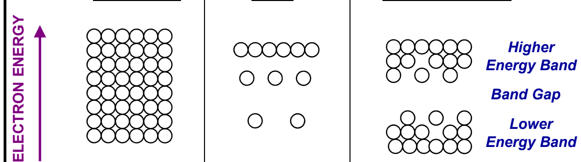
## Outline of Course





## Allowed Electron Energy States Differ in Free Space, Atoms and Crystals

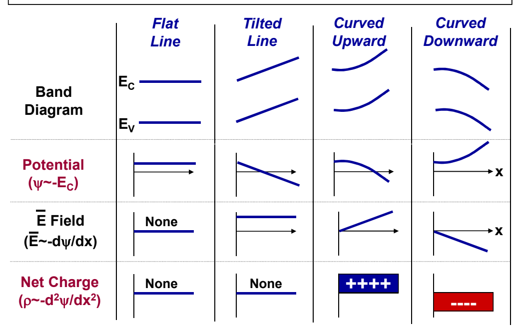



| Free Space | Atom | Crystalline Solid |
|---|---|---|
| Electrons Have No Interactions | Interaction With Single Nucleus | Interaction With Periodic Lattice |
| *All Energies Allowed* | *Only Discrete Energies Allowed* | *Quasi-Continuous Energy Bands Separated by Band Gaps* |

○ = *Allowed electron energy state*

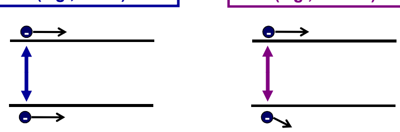


## The Shape of the Energy Vs. Position Determines The E Field and Net Charge






## Two Types of Semiconductors: *Direct and Indirect Bandgap*




**Direct Bandgap Semi (e.g., GaAs)**

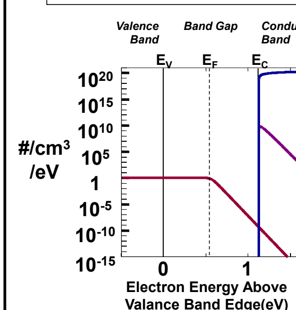
- When electron goes from one band to the other
  - *Energy change*
  - ***NO** momentum change*

**Indirect Bandgap Semi (e.g., Silicon)**

- When electron goes from one band to the other
  - *Energy change*
  - *Momentum change (electron changes direction)*



## The Distribution of Electrons in The Conduction Band in Intrinsic Silicon



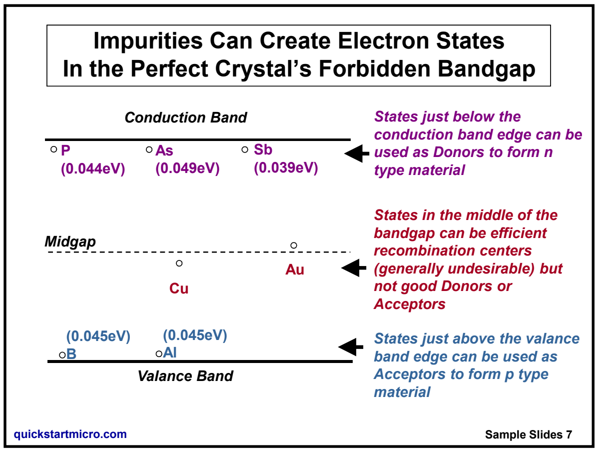

**Density of Allowed Electron States, N(E)** ($eV^{-1}cm^{-3}$)

**Density of Electrons In the Conduction Band** $n(E)=N(E)\ f(E)$ [$eV^{-1}cm^{-3}$]

**Probability That An Allowed State Will Be Occupied, f(E) [Fermi Dirac Distribution]**

- *Very small fraction of states occupied*
- *# $e^-$ decreases above band edge*

*300K, Thermal Equilibrium*


Impurities Can Create Electron States In the Perfect Crystal's Forbidden Bandgap
Conduction Band
P (0.044eV)
As (0.049eV)
Sb (0.039eV)
States just below the conduction band edge can be used as Donors to form n type material
Midgap
Cu
Au
States in the middle of the bandgap can be efficient recombination centers (generally undesirable) but not good Donors or Acceptors
B (0.045eV)
Al (0.045eV)
Valance Band
States just above the valance band edge can be used as Acceptors to form p type material
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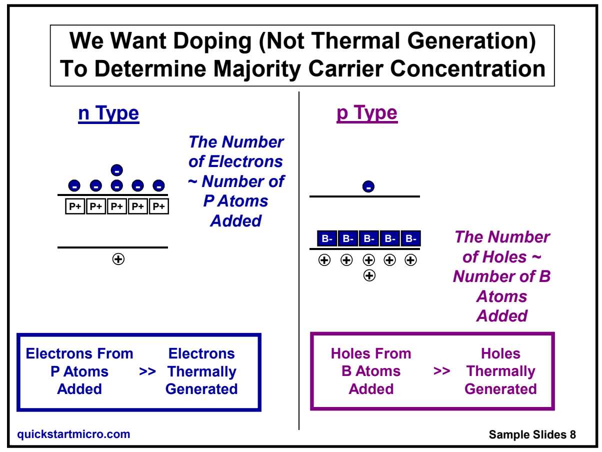
We Want Doping (Not Thermal Generation) To Determine Majority Carrier Concentration
n Type
P+ P+ P+ P+ P+
The Number of Electrons ~ Number of P Atoms Added
Electrons From P Atoms Added >> Electrons Thermally Generated
p Type
B- B- B- B- B-
The Number of Holes ~ Number of B Atoms Added
Holes From B Atoms Added >> Holes Thermally Generated
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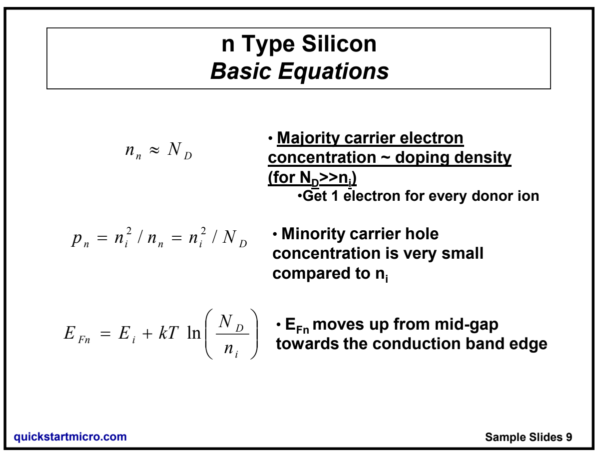
n Type Silicon
Basic Equations
$n_n \approx N_D$
• Majority carrier electron concentration ~ doping density (for $N_D$>>$n_i$)
•Get 1 electron for every donor ion
$p_n = n_i^2 / n_n = n_i^2 / N_D$
• Minority carrier hole concentration is very small compared to $n_i$
$E_{Fn} = E_i + kT \ln\left(\frac{N_D}{n_i}\right)$
• $E_{Fn}$ moves up from mid-gap towards the conduction band edge
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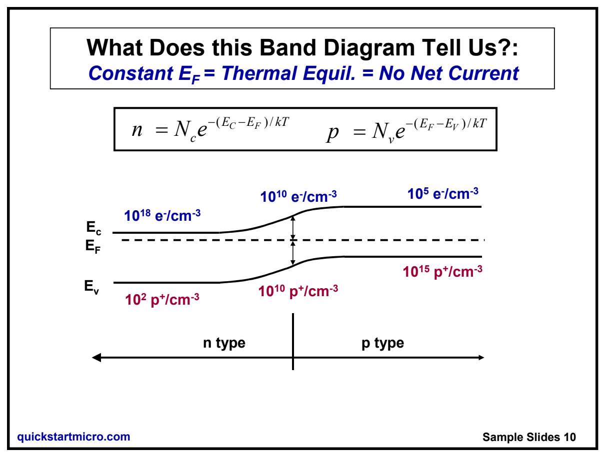
What Does this Band Diagram Tell Us?:
Constant $E_F$ = Thermal Equil. = No Net Current
$n = N_c e^{-(E_C - E_F)/kT}$ $p = N_v e^{-(E_F - E_V)/kT}$
$E_c$
$E_F$
$E_v$
$10^{18}$ e-/cm-3
$10^{10}$ e-/cm-3
$10^{5}$ e-/cm-3
$10^{2}$ p+/cm-3
$10^{10}$ p+/cm-3
$10^{15}$ p+/cm-3
n type
p type
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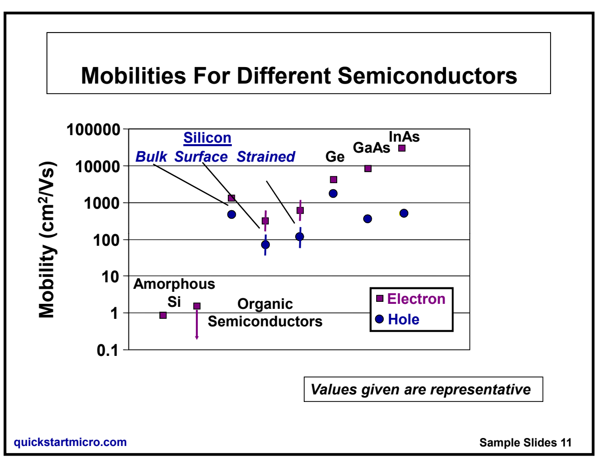
Mobilities For Different Semiconductors
Mobility (cm2/Vs)
100000
10000
1000
100
10
1
0.1
Silicon
Bulk Surface Strained
Ge
GaAs
InAs
Amorphous Si
Organic Semiconductors
Electron
Hole
Values given are representative
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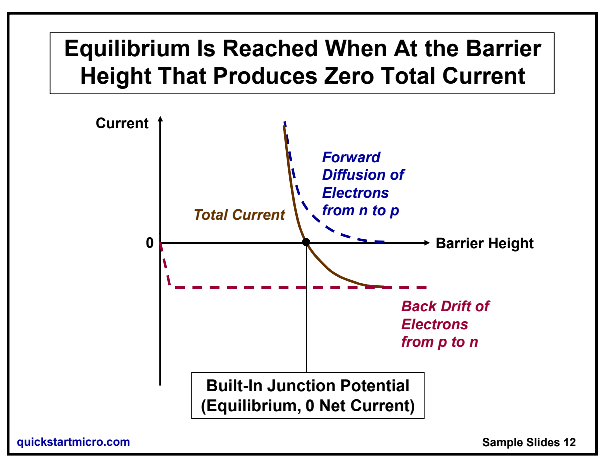
Equilibrium Is Reached When At the Barrier Height That Produces Zero Total Current
Current
0
Barrier Height
Forward Diffusion of Electrons from n to p
Total Current
Back Drift of Electrons from p to n
Built-In Junction Potential (Equilibrium, 0 Net Current)
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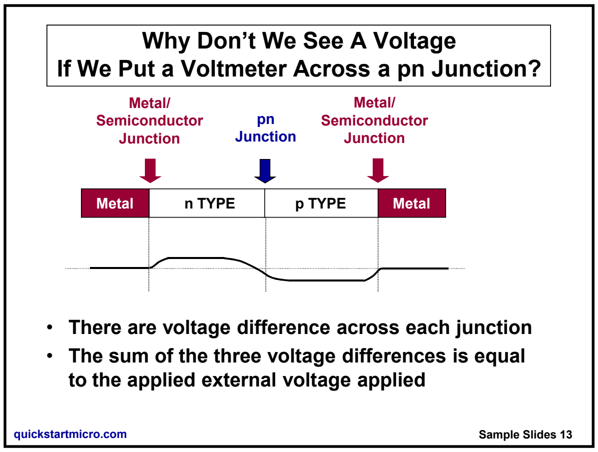

Why Don't We See A Voltage
If We Put a Voltmeter Across a pn Junction?
Metal/ Semiconductor Junction
pn Junction
Metal/ Semiconductor Junction
Metal
n TYPE
p TYPE
Metal
• There are voltage difference across each junction
• The sum of the three voltage differences is equal to the applied external voltage applied
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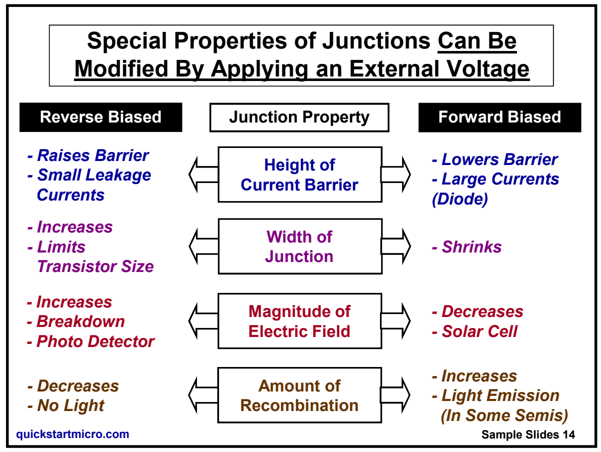

Special Properties of Junctions Can Be Modified By Applying an External Voltage
Reverse Biased
Junction Property
Forward Biased
- Raises Barrier
- Small Leakage Currents
Height of Current Barrier
- Lowers Barrier
- Large Currents (Diode)
- Increases
- Limits Transistor Size
Width of Junction
- Shrinks
- Increases
- Breakdown
- Photo Detector
Magnitude of Electric Field
- Decreases
- Solar Cell
- Decreases
- No Light
Amount of Recombination
- Increases
- Light Emission (In Some Semis)
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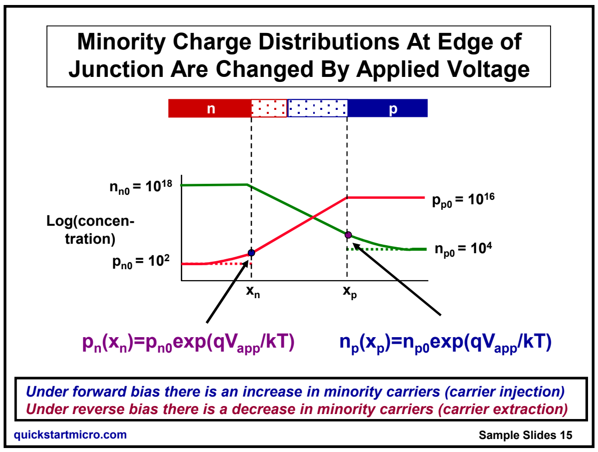

Minority Charge Distributions At Edge of Junction Are Changed By Applied Voltage
n
p
$n_{n0} = 10^{18}$
$p_{p0} = 10^{16}$
Log(concen-tration)
$p_{n0} = 10^{2}$
$n_{p0} = 10^{4}$
$x_n$
$x_p$
$p_n(x_n)=p_{n0}\exp(qV_{app}/kT)$
$n_p(x_p)=n_{p0}\exp(qV_{app}/kT)$
Under forward bias there is an increase in minority carriers (carrier injection)
Under reverse bias there is a decrease in minority carriers (carrier extraction)
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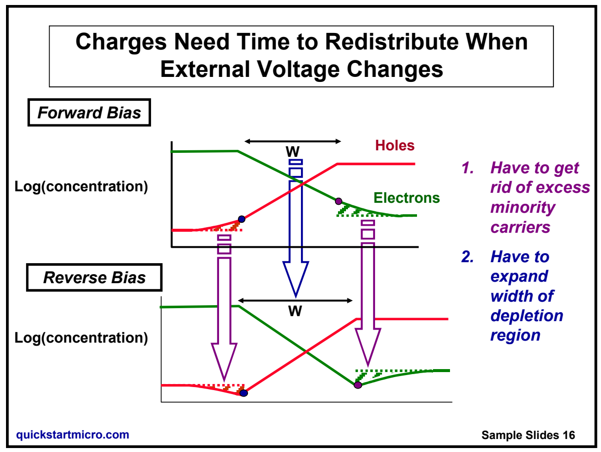

Charges Need Time to Redistribute When External Voltage Changes
Forward Bias
Log(concentration)
W
Holes
Electrons
Reverse Bias
Log(concentration)
W
1. Have to get rid of excess minority carriers
2. Have to expand width of depletion region
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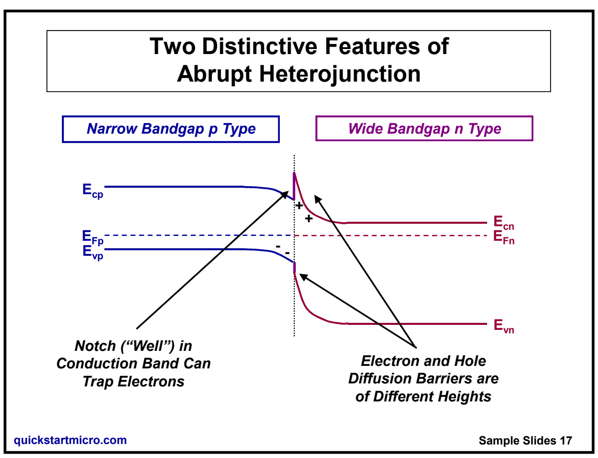

Two Distinctive Features of Abrupt Heterojunction
Narrow Bandgap p Type
Wide Bandgap n Type
$E_{cp}$
$E_{Fp}$
$E_{vp}$
$E_{cn}$
$E_{Fn}$
$E_{vn}$
Notch ("Well") in Conduction Band Can Trap Electrons
Electron and Hole Diffusion Barriers are of Different Heights
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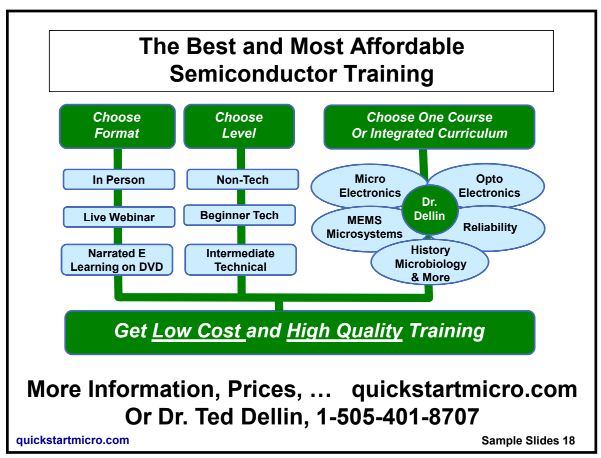

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