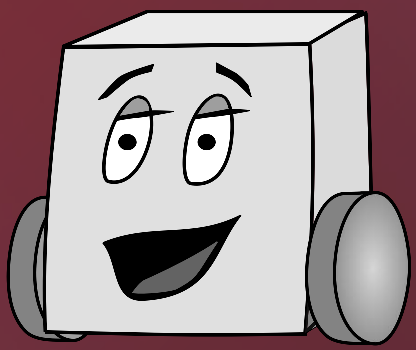

E11 Lecture 12: Diodes & Transistors

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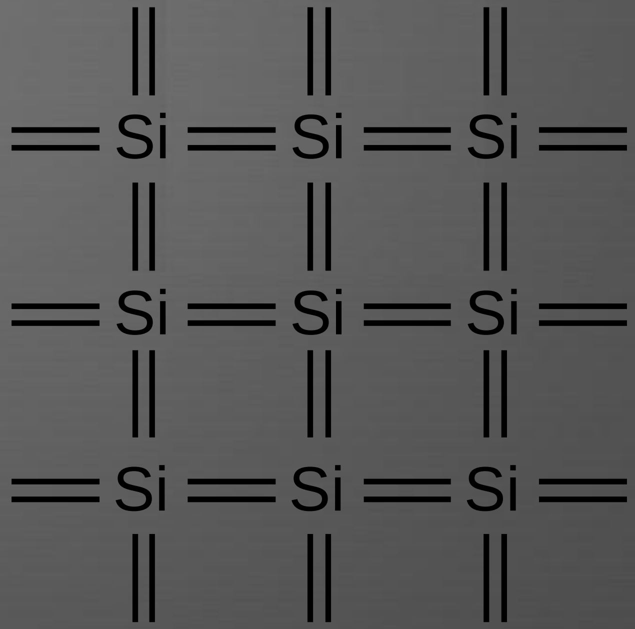
Fall 2011

Outline

- Semiconductors
- Diodes
- Transistors

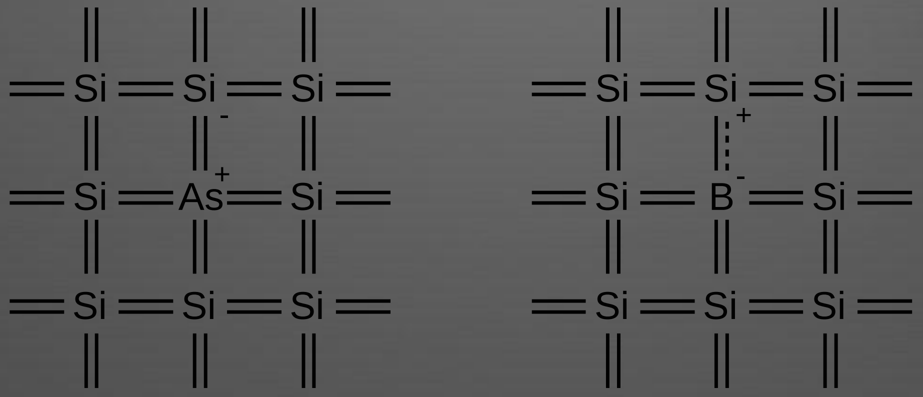
Semiconductors

- Silicon is a Group IV Material
- Forms tetrahedral crystal with bonds to four neighbors
- Adjustable conductivity



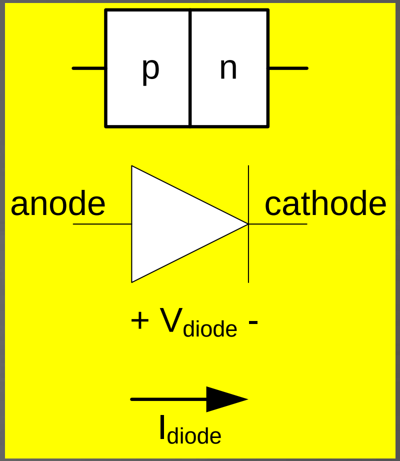
Dopants

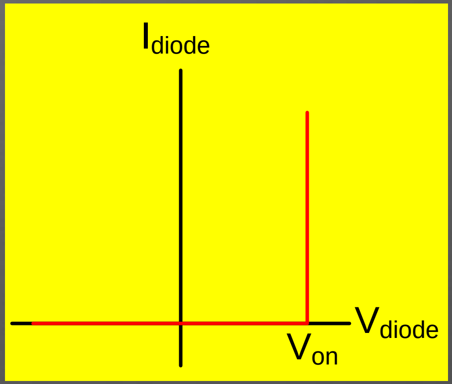
- Silicon is a semiconductor
- Pure silicon has no free carriers and conducts poorly
- Adding dopants increases the conductivity
- Group V: extra electron (n-type)
- Group III: missing electron, called hole (p-type)



Diodes

- A p-n junction is called a *diode*
  - p side is called *anode*
  - n side is called *cathode*
- Current only flows from anode to cathode
  - When $V_{diode} > V_{on}$
  - $V_{on} \approx 0.7$ V for silicon diodes
- Approximate I-V behavior





Light Emitting Diode

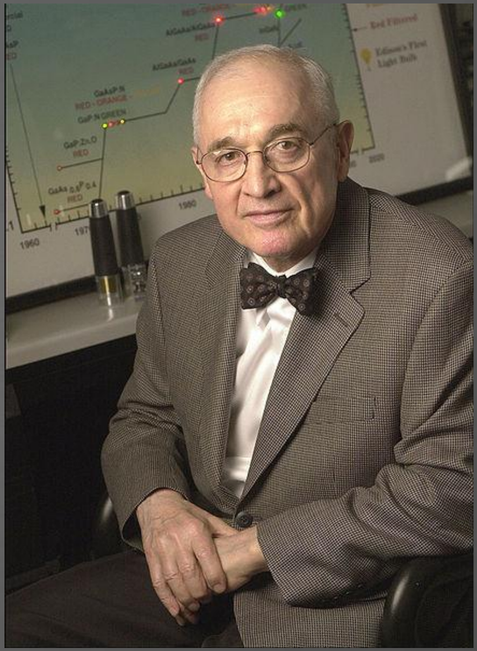
- Electron-hole recombination in a diode releases photons
- Wavelength of photons depends on semiconductor's bandgap
- GaAs and related materials glow red, yellow, green, or blue
- V_{on} depends on material, typically ~1.7 V
- Typically 5-20 mA gives satisfactory brightness

www.desktopedia.com

Nick Holonyak

- 1928-
- Invented the first practical

  visible LED in 1962 while at GE
- EE Prof at University of Illinois
- Also invented laser diode and light dimmer



en.wikipedia.org/wiki/File:Nick_Holonyak_Jr.jpg

LED Circuit Analysis

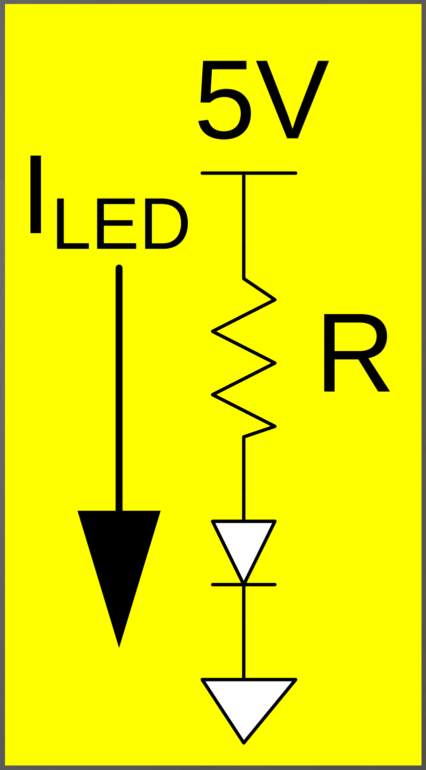
- What value of R makes I_{LED} = 10 mA?

a) 10 Ω

b) 100 Ω

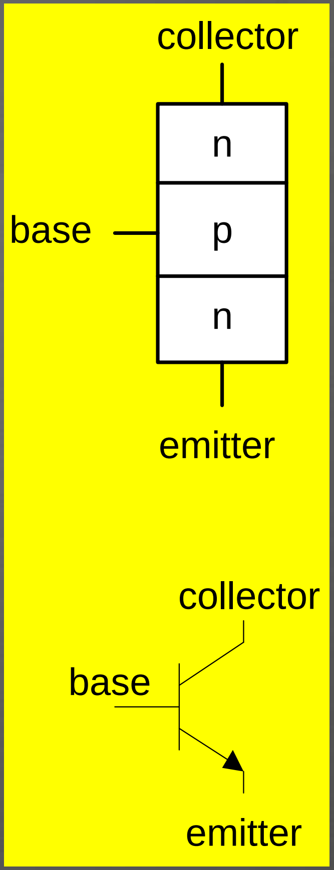
c) 330 Ω

d) 3 kΩ



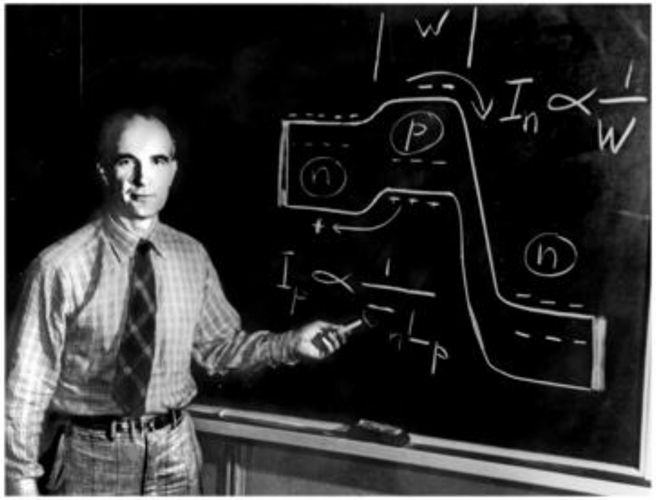
npn Bipolar Junction Transistor

- Made of two back-to-back diodes
- Behaves as a current-controlled switch
- 3 Terminals
  - Base (control)
  - Emitter (negative switch terminal)
  - Collector (positive switch terminal)



William Shockley

- 1910-1989
- Son of a mining engineer
- B.S. Caltech, Ph.D. MIT
- Invented BJT in 1948 @ Bell Labs
- Supervised Bardeen & Brattain
  - who invented first transistor in 1947
  - The three received the Nobel Prize in Physics in 1956



computerhistory.org

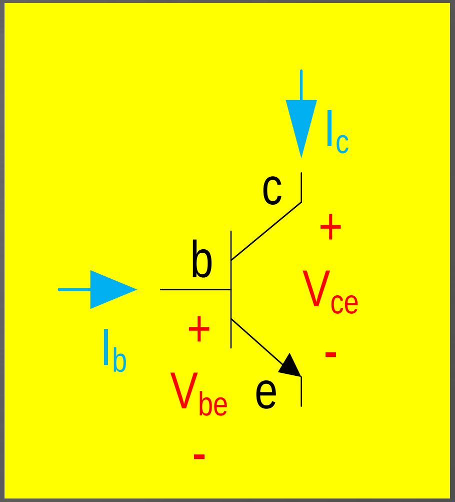
npn Transistor Behavior

- Base-to-emitter junction is a diode
- Small base current allows larger collector current to flow
- Three operating regions:
  - Cutoff:
    - no current flows
  - Linear:
    - collector current proportional to base current
  - Saturation:
    - collector current ceases to increase with base current

Operating Regions

- Three operating regions:
  - Cutoff:
    - base-emitter diode off — $V_{be} < V_{on}$
    - no current flows — $I_c = 0$
  - Linear:
    - base-emitter diode on — $V_{be} = V_{on}$, $V_{ce} > 0$
    - collector current proportional to base current — $I_c = \beta I_b$

      β typically around 100, but highly variable
  - Saturation:
    - base-emitter diode on — $V_{be} = V_{on}$, $V_{ce} \approx 0$
    - collector current independent of base current — I_c const

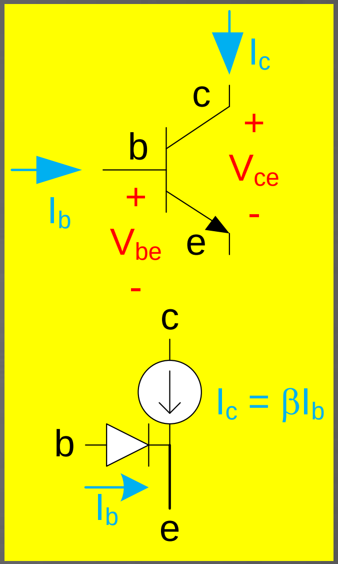


Linear and Saturation Models

- When $V_{be} \approx 0.7V$, transistor turns ON
- If $V_{ce} > 0$, transistor behaves as a

  current amplifier

  $I_c = \beta\, I_b$



- If V_{ce} falls to 0, I_c ceases to rise with I_b
  - Saturation

Transistor Applications

- Amplifiers
- Switches

Transistor Amplifier

- For $V_{in} < 0.7$, Cutoff, $I_c = 0$, $V_{out} = V_{cc}$
- For $V_{in} > 0.7$, linear mode of operation

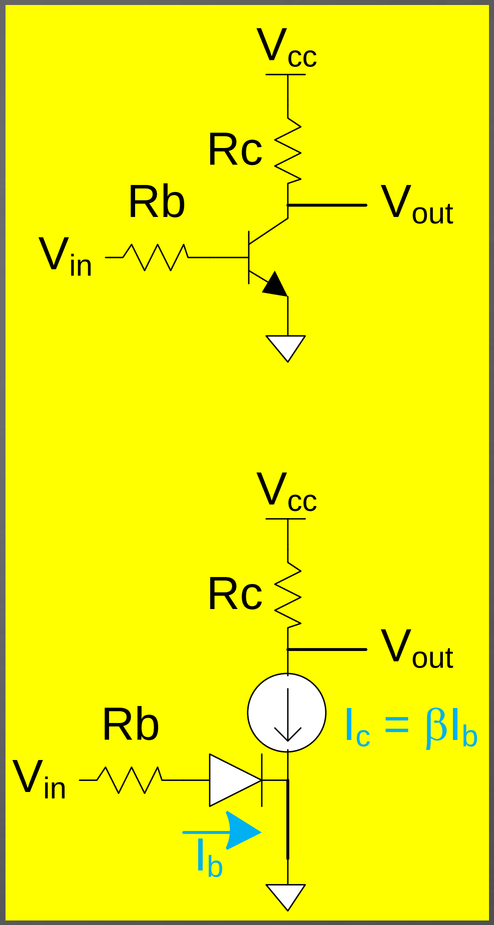
$$I_b = \frac{V_{in} - 0.7}{R_b}$$

$$I_c = \beta I_b$$

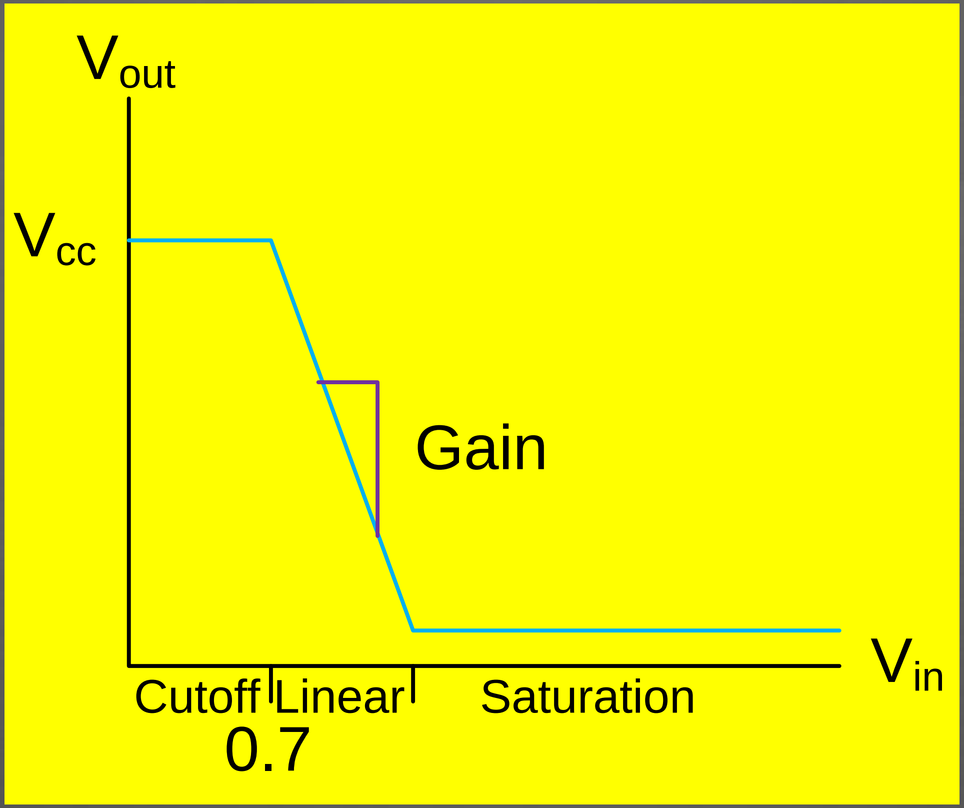
$$V_{out} = V_{cc} - I_c R_c = V_{cc} - \beta \frac{R_c}{R_b}(V_{in} - 0.7)$$

$$Gain = \frac{dV_{out}}{dV_{in}} = -\beta \frac{R_c}{R_b}$$

- But V_{out} never falls below 0
  - Transistor saturates first



Amplifier Behavior



Transistor as Switch

- Turn on or off a high-current load
  - Such as the motor
  - Needs more current than digital I/O
- If D2 = 0, transistor is cutoff
  - No current flows to load
- If D2 = 1 (5V), transistor saturates
  - $I_b = (5-0.7) / 215 = 20$ mA
  - I_c of up to ~2A flows to load
  - Enough to pull x down close to 0