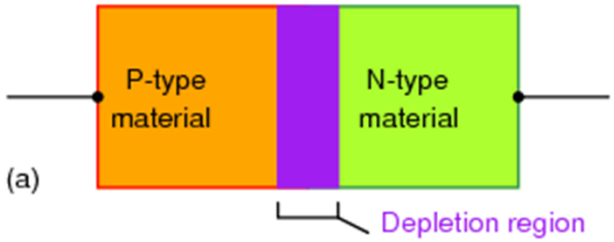
Diodes and Transistors
Semiconductors

- Semiconductor devices are made of alternating layers of positively doped material (P) and negatively doped material (N).
- Diodes are PN or NP, BJTs are PNP or NPN, IGBTs are PNPN. Other devices are more complex

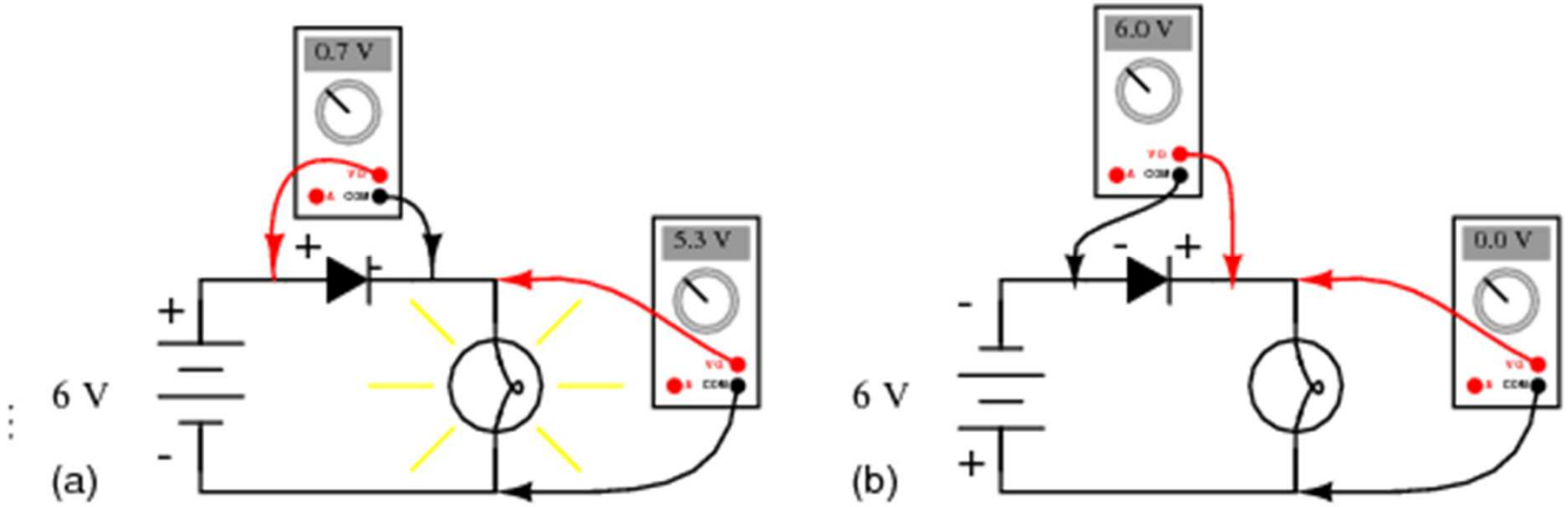
Diodes

- A diode is a device which allows flow in one direction but not the other.
- When conducting, the diodes create a voltage drop, kind of acting like a resistor
- There are three main types of power diodes
  - Power Diode
  - Fast recovery diode
  - Schottky Diodes



Power Diodes

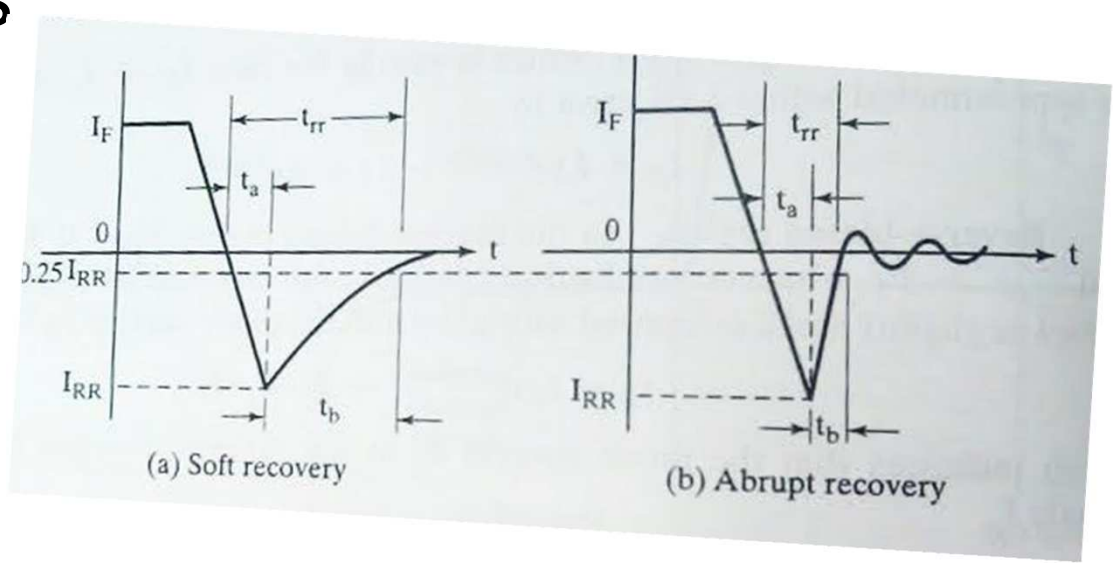
- Max properties: 1500V, 400A, 1kHz
- Forward voltage drop of 0.7 V when on



Diode circuit voltage measurements: (a) Forward biased. (b) Reverse biased.

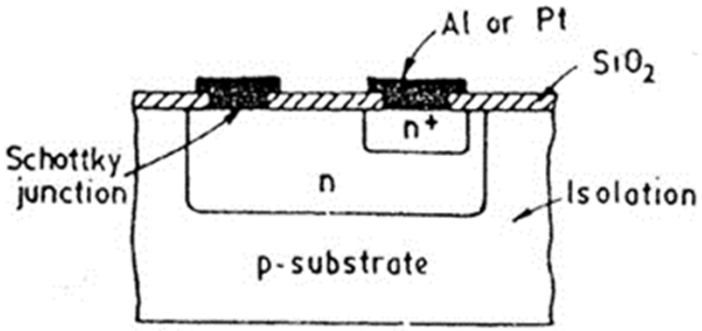
Fast Recovery Diodes

- Max properties: similar to regular power diodes but recover time as low as 50ns
- The following is a graph of a diode's recovery time. trr is shorter for fast recovery diodes



Schottky Diodes

- Max properties: 400V, 400A
- Very fast recovery time
- Lower voltage drop when conducting than regular diodes
- Ideal for high current low voltage applications



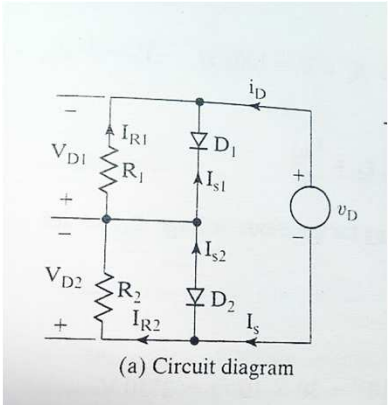
Cross-section view of Schottky diode.

Current vs Voltage Characteristics

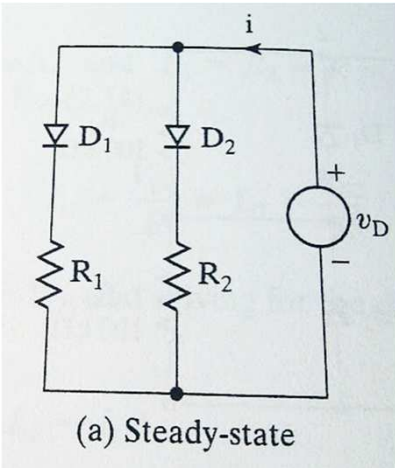
- All diodes have two main weaknesses
  - Leakage current when the diode is off. This is power loss
  - Voltage drop when the diode is conducting. This is directly converted to heat, i.e. power loss
- Other problems to watch for:
  - Notice the reverse current in the recovery time graph. This can be limited through certain circuits.

Ways Around Maximum Properties

- To overcome maximum voltage, we can use the diodes in series. Here is a voltage sharing circuit



- To overcome maximum current, we can use the diodes in parallel. Here is a current sharing circuit



- More information
  http://users.ece.gatech.edu/mleach/ece3050/notes/diode/diode.pdf

Transistors

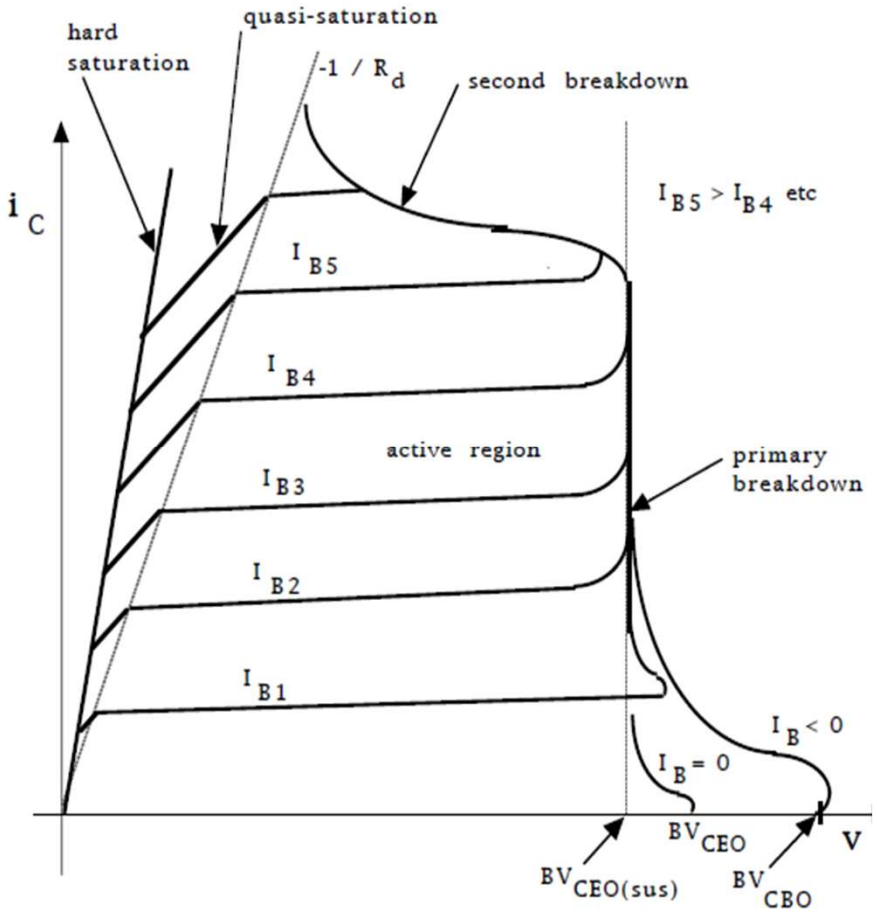
- Types of Transistors
  - BJT – Bipolar Junction Transistors
  - IGBT – Insulated-Gate Bipolar Transistor
  - MOSFET – Metal-Oxide Semiconductor Field Effect Transistor
  - COOLMOS - proprietary name
  - SIT – Static Induction Transistor

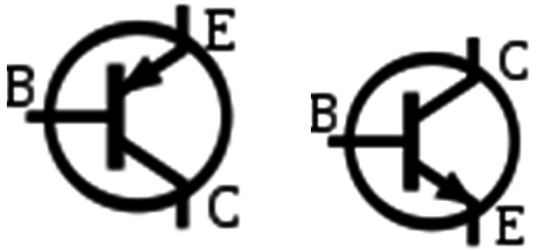
BJT

- There are two types of BJTs. PNP and NPN. NPN are most common
- BJTs are current controlled devices. Putting current into the gate will allow current to flow from the collector to the emitter.
- When operating as a switch, the BJT operates deep in the saturation region (with base current really really high)
- When operating as an amplifier the BJT works in the active region
- Like diodes, they have a voltage drop when conducting but it is very low
- More info
  - http://www.gyte.edu.tr/dosya/102/dersler/ELM%20629/Ch21.pdf

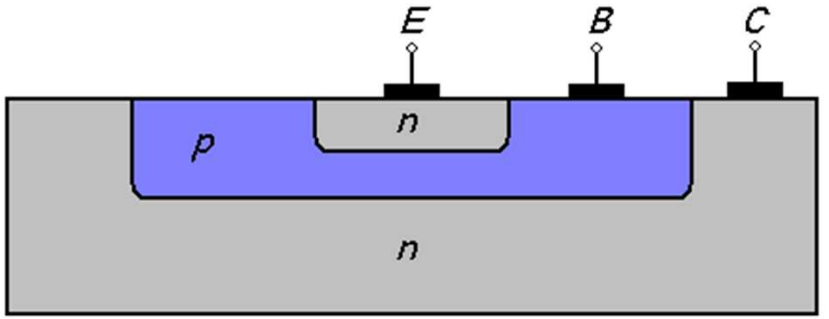
Applied voltages	B-E Junction Bias (NPN)	B-C Junction Bias (NPN)	Mode (NPN)
E < B < C	Forward	Reverse	Forward active
E < B > C	Forward	Forward	Saturation
E > B < C	Reverse	Reverse	Cut-off
E > B > C	Reverse	Forward	Reverse-active
Applied voltages	**B-E Junction Bias (PNP)**	**B-C Junction Bias (PNP)**	**Mode (PNP)**
E < B < C	Reverse	Forward	Reverse-active
E < B > C	Reverse	Reverse	Cut-off
E > B < C	Forward	Forward	Saturation
E > B > C	Forward	Reverse	Forward active

Voltage and Current Characteristics of a BJT





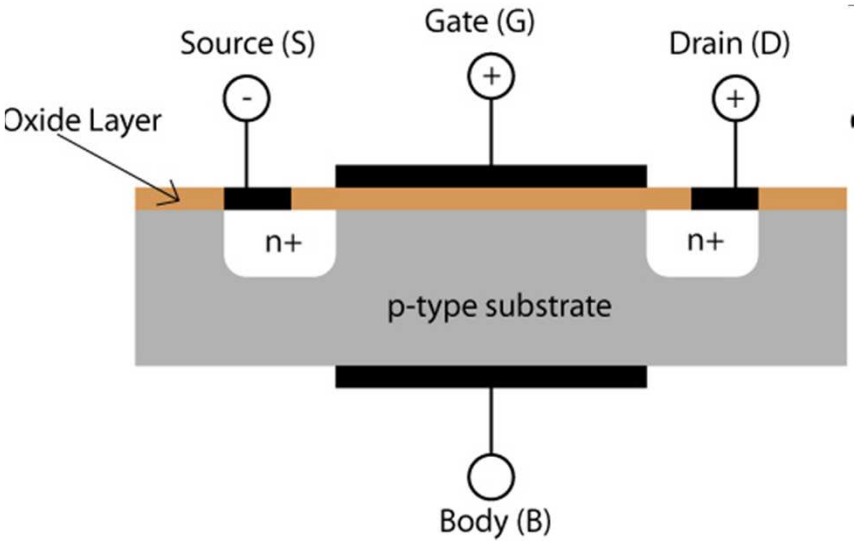
PNP (left) NPN (right)

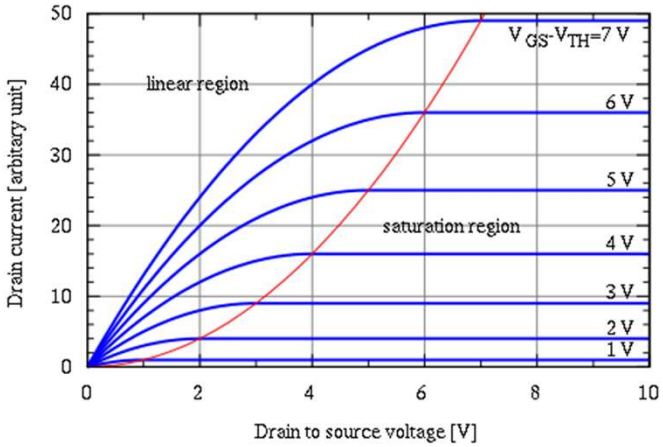


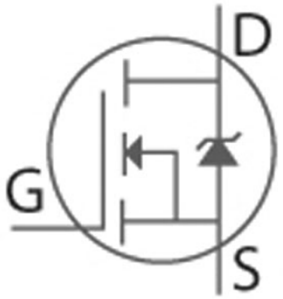
MOSFET and COOLMOS

- Advantages of MOSFET
  - Voltage controlled device (Voltage at the gate will make current flow. Very small input current required, less power loss)
  - No second breakdown
  - High speed
- Disadvantages of MOSFET
  - High voltage drop when conducting
  - Can only support low power compared to BJT
- Two main types of MOSFETS
  - Enhancement type (Normally off), Depletion type (Normally on)
- COOLMOS is a better version of a MOSFET because it has much lower voltage drop when conducting but it has lower power capabilities so it’s uses are limited.

MOSFET and COOLMOS cont'd







MOSFET

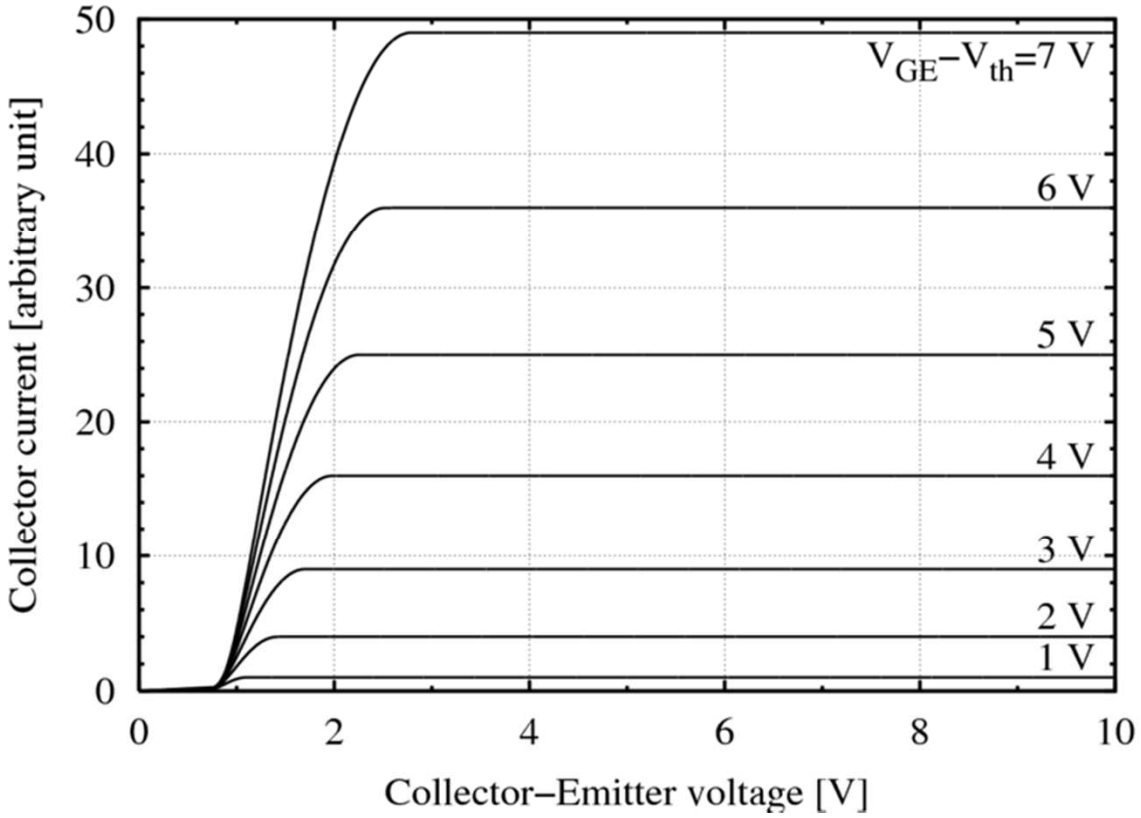
Metal Oxide Semiconductor Field-Effect Transistor

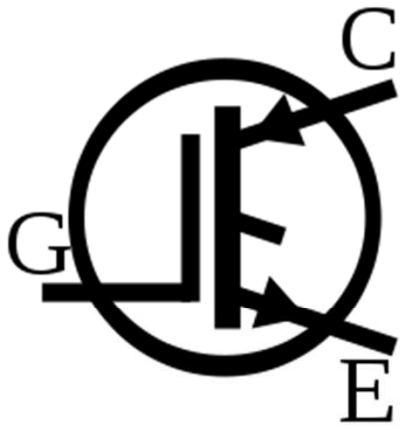
MOSFET

IGBT

- A cross between BJT and MOSFET
  - Low voltage drop when conducting (like BJT)
  - Voltage controlled (like MOSFET)
- IGBTs are used under 20kHz
- IGBT vs. MOSFET
  - http://www.irf.com/technical-info/whitepaper/choosewisely.pdf

Voltage and Current Characteristics of an IGBT





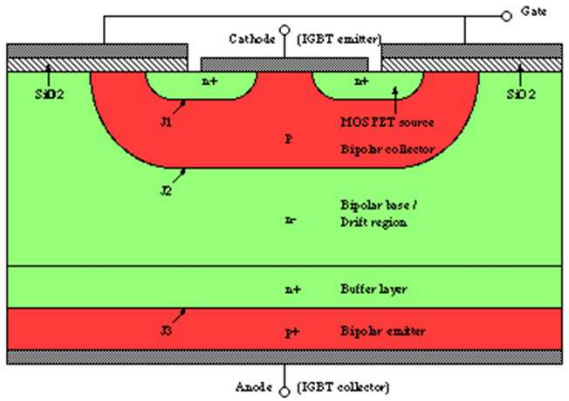


Fig.1: A typical IGBT structure

Table of Transistors and their Applications

TABLE 4.1 Comparisons of Power Transistors

Switch Type	Base/Gate Control Variable	Control Characteristic	Switching Frequency	On-State Voltage Drop	Max. Voltage Rating V_s	Max. Current Rating I_s	Advantages	Limitations
BJT	Current	Continuous	Medium 20 kHz	Low	1.5 kV $S_s = V_s I_s$ = 1.5 MVA	1 kA $S_s = V_s I_s$ = 1.5 MVA	Simple switch Low on-state drop Higher off-state voltage capability High switching loss	Current controlled device and requires a higher base current to turn-on and sustain on-state current Base drive power loss Charge recovery time and slower switching speed Secondary breakdown region High switching losses Unipolar voltage device
MOSFET	Voltage	Continuous	Very high	High	1 kV $S_s = V_s I_s$ = 0.1 MVA	150 A $S_s = V_s I_s$ = 0.1 MVA	Higher switching speed Low switching loss Simple gate drive circuit Little gate power. Negative temperature coefficient on rain current and facilitates parallel operation	High on-state drop as high as 10 V Lower off-state voltage capability Unipolar voltage device
COOLMOS	Voltage	Continuous	Very high	Low	1 kV	100 A	Low gate drive requirement and low on-state power drop	Low-power device Low voltage and curren ratings
IGBT	Voltage	Continuous	High	Medium	3.5 kV $S_s = V_s I_s$ = 1.5 MVA	2 kA $S_s = V_s I_s$ = 1.5 MVA	Low on-state voltage Little gate power	Lower off-state voltage capability Unipolar voltage devic
SIT	Voltage	Continuous	Very high	High			High-voltage rating	Higher on-state voltage Lower current ratings

How to Overcome Transistor Limits

- Like diodes, use them in series to increase voltage capacity and parallel to increase current capacity. Timing is CRUCIAL. If one turns on or off first it will take all the current or voltage and break!