EEE213 Power Electronics and Electromechanism

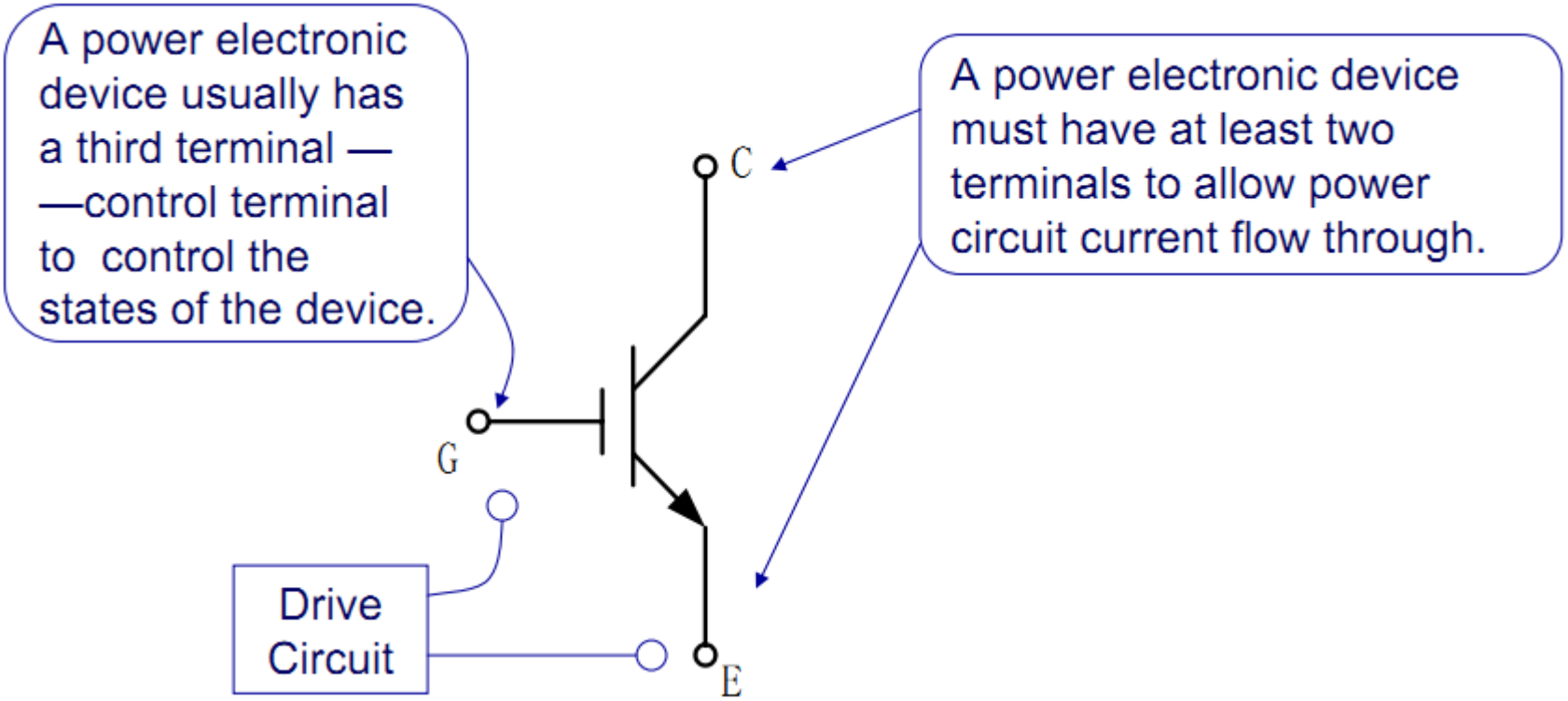
7. Power Electronic Devices

Outline

- Power Electronic Devices
- Power Transistors
  - Power BJT
  - Power MOSFET
  - IGBT
- Comparison

Power Electronic Devices

- Terminals of a controllable power electronic device



Power semiconductor devices

- Power Diode – uncontrollable
- Thyristor (晶闸管)
  - SCR (Silicon Controlled Rectifier) – on controllable
  - TRIAC (Triode ac switch)
  - GTO (Gate turn-off thyristor) – on/off controllable
- Power Transistors
  - Power BJT
  - Power MOSFET
  - IGBT

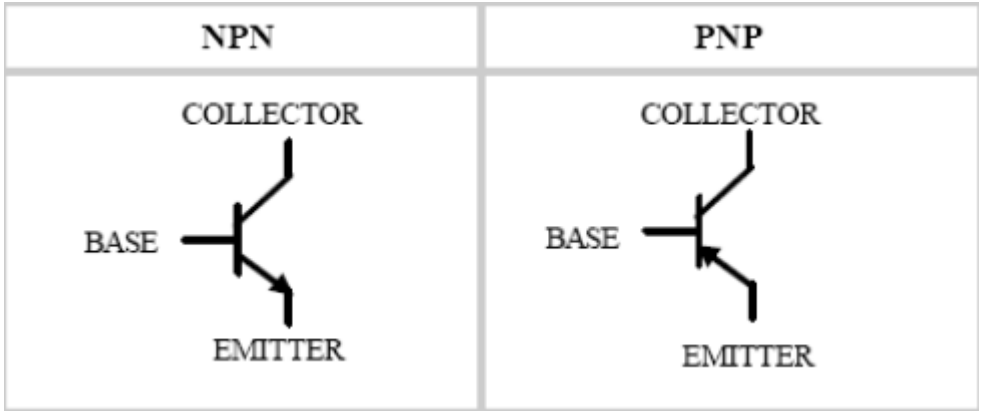
2. Power Transistors

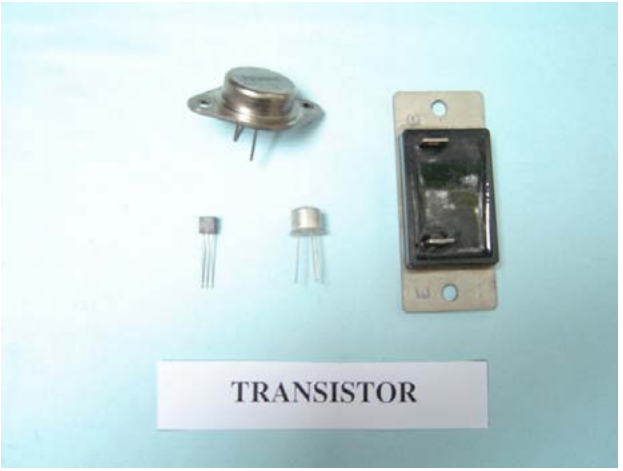
- Features
  - Fully-controllable
  - High frequency
  - IC fabrication technology

- Applications
  - From 1980s
  - GTR and GTO are seldom in use today
  - IGBT and power MOSFET are the two major power semiconductor devices nowadays

2.1 Power BJT

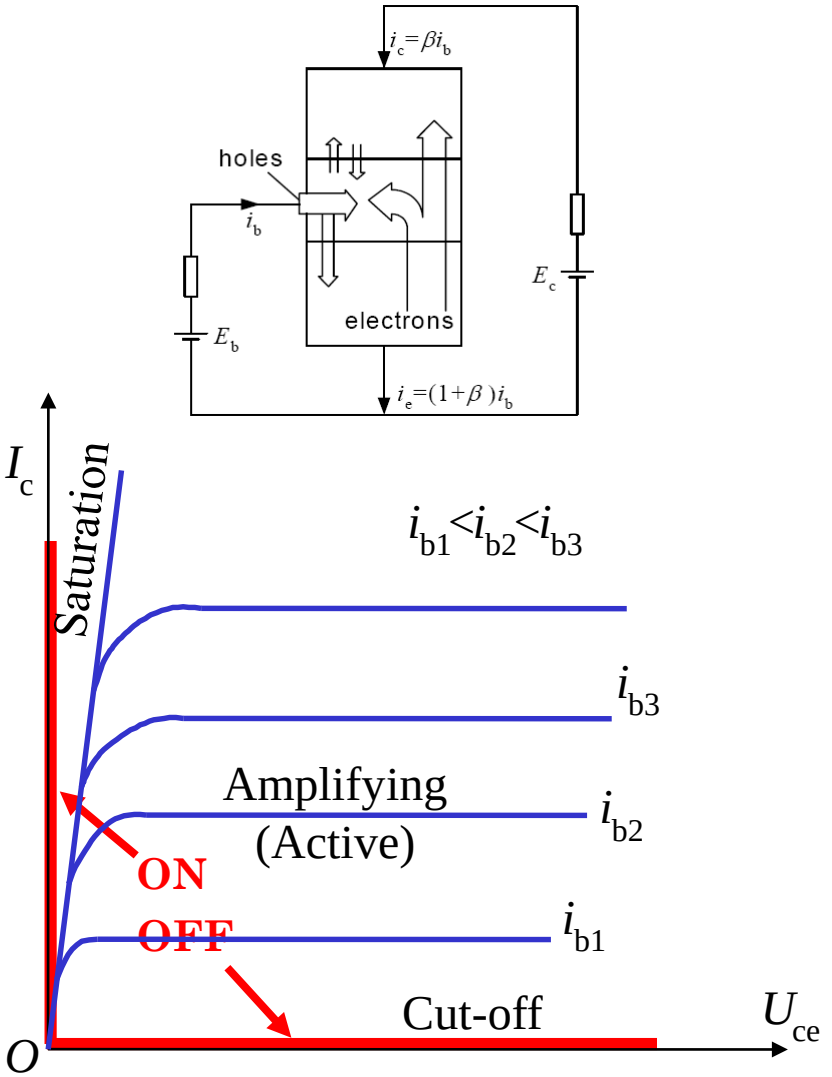
- Three-terminal devices with NPN or PNP type
- The terminals c-e are used as a fully controllable (one-way) switch controlled by the current signal through b-e
- Also called GTR (Giant Transistor)





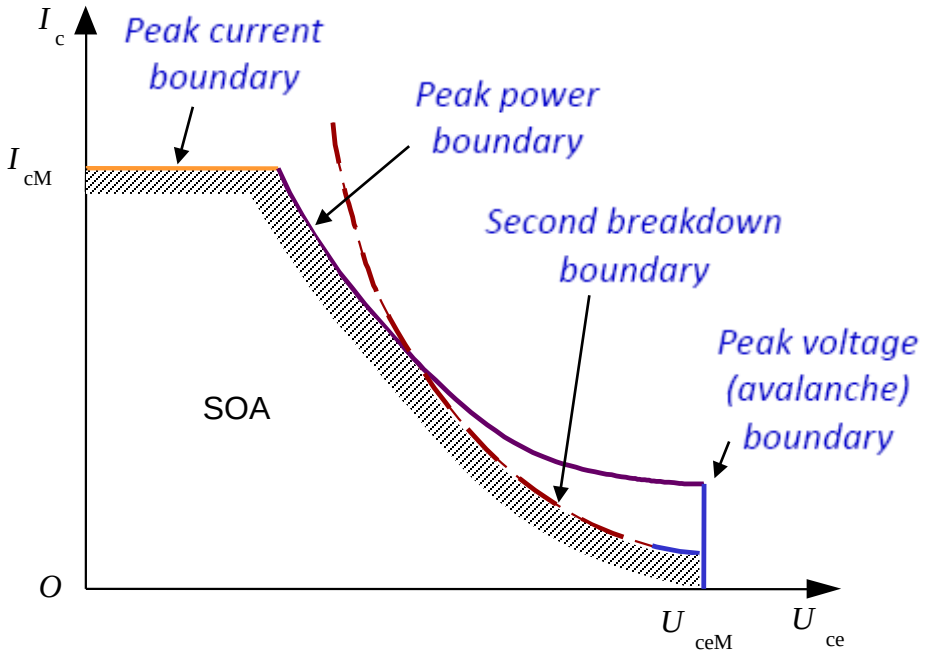
BJT I-V Characteristics

- Comparing with information-processing BJT
  - Basic operation principles are the same
  - Special features: higher voltage withstand, larger current, better switching characteristics
  - Common-emitter connection
  - Operating in ON-OFF states



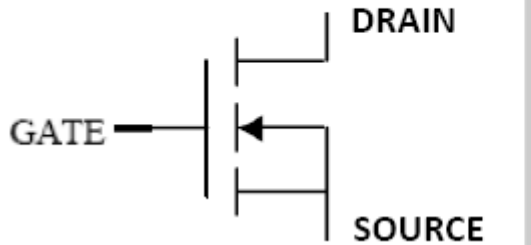
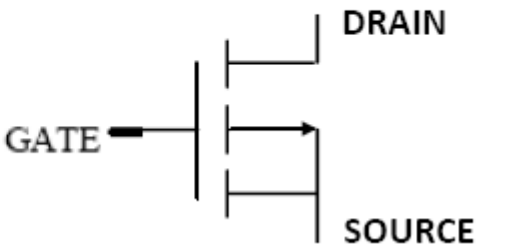
Breakdown and SOA

- Avalanche breakdown
  - the 1st breakdown
- The 2nd breakdown
  - A destructive phenomenon
  - Due to the current flow to a small portion of the base, producing localized hot spots
  - A localized thermal runaway
  - Cause the permanent damage of the device
- Safe operating area (SOA)



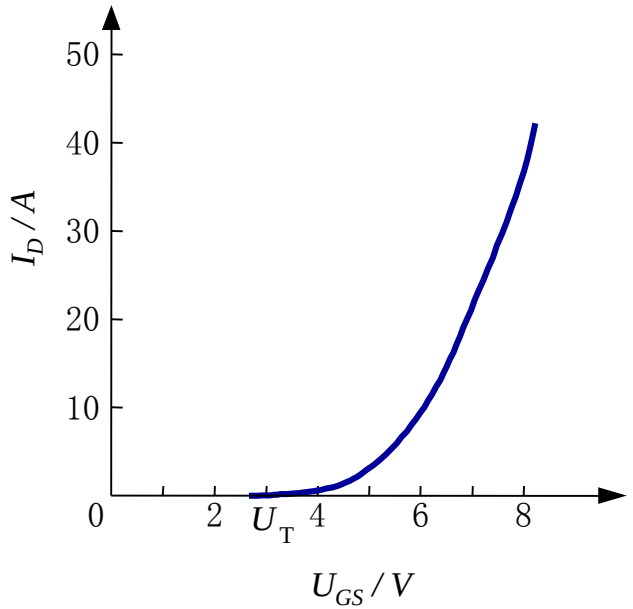
2.2 Power MOSFET

- Three-terminal devices with a P or N channel
- Relatively high input impedance
- The switch between d-s is fully controlled by a voltage signal between g-s.

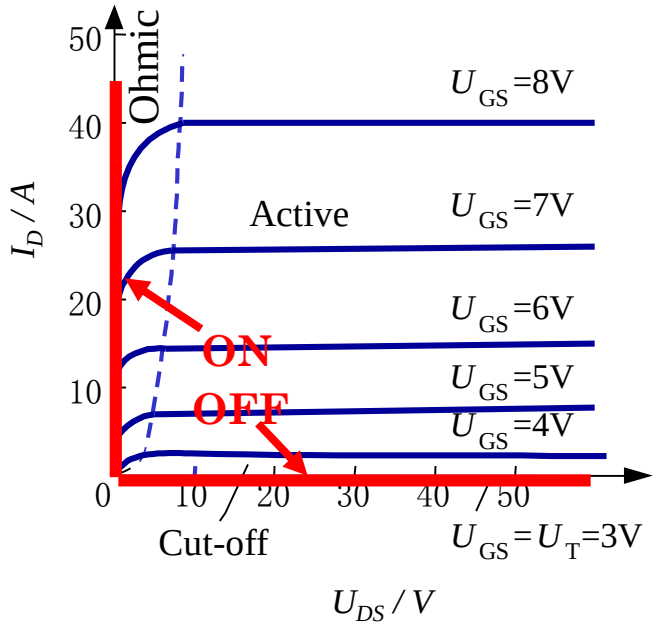
N-CHANNEL	P-CHANNEL
	

MOSFET I-V Characteristics

- Operating in switching mode: On-Off
- No 2nd-breakdown problem

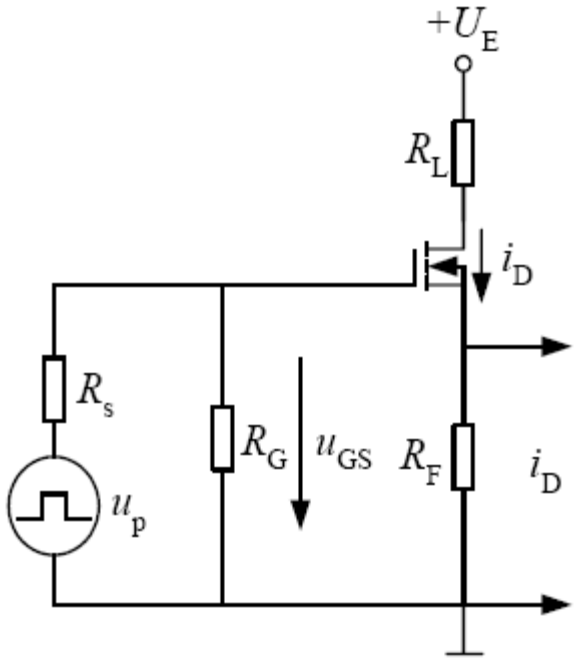


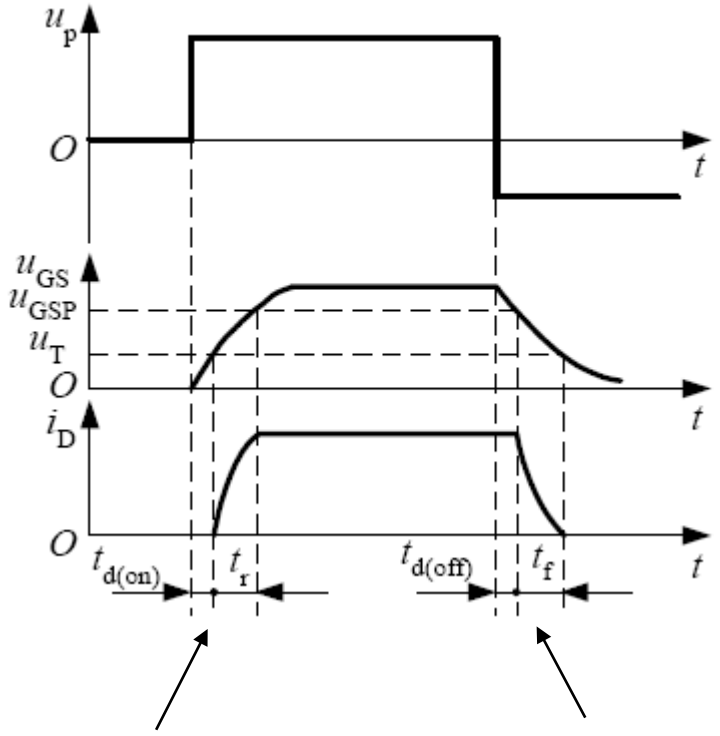
Transfer



Output

Switching characteristics





- Turn-on transient
  - Turn-on delay time $t_{d(on)}$
  - Rise time t_r

- Turn-off transient
  - Turn-off delay time $t_{d(off)}$
  - Falling time t_f

Features and applications

- Very fast switching speed, high operating frequency (could be hundreds of kHz)
- High input impedance; voltage controlled device; easy to drive
- No 2nd-breakdown problem => wider SOA than BJT
- Easy to use in parallel
- Conduction loss of MOSFET is larger than that of BJT due to a larger voltage drop for high-voltage applications

- On-resistance increases rapidly with rated blocking voltage
  - Usually used at voltages less than 500V and power less than 10kW
  - 1000V devices are available, but are useful only at low power levels (100W)

2.3 IGBT

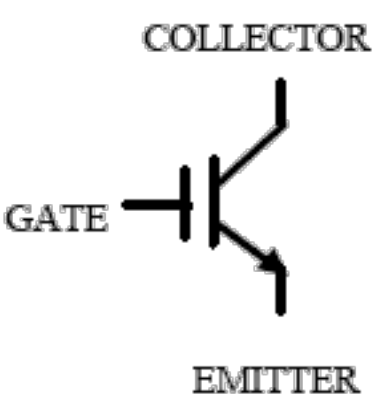
- A hybrid MOS-gated bipolar transistor
- Combination of power transistor and MOSFET

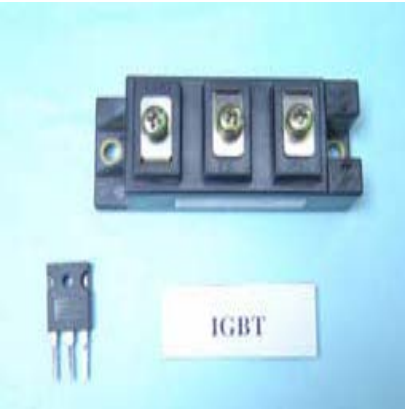
GTR: ☺ low conduction losses (especially at larger blocking voltages),
☹ longer switching times, current-driven

MOSFET: ☺ faster switching speed, easy to drive (voltage-driven),
☹ larger conduction losses (especially for higher blocking voltages)

→ IGBT

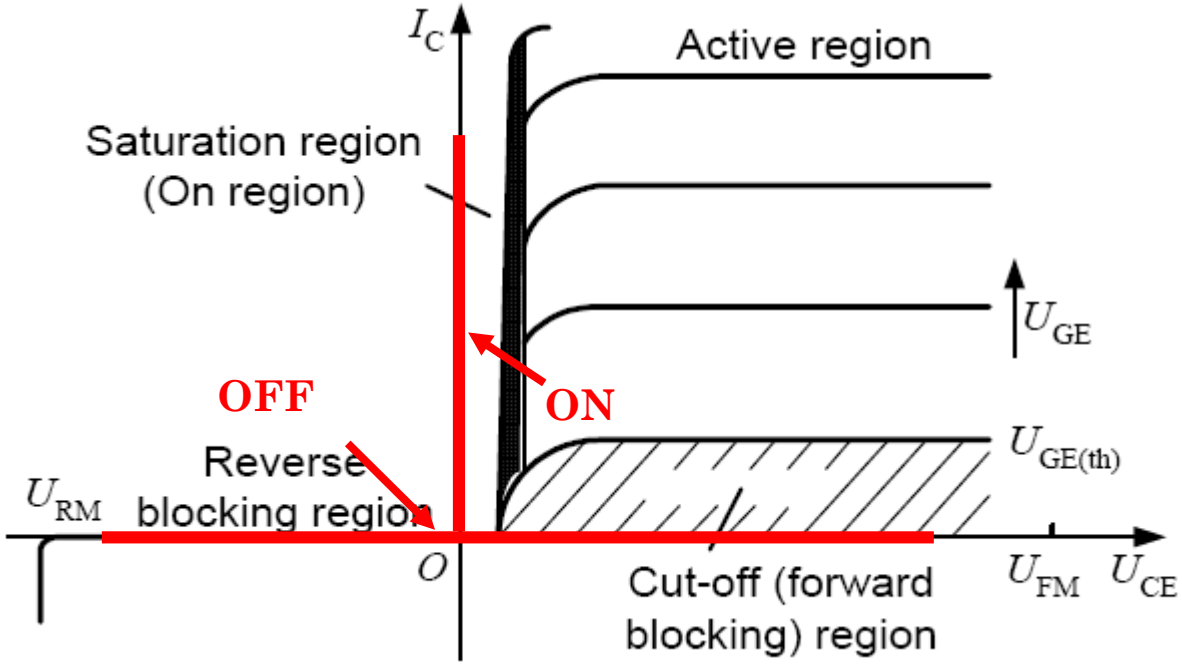
- Features
- Low conduction loss (BJT)
  - High-speed turn-on (MOSFET)
  - Low-power, easy drive (MOSFET)





IGBT I-V Characteristics

- On-state losses are much smaller than those of a power MOSFET
- Faster than GTR, but slower than power MOSFET
- Easy to drive —similar to power MOSFET



Review of the classifications

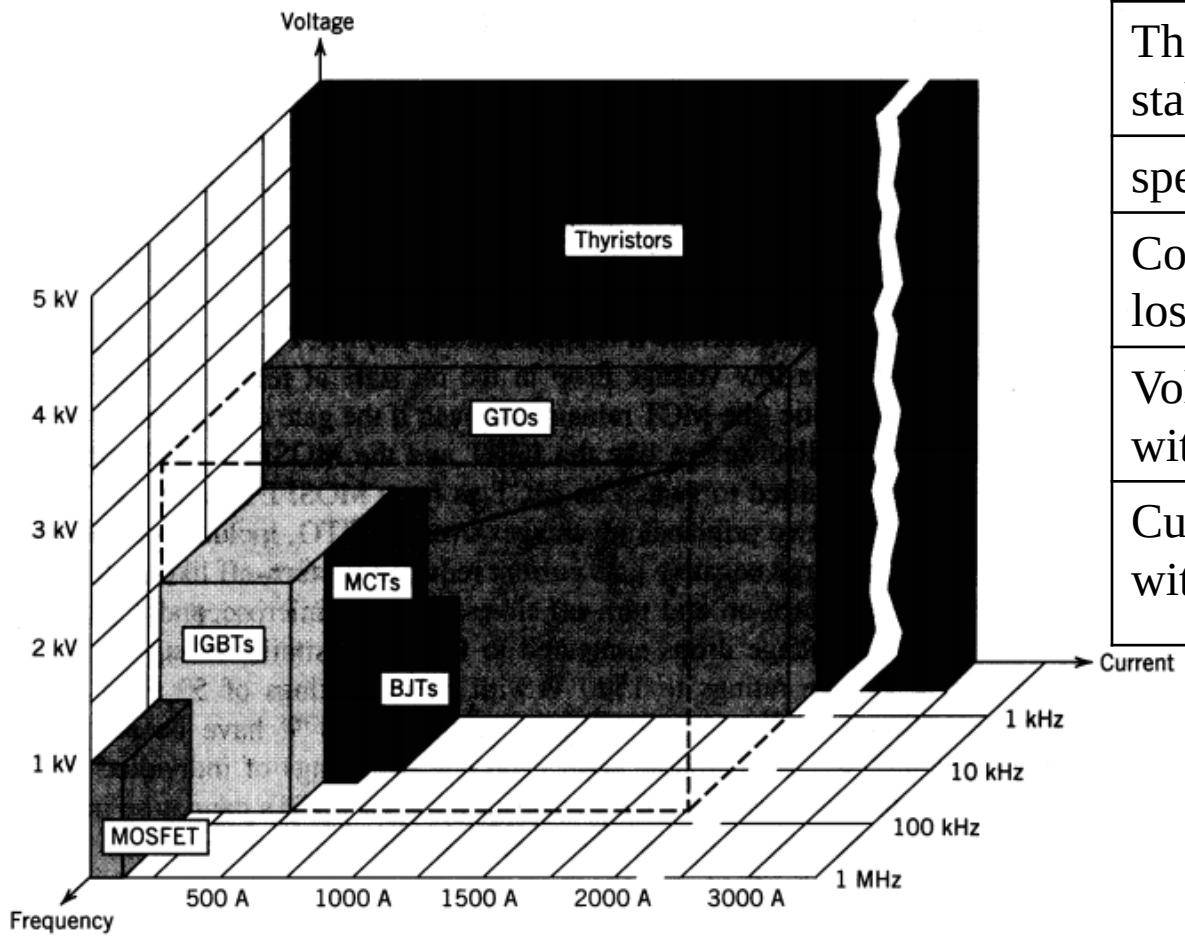
power electronic devices

- Current-driven (current-controlled) devices: thyristor, GTO, GTR
- Voltage-driven (voltage-controlled) devices (Field-controlled devices):power MOSFET, IGBT, SIT, SITH, MCT, IGCT

power electronic devices

- Pulse-triggered devices: thyristor, GTO
- Level-sensitive (Level-triggered) devices: GTR,power MOSFET, IGBT, SIT, SITH, MCT, IGCT

Comparison of power semiconductor devices



	GTR	MOSFET	IGBT
Driven	I	V	V
Input impedance	low	high	high
Thermal stability	Bad(2^{nd} BR)	Good (no 2^{nd})	Good (no 2^{nd})
speed	low	high	medium
Conduction loss	low	high	low
Voltage withstand	high	low	high
Current withstand	high	low	high