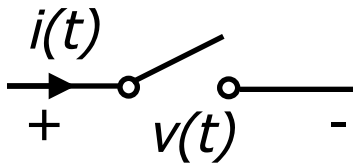
Electronic Power Conversion

Power Semiconductors

2. Overview of Power Semiconductor Devices

- Ideal switch:
  - Off $i(t)$ =0
  - On $v(t)$=0
  - Power loss $p(t)=v(t)i(t)=0 \rightarrow$ lossless device

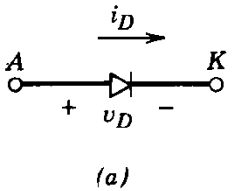


- Use of idealized switches in analysing circuits is justified if:
  - On-state voltage << supply voltage
  - Switch transition time << switching period
- Classification according to controlability:
  - Diodes (uncontrollable)
  - Thyristors (half controllable)
  - Fully controllable switches

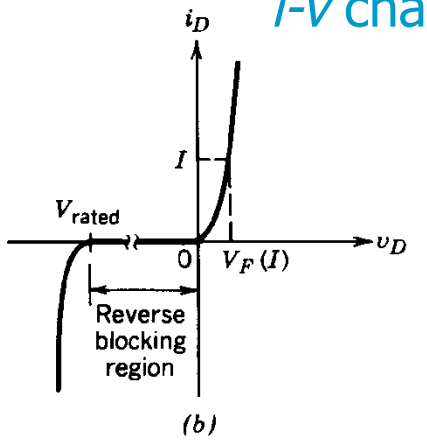
reverse blocking = *sperren*
forward blocking = *blokkeren*
on-state = *doorlaten*

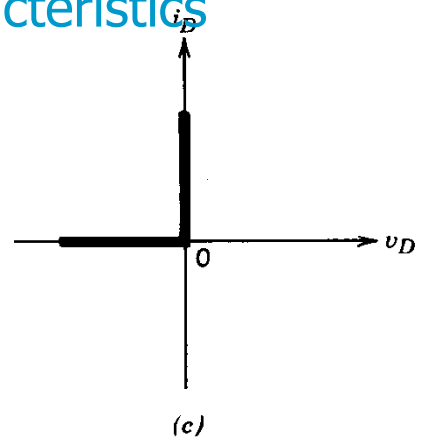
Diodes

symbol

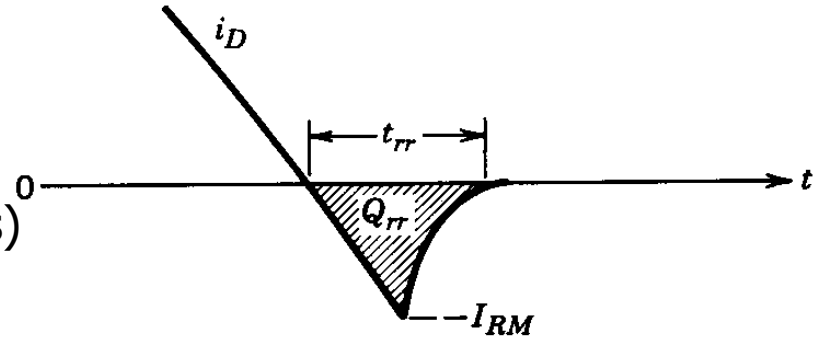


i-v characteristics





- Reverse recovery:
  - losses
  - overvoltages
  - EMI
- t_{rr} reverse recovery time
- Types:
  - Schottky diodes (t_{rr} <<0.1 µs) (metal-silicon junction)
  - Fast recovery diodes (t_{rr} =0.1…1 µs)
  - Line frequency diodes (t_{rr} >10 µs)

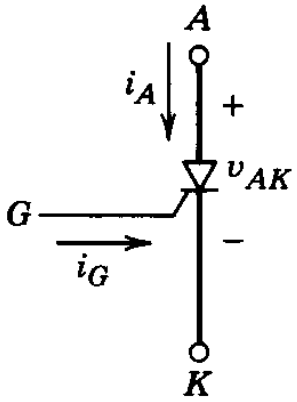


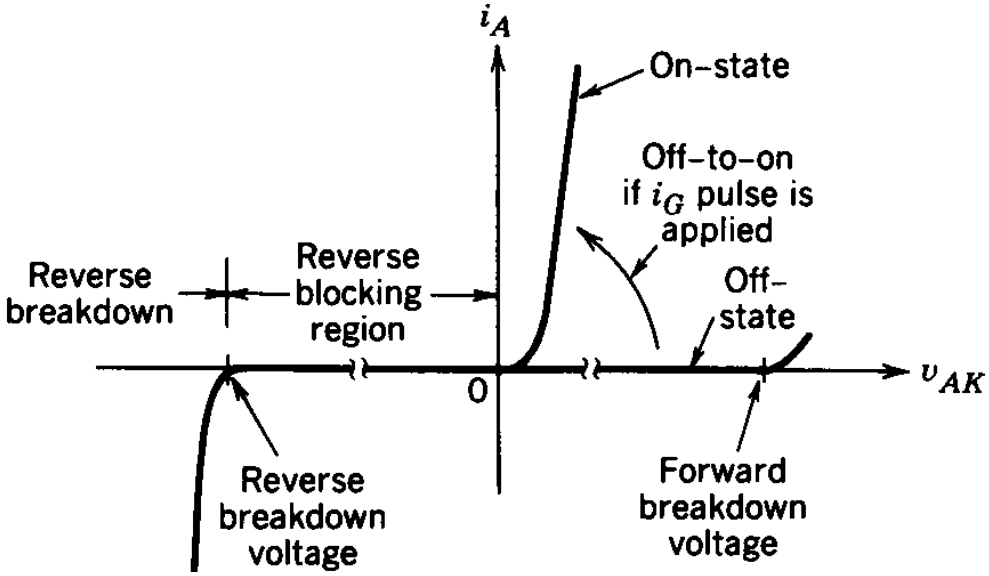
Diode turn-off

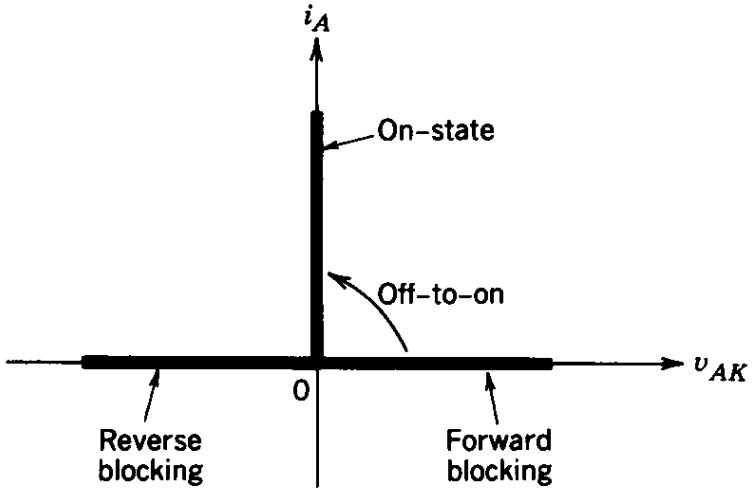
Thyristors

- Turned on by positive gate current
  - Device must be in forward blocking state
- Turned off by anode current

symbol

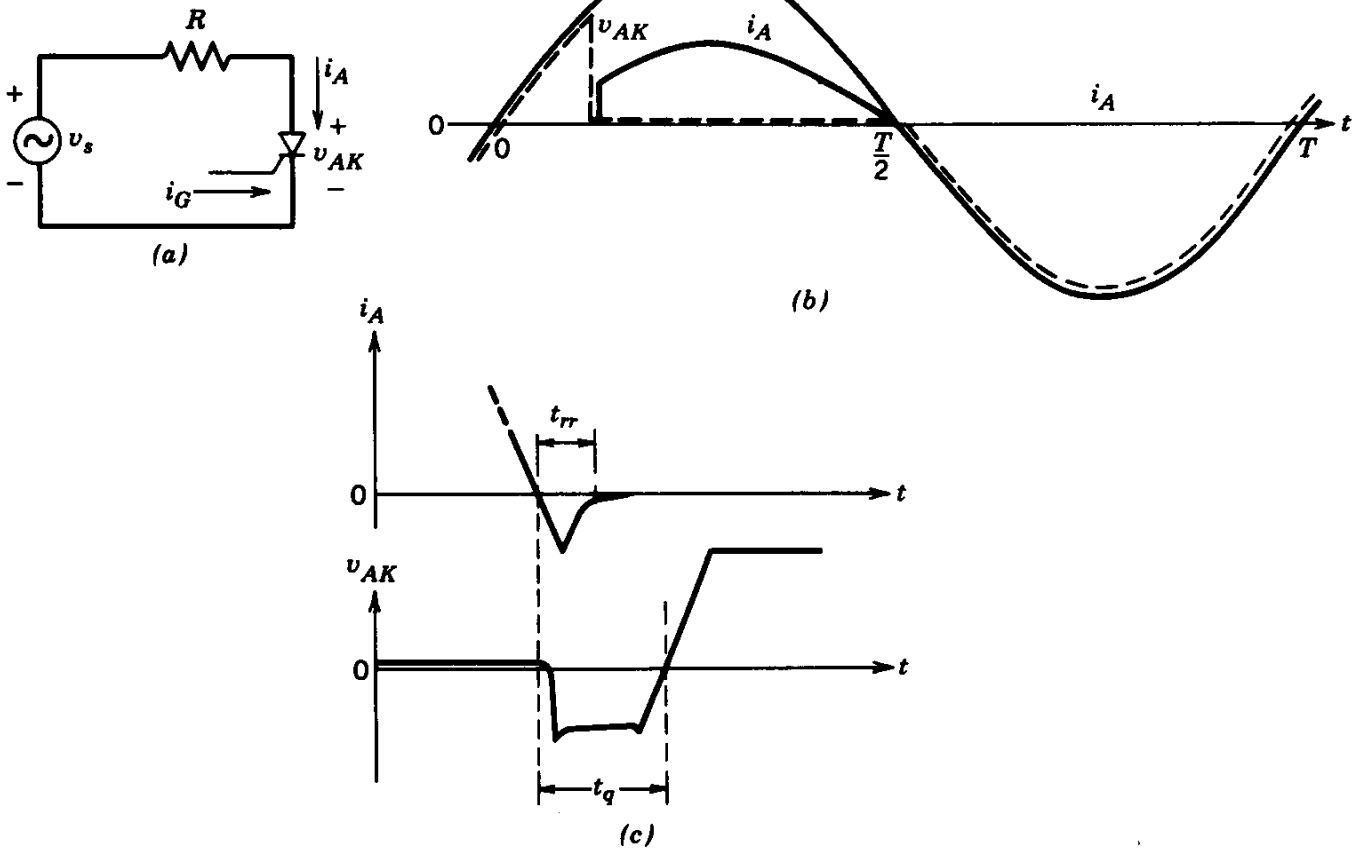






i-v characteristics

Thyristors



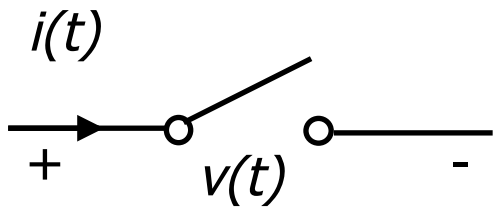
t_{rr} reverse recovery time (*hersteltijd*)
t_q circuit commutation time (*circuit commutatietijd*)

Note: Fig. c) does not concern a detail of fig. b); it concerns another case

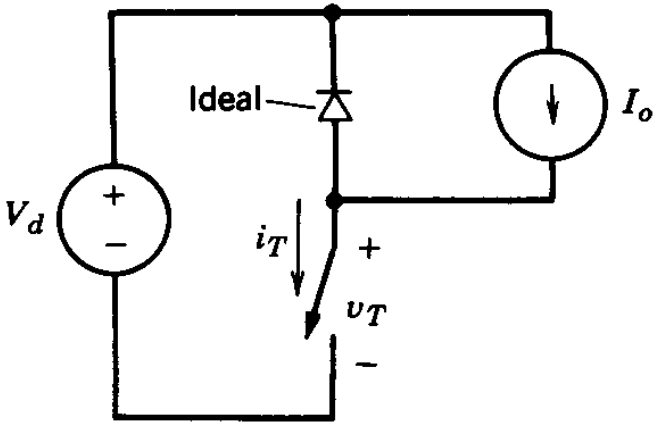
Controllable Switches

- Desired properties
  - High forward and reverse blocking voltage at low leakage current
  - High current carrying capability at low forward voltage drop
  - Low drive power
  - Fast switching → low switching loss

- BJT, MOSFET, GTO, IGBT, IGCT, …



Power Semiconductor Device Losses



$$W_{c,on} = \tfrac{1}{2} V_d \, I_o \, t_{c,on}$$

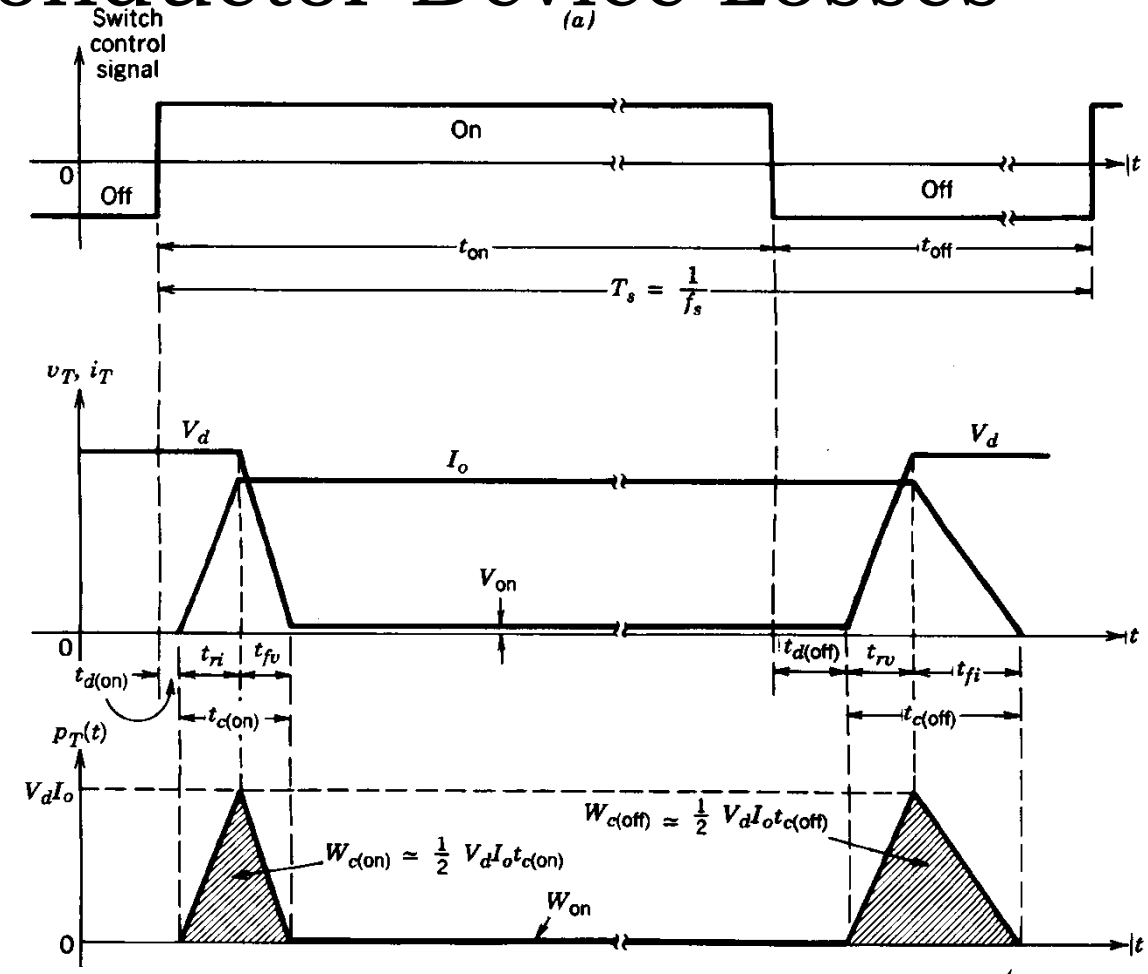
Turn-on energy

$$W_{c,off} = \tfrac{1}{2} V_d \, I_o \, t_{c,off}$$

Turn-off energy

$$P_s = \tfrac{1}{2} V_d \, I_o \, f_s \left(t_{c,on} + t_{c,off} \right)$$

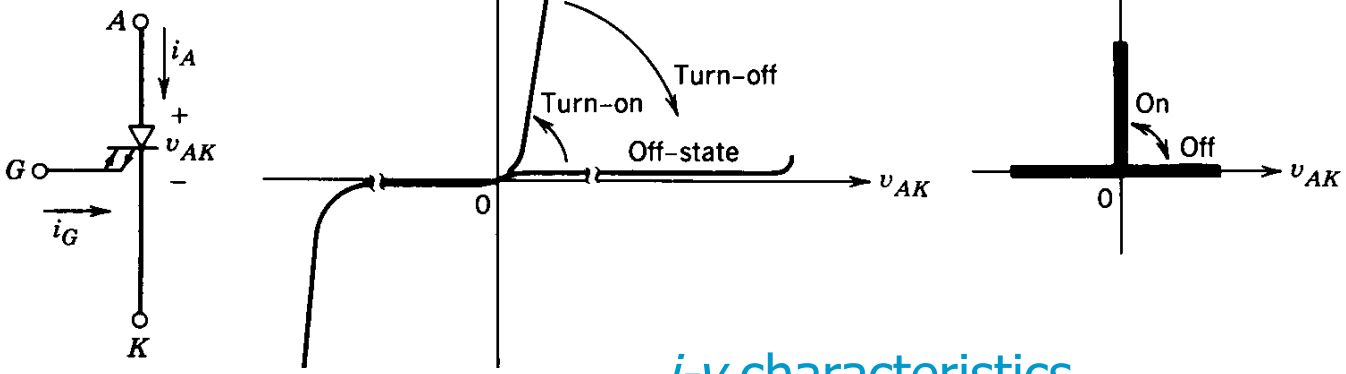
Switching loss



Conduction loss $P_{on} = V_{on} \, I_o \, \dfrac{t_{on}}{T_s}$

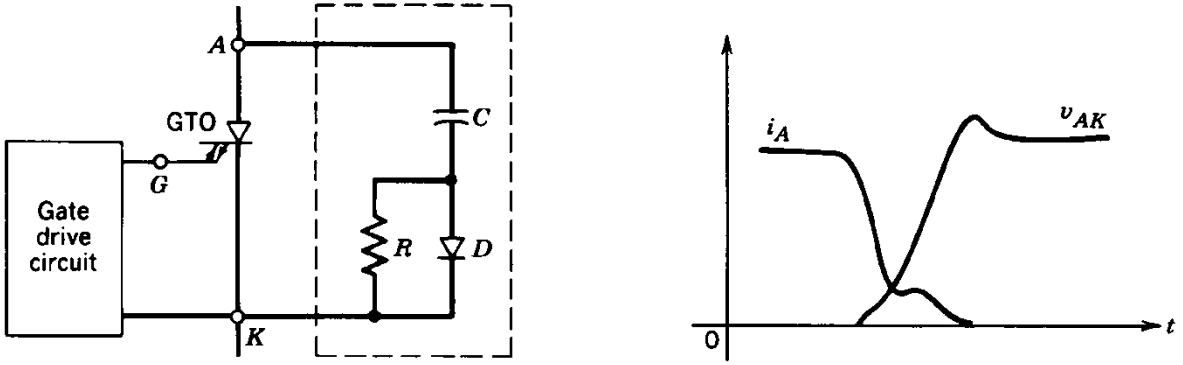
GTO-thyristor (Gate Turn Off thyristor)

- Can be turned-off by negative gate current
- Snubber needed to reduce dv/dt at turn-off



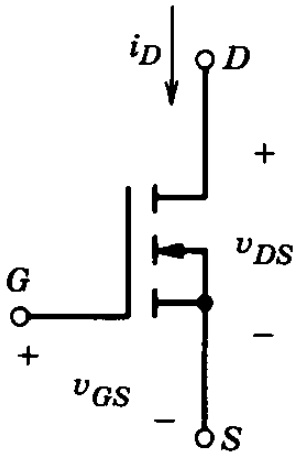
symbol

i-v characteristics

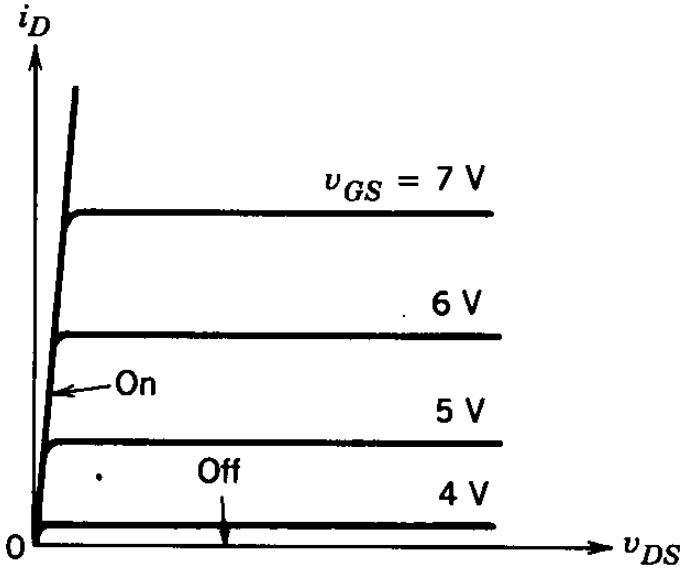


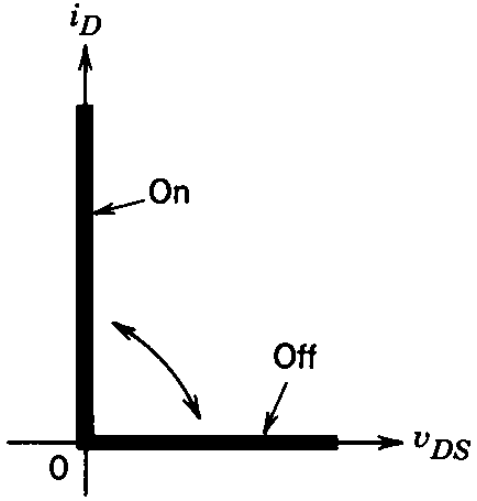
MOSFET

- Voltage controlled device;
- Fast, switching times ~ns to ~a few hundred ns;
- On-resistance increases exponentially with blocking voltage rating



symbol

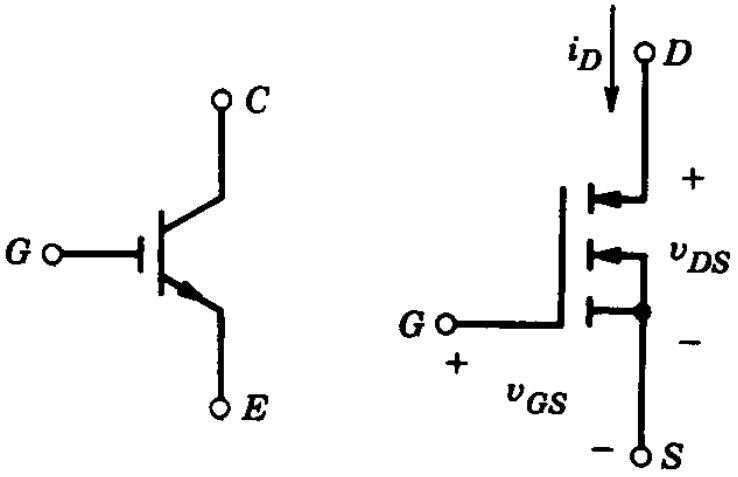




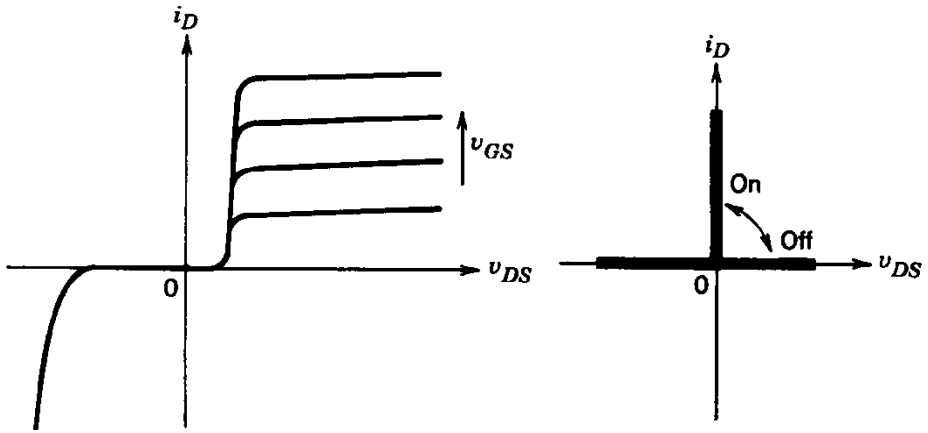
i-v characteristics

IGBT (Insulated Gate Bipolar Transistor)

- High impedance gate (like MOSFET);
- Low on-state voltage (like BJT);
- Switching times ~1µs (new devices are faster).

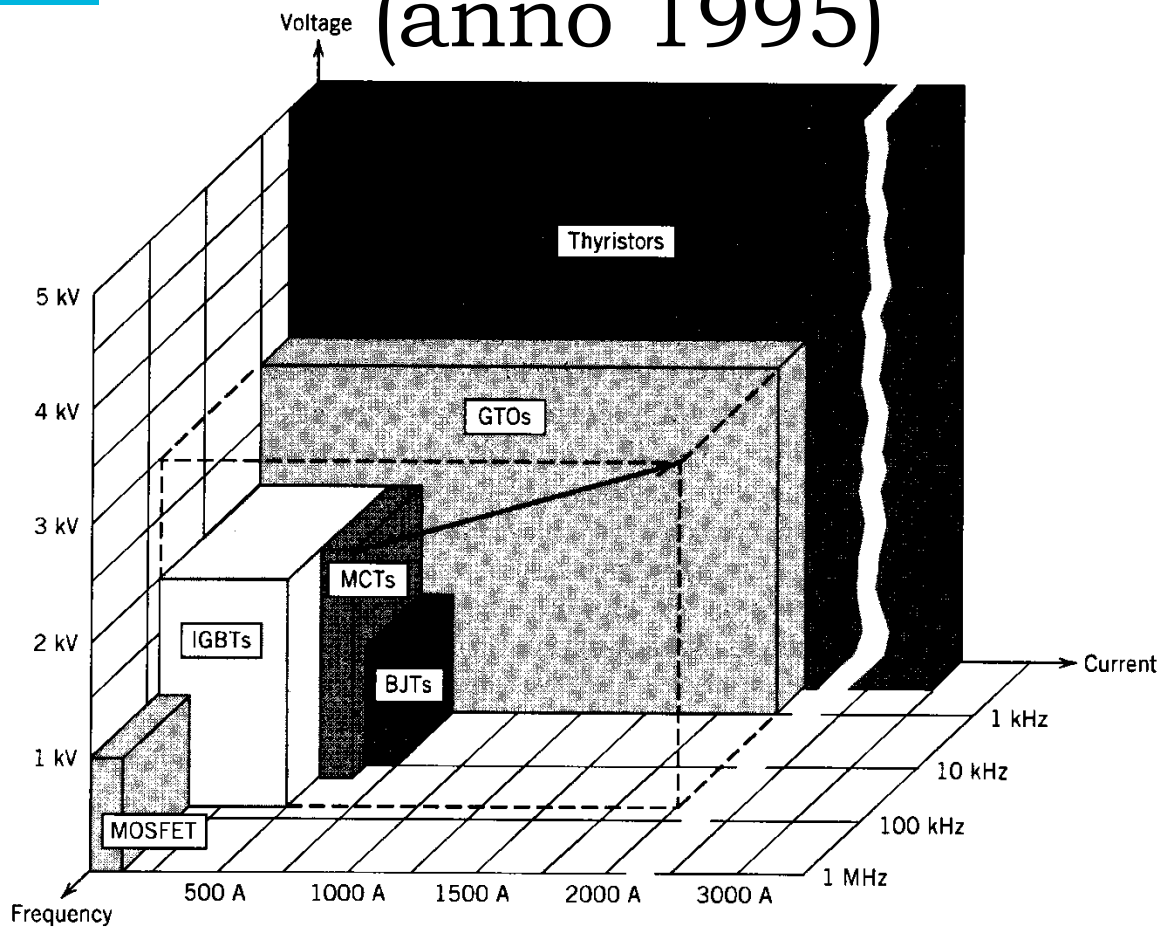


symbol



i-v characteristics

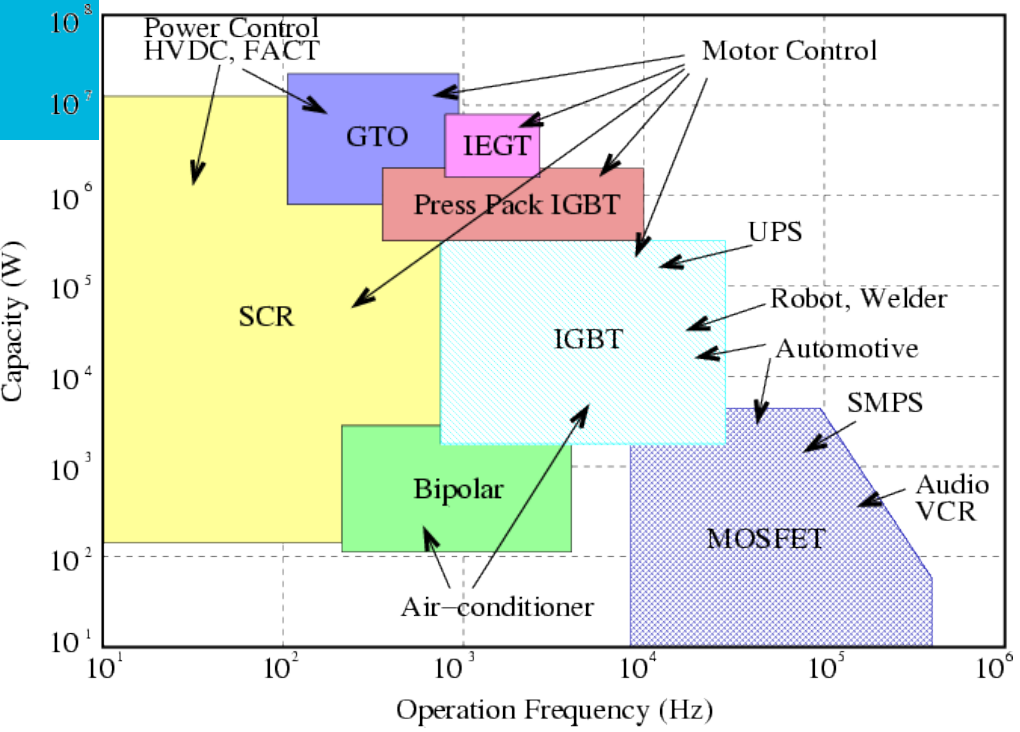
Overview of Power Semiconductors (anno 1995)

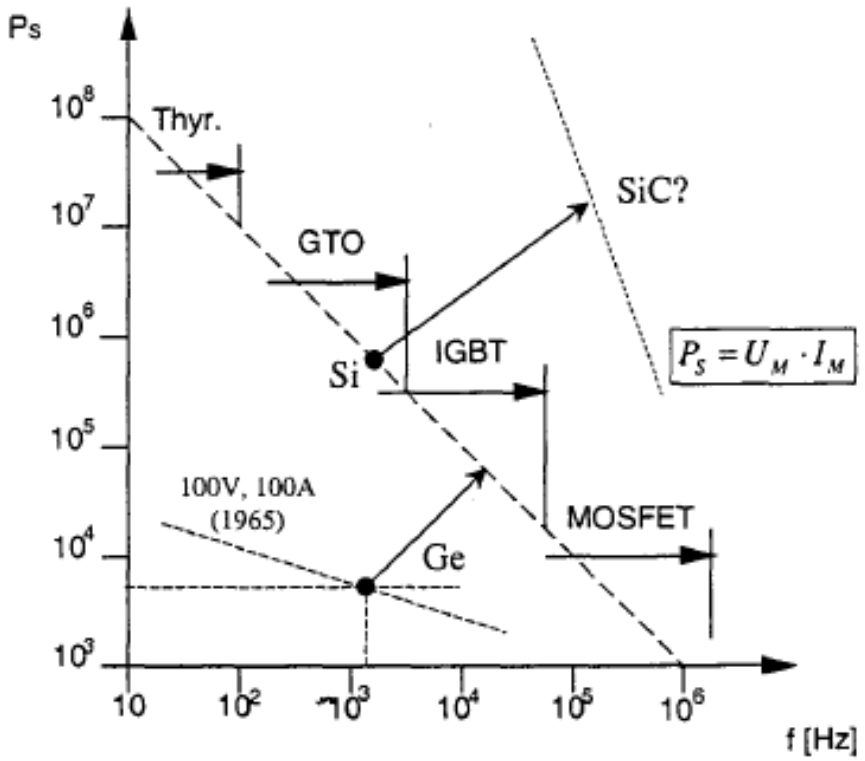


Anno 2008:

Thyristor: see figure
IGBT: 600V-1200V@ a few A (fast)
1kA@6.5kV (10kHz)
3.6 kA@1.7 kV
GTO: replaced by IGBT
MOSFET: 100A@30V,
1kV@few amps

Overview of Power Semiconductors





Source: van Wyk, "Power electronics technology at the dawn of the new millenium-status and future", IEEE PESC 1999.

Image credits

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