EE-463 STATIC POWER CONVERSION-I

Power Semiconductor Devices

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keysan.me

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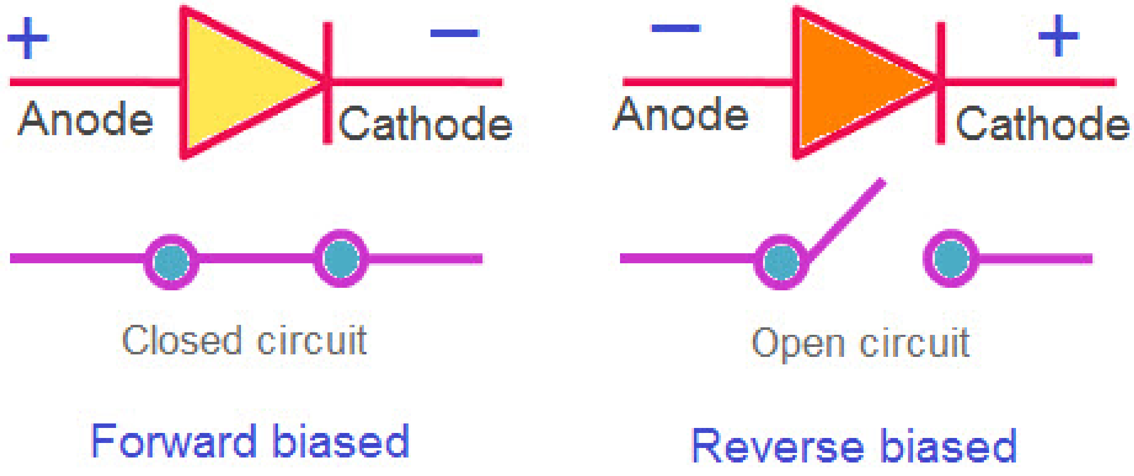
Diode

Power Diode (>50 A)

Ideal Diode


+
−
Anode
Cathode
Closed circuit
Forward biased
−
+
Anode
Cathode
Open circuit
Reverse biased

Ideal Diode

V-I Characteristics

Ideal Diode

V-I Characteristics

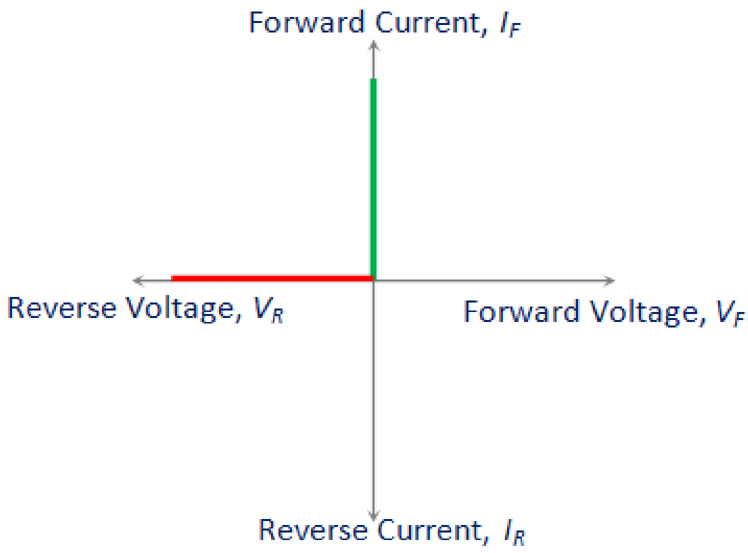


Figure 1 I-V Characteristics of an Ideal Diode

Practical Diode

Important Parameters

Practical Diode

Important Parameters

- Forward Voltage

Practical Diode

Important Parameters

- Forward Voltage
- Reverse Break-down Voltage

Practical Diode

Important Parameters

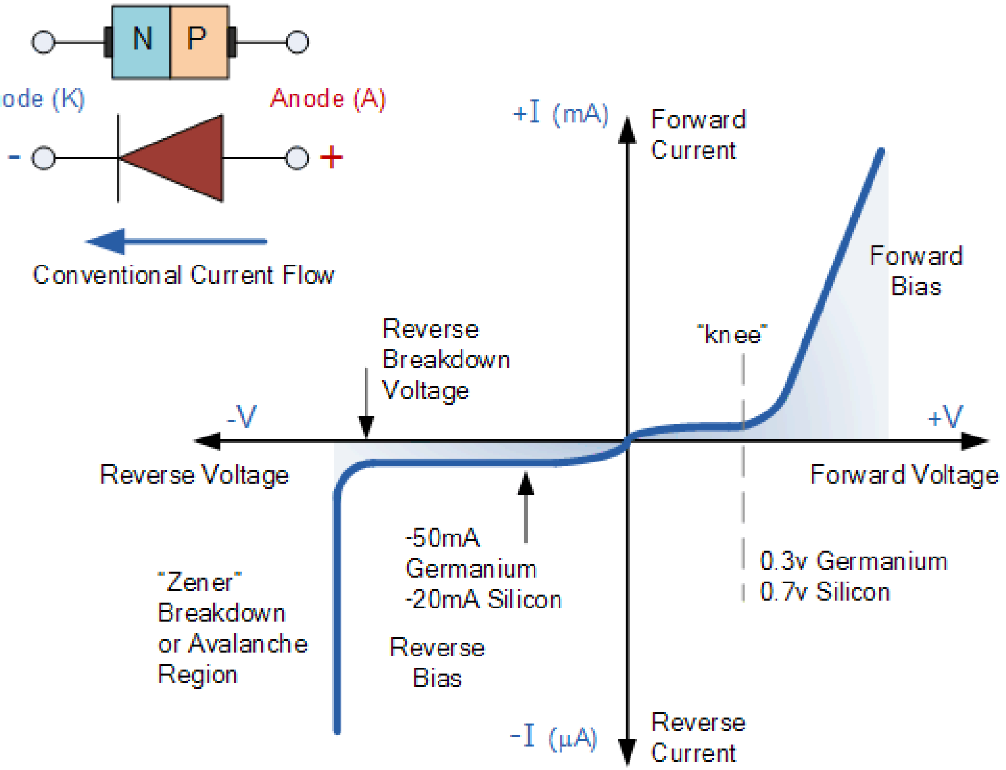
- Forward Voltage
- Reverse Break-down Voltage
- On-resistance

Practical Diode

Important Parameters

- Forward Voltage
- Reverse Break-down Voltage
- On-resistance
- Turn-on, turn-off times (forward, reverse-recovery)

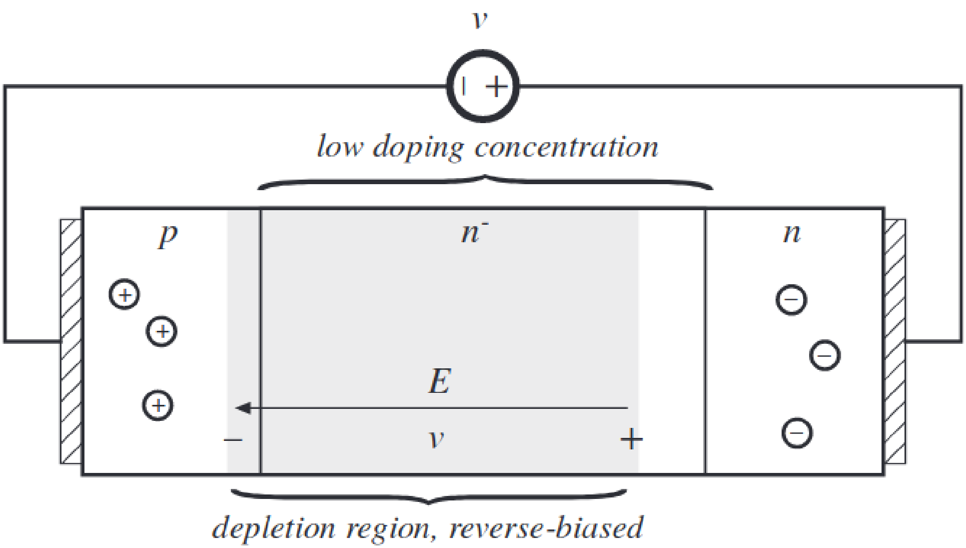
Practical Diode: V-I Characteristics



A few Data-sheets

- STTH6012, 1200V, 60A Diode
- FERD20S100S, 100V, 20 A Diode

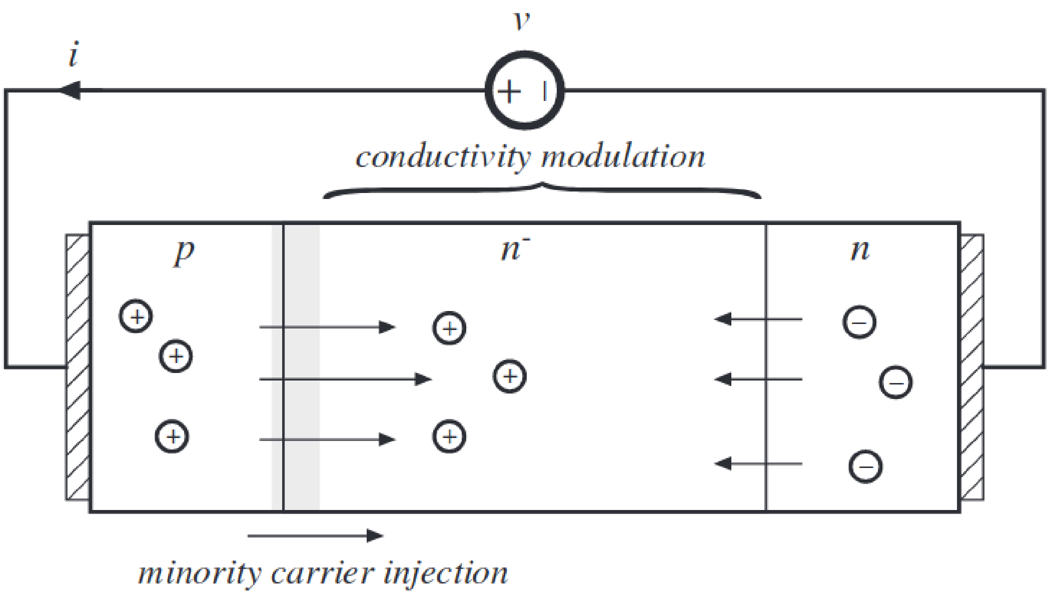
Reverse Biased Diode



[More info]

Eriksson, Fundamentals of Power Electronics, Ch4

Forward Biased Diode



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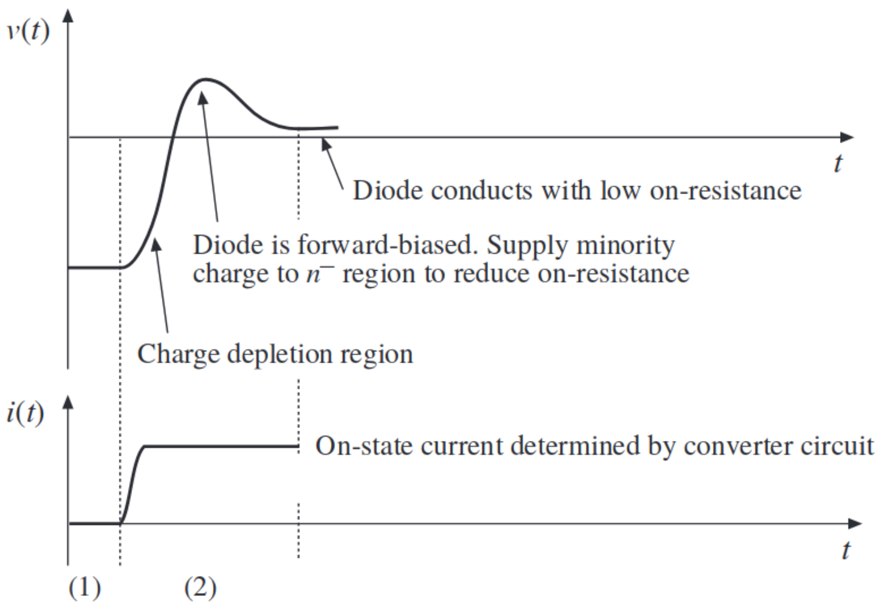
Eriksson, Fundamentals of Power Electronics, Ch4

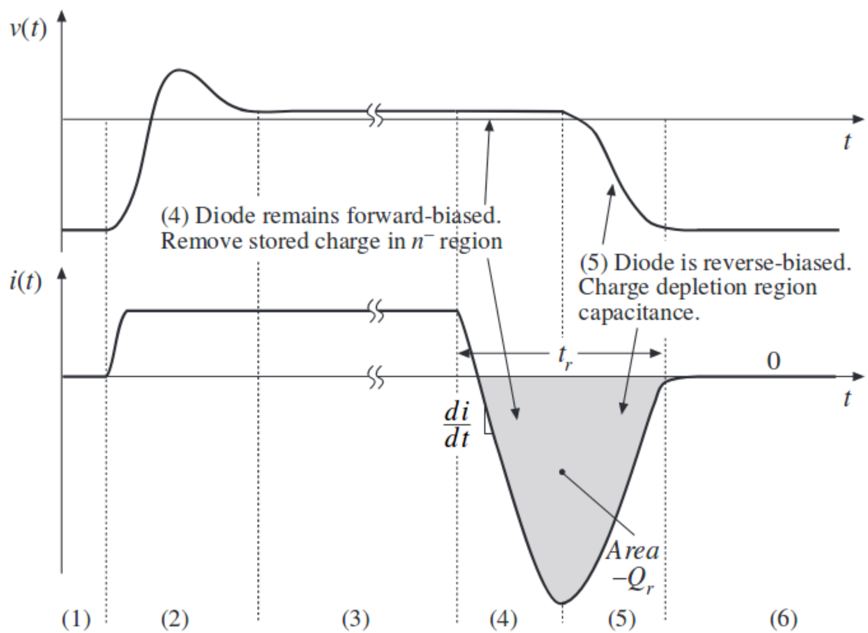
Diode Switching Waveforms

Turn-on transient



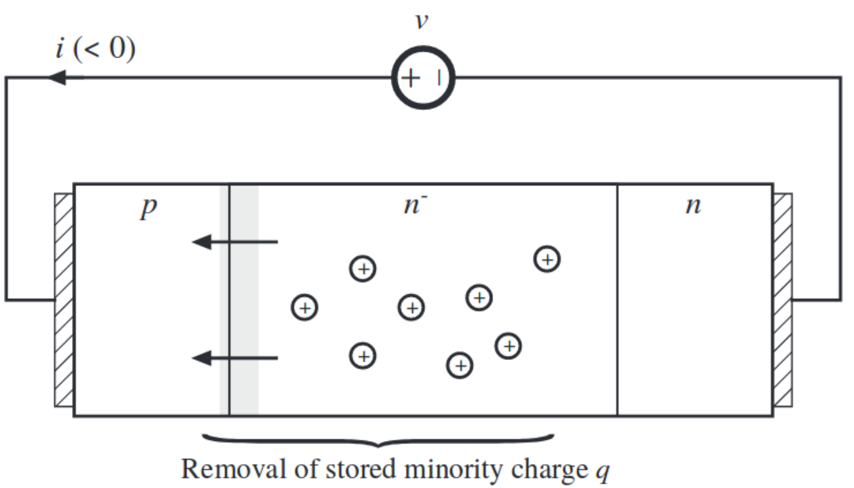
Diode Switching Waveforms

Turn-off transient



Diode Switching Waveforms

Turn-off transient



Reverse current is required to remove carrier charges

Reverse Recovery

Diode conducts a reverse current during turn-off

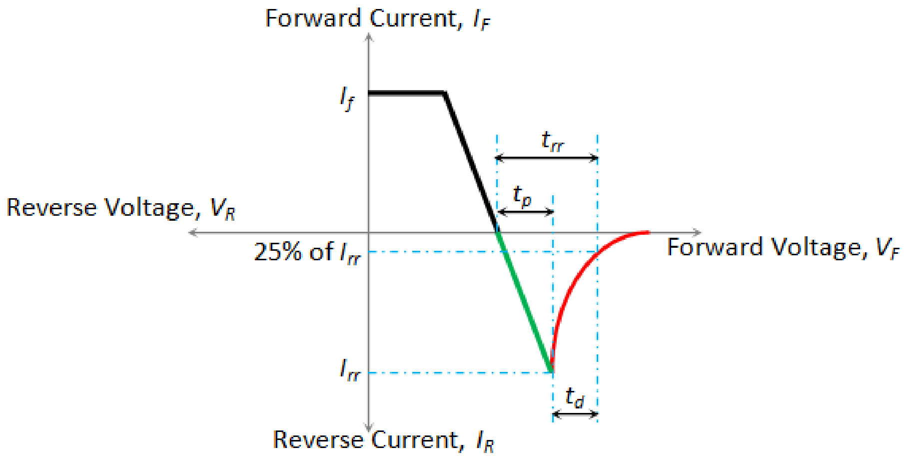
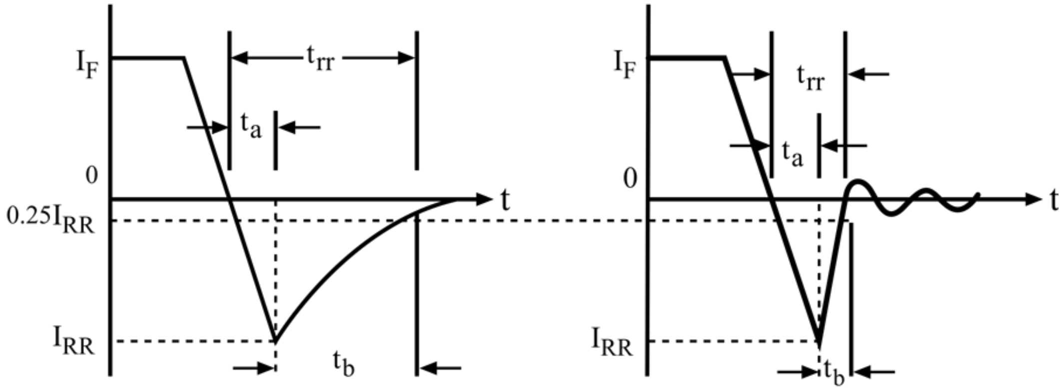


Figure 1 Reverse Recovery Characteristics of the Diode

t_{rr}: Reverse recovery time, I_{rr}: Reverse recovery current

Reverse Recovery



(a) Soft recovery (b) Abrupt recovery

[Softness Factor]

[Reverse recovery]

[Fast diode vs Slow Diode]

Types of Power Diodes

Types of Power Diodes

- Standard Recovery

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- Standard Recovery
- Fast (ultra-fast) Recovery

Types of Power Diodes

- Standard Recovery
- Fast (ultra-fast) Recovery
- Schottky Diode
  - Majority carrier (due to metal layer)
  - No recovered charge, $t_{rr} = 0$
  - Limited to low voltage (<100V)

Types of Power Diodes

Types of Power Diodes

Part number	*Rated max voltage*	*Rated avg current*	V_F *(typical)*	t_r *(max)*
Fast recovery rectifiers				
1N3913	400V	30A	1.1V	400ns
SD453N25S20PC	2500V	400A	2.2V	2μs
Ultra-fast recovery rectifiers				
MUR815	150V	8A	0.975V	35ns
MUR1560	600V	15A	1.2V	60ns
RHRU100120	1200V	100A	2.6V	60ns
Schottky rectifiers				
MBR6030L	30V	60A	0.48V	
444CNQ045	45V	440A	0.69V	
30CPQ150	150V	30A	1.19V	

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What is the relation between V_{max} and V_F?

Losses

Losses

Conduction Losses

Losses

Conduction Losses

- Increases with current

Losses

Conduction Losses

- Increases with current

Switching Losses

Losses

Conduction Losses

- Increases with current

Switching Losses

- Increases with turn-on, turn-off-time

Losses

Conduction Losses

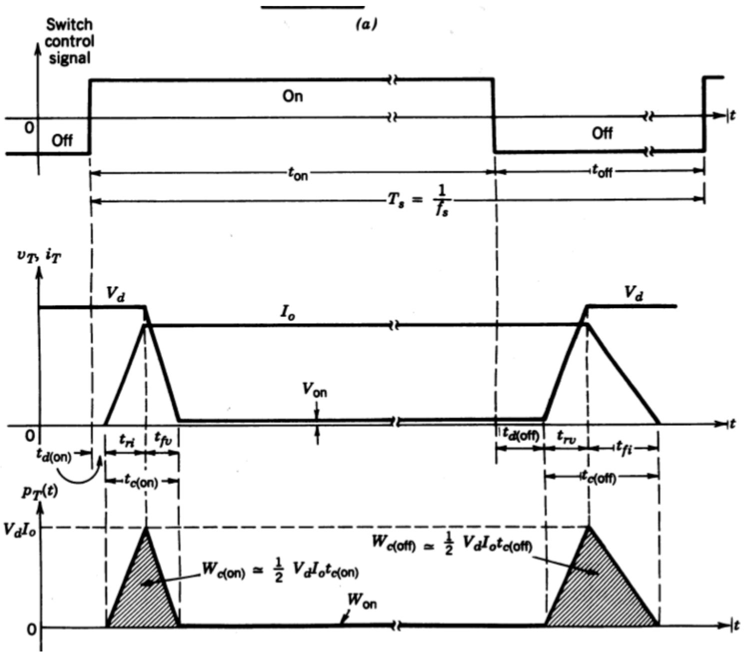
- Increases with current

Switching Losses

- Increases with turn-on, turn-off-time
- Increases with switching frequency

Switching Losses

Linearized



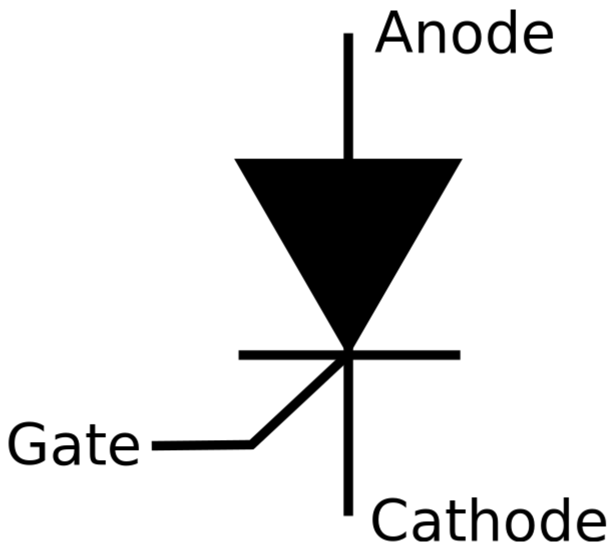
Losses

Extra Reading Material

- Fast, Faster, Fastest
- Power Losses, Thermal Considerations
- Calculation of conduction losses in a power rectifier

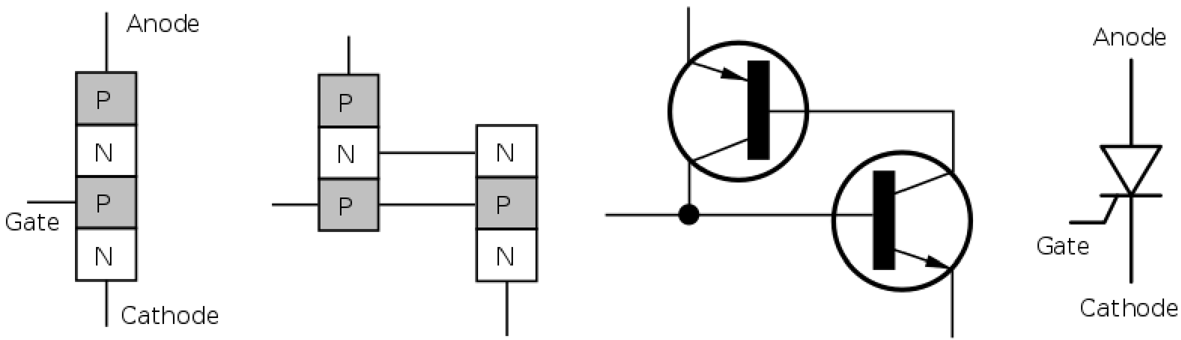
Thyristor

Thyristor

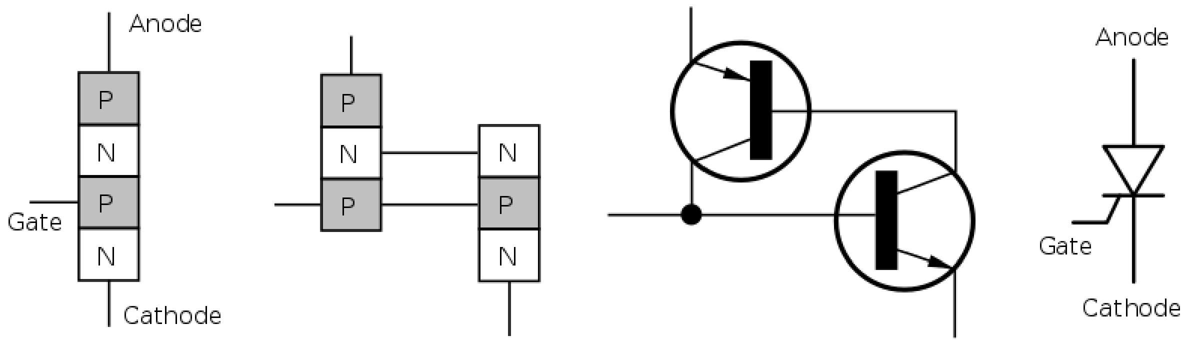


A diode with a gate terminal!

Thyristor

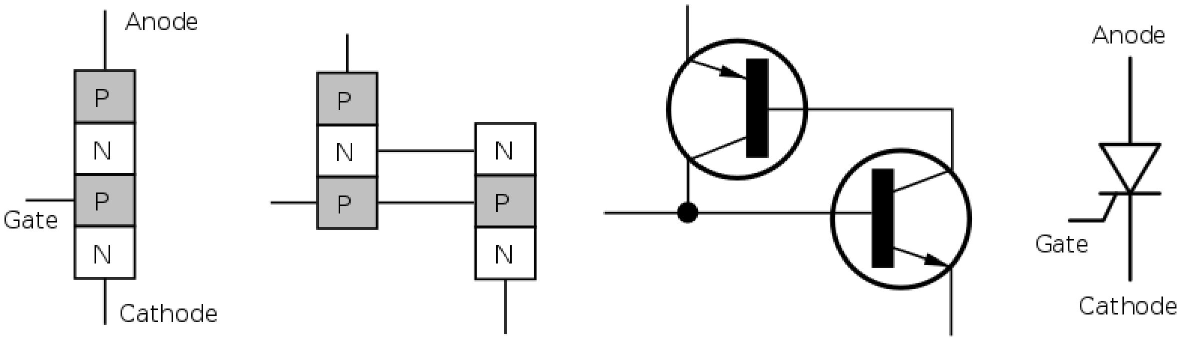


Thyristor



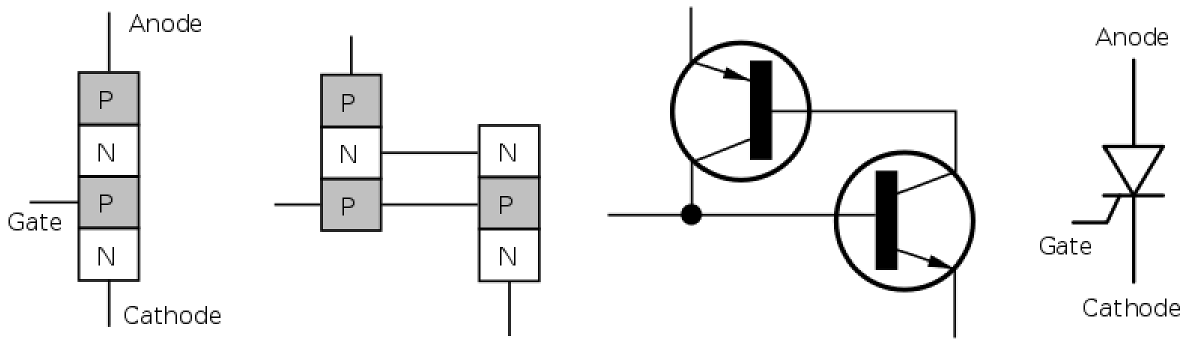
Four layer PNPN semiconductor (and two-transistor equivalent circuit)

Thyristor



A diode that you can delay on-state with gate signal(pulse)

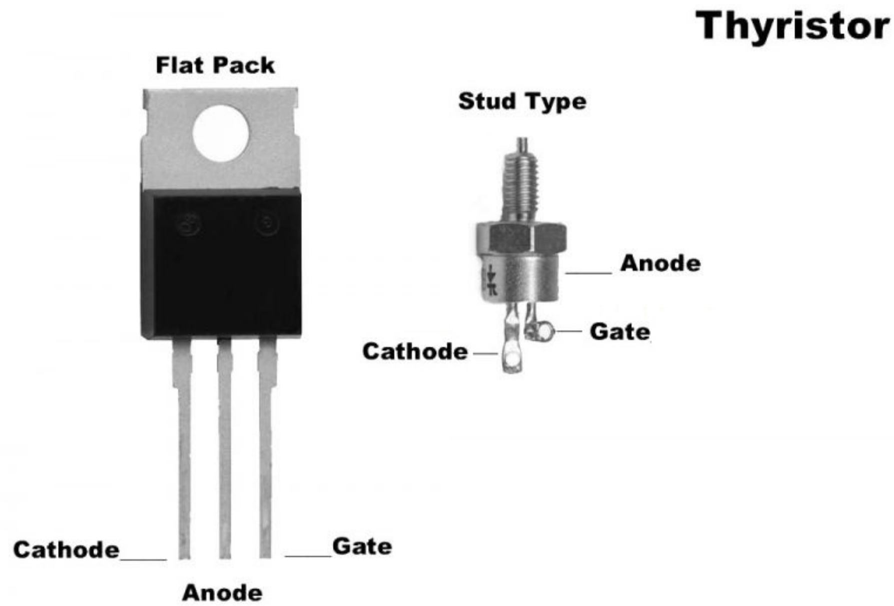
Thyristor



A diode that you can delay on-state with gate signal(pulse)

but no control while turning-off

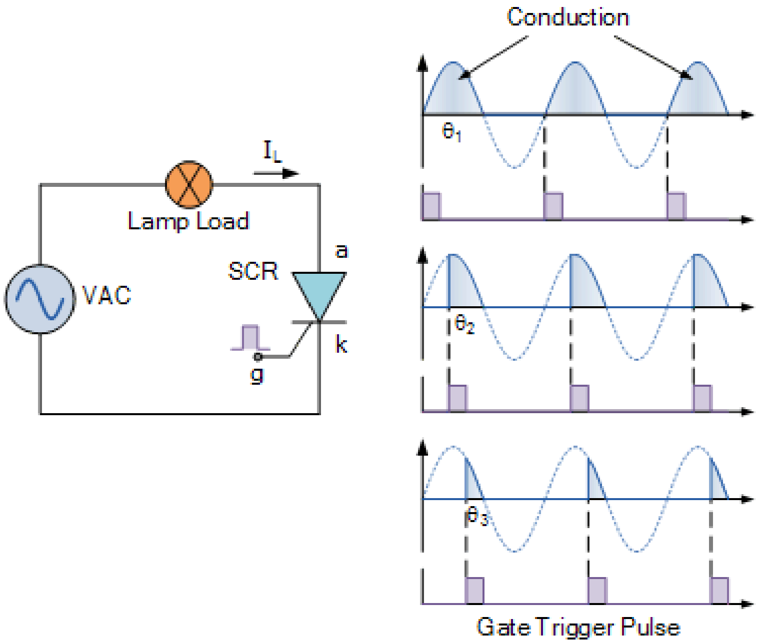
Thyristor


Thyristor
Flat Pack
Stud Type
Anode
Gate
Cathode
Cathode
Gate
Anode

Thyristor

Thyristor: Controlled Rectifier

Thyristor: Controlled Rectifier



More on thyristor rectifiers next week!

Thyristor

Thyristor

- Has the highest current and voltage rating among other devices

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- Slow switching device (eg compared to MOSFET)

Thyristor

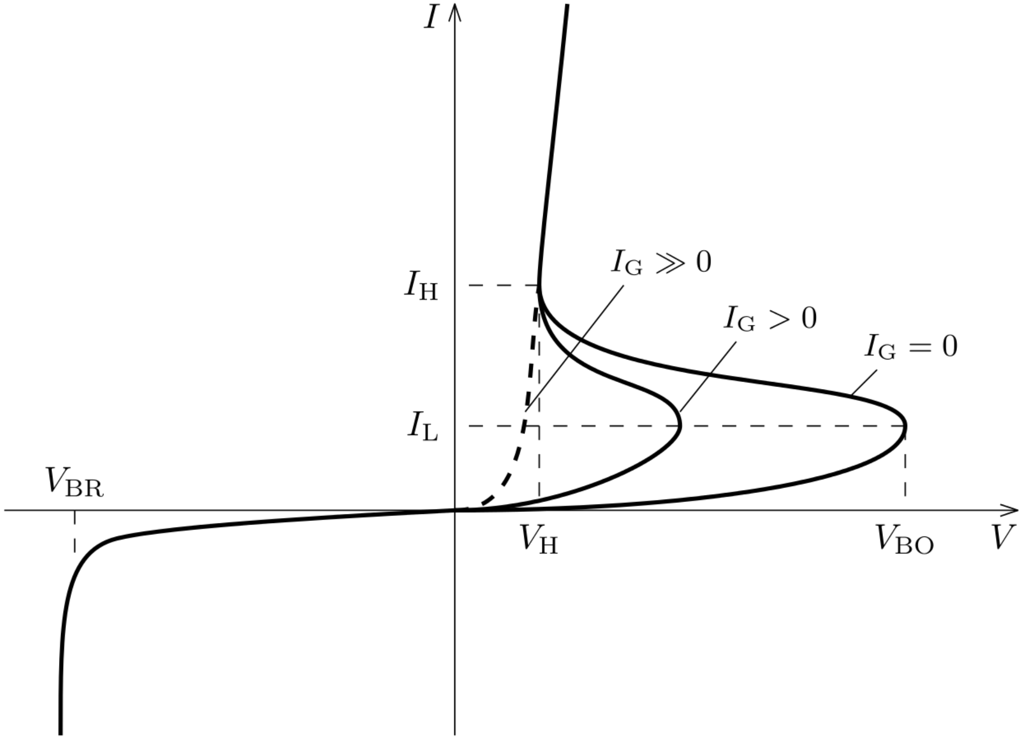
- Has the highest current and voltage rating among other devices
- Slow switching device (eg compared to MOSFET)
- Latching switch (can be turned on by I_g, but cannot be turned off)

Thyristor

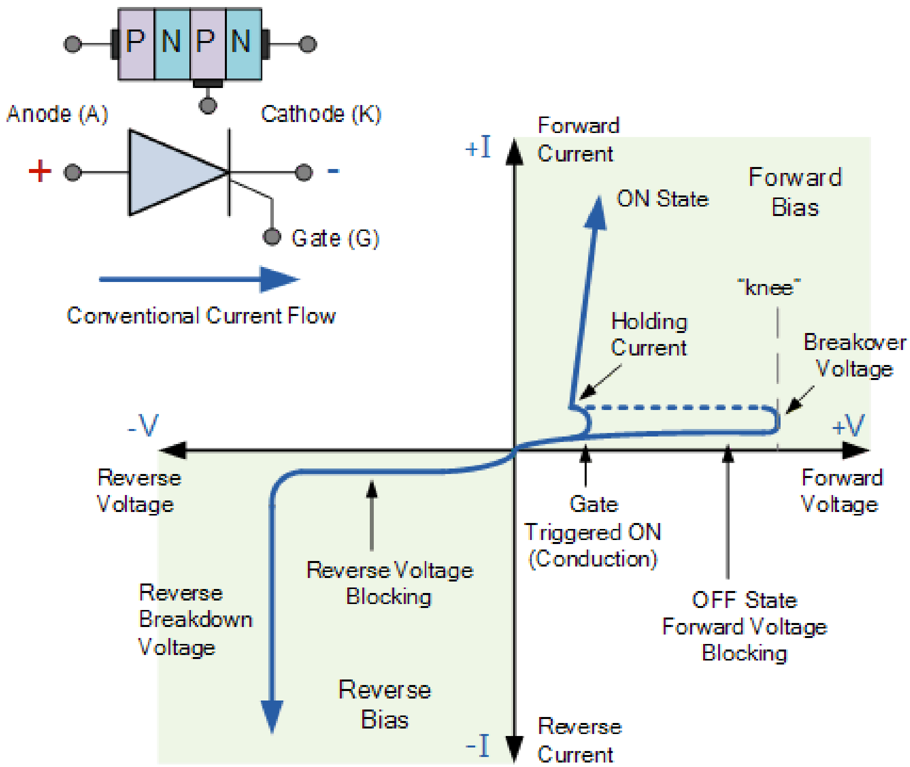
V-I Characteristics

- Reverse Blocking
- Forward Blocking
- Forward Conducting

V-I Characteristics



V-I Characteristics



Types of Thyristors

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- SCR (Silicon Controlled Rectifier)

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- TRIAC, DIAC

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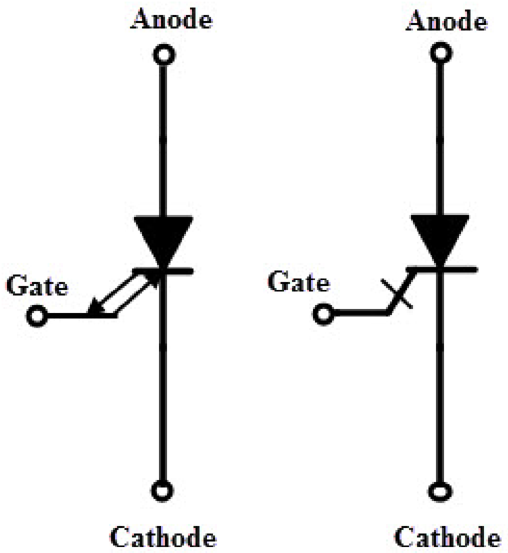
- SCR (Silicon Controlled Rectifier)
- TRIAC, DIAC
- GTO (Gate Turn-Off Tyhristor)

GTOs



Gate Turn-Off Thyristor Symbols

GTOs

4500 V, 3000 A GTO

- Used at very high power levels

GTOs

- Fully contrallable switch
- Can be turned-on and turned-off
- Turn-on achieved by positive current pulse
- Turn-off achieved by negative current pulse

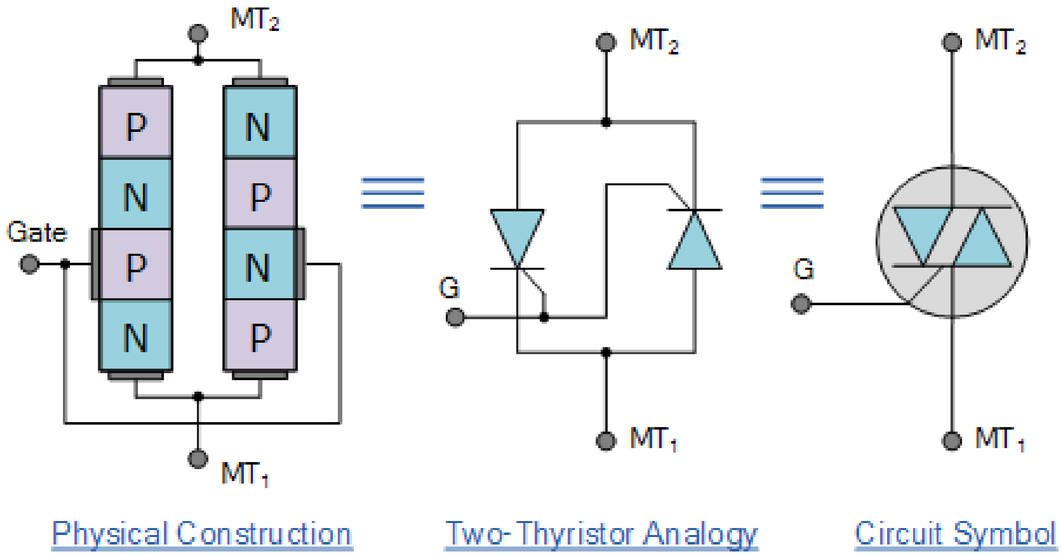
Types of Thyristors

TRIAC

- Bi-directional device
- TRIACs can be triggered by positive or negative current

Types of Thyristors

TRIAC: Two anti-parallel thyristors



Datasheet Exercise

- 50 A - 1200 V automotive grade SCR Thyristor

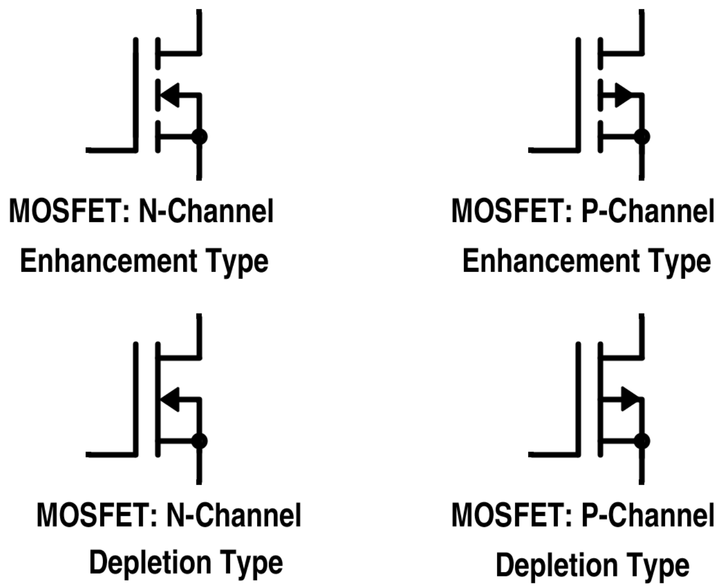
MOSFET

MOSFET

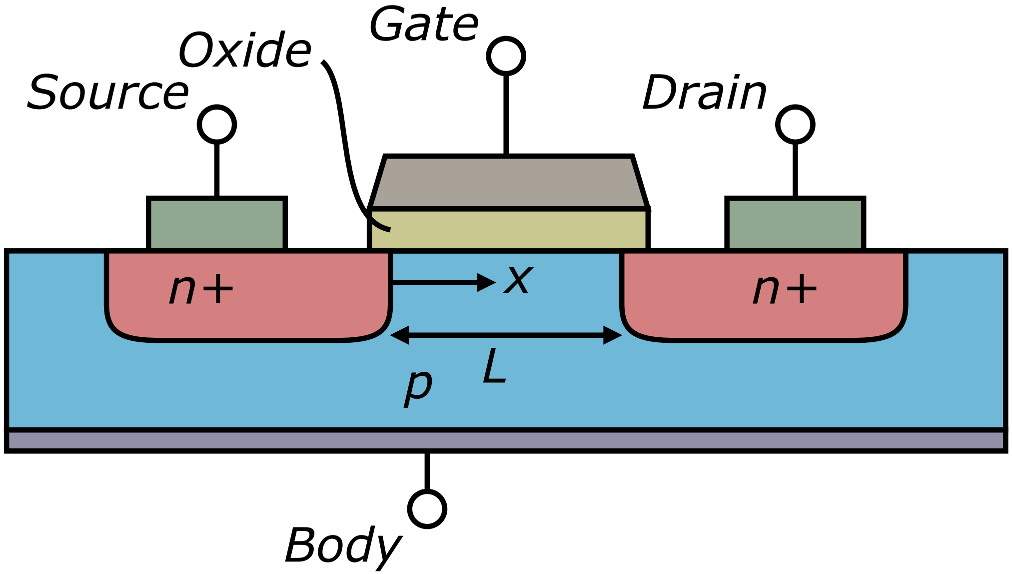
Metal-Oxide Semiconductor Field-Effect Transistor

MOSFET

Metal-Oxide Semiconductor Field-Effect Transistor

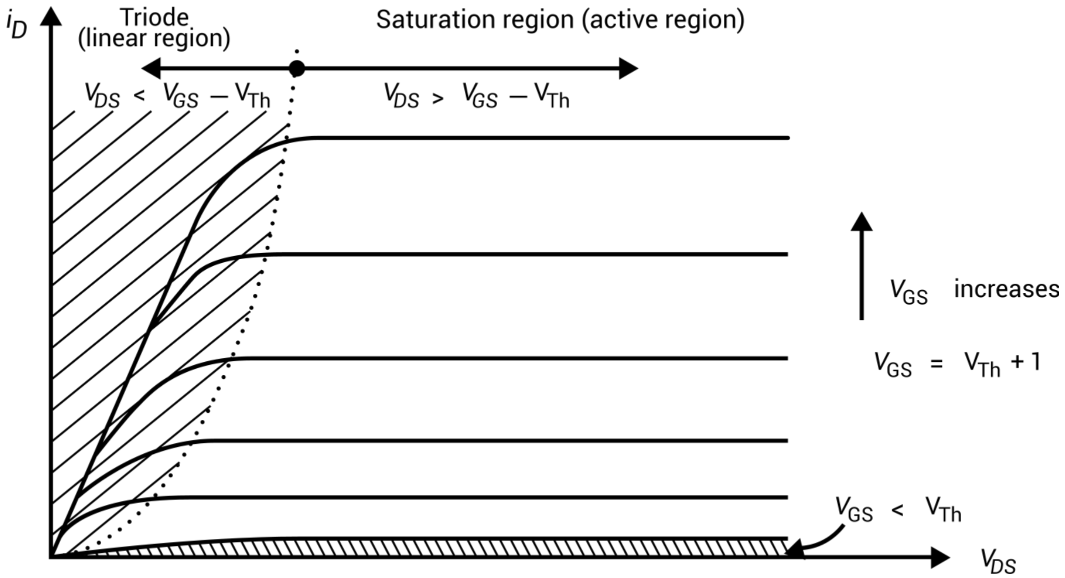


MOSFET



MOSFET

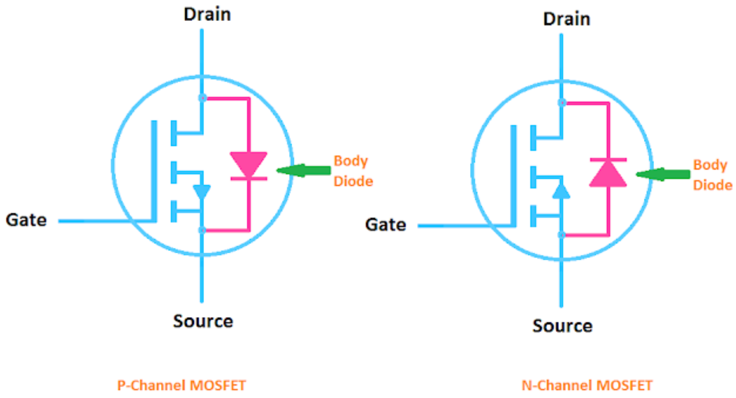
V-I Characteristics



To be discussed more in detail throughout the semester

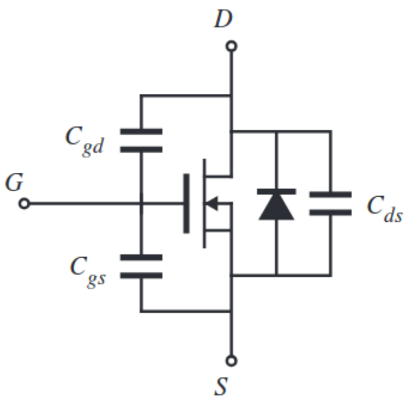
MOSFET

Body Diode



[Power MOSFET Basics]

Equivalent Circuit



Cgs: large, constant

Cgd: small, highly nonlinear

Cds: intermediate, nonlinear

MOSFET Comparison

Part number	*Rated max voltage*	*Rated avg current*	R_{on}	Q_g *(typical)*
IRFZ48	60V	50A	0.018Ω	110nC
IRF510	100V	5.6A	0.54Ω	8.3nC
IRF540	100V	28A	0.077Ω	72nC
APT10M25BNR	100V	75A	0.025Ω	171nC
IRF740	400V	10A	0.55Ω	63nC
MTM15N40E	400V	15A	0.3Ω	110nC
APT5025BN	500V	23A	0.25Ω	83nC
APT1001RBNR	1000V	11A	1.0Ω	150nC

MOSFET

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- Fast device (ten to hundreds kHz)

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MOSFET

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- Easy to drive
- Blocking voltage is usually <500 V
- Positive Temperature coefficient (easy to parallel)
- Body diode can conduct the full rated current (but usually slow)
- Switching time determined by charging/discharging gate capacitors

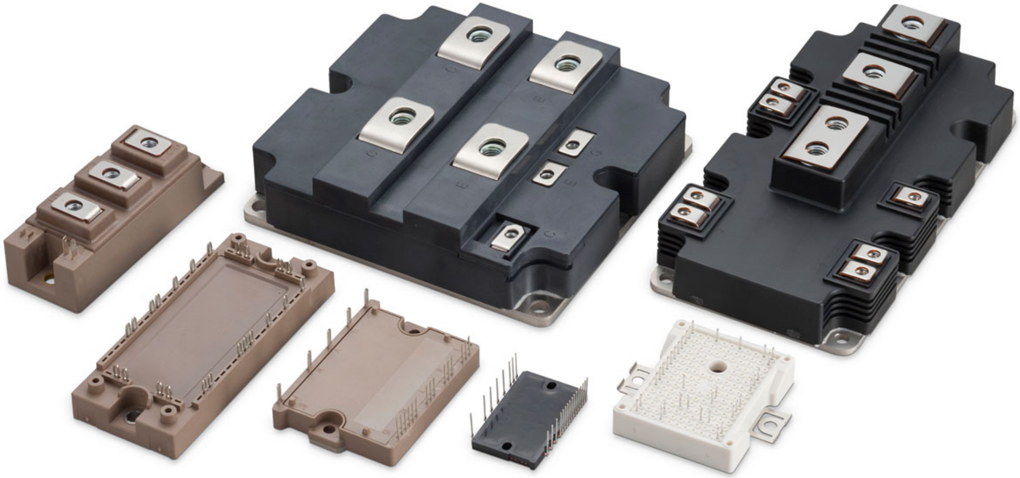
IGBT

IGBT

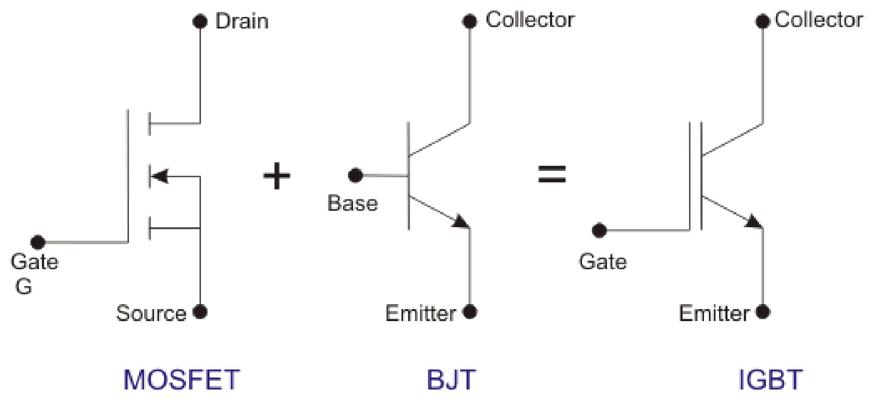
Insulated-Gate Bipolar Transistor

IGBT

Insulated-Gate Bipolar Transistor



IGBT



[IGBT]

[IGBT, when to use them?]

[IGBT or MOSFET?]

IGBT

IGBT

- Slower compared to MOSFET (<20-30kHz)

IGBT

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- Lower on-resistance

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- Can withstand higher voltages (upto 1700V)

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- Slower compared to MOSFET (<20-30kHz)
- Lower on-resistance
- Can withstand higher voltages (upto 1700V)
- Possible to parallel for new generations
- Probably best choice for 500-1700V, kWs of applications

IGBT Comparison

Part number	*Rated max voltage*	*Rated avg current*	V_F *(typical)*	t_f *(typical)*
Single-chip devices				
HGTG32N60E2	600V	32A	2.4V	0.62μs
HGTG30N120D2	1200V	30A	3.2A	0.58μs
Multiple-chip power modules				
CM400HA-12E	600V	400A	2.7V	0.3μs
CM300HA-24E	1200V	300A	2.7V	0.3μs

To be discussed more in detail throughout the semester

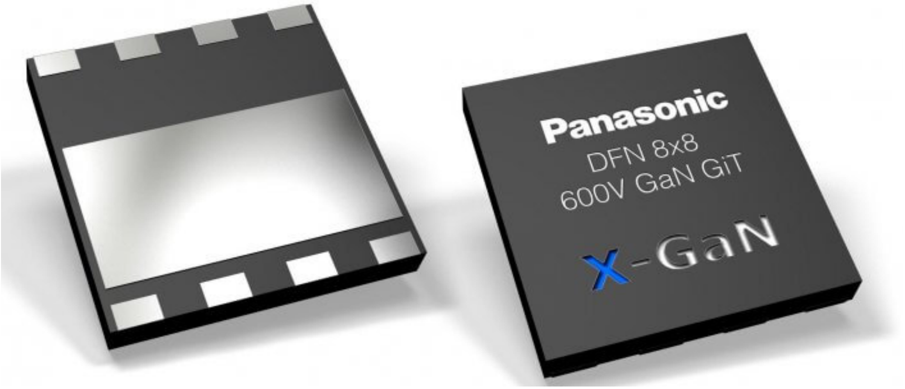
Data-Sheet Exercise

- IGBT, H series 1200 V, 40 A high speed

Some New Transistor Technologies

Some New Transistor Technologies

GaN



[Advancing power supply solutions through the promise of GaN]

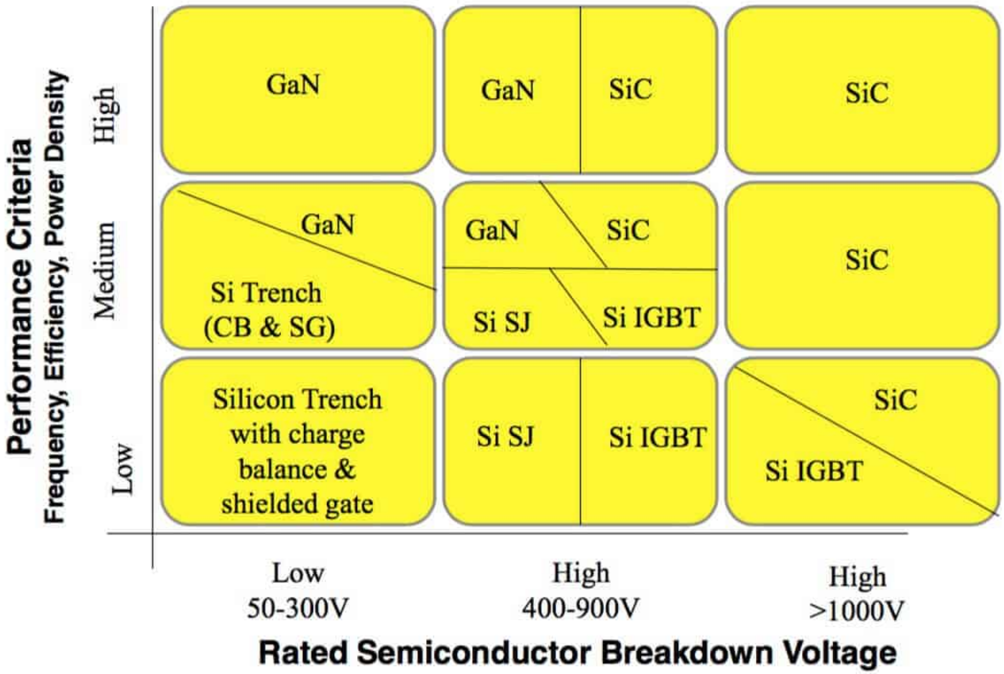
[Power GaN Opens New Applications]

Some New Transistor Technologies

SiC

Next Generation Power Semiconductors: What is GaN / SiC?

Some New Transistor Technologies



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