Power Electronics

Chapter 2

Power Electronic Devices

Power Electronics

Outline

Power Electronics

2.1 An introductory overview of power electronic devices

- The concept and features
- Configuration of systems using power electronic devices
- Classifications
- Major topics

The concept of power electronic devices

- Power electronic devices:

  are the electronic devices that can be directly used in the power processing circuits to convert or control electric power.

- In broad sense

  power electronic devices
  - Vacuum devices: Mercury arc rectifier thyratron, etc. . seldom in use today
  - Semiconductor devices: major power electronic devices since late 1950s

- Very often: Power electronic devices = Power semiconductor devices

- Major material used in power semiconductor devices

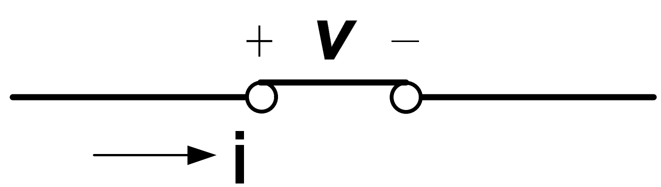
  —— Silicon

Features of power electronic devices

- The electric power that power electronic device deals with is usually much larger than that the information electronic device does.
- Usually working in switching states to reduce power losses

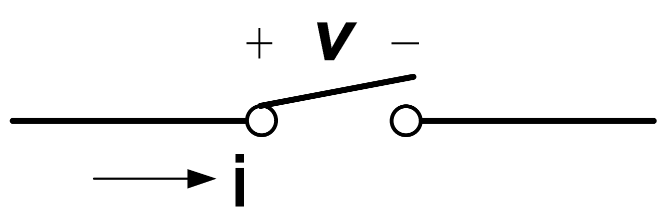
On-state → Voltage across the device is 0 → p=vi=0

v=0



Off-state → Current through the device is 0 → p=vi=0

i=0

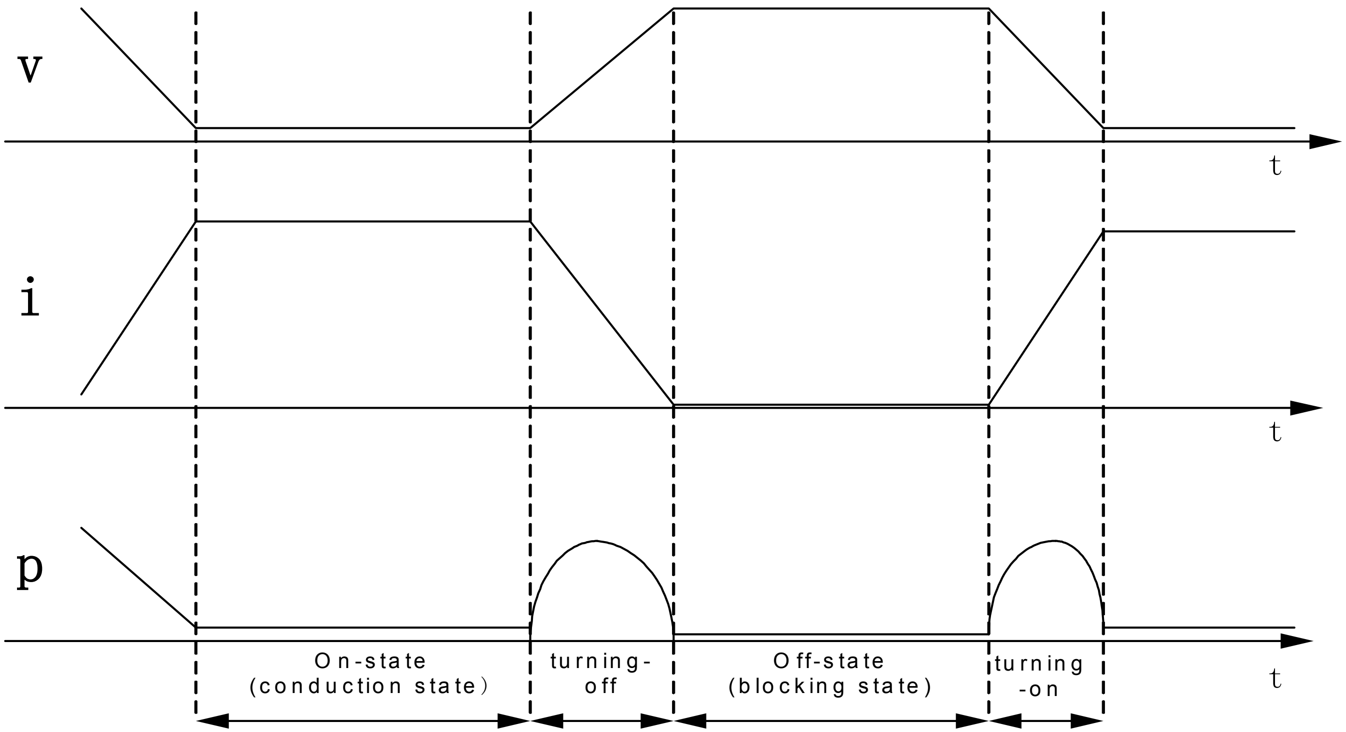


Features of power electronic devices

- Need to be controlled by information electronic circuits. Very often, drive circuits are necessary to interface between information circuits and power circuits.

- Dissipated power loss usually larger than information electronic devices — special packaging and heat sink are necessary.

Power losses on power semiconductor devices



Total power loss on a power semiconductor device = conduction loss + turn-off loss + off-state loss + turn-on loss

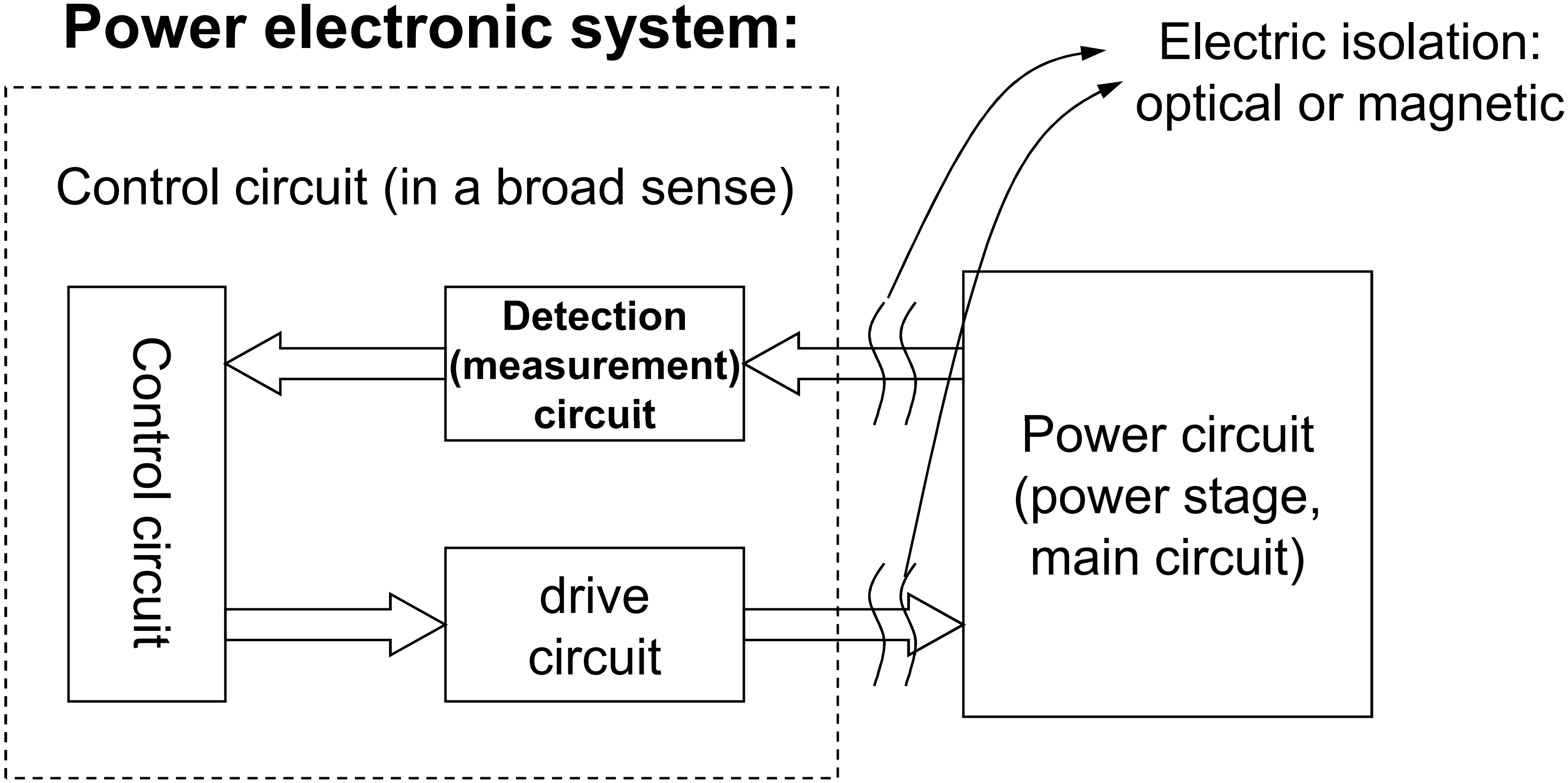
(on-state loss)

(usually very small and can be neglected)

Switching loss

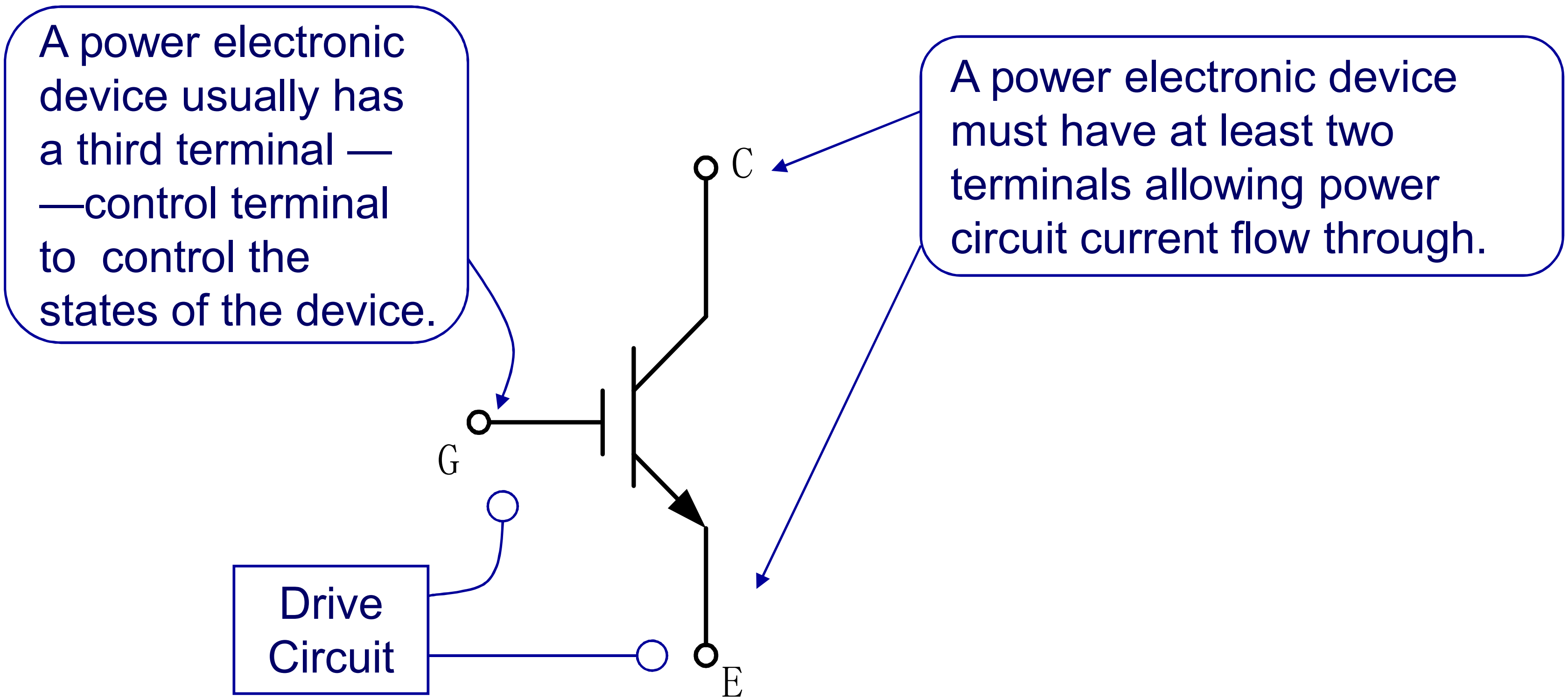
Configuration of systems using power electronic devices

Power electronic system:



- Protection circuit is also very often used in power electronic system especially for the expensive power semiconductors.

Terminals of a power electronic device



- The control signal from drive circuit must be connected between the control terminal and a fixed power circuit terminal (therefore called common terminal).

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A classification of power electronic devices

- Uncontrolled device: diode
  (Uncontrollable device)
  has only two terminals and can not be controlled by control signal. The on and off states of the device are determined by the power circuit.

- Half-controlled device: thyristor
  (Half-controllable device)
  is turned-on by a control signal and turned-off by the power circuit

- Fully-controlled device: Power MOSFET, IGBT,GTO, IGCT (Fully-controllable device)
  The on and off states of the device are controlled by control signals.

Other classifications

power electronic devices
- Current-driven (current-controlled) devices
- Voltage-driven (voltage-controlled) devices (Field-controlled devices)

power electronic devices
- Pulse-triggered devices
- Level-sensitive (level-triggered) devices

power electronic devices
- Unipolar devices (Majority carrier devices)
- Bipolar devices (Minority carrier devices)
- Composite devices

Major topics for each device

- Appearance, structure, and symbol
- Physics of operation
- Characteristics
  - Static characteristics
  - Switching characteristics (Dynamic characteristics)
- Specification
- Special issues
- Devices of the same family

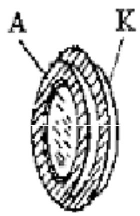
Passive components in power electronic circuit

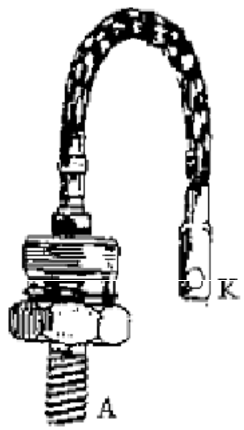
- Transformer, inductor, capacitor and resistor
  These are called passive components in a power electronic circuit since they can not be controlled by control signal and their characteristics are usually constant and linear.

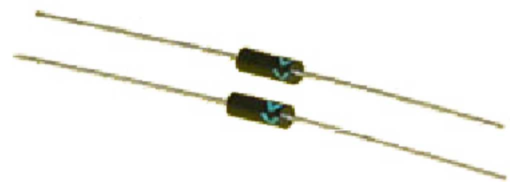
- The requirements for these passive components by power electronic circuits could be very different from those by ordinary circuits.

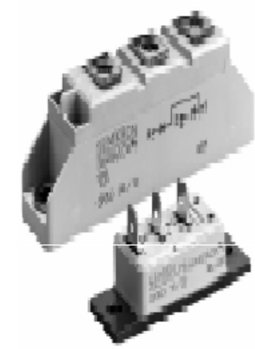
2.2 Uncontrolled device —Power diode

Appearance

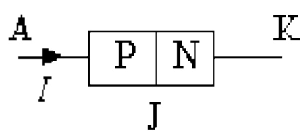






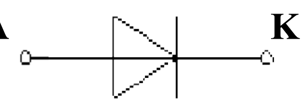


Structure

Anode 

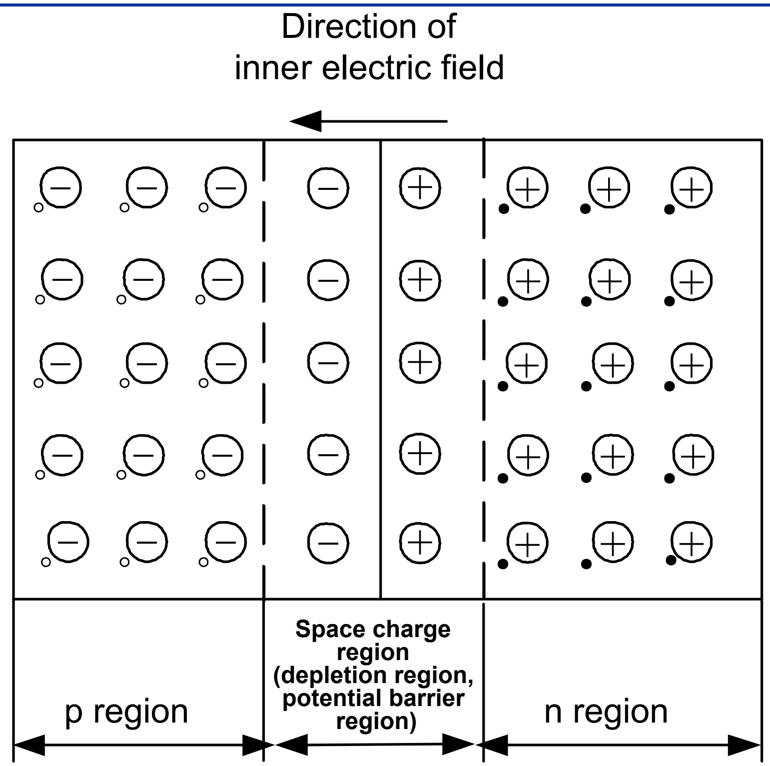
Cathode

Symbol

Anode 

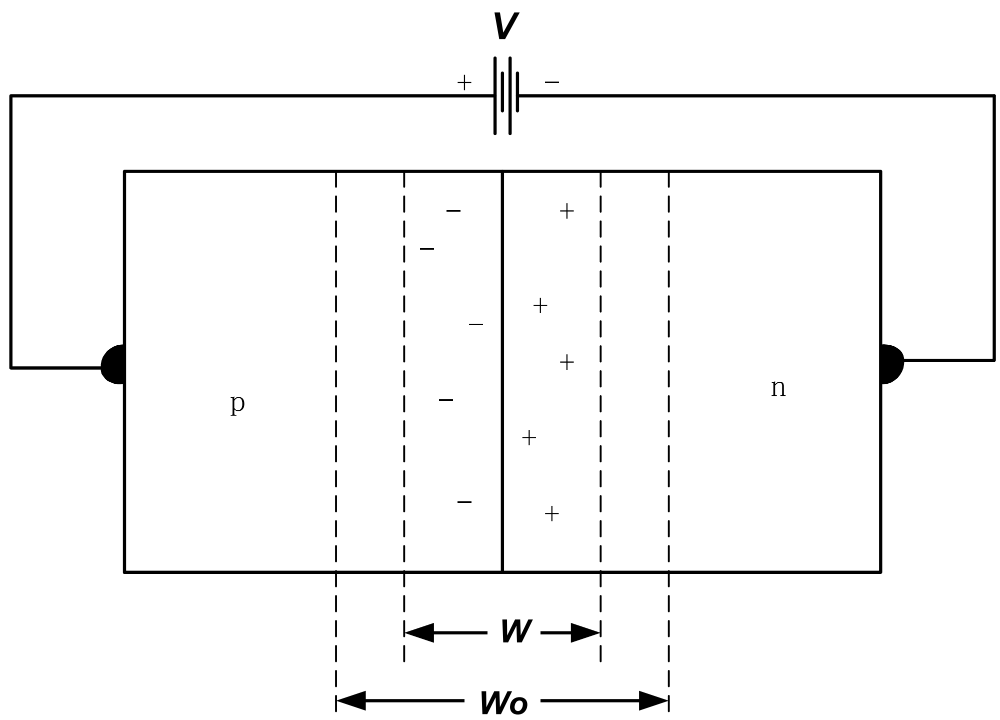
Cathode

PN junction

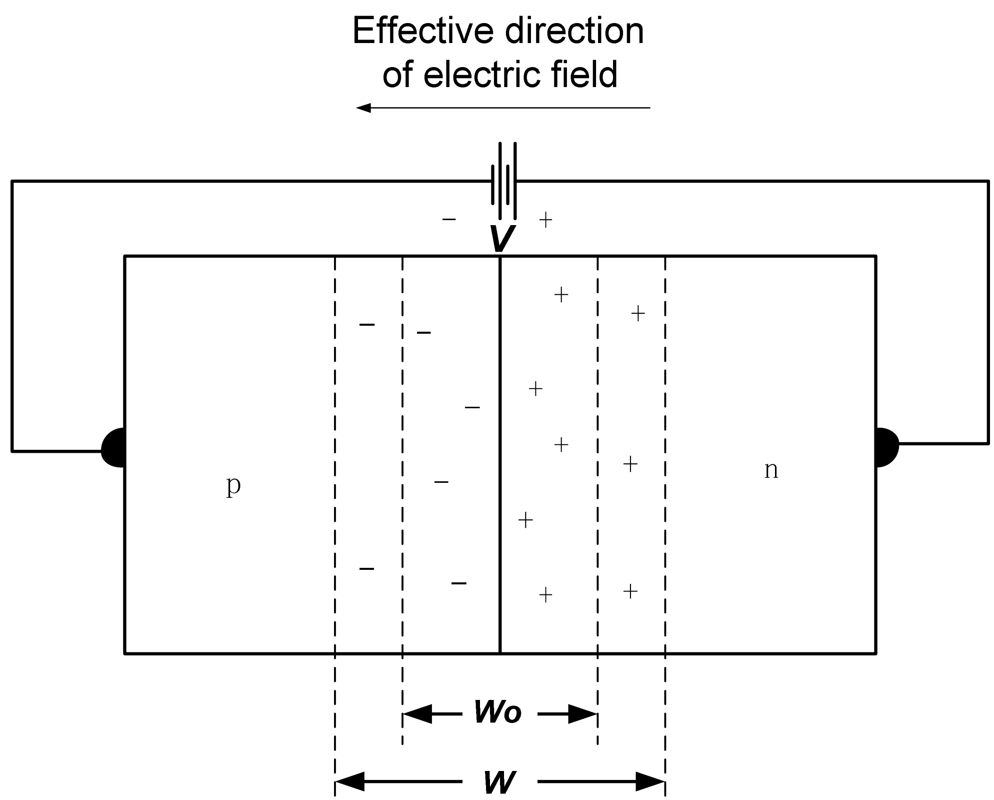


- Semiconductor (Column IV element, Si)
- Electrons and holes
- Pure semiconductor (intrinsic semiconductor)
- Doping, P-type semiconductor. N-type semiconductor
- PN junction
- Equilibrium of diffusion and drift

PN junction with voltage applied in the forward direction



PN junction with voltage applied in the reverse direction



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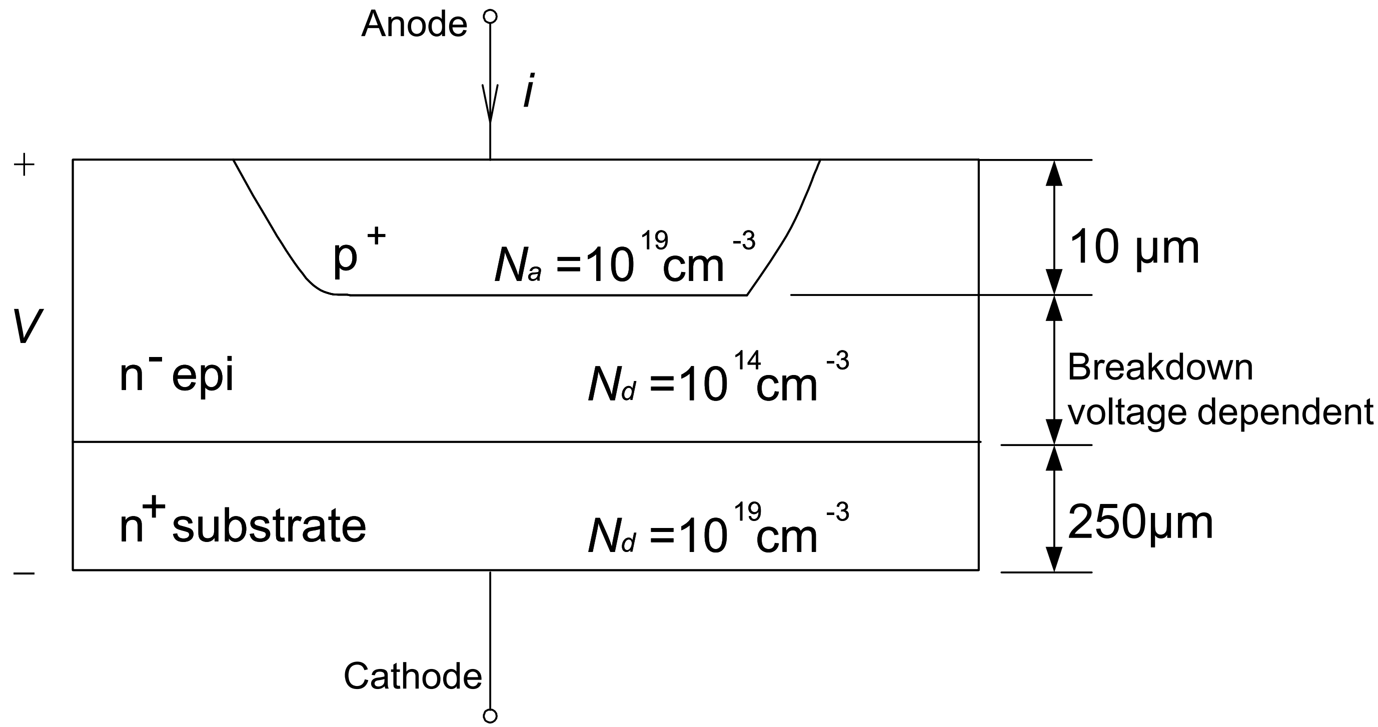
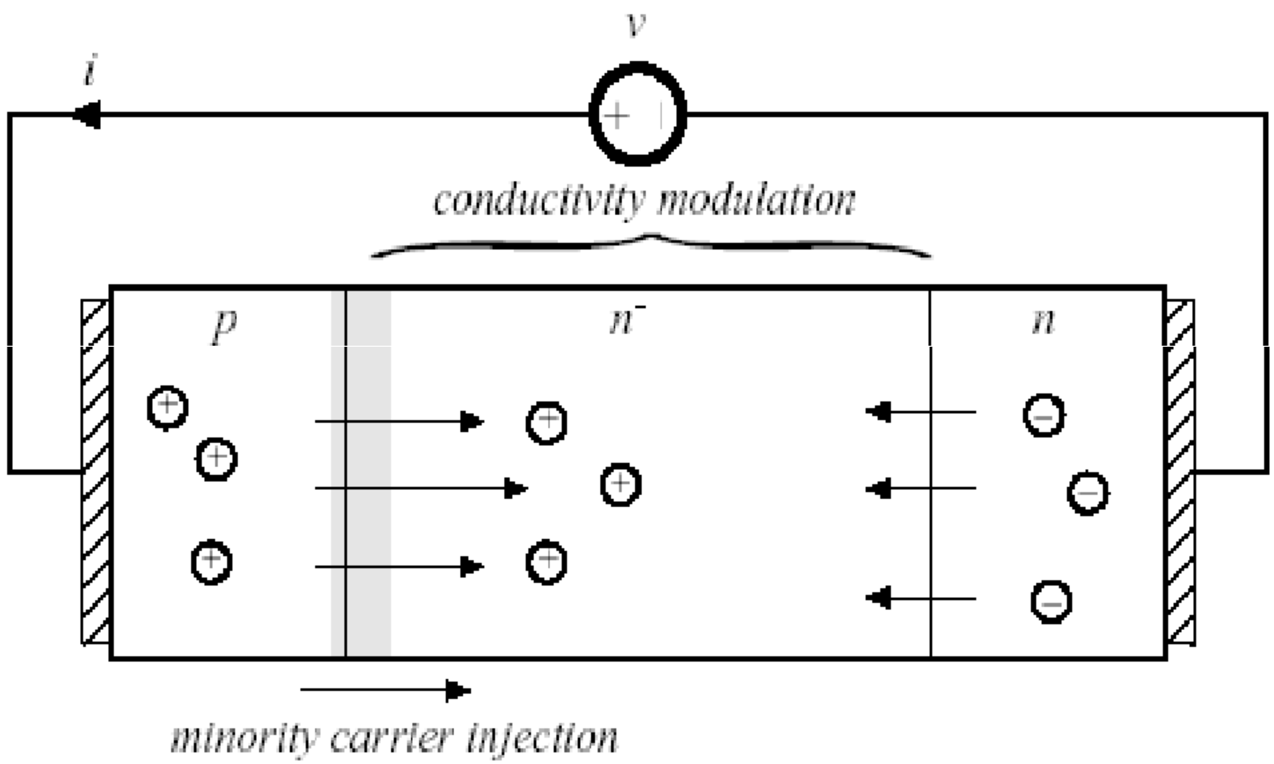
Construction of a practical power diode



- Features different from low-power (information electronic) diodes
  - Larger size
  - Vertically oriented structure
  - n^- drift region (p-i-n diode)
  - Conductivity modulation

Forward-biased power diode



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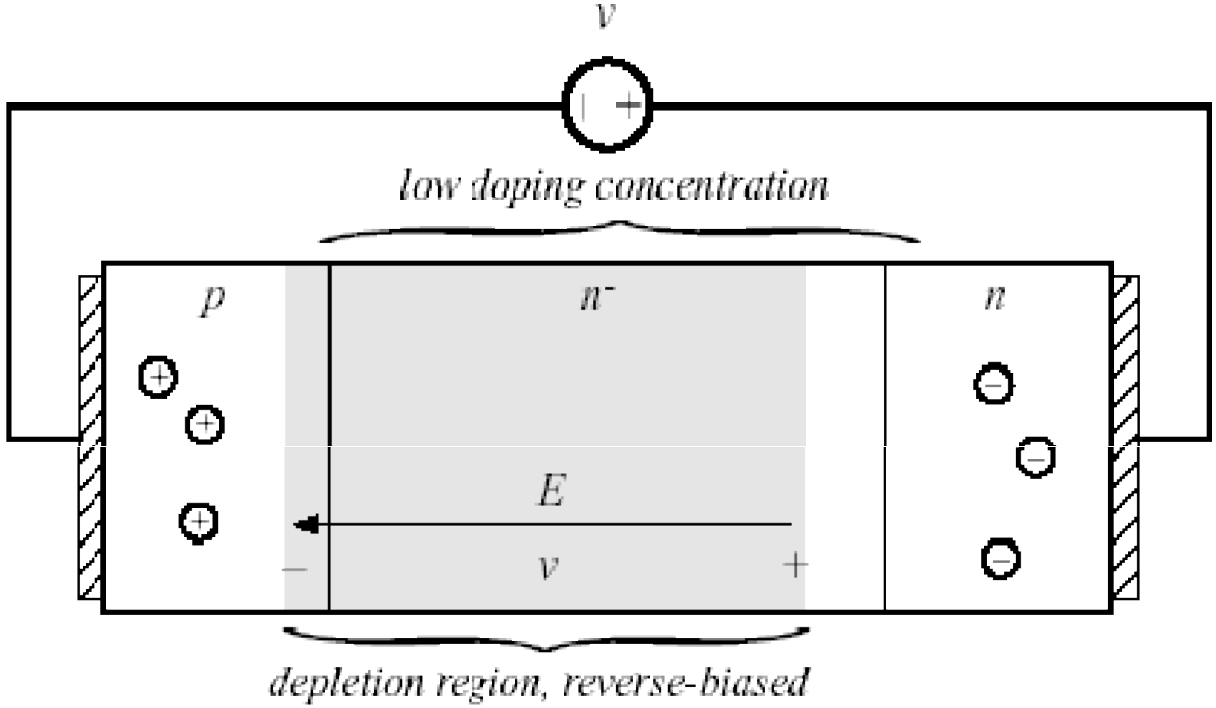
Reverse-biased power diode



- Breakdown
  - Avalanche breakdown
  - Thermal breakdown

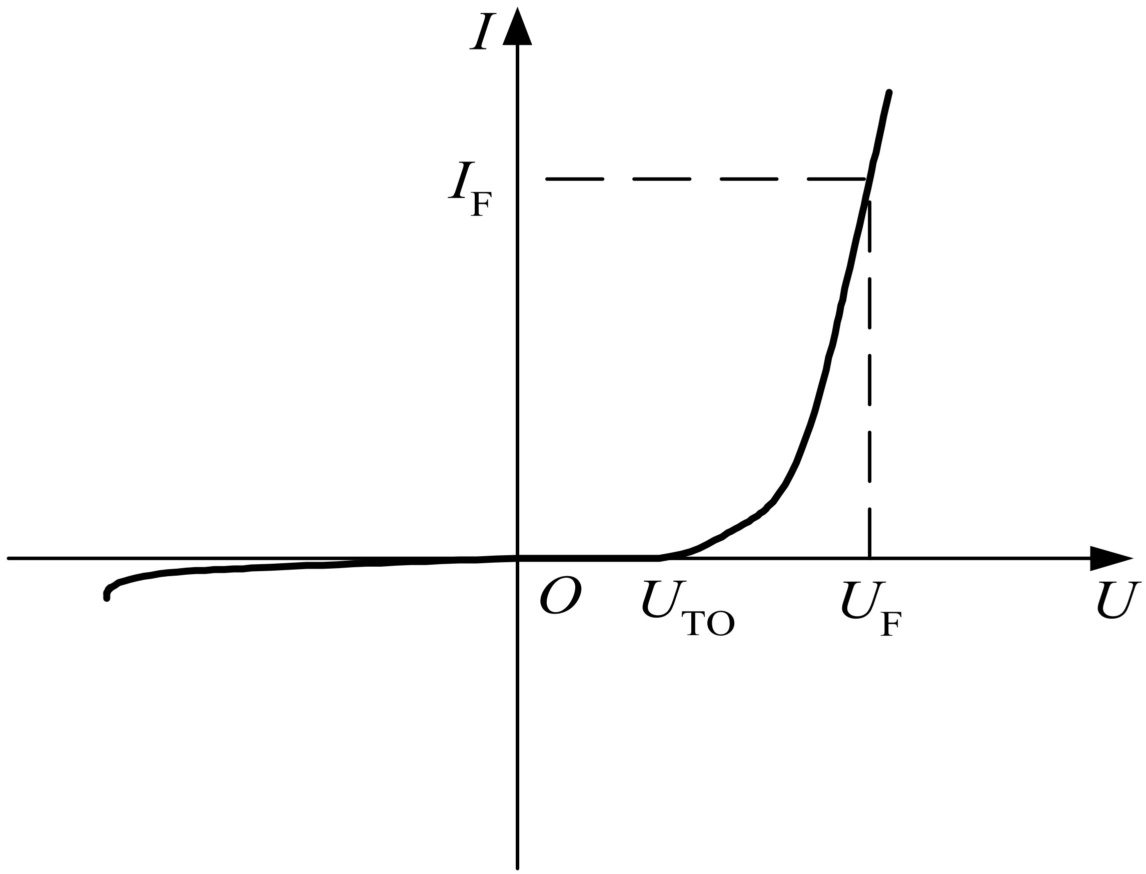
Junction capacitor

- The positive and negative charge in the depletion region is variable with the changing of external voltage.
  ——Junction capacitor C_J .

- Junction capacitor C_J
  - Potential barrier capacitor C_B
  - Diffusion capacitor C_D

- Junction capacitor influences the switching characteristics of power diode.

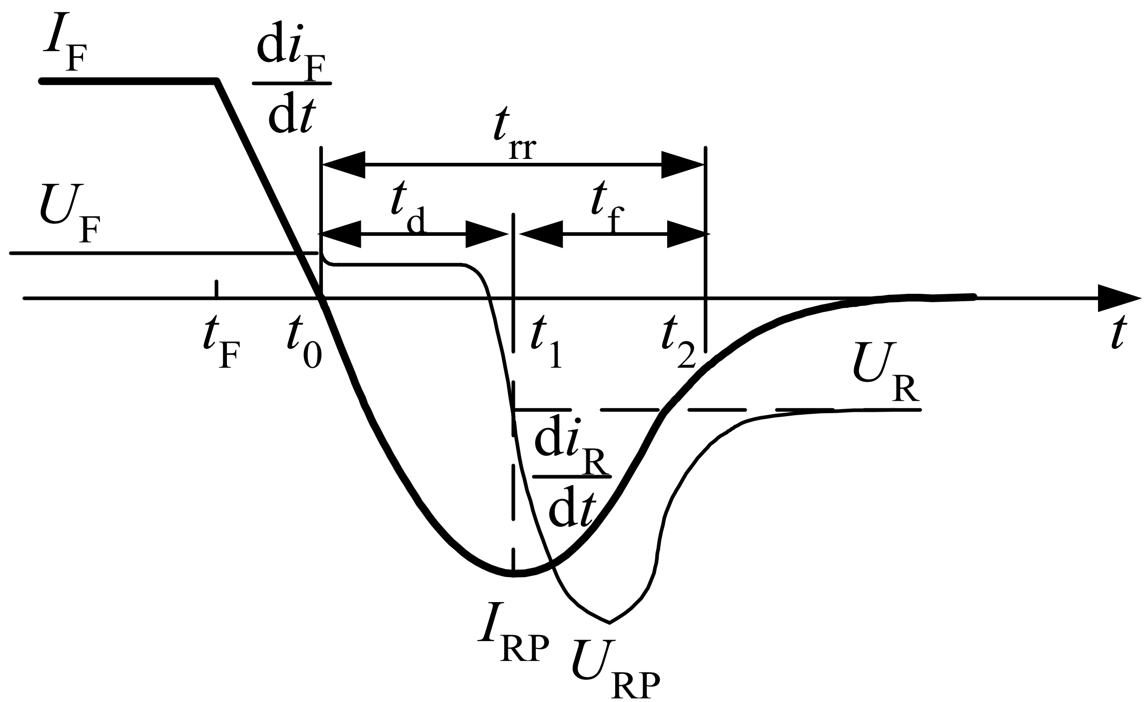
Static characteristics of power diode



The I-V characteristics of power diode

Switching (dynamic) characteristics of power diode

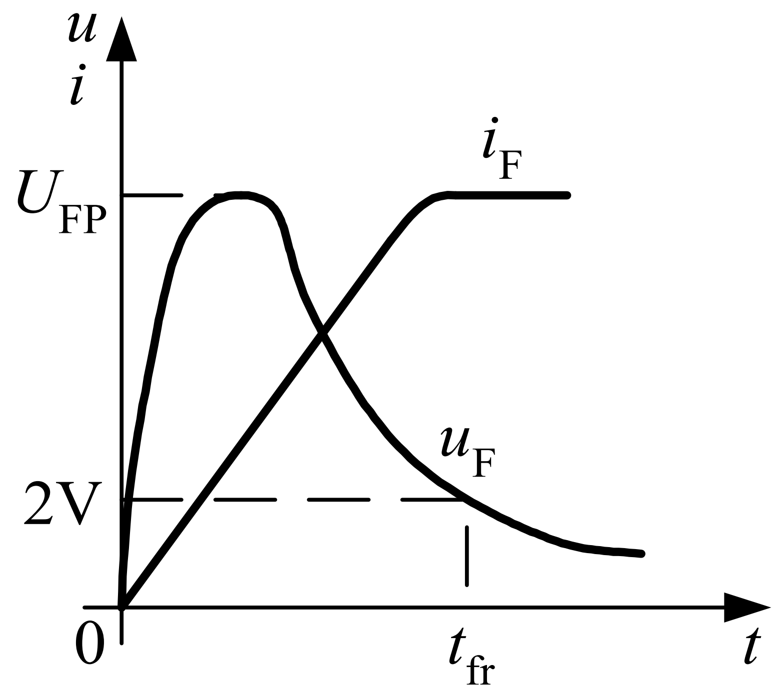
Turn-off transient



- Reverse-recovery process:
  Reverse-recovery time, reverse-recovery charge, reverse-recovery peak current.

Switching (dynamic) characteristics of power diode

Turn-on transient



- Forward recovery process:
  forward-recovery time

Specifications of power diode

- Average rectified forward current $I_{F(AV)}$
- Forward voltage U_F
- Peak repetitive reverse voltage U_{RRM}
- Maximum junction temperature T_{JM}
- Reverse-recovery time t_{rr}

Types of power diodes

- General purpose diode (rectifier diode):
  standard recovery

- Fast recovery diode
  Reverse recovery time and charge specified. t_{rr} is usually less than 1μs, for many less than 100 ns —— ultra-fast recovery diode.

- Schottky diode (Schottky barrier diode-SBD)
  - A majority carrier device
  - Essentially no recovered charge, and lower forward voltage.
  - Restricted to low reverse voltage and blocking capability (less than 200V)

Examples of commercial 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	

History and applications of power diode

- Applied in industries starting 1950s
- Still in-use today. Usually working with controlled devices as necessary components
- In many circumstances fast recovery diodes or schottky diodes have to be used instead of general purpose diodes.

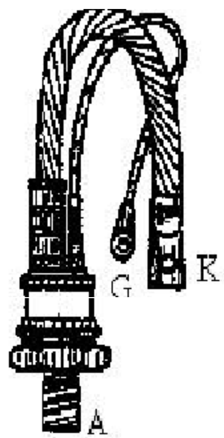
2.3 Half-controlled device—Thyristor

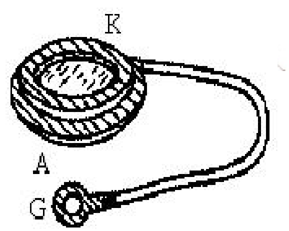
History

- Another name: SCR—silicon controlled rectifier
- Thyristor Opened the power electronics era
  – 1956, invention, Bell Laboratories
  – 1957, development of the 1st product, GE
  – 1958, 1st commercialized product, GE
  – Thyristor replaced vacuum devices in almost every power processing area.
- Still in use in very high power situation. Thyristor still has the highest power-handling capability.

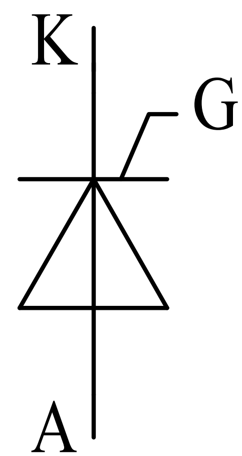
Appearance and symbol of thyristor

Appearance



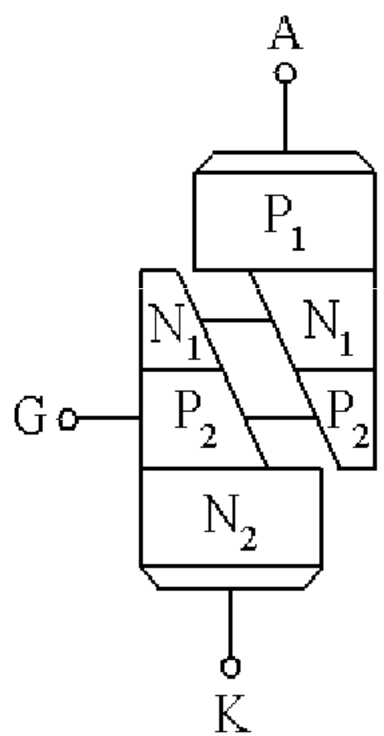


Symbol



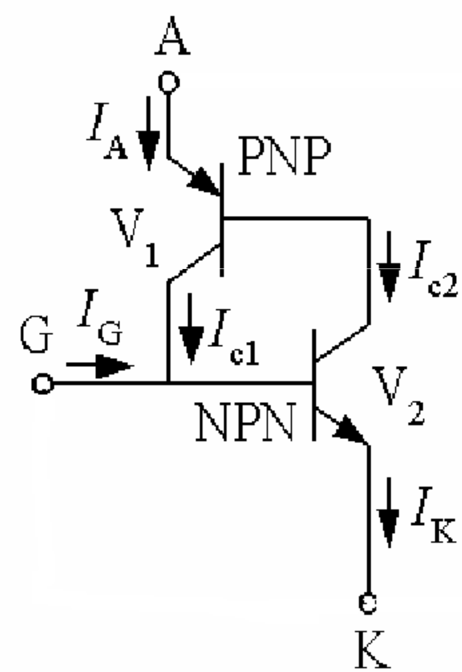
Structure and equivalent circuit of thyristor

- Structure



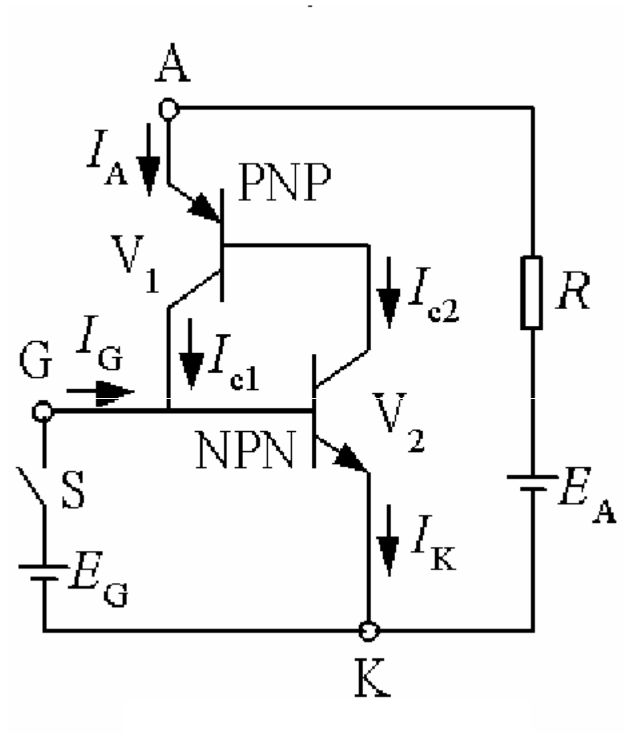
a)

- Equivalent circuit



b)

Physics of thyristor operation



- Equivalent circuit: A pnp transistor and an npn transistor interconnected together.
- Positive feedback
- Trigger
- Can not be turned off by control signal
- Half-controllable

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Quantitative description of thyristor operation

$$I_{c1}=\alpha_1 I_A + I_{CBO1} \qquad (2\text{-}1)$$

$$I_{c2}=\alpha_2 I_K + I_{CBO2} \qquad (2\text{-}2)$$

$$I_K=I_A+I_G \qquad (2\text{-}3)$$

$$I_A=I_{c1}+I_{c2} \qquad (2\text{-}4)$$

$$I_A=\frac{\alpha_2 I_G+I_{CBO1}+I_{CBO2}}{1-(\alpha_1+\alpha_2)} \qquad (2\text{-}5)$$

When $I_G=0$, $\alpha_1+\alpha_2$ is small.

When $I_G>0$, $\alpha_1+\alpha_2$ will approach 1, and I_A will be very large.