INTRODUCTION TO POWER ELECTRONICS

30.03.2021

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What is Power?

- Electric Power= Voltage X Current
- Units are Watts

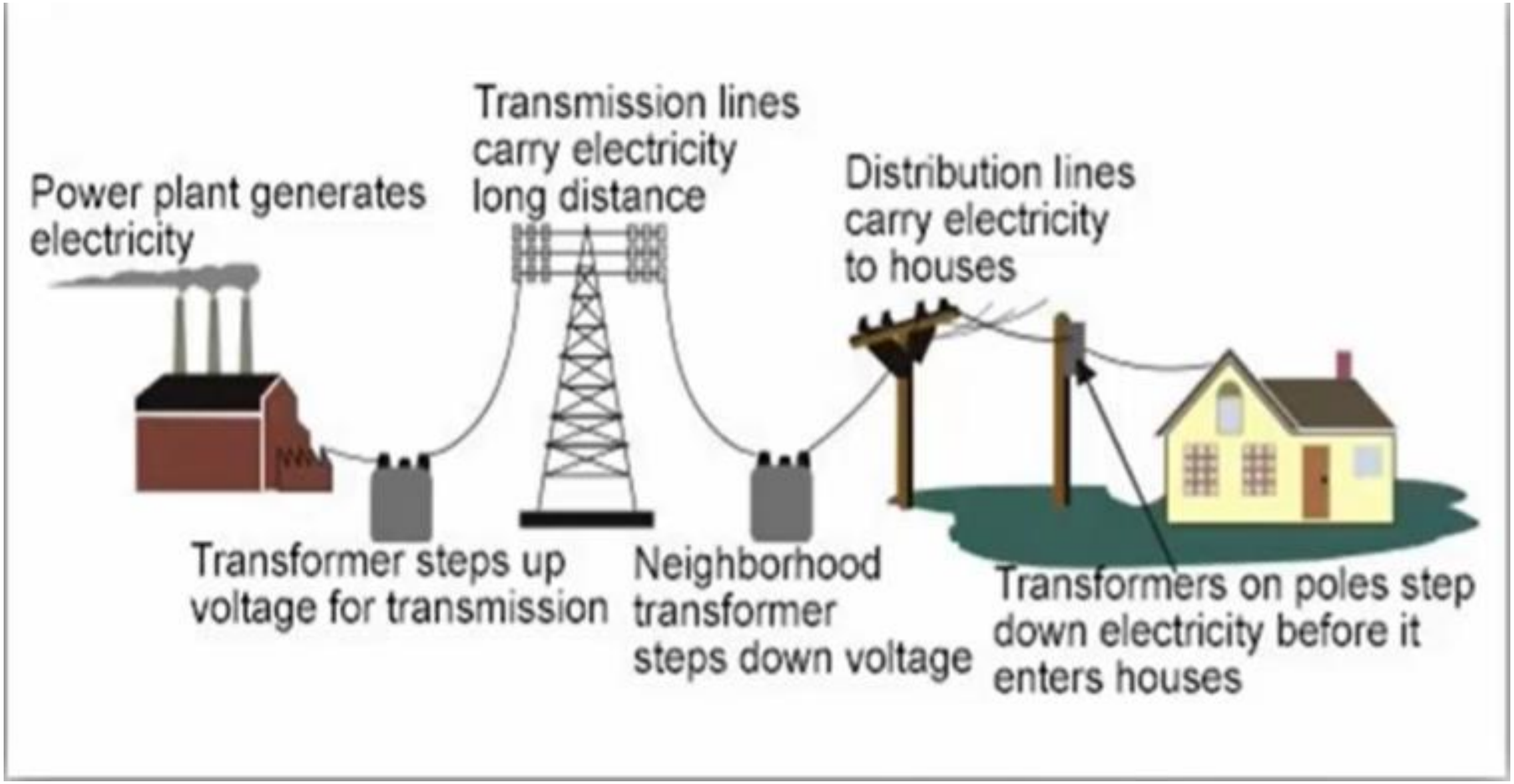
What is Energy?

- Energy = Power X Time
- Units are Watt-Hours or kWhr

Power Electronics – Where is it Used?

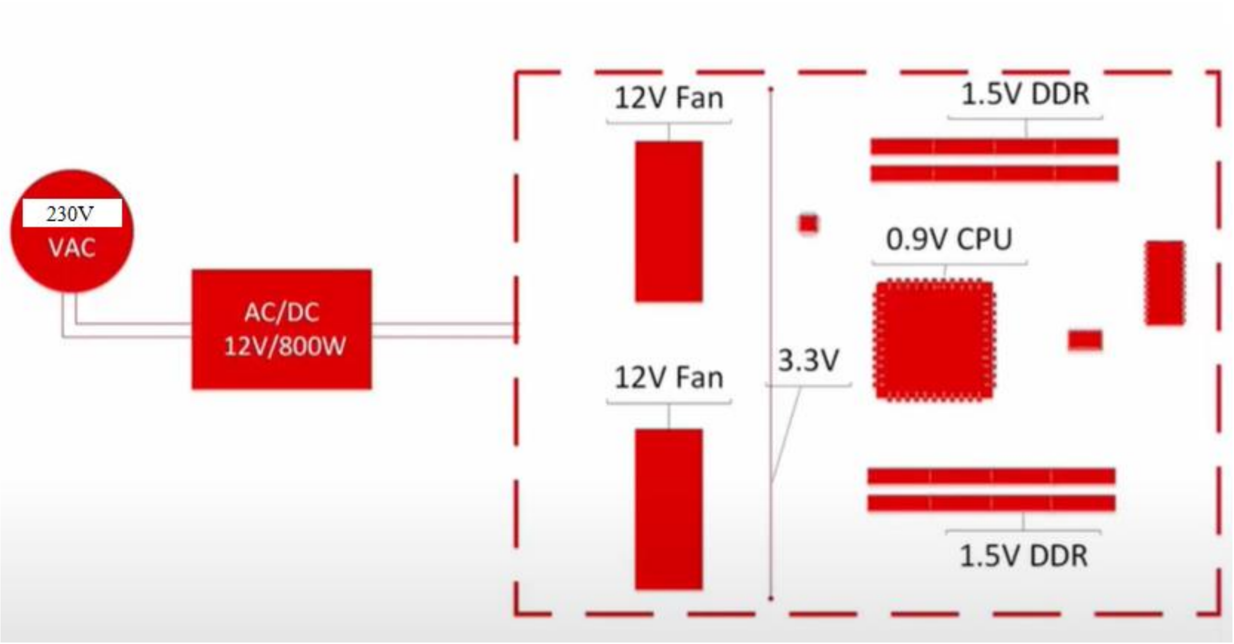
- Electrical power is used to support the activity of Loads
  - Electric Motors
  - Speakers
  - Microcontrollers
  - FPGAs
  - DSPs
  - Sensors
  - Displays
  - Analog Circuitry

From where do we get Power?



- Power Loss = I^2R
- Thus, HV Transmission lines are used for distribution
- Step-up for distribution and Step–down to be used at safer levels

Power Distribution at Micro-Level



- “Point of Load” Conversion

What is Power Electronics?

- Power electronics circuits convert electric power from one form to another using electronic devices.
- Power electronics circuits function by using semiconductor devices as switches, thereby controlling or modifying a voltage or current.

Applications

- High-power conversion equipment such as dc power transmission to everyday appliances, such as cordless screwdrivers, power supplies for computers, cell phone chargers, and hybrid automobiles.
- Power electronics includes applications in which circuits process milliwatts or megawatts.

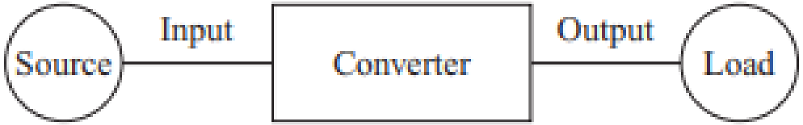
POWER ELECTRONICS BASIC CONCEPTS

Lecture 2

6.04.2020

Power Converters

- ac-dc
- dc-dc
- dc-ac
- ac-ac

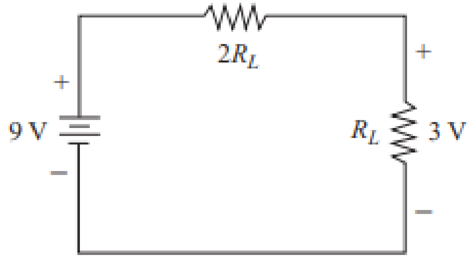


A source and load interfaced by a power electronics converter.

POWER ELECTRONICS CONCEPTS

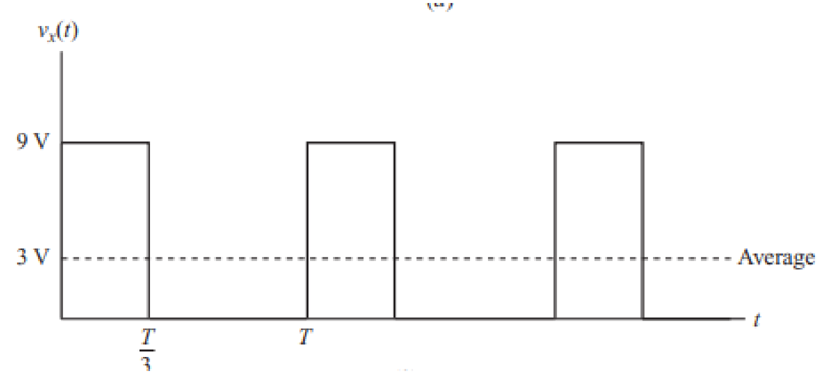
Problem: 9V to 3V Converter

- A simple voltage divider



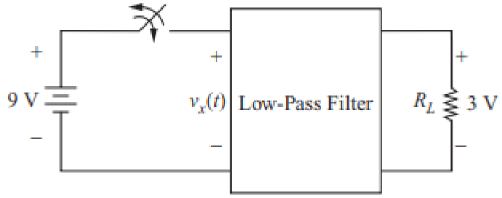
- A switched Circuit

(a)



Average value is computed from the equation

$$\mathrm{avg}(v_x) = V_x = \frac{1}{T}\int_0^T v_x(t)\,dt = \frac{1}{T}\int_0^{T/3} 9\,dt + \frac{1}{T}\int_{T/3}^{T} 0\,dt = 3\text{ V}$$



ELECTRONIC SWITCHES

- Diode
- BJT
- MOSFET
- SCR
- Thyristor
- IGBJT

POWER FACTOR

Lecture 3

08.04.021

Outline

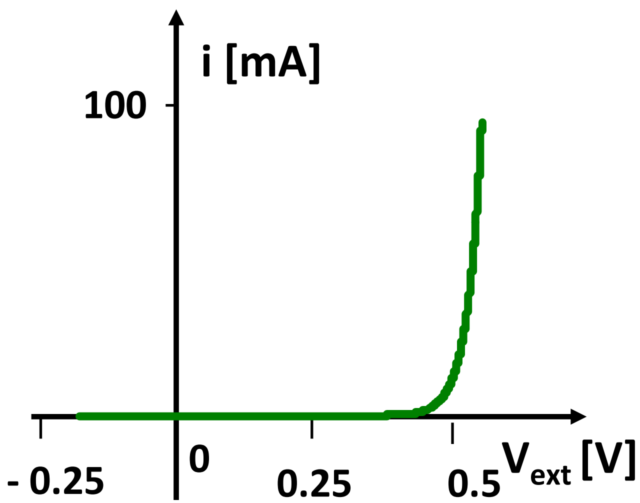
- The main topics to be addressed in this lesson are the following:
  - **Review of diode operation.**
  - **Power diode packages.**
  - **Internal structure of PN and Schottky power diodes.**
  - **Static characteristic of power diodes.**
  - **Dynamic characteristic of power diodes.**
  - **Losses in power diodes.**

Review of PN-diode operation (I)

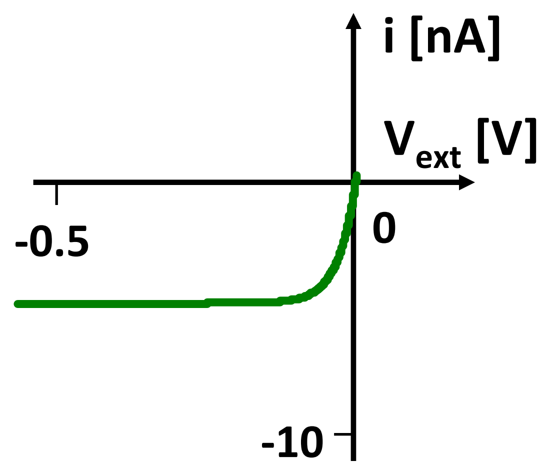
•**Reverse bias and moderate forward bias are properly described by the following equation (by Shockley):**

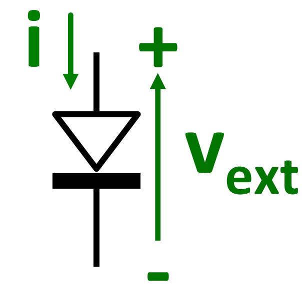
$i = I_S \cdot (e^{V_{ext}/V_T} - 1)$, where $V_T = kT/q$ and I_s is the **reverse-bias saturation current** (a very small value).

$$i \approx I_S \cdot e^{\frac{V_{ext}}{V_T}}$$ (exponential)



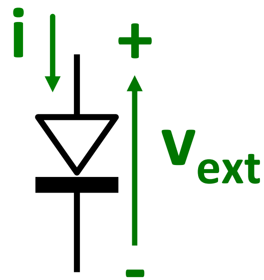
$$i \approx -I_S$$ (constant)

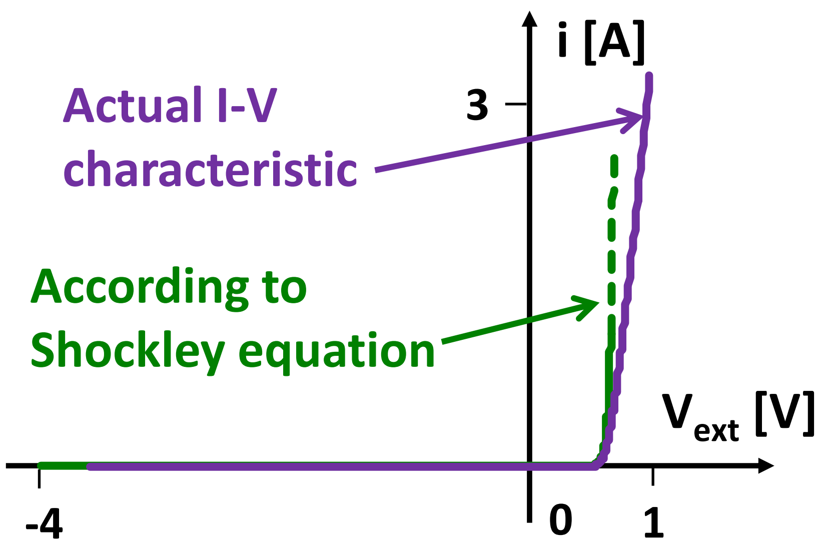


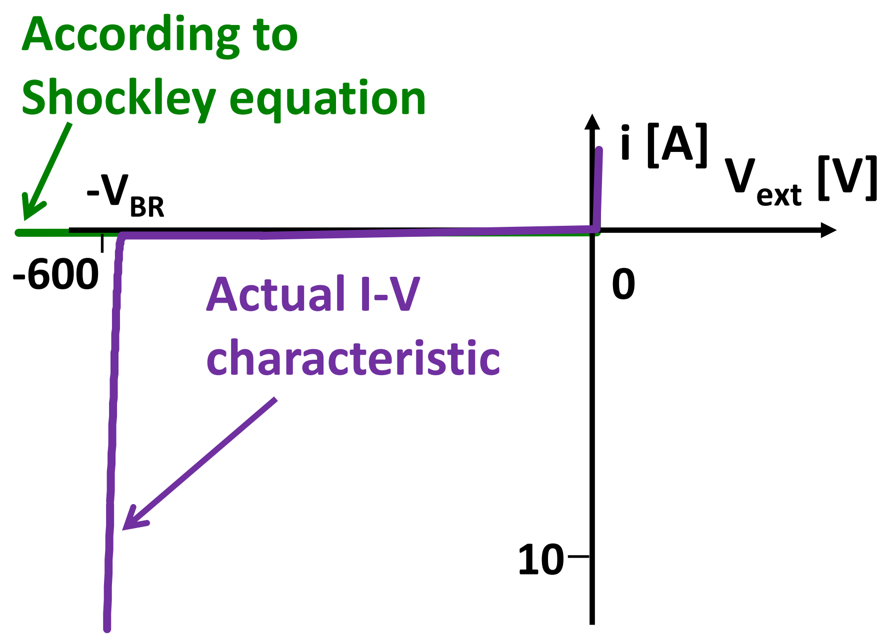


Review of PN-diode operation (II)

- When the diode has been heavily forward biased (high forward current), the voltage drop is proportional to the current (it behaves as a resistor).
- When the reverse voltage applied to a diode reaches the critical value V_{BR}, then the weak reverse current starts increasing a lot. The power dissipation usually becomes destructive for the device.

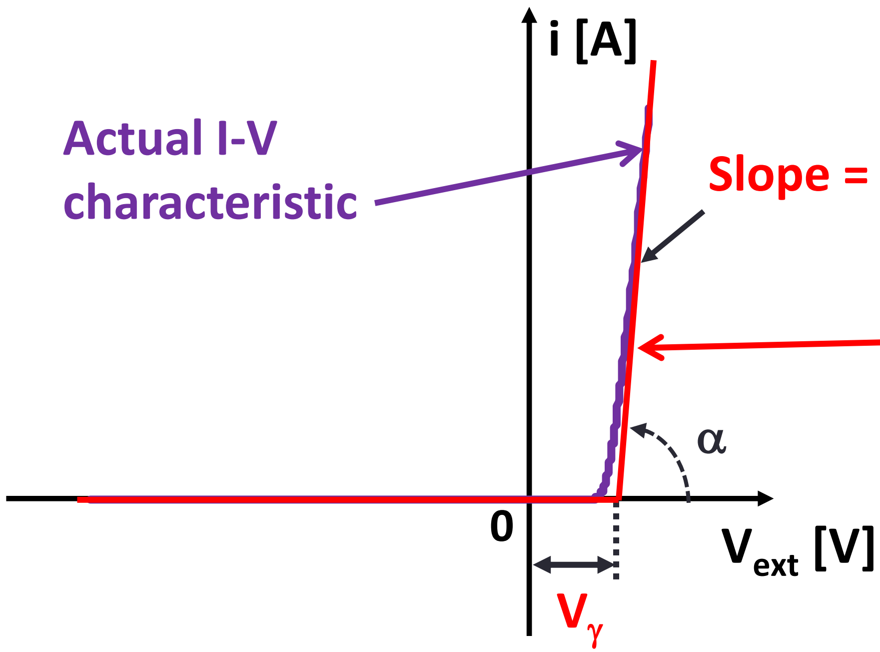


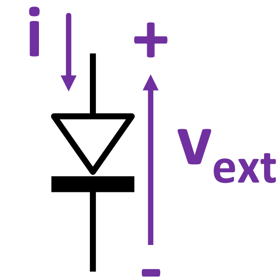




Review of PN-diode operation (III)

- **Static model for a diode (asymptotic):**

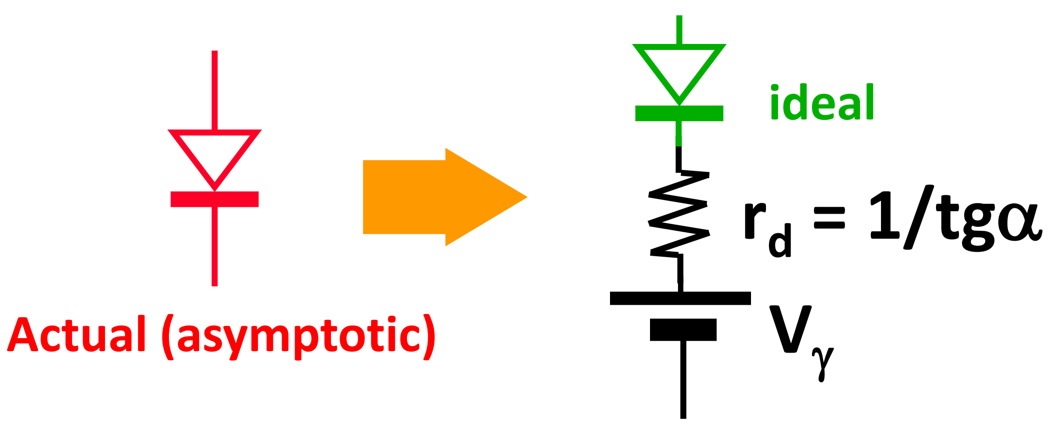




V_γ = Knee voltage

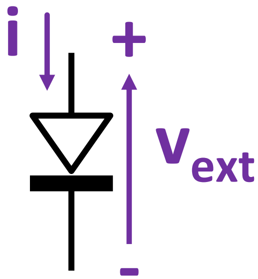
r_d = Dynamic resistance

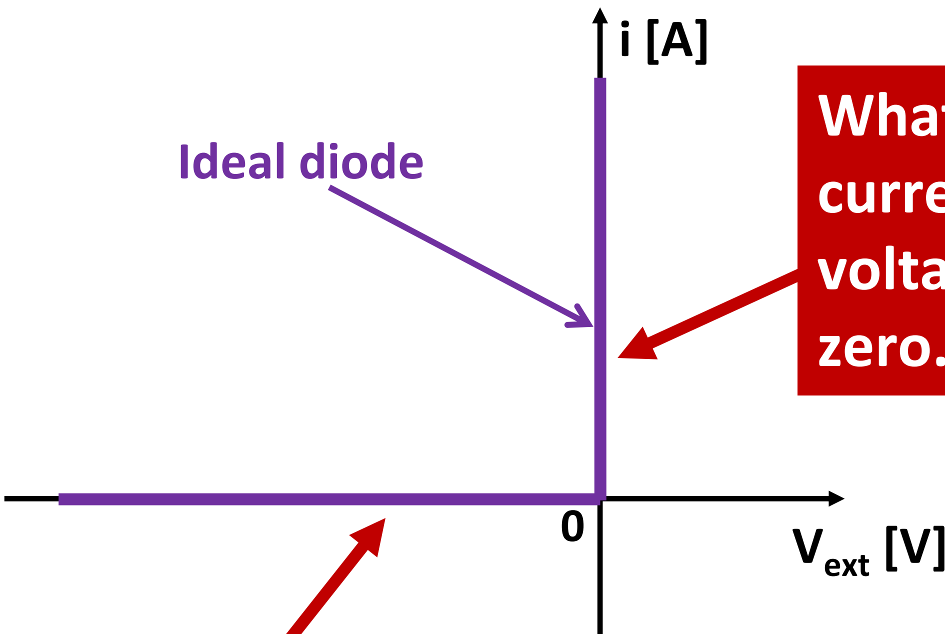
- **Equivalent circuit:**



Review of PN-diode operation (IV)

- **Ideal diode:**





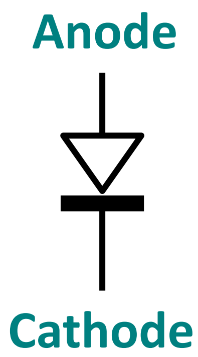
Whatever the forward current is, the forward voltage drop is always zero.

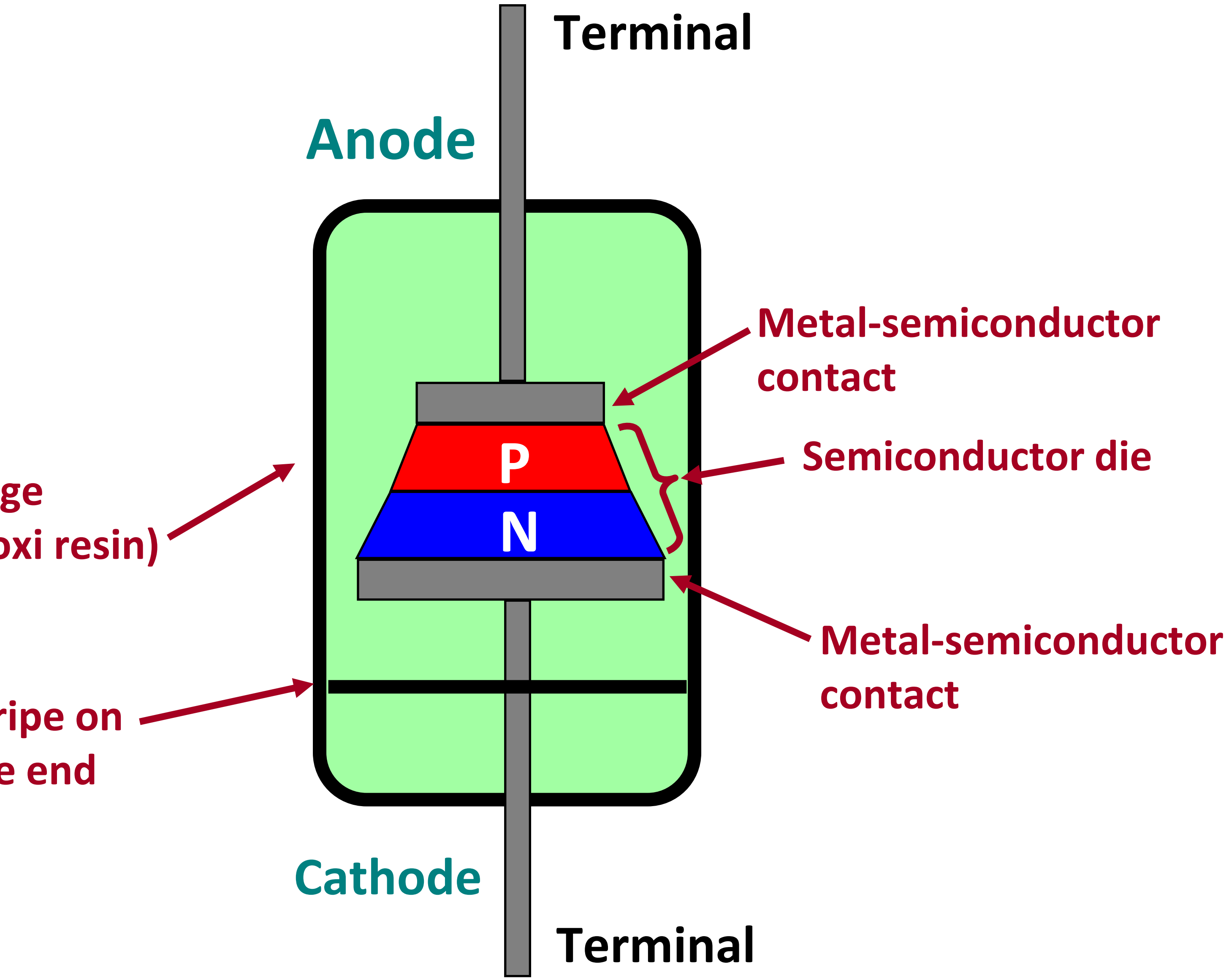
Whatever the reverse voltage is, the reverse current is always zero.

- **The ideal diode behaves as a short-circuit in forward bias.**
- **The ideal diode behaves as a open-circuit in reverse bias.**

Review of PN-diode operation (V)

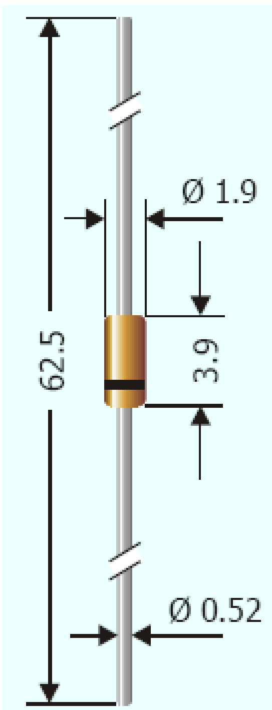
- Low-power diode.



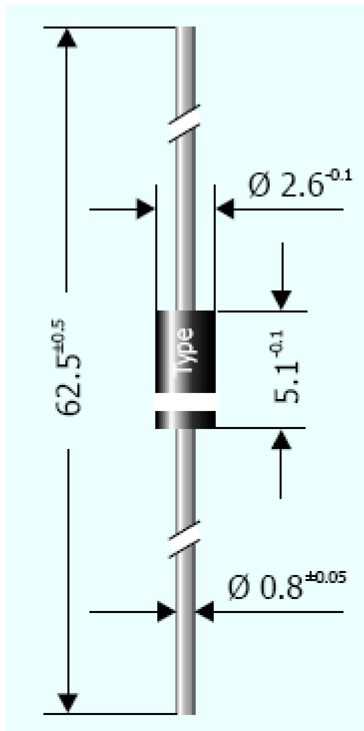


Packages for diodes (I)

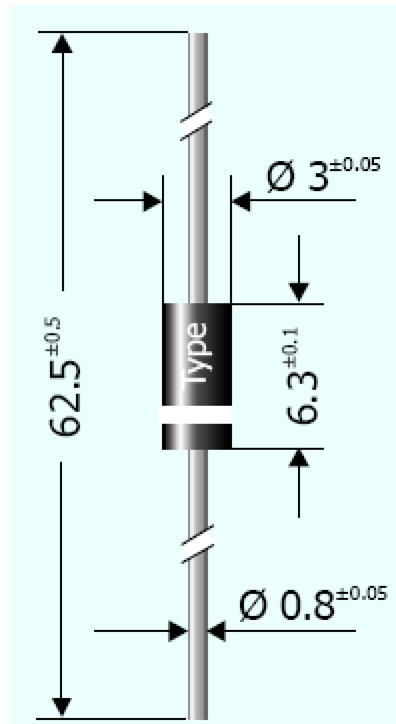
- **Axial leaded through-hole packages (low power).**



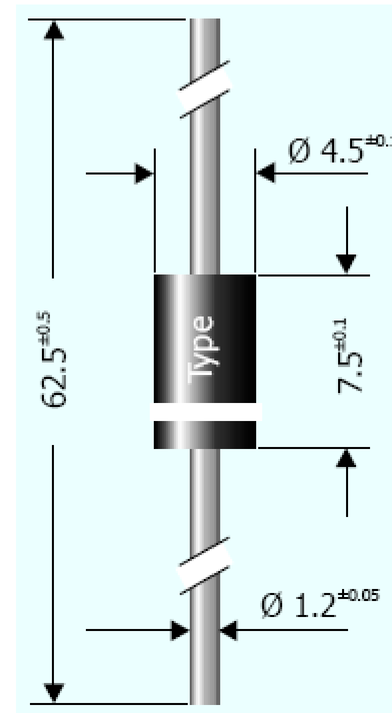
DO 35



DO 41



DO 15

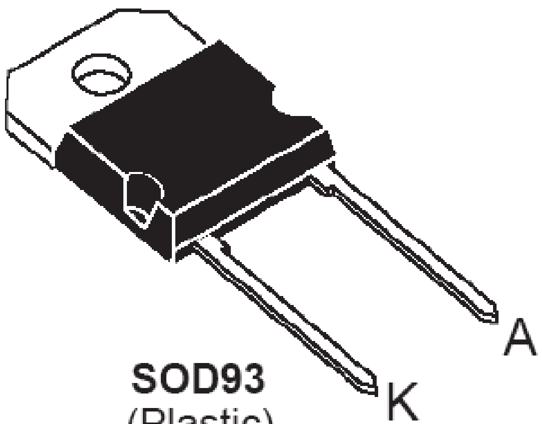


DO 201

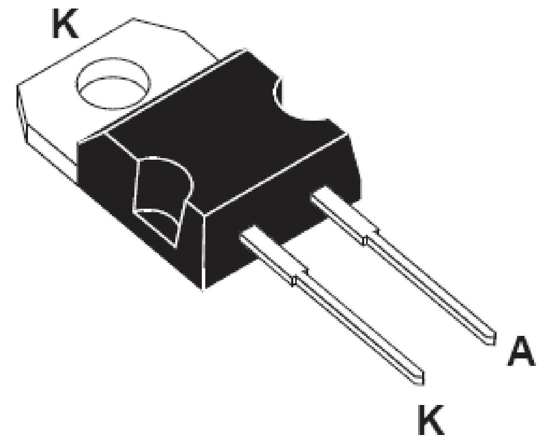
Packages for diodes (II)

- **Packages to be used with heat sinks.**

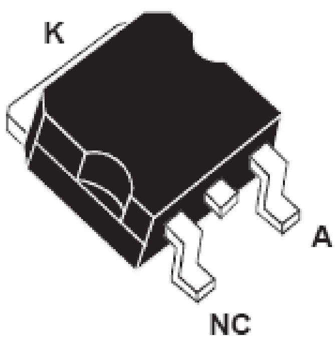
Cathode connected to case



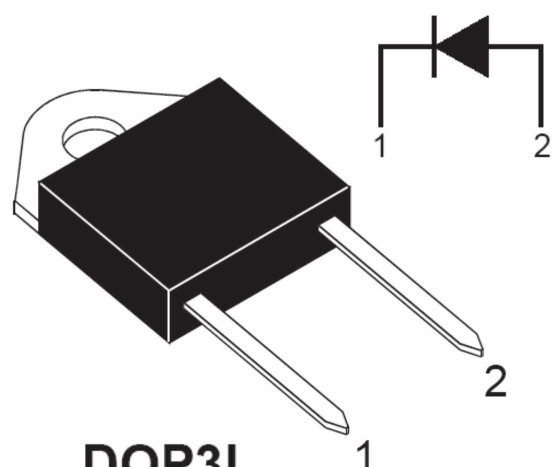
SOD93
(Plastic)



TO-220AC



D²PAK

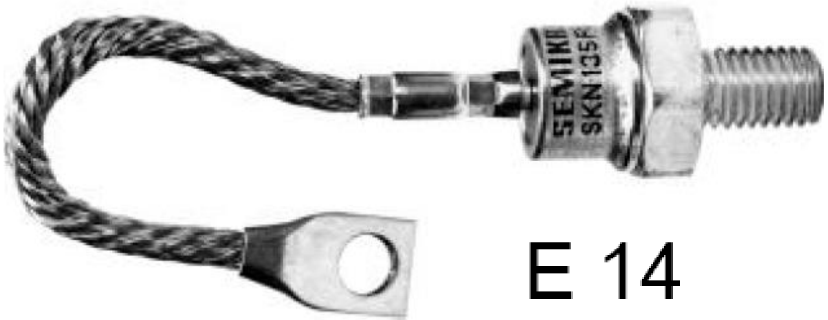


DOP3I

Packages for diodes (III)

- **Packages to be used with heat sinks (higher power levels).**

DO 5



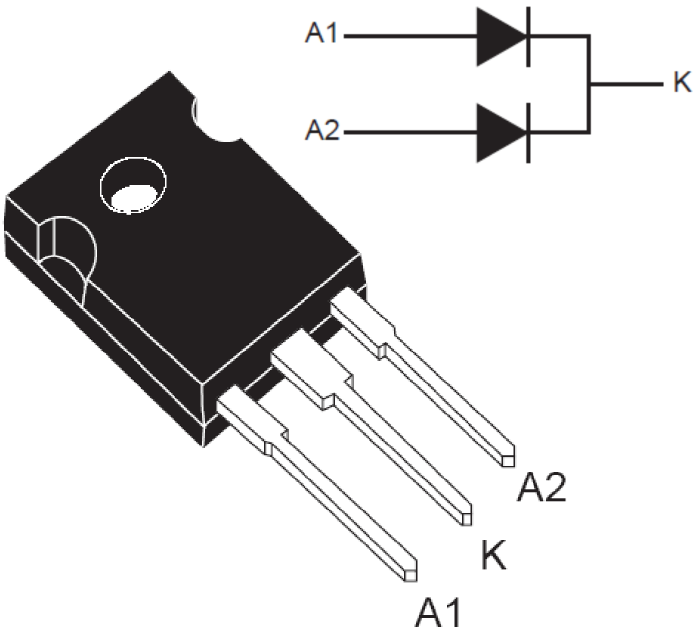
E 14

B 44

E 35

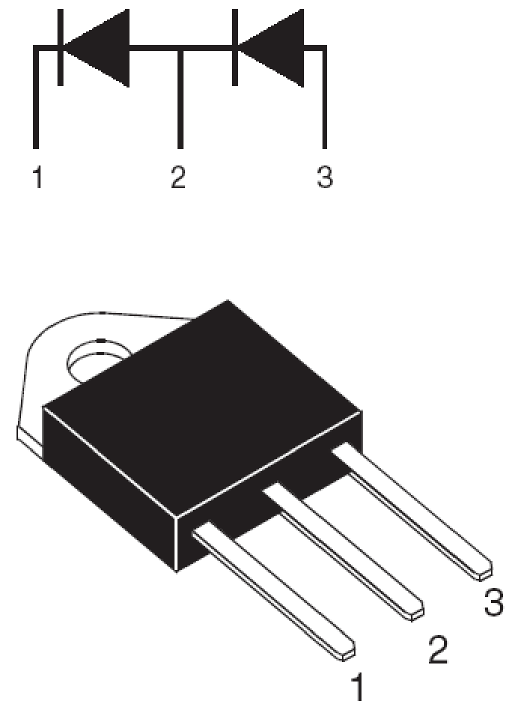
Packages for diodes (IV)

- **Assembly of 2 diodes (I).**



TO-247

Common cathode
(Dual center tap Diodes)

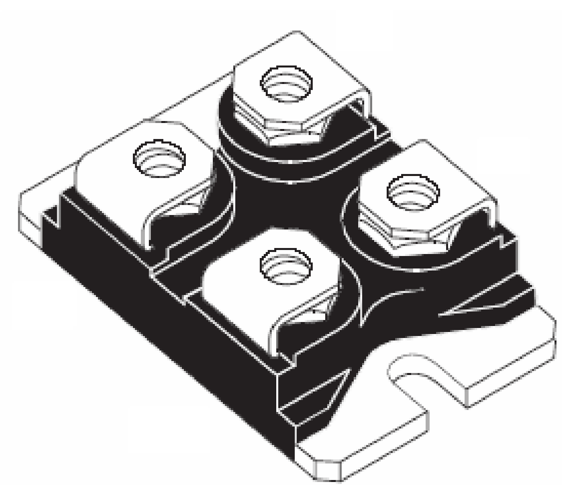


TOP-3
(Insulated)

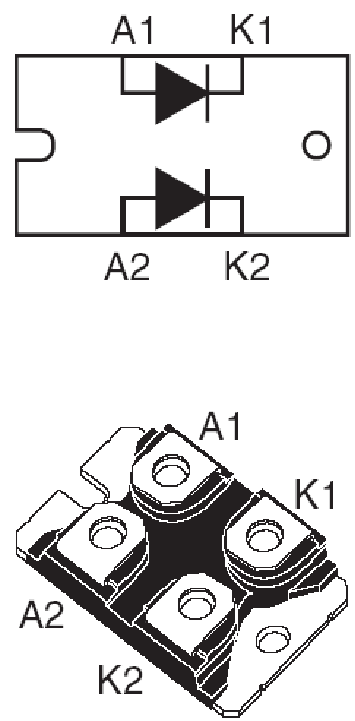
Doubler
(2 diodes in series)

Packages for diodes (VI)

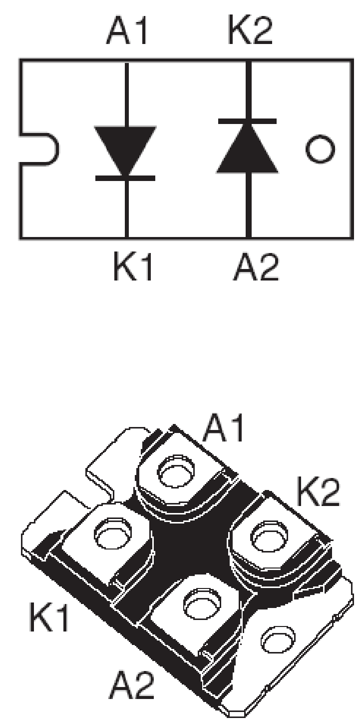
- **2 diodes in the same package, but without electrical connection between them.**



ISOTOP™



ISOTOP
STTH12010TV1



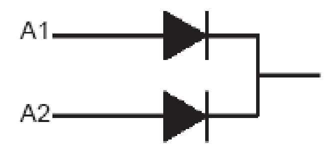
ISOTOP
STTH12010TV2

Packages for diodes (VII)

- **Manufacturers frequently offer a given diode in different packages.**

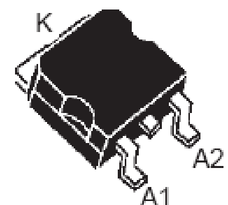
STTH2003CT/CG/CF/CR

Name ***Package***

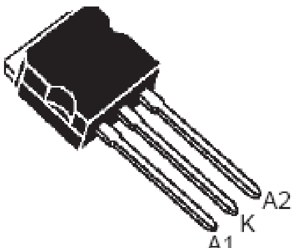


MAJOR PRODUCT CHARACTERISTICS

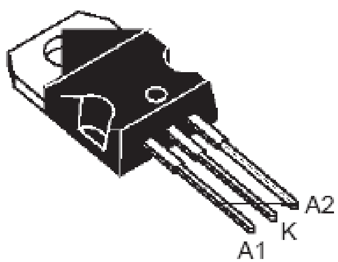
$I_{F(AV)}$	2 x 10 A
V_{RRM}	300 V
Tj (max)	175 °C
V_F (max)	1 V
trr (max)	35 ns



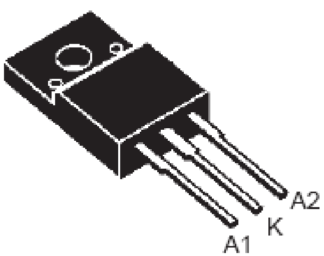
D^2PAK
STTH2003CG



I^2PAK
STTH2003CR



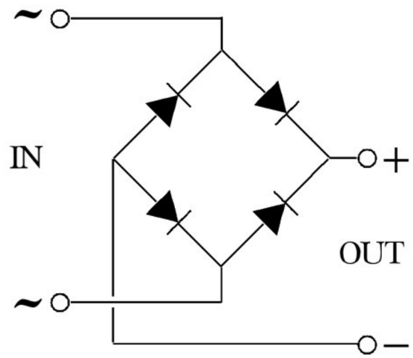
TO-220AB
STTH2003CT



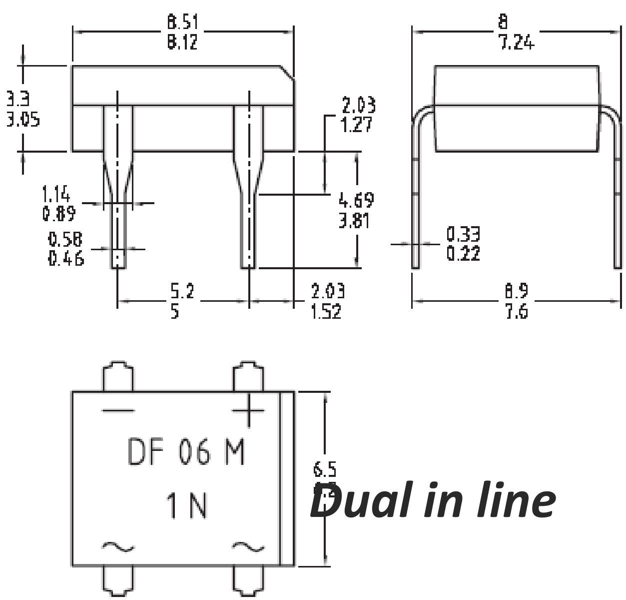
ISOWATT220AB
STTH2003CF

Packages for diodes (VIII)

- **Assembly of 4 diodes (low-power bridge rectifiers).**

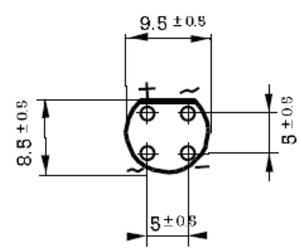


Dimensions in mm. **DF - M**

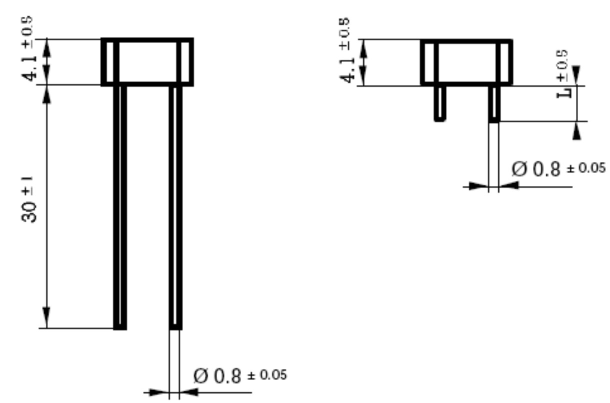


Dual in line

Dimensions in mm.

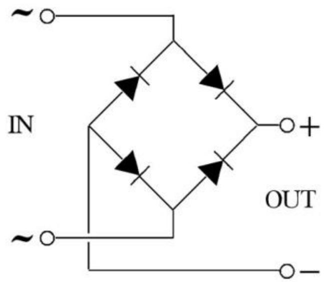


Sufflix	L ± 0.5
"A"	4
"B"	3



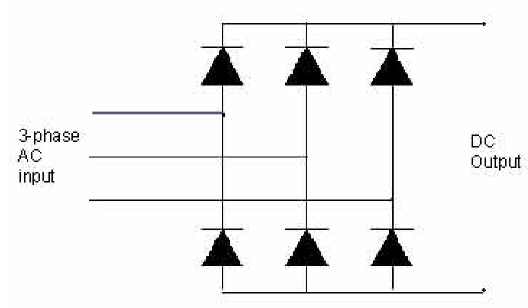
Packages for diodes (X)

- **Assembly of 4 diodes (high-power bridge rectifiers).**



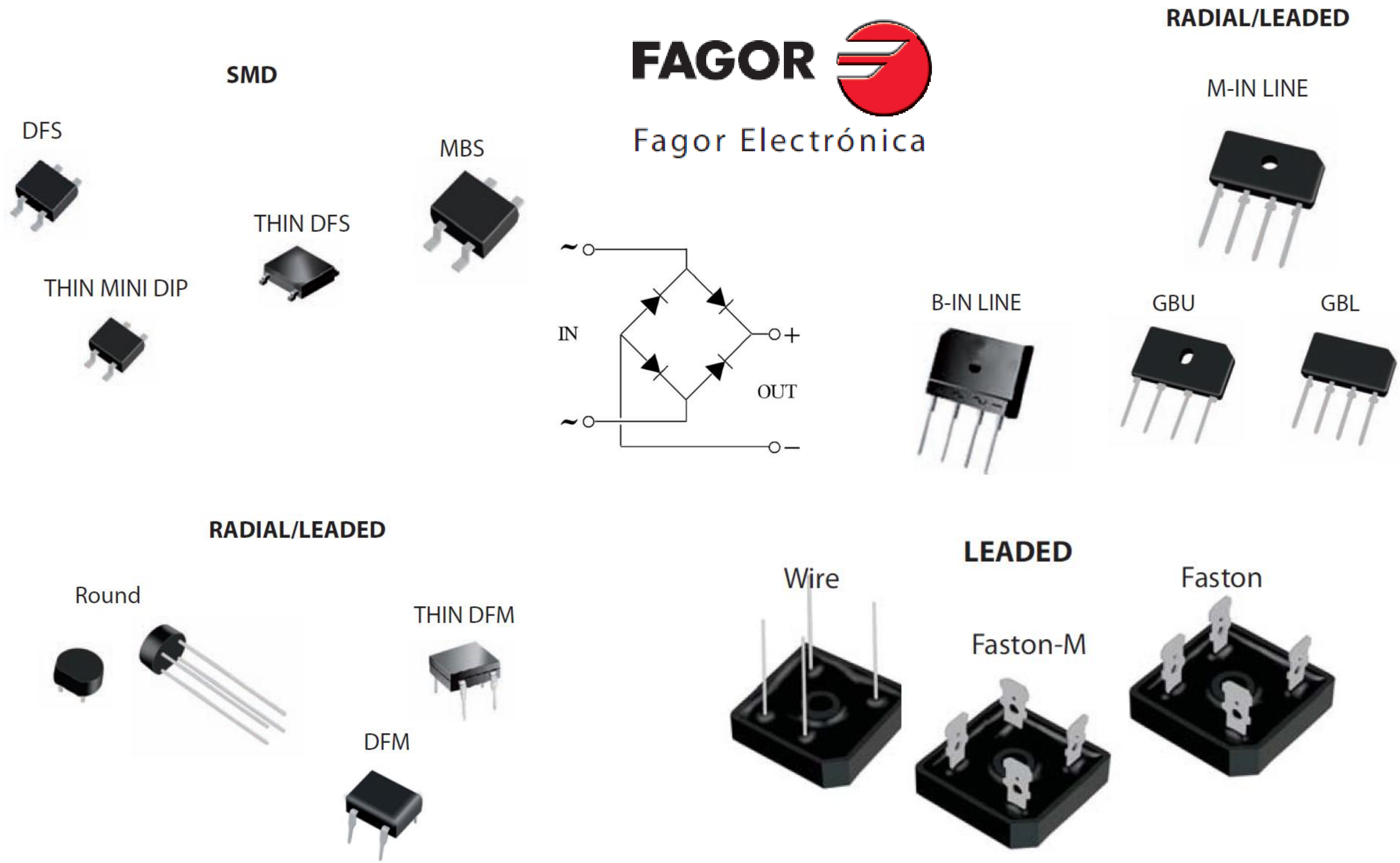
Packages for diodes (XI)

- **Assembly of 6 diodes (Three-phase bridge rectifiers)**



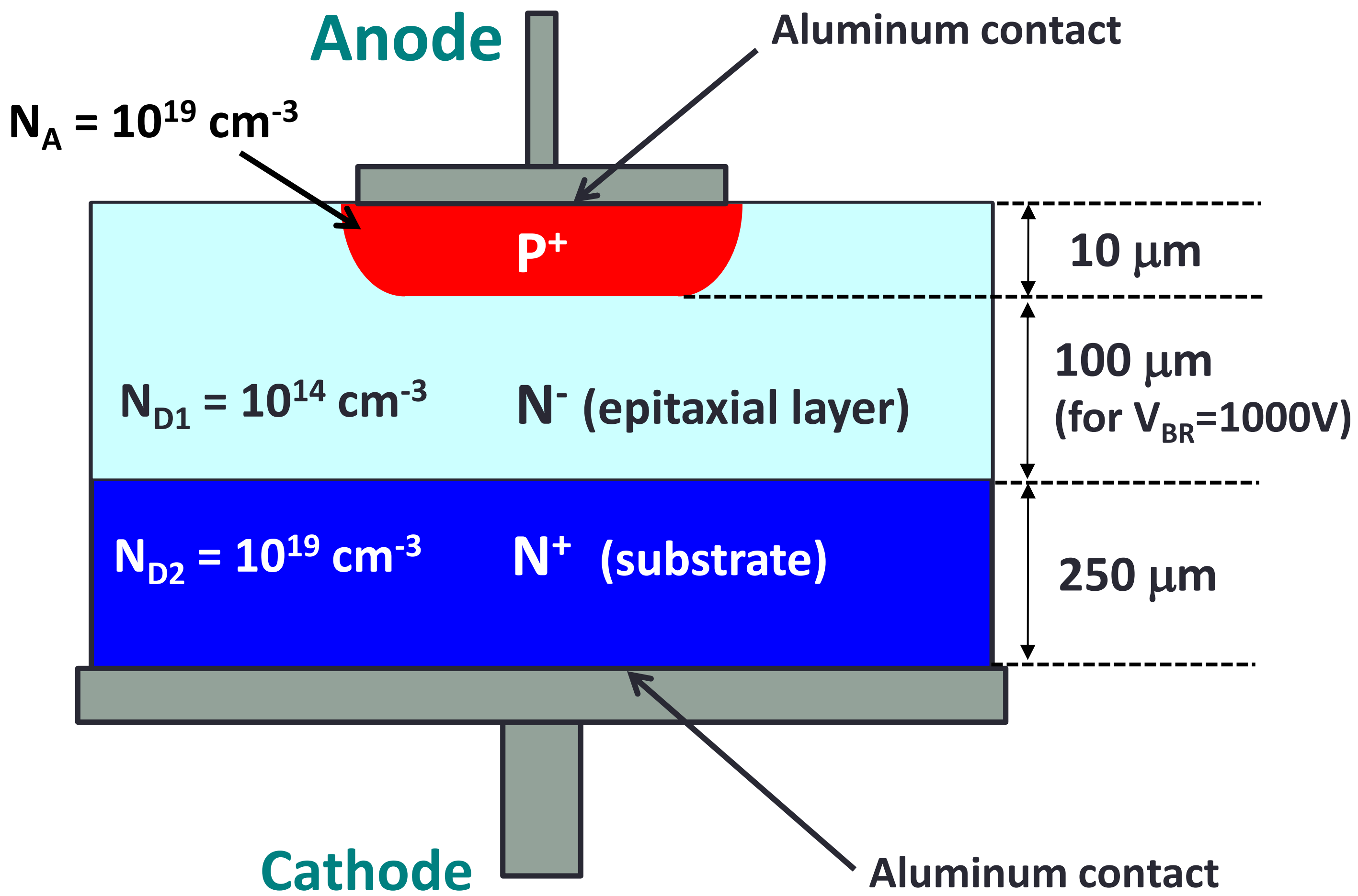
Packages for diodes (XII)

- **Example of a company portfolio regarding single-phase bridge rectifiers.**



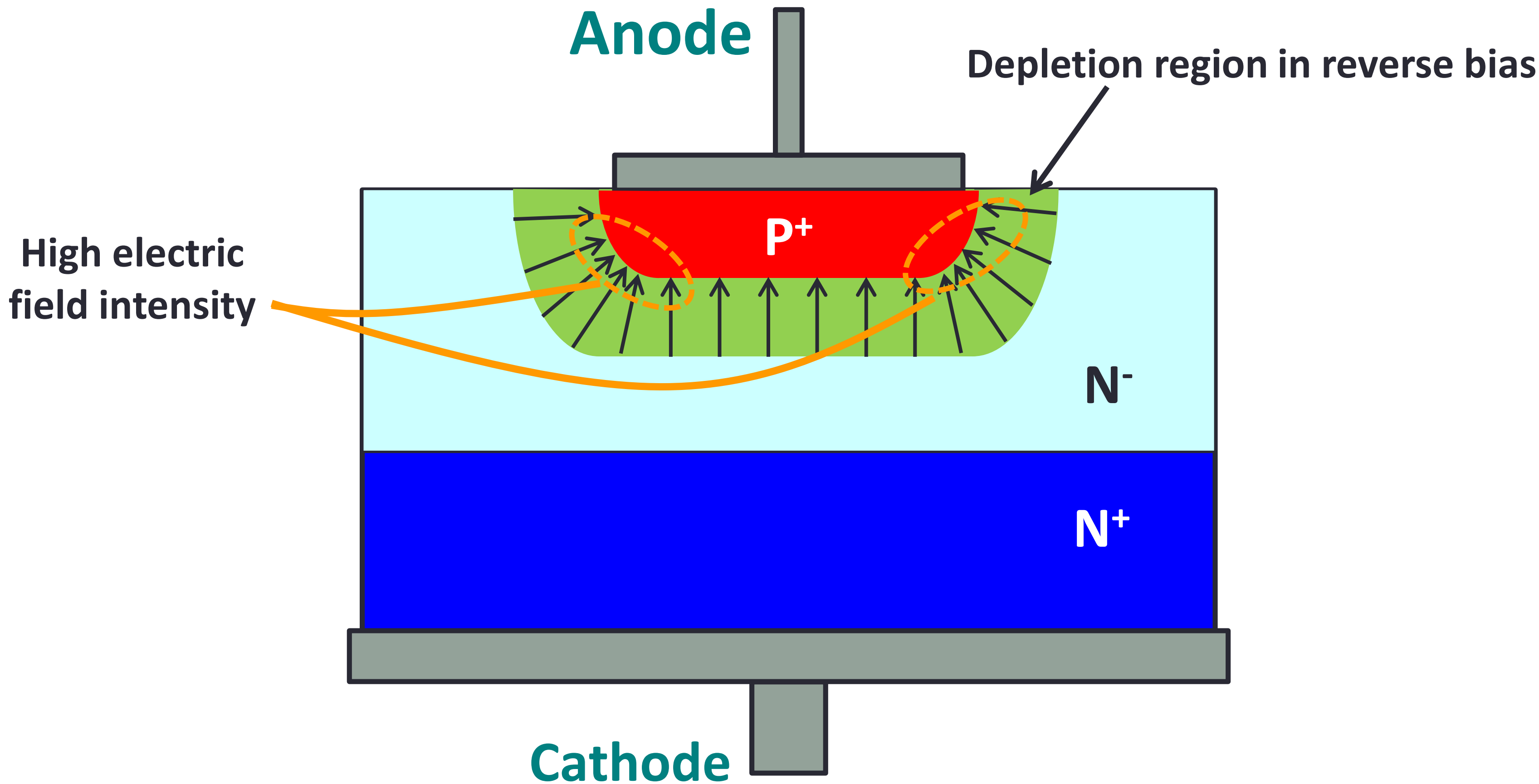
Internal structure of PN power diodes (I)

- **Basic internal structure of a PN power diode.**



Internal structure of PN power diodes (II)

• **Problems due to the nonuniformity of the electric field.**

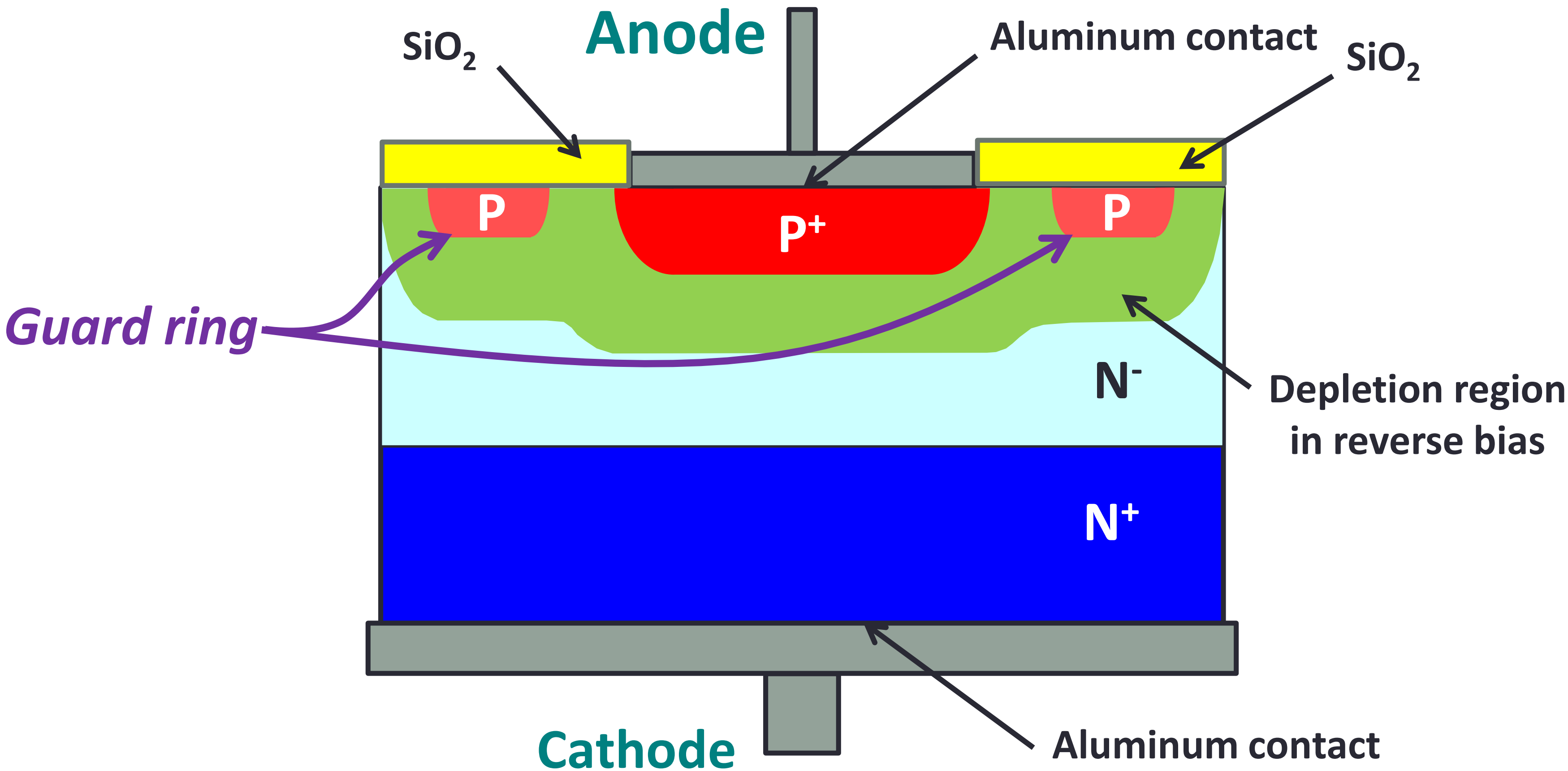


• **Breakdown electric field intensity can be reached in these regions.**

• **Regions with local high electric-field should be avoided when the device is designed.**

Internal structure of PN power diodes (III)

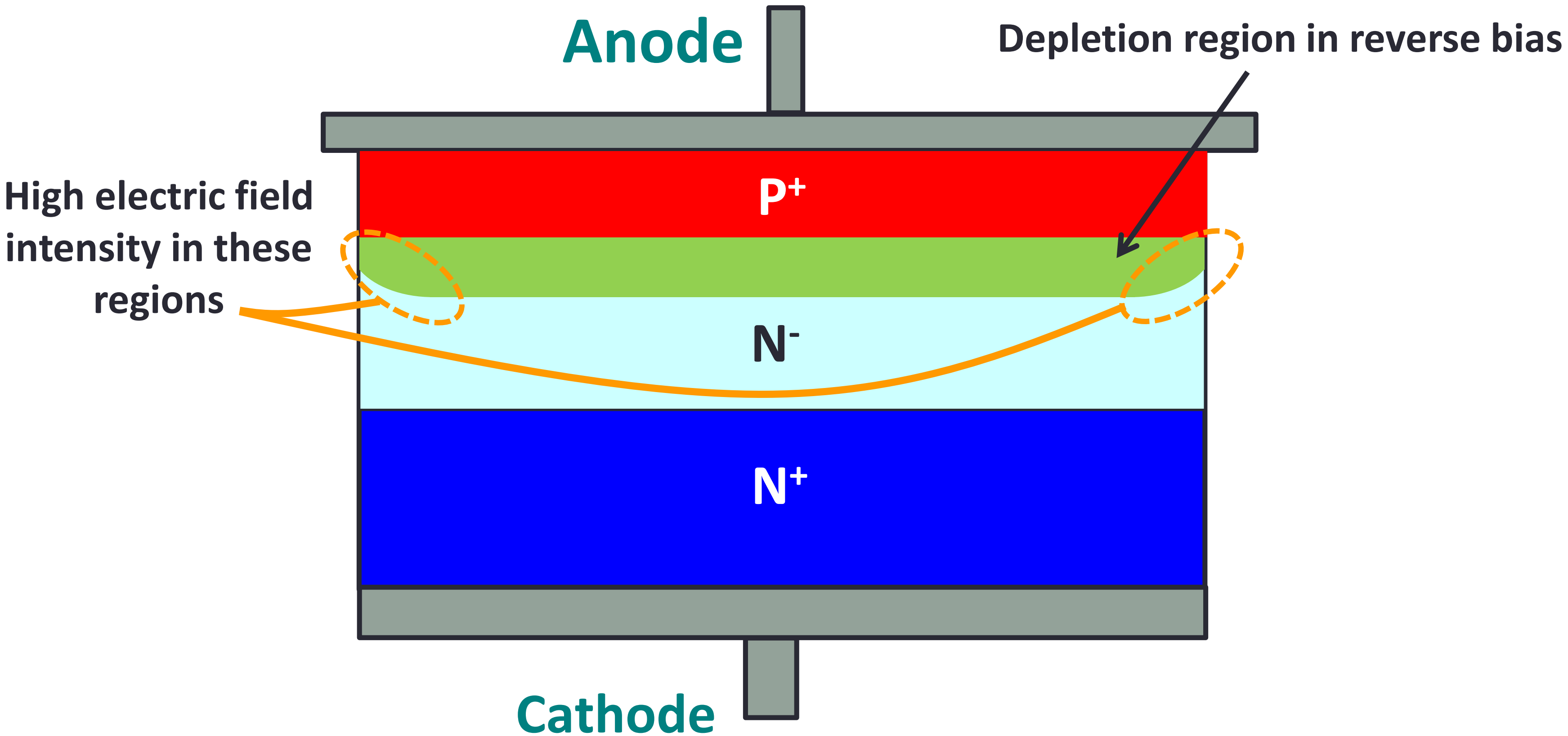
- Use of guard rings to get a more uniform electric field.



- The depletion layers of the guard ring merge with the growing depletion layer of the P^+N^- region, which prevents the radius of curvature from getting too small. Thus there are not places where the electric field reaches very high local values.

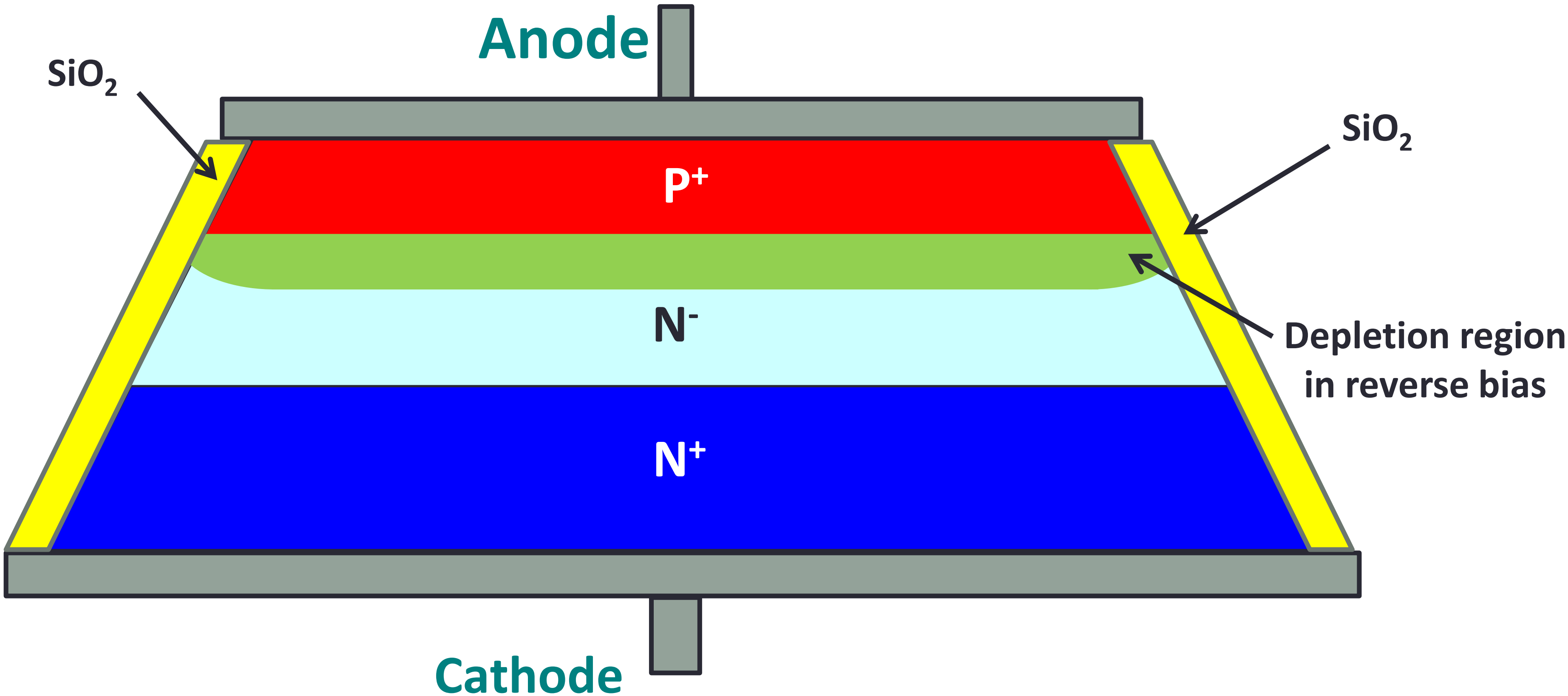
Internal structure of PN power diodes (IV)

- **Case where the metallurgical junction extends to the silicon surface (I).**



Internal structure of PN power diodes (V)

- Case where the metallurgical junction extends to the silicon surface (II).



- The use of beveling minimizes the electric field intensity.
- Coating the surface with appropriate materials such as silicon dioxide helps control the electric field at the surface.

Information given by the manufacturers

- **Static characteristic:**
  - **- Maximum peak reverse voltage.**
  - **- Maximum forward current.**
  - **- Forward voltage drop.**
  - **- Reverse current.**
- **Dynamic characteristics:**
  - **- Switching times in PN diodes.**
  - **- Junction capacitance in Schottky diodes.**

Forward voltage drop, V_F (II).

- **The higher the value of the maximum peak reverse voltage V_{RRM}, the higher the forward voltage drop V_F at $I_{F(RMS)}$.**

STTA506D/F/B

$I_{F(AV)}$	5A
V_{RRM}	600V
t_{rr} (typ)	20ns
V_F (max)	1.5V

STTH4R02

$I_{F(AV)}$	4 A
V_{RRM}	200 V
$T_{j\ (max)}$	175° C
V_F (typ)	0.76 V
t_{rr} (typ)	16 ns

STTH802

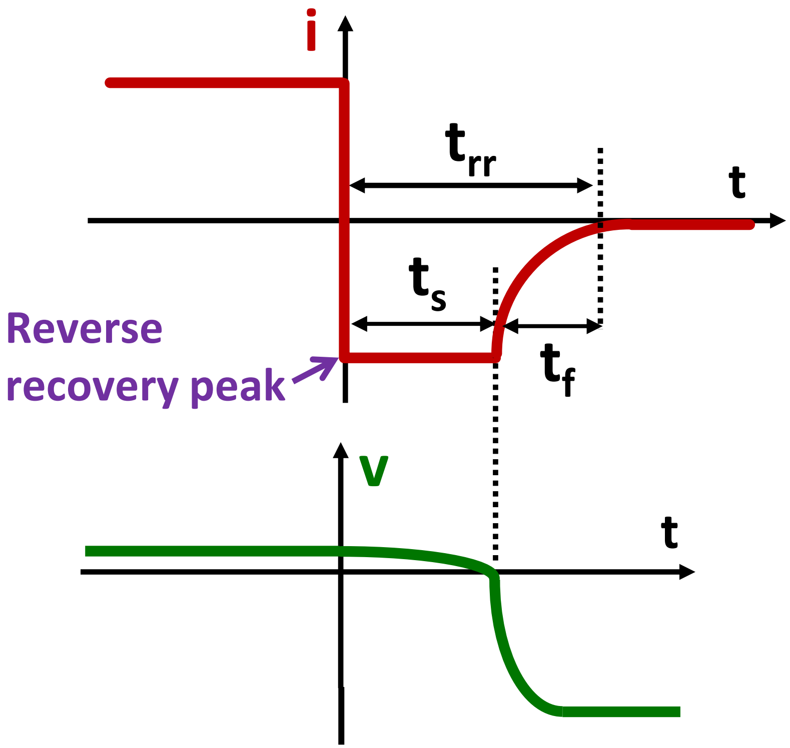
$I_{F(AV)}$	8 A
V_{RRM}	200 V
$T_{j\ (max)}$	175° C
V_F (typ)	0.8 V
t_{rr} (typ)	17 ns

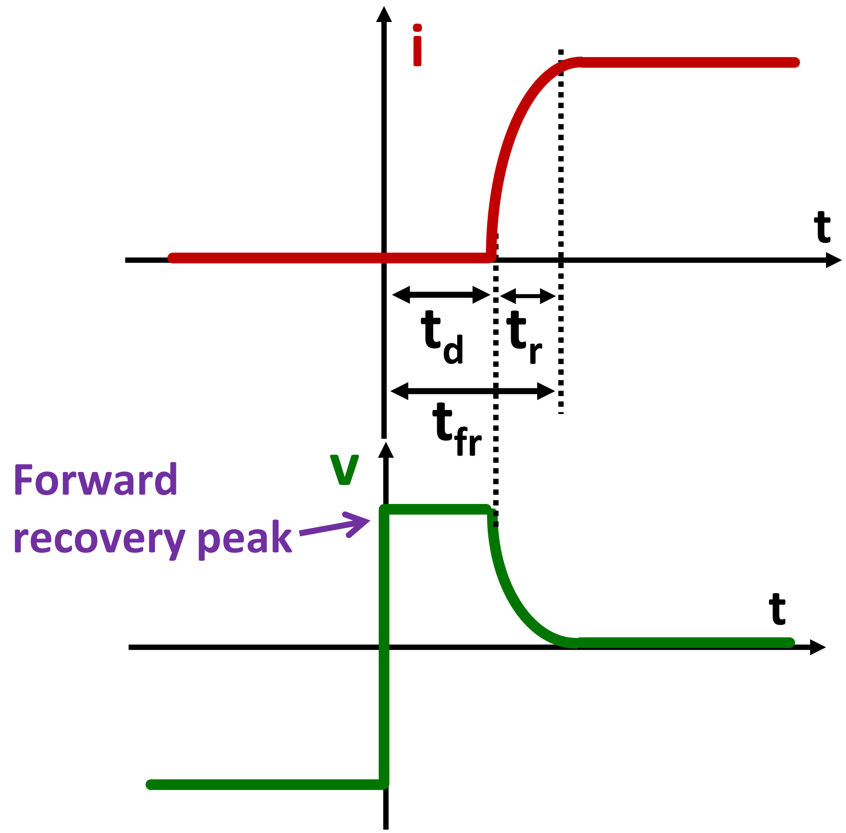
STTH512

$I_{F(AV)}$	5 A
V_{RRM}	1200 V
T_j	175° C
V_F (typ)	1.25 V
t_{rr} (typ)	48 ns

Dynamic characteristic of power diodes (I).

- **In the case of PN diodes, manufacturers give information about switching times, reverse recovery current and forward recovery voltage (slides 108-111, Lesson 1).**





t_s = storage time.

t_f = fall time.

$t_{rr} = t_s + t_f$ = reverse recovery.

t_d = delay time.

t_r = rise time.

$t_{fr} = t_d + t_r$ = forward recovery time.