

## Homework1

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### Question 1.1

Shaded area in Fig. 2-30 illustrates the current waveform of a thyristor in conduction mode.

The maximum value of each current waveform is  $I_m$ , try to derive the average value  $I_{d1}, I_{d2},$

$I_{d3}$  and the effective value (RMS value)  $I_1, I_2, I_3$  of each waveform.

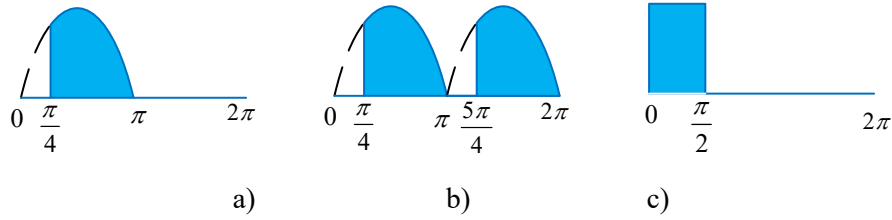


Fig.2-30 Thyristor current waveform

### Answer 1.1

a)

$$I_{d1} = \frac{\int_{\frac{\pi}{4}}^{\pi} I_m \sin t dt}{2\pi} = \frac{1 + \frac{\sqrt{2}}{2}}{2\pi} I_m = \frac{2 + \sqrt{2}}{4\pi} I_m \approx 0.27169 I_m$$

$$I_1 = \sqrt{\frac{\int_{\frac{\pi}{4}}^{\pi} I_m^2 \sin^2 t dt}{2\pi}} = \sqrt{\frac{3}{16} + \frac{1}{8\pi}} I_m \approx 0.47675 I_m$$

b)

$$I_{d2} = \frac{\int_{\frac{\pi}{4}}^{\pi} I_m \sin t dt + \int_{\frac{5\pi}{4}}^{2\pi} I_m \sin t dt}{2\pi} = \frac{2 + \sqrt{2}}{2\pi} I_m \approx 0.54339 I_m$$

$$I_1 = \sqrt{\frac{2 \int_{\frac{\pi}{4}}^{\pi} I_m^2 \sin^2 t dt}{2\pi}} = \sqrt{\frac{3}{8} + \frac{1}{4\pi}} I_m \approx 0.67422 I_m$$

c)

$$I_{d3} = \frac{\int_0^{\frac{\pi}{2}} I_m dt}{2\pi} = \frac{1}{4} I_m$$

$$I_3 = \sqrt{\frac{\int_0^{\frac{\pi}{2}} I_m^2 dt}{2\pi}} = \frac{1}{2} I_m$$

### Question 1.2

In 1.1, if safety margin is not concerned, how much average current  $I_{d1}$ ,  $I_{d2}$ , and  $I_{d3}$  can a 100A thyristor transfer, and how much is the corresponding maximum current  $I_{m1}$ ,  $I_{m2}$ ,  $I_{m3}$  respectively?

### Answer 1.2

100A here refers to the forward average current ( $I_{F(AV)}$ ) of the thyristor, which refers to the average value of the halfwave current with maximum working frequency.

Since:

$$I_{F(AV)} : I_{MRS} = 1 : 1.57$$

We can see:

$$I_1 = I_2 = I_3 = 157 \text{ A}$$

Hence, in 1.1

$$I_{m1} = \frac{I_1}{0.47675} \approx 329.31 \text{ A}$$

$$I_{d1} \approx 0.27169 I_{m1} = 89.47 \text{ A}$$

$$I_{m2} = \frac{I_2}{0.67422} \approx 232.86 \text{ A}$$

$$I_{d2} \approx 0.54339 I_{m2} = 125.53 \text{ A}$$

$$I_{m3} = 2 I_3 = 314 \text{ A}$$

$$I_{d3} = \frac{1}{4} I_{m3} = 78.5 \text{ A}$$

### Question 1.3

Compared with MOSFET in information electronic circuits, what are the structural characteristics of power MOSFET that allow them to withstand high voltages and currents?

### Answer 1.3

- 1) Power MOSFET often adopts the **vertical oriented structure**, increasing the effective area of the silicon wafer which conducts the current, thus greatly enhancing the ability to withstand high voltage and high current.
- 2) A Power MOSFET often has **multiple parallel cells**. With numerous MOSFET units, the device can also withstand high voltage and high current.
- 3) Power MOSFET also contains  $N^-$  **drift region**. Although it does not have conductivity modulation (Power MOSFET is a majority carrier device), this region can still enhance the ability to withstand high voltage.

### Question 1.4

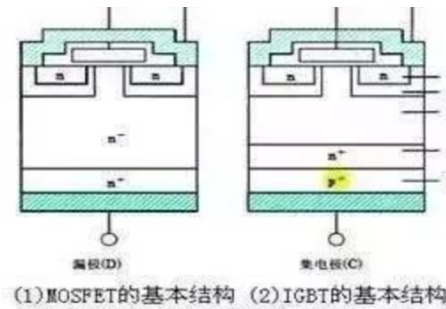
Try to analyze the similarities and differences between IGBT and power MOSFET in terms of internal structure and switching characteristics.

### Answer 1.4

Similarities:

An IGBT device consists of a MOSFET and GTR. So the driving principle of IGBT and Power MOSFET is identical, both of which are voltage-driven devices(easy to drive). Both have relatively high input impedance and  $N^-$  drift region, and both of them are level-sensitive devices.

Differences:



Compared with Power MOSFET, IGBT has an extra P+ injection area. Switching speed of IGBT is lower than Power MOSFET, and the working frequency of Power MOSFET is higher, which avoids the secondary breakdown. Nevertheless, the IGBT's capacity of withstanding high voltage and current (500-4500V, several KW to several MW) is better than Power MOSFET (<600V, <10KW). Power MOSFET is a majority-carrier device, while IGBT is a minority carrier device, which means IGBT has lower on-resistance especially at higher voltages (up to 4500V).

### Question 1.5

Try to analyze what benefits power electronics integration technology can bring. What is the difference between the ideas of power integrated circuits and integrated power electronic modules to achieve integration?

### Answer 1.5

Benefits:

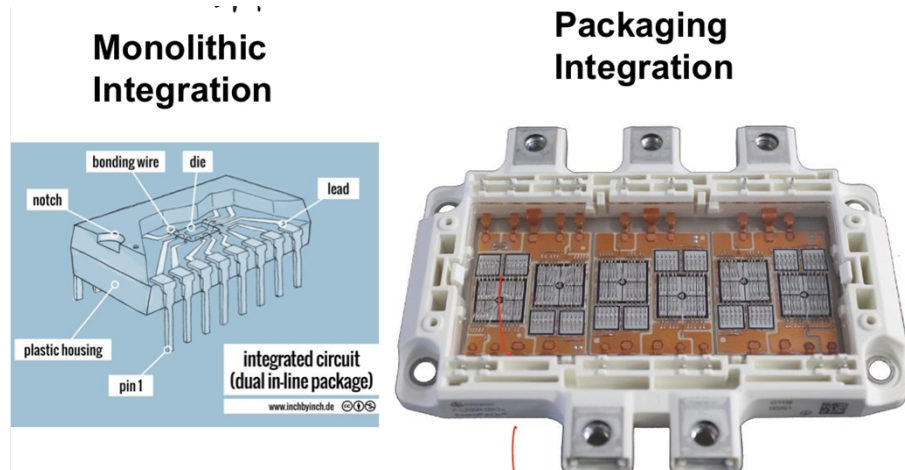
The whole device **size** can be reduced, **costs** of production, installation and maintenance can be lowered, **reliability and performance** can be improved by using power electronics integration technology. Moreover, the **line inductance** can be greatly reduced for circuits with higher working frequencies, thereby simplifying the requirements for protection and buffering circuits.

Difference:

If power electronic devices and information electronic circuits such as **logic, control, protection, sensing, detection, and self diagnosis** are fabricated on the **same chip (Monolithic Integration)**, it is called a power integrated circuit.

Due to the **isolation and thermal** issues, Power Integrated Circuits are mainly utilized in low-power circumstances. However, these two issues can be largely avoided by means of packaging

**multiple** identical power electronic device **chips** or multiple different power electronic device chips that are used in conjunction with one another **in one module**. This module is called power module. If power electronic devices and information electronic circuits such as control, drive, and protection are packaged together, it is called IPEM (Integrated Power Electronic Module).



### Question 1.6

List typical wide-band semiconductor materials. In what ways are power electronic devices based on these wide-band semiconductor materials superior to silicon devices?

### Answer 1.6

Wide bandgap semiconductor materials refer to semiconductor materials with a bandgap width of over 2.3 eV, such as silicon carbide (SiC), gallium nitride (GaN), diamond.

Compared with silicon devices, wide-band semiconductor materials have higher thermal stability(>>500°C) and conductivity, higher chemical stability, higher mechanical hardness and excellent stability versus cosmic radiation. Besides, wide-band semiconductor materials are transparent and non-toxic.