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New Development of Modern Power Electronic Devices

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Abstract

Power electronic devices made of wide-bandgap semiconductor materials represented by SiC have broken through the limitations of traditional semiconductor materials and can be widely used in high-voltage, high-frequency, high-power and other complex situations. At the same time, the research on ultra-wide bandgap semiconductor materials represented by Ga2O3 has also made major breakthroughs. This article mainly introduces the advantages of wide-bandgap semiconductor materials and power electronic devices made from them, and makes several analyses of their mass production.

Keywords

Wide Bandgap Semiconductor Materials; High Frequency and High Voltage; Power Electronic Devices.

1. Introduction

Power electronic devices, also known as power semiconductor devices, are high-power electronic devices made of semiconductor materials and mainly used for power conversion and control circuits of power equipment. Its development stage can be roughly divided into the early stage marked by electron tubes and transistors, the silicon controlled rectifier period marked by the birth of thyristors, and the integrated and fully controlled period based on fully controlled devices [1]. Nowadays, with the development of wide-bandgap semiconductors and power modules, power electronic technology is widely used in high power, high voltage, high frequency, high efficiency, and other occasions. It can be said that where there is electricity, there will be power electronic devices.

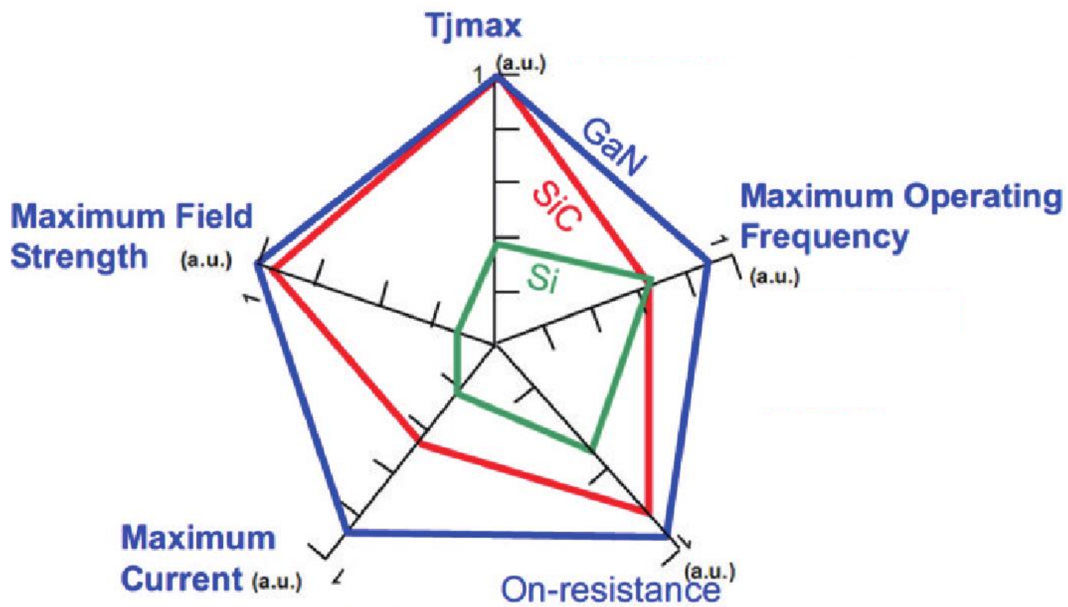

Figure 1. Features and advantages of wide bandgap semiconductor electronic devices

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2. Wide bandgap semiconductor devices represented by SiC

2.1 Main advantages

SiC is currently the most mature wide-gap semiconductor material. Since the International Society of Silicon Semiconductors was held in 2013, some internationally renowned semiconductor device manufacturers have demonstrated the latest mass-produced silicon carbide devices, and many manufacturers have produced them. A global industrial chain of materials, devices, and applications has been formed. Compared with traditional silicon materials, wide-bandgap semiconductor materials represented by SiC and GaN have obvious advantages and have better high-temperature, high-pressure, and high-frequency characteristics. Figure 1 shows the main characteristics and advantages of wide bandgap semiconductors [2].

2.2 Products and applications of SiC devices

2.2.1 Products

From the perspective of silicon carbide crystal materials, 4H-SiC and 6H-SiC are the most widely used in the semiconductor field. Among them, 4H-SiC is mainly used to prepare high-frequency, high-temperature, high-power devices, and 6H-SiC is mainly used to produce optoelectronics. Power devices [3].

In terms of SiC devices, samples of SiC MOSFETs of 10kV~15kV/10A~20A, SiC power diodes of more than 20kV, and SiC IGBT chip samples have been reported internationally. Cree and Rohm have developed SiC MOSFET products with voltage levels ranging from 650V to 1700V, single-chip current exceeding 50A, and developed 1200V/300A, 1700V/225A all-silicon carbide power module products [4]. In recent years, 1700V/3.5A SiC JFET chips, 4500V/50A SiC diodes, 4500V/100A SiC JFET modules have been developed in China, and the key technology of 15kV high voltage SiC diodes have been overcome [5]. At present, my country has a mass production capacity of 600V~3.3kV SiC diode chips, and the industrialization capacity of SiC MOSFET chips is taking shape. But on the whole, my country's wide bandgap power electronic device technology and industrial level are still lagging behind the international advanced level [4].

2.2.2 Application

Because SiC material has good high temperature and high-pressure characteristics, Schottky diodes made from it can be widely used in the aerospace industry. The large-area 3.3kV SBD has been used to manufacture high-temperature applications with a forward current range of 10-20A [8]. For example, the 300V/SA SBD was developed for the harsh space environment during the European Space Agency's Mercury probe mission.

The Fraunhofer Institute in Germany replaced SiIGBTs with SiC MOSFETs at the 1200V voltage level and developed a 7kW/750V two-phase photovoltaic inverter. The conversion efficiency was increased to 99.05%, the loss was reduced by 30%-50%, and the inductor and capacitor volume of the device was greatly reduced [9].

SiC IGBT combines the advantages of GTR (Power Transistor) and MOSFET, simple gate drive, and large current capacity makes it have a good prospect in the field of high voltage applications [10]. CRRC uses SiC hybrid IGBT modules (Si power devices and SiC) in the traction system of next-generation subway trains. Compared with the ordinary IGBT, the power consumption of the SiC hybrid IGBT is reduced by about 3000, and the increase of the switching frequency also effectively reduces the output harmonics, reduces the pulsating torque of the motor, and improves the efficiency of the entire system [11].

2.3 Difficulties in the development of SiC devices

Judging from the current progress in my country and the production and manufacturing of advanced semiconductor technology companies in the world, it is not design issues that limit the development of SiC devices, but manufacturing process issues, mainly as follows:

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The extension efficiency is low. Different from the traditional silicon power device manufacturing process, silicon carbide power devices cannot be directly fabricated on silicon carbide single crystal materials. High-quality epitaxial materials must be grown on the conductive single crystal substrate and manufactured on the epitaxial layer. For various devices [6], due to the sublimation phenomenon, the temperature of the vapor phase epitaxy cannot be too high, so the growth rate is low; the temperature of the liquid phase epitaxy is lower, the rate is higher, but the yield is low.

Microtube defects of silicon carbide wafers. Microtubes are macroscopic defects that can be seen by the naked eye. The use of silicon carbide substrates with a size of 6 inches or more is the main prerequisite for the large-scale promotion and application of power devices. However, the silicon carbide interface has higher density defects and lower defects. The electron migration of electrons often leads to a decrease in the performance of silicon carbide semiconductor materials [7].

In the production and manufacturing of SiC devices, there are still many problems that need to be solved urgently, such as the special requirements of the doping process, the device packaging does not meet the requirements, and the SiC technology and industry maturity still have a certain gap. These problems have greatly hindered the development and manufacturing of SiC devices.

3. Ultra-wide bandgap semiconductor devices represented by Ga2O3

Gallium oxide is considered to be the "third-generation wide-bandgap semiconductor for power devices" after silicon carbide and gallium nitride. This material was originally planned to be used in LED (light-emitting diode) substrates, deep ultra-violet light (Deep Ultra Violet) light-receiving elements, etc. It was only used in the direction of power semiconductors in the past ten years, which then triggered a global R&D boom. There are 6 known crystalline phases of Ga2O3, including 5 stable phases such as α, β, and γ, and one transient phase k-Ga2O3, of which β-Ga_2 O_3 has more application value [12]. Studies have shown that the band gap of gallium oxide is 4.9eV, which exceeds that of silicon carbide, gallium nitride, and other materials. The use of materials with a wider band gap can make power devices with thinner, lighter, and higher power systems; breakdown field Stronger than silicon carbide and silicon nitride, the current β-Ga_2 O_3 breakdown field strength can reach 8MV/cm, which is twice that of silicon carbide.

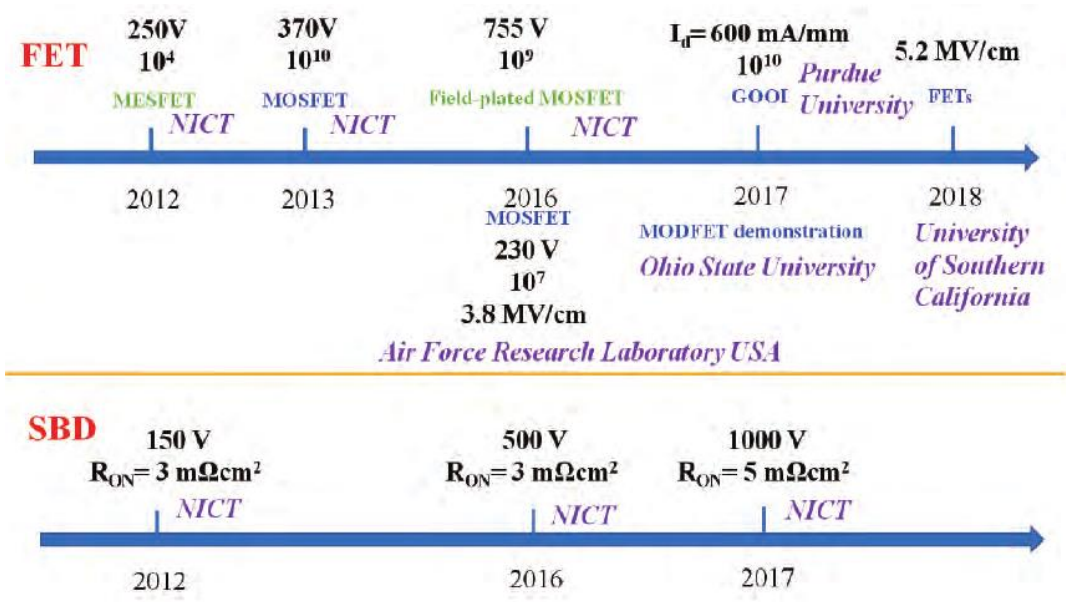

Figure 2. The development process of power devices based on β-Ga_2 O_3 [12]

According to domestic media reports, in the National Science and Technology Week held last year, Beijing Gallium Group Technology Company publicly demonstrated its research and development

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of gallium oxide embryos, epitaxial wafers and base sun blind ultraviolet detection array devices. In addition, China Electronics 46 Institute has successfully prepared high-quality 4-inch gallium oxide single crystals with a width of close to 100mm and a total length of 250mm using the guided mold method. It can process 4-inch wafers, 3-inch wafers and 2-inch wafers. Wafer. After testing, the crystal has very good crystalline quality, which will provide strong support for the development of domestic related devices [13].

4. Conclusion

With the rapid development of semiconductor technology, power electronic devices are ushering in new changes. Due to their inherent limitations, traditional silicon power electronic devices will gradually be made of silicon carbide in high temperature, high pressure, and high frequency applications. Replaced by power electronic devices, there is reason to believe that this day will not be too late. In recent years, as the international situation has changed, my country has also increased its investment in "stuck neck" technology, which includes related technologies such as silicon carbide and gallium oxide. It is believed that my country will shorten the gap with the world's advanced level in this regard, and even Beyond.

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