The Application Status of the Third Generation of Semiconductor Materials in the FIeld of Electric Power

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Abstract. With the vigorous development of semiconductor materials, the third generation of semiconductors represented by SiC, GaN, and diamond have gradually become the mainstream materials of modern semiconductors, and this paper introduces the application of SiC, GaN, and diamond, respectively, and analyzes their existing properties. The advantages and disadvantages of each are drawn in more detail.

Keywords: application of third-generation semiconductors, SiC, GeN, diamond.

1. Introduction

The development process of semiconductor materials has lasted for more than a century, The first generation of semiconductor materials are mainly silicon, germanium and other element materials, its built transistors have replaced bulky electronic tubes, promoting the rapid development of integrated circuits, focusing on low voltage, low frequency, medium power transistors and photodetectors and other devices [1].with the rapid development of mobile communication technology in the 1990s, GaAs and InP The second generation of semiconductor materials represented by the representative gradually became the mainstream at that time, which was characterized by its application for the production of high-speed, high-frequency, high-power and light-emitting electronic devices, which well met the needs of emerging technologies such as communication technology and the Internet at that time. Like the first generation of semiconductors, most of the devices made of t-

-hese materials can only work in a thermal environment below 200 °C due to the limitations of material properties, and the radiation resistance, high breakdown voltage performance and the wavelength range of emitted visible light cannot meet the requirements of modern electronic technology. The third-generation semiconductors made of SiC, GaN, and diamond are made of high breakdown voltage, high thermal conductivity, high electron saturation drift rate, and small dielectric constant. Unique properties such as strong radiation resistance and good chemical stability have gradually occupied the mainstream position of semiconductor raw materials, Across the energy conversion chain, the energy-saving potential of third-generation semiconductor technologies can contribute greatly to the realization of long-term global energy-saving goals and its development prospects are very broad [2].

II. Characteristics of the third generation of semiconductors

The third generation of semiconductor materials refers to wide bandgap semiconductor materials (2.0 ~) with a band gap width significantly greater than Si (1.1eV) and GaAs (1.4eV). 6.0eV), including group III nitrides such as GaN, AlN, etc., SiC, wide bandgap oxides such as ZnO , wide bandgap semiconductor materials such as Ga_2O_3 $CaTiO_3$ and diamond film, compared to first-generation and second-generation semiconductors The third generation of semiconductor materials with large bandgap width, high breakdown electric field, high thermal conductivity, high electronic saturation rate, strong radiation resistance and other superior properties, the third generation of semiconductor devices can not only operate stably at higher temperatures, but also more reliable at high voltage and high frequency, in addition to less power consumption, Gain higher operational capability. It seems that the third-generation semiconductor materials, which have many advantages, are becoming an important part of strategic emerging industries such as seizing the strategic commanding heights of next-generation information technology, energy conservation and emission reduction, and national defense and security technology. The third generation of semiconductor materials are mainly used in the three directions of optoelectronic devices, power electronic devices, and microwave frequency devices. The third generation of semiconductor materials has made a scientific breakthrough in principle, and is about to subvert the stage of technological innovation and application. The development of the third generation of semiconductor technology is not only reflected in the continuous development of substrate and epitaxial material size from small diameter to large diameter, but also in the continuous leap of material quality and device performance. At the same time, costs and prices continue to fall, promoting the upgrading and development of related industries.

2. Status quo and application of three mainstream third-generation semiconductor materials

2.1. SiC

With the development of some high-tech technologies such as semiconductor lighting, 5G technology, smart grid, and new energy, as well as the rise of emerging applications such as high-speed rail transit, national defense and military industry, uninterruptible power supply, new energy vehicles, fast charging, and wireless charging, the market has put forward new demands for the performance of semiconductor devices. However, the traditional silicon device has reached the theoretical limit due to the influence of silicon material properties, and its performance is far from meeting the needs of emerging applications. Driven by Moore's Law, it is urgent to find a replacement for the next silicon device, so international semiconductor manufacturers have set their sights on the third-generation semiconductor material: SiC.

The current global industrial pattern of silicon carbide (SiC) shows the trend of the United States, Europe and Japan. Among them, the United States is a global dominant, by the United States Cree, the United States II.-VI. company, the United States Transphorm, the United States Dow Corning and other industry giants occupy more than 70% of the global market share [3], Europe has Infineon, IQE, Siltronic and other representative companies So they have a relatively complete SiC from the substrate to the epitaxial to the device application. Japan's ROHK Semiconductors, Mitsubishi Electric, Fuji Electric, Panasonic, etc. are leading the development of terminal equipment and power modules. Although the domestic silicon carbide industry started later than the first three, it has formed a certain foundation and is currently in a period of rapid development.

At present, SiC as a semiconductor material in LED technology has been well applied, compared to the traditional material Al_2O_3 SiC has the characteristics of high brightness and high power, one SiC-based LEDs are equivalent to 4 to 5 Al_2O_3. Base luminous intensity. At present, general SiC is used in more high-end products. The SiC substrate has a small lattice mismatch with the GaN-based material, which helps to improve the quality of the epitaxial material, and the SiC itself acts as a conductive substrate It has many advantages, such as the preparation of vertically structured light-emitting devices, the reduction of the process of making cathode electrodes, and the increase of light-emitting area. Silicon carbide also has the characteristics of high thermal conductivity, high breakdown field strength, high saturation electron drift rate and so on, especially suitable for high temperature, high power, high pressure, high frequency and radiation resistance and other harsh conditions require high requirements.[4]

New energy vehicles are in the key stage of the transition from the market introduction period to the industrial growth period, new energy vehicle technology is also closely related to SiC, the rapid development of the new energy automobile industry, greatly promoted the development of SiC industry and technological innovation, A large number of data samples are provided for the technical verification and update iterations of silicon carbide products. It can be said that the acceleration performance of new energy vehicles is closely related to the maximum power and maximum torque output of the power system, and the silicon carbide (SiC) technology allows the drive motor to withstand greater input power at low speeds, and is not afraid of the thermal effect and power loss caused by excessive current. This means that the drive motor can output more torque to enhance acceleration when the vehicle starts [5], although the cost of SiC devices is slightly higher than that of silicon-based devices The use of SiC devices can achieve a significant reduction in battery cost and an increase in cruising range, thereby reducing the cost of the whole vehicle. Therefore, from the cost point of view, SiC devices have advantages. SiC is also helpful for new energy vehicles to achieve lighter weight and simplicity, because the SiC material has high carrier mobility and can provide higher current density, so the package size is smaller at the same power level It can be seen that the inverter made of SiC has a smaller size and lighter weight, and is favored by more and more new energy vehicle brands.

2.2. GaN

The third generation semiconductor gallium nitride based electronic devices have gained the more and wider status in the industry[6].Among them, the use of GaN made of chargers has the advantages of small size, fast charging, etc., many of the fast charging chargers widely sold on the market are made of GaN, and the characteristics of the third generation of semiconductor materials are the same, it has the advantages of high switching frequency, large band bandgap width, lower on-resistance and so on, compared with traditional fast charging GaN fast charging has a greater power density, its charging speed is faster, small size and easy to carry, these advantages are well met by consumers for electronic products charging fast and lightweight dual requirements. This year, the fast charging market takes 55W to 65W as the mainstream power band. Benefiting from the demand for fast charging from electronic products such as mobile phones, the power market size for GaN is also growing rapidly. According to the latest survey by TrendForce Consulting, a global market research organization, the output value of the third type of power semiconductors will grow from 980 million US dollars in 2021 4.71 billion US dollars in 2025, of which the market size of gallium nitride power semiconductors will reach 1.32 billion US dollars in 2025. [7]

With higher spontaneous polarization coefficient and larger piezoelectric coefficient, it can withstand higher power density, which is suitable for high frequency, high temperature and high power electronic devices [8].GaN also has broad prospects in the new energy automobile industry, taking fast charging as an example, as with the consumption of electronic fast charging, electric vehicles also have extremely high fast charging demand, based on the special performance of GaN, the use of GaN can greatly shorten the charging time, and its light weight and small volume characteristics are also conducive to the development of electric vehicles. At present, the low range of electric vehicles and the problem of fewer charging piles still make electric vehicle owners feel distressed, and GaN power semiconductors are expected to help this problem.

GaN is also used in the field of lasers and detectors, GaN-based lasers have a wide spectrum coverage, which can realize the manufacture of blue, green, ultraviolet lasers and ultraviolet detection. Blue laser is mainly with the green laser, red laser together to achieve full true color display, to meet the production and application requirements of laser TV [9], purple laser can be used to manufacture data storage disk space is 20 times higher than Blu-ray disc large-capacity disc. Among them, violet laser can be used in medical disinfection, fluorescence excitation light source and so on. GaN-based ultraviolet detectors have great advantages in anti-interference, anti-harsh environment, high sensitivity, and can be applied in high-speed flight object early warning, nuclear radiation monitoring, chemical and biological detection and other fields, but the current progress is in theory, and there is still a distance from industrialization.

2.3. Diamond

Diamond as a cutting tool and heat sinking is a material that we are more familiar with, but the use of diamond materials as an application of electronics and optics is a subject of research in recent years, with a very broad application prospect. Diamond is a wide bandgap (5 5eV) Semiconductor materials, similar to other third-generation semiconductor materials, have very high breakdown electric fields, and high temperatures and electron hole pairs under the radiation line rarely occur, and the properties of diamond are in semiconductor materials It is also very prominent, for example, its thermal conductivity is the highest, in the wide-bandgap material, the electron and hole mobility of the diamond material is the highest, and its breakdown electric field is SiC 3 to 4 times, 10 times that of GaN; The thermal conductivity is 4 times that of SiC and 15 times that of GaN[10].

The application of diamond is mainly in the field of microwave and optoelectronic devices, mainly using single crystal and thin film technology, from a technical point of view, diamond thin film semiconductor research is mainly divided into two technical pathways, one is epitaxial growth doped diamond single crystal film, generally using homogeneous epitaxy, Because so far, it has been found that good diamond heteroepitaxial results can be obtained on cubic boron nitride, but high-quality cubic boron nitride is not easier to prepare than diamond single crystal; The second is to grow diamond semiconductor polycrystalline film on a non-diamond substrate, and the application direction of this technology is mainly in semiconductor devices, especially traditional semiconductors cannot be applied to high temperature, high voltage, high frequency, strong radiation, high power microwave solid devices. of course, the research and application of diamond thin film semiconductors still face many economic and technical problems, such as the preparation of high-purity gold diamond single crystal film, heterogeneous epitaxy, and the design, production and packaging technology of diamond semiconductor devices, etc., which still need to be studied and solved.

3. Comparison of some performance between SiC and GaN

SiC and GaN power electronic devices have their own advantages and immaturity due to their own material characteristics, so there are differences in application. The general industry consensus is that SiC is suitable for high voltage and high power applications above 1200V; GaN devices are more suitable for high frequency applications from 40 to 1200 V. SiC and GaN compete in 600V and 1200V device applications.

The following Figure1 shows the partial performance comparison between the new semiconductor material SiC and GaN

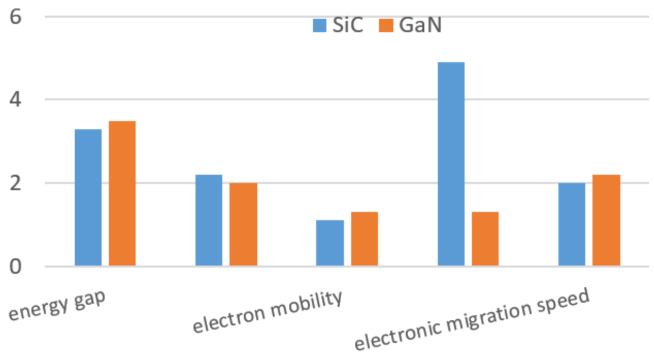

Figure 1. partial performance of SiC and GaN

Obviously, the performance of SiC and GaN materials is better than that of elemental silicon, and GaN and SiC have their own advantages and disadvantages in material properties, so they have their own emphasis and complementarity in the application field. At present, GaN components are often used in fields below 900V, such as chargers, base stations, 5G communication related and other high-frequency products; SiC is a voltage greater than 1200V, such as electric vehicles, electric vehicle charging infrastructure, solar energy and offshore wind power and other green energy power generation equipment. Today's battery power system of electric vehicles is mainly 200V-450V, and more high-end models will develop towards 800V, which will be the main market for SiC.

4. Conclusion

The discovery and research of semiconductor materials has promoted the rapid progress of industry and industrial technology in the world, providing important opportunities for the transformation and upgrading of traditional equipment. After the efforts of several generations of scientists, the third generation of semiconductor materials has gradually become the mainstream, and plays an important role in emerging industries such as big data, the Internet, and intelligence, and its advantages of energy conservation and environmental protection have also been recognized by relevant protection organizations and consumers. The global energy technology revolution has opened and penetrated into the field of materials, the third generation of semiconductors has a good development prospects. Based on the good performance of the third generation semiconductor,it will play an important role in the future development of science and technology.

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