Application of GaN in 5G Technology

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Abstract—With the progress of informatization, the development of communication technology and the wide application of wide bandgap semiconductors represented by GaN, the application of GaN in 5G technology has received increasing attention. In this paper, various characteristics of GaN application in 5G technology were emphatically introduced and a detailed analysis of these characteristics was conducted on the basis of the GaN application in 5G technology via literature searching and combining what we have learned. In addition, the development and innovation of GaN power devices in recent decades and some problems encountered at the present stage were explained and a certain prediction of the GaN application in 5G technology were proposed that this area will be a great part of industry in 21th century.

1. INTRODUCTION
In recent years, with the rapid development of 5G communication, the requirements for hardware of 5G base stations are also increasing. 5G communication, which aims to further improve the transmission speed of signals, is designed to increase the transmitting power to improve the signal-to-noise ratio, so as to transmit increasingly accurate signals. Therefore, in order to obtain a high power signal, a signal with a sufficiently high frequency will be required. Therefore, the development of the third-generation of wide bandgap semiconductors has become crucial [1].

In this paper, GaN will be taken as an example to explore the application of third-generation semiconductor in 5G technology. The advantages of GaN characteristics in 5G technology will be analyzed on the basis of the characteristics of GaN itself, and the incomparable superiority of GaN in 5G technology will be explained. Afterwards, the development process of GaN is going to be described and the deficiencies and defects of GaN application in 5G technology will be explained. In the end, the future development trend will be predicted and estimated correspondingly.

2. GAN IN 5G TECHNOLOGY
Third-generation semiconductors generally refers to wide bandgap semiconductors such as silicon carbide and gallium nitride possessed with the characteristics of large forbidden bandwidth, high electron saturated drift velocity, small dielectric constant, and excellent electrical conductivity, which are suitable for manufacturing anti-radiation, high frequency, high power and high density integrated electronic devices. Therefore, they can be applied in the manufacture of high power radio frequency devices in 5G base stations and power electronic devices in circuits [2].
Figure 1 GaN crystal’s hexagonal wurtzite structure

2.1 GaN
GaN is an extremely stable compound and a direct bandgap semiconductor with a very wide bandgap (3.4eV) compared with other material, which can be seen in Table 1. It is also a hard material with a high melting point of about 1700°C. GaN crystals usually have hexagonal wurtzite structure under atmospheric pressure. These tremendous characteristics have created good conditions for its application in the field of 5G technology.

2.2 Various Characteristics of GaN Devices Applied in 5G Technology

1) High pressure resistance and radiation resistance
GaN crystals are possessed with stronger chemical bonds, thus they are capable to withstand electric fields numerous times higher than those of silicon devices without collapse. Therefore, it is possessed with the characteristic of high pressure resistance; the bandgap width of GaN is large, electrons are not easy to be excited to the conduction band, and interference signal has little effect on the device, thus it is resistant to radiation. These characteristics permit the device to resist higher voltage in order to emit the 5G signals with higher power. Besides, its radiation resistance allows the signals away from other disturbing signals, keeping the 5G signals in a relative steady circumstance, capable to transmit the information more accurately.

2) High frequency
The gate charge of GaN is relatively low, and the gate charge must be supplemented in each switching cycle. So the lower the gate charge it is, the more likelihood the device can achieve the state of high frequency. GaN is capable to work at a frequency as high as 1MHz without loss of efficiency, but this excellent performance can’t be kept when it comes to other material, for example, the silicon is difficult to reach more than 100 kHz; In addition, GaN has a strong chemical bond and high loading capacity, so the distance between each electrical terminal of the transistor is shortened many times, thus the conversion time of electrons is shorter. Moreover, the bottom of the conduction band of GaN is at the \( \Gamma \) point, and the energy difference between it and the other energy valleys of the conduction band is large, thus it is not easy to produce inter-valley scattering, and the electron drift rate is not easy to be saturated as well. Coupled with the heterojunction formed by GaN and semiconductor materials such as AlGaN, a two-dimensional electron gas will be formed, which has high mobility [3,4]. Therefore, its electronic devices are possessed with faster switching characteristics. In addition, such a characteristic will play a significant role in 5G application for a fast calculation speed [5].

3) High operating temperature
Since GaN has a vastly wide bandgap, the intrinsic excitation of GaN is weaker than other narrow bandgap semiconductors at the same temperature, and thus its device has a higher signal-to-noise ratio for signal transmission. Therefore, it has a higher operating temperature, and this property is of great significance for the circuit to operate under higher power with a higher temperature condition, such as the 5G base station. In addition, GaN has high thermal conductivity and excellent heat dissipation performance, which are conducive to its operation under high temperature conditions.

4) Low energy loss
GaN has a high pressure-bearing energy level, thus the distance between each terminal of the transistor can be designed to be shorter, which is possible to achieve lower resistance loss. In addition, the high mobility and high carrier concentration also decrease the resistivity, therefore, the electronic devices get low conduction resistance and further reduces the resistance energy loss. This character can reduce the energy consumed on 5G signals transmitting, making it possible to realize the idea that the lower energy it consumes, the higher power the signal it emits.

**TABLE 1 COMMON SEMICONDUCTOR MATERIAL’S CHARACTERISTIC PARAMETER**

| Material | Bandgap (eV) | Breakdown Electric Field (V/m) | Electron Mobility (cm²/Vs) | Pyroconductivity (W/cm • K) | Saturation Electron Drift Rate (10⁷ cm/s) |
|----------|--------------|-------------------------------|---------------------------|-----------------------------|------------------------------------------|
| Si       | 1.12         | 0.3                           | 1500                      | 1.5                         | 1.00                                     |
| GaAs     | 1.43         | 0.4                           | 8500                      | 0.46                        | 1.00                                     |
| GaN      | 3.39         | 2.0                           | 1250                      | 1.3                         | 2.20                                     |

2.3 Development of GaN power devices

GaN is a kind of III-V group compound semiconductor material synthesized by Jonason et al. in 1928; The most remarkable exploit of GaN materials was that in 1991, Akasaki Isamu, Amano Hiroshi and Nakamura Shuji invented blue light LED based on the GaN. And they won the Nobel Prize in Physics in 2014 for their invention of this, which take a long-lost blue light to human illumination. This breakthrough also allowed the world to see the future and potential of GaN, and it has also begun an unprecedented development in the field of power devices. In 1999, a research in California Institute of Technology has reported GaN SBD power rectifier. Also, there were new developments in Florida State University and Auburn University subsequently. At the same time, the exploration of GaN in power switching also kept moving forward. In 2000, University of Southern California adopted P-type GaN Grid to realize an enhanced AlGaN/GaN HEMT, and breakthroughs have been made in this technology in Japan, Hong Kong, etc. The biggest development of GaN power devices is undoubtedly the rapid development in the past ten years. With the rapid progress of informatization and the research of 5G technology, GaN power devices have gradually come into the view of the public. In 2010, IR Company released the first GaN-based power device on the market, which also heralded the beginning of the marketization of GaN power devices. In 2011, MicroGaN released a 600V GaN-based HEMT. In 2013, Panasonic and Sharp Corporation in Japan successively introduced Schottky diode products with a withstand voltage of 600V. Next, companies, such as MicroGaN and Transphorm, introduced their own GaN power device products with a withstand voltage of up to 1,200V. Nowadays, with the continuous development and promotion of 5G technology, GaN power devices are in a stage of rapid development and entry rapidly into the market. The application of 5G technology in a series of communication companies such as Samsung and Huawei has made GaN the new darling of the present semiconductor industry and one of the hottest topics in the 21st century.

2.4 Problems to be solved and shortcomings

There are still numerous shortcomings in the application of GaN in 5G, such as the shortage of raw materials. Gallium nitride is a substance that does not exist in nature, and it is completely artificially synthesized. To obtain high-quality and large-size GaN seed crystals, it will take several years to grow a two-inch seed crystal by applying the ammonia heating method directly [6]. Due to its long reaction time, slow reaction speed, excessive reaction by-products, and extremely complex technology, its production capacity is extremely low. In addition, the cost of gallium nitride packaging is extremely high as well. Gallium nitride is mainly packaged in cermet, and the packaging cost accounts for one-third to half of the entire device cost. The industry has tried pure copper, cavity plastic packaging and other forms to replace cermet packaging. However, the cermet packaging is still the first choice for GaN devices due to its heat dissipation and reliability.
2.5 Future forecast
In the future, with the development of the industry chain, the GaN industry is going to be more mature. And under the condition of mass production, the shortage of raw materials seems not to be a big problem. Besides more new materials which have gorgeous characteristic with low-cost will be discovered and the packaging cost accounts become lower, which will also promote this industry to industrialize and marketize. In the future, 5G technology is indispensable, and even to the later 6G and 7G, GaN will play an extremely important role. As can be seen from the market and relevant policies of the government, the development of 5G technology and wide bandgap semiconductor devices has become an unstoppable trend. As a representative of wide bandgap semiconductors, GaN is bound to play an increasingly important role and apply in tremendous fields.

3. CONCLUSION
As can be seen from the above, GaN has a good performance in 5G technology due to its radiation resistance, high voltage resistance, high frequency resistance, high working voltage and low energy loss and other characteristics, and it is mainly applied in the fields of power radio frequency devices and highly integrated electronic devices. After decades of development, GaN and other wide bandgap semiconductors have also enter into their spring. Especially in the past ten years, due to the rapid development of 5G technology, GaN has achieved unprecedented achievements in the development of these fields. It is believed that gallium nitride will play an increasingly important role in the following decades, and its application in 5G technology will become increasingly mature and common.

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