PHYSICAL AND ELECTRICAL PROPERTIES OF WIDELY USED AND PROMISING SEMICONDUCTOR MATERIALS

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ABSTRACT

Modern and promising semiconductor materials (silicon (Si), silicon carbide (SiC), gallium nitride (GaN), diamond, gallium oxide (Ga2O3), aluminum nitride (AlN), bor nitride (BN) have been analyzed in literature in terms of import substitution and use of existing microelectronics products in the creation of new ones.

Keywords: silicon (Si), silicon carbide (SiC), gallium nitride (GaN), diamond, gallium oxide (Ga2O3), nitride aluminum (AlN), bor nitride (BN), power microelectronics.

INTRODUCTION

One of the areas of electronics that is rapidly developing and requires the advance of science is power electronics. Currently, about 40% of the world's energy is consumed in the form of electricity and plays a key role in the production-storage-distribution cycle of power electronics. The range of power electronics products is very wide: induced heating devices, frequency modifiers, soft switching electrical appliances, contactless devices for replacing power sources, automotive electronics, railway power modules, radar stations, and so on. At the same time, consumer demand for the final product is growing steadily. They need to work faster and in more difficult conditions, their size and price should fall.

Silicon-based power electronics gradually meet the growing requirements for the functionality, mass, size, duration and reliability of converter devices. The development of electronics in general, especially power microelectronics, comes with the introduction of new technologies and semiconductor materials that can improve the efficiency and reliability of converters. It should be noted that silicon (Si) and Gallium arsenide (GaAs) remain the dominant semiconductor materials in power electronics, but they have significant limitations on their ability to change voltage, working temperature, switching frequency, etc. The subsequent development of microelectronics requires the transition from silicon to broad-zone semiconductors, which are superior to silicon in terms of a number of electrical properties and represent the most suitable class of basic semiconductor materials for extreme power electronics. Specifically, zone width larger than Si and GaAs has the following advantages:

- the size of the working temperature
- the ability to create devices with visible diaphragms and devices that emit light based on these materials;
- breakdown of high areas;
- radiation resistance.

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Table 1. Physics and electrical properties of publicly applied (Si, GaAs) and promising semiconductor materials (wide zone SiC, GaN, Ga2O3 and very wide zone diamond). α - mobility along the axis.
Mobility along the c- c axis.

Material	Forbidden zone width E_g House	Concentration of private charge carriers (cm-3)	Relative dielectric synchronization ε_r	Electron Mobility μ_n sm2/(v*s)	Power of migration E_c (MV/cm)	Electrons' satiation dreyf speed ns, 107cm/s	Thermal conductivity Λ, Vt/sm*k	Debay temperature ΘD, K
Materials applied in bulk								
Yes	1,12	1,5 ·1010	11,8	1350	0,25	1,0	1,5	650
GaAs	1,42	1,8 ·106	13,1	8500	0,4	1,2	0,55	350
Newly introduced spacious materials								
4H-SiC	3,26	$8{,}2 \cdot 10^{-9}$	10	720a 650c	2,0a	2,0	4,5	1200
2H-GaN	3,39	1,9 ·1010	9,9	1000a 2000**	3,3*	2,5	2,5 4,1*	600
Promising Spacious Zone Materials								
Ga2O3	4,5-4,9	$2{,}6 \cdot 10^{-19}$ $1{,}2 \cdot 10^{-22}$	10	300	8	1,0	0,13-0,21	240
Elms	5,45	$1{,}6 \cdot 10^{-27}$	5,5	2800	10	2,7	22	1850
2H-AlN	6,2	$\sim 10^{-34}$	8,5	300	12*	1,7	2,85	1150

* Approximate value.
**2DEG - two-dimensional electronic gas.

Currently, the most studied representatives of wide-zone semiconductors are silicon carbide (SiC), Gallium nitride (GaN) and diamonds. In this analysis, we will consider the most promising, according to the authors [1] broad zone semiconductors, whose use allows for the creation of electronic and microelectronic technology products with parameters that significantly exceed existing silicon analogues.

The most promising wide zone semiconductor materials (SiC, GaN, Ga2O3, diamond and alN) are listed in Table 1. The strength of the critical piercing area (Es) in Table 1 increases as the width of the forbidden zone increases (Eg). The massive introduction of sic and GaN of new wide-zone semiconductor materials, the critical piercing area, constitutes a larger order than that of silicon, which dominates the market. In addition, thermal conductivity of SiC and GaN is 3 and 1.5 times better than Si, which makes them very consumer-switching devices for power switching devices.

The value of debay temperature can be considered as the characteristic of a high temperature chegra for the performance of devices based on this material. It should be noted that Td GaN is lower than SiC. In addition, there is a whole class of broadband materials (II-VI), for which it is even lower than the GAN. This condition explains that so far it has not been possible to produce high-powered, high-temperature devices based on II-VI compounds, despite the fact that their energy tires are wider.

Currently, the attention of manufacturers of world power semiconductor devices is primarily focused on two new materials with a widely prohibited zone - silicon carbide (SiC) and Gallium nitride (GaN). Demidov's A.A. work [1] shows various current characteristics for Si, 4N-SiC and GAN, as well as comparative characteristics of basic electrophysical characteristics. Improving and developing the methods of sublimational cultivation of crystals has enabled the development of a technique to cultivate mass monocrystals for new wide zone SiC and GaN materials to replace dominant silicon in the field of extreme power electronics. Currently, almost all types of products based on SiC and GAN are developed like classic Si (see chart 2), but, due to the significantly higher price of final products, their mass introduction is being delayed.

According to IHS Technology, The SiC/GaN-powered semiconductor devices market [2], whose growth is stimulated by increased use in energy sources, photovoltaic converters and industrial electric drives, has increased 18 times in a decade (from 2012 to 2022), from 143 million to $2.8 billion.

Table 2. Basic materials used in microelectronics products [1]

Product type		GaAs	Yes	SiC	By
Very high frequency	Transistors	70 GGts gacha	6 GGts gacha	8 GGts gacha	110 GGts gacha
	Diodes	+	+	+	+
	IS	+	+	-	+
Quvvat Electronics	Transistors	-	+	+	+
	Diodes	-	+	+	+
	Modules	-	+	+	+
	Drivers	-	+	+	+
SBIS		-	+	-	+
Svetodiodare		-	-	-	+
MEMS		+	+	-	+
Solar elemets		+	+	-	-

Carbide silicon (SiC). According to a number of authors[1,2,3], sis in general is a much more promising material for creating high-power devices compared to GaN and other nitrides (III – N). A comparison of the main electrical parameters of silicon carbide semiconductors 3C-SiC, 6H-SiC, 4H-SiC and semiconductor material GaN are presented. The number of charge carriers on GaN- limits the latter's application to the creation of bipolar devices during the long period of residence, which is pritsipially inaccessible (due to high probability of radiation recombination). Low thermal conductivity of unipolar devices and low Debay temperatures reduces maximum power consumption. In other electrophysical indicators (carrier saturation rate, decomposition area (pole proboscis), mobility, mass GaN also has no significant advantage over silicon carbide. Nevertheless, Because gaN Scottki diodes are significantly cheaper, they can be competitive with SiS SHottki diodes at a power of up to 1000 V.

SiS is widely used as the basis for light emitting diodes in the visible range of light in optoelectronics, as well as transistors capable of working in high-power diodes and harsh conditions, such as high temperatures, passing radiation and electrical and magnetic fields. In recent times, serious attention has been paid to the prospects for using SiS to create quantum amplifiers (mazers).

The sources of single photons in silicone vacancies running at room temperature in the infrared (IQ) range, which is important from the point of view of its use in medicine, are also of great interest [3]. The 4N-SiC-based Shottki Diodes (SHD) are already gradually replacing high-voltage rapidly recovering diodes (BVDs) based on silicon. The main drawback of creamy BVDs is that they work with non-core carrier injections, and the accumulation of non-core carriers on the device limits its switching speed. In an existing silicon SHD, although they exchange quickly and work without injections, the reverse voltage they are able to block does not exceed 200 V. In 4H-SiC, the area of the 4H-SiC landfill is in higher order than the silicon. This allows the prohibition base to achieve a large reverse voltage with a relatively high alloy rate, and the high alloy level, in turn, provides relatively low resistance in the right direction.

In the coming years, we must anticipate an expansion of the application area, primarily for devices with large range materials based on 4H-SiC . High-powered 4H-SiC diodes and key-type 4H-SiC transistors are promising to create small-scale power converters in a wide range operating with high power density due to high conversion frequency, allowable high working temperatures and simplified cooling. High-powered impulse 4H-SiC diodes must be in demand in new communication and information transmission systems (pulsed ultra broadband radio), ultra broadband radars, and impulse energy systems. The key to the wider use of SiC is the search for more economical technologies for the production of monocrystal structures, which makes it possible to produce plastics with optimal dimensions for mass production.

According to The Yole Development forecast, sales volumes of the SiC-based power electronics market will reach $2.5 billion by 2025, while the sales growth rate from 2021 has begun to grow significantly and will be 50% by 2025.

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