مجلة جامعة صنعاء للعلوم التطبيقية والتكنولوجيا
Sana'a University Journal of Applied Sciences and Technology
https://journals.su.edu.ye/index.php/jast/
SUN PUBLISHER

Power Electronics Development Trends

R. M. Al-Bouthigy [1] * and H. AL Makleh[2]

[1]**Department of Electrical, Faculty of Engineering, Sana'a University, Sana'a, Yemen,**
[2]**Department of Mechatronics, Faculty of Engineering, Sana'a University, Sana'a, Yemen**

*Corresponding author: r.albouthigy@mail.com

Abstract

Power electronics and high-power semiconductor devices are of great importance in the national economy and are closely related to other industries. They can be considered a supporting infrastructure that ensures the functioning of different sectors of the economy. Currently, the main consumer of power electronics products is the manufacturing industry. In the future, the automotive industry may take the palm from it - due to the expansion of the use of electric/hybrid cars, as well as autonomous vehicles. The paper points out the relevance of power electronics to various industries and also assesses the transition from silicon-based devices to the advanced GaN and SiC technologies. The review looks at the trends in the power electronics market, with special attention to industrial and automotive, together with a glance at the growth in demand derived fromelectric and hybrid vehicles. Aside from that, further development of GaN-on-SiC technology and its prospects for application to high-power electronic devices are included in this work.

Article Info

Keywords:
Power electronics, Gallium(GaN) devices, Silicon carbide (SiC) devices, General trends

Article History:
Received: 18-January-2025,
Revised: 2-February-2025,
Accepted: 3-February-2025,
Available online: 30 April 2025.

1. INTRODUCTION

Power electronics is interconnected with other industries. On one hand, its development impacts other industries, opening up new opportunities for them. On the other hand, the development of existing industries and the emergence of new ones have led to an increase in energy consumption and stimulated the development of power electronics and high-power semiconductor devices, with an emphasis on increasing energy efficiency. The main areas of use for power electronics and high-power semiconductor devices include industrial electric motors, wind turbines, solar technology, charging infrastructure, electric/hybrid vehicles, the railway industry, high-voltage power lines, and uninterruptible power supplies.

Progress is also being observed in the area of power semiconductor devices. The currently dominant silicon devices will be replaced in the future by GaN and SiC devices.

Moreover, it is possible to develop a sector of GaN-on-SiC devices that combines the advantages of both technologies and promises to become a promising direction for the development of high-power semiconductor devices. This paper highlights the relevance of power electronics to various industries and also assesses the transition from silicon-based devices to advanced GaN and SiC technologies. This review looks at the trends in the power electronics market, with special attention to the industrial and automotive industries, together with a glance at the growth in demand derived from electric and hybrid vehicles.Further development of the GaN-on-SiC technology and its prospects for application in high-power electronic devices are included in this work

2. POWER ELECTRONICS MARKET

2.1. General trends

Two research firms, Yole Development (Lyon, France) and System Plus Consulting (Nantes, France), which are members of the Yole Group of Companies, recently conducted a joint study of the current state and prospects for the development of the power electronics market. This study confirmed that the majority of manufactur-

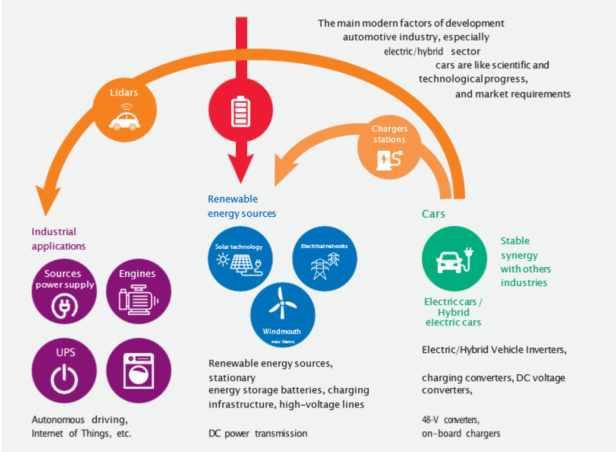

Figure 1. Key factory and tendentious of development power electronics. Source: Status of the Power Electronics Industry 2019 report, Yole development, 2019

ers and the largest sales volumes of power electronics currently focus on industrial enterprises. However, the explosive development of electric vehicles and hybrid vehicles expected in the coming year's funds, as well as the corresponding infrastructure, will lead to a significant change in the situation. By 2024 and beyond, automakers are expected to consume an increasing share of power electronics. True, because electric vehicles and hybrid vehicles are focused on reducing power consumption, and for industrial electronics these requirements are not so significant, the share of industrial electronics in energy consumption will exceed the share of the automotive industry. It is noted that in modern conditions, the main factors in the development of the automotive industry, especially the electric vehicles/hybrid vehicles sector, are both scientific and technological progress and market requirements (Fig. 1) [1, 2].

3. MUTUAL INFLUENCE OF POWER ELECTRONICS AND OTHER INDUSTRIES

The development of the power electronics market also has an impact on other markets and areas of human activity.

Increasing energy consumption and the development of environmentally friendly vehicles create a need to expand electrification, increase the use of renewable energy sources, etc. To service electric vehicles and hybrid vehicles, it is necessary to expand the network of charging stations both in cities and outside them. Considering that large stations will be needed on highways to quickly charge many vehicles at the same time, the need for the development of electrical networks becomes obvious.

To better meet the electricity needs of power grids, it is also necessary to develop the energy storage systems sector. It is planned to deploy large solar panel systems near charging stations.

However, the issue of using renewable energy sources to power electric vehicles and hybrid cars is questionable. Until now since then, the price of "solar electricity" produced by solar technology has been significantly higher than that of gas or coal power plants. And fields of solar panels take up a lot of space. As for wind turbines, their locations become uninhabitable due to infrasound, although their deployment leads to an increase in inverter sales In addition, as autonomous driving becomes more widespread, more data exchange will be required, including via V2X communication systems. V2X (Vehicle-to-Everything) is a generalized name for technology vehicle-to-vehicle (V2V) and vehicle-to-vehicle communications infrastructure (V2I), which are the main unified re-working in a connected car environment. Within this concepts road services, infrastructure, cars, water drivers and other road users must cooperate work with each other to ensure the most effective, safe, reliable and comfortable trip. V2X communication is formed makes one of the main contributions to the concept of cooperative mobilities. V2X communication is based on DSRC radio technology on frequency 5.9 GHz; is a two-way wireless technology short range, designed specifically for moving existing objects. In general, it allows cars to exchange share data with other vehicles and roadside equipment communication, sensors and participants, similar to Wi-Fi communication, but using special efficient network functions, increase the number of data centers, a larger number of radar and lidar systems, as well as other infrastructure support technologies.

Yole analysts highlight the strong synergies between all the sectors mentioned and the growth of the automotive market, in particular, driven by electric/hybrid vehicles [2]. The impact of these factors as a whole will result in sustainable growth of the power electronics industry - its sales will increase from \$53.4 billion in 2018 to \$72.6 billion in 2024 (Fig. 2).

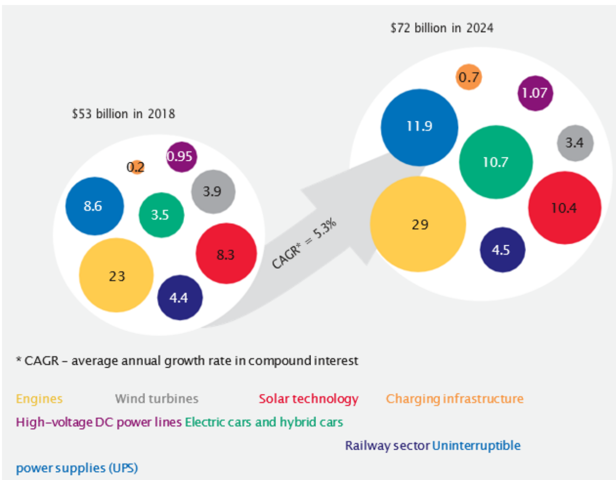

Figure 2. Evolution of the power electronics market over 2018–2024 by application Source: Status of the Power Electronics Industry 2019 report, Yole Development, 2019

4. POWER SEMICONDUCTOR DEVICES

When looking at the market at the device level, it turns out that the largest sales of discrete devices come from MOSFETs. However, the greatest growth is in the high-power sector, which requires insulated gate bipolar transistors (IGBTs) or SiC devices to achieve the desired efficiency. However, according to Yole Development's forecasts, in the period 2024–2030, the CAGR of sales of IGBT and MOS field-effect transistors will be 3.7 and 4.6%, respectively. At the same time, the growth in sales of MOS field-effect transistors is due precisely to the penetration of SiC devices into this market - their consumption in electric vehicles will show the highest growth rates in the forecast period [2].

4.1. GaN and SiC high-power semiconductor devices: proponents' positions

In the long term, GaN and SiC power semiconductors will gradually replace their silicon counterparts, largely because the use of GaN or SiC power transistors can lead to simpler and more efficient energy storage solutions. By 2025, the combined market for GaN and SiC devices is projected to be worth more than $3 billion (GaN System data) and will be heavily dependent on renewable energy sources and electric vehicles. In addition, there are more and more data processing centers (DPCs), hybrid cars, and industrial engines in the world [3].

Power requirements are increasing in every market, with global electricity demand expected to increase from 25,000 TWh today to 38,000 TWh in 2050. In the world, 8 million data centers use 2–3% of global energy consumption, and this share will grow to 5% or more. Industrial applications consume 30% and their energy consumption is also growing. Electric vehicles are becoming large consumers of electricity – in 2040 they will account for up to 5% of global consumption. GaN power semiconductors reduce losses in all of these systems.

GaN technology plays an important role in driving innovation in power semiconductor devices. She allows you to meet new needs, achieve an increase in power and productivity, greater efficiency, and reduced size.

Compared to wide band gap devices such as SiC transistors, GaN devices have several advantages, including in terms of pricing, material availability, and the ability to create designs for low and medium voltage requirements. Current. Systems built using GaN power semiconductors have better power density than systems using SiC devices. Other advantages include low gate charge, zero reverse recovery current, and flat output capacitance. All this ensures high switching performance. Prices for GaN power semiconductor devices are easy to scale so that over time they become competitive with silicon device prices, especially since GaN power semiconductor devices are manufactured on silicon wafers.

Proponents of GaN power semiconductor devices argue that their devices have undergone significant evolution. While a few years ago GaN technology was largely confined to university research laboratories, today established firms such as Denso, GaN Systems, Sonnen, and Supermicro are participating in conferences and discussions and informing the scientific community about How GaN power semiconductors improve the performance of the systems in which they are used. As systems with high-power GaN semiconductor devices begin to be commercialized, there is much more opportunity for innovation in this area. GaN devices with voltages of 100 and 650 V meet the requirements of power systems now and shortly [3].

Returning to SiC power semiconductor devices, it can be noted that their supporters, on the contrary, believe that their technology is superior to GaN technology. Recently, Cree Corporation, a world leader in SiC technology, announced plans to create a "silicon carbide cluster" on the east coast of the United States. It is planned to create the world's largest plant (in New York State) for the production of silicon carbide. In addition, the corporation will build a completely new plant in Marcy, New York. On processing 200 mm wafers on which SiC high-power semiconductor devices for automobiles and SiC high-power RF devices will be produced. Finally, the existing megafactory in Durham, Carolina, for the production of SiC wafers and other materials will be expanded. It is located in the Science Triangle and enjoys the support of the universities located there.

The new plant is part of a previously announced project to dramatically increase the production capacity of Wolf Speed, a division of Cree. This plant will deal with both SiC and GaN technologies. It will be a highly automated enterprise with increased productivity. The project is a strategic partnership with New York State and other state and local agencies and the decision to build in New York will allow for continued future expansion of capacity and significant net cost reductions. at Cree manufacturing facilities. As a result, Cree will continue to make the transition from silicon technology to SiC technology. Its Wolf speed division will produce devices for electric vehicles, 4G/5G communications, and industrial electronics [4].

As part of the partnership, Cree will invest approximately $1 billion in construction, equipment, and other expenses of the New York facility. New York State will provide a $500 million grant through the Empire State Development Investment Fund, and Cree will be eligible for additional local incentives and the use of State University of New York Polytechnic Institute equipment and tools. (SUNY). As a result, the company expects to realize net capital savings of approximately $280 million on its $1 billion capacity expansion investment through

2024. In addition, the implementation of the project will allow for a 25% increase in production volumes compared to previously planned figures. After completion of construction, in 2022, the area of the new facility will be up to 44.6 thousand m2, approximately one-quarter of which will be clean room space that can provide the ability to expand capacity as needed. This will further improve Cree's competitive position in the market and accelerate the adoption of SiC in several high-growth industries [5].

IGBT modules are also experiencing significant growth in sales due to their ability to meet the high-power output and density requirements of major power applications. Today, these modules account for 23% of the total market. New applications such as energy storage systems, charging infrastructure, and electric vehicles will require modules with different power levels and reliability requirements in the coming years, leading to an increase in the diversity of these devices.

5. STMICROELECTRONICS CORPORATION STRATEGY

STMicroelectronics Corporation (Geneva, Switzerland) has relied on SiC technology as an important component of its development and revenue strategy. It intends to capture 30% of the SiC devices market, whose capacity in 2025 will be $3.7 billion (STMicroelectronics data).

SiC is one of the wide bandgap technologies increasingly used by semiconductor suppliers to create high-power, high-efficiency vehicle electrification solutions. However, due to supply constraints and ecosystem issues such as the global shortage of SiC wafers, STMicroelectronics is taking several steps to ensure control of the entire supply chain. Such steps include a recent agreement with Cree to guarantee the supply of 150mm raw and epitaxial SiC wafers by its division, Wolf Speed, as well as the purchase of a 55% stake in Swedish SiC wafer manufacturer Nortel to eventually consume her completely.

STMicroelectronics management believes that in 30 years more than 50% of the market for power semiconductor devices will be produced based on SiC technology. Currently, the company purchases ingots and substrates externally, and their processing is carried out at a plant in Catania (Italy). STMicroelectronics already has plans to integrate Nortel into its supply chain. The collaboration with Cree also increases STMicroelectronics' flexibility and integration capabilities. Currently, sic devices from a Swiss company are produced on wafers with a diameter of 150 mm. After the final takeover of Nortel and its associated research facilities, they are planned to be transferred to work with wafers with a diameter of 200 mm (by 2025).

At the end of 2018, the income of STMicroelectronics in the field of SiC technology amounted to $100 million,

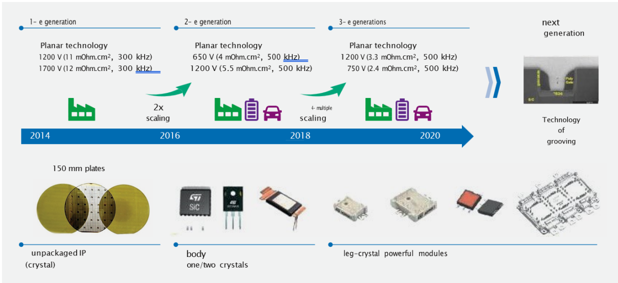

Figure 3. Development route mapSiC technologies. Source: STMicroelectronics

in 2019 it is expected to increase to $200 million, and in 2025 to $1 billion. To achieve the set goals, it will be necessary to modernize and take control of the entire supply chain. The main target markets for STMicroelectronics SiC devices will be the Internet of Things, intelligent driving (autonomous vehicles), power management, and power management. The company's management intends to consistently invest in its developments by the amount of income received.

STMicroelectronics has two problems to solve, at least in the short term: supply chain and cost/cost. Raw material and device suppliers must agree on supply volumes, and SiC device manufacturers must demonstrate that SiC MOSFETs are an energy-efficient solution for electric vehicles.

The second goal is to reduce costs as production increases. There is a need to scale devices, increase the diameter of processed wafers (to reduce unit costs), reduce the cost of materials, and optimize the design of devices/modules. The STMicroelectronics plant in Catania produces both bare ICs and packaged modules. The STMicroelectronics route map for the development of SiC MOSFETs, in 2020 is planned, in parallel with the development of the third generation of planar technology, to master a promising technology for forming grooves (Fig. 3).

SiC is more difficult to process than silicon, which is one of the reasons for rising costs. This, in turn, is a limiting factor in the widespread development and application of SiC technology. In addition, SiC has a high inherent defectiveness, which makes itself felt during the production of the substrate, leading to the need to use a more complex technological process to ensure the required quality and reliability. Since SiC as a material is quite difficult to process, there is a need to use a more complex manufacturing process at the main stages of diffusion operations.

Consequently, SiC devices will be more expensive (silicon devices). However, STMicroelectronics experts point to the ultimate cost savings from their use. For example, in an electric vehicle, SiC devices can initially increase costs by $300, but the final savings can reach $2 thousand - due to a reduction in the cost of battery power supplies, the space they and SiC devices occupy in the electric vehicle, and cooling issues.

The Catania plant not only produces SiC devices but also uses gallium nitride (GaN) technology. Thus, STMicroelectronics is collaborating in the field of GaN-on-silicon technology for 5G tools/systems with Macom Corporation.

STMicroelectronics has been working with SiC technology since 1996, in 2004 the company produced its first SiC devices, and in 2009 the first SiC MOSFETs (available in 1200 and 650 V versions). STMicroelectronics, like several other companies, produces powerful SiC devices for cars, and they are one of the key elements that tailor the electrification of trans-funds. Production The company launched SiC wafers with a diameter of 150 mm in 2017, while, in addition to ICs for automotive applications, STMicroelectronics produces devices for applications such as solar inverters, industrial electric drives, home equipment, source adapters power supplies (power adapters) [6].

6. MASTERING TECHNOLOGY "GAN-ON-SIC" – A PROSPECT?

With the development of new technologies, it often happens that seemingly incompatible approaches can be used together, generating, thanks to a synergistic effect, something new and more advanced. The first mentions of GaN-on-SiC date back to 2002, and data about the beginning of experimental go and mass production - by the beginning of the 2010s. What are the advantages of this technology? It allows you to create high-power transistors that exhibit (in certain ranges) the highest output power and gain in the industry. Moreover, their use makes it possible to reduce the size of systems compared to systems using other previously mentioned technologies.

In principle, GaN-on-SiC technology is more complex and expensive compared to GaN-on-silicon. The main determining factor is performance, not price. That is why its main area of application for the GaN-on-SiC technology is military devices and systems, and wireless infrastructure. It also partially covers such areas as fiber optics, cable television, and small satellite ground stations (VSAT) (Fig. 4).

The main manufacturers of high-power GaN-on-SiC transistors and circuits are Cree, Integra, Microsemi, and microwave & RF corporations. The undisputed leader is the Cree Corporation [7]. Integra Corporation specializes in HEMT RF power transistors for pulsed laser systems [8], Microsemi Corporation produces high-power pulsed GaN-on-SiC transistors for radars [9], and Microwaves &RF Corporation produces GaN-on-SiC high-power HEMT transistors. With a frequency of up to 18 GHz (also for radars) [10, 11].

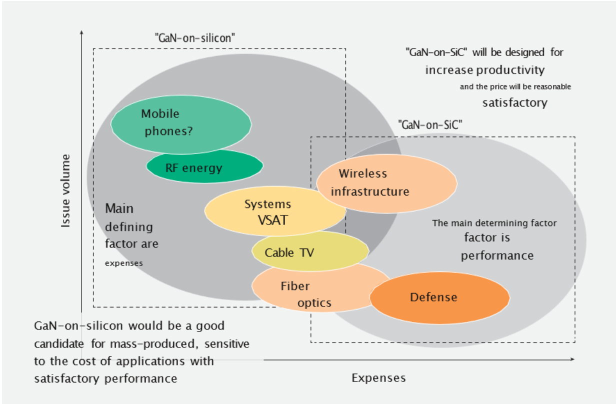

Figure 4. Prospects for using structuresGaN-on-Si and GaN-on-SiC. Source: Yole Development

7. CONCLUSION

The emergence of new industries causes a change in the development paradigm of power electronics and high-power semiconductor devices. In the field of power semiconductor devices, GaN and SiC technologies are gradually replacing silicon technology. The reason is that the use of GaN and SiC transistors can lead to simpler and more efficient energy storage solutions. Interesting prospects are also opening up in connection with GaN-on-SiC technology.

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