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TECHNOLOGY

WIDE BANDGAP

KEY SOLUTIONS WITH SILICON CARBIDE AND GALLIUM NITRIDE

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key solutions with silicon carbide and gallium nitride

The process of converting electric current into AC and DC levels for applications in drive technology or power supplies, for example, has changed considerably over the years.

One of the most drastic changes is the use of the “switched mode”. Switched mode techniques, which are used almost exclusively by semiconductor switches, exponentially increase the efficiency of power conversion. There is now a large selection of circuit breakers available for this purpose: These are IGBTs (Insulated Gate Bipolar Transistors) and silicon MOSFETs as well as “wide-bandgap” devices based on silicon carbide (SiC) and gallium nitride (GaN).

What are wide-bandgap semiconductors?

Without going into the depths of crystal lattice structures and energy levels of a semiconductor, it can be said that the wide-bandgap model is the way electrons (current) flow in a semiconductor of a particular material. It is the energy required to release an electron from the outer atomic shell so that it moves freely in the solid (e.g. metal). In other words, it is the energy difference between the upper valence band and the lower end of the conduction band in a crystalline semiconductor. Table 1 shows the bandgap energy of various semiconductor materials.

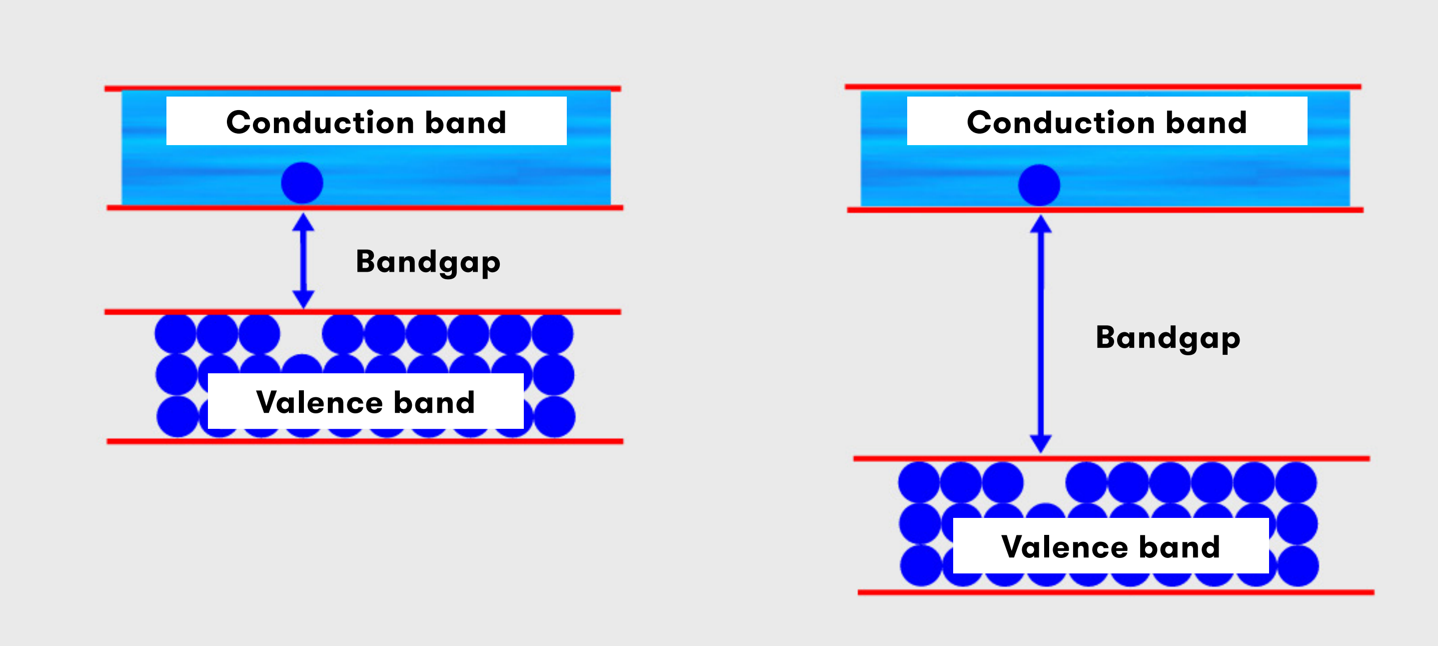

Fig. 1. The bandgap determines the amount of energy required to release an electron from the outer shell so that it can move freely in the solid.

In wide-bandgap semiconductors such as SiC and GaN, the band gap, i.e. the energy difference between the insulating and conductive state (valence band and conductive band), is significantly higher than with silicon. The practical consequences of this wider gap are lower energy consumption. The device can operate at high voltage, high temperature and high switching frequencies.

Applications with SiC and GaN semiconductors therefore have a high power density, smaller dimensions, a high reverse voltage, low power losses, higher EMC compatibility and better failure and temperature behaviours compared to silicon-based applications.

Semiconductor bandgap comparison

Material	**Chemical symbol**	**Bandgap energy [eV]**
Germanium	Ge	0,7
Silicon	Si	1,1
Gallium Arsenide	GaAs	1,4
Silicon Carbide	SiC	3,3
GalliumNitride	GaN	3,4
Diamond	C	5,5

Table 1. Overview of the bandgap energy of various semiconductor materials.

SiC or GaN?

GaN came later than SiC and was slow to take off due to cost, revenue and reliability concerns. Although, in theory, this material can achieve a higher switching speed than SiC or Si with its much higher electron mobility, its power density potential is limited with a thermal conductivity that is three times lower than SiC.

Currently, SiC devices with a rated power of about 650V to 1.2kV and higher are common, while GaN is limited to about 650V. With the current lower cost and proven robustness of the more sophisticated SiC features, GaN struggles to compete with SiC at the same voltage.

Fig. 2 shows the areas of application of the different technologies in terms of power and switching frequencies. It should be noted that the displayed areas show the “approximate” area of application, but technology developments can shift the areas of application. There is a considerable overlap between competing solutions, and the price/performance ratio for different areas of application is not taken into account.

GaN suppliers hope that the low-voltage/electricity market including data centres, EV/HEV and photovoltaics will open up when the promised cost savings do materialise. However, SiC cascodes (series connection of a self-blocking silicon MOSFET and a self-conducting SiC JFET) also address these market areas, especially in applications for bidirectional DC/DC converters and totem pole PFCs. SiC has now established itself well in the supply chain and components feature in the catalogues of high-service distributors.

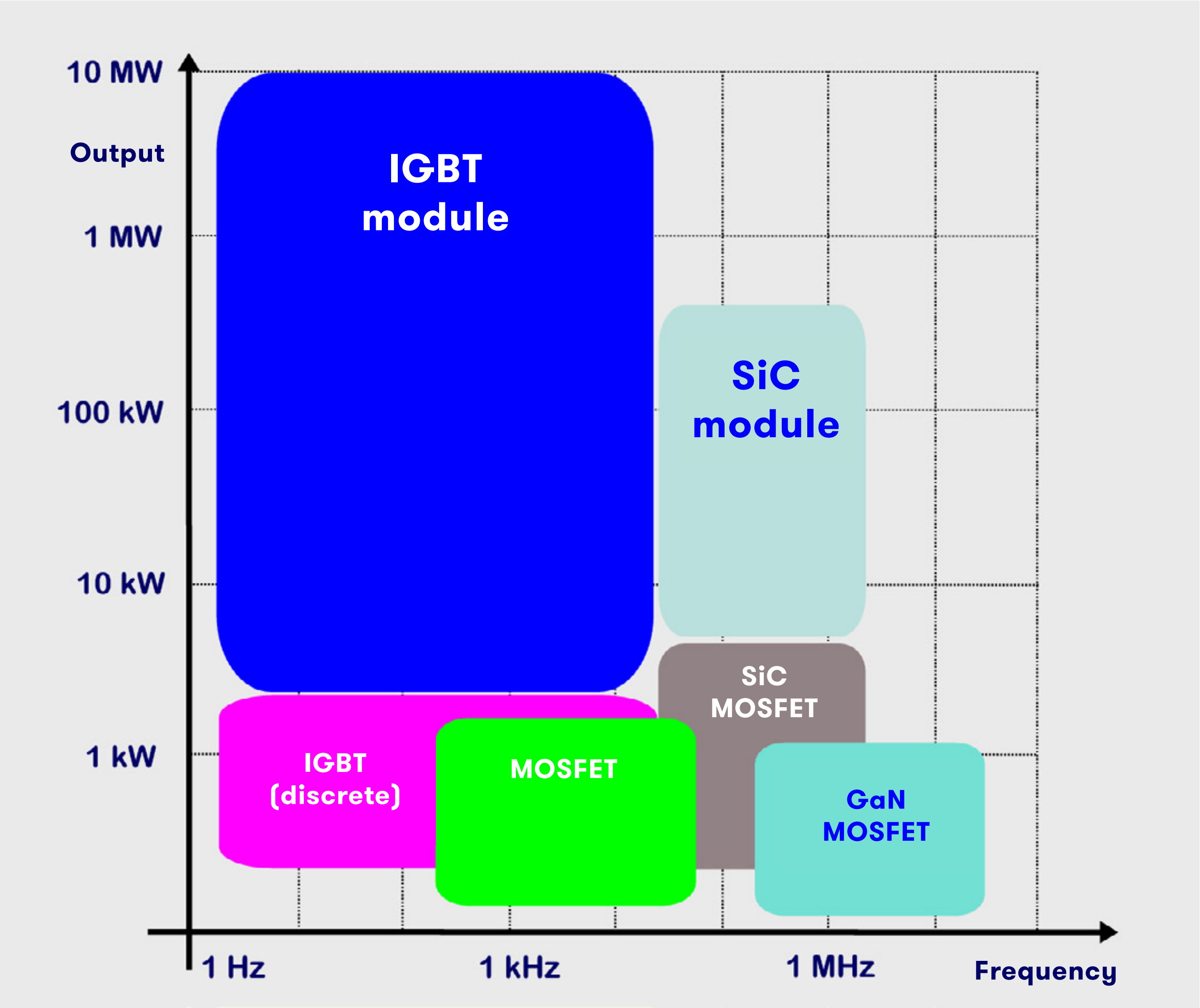

Image 2. Areas of application of the different technologies in terms of power and switching frequencies.

Who supplies what?

The market for wide-bandgap components is reflected with some relevance in the SiC segment. According to market researcher Trendforce, sales of SiC power semiconductors are expected to amount to US$ 660 million in 2021. Forecasts from Yole Développement look like this: US$ 973.4 million in 2022 and US$ 2.5 billion in 2025 (Fig. 3).

The supply chain in the area of SiC wafers is turbulent as a result: the planned acquisition of Cree's Wolfspeed wafer production business unit by Infineon was prohibited by the then US administration. Cree was forced to shut down its LED business and, as Wolfspeed, is now concentrating on wafer and power semiconductor production.

STMicroelectronics has acquired Norstel, one of its preferred suppliers for wafers, and Korean SK Siltron acquired DuPont's SiC wafer business for US$ 450 million. With its €124 million acquisition of Siltectra, Infineon, on the other hand, has acquired a technology that can be used to turn one thick SiC wafer into two thin ones. The ranking in this wafer market is now as follows: Number one with 40% market share is Wolfspeed, followed by II-VI with 35%. Third place goes to SK Siltron.

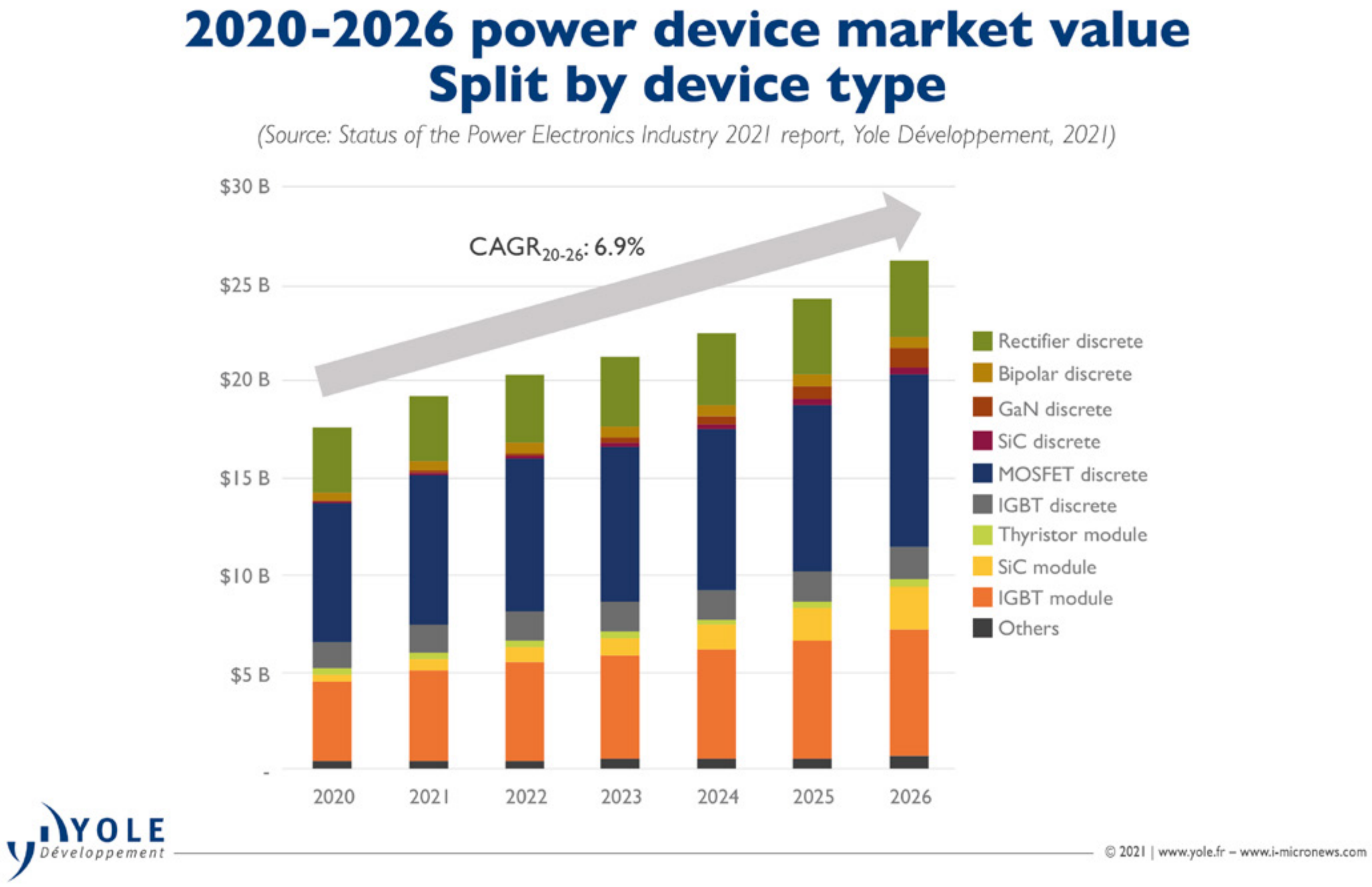

Image 3. The market for power semiconductors, projected until 2026. (Image: Yole)

To stay abreast with this development, the European Union has pledged almost €90 million into funding a consortium to establish a European supply chain for silicon carbide semiconductor technology. Under the consortium leadership of Bosch, the “Transform” project brings together 34 key players from seven countries across the Europe’s entire silicon carbide value chain. The funded project will see the development of new SiC technologies as well as processes and procedures for their production. It will also ensure the availability of machines and systems to produce elements such as substrates and wafers, to the power electronics of European suppliers.

Diamond FETs

As a semiconductor material, diamond has a larger bandgap (Table 1) than SiC and GaN. Its thermal conductivity is also far higher than that of materials currently used in electronics – it conducts heat 22 times better than silicon and five times better than copper. Diamond can isolate high stresses with a fraction of the material thickness that would be required in today’s techniques (Fig. 4). To isolate e.g. 10kV, a 50 times smaller amount of diamond is required than silicon.

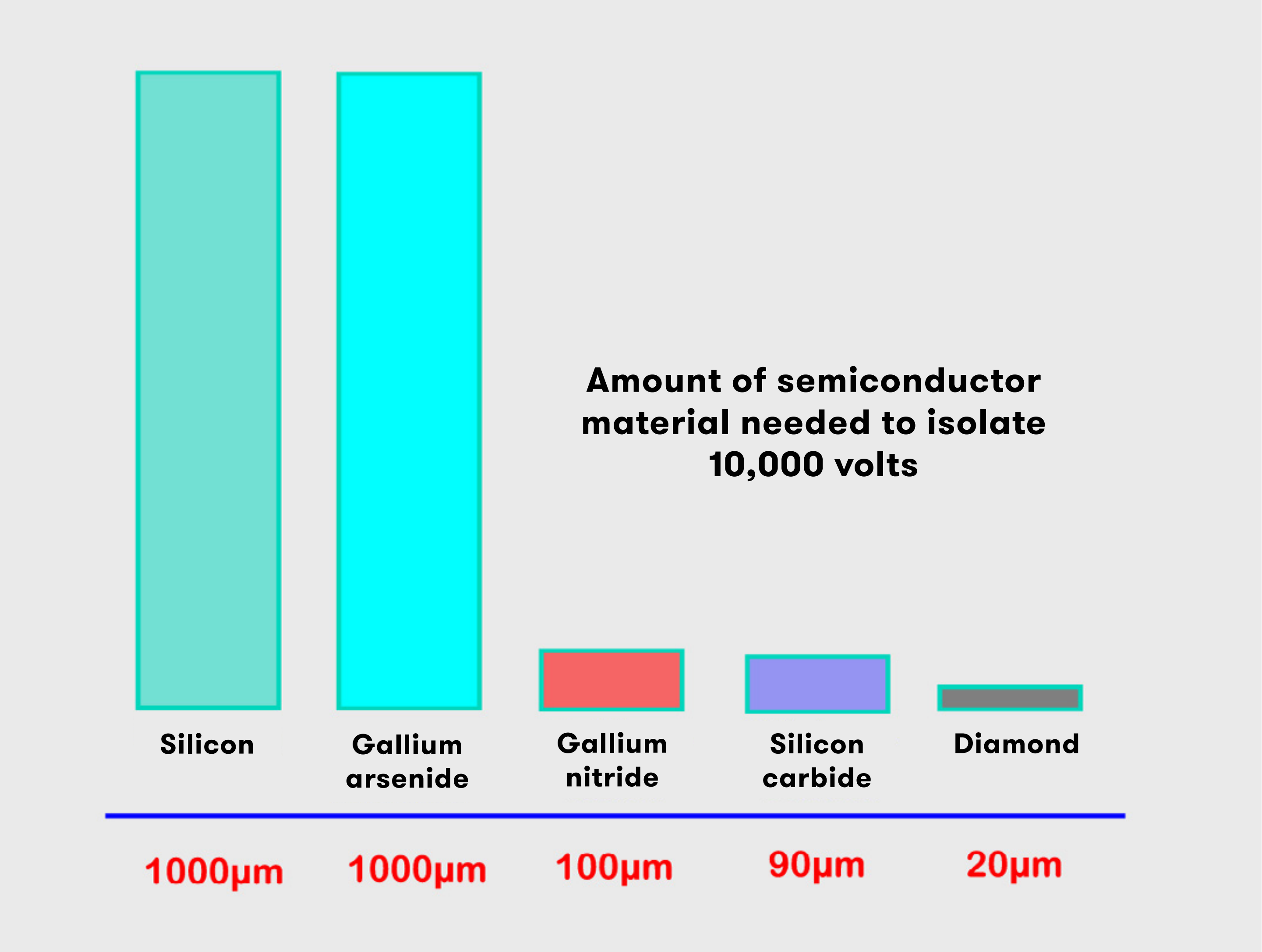

Image 4. Diamond can isolate high stresses with a fraction of the material thickness.

This should ultimately mean that semiconductor chips that are thinner and require less power can operate at even higher temperatures than previously available wide-bandgap semiconductors.

Akhan Semiconductor is committed to diamond semiconductors and is working on the Miraj Diamond platform. However, semiconductor products still do not feature on the company's website, instead there is a particularly resistant "Gorilla" glass for smartphones.

Evince from the UK is another startup pursuing diamond technology: "We have explored a principle that is only possible with diamond – field-reinforced quantum tunnelling – to develop the first all-new electronics concept since the 1960s. Our unique approach combines embedded field emission structures with advanced surface technology to inject electrons directly into diamond with high efficiency. These "free electrons" can then be manipulated within the substrate or extracted for other purposes." Again, the company website does not claim any practical components.

Diamond chips do not seem to be sophisticated enough yet, which is why SiC and GaN technologies are currently thriving in the wide bandgap area.