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Application Readiness Map for WBG-Semiconductor-Based Applications

Markus Thoben[a], Martin Pfost[b]
UAS Dortmund[a], TU Dortmund[b]

Dortmund, Germany
Tel.: +49 (231) 755-4817 +49 (231) 9112-8390
E-Mail: markus.thoben@fh-dortmund.de, martin.pfost@tu-dortmund.de
URL: http://www.fh-dortmund.de, www.tu-dortmund.de

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Keywords

«Wide bandgap devices», «Silicon Carbide (SiC) », «Gallium Nitride (GaN) », «SiC MOSFET»

Abstract

The Power Electronic Conversion Technology Annex (PECTA) application readiness map for Wide bandgap (WBG) semiconductors describes their expected market position up to 2035. It is based on interviews with many experts and different roadmaps and could be used as one basis to decide which power semiconductor technology to choose. This paper presents an updated version and the underlying assumptions.

Introduction

One of the goals of PECTA is to analyze and aggregate informations about wide-bandgap-based power electronic devices and to develop a greater understanding, also among governments and policy makers [1]. One subtarget is the derivation of roadmaps dealing with the integration of WBG components into current applications. **To present an overall view of all markets, a first application readiness map (ARM) was developed in 2020, using the ECPE WBG roadmap as basis.**

In this paper, an update of the ARM is presented. The actual status of the WBG market is considered, changes of roadmap topics will be explained, and additional, now also WBG-relevant market segments are added. To allow a better assessment of the prediction validity of the presented ARM, the most influencing factors are presented and discussed.

Target and description of the ARM

Readiness levels can be defined in many different ways. For example, there is the Technology Readiness Level (TRL), the Market Readiness Level (MRL), and the Adoption Readiness Level (ARL), focusing on the technology, the market, and the adoption risks, respectively,

The target of the ARM as seen by PECTA is to visualize the readiness level of different WBG devices/technologies for usage in different applications. The ARM is describing the introduction of WBG devices in existing markets in these steps: 1) Demonstrator available, 2) first product available, 3) significant market share, and 4) predominant market share achieved.

For power electronics, application readiness is strongly dependent on the specific application requirements. Here, the improved power efficiency and increased power density possible with WBG semiconductors are the main drivers for their usage. Moreover, higher integration levels can be achieved in conjunction with advanced packaging and integrations technologies such as sintering, chip embedding, and gate driver integration.

However, application readiness asks for more. Compatibility with existing control and protection systems as well as with existing production processes is essential for bringing products into the market. Requirements on operational safety (e.g., ISO26262 for automotive), robustness (e.g., short circuit capability in drives applications), and reliability are influencing the technology selection, often asking for normally-off devices. In applications with long lifetime and many operations hours (e.g., railway with 30 years lifetime), the introduction of products requires high maturity of the technology and achievement of signification market share is delayed compared to consumer applications.

Depending on the degree of application readiness, other factors become also important. Most notably, a significant/predominant market share can only be achieved if cost savings compared to the silicon-based solution are realized, e.g. by reduced effort for passive components, lower electricity costs for server power supply and smaller battery in electric vehicles. Clearly, this depends strongly on the specific application. Finally, to reach a significant market share, the supply chain has to be capable to fulfil market demands, often asking for a mandatory second source.

All these factors need to be fulfilled by a different degree depending on the specific application, but also depending on the four steps in the ARM described above. This is summarized in Table I.

Status of the WBG market

Tables II and III show the market share of WBG power device supplier in 2020 and 2021. The market size for Gallium Nitride (GaN) power devices is growing faster compared to Silicon Carbide (SiC), but also in 2027 the market size for SiC power devices is expected to be three times larger compared to GaN.

For SiC, all large power semiconductor manufacturers are producing in their own frontend wafer fabs and packaging in their backend production lines. Investments in new 200 mm wafer fabs are announced, samples are available and from 2027 all large SiC power device manufacturers will have 200 mm SiC production facilities [3][8]. Further cost reduction for SiC substrates is expected, e.g. [9].

For power GaN, the supply chain looks different. As shown in Fig. 1, most of the power device supplier with a large market share are designing the transistor but are not producing the chips and the packages. Changes in the supply chain are expected, e.g. Infineon plans to acquire GaN Systems [7].

Table I: Requirements for power electronics to achieve readiness level

(SMS and PMS in the rightmost columns denote Significant and Predominant Market Share.)

Requirement	Demo	Product	SMS	PMS
Power density	x	x	x	x
Efficiency	x	x	x	x
Integration and packaging	x	x	x	x
Compatibility		x	x	x
Operational safety		x	x	x
Reliability		x	x	x
Robustness		x	x	x
Cost effectiveness			x	x
Delivery capability			x	x

Table II: Market shares of SiC power devices suppliers, (revenue estimates) [3]

Global power SiC sales $1090M (2021)

Company	**2020**	**2021**
ST Micro	42%	42%
Infineon	16%	23%
Wolfspeed	16%	15%
Rohm	15%	10%
Onsemi	8%	7%
Mitsubishi Electric	4%	3%

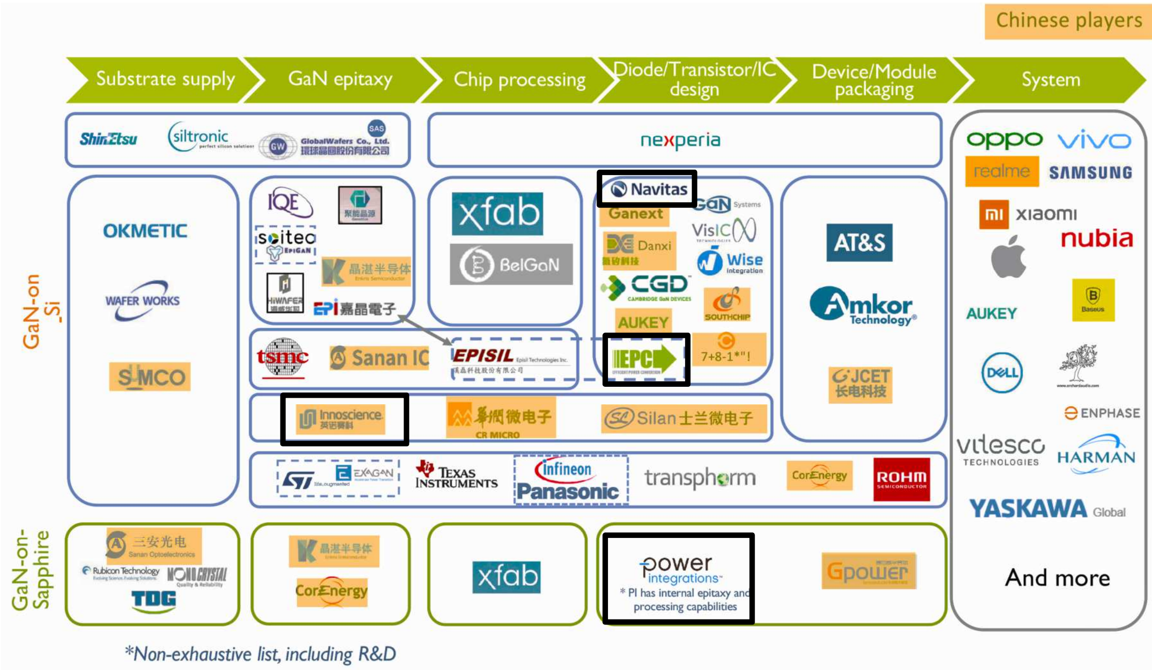

Fig. 1: Global power GaN supply chain [5]

Table III: Market shares of GaN power devices suppliers, (per million chips shipped) [4] Global power GaN sales $126M (2021)

Company	2020	2021
Navitas	26%	29%
Power Integrations	27%	24%
Innoscience	6%	20%
EPC	21%	14%
Transphorm	8%	6%
Infineon	5%	3%
GaN Systems	6%	3%
Other	1%	1%

Expected Developments of WBG Technologies

SiC power semiconductors are nowadays mostly MOSFETs and Schottky diodes, JFETs being the exception, in all cases vertical devices. Continuous improvement is expected, the MOSFET channel resistance will decrease. Even superjunction MOSFETs are likely to appear on the market, but in contrast to the introduction of silicon superjunction devices they will not open up a completely new market segment, but rather help to further lower cost.

The situation for GaN devices is very likely to be more dynamic. The strive for higher blocking voltages and higher power densities will be addressed by vertical power devices, made possible by lower GaN substrate cost, introduction of new backside wafer handling techniques, possibly including ceramic substrate carriers. Even in 2023 first vertical GaN devices are announced [20]. Moreover, we expect that bidirectional GaN HEMTs with two gates will soon be available. Such devices are very attractive for T-type NPC architectures.

Other WBG materials are currently under research. Diamond has long been considered to be the perfect power semiconductor material, but technological challenges such as doping remain difficult, the cost position questionable. The authors of this paper do not expect that application readiness of these devices will be achieved before 2035, probably disregarding a few niche applications.

Also being discussed is Gallium Oxide (GaO). This could have a much better cost position, but significant technical difficulties remain, and considering the number of publications it is still a long way to go. Therefore, we will not consider diamond nor GaO in the ARM.

Development of WBG Market and impact on ARM

As shown in Table IV, in 2027 it is expected that share of SiC power devices is approx. 80% in automotive and transportation whereas the majority of GaN devices (approx. 50%) will be used in consumer applications.

Table IV: WBG power device market in 2027 [3,6]

SiC/GaN Power device market \$6.3B/\$2B (2027)

Application	SiC	GaN
Automotive+Transportation	82%	15%
Industrial	9%	4%
Energy	7%	1%
Telecom	1%	31%
Consumer	<1%	48%

Fig. 2 shows different applications that are suited for WBG devices. An overlap in the voltage range of 600 to 900 V is affecting the PV inverter and automotive market. To reduce the charging of large batteries to less than 20 min (from 10% to 80% SOC), battery voltages of a large share of EVs will increase from 400 V to 800-850 V, some even higher.

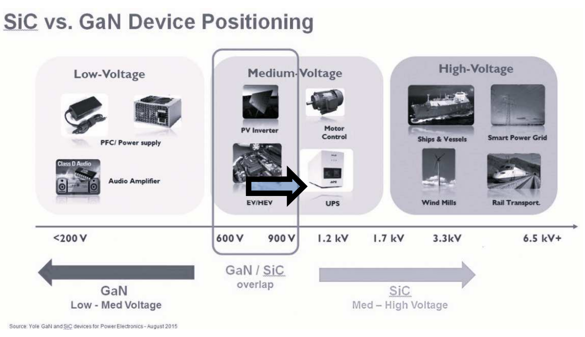

Fig. 2: Automotive: shift to higher battery voltage, figure from [2], graph originally from Yole “GaN and SiC Devices for Power Electronics”, August 2015

Mapping this to WBG devices, we see that 1200 V SiC MOSFET are highly beneficial and were consequently already introduced in products, even earlier than predicted in the previous ARM. GaN for On-Board-Chargers (OBCs) and DC/DC-converters is expected to achieve a significant market share once 1200 V devices become available from major suppliers.

The major share of SiC devices are used in the drive inverter of electric vehicles. As shown in Fig. 3, the predominant operation is in the partial load condition, where SiC MOSFET inverters are superior.

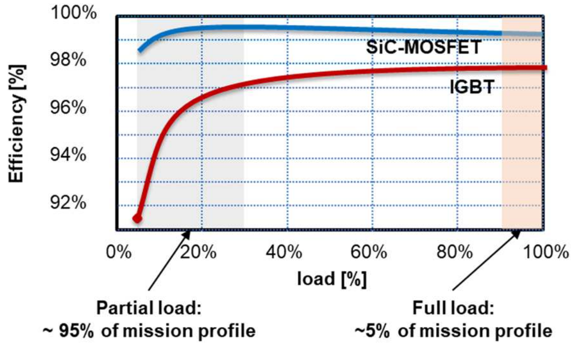

Fig. 3: Efficiency for SiC- and Si-based automotive drive inverters plotted over the load condition [10],[11]. Note that the inverter mostly operates in partial load condition.

Because of this advantage, some scenarios show that the SiC device market in automotive is expected to grow from 2022 until 2028 with CAGR larger than 26%, even considering recent announcements to lower the SiC component count in automotive drive trains [8].

In the consumer market, GaN-HEMTs already reach a predominant market share for USB power delivery. Here, the priority of application requirement is first cost, then power density, finally efficiency. A typical efficiency of USB power adapters of 91% is accepted. The demand for smaller adapters asks for high switching frequencies of 150 kHz or more, which can be realized with GaN-HEMT devices.

In comparison to this, server power supplies have a different priority in the application requirement due to 24/7 service. Now, it is first efficiency, then cost, finally power density. Therefore, this application uses 40 to 70 kHz switching frequency to realize an efficiency >96% (99% for PFC), where also SiC devices are a good choice [12],[13].

Additional energy-relevant segments

In the appendix in Figures 4-6, the status of the ARM for the different application areas is visualized. Compared to [2] additional WBG-relevant market segments are added.

PV micro inverter products with 650V GaN devices are already available [14]. Products for bidirectional charging integrated into the vehicle as OBC and also wall-mountable are introduced with SiC MOSFETs [15]. GaN HEMT devices are used in automotive backup DC/DC converter. For high power DC/DC converters, SiC MOSFET solutions are used now, and GaN is expected to be used later, when reliable 1200V devices are available.

In railway application, auxiliary converter products are equipped with SiC MOSFETs and 3.3 kV devices, e.g., are used in battery-operated hybrid train demo for DC/DC converter [16],[17].

Inductive charging is expected to remain a niche market for automotive, but SiC will be used also in industrial applications, e.g., wireless charging of electric forklifts. GaN HEMT devices are used for 48 V servo drives at different system supplier but also for higher voltage GaN devices are suited, e.g. for flying capacitor multilevel topologies in line infeed modules [18].

Multiple applications with partial load conditions will benefit from WBG devices. In HVAC (Heating, Ventilation, Air Conditioning) applications, efficiency regulations are considering the seasonal energy efficiency in heating and cooling and therefore the partial load conditions. It is expected that SiC-MOSFETs are introduced in HVAC applications [19], but because of the uncertainty of the product introduction is marked with a dotted line in the ARM, see Fig. 5.

Conclusion and Outlook

The PECTA ARM will be continuously monitored and updated. In the next phase, a closer look on drives applications will be in focus, as a more dynamic development is expected in this field. Also, further power electronics for energy conversion technologies, e.g., large-scale green hydrogen production or fuel cells will be observed.

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Appendix

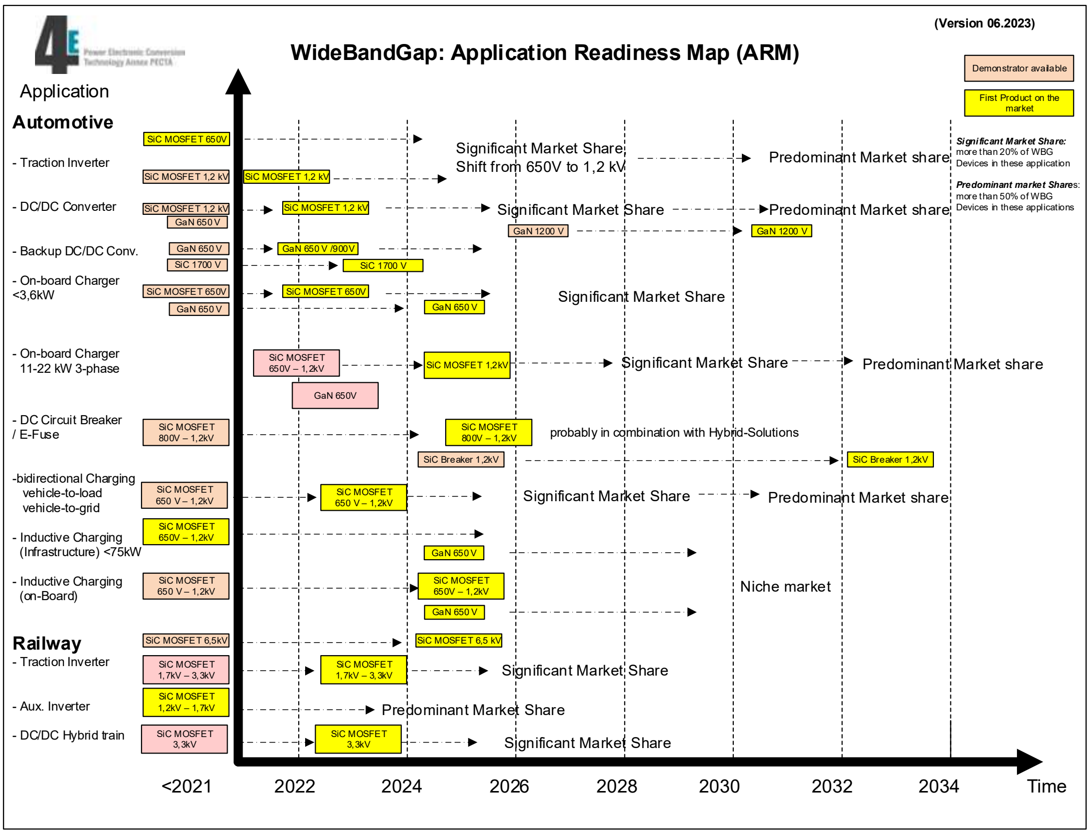

Fig. 4: Applications Readiness Map (ARM) for Automotive and Railway

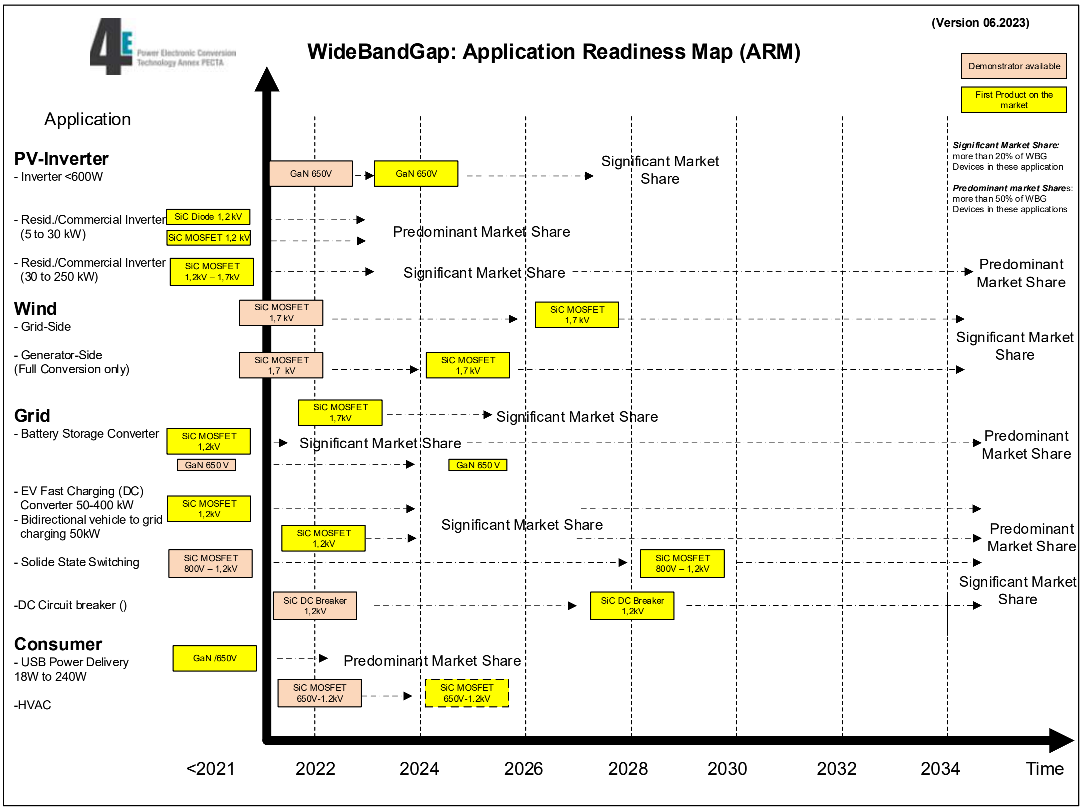

Fig. 5: Applications Readiness Map (ARM) for PV-Inverter, Wind, Grid, and Consumer

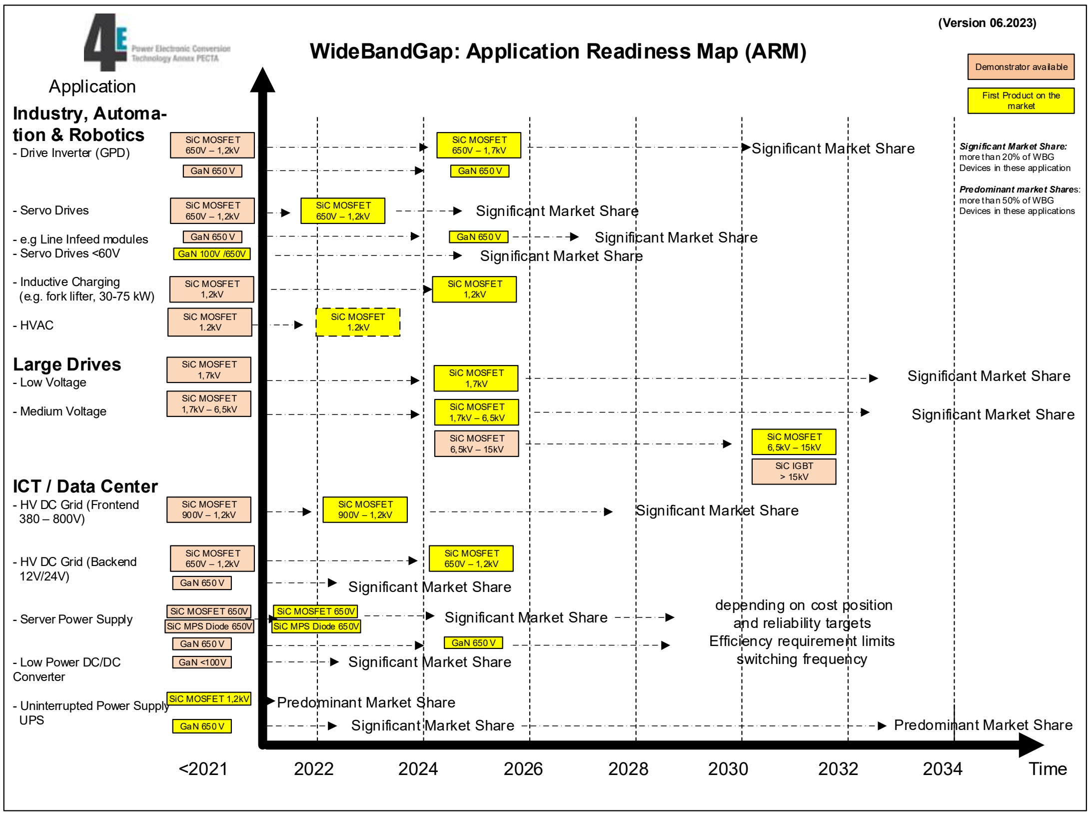

Fig. 6: Applications Readiness Map (ARM) for Industry, Automation & Robotics, large Drives, and ICT/Data Center