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Future of Power Electronics from TCAD Perspective

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Power electronics are an integral part of our daily life. The applications of power electronics are widespread, supporting multiple industries such as automotive, telecommunication, transportation, utility systems, aerospace, etc. According to a new market research report including the analysis of the COVID-19 impact [1], the global power electronics market is expected to grow at a Compounded Annual Growth Rate (CAGR) of 4.7% from $35.1 billion in 2020 to $44.2 billion by 2025. As depicted in Figure 1, the key drivers of growth are 1) increasing integration of power electronics, and 2) increasing use of wide bandgap (WBG) materials. In terms of regional growth, Asia Pacific (APAC) including China, Japan, South Korea, and India is expected to grow the fastest compared to North America, Europe, and Rest of the World (Figure 2).

Power electronics can be classified as discrete such as IGBT, which can also be configured in modules for EV/HEV automotive applications, Si-based ICs for power management in mobile applications, and Wide Bandgap (WBG) devices for medium (up to 500V) and high (>1000V) voltage applications. While the demand for Si-based discrete and power IC continues to grow, higher efficiency power electronics drive the development of WBG devices based on GaN and SiC materials. Figure 3 shows the applications of both Si-based and WBG power electronics with respect to power and switching (frequency) levels.

One of the areas that fuels the growth of Si-based power electronics is the increasing electronics content in automotive as depicted in Figure 4. Power electronics provides efficient conversion, control, and conditioning of electric power in automotive (Figure 5). By 2030, the electronics system cost can reach as high as 50% of the cost of a car [2]. In addition to the growth in automotive industry, power electronics, particularly, power management IC used in consumer and industrial electronics such as smartphones, tablets, TV, electrical appliances, etc. will continue to drive the overall market.

Unlike advanced CMOS logic development that follows the Moore's Law, development of power electronics is based on demand in a wide range of applications that serve multiple industries. Figure 6 contrasts the requirements between mobile and automotive chip designs. In terms of development direction, IGBT and power management IC will continue to drive the Si-based development to improve energy efficiency and push to reach their theoretical limits. For instance, IGBT development is in its 7th generation to reduce its size, lower Ron, and operate at higher junction temperature as shown in Figure 7. As mentioned in the first paragraph, increasing integration of power electronics is one of the growth drivers. Thus, the development focus is not only on individual power devices, but it must also include co-optimizing the components and packaging in the power module or system. Figure 8 shows a TCAD simulation example of co-optimizing a power module over multiple design parameters including electrical, thermal and mechanical effects.

For WBG applications, SiC IGBT significantly reduces switching loss and size (form factor) compared to Si-based IGBT. GaN-on-Si is gaining momentum to become the main technology for medium power applications as it offers lower cost and compatibility with Si fab lines. The device performance of both SiC and GaN is still far from the theoretical limit, motivating continued exploration and innovation to drive higher performance and efficiency (see Figure 9), as well as increasing reliability [3]. In terms of growth, the WBG power electronics market is expected to grow at a CAGR of 30% between 2020 and 2025. The largest market opportunity for WBG devices is in power converters and inverters for EV/HEV vehicles.

To support the increasing demand for power electronics, top manufacturers have been shifting from 200mm to 300mm fab lines. Figure 10 shows the timeline and investment that major players made and are expected to make. In addition, WBG technology has recently achieved a critical milestone for high volume production with the availability of 200mm wafer.

From the TCAD perspective, the future of power electronics is bright as the development of new Si-based and WBG applications for power electronics is unabated. However, the boom in the power electronics market represents both challenges and opportunities for TCAD. Over the past decade, the nature of TCAD simulation of power electronics has evolved rapidly in four areas: 1) 2D to 3D, 2) small to large scale, 3) Silicon to WBG materials [4], and 4) single device to integrated modules. Despite these challenges, the recent improvements and enhancements in commercial TCAD tools such as Synopsys' Sentaurus line of products enable power electronics suppliers to explore and innovate new capabilities and functionalities in the form of single discrete device and multiple devices as power ICs, as well as new materials (e.g. GaN, SiC) and device architectures (e.g. super-junction). The types of analysis range from the traditional breakdown characteristics (Figure 11) to electro-thermal interactions (Figure 12) of power electronics modules [5] and reliability impact [6]. TCAD is poised to help innovate and develop a new wave of power electronics to support the growth in adoption in the automotive, consumer, industrial, and renewable industries in the next decade.

References

[1] Power Electronics Market with COVID-19 Impact Analysis by Device Type (Power Discrete, Power Module and Power ICs), Material (Silicon, Silicon Carbide and Gallium Carbide), Voltage (Low Voltage, Medium Voltage and High Voltage), Vertical (ICT, Consumer Electronics, Industrial, Automotive & Transportation, Aerospace & Defense), and Geography - Global Forecast to 2025, Power Electronics Market, Published Date: June 2020 | Report Code: SE 2434.

[2] Semiconductors – The Next Wave Opportunities and Winning Strategies for Semiconductor Company, April 2019, Deloitte.

[3] Improving Reliability For GaN And SiC: Why these chips are gaining ground, and what still needs to be addressed, June 18, 2020, M. Lapedus, https://semiengineering.com/improving-reliability-for-gan-and-sic/

[4] S. Stoffels, et al., "From TCAD Device Simulation to Scalable Compact Model Development for GaN HEMT Powerbar Designs," 1st IEEE Workshop on Wide Bandgap Power Devices and Applications, October 2013.

[5] A. Chvála, et al., "Advanced 3-D Device and Circuit Electrothermal Simulations of Power Integrated Circuit," 46th European Solid-State Device Research Conference (ESSDERC), September 2016.

[6] T. Cilento, et al., "Investigation of Layout Effects in Diode-triggered SCRs under very-fast TLP Stress through Full-size, Calibrated 3D TCAD Simulation," Microelectronics Reliability 88–90 (2018) 1103–1107.

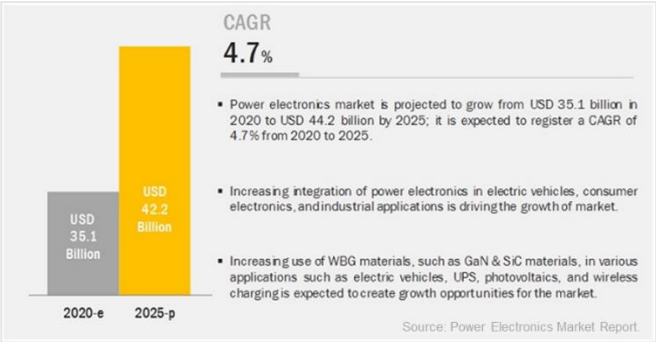

Figure 1. Power electronics market is expected to grow to $42.2 billion by 2025.

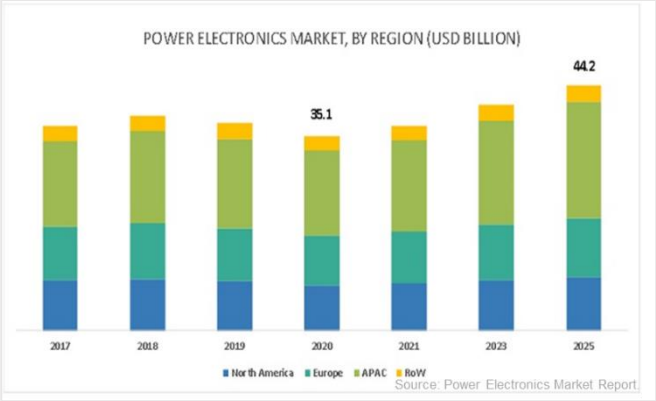

Figure 2. Asia Pacific grows the fastest compared to North America, Europe and Rest of the World.

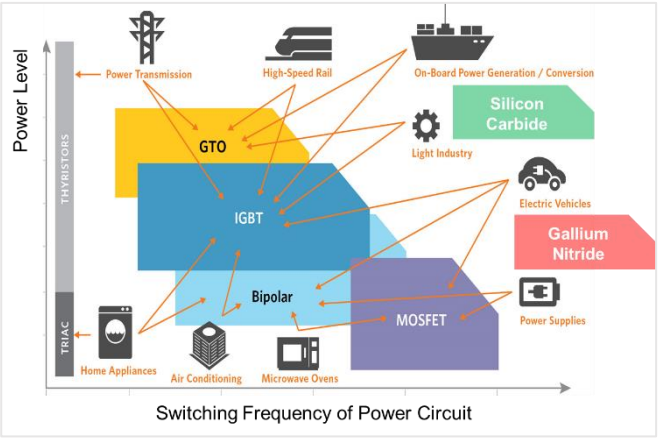

Figure 3. Power electronics and their applications.

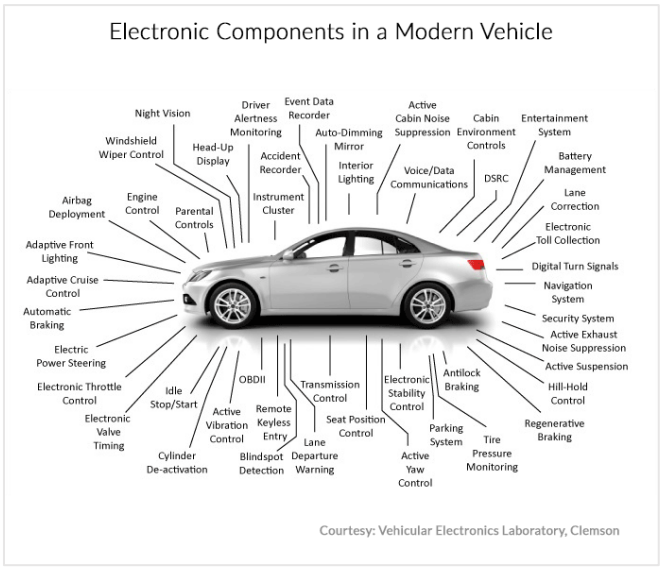

Figure 4. Cost of electronics in modern vehicles can reach as high as 50% of the car cost.

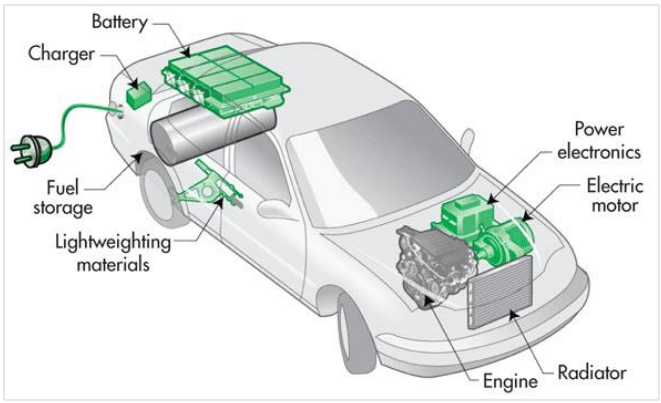

Figure 5. Power electronics play an important role of controlling electrical systems in modern vehicles.

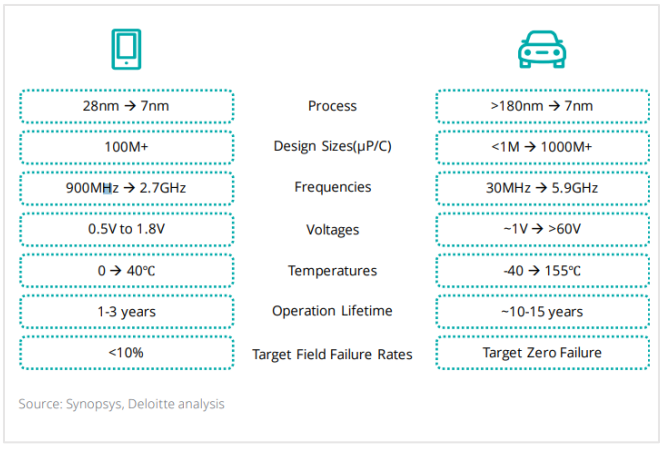

Figure 6. Comparison of IC requirements between mobile and automotive.

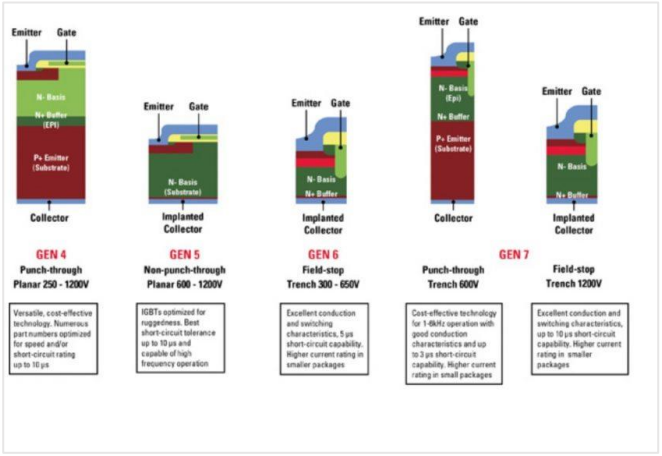

Figure 7. Evolution of IGBT development from 4th to 7th generation.

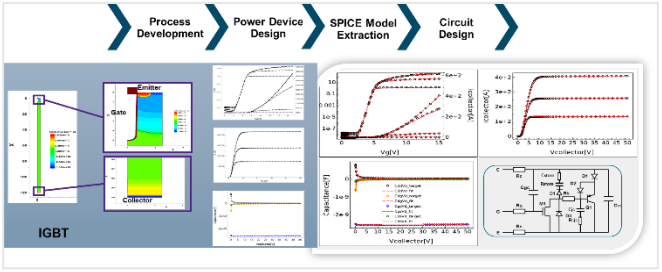

Figure 8. An example of using TCAD simulation for co-optimization of a power module,

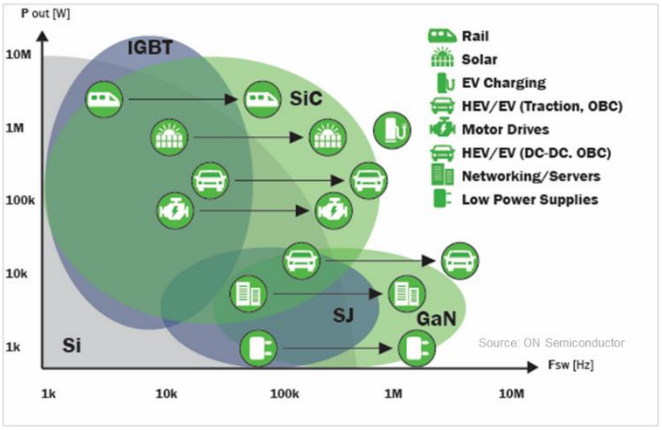

Figure 9. Development of SiC and GaN to support the growth in applications requiring higher energy efficiency.

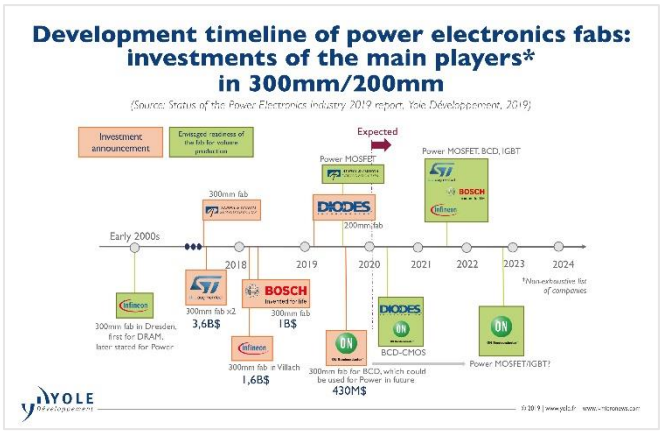

Figure 10. Key power electronics manufacturers are preparing to switch from 200mm to 300mm production.

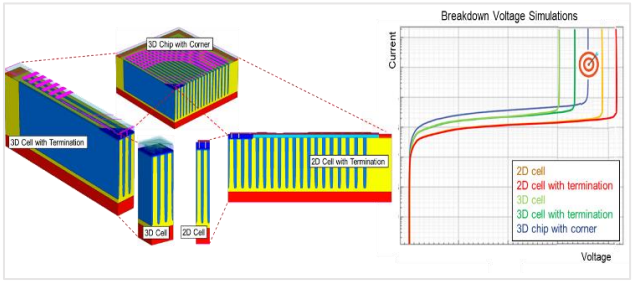

Figure 11. TCAD simulation expands from 2D to 3D and increased scale from a small portion of the device to multiple junctions of the device.

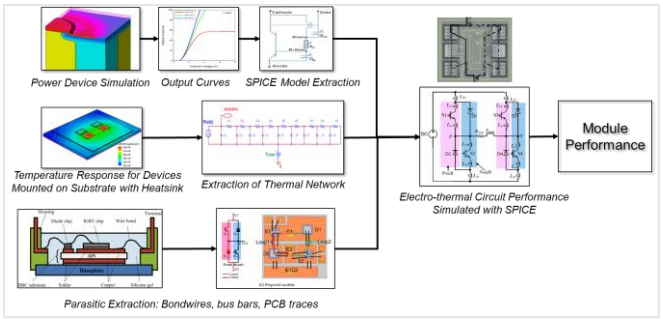

Figure 12. An example of using TCAD for Design Technology Co-Optimization (DTCO) for electro-thermal analysis of device-circuit interaction of power electronics modules.