Expert View

by Victor Veliadis and Nam Kyun Kim

The South Korean Silicon-Carbide Semiconductor Industry: An Emerging Powerhouse

South Korea is a leading player in the world semiconductor industry. Samsung was the number-one-ranked semiconductor company in 2018, based on sales revenues. And another South Korean company, SK Hynix, ranked third according to Gartner [1], [2], as shown in Figure 1. The main products of these semiconductor leaders are memory devices, such as dynamic random access memory and NAND flash memory, and they currently have no significant power semiconductor presence. As a result, when looking at the global power semiconductor industry rankings, there is no South Korean-based manufacturer among the world's top-15 power device suppliers.

Nevertheless, South Korea can rapidly become a mighty force in the global silicon-carbide (SiC) power semiconductor stage, considering its excellent technical education system, its large and well-trained microelectronics workforce, its history of translating microelectronics innovation into efficient large-scale manufacturing, its business-friendly environment and effective leadership model, and its extensive and highly competitive foundry infrastructure.

Multiple South Korean companies are presently engaged in SiC technology development. In fact, four of the five largest South Korean industrial conglomerates (LG Electronics, Hyundai Motor Company, SK Corporation, and POSCO) have actively pursued

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2018F Top-15 Semiconductor Sales Leaders (US$M, Including Foundries)

2018F Rank	2017 Rank	Company	Headquarters	2017 Total Semi Sales (US$M)	2018F Total Semi Sales (US$M)	2018F/2017 % Change
1	1	Samsung	South Korea	65,882	83,258	26
2	2	Intel	United States	61,720	70,154	14
3	4	SK Hynix	South Korea	26,722	37,731	41
4	3	TSMC (1)	Taiwan	32,163	34,209	6
5	5	Micron	United States	23,920	31,806	33
6	6	Broadcom Ltd. (2)	United States	17,795	18,455	4
7	7	Qualcomm (2)	United States	17,029	16,481	–3
8	9	Toshiba/Toshiba Memory	Japan	13,333	15,407	16
9	8	TI	United States	13,910	14,962	8
10	10	Nvidia (2)	United States	9,402	12,896	37
11	12	ST	Europe	8,313	9,639	16
12	15	WD/SanDisk	United States	7,840	9,480	21
13	11	NXP	Europe	9,256	9,394	1
14	13	Infineon	Europe	8,126	9,246	14
15	14	Sony	Japan	7,891	8,042	2
—	—	Top 15 Total		323,302	381,160	18

(1) Foundry (2) Fabless

FIG 1 Samsung and SK Hynix of South Korea were the number one and number three semiconductor sales revenues leaders in 2018. M: million; TSMC: Taiwan Semiconductor Manufacturing Company; TI: Texas Instruments; ST: STMicroelectronics; WD: Western Digital. (Adapted from [9].)

SiC R&D, while Samsung has announced a US$116 billion investment in nonmemory semiconductor chip manufacturing that might potentially include SiC power devices [3]. In this column, we report on the emerging South Korean SiC power semiconductor industry by reviewing recent activities and evaluating future trends.

South Korean Projects Advancing SiC

As with some other countries, the South Korean government will fund R&D efforts that build upon existing domestic infrastructure and have the potential for large industrial growth. Looking into its recent R&D program portfolio, the South Korean government clearly considers SiC power electronics a key technology for maintaining microelectronics leadership and competitiveness. Several long-term SiC material and device development projects have been recently awarded and managed by the South Korean Ministry of Trade, Industry and Energy (MOTIE).

The World Premier Materials (WPM) Ultra High-Purity SiC is an example of a project that lasted for 10 years (2009–2019) and invested more than US$110 million. Two major achievements of the WPM project are 1) POSCO, the lead agency for single-crystal wafer growth, established 100- and 150-mm 4H-SiC substrate technology, and 2) LG Innotek, an LG Electronics subsidiary and lead for substrate epitaxy, developed commercial-grade 150-mm SiC epitaxy technology for power electronics applications [4].

Another notable achievement of the project is the successful formation of an industrial ecosystem from SiC raw material to power electronics. MOTIE is executing a seven-year (2017–2024), US$75 million power semiconductor development program, the New Industry Creation: Power Semiconductor Commercialization Project. It aims to develop power module technology and key power devices, such as 1,200–1,700-V SiC MOSFETs for industrial applications and 4.5-kV SiC MOSFETs for high-voltage applications, such as rail traction [5].

Busan Metropolitan City, South Korea, is managing the Power Device Industry Clustering Plan, a joint project with MOTIE that aims to set up a test production facility that provides 150-mm SiC-wafer pilot fabrication services [6]. The facility is scheduled to become operational in the third quarter of 2019, and a device reliability assessment service center is to open soon after. Another project, Development of High-Efficiency, High Power Density Converters Using Next-Generation Power Semiconductors, is under operation as a MOTIE program. The main goal of this project is to develop a 1-MVA multichannel charging system using SiC power semiconductors, with direct connection to the 22.9-kV grid distribution line.

Established Infrastructure and SiC-Related Activities

Multiple South Korean companies are engaged in SiC technology development. POSCO, one of the world's top-five steel-producing companies, performed SiC single-crystal growth research for more than a decade. As a WPM program participant, POSCO established high-quality 100-mm and 150-mm SiC-substrate technology that is close to commercialization. SKC, another WPM program participant, is a 100-mm SiC substrate supplier. An SK Corporation company, SKC, is on its way to commercializing 150-mm SiC wafers. As noted previously, LG Innotek, a subsidiary of LG Electronics, has developed 150-mm SiC epitaxial technology. As a consumer electronics giant, LG Electronics not only is potentially a large consumer of SiC power semiconductors but also is likely engaged in internal development. However, no official announcement has been made to that effect.

Similarly, Hyundai Motor Company, one of the world's top-five manufacturers of vehicles, has published its SiC power electronics work and developed intellectual property (IP), as shown in Figure 2. Two technical papers were presented at the 2015 Electric Vehicle Symposium that discussed a trench-gate SiC MOSFET with an accumulation-channel structure and an advanced junction barrier Schottky diode [7], [8]. Given the large automotive application volumes, Hyundai is likely continuing to execute on internal SiC power semiconductor R&D programs for electric vehicle inverters.

In terms of SiC power semiconductor manufacturing, Yes Powertechnix (YPT) is in production of 600–1,700-V SiC Schottky diodes and 1,200–1,700-V SiC MOSFETs. The company is dedicated solely to SiC power device manufacturing, and it operates a class-10 foundry processing 100-mm SiC wafers. Additionally, YPT provides SiC foundry services, including design and custom process development. This is a key offering, as it enables fabless companies to customize and manufacture their SiC products.

Samsung, the world's number one-ranked semiconductor company in 2018, announced plans in April 2019 to invest US$116 billion (KR₩140.534 trillion) over the next 12 years to become the world's number one manufacturer of nonmemory chips [3]. Although Samsung is the world's largest memory device manufacturer, it does not rank within the top 10 of nonmemory semiconductor companies. Nevertheless, it is unclear whether the massive investment plans include development of power semiconductors. Samsung can also rapidly become a major player in gallium-nitride (GaN) power devices, as GaN-based blue LED technology is one of its large business activities.

Dongbu (DB) HiTeK is a South Korean open-foundry semiconductor company that regularly ranks among the world's top-ten pure-play foundries in terms of sales revenues. It operates two fabrication facilities, strategically centered in South Korea's vibrant semiconductor infrastructure, with a total capacity of approximately 120,000 wafers per month. Although DB HiTek's foundry services presently encompass analog, logic, and specialized Si CMOS processing, the company is uniquely positioned to serve the rapidly growing SiC fabless market in a cost-competitive way by leveraging its large manufacturing capacity to produce SiC devices at the economy scale of Si. This model entails making a modest SiC-specific equipment investment and fabricating Si and

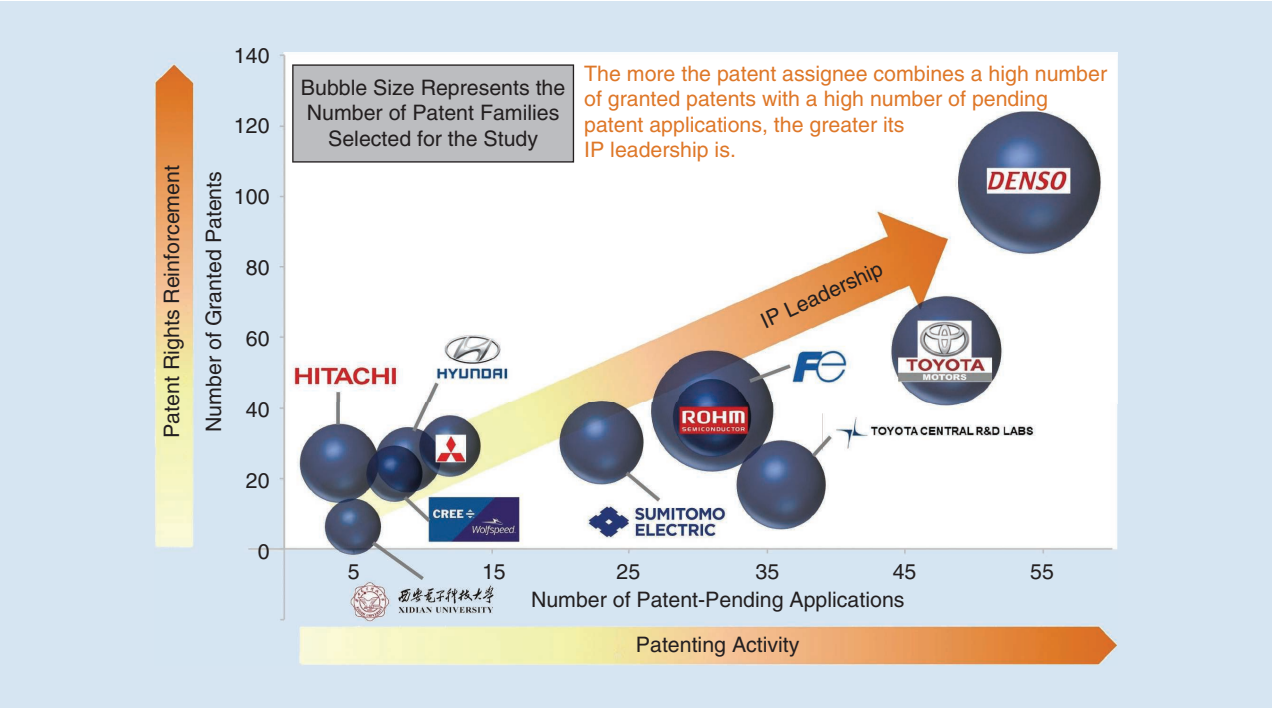

FIG 2 The IP leadership of trench SiC MOSFET patent assignees includes Hyundai Motor Company. (Source: Power SiC: MOSFETs, SBDs, and Modules 2019—Patent Landscape Analysis, 2019, Knowmade; used with permission.)

SiC devices on the same production line, similar to Infineon in Europe and X-FAB in the United States.

The Korea Electrotechnology Research Institute (KERI) is a nonprofit government-funded research organization that has been at the forefront of technological excellence. KERI advances science and technology by leading R&D efforts in the electric power and utility fields, and it plays a central role in South Korean SiC power electronics research. It has developed SiC diode and MOSFET technologies, some of which have been transferred to its industrial partners.

KERI has also provided SiC-wafer heated implantation, an essential process for fabricating SiC power semiconductors, as a service to numerous SiC research groups in South Korea. KERI developed a high-efficiency, three-phase 6.6-kV solid-state transformer (SST) based on SiC devices, and it is now developing a 13.2-kV SST. The ultimate goal is to demonstrate a 22.9-kV 1-MW SST for electric vehicle charging systems. Finally, the Korea Institute of Ceramic Engineering and Technology, the Electronics and Telecommunications Research Institute, and the National Institute for Nanomaterials Technology are also part of the South Korean SiC infrastructure and should be acknowledged for their technical achievements in SiC single-crystal growth and SiC MOSFET fabrication technology.

Building a South Korean SiC Community

The SiC division of the Korean Institute of Electrical and Electronic Materials Engineers was founded in 2018 and is currently the only domestic SiC-specific community. In 2019, it launched the first South Korean SiC Semiconductor Conference (SiC^2) in Busan, South Korea, attracting more than 140 participants from across South Korea. Thirty-six technical papers were presented in oral and poster sessions. Technical papers covered diverse SiC topics, such as material defect analysis, top-seeded solution growth, trench MOSFETs, and gate driver integrated circuit design for SiC MOSFETs. SiC^2 also featured an industry session where participating companies gave technical presentations that promoted their SiC-related product lines. More than 10 international and South Korean companies participated as exhibitors, including DowDuPont, Silvaco, Nissin Ion Equipment, YPT, and EtaMax. SiC^2 2019 was chaired by Dr. Nam Kyun Kim. Going forward, SiC^2 will be held annually in March to review the latest South Korean SiC developments and contribute to worldwide SiC power technology.

Future Trends

Multiple areas of the semiconductor supply chain must seamlessly come together to synergistically culminate in large-scale cost-competitive SiC power device manufacturing. South Korea has made sizeable investments to produce an ample supply of SiC substrates and epitaxy

that can feed its large fabrication infrastructure, which includes both integrated device manufacturers and pure-play foundries. To accelerate growth, it is setting up service facilities that offer pilot SiC wafer fabrication and device reliability assessment. Public laboratories are developing next-generation SiC technologies in collaboration with leading domestic universities and industry.

Located in the Far East, South Korea can complement its domestic power module industry with access to nearby low-cost volume production centers. Talent recruitment availability and continuity are secured through an excellent technical education system as well as an existing large and well-trained microelectronics workforce. Some of the world's largest South Korean conglomerates are active in developing SiC power technologies, and they can create the large device demand that leads to mass domestic manufacturing with its cost-lowering benefits. The aforementioned aspects combined with South Korea's business-friendly market environment and history of translating microelectronics innovation into efficient large-scale manufacturing point to the emergence of a mighty SiC force about to be unleashed in the global marketplace.

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