Commercial status of the GaN-on-silicon power industry

Firms developing and producing GaN-on-silicon devices for the power electronics industry come in many different flavours. Some sell on the open market; some just ship to a chosen few; others offer foundry services; and there are also those that form partnerships. Zel Diel from Venture-Q LLC considers these various approaches and their implications, before looking at how far companies have progressed towards commercialization of their technology.

The developers and producers of GaN-on-silicon power electronics are pursuing various strategies. Some are looking to sell their devices on the open market; others are targeting the closed merchant market; and there are also those that are offering foundry services, or licensing their technology (see Figure 1 for a pictorial representation of these different approaches).

Launching products on the open merchant market is a well-known business strategy that is common for mature technologies. The manufacturer tries to win sales directly or through a distributor. US firm Efficient Power Conversion (EPC) operates in this manner, with its distributor, Digi-Key, selling the eGaN transistors that it introduced in 2010.

An alternative approach is to offer a product in the closed merchant market. This strategy, which is common with a new technology, is often employed within the scope of a partner business engagement. The primary virtue of this approach is that it limits access to a vendor's know-how and its intellectual property (IP). Companies pursuing this strategy include the US firms International Rectifier (IRF) and Transphorm. One feature of this form of commercialization is that the vendor-partner relationship is often conducted within the scope of a non-disclosure agreement.

Within the compound semiconductor industry, there are also manufacturing foundry services providing access to GaN-on-silicon technology. Companies offering this include RF Micro Devices, which has an rGaN-HV technology that is available to its merchant customers and business partners. A noteworthy feature of this commercialization is the vendor-customer or partner relationship that enables access to the vendor's technology and manufacturing.

Markets for GaN-on-silicon products include inverters for wind turbines and solar farms. This class of electronics is more efficient than the incumbent silicon technology at converting the output from these renewable sources into a form that can be fed into the grid

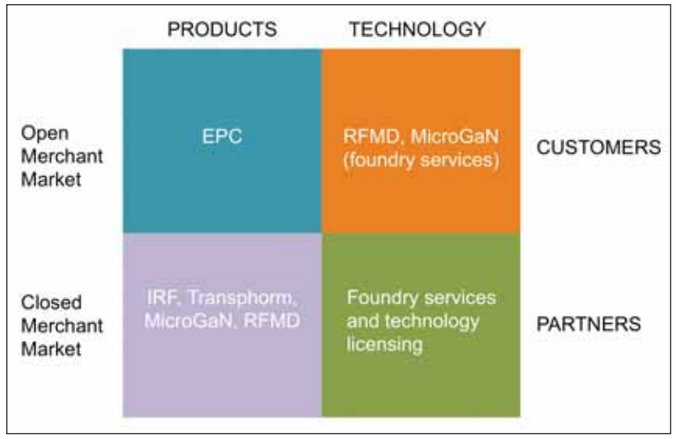

Figure 1. Analyst Venture-Q categorises the developers of GaN-on-silicon technology into those operating in either open or closed markets; and those that develop products, or develop technologies

In many established and evolving industries some companies offer a license to access new or mature technologies. Although this may not be that prevalent in the III-V industry to date, it is a feature of the silicon industry – for example, IBM Microelectronics licensed its SiGe technology in the late 1990s.

In addition to these different types of models for commercialization, firms are differentiating themselves by either pursuing their goals single-handedly, or teaming up with others through business partnerships and joint ventures. The later option is commonly found in new technologies, with partnerships bringing together complementary resources and capabilities of two or more vendors. Two examples of this are: the Fuji-Furukawa partnership, formed for the commercialization of GaN MOSFET technology; and the joint venture between Fujitsu and Sumitomo's Eudyna (now Sumitomo Electric Device Innovations, SEDI), which was established in 2004 to commercialize RF power GaN technology.

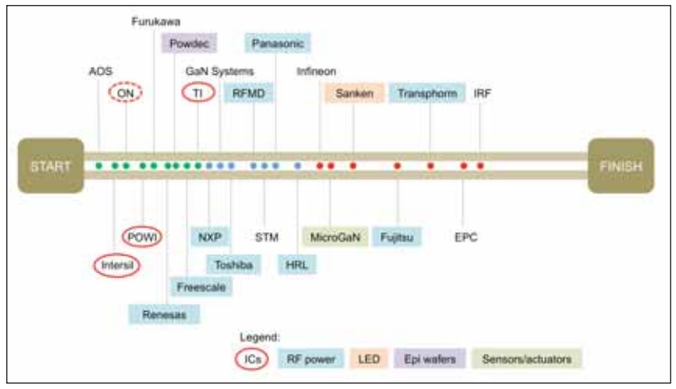

Figure 2. Venture-Q has grouped 23 firms involved in GaN-on-silicon technology into a leading group of seven (red circles), a subsequent group of 8 (blue circles), and a trailing group of 8 (green circles)

The variations outlined so far reveal that there is much to consider in order to objectively assess the status of commercialization of GaN-on-silicon technology. At Venture-Q LLC, a provider of market reports, we have made such an assessment in a rigorous manner, and in the remainder of this article we will provide a high-level view of the commercial status of the GaN-on-silicon power industry. For all of the leading firms, we detail how close they are to commercializing their technology, and where they rank in relation to each other. Our findings represent the status of the market as of December 2012.

At that point in time we believe that 23 vendors were engaged in the commercialization of high voltage GaN-on-silicon HEMTs, ICs, and modules for power conversion applications. Their activities range from patent filing activity to device design, fabrication, and packaging. Only those with development efforts directed towards technology commercialization are included in our vendor list, which implies that those pursuing exploratory research activities are omitted from our study. Additional exclusions include pure-play vendors of RF power GaN HEMTs. However, we do consider vendors that are now producing high-voltage GaN HEMTs on SiC and plan to make the transition to a silicon platform.

The types of GaN-on-silicon power devices that we consider include HEMTs, MOSFETs, and hybrid HEMT-MOSFET devices, while ICs include integration of GaN-only devices and both GaN and silicon devices. The makers of modules that we account for include those producing system-in-package and sub-system level modules, such as motor drives and power supplies.

Some of the features worth noting in Table 1 are: Efficient Power Conversion is the only vendor offering products in the open merchant market; there are only three vendors offering product in the closed merchant market – Transphorm, MicroGaN and RFMD; only two firms are providing foundry services (MicroGaN and RFMD); and only NXP and ON Semiconductor are engaged in collaborative developments with major R&D institutions. Another way of looking at this data is that, in 2012, only five vendors offered products and/or foundry services in the merchant market, with the remaining 18 vendors engaged in technology development – either in collaboration with R&D institutions, or within their internal R&D organizations.

Pecking order

We have placed all 23 companies on a commercialization timeline (see Figure 2). Positions are determined by a number of technology and business related factors, which vary widely among vendors. The 23 firms can be divided into three groups: a leading group of seven vendors, which predominantly focus on discrete power devices and modules (these firms are shown by red circles); a subsequent group of eight vendors, mostly offering RF power GaN devices (blue circles are used to define this group); and a group of eight vendors, most of which are silicon IC vendors (identified by green circles).

Most of the vendors in our list of developers and producers of GaN-on-silicon devices are addressing emerging high-voltage, power-conversion applications by leveraging their existing expertise and capabilities in GaN-based technologies (see over for specific details of all 23 firms). Nine vendors, including Transphorm, Fujitsu, HRL, Panasonic, RFMD, Toshiba, NXP, Freescale and Renesas, have a background in RF power GaN technology. Another, Sanken, can leverage its expertise in LED manufacturing, while MicroGaN and Powdec can build on their strengths in sensor/actuator technology and epiwafer manufacturing, respectively.

One other common background for our 23 companies is that of silicon MOSFET vendors. IRF, Infineon, STM, TI, ON Semiconductor and Alpha & Omega all fall into this category. They have approaches to GaN technology development that include internal R&D, acquisitions, and partnerships. Meanwhile, start-ups EPC and GaN Systems, plus Furukawa (R&D), are focusing exclusively on GaN-on-silicon power technology, and two vendors - Power Integrations and Intersil – are concentrating on ICs.

It's interesting to note that there is only one company in our list of 23, Sanken, that is looking to leverage its LED manufacturing technology. Its efforts are limited to manufacturing equipment, rather than know-how, and its development of GaN-on-silicon HEMT technology for power conversion spans more than a decade. The plans and progress of Sanken reveal that the publicized near-term threat of LED vendors entering the power electronics market is both unrealistic and unfounded. Why? Because LED manufacturing has minimal correlation with the technological know-how required to manufacture high-voltage, GaN-on-silicon power HEMTs. Gaining that expertise requires a decade of R&D effort. It is possible, however, that LED vendors could gain access to such expertise via either acquisitions, partnerships or joint ventures.

The companies that are developing GaN-on-silicon technology have three big challenges ahead of them: containing the current collapse phenomenon; developing the technologies for manufacturing E-mode HEMTs; and validating device reliability. On top of this, GaN HEMT production costs must fall to drive deeper penetration into the power electronic market, a step that will require manufacture on 200 mm silicon. In our view, to address these issues while reducing the time it takes to generate revenue and profits, vendors will start to partner with each other more strongly than before, while some firms will be acquired by others.

Any questions relating to this article can be directed to the author: ZelDiel@venture-Q.com

Vendor	Products		Technology	Development		Product Types		
	Open market	Closed market	Foundry services	Collaborative	In-house	Discrete	IC	Module
IRF		●				●		●
EPC	●					●		
Transphorm		●						●
Fujitsu					●			
Sanken					●	●	●	
MicroGaN		●	●			●		
Infineon					●	●		
HRL					●	●		
Panasonic					●	●	●	
STM					●	●	○	
RFMD		●	●			●		
Toshiba					●	●		
GaN Systems					●	●		
NXP				●		●		
TI					●	○	●	
Freescale					●	●	○	
Powdec					●	●		
Renesas					●			
Furukawa					●	●		
POWI					●		●	
ON Semi				●		●	○	
Intersil				●	●		●	
Alpha & Omega					●	●		

Table 1. Vendor commercialisation status for GaN-on-silicon HEMT technology, as of December 2012

industry ◆ GaN power electronics

Key features of the GaN-on-silicon developers and producers

The leading group of seven vendors (identified in red circles in figure 2) currently focuses on discrete power devices and modules for power conversion applications.

- **International Rectifier (IRF),** which leads the time-to-commercialization race, is driven by a strong motive — re-entry into the high-voltage power arena. The company is reinforcing its lead with a comprehensive portfolio of patents and patent applications.
- **Efficient Power Conversion (EPC)** remains the only vendor offering commercial-grade, E-mode GaN-on-silicon HEMTs for power conversion applications in the open merchant market.
- **Transphorm** focuses on application-specific modules. It leverages RF power GaN-on-SiC device technology developed at the University of California, Santa Barbara, and Cree, which has assigned its high-voltage GaN power device patents and patent applications to Transphorm.
- **Fujitsu Semiconductor** announced its commercialization effort in November 2012. The company leverages its legacy leadership in RF power GaN technology for power conversion applications. It invented the HEMT and led commercialization of RF power GaN technology by forming Eudyna in 2004.
- **Sanken Electric** focuses on high voltage GaN-on-silicon power HEMTs for use in power conversion applications, such as power supplies, at both the component and system level. It leverages LED manufacturing expertise and more than a decade of R&D efforts in GaN HEMT technology.
- **MicroGaN** is building on its legacy, GaN-based sensor and actuator technology. It is a member of the German NeuLand programme and it is in a close relationship with Infineon.
- **Infineon** is leading two major German programmes related to GaN technology—NeuLand and HiPo. Through this it has established a 150 mm GaN-on-silicon processing pilot line in Villach, Austria. Infineon and STMicroelectronics essentially share a market duopoly in super-junction MOSFETs. Therefore, Infineon's commercialization motive and strategy tends to be, in contrast to IRF, of a defensive nature. As a result, Infineon's position on the commercialization timeline lags the leading vendors featuring offensive strategies.

The second group consists of eight vendors (identified in blue circles in figure 2), most of which are currently vendors of RF power GaN devices.

- **HRL Laboratories** leverages its RF power GaN technology in automotive power conversion applications, such as battery chargers for electric vehicles. General Motors is a HRL owner.
- **Panasonic** is looking to build on its RF power GaN technology in power conversion applications, including inverters for industrial use and uninterruptible power supplies. In late 2009, Panasonic demonstrated the first monolithic integration of a six-HEMT inverter circuit.
- **STMicroelectronics (STM)** entered into the GaN-on-silicon technology arena by licensing Velox's GaN-on-silicon diode manufacturing technology. However, the current business focus is on SiC devices.
- **RF Micro Devices'** efforts to commercialize GaN technology in power conversion applications represent an expansion of its legacy RF power business.
- **Toshiba** leverages its RF power GaN technology, while its GaN-on-silicon technology development efforts are confined to its central corporate research centre.
- **GaN Systems** is a start-up established by the Canadian government to develop GaN-on-silicon products for power conversion applications.
- **NXP Semiconductors** leverages its RF power GaN technology by co-developing high-voltage, GaN-on-silicon power devices using 200 mm wafers with A*STAR Research Institution in Singapore.

The third group consists of eight firms (identified by green circles in figure 2) that are mainly silicon IC vendors. These vendors explore and/or develop monolithically integrated GaN HEMTs with silicon devices for power conversion applications.

- **Texas Instruments (TI)** is developing a high-voltage, GaN-on-silicon technology for power conversion applications. The company focuses on monolithic integration of GaN HEMTs and silicon devices. Discrete GaN power devices would play the role of its low-voltage NexFET power MOSFETs in high-voltage applications. TI is not in the discrete power devices business, but rather develops such products to complete its system-level solutions.
- **Freescale Semiconductor** leverages its new RF power GaN technology for power conversion in electric and hybrid electric vehicles.
- **Powdec** leverages its epiwafer technology in power conversion applications in close relationships with Furukawa (a minority investor) and Sheffield University, UK.
- **Renesas Electronics** gained access to RF power GaN technology via the NEC Electronics acquisition in 2010. Renesas recently engaged in the commercialization of GaN-on-silicon technology for use in industrial power conversion applications.
- **Furukawa Electric** formed an R&D partnership with Fuji Electric to develop GaN MOSFETs for power conversion applications. Prior to partnering, Furukawa's focused on the development of GaN HEMTs in its Yokohama R&D Laboratories.
- **Power Integrations' (POWI)** business focus is on monolithic integration (ICs). It acquired Velox (a vendor of GaN-on-silicon based diodes and HEMTs) in addition to licensing SiC technology for power ICs from SemiSouth (now defunct).
- **ON Semiconductor** collaborates with imec to develop GaN-on-silicon power devices in its facility in Oudenaarde, Belgium.
- **Intersil** explores the use of GaN-on-silicon technology for monolithic integrations (ICs). It collaborates with GeorgiaTech University on the development of this technology and has filed relevant US patent applications.
- **Alpha & Omega Semiconductor (AOS)** collaborates with GeorgiaTech on the development of GaN-on-silicon power devices. The current focus is on Schottky diodes.