Q&A GaN

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Q.1 How does GaN-on-Silicon fit into Infineon's strategy?
A.1 Infineon has been the global market leader in power semiconductors for 11years (source: IHS 2014). With our solutions, we continuously minimize the loss of power in our customers' systems and enable ever more compact system designs. We have, therefore, already worked intensively on GaN-based power semiconductors for a number of years. Meanwhile, we do not focus solely on performance but also on the high standards we have set ourselves in terms of quality, reliability and delivery for the customer. Moreover, Infineon continues to strive for technology leadership, complementing our broad technology portfolio of CoolMOS™, OptiMOS™ and SiC active devices. We will start by developing a portfolio of discrete switches but, in line with the Infineon strategy 'From product to system`, we will soon also offer integrated solutions; leveraging the fact that GaN is a viable alternative technology.
Infineon recognizes that Gallium Nitride (GaN) switches will enable the next level of system efficiency, energy saving and power density and, therefore, decided to invest a significant amount of its R&D effort to pursue this challenge. Infineon Technologies strives to maintain its technology leadership in power semiconductors. Infineon will produce GaN-on-Silicon transistors, the only way to make GaN cost competitive with Si in the medium term. GaN-on-Silicon (Si) will offer the opportunity for highest efficiency and most compact designs in focus applications such as SMPS in server/telecom, mobile power and consumer applications, complementing Infineon's high-end product portfolio.

Q.2 How does the acquisition of International Rectifier change Infineon's GaN strategy?
A.2 While Infineon's GaN-on-Silicon development has made good progress over the past years, the acquisition of International Rectifier now substantially expands our competence in this field and positions Infineon clearly as the technology leader in GaN. International Rectifier has developed a broad patent portfolio, great GaN-on-Silicon epitaxy capabilities, working technologies in different voltage classes, as well as first qualified products. International Rectifier developed normall y OFF GaN HEMTs (High Electron Mobility Transistors) by cascoding depletion mode HEMTs with low-voltage FETs while Infineon developed enhancement mode HEMTs technology. Infineon has now both technologies available and is planning to bring them to the market by exploiting the individual advantages versus Silicon by application/system. At the same time, Infineon is committed to developing the necessary Surface Mount Device (SMD) packages and ICs to fully exploit the superior performance of GaN.

Q.3.What does this acquisition mean for IR and the IR GaN strategy?
A.3 IR's GaN activities have been fully integrated into the Infineon GaN program and we are now working on the execution of a joint and powerful GaN roadmap.

Q.4 What relevance do the new GaN-on-Silicon products have in supporting Infineon's contribution to the three key questions of modern society - energy efficiency, mobility, security?
A.4 Infineon´s GaN-on-Silicon product portfolio will support energy efficiency through further minimizing losses compared to Silicon. In addition, we expect that GaN will play a role in the automotive market - not only due to higher efficiency but also because GaN enables smaller form factors. However, we expect GaN will take off in the automotive market once its reliability under adverse conditions has been fully proven. In a nutshell: GaN-on-Silicon devices and solutions will enable the next major step in reducing energy consumption and size/weight of power converters.

Q.5 How does GaN fit into the existing Si and Silicon carbide (SiC) portfolio?
A.5 600 V GaN-on-Silicon products will allow our customers to reach highest efficiency levels or particularly small form factors in areas where this is required. GaN opens up new possibilities since it can operate at higher frequencies compared to Silicon and allows new topologies in electric circuits. However, we will continue to offer high performance Si products which we expect to remain the larger part of our Power business for years to come, in particular in the mid-performance range. We see SiC more in the 600 V and above range, whereas GaN will be covering the range below and up to 600 V.

Q.6 In what ways are both companies' technologies complementary?
A.6 The cascode (depletion mode) concept has the advantage of being suitable for standard gate drivers. Furthermore, the cascode solution offers a very low Vf body diode for reverse operation; turn-off speed is very fast and unconstrained by any feedback capacitance. The cascode can also be used in low to medium switching frequencies in resonant applications such as ZVS PFC up to a few MHz. The enhancement mode concept in contrast offers fast turn-on and turn-off speed and offers a better path towards integration either on a chip or package level. Enhancement mode works better for hard switching applications such as Totem pole. Low-voltage applications will require enhancement mode concepts in order to achieve the highest performance with regards to next-generation Silicon transistors. Finally, enhancement mode is more suitable for multi-chip integration. First products will focus on high-power applications.

In addition to technology, we also complement each other on the product level: the first cascode production generation focuses on medium-power applications, while the first enhancement mode products will focus on high-power applications.

Q.7 Which approach does Infineon pursue for GaN: cascode or enhancement mode?
A.7 Infineon GaN devices will be normally OFF. Depending on the system, cascode configuration or enhancement mode render advantages that we are looking into and considering with regard to the target application.

Q.8 Infineon has now cascode and enhancement mode GaN: what´s the best that fits a given application?
A.8 Both device concepts have specific advantages depending on the target application. Cascode and enhancement-mode GaN are two different methods to achieve the same goal: a GaN HEMT-based power switch with performance benefits of GaN and a normally-off characteristic, making it easier to deploy in power electronic systems.

The cascode configuration is fully compatible with existing drivers for low-voltage MOSFETs and offers a low Vf integrated body diode for reverse operation. The enhancement mode concept is a single-chip solution and hence facilitates further integration either on the chip or package level. For most early GaN applications so far identified either cascode or enhancement mode GaN devices will suffice. Therefore, early applications will be chosen around the maturity of the solution including availability of appropriate $R_{DS(on)}$switch, drivers and controllers. As enhancement mode-based solutions reach maturity, ease-of-use and solution costs will very likely make them the more prominent solution.

Q.9. What are the benefits for customers?
A.9 Customers receive a greater level of power density and higher efficiency: the ultimate goal is to bring applications, such as a Power Supplies, into a new era of miniaturization and light weight.

GaN – in comparison to the next best silicon alternative – will enable higher power density through the ability to switch at high frequencies, as well as highest efficiency, especially in the partial load range, through novel topologies, such as the Totem pole PFC stage. Moreover, GaN switch performance features low charge and excellent dynamic performance in reverse conduction compared to Silicon FET options. This enables more efficient operation at existing frequencies, and much higher frequency operation which can improve power density by shrinking the size of passive components in power electronics.

Q.10 In which applications will GaN be used and offer the biggest benefit?
A10: GaN will make an impact in many segments such as mobile power, telecom, servers, Class D audio systems and motor drives bringing benefits such as higher efficiency, smaller form factor, and lower harmonic distortion. Adoption rates will differ from application to application, starting with those where highest performance is required or system cost or Total Cost of Ownership reduction is achieved. Also, high efficiency / high density AC/DC and DC/DC in telecom/server applications and high density AC/DC in consumer SMPS. As an example, Infineon expects GaN to be the key technology enabling 98% A-Z efficiency in high-power SMPS for Telecom rectifiers. GaN HEMTs devices complement the existing 600 – 650 V CoolMOS™ portfolio by providing a high performance switch option that addresses the need for operating frequencies higher than those addressed by CoolMOS™. GaN extends the power switch portfolio from a few hundred kHz up into the MHz range to enable high density power supplies.

Q11. When will Infineon launch GaN products?
A.11 Infineon's first products will be discrete GaN switches in SMD packages targeting high power SMPS in the PFC and main DC/DC stage and high density AC/DC for server/telecom and consumer applications.

Enhancement mode 600 V: information is available for key customers under NDA in the case of specific design-in opportunities.
Cascode 100 V and 600 V: the first 100V GaN product has been in mass production with leading class-D Audio customer since 2013. All other products: information is available to key customers under NDA in case of specific design-in opportunities.

Q.12 What are the (technical) challenges for a customer?
A.12 Any device capable of very fast switching will have to be optimally integrated into a good package and PCB, since otherwise parasitic behavior will destroy the performance benefit of GaN. The use of SMD packages is key, as well as careful management of the system and PCB layout. All this combined will help to take full advantage of the capability of GaN. In addition, new high frequency topologies and circuits using GaN will require advanced controllers and control strategies to extract the ultimate performance capability that GaN offers. Driving cascode GaN transistors is straightforward. Care must be taken to minimize loop inductance both in the gate drive as well as the power loop to minimize voltage and current peaks, and gain the maximum benefit out of the fast switching devices. This is also true for the enhancement mode transistors. However, this device has increased gate drive complexity. Infineon will be providing application notes and evaluation boards to explain how this works in detail. All documentation will be released in combination with dedicated product launches. GaN devices exhibit a much lower output capacitance. In resonant applications, care must be taken to design the resonant part of the switching, including parameter variations of the resonant tank, to accommodate this behavior.

Q.13 Pricing - How much will it cost? How does it compare to MOSFET / SiC Devices?
A.13 Simply comparing the price of a GaN device to an existing Silicon FET is not meaningful. GaN could be a drop-in replacement for an existing Silicon FET, but the incremental benefit of that approach does not realize the full value GaN can offer. GaN will be used in advanced topologies enabling higher performance, efficiency, and power density than today's Silicon FETs. One has to consider the overall system value – the total BOM and SYSTEM costs and TCO and the additional performance. Clearly the overall price/performance has to offer value over existing solutions, or there would be no motivation to adopt this new technology.

Q.14 Where is the regional market focus?
A.14 The focus is on applications rather than regions. Initial application focus is commercial and consumer power supplies for markets where power density, size and form-factor (thickness for example) are key value drivers. Infineon's first products will be discrete GaN switches in SMD packages targeting high power SMPS in the PFC and main DC/DC stage and high density AC/DC for server/telecom and consumer applications.

Q.15 When will samples be available?
A. 15 Enhancement mode: Samples are available under specific NDAs. Cascode: Samples are available under specific NDAs.

Q.16 Are samples also available for other customers?
A.16 We are working with a select group of customers based on the demands placed on applications engineering teams. As the product portfolio develops, including the controller and driver ICs, additional demo boards and support collateral will also become available. All documentation will be released in combination with dedicated product launches.

Q.17 When will it go into high volume production?
A.17: Infineon is in volume production on 100 V technology devices in Class-D Audio amplifiers used in consumer products. We are not in a position to commit on other 100 V or 600 V products.

Q.18 Where are products developed and where are they produced?
A. 18 We kindly ask for your understanding that this information is not shared at this point in time.

Q. 19 What exactly is the status of development right now?
A.19 We kindly ask for your understanding that this information is not shared at this point in time.

Q.20 Can I have application notes, samples, ongoing prepared material, Demo-boards?
A20.We are working strategically with a select group of customers based on the demands placed on applications engineering teams. As the product portfolio develops, including the controller and driver ICs, additional demo boards and support collateral will also be available. All documentation will be released in combination with dedicated product launches.

Q.21 Why should customers wait for the IFX Solution?
A.21 Combining Infineon and IR's GaN teams has led to a level of GaN expertise that is unmatched. We are working hard and will bring GaN products into the market as soon as our quality and reliability requirements are met. In addition, once we launch our products we will have enough capacity to sustain high volume ramp-up and can even offer a second source for part of our portfolio.

Miniaturization and energy savings will be enabled by GaN devices and solutions. Being in the leading position on this path is a common goal for Infineon and its customers

Q.22 Which key customers have already sampled with GaN Devices?
A. 22 We kindly ask for your understanding that this information is not shared at this point in time.

Q.23. What is the initial feedback?
A.23 100 V GaN product is released in volumes for Class-D Audio amplifiers with a worldwide leader in Audio systems that has an excellent track record. All other samples of cascode and enhancement mode HEMTs are in evaluation with some of Infineon´s key customers who are building their experience around GaN in PFC Totem Pole FB and main DCDC boards targeting the highest efficiency. SMD packages are much appreciated as customers also perceive thru-hole is a no-go for high frequency designs. They are seeking a thermally optimized SMD package for high power applications (currently covered by TO220/TO247 standard packages).

Q24. What current ratings are offered? What voltage ratings?
A.24 100 V and 600 V class, although not fully released as of today. No information yet released regarding $R_{DS(ON)}$ /current ratings.

Q.25a How does GaN compare to SiC?
A.25a: We see the sweet spot for active SiC devices in the high-voltage / high power domain that is above 600 V. At this point in time Infineon believes that in these higher voltage areas (e.g. at 1200 V) SiC FETs are more competitive than GaN and much more mature. Additionally, they feature full avalanche ruggedness and high short circuit robustness due to excellent thermal conductivity of SiC.

Q.25b: How does GaN-on-Si compare to GaN-on-SiC?
A.25b: Very good high-performance 600 V FETs can be made with GaN-on-SiC. Performance is not the issue. Substrate cost is the major issue that will limit the value proposition of GaN-on-SiC FETs. Infineon is making its GaN HEMTs on Si substrates which have a far lower intrinsic material cost than SiC combined with an interesting cost roadmap as wafer diameter moves to 200mm and further.

Q.26. Is a specific support /driver required? If yes: when will this driver become available?
A.26: Driving cascode GaN transistors is straightforward, for the cascode concept a standard driver is sufficient. For the enhancement mode devices we recommend a specific isolated driver which is proven to perfectly handle them (1EDI EiceDRIVER™ - PN: 1EDI20N12AF), with an RC-network in the gate drive path to allow for fast turn-on and turn-off transitions. Application notes and evaluation boards are provided to customers to explain how this works in detail, based on regular MOSFET drivers. They will be made available to the broader market along with product launch. In general, care must be taken to minimize loop inductance both in the gate drive as well as the power loop to minimize voltage and current peaks, and gain the most benefit out of the fast switching devices. Moreover, the cascode switch is compatible with standard FET gate drivers. The enhancement-mode devices can be driven with conventional gate drivers plus an external R-C network. But a dedicated driver IC will ultimately provide higher performance using lower power.

For either type of GaN, new controller ICs will be necessary to take full advantage of the topologies and higher frequencies enabled by GaN.

Q.27 Where do you get your base material from?
A.27 We kindly ask for your understanding that this information is not shared at this point in time.

Q.28 Why do you launch GaN in a non-standard package?
A.28 Whether cascode or enhancement mode, specific internal connections are required which prevent the use of standard pinouts. Moreover, thru hole packages, albeit standard for the industry, prevent the full exploitation of the fast switching potential of GaN due to their high parasitics. Therefore, moving to SMD packages is a must for GaN, and Infineon has developed specific packages tailored on individual application needs, optimized for low profile or the highest thermal capability. They will be presented along with individual product launches.

Q.29 Can you comment on your GaN compared to main competitors?
A.29, Infineon does not comment on competitor activities.

Q.30 We have heard that Infineon is cooperating with Panasonic? Can you comment?
A.30 Yes, this is correct. We agreed to manufacture enhancement mode transistors in SMD packages in a compatible way, establishing a second source for our respective customers. For that purpose Infineon has licensed Panasonic's enhancement mode transistor technology.

Q.30.1 The recently announced partnership with Panasonic, focused on the transfer and optimization of certain modules of their enhancement mode GaN on Silicon HEMT technology, puts Infineon at the leading edge of GaN: we target offering dual source capabilities at an early stage, which is unique for new technologies, a significant capacity which is aimed at supporting a growing market and we will protect our know-how with the industry`s broadest patent portfolio.

Q.31 What will happen to International Rectifier's Product Brands for GaN?
A.31 No changes are planned at this point in time. GaNpowIR™ is a valuable brand and is recognized in the market.

Q.32 Some competitors have already launched First GaN Devices – what makes Infineon GaN different? What sets Infineon apart?
A.32 Infineon has the largest GaN expert team with the deepest understanding of the technology, a very strong GaN patent portfolio, scalable manufacturing setup, availability of SMD packages for low and high power applications and deep application understanding.

Summary

- Infineon, as the market leader for power semiconductors, is committed to reaching the next level of **system efficiency**, **energy savings** and **power density** at an affordable **system cost** and has, therefore, developed GaN-based semiconductors and is preparing a technology portfolio which is perfectly suited to unlock the full potential of GaN in the future, e.g. through fully integrated solutions.

- Infineon has pursued a **partnership approach** to accelerate our GaN development: e.g. intense collaboration with the **Fraunhofer** society. Infineon recently announced a partnership with **Panasonic,** transferring its **enhancement mode transistor technology** which started in 2014; this will allow Infineon to offer easy-to-use enhancement mode GaN switches in a **dual sourcing** approach unique in the industry.

- Infineon's first products will be discrete GaN switches in SMD packages targeting **high power SMPS** in the PFC and main DC/DC stage.

- The **acquisition of IR** has strengthened Infineon's position in GaN even further, e.g. by expanding our **patent portfolio** by more than 400 GaN patents and giving us access to **high quality GaN-on-Si epitaxy**, a strong barrier to entry for many of our competitors.

- IR's product portfolio is complementary to Infineon's with 100 V products (available). 600 V products in a cascode configuration targeting mid-power SMPS are in qualification.

- Infineon is committed to **maintaining its differentiating quality standards** also in new technologies such as GaN without compromise on long term **quality and reliability**.

- With both, the **acquisition of IR** and the **partnership with Panasonic**, Infineon is in the **pole position** with GaN.