POWER ELECTRONICS TECHNOLOGY

600 V GAN ON SI-BASED POWER USE GANPOWIR

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Commercially availability of 600 V rated GaN on Si based power devices has engendered widespread evaluation of these revolutionary switch components in various power system applications. In all cases, the use of GaN based power devices provides significant performance advantages over incumbent silicon based alternatives.

The performance advantages of GaN based HEMT (high electron mobility transistor) power devices over the incumbent silicon based alternatives derives mainly from two fundamental characteristics. The first is the inherently lower specific on-state resistance, due to the higher majority carrier electron mobility in the HEMTs two dimensional electron gas and the smaller source-drain spacing of the HEMT for a given operating voltage capability, made possible by the wide-bandgap nature of the materials involved. The second is the significantly lower switching charge due to the reduced terminal overlaps present in the lateral HEMT structure compared to the vertical silicon device, as well as the shorter gate length, also due to the higher (punch-through) field withstand capability of the wide-bandgap structure. The combination of these inherent advantages leads to revolutionary improvements in performance of power conversion circuitry, which utilizes GaN based power devices.

It should be noted that the two material based device technology platforms are at very different stages of maturity. While the silicon-based technology has effectively reached diminishing returns due to over 30 years of development efforts, the GaN based platform is only in its initial infancy and is expected to undergo significant improvements towards its fundamental capability limits of 10 to 100 fold over the next 10 to 20 years.

In order to provide ease of use in the early stages of adoption of this transformational technology platform, a cascaded circuit configuration is utilized, as shown in **Fig. 1**. The use of a low voltage enhancement mode silicon FET provides for convenient normally off operation, with familiar and well-established robust interface to the power conversion control circuitry. In this way, no extraneous limitation is provided for the use of the GaN-based devices (e.g. can drive 20 V) and standard drive ICs may be easily used. This configuration has the added advantage of providing a mΩ level gate drive for the GaN device which maintains the GaN gate voltage between ground and the negative avalanche clamping voltage of the silicon device. This prevents the catastrophic spillover of the two-dimensional electron gas of the HEMT, which occurs when the applied positive gate overdrive exceeds the built in field of the AlGaN barrier.

Due to the increasing use of power electronics in today s society and out of an interest to conserve energy, much attention has been paid to the power factor correction filter used to ensure clean supply of the power grid. The most common active topology for this filter is a boost circuit. Such a filter is now a practical requirement above a power rating of 50-75 W in countries that have set minimum EMI and power factor limits The device rating of the switch and rectifier elements must accommodate the maximum output boost voltage of about 430 V. Together with voltage transients, this leads to the use of a 600 V rated silicon devices. A small segment of the very high performance market has adopted the use of expensive SiC based rectifiers, which exhibit low reverse recovery charge due to the wide bandgap.

Wide Bandgap Devices

As can be seen in **Fig. 2**, as expected, wide bandgap GaN based rectifiers provide very similar performance, at a substantially reduced cost. High performance circuits most often use a silicon superjunction power MOSFET in the switch socket. This is due to the significantly improved specific on-state resistance offered by this technology over non-highly compensated unipolar silicon devices. Though the superjunction based silicon switch has significantly higher minority carrier stored charge, the nature of the off-state transition in the circuit topology allows for its use. Silicon based IGBTs, which exhibit much lower on state resistance than superjunction MOSFETs are generally too slow and provide too high switching losses to be useful in this circuit, which is generally designed to operate between 50 and 150 kHz switching frequency. Therefore, it is not the remarkable reduction in reverse recovery charge that promotes the use of GaN based power switches for this application, rather it is the considerable reduction in output charge based switching losses, together with substantial improvements in specific on resistance that make the GaN based device far superior to the silicon based alternatives.

In fact, the first generation 600 V rated GaNpowIR exhibit a performance figure of merit ($R_{DS(ON)}$ Q_{OSS})which is at least four

times better that the latest generation, best in class silicon based superjunction devices. Since it is expected that the GaN based devices will improve by at least a factor of 10 over the next 5-10 years, while the silicon technology is not expected to be able to accommodate more than an improvement of a fact of two, it is clear that this performance advantage will only increase in the future.

The effect of this initial performance advantage can be clearly seen in **Fig. 3** and **Fig. 4**, where a direct comparison between silicon based and GaN based circuits is shown for nominal 450 W PFC circuits optimized for 100 kHz and a nominal 200 W PFC circuit optimized for 400 kHz operation, respectively. In the case of the commonly used 100 kHz topology, a SiC diode is used as the rectifying element in both the silicon and GaN based switch examples. Here, the power losses in the boost stage, including inductor losses, is reduced by about 10 % through the use of a GaN based switch. The 400 kHz example uses all silicon or all GaN based active devices. Here it can be seen that the all GaN based device example exhibits excellent performance from light to full load, where the silicon based devices, as expected, cannot provide efficient operation at higher frequencies. The use of GaN based devices will therefore permit significant reduction in ac-dc front end size and cost, through the reduction in magnetic filter element requirements at higher frequency operation.

Resonant DC / DC Converter Performance

Moving further into a typical ac-dc converter circuit, a comparison is made of the performance of silicon and GaN based devices in a LLC resonant dc-dc converter from 300 to 30 V (as might be used in a class-D audio power supply). Here, a combination of 600 V rated primary switches and 100 V rated secondary switches (also as synchronous rectifiers) are used. The results, shown in **Fig. 5**, are particularly stunning. Due to the reduced switching charges, the light load efficiency is improved by some 17 %, while the full load efficiency, benefitting from the improved $R_{DS(ON)}$, is 3% better than using best in class silicon devices.

These represent only a few of many examples of improvement in power conversion circuit performance that are obtainable using GaN based power devices. While these improvements are noteworthy, the potential for GaN to make major inroads into the silicon transistomer market is more significant. The greatest improvements and the truly revolutionary advances will be achieved when the circuit topologies are optimized to take full advantage of the inherent capabilities of GaN based power devices.

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