GaN switches offer the next generation power conversion solution

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Recent progress in Gallium Nitride based power electronic devices has been remarkable. While lateral GaN devices (up to 600V) have entered into the medium power conversion market, vertical GaN devices are getting more research attention to provide solutions for the high power market. The two big innovations enabled by GaN devices that helped power electronics push the limits above Silicon are 1) higher efficiency at higher frequency of operation and 2) higher efficiency at operating temperature. The high frequency of operation has allowed reduction in size, weight and cost of the overall system by reducing the size of the passive components. Furthermore it has also enabled new functionality like adding of compact filters to the inverter board leading to an overall increase in electro mechanical efficiency of the motor by 5% at mid load [1]. The capability of GaN devices to run at higher efficiencies, for example in a PV inverter at an efficiency above 98% (vs 96.5% with Si), have resulted in smaller size and possibly cost due to reduction in the cooling requirements. All these innovations have resulted in new possibilities with circuit architecture, to further enhance the efficiency and add portability to existing applications. GaN lateral devices on Si substrates have demonstrated breakdown voltages up to 1.1KV running induction motor and ultra high-speed permanent magnet motors with higher efficiencies than Si.

A lateral AlGaN/GaN HEMT works as a high voltage switch by holding the blocking voltage in the "off-state" between the gate and the drain by depletion of the 2D electron gas in the channel. The high mobility 2D electron channel with high charge (~1E13/cm^2) at the AlGaN/GaN interface leads to low switching capacitance resulting into a 40% reduction in output charging energy. The JEDEC qualified normally –off device offered by Transphorm, utilizes a cascode configuration with a low voltage Si FET, resulting in a threshold of +2.1V measured at 1mA drain current [2]. The drain leakage is 10 µA typical at V_{gs}=0V and V_{ds}=600V. The pulsed drain current is 40 A at a V_{gs}=8V & V_{ds}=10V. The continuous (CW) drain current is 8.5 A at a case temperature of 25 ºC. Compared with similarly rated state-of-the-art Si super-junction MOSFETs on the market, this 1st generation GaN HEMT offers about 28% reduction in on-resistance, 80% increase in pulsed current. Similar performance with GaN devices have been measured at 1.1KV, attests the fact that lateral devices are very attractive up to 1-1.5KV limits. in the device performance is achieved with achieving a good gate and field-plated region to manage peak electric field and dispersion along with optimized epitaxial layer growth. Although robust, the technology suffers from over design of the devices and therefore higher than 1-1.5KV operations needs vertical design to maintain the performance benefit over Si devices.

A vertical GaN HEMT is best designed using a CAVET like structure has the advantage of a high charge high mobility channel added to a thick drift region to hold the blocking voltage under a vertical electric field [3]. The electrons in these devices flow from the source through the 2DEG modulated by a planar gate and then vertically down through an aperture to the drain. The blocking voltage between the gate and the drain is supported by depleting a lightly doped n-type GaN drift region. Current blocking layers, which form an integral part of the device, are designed to prevent current flowing through any other path than the aperture. The CBL also acts as built-in field plates managing the electric field without requiring complex metal field plates unlike used for a lateral design. When compared to a lateral device a vertical device saves more chip area for a given operating current because the blocking voltage is held by the thickness of the epi layers and therefore can be scaled to higher operating voltages demanded by the high power application. Since the high electric field points are buried in the bulk of the material these devices do not suffer from surface state related dispersion. A typical CAVET fabricated and measured at UCSB offered R_{on} less than 2 mΩ-cm^2 with a breakdown voltage over 200V translating to an electric field of 100V/µm. The devices were dispersion-free under 80µs pulsed applied to the gate and registered a maximum current of 4KA/cm^2. The technology looks definitely very promising since these early results have demonstrated breakdown electric field at least 3 times a than any lateral device and closest to the theoretically predicted value.

[1] J.Honea, J. Kang, "High-Speed GaN Switches for Motor Drives", Power Electronics Europe, 3 (2012) 38-41.
[2] S.Chowdhury and U.K Mishra, Lateral and Vertical transistors using the AlGaN/GaN heterostructure IEEE Transaction on Electron Devices, Volume 60, Issue 10, (7 pages)
[3] S. Chowdhury, B.L.Swenson, M.Wong and U K Mishra, Current status and scope of gallium nitride-based vertical transistors for high-power electronics application" Semiconductor Science and Technology Volume 28 Number 7 07401(8pages)

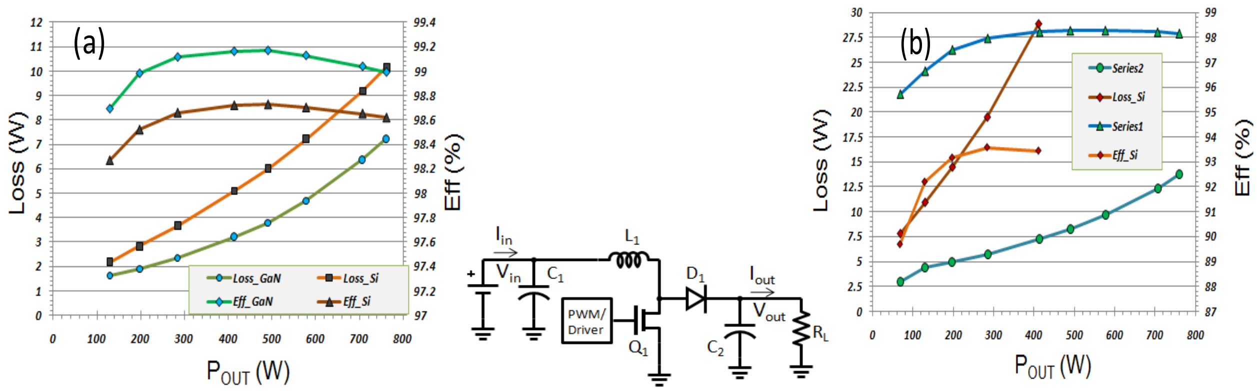

Figure 1. Conversion efficiency and loss as a function of the output power in a dc boost converter for (a) 100KHz and (b) 800KHz. The data has been compared to a Si-based dc converter (the circuit diagram is shown). This shows the current status of GaN devices in power market. The devices were designed, fabricated and tested at Transphorm.

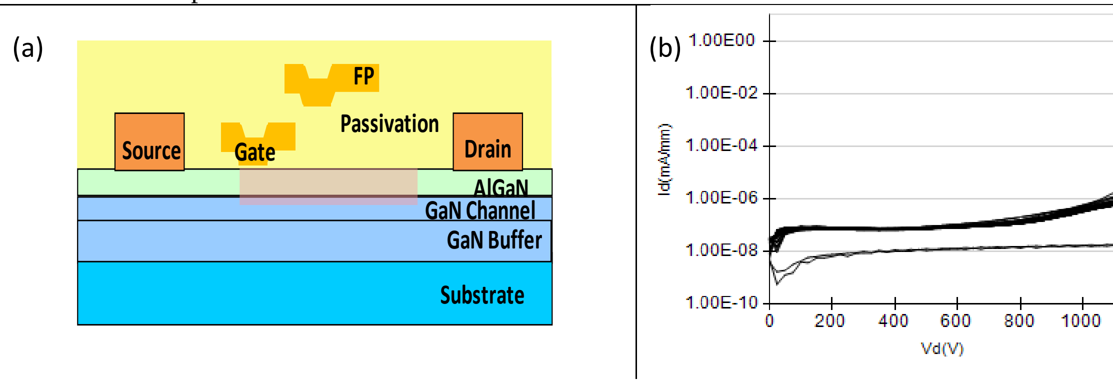

Figure 2. (a) A Lateral GaN HEMT with FPs and (b) GaN-on-Si HEMTs with blocking voltages over 1KV(fabricated and measured at Transphorm)

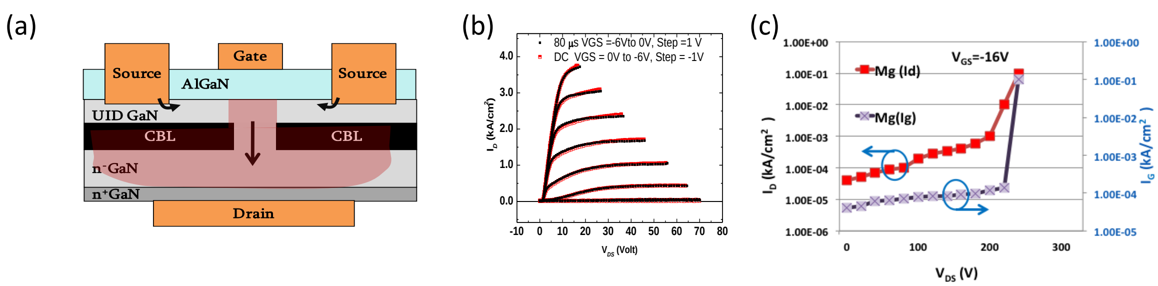

Figure 3. (a) A vertical device (CAVET) on bulk GaN substrates (Provided by Toyota Motor Corporation, Japan) (b) showing no dispersion under 80 µs pulses applied to the gate with a maximum current of 3.5 KA/cm^2 and low R_{on} (< 2.2 mΩcm^2). (c) Breakdown electric field of 1MV/cm was recorded.