Novel 600 V GaN Schottky Diode Delivering SiC Performance Without the SiC Price

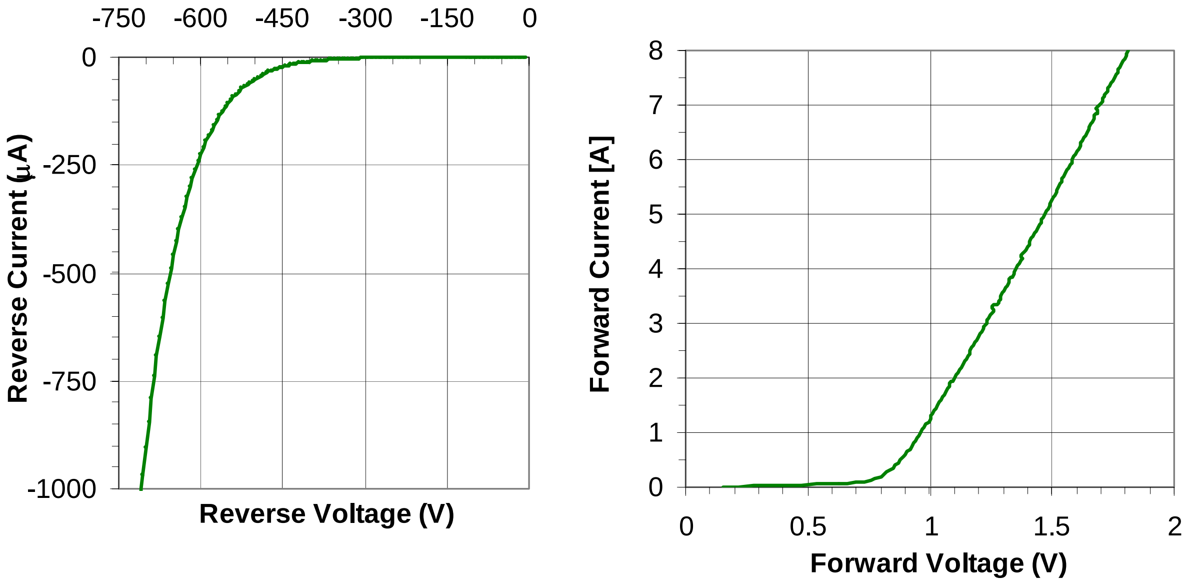
***Abstract*-GaN Schottky diodes offer the same performance benefits as SiC-based devices at a significantly lower cost. A 600 V GaN-based Schottky diode was substituted in a power conversion circuit to reduce its size and complexity. The resulting circuit had a higher efficiency and lower operating temperature than a Si-based configuration.**

I. Introduction

Current trends in power supply design are focused on reduced size, weight, and cost to improve performance. A significant barrier on the way to size and cost reduction is the availability of inexpensive high voltage (>300 V) Schottky diodes [1]. Currently available 600 V silicon carbide (SiC) Schottky diodes are too expensive to find a broad acceptance in the industry. We developed an innovative gallium nitride (GaN) Schottky diode that has the same or better performance as SiC devices but is several times less expensive. By using a GaN device, many advantages are apparent: reduced switching losses in both the diode and the MOSFET, elimination of active snubber components, higher efficiency, and improved temperature performance.

II. Description of the GaN Schottky Diode

GaN Schottky diodes are capable of excellent performance because the material quality of the active device can be grown within a metal-organic chemical vapor deposition (MOCVD) reactor with a very high mobility resulting in a very low on-state resistance. Additionally, due to the wide bandgap of GaN, Schottky diodes with exceptionally high breakdown field strength of 600 V can be fabricated. Current-voltage characteristics for a 600 V GaN Schottky diode are shown in Fig. 1. The performance of the diode is very good with a breakdown voltage well over 600 V and a forward turn-on voltage of less than 1 V.



(a) (b)

Figure 1. Room temperature I-V characteristics for a 6 A / 600 V GaN Schottky diode in (a) reverse and (b) forward bias.

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These device parameters are very similar to SiC Schottky diodes at the same rating as shown in Table I.

TABLE I
PERFORMANCE COMPARISON BETWEEN 600 V GAN-BASED AND SIC-BASED SCHOTTKY DIODES

	6 A / 600 V GaN Schottky Diode	6 A / 600 V SiC Schottky Diode [2]
Reverse Voltage	600 V	600 V
Forward Voltage @ T_j= 25 ºC	1.5 – 1.8 V	1.5 - 1.8 V
Reverse Recovery Charge	9 nC	17 nC

Both GaN and SiC offer efficiency advantages over conventional Si devices because the switching charge is much lower and is independent of di/dt, temperature, and current level. The very low recovery charge of the GaN Schottky diode is shown compared to Si and SiC diodes in Fig. 2. The performance characteristics of the GaN devices are very similar compared to SiC devices, yet GaN diodes can be manufactured for much lower cost.

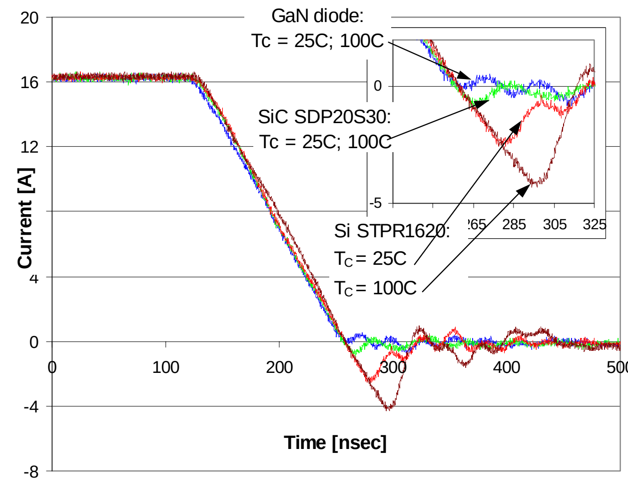


Figure 2. Temperature-independent short reverse recovery time of GaN Schottky diodes.

III. DESCRIPTION OF TEST CIRCUIT

Because of a combination of short recovery time, high breakdown voltages, and large operating currents, GaN Schottky diodes have an excellent application in power factor correction (PFC) units. The generic circuit utilizing Si devices is shown in Fig. 3 with a total of 8 Si diodes. These Si Panasonic YG902C3R 300 V / 10 A Si power rectifiers were replaced with two VSD06060 600 V / 6A GaN devices . When the GaN devices were used, the highlighted snubber circuit components in Fig. 3 were not necessary. The resulting circuit is shown in Fig 4.

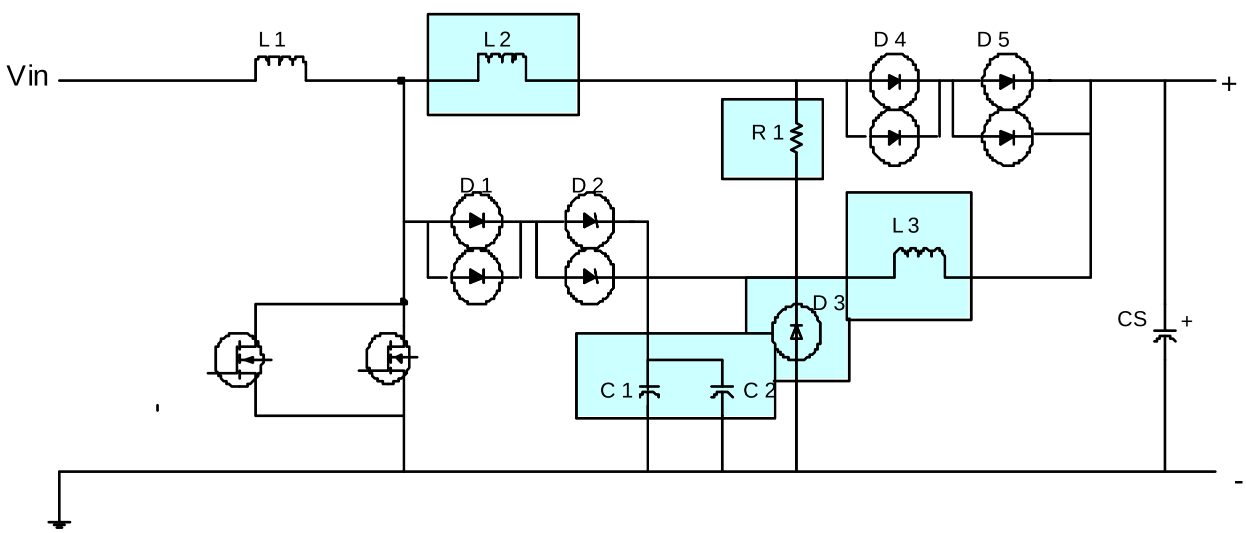


Figure 3. Si-based diode circuit implementation with snubber elements highlighted.

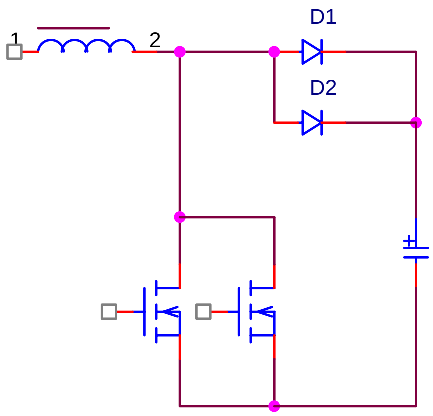
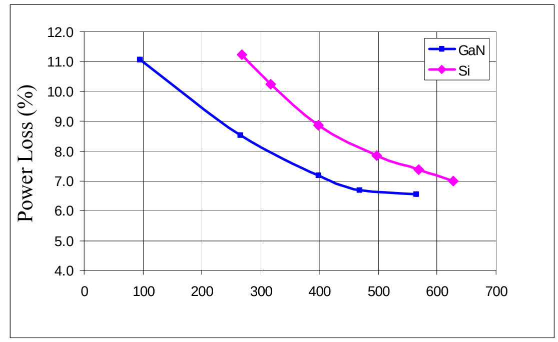


Figure 4. Resulting circuit from Fig. 3 shown with the diodes replaced with two 600V GaN Schottky diodes.



Power Out (Watts)
(Vin=120Vdc, Vout = 350Vdc)

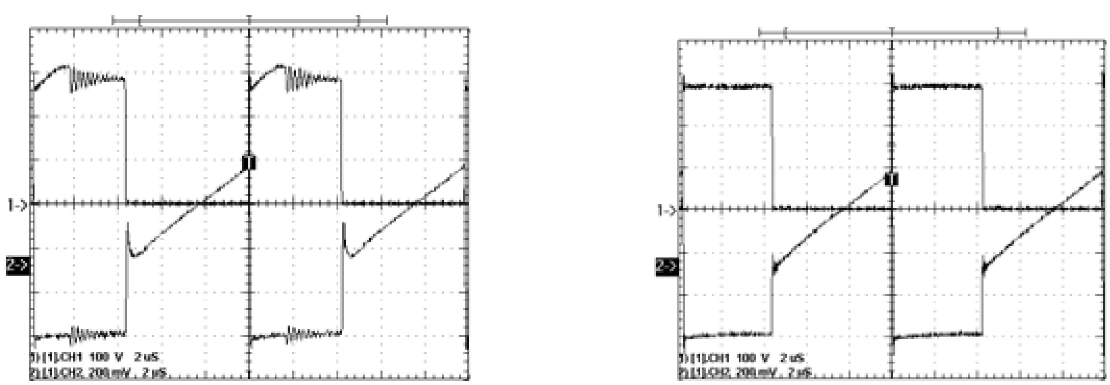
Figure 5. Comparison of circuit power losses in Si-based and GaN-based systems.

The resulting circuits with GaN devices had better efficiency (lower power losses) than circuit with Si devices as shown in the Fig. 5. The turn-on switching losses of the MOSFET are strongly dependent on the reverse recovery characteristics of its freewheeling diode. The neglible reverse recovery time in the GaN Schottky diode improves the performance of the circuit as compared to a Si device operating at the same power level, because an increase in the current rating means a larger device must be used, which increases the reverse recovery time of the Si device.

The reasons for improved efficiency were the significantly better waveforms on transistor and diode that led to lower power dissipation. See Figs. 6 and 7 below.

Transistor in Si System

Transistor in GaN System



CH1 Vds, CH2 Ids (2A/div)

Vin = 120Vdc, Vout = 300Vdc, Pout = 590W

Figure 6. Improved power dissipation and waveforms of transistors in the circuit.

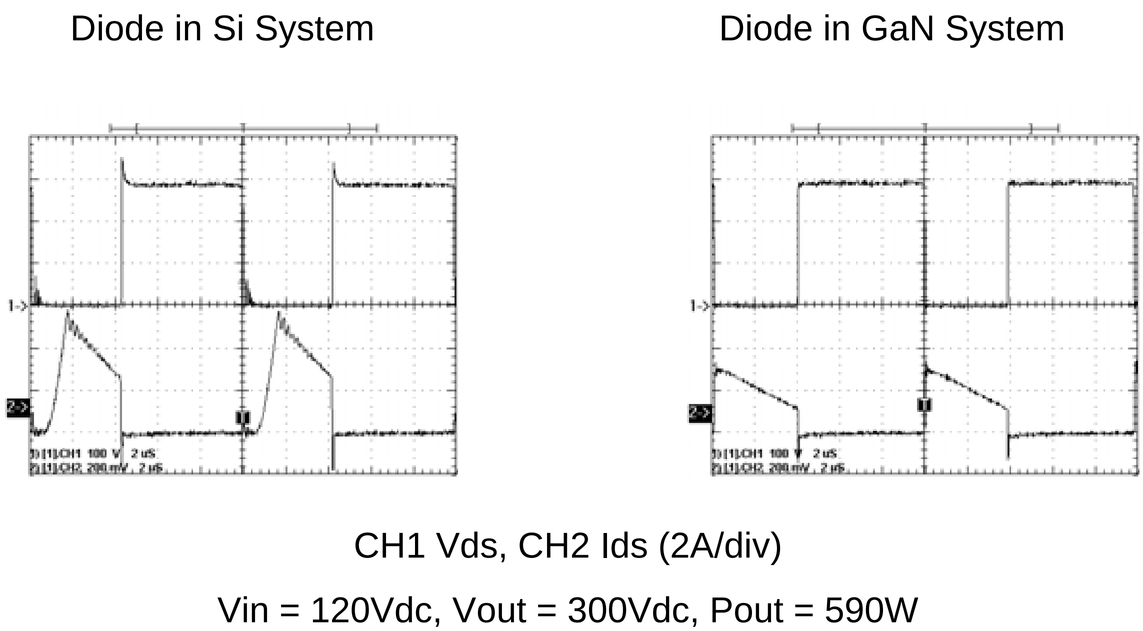


Figure 7. Improved power dissipation and waveforms of diodes in the circuit.

Improved circuit response is not the only advantage of using GaN devices in PFC circuits. Even though the forward voltage of GaN devices used in this study was slightly higher than Vf of Si devices the diode temperature was lower due to much better recovery characteristics as shown in Figure 8. The improvement in efficiency directly translates to the circuit's maximum operating temperature. The forward voltage and maximum current carrying capability of GaN devices is improving consistently, whereas there is little room in Si devices for improvement. Additionally, more expensive 600V Si devices are even less efficient than the 300V Si diodes used in this study. The heat sink and packaging of the power supply can thus be decreased in size, while maintaining the performance advantages in efficiency.

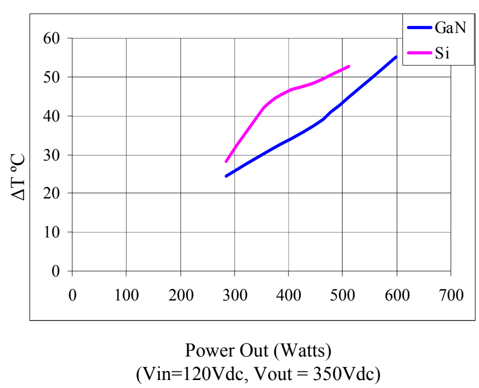


Figure 8. Temperature increase of GaN devices is significantly lower than that of Si devices.

IV. Benefits and Conclusion

The impact of the GaN Schottky diode on switching performance is of great importance to the circuit designer. Based on the measurements presented above, there are significant advantages offered by GaN Schottky diodes. While the reverse recovery current of the Si diode shows strong temperature dependence, the GaN Schottky diode is unaffected. At a high di/dt the Si diode exhibits a voltage overshoot on turn-off due to snap off during reverse recovery, but the GaN Schottky diode is unaffected. Si diode also causes oscillations in the transistor voltage, which generates RFI/EMI. This oscillation is not present with the GaN diode as shown in Figs. 6 and 7.

The reduction in switching losses can be applied in a number of ways to optimize the circuit design; to increase efficiency, reduce cooling requirements, or reduce the current rating of the transistor. The operating frequency can be increased to allow the use of smaller passive components, or to achieve acoustic requirements. The absence of a voltage overshoot eliminates the need for snubber networks. The absence of the high frequency oscillation also reduces the RFI/EMI filter requirements. Compared to SiC devices, GaN devices are significantly less expensive and could be adopted in a significantly broader range of applications.

References

[1] C. Miesner, R. Rupp, H. Kapels, M. Krach, and L. Zverev, "thinQ! Silicon Carbide Schottky Diodes: An SMPS Circuit Designer's Dream Coomes True!," available on the Infineon website at: http://www.infineon.com/cmc_upload/documents/027/313/WhitePaper_SiC.pdf.

[2] SiC Schottky diode Cree data sheet CSD06060, available on the Cree, Inc. website at: http://www.cree.com/ftp/pub/CSD06060.pdf.