Key Engineering Materials
ISSN: 1662-9795, Vol. 948, pp 89-93
doi:10.4028/p-tuypqj

Submitted: 2022-08-26
Revised: 2022-10-28
Accepted: 2022-11-25
Online: 2023-06-06

High Density 65W AC-DC Adaptor Enabled by SiC MOSFET with Ultralow $V_{GS(on)}$

Fu Jen Hsu[1,2,a], Cheng-Tyng Yen[1,b], Hsiang-Ting Hung[1,c], Jia-Wei Hu[2,d], Chih-Fang Huang[2,e]

[1)]Fast SiC Semiconductor Inc., Rm.510, Bldg.2, No.321, Sec.2 Guangfu Rd., Hsinchu, Taiwan

[2)]National Tsing Hua University, No.101, Sec.2, Guangfu Rd., Hsinchu, Taiwan

E-mail: [a*]Frane.Hsu@fastsic.com (corresponding author), [b]CT.Yen@fastsic.com, [c]hhung@fastsic.com, [d]jacky21513@yahoo.com.tw, [e]cfhuang@ee.nthu.edu.tw

Keywords: SiC MOSFET, AC-DC, ACF, Application

Abstract. SiC MOSFETs are rarely used in low-power consumer applications because of their cost and gate driving circuitry requirement. In this work, a cost-efficient SiC MOSFET with a usable 10V of V_{GS} is proposed. The proposed SiC MOSFET could enable low-power applications, which is around tens to hundreds of watt, to implement SiC MOSFETs. As a result, the thermal performance is better than the GaN solution thanks to the better thermal conductance of the SiC.

Introduction

Silicon Carbide MOSFET has been applied in many high-end applications due to its high breakdown voltage, high power capacity, and excellent reliability. However, SiC MOSFETs are rarely implemented in consumer applications because of their requirement of additional gate driver and auxiliary circuitries [1 – 3]. Conventional SiC MOSFETs seem not suitable for typical silicon-based PWMIC solutions and need relatively complicated peripheral circuitries, which increases the total B.O.M. cost and occupies more room in limited PCB spaces. Therefore, to penetrate the consumer market, a SiC MOSFET with ease-of-use features and low driving voltage is required. Typically, a lower $V_{GS(on)}$ level is accompanied with a more relaxed oxide field and higher channel mobility. In this work, a SiC MOSFET with a 12V of low $V_{GS(on)}$ is proposed, fabricated, and finished with the verification process. Then, a portable adaptor built with active clamp flyback (ACF) topology is demonstrated. Based on this test platform, this work discusses the efficiency, critical waveforms, and compares the results with a commercial GaN HEMT solution.

TABLE 1. COMPARISON OF KEY DEVICE PARAMETERS

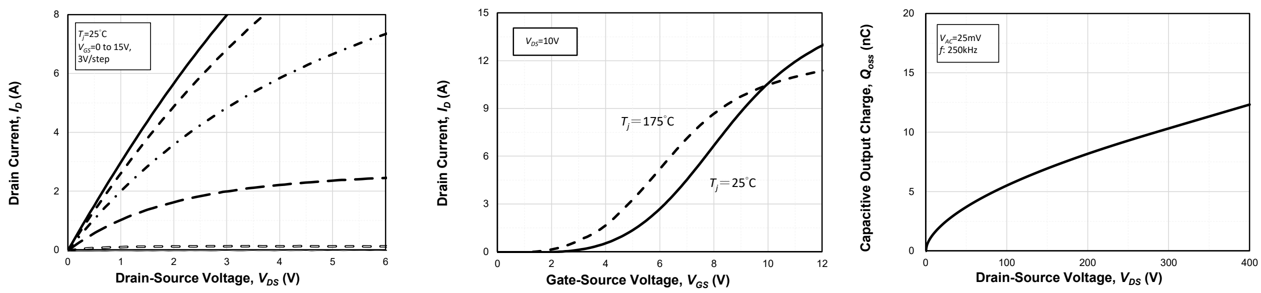
Item \ Material	SiC MOSFET	Cascode GaN	Unit
BV_{DSS}	650	650	V
$R_{DS(on)}$ (@25°C)	365	240	mΩ
$R_{DS(on)}$ (@150°C)	415	505	mΩ
Q_G	12.9	7	nC
E_{oss}	1.83	2.0	µJ
C_{iss}	344	760	pF
C_{oss}	20	16	pF
C_{rss}	4.4	2	pF
Q_{oss}	12.3	18.7	nC
$R_{DS(on)} \times Q_{oss}$ (25°C)	4,490	4,488	pΩC
$R_{DS(on)} \times Q_{oss}$ (150°C)	5,105	9,444	pΩC

TABLE 2. KEY QUALIFICATION ITEMS

Item	Test Condition/Criteria	Fail/Qty.
HTRB	JESD22-A108, T_A=175°C, V_R=80% Rated BV_{DSS} 1,000 hrs	0/231 PASS
HTGB	JESD22-A108, T_A=175°C V_{GS}=+/-100% Rated V_{GS} 1,000 hrs	0/616 PASS
HV-H³TRB	JESD22-A101, T_A=85°C, 85%RH, V_R=80% Rated BV_{DSS} 1,000 hrs	0/154 PASS

Approach

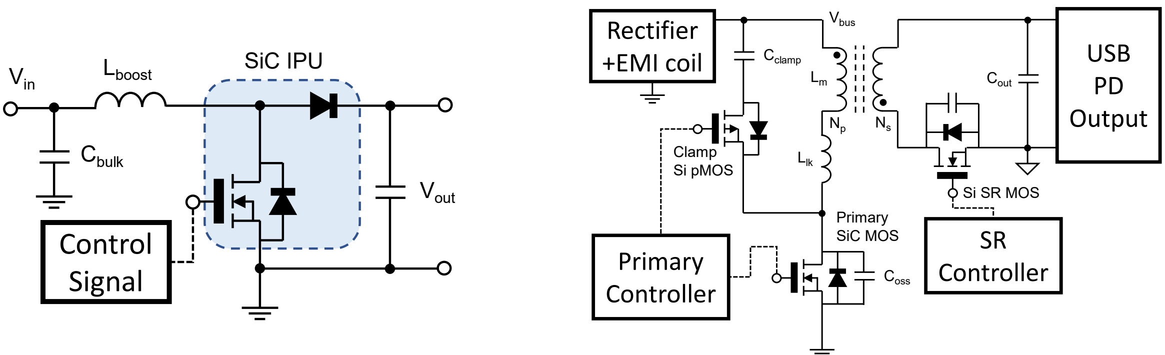
First, the key parameters of the proposed SiC MOSFET and a commercialized cascode GaN HEMT are listed in Table 1, and both devices present extraordinary performance. Moreover, SiC MOSFET provides a similar $R_{DS(on)}*Q_{oss}$ FOM at room temperature and better $R_{DS(on)}*Q_{oss}$ than GaN at 150°C, which suggests SiC MOSFETs are more favorable in high-temperature bridge-type hard switching applications than the GaN counterparts [4]. Fig. 1 provides the I_D-V_D, I_D-V_G, and Q_{oss} characteristics of the proposed SiC MOSFETs. Meanwhile, the proposed SiC MOSFETs have passed the qualification based on AEC-Q101 and some of the critical items are listed in Table 2.



(a) (b) (c)

Fig. 1: Typical (a) I_D-V_D, (b) I_D-V_G, and (c) Q_{oss} *vs.* V_{DS} curves of proposed SiC MOSFET.

Second, a series of dynamic behavior verifications are executed as in Fig. 2 and 3. To be more specific, a clamped inductive load switching test was done to verify the switching characteristics of the proposed device. Then, the proposed MOSFET is put into an open-loop high frequency boost converter without any heat-sink added. Fig. 4(a) shows a co-packaged SiC MOSFET and diodes in an IPU (integrated power unit) to be operated at different switching frequencies after start-up to reach steady-state. After the above tests, a 65W output ACF-based adapter with a power density of 29.55 W/in^3 under USB-C PD3.0 protocols is used as a test vehicle. In the meantime, to benchmark the low gate voltage capability, this work chooses a controller/driver with only 10V of output signal.



(a) (b)

Fig. 2: The test platforms that were used in this work. (a) a high frequency open loop boost converter with an integrated power unit (IPU) (b) a high density 65W ACF USB-PD3.0 compact adapter.

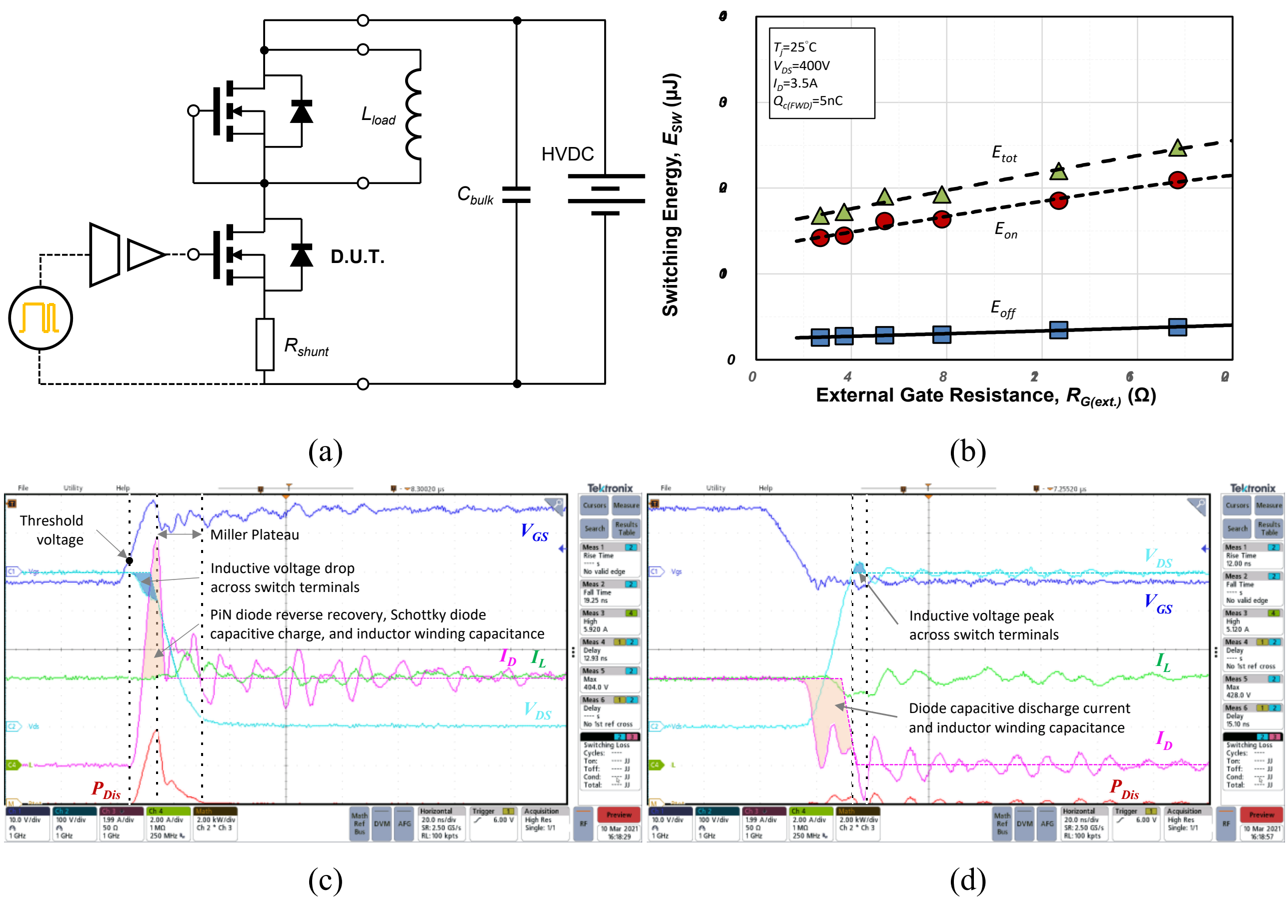


Fig. 3: Test results and typical waveforms in clamped inductive switching with proposed 650V/ 320mΩ SiC MOS

Results

In Fig. 4, the test results of the proposed boost converter are shown. These results demonstrate that the proposed devices could possibly operate at 1 MHz hard switching systems stably. Furthermore, Fig. 5–7 plots the full range waveforms and efficiency of the proposed SiC MOSFET in a 65W ACF adapter. As a result, it could be observed that when the system is operated under light to medium load, GaN show a slightly superior efficiency. However, when the system is under heavy to full load, even we choose a SiC MOSFET with a 81.25% higher $R_{DS(on)}$, the efficiency is better than the GaN solution. The possible reasons could be divided into two parts – the first one is the difference in the temperature coefficient of $R_{DS(on)}$ between SiC and GaN devices as shown in Fig. 6. The second possibility is current collapse. As shown in Fig. 7(d)(e), the waveform of GaN HEMT is significantly affected by the dynamic $R_{DS(on)}$ which may induce additional losses.

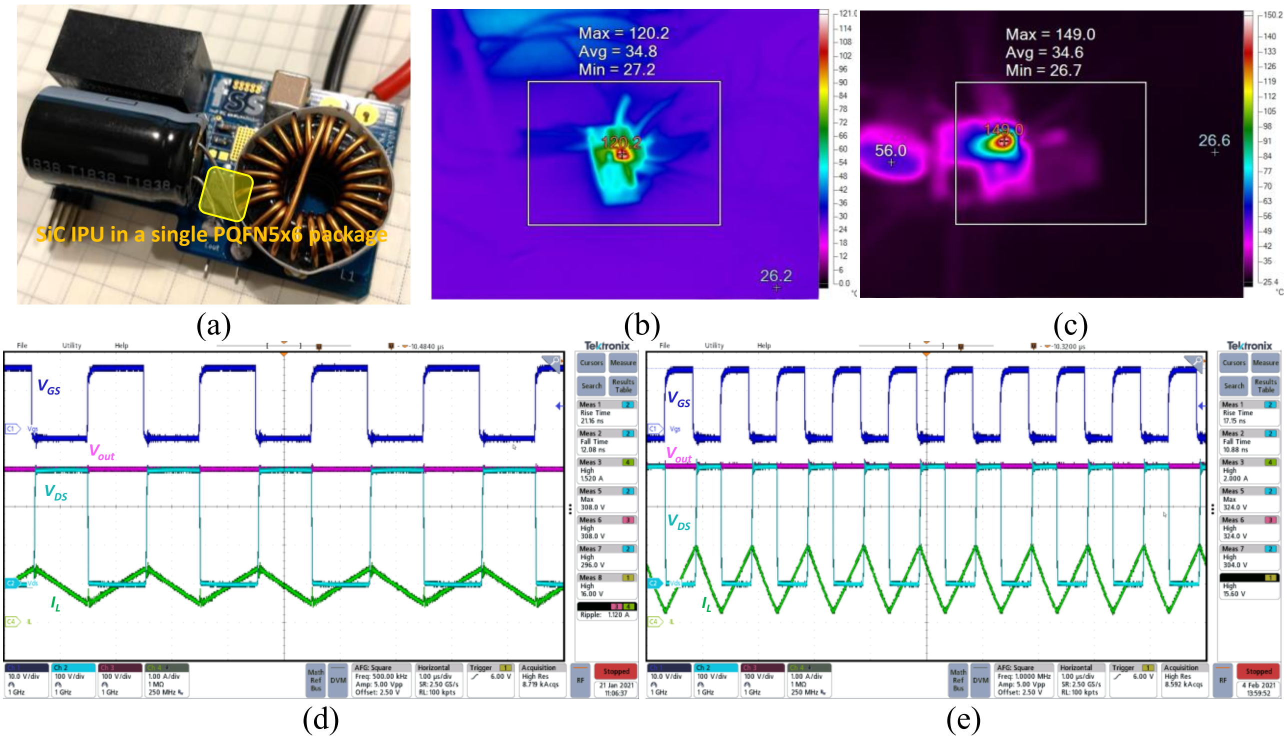


Fig. 4: (a) proposed V_{in}=150V, V_{out}=300V, P_{out}=150W C.C.M. boost converter with a dimension of 49*27*14 mm^3; (b)(d) thermal image and waveforms at f_{sw}=500kHz, the steady state temperature is 120°C; (c)(e) thermal image and waveforms at f_{sw}=1MHz, the steady state temperature is 149°C. The waveforms are staying clean even the devices are operated under extremely high frequency and high temperature in hard-switching conditions.

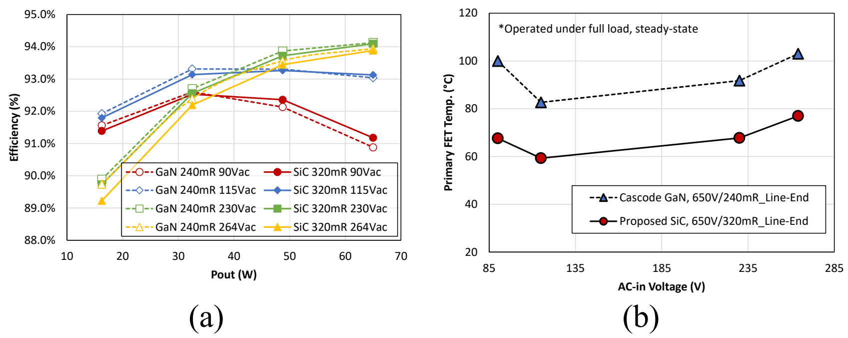


Fig. 5: The efficiency & Thermal comparison of the proposed SiC and GaN solution.

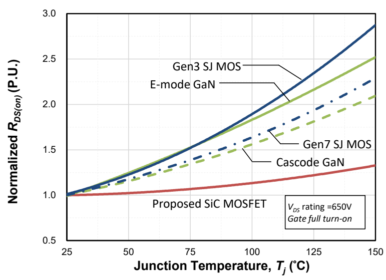


Fig. 6: $R_{DS(on)} - T_j$ dependency of current commercialized devices.

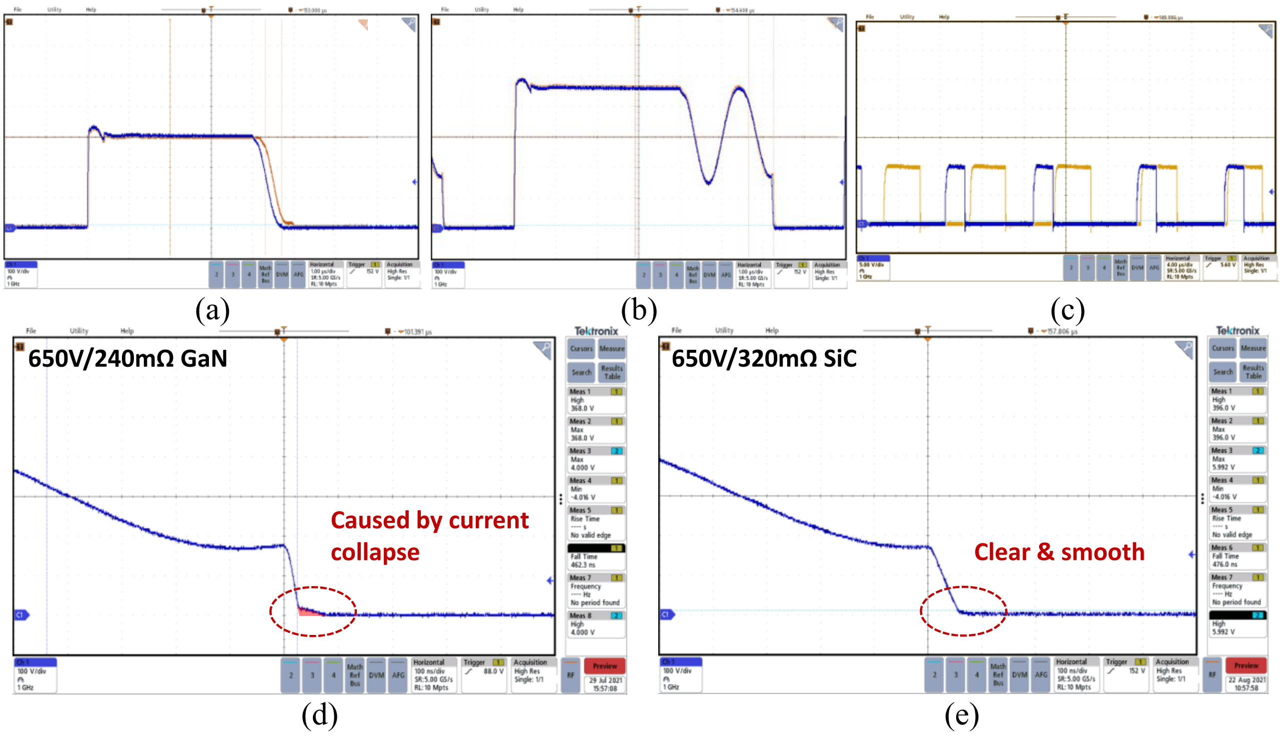


Fig. 7: Crucial waveforms of SiC and GaN ACF solutions. (a) V_{DS} of 115V_{AC} (blue: SiC red: GaN) (b) V_{DS} of 230V_{AC} (blue: SiC red: GaN) (c) V_{GS} of proposed SiC MOSFET (yellow: 115V_{AC} blue: 230V_{AC}) (d)(e) The comparison of V_{DS} turn-on waveforms between GaN (left) and SiC (right) at 230V_{ACin}, the current collapse phenomenon is significant in the GaN solution.

In conclusion, this work provides a series of tests and discussions from the device characteristics verification to a complete system-level demonstration. The test results reveal that low V_{GS} SiC MOSFETs have great potential for the consumer market and could well be driven by commercially available silicon PMICs without any auxiliary driver IC, opening them up to wider applications.

References

[1] R. Lamichhane et al., “A wide bandgap SiC gate driver for high-temperature and high-voltage applications”, ISPSD 2014

[2] A. Camacho et al., “A Novel Active Gate Driver for Improving SiC MOSFET Switching Trajectory”, IEEE T-IE, Nov. 2017

[3] Z. Zhang et al., “Active Gate Driver for Crosstalk Suppression of SiC Devices in a Phase-Leg Configuration”, IEEE TPEL, Apr. 2014

[4] M. Treu et al., “The role of silicon, silicon carbide and gallium nitride in power electronics”, IEDM 2012