1.2 kV, 10 A, 4H-SiC Bi-Directional Field Effect Transistor (BiDFET) with Low On-State Voltage Drop

Ajit Kanale, Tzu-Hsuan Cheng, Aditi Agarwal, B. Jayant Baliga, Subhashish Bhattacharya and Douglas C. Hopkins

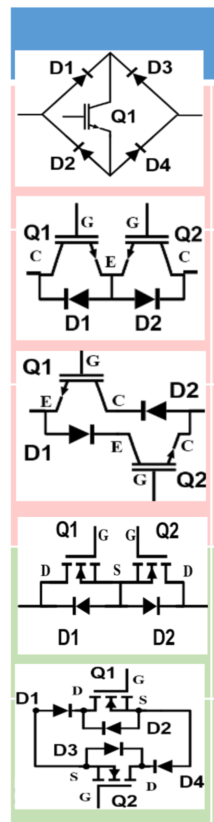
FREEDM SYSTEMS CENTER

NC STATE UNIVERSITY

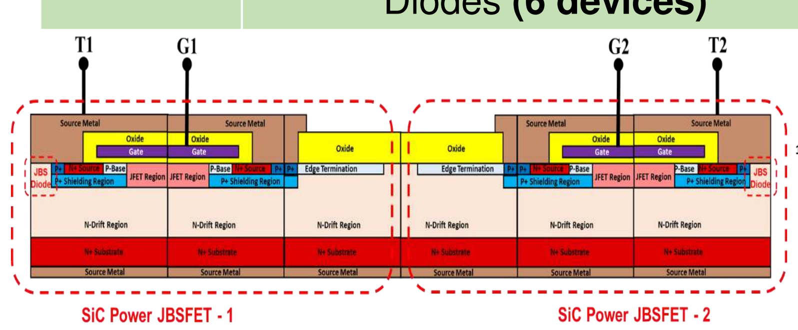
Overview[1,2]

1. BiDirectional Power Switches are used in Matrix-, or Cycloconverters and Multistage Inverter Circuits to facilitate high-frequency AC-to-AC conversion, eliminate bulky DC link capacitors, achieve high power density, and enhance its operating temperature range.
2. There is a lack of commercial SiC-based bidirectional switches, with prior implementations with discrete devices having a large semiconductor count, high on-state voltage, and large switching losses.
3. **NCSU has fabricated the first Monolithic 4H-SiC, 1.2 kV, 10 A Bidirectional Field Effect Transistor (BiDFET) using PRESiCE™ process at X-FAB, TX**.
4. The BiDFET is shown to have a **low forward voltage** (**0.6 V at 10 A**), atleast **2.5x smaller** than previous Si IGBT and SiC MOSFET based bidirectional switch implementations.
5. The BiDFET has symmetric blocking behavior, transfer characteristics and capacitance in both first and third quadrants.

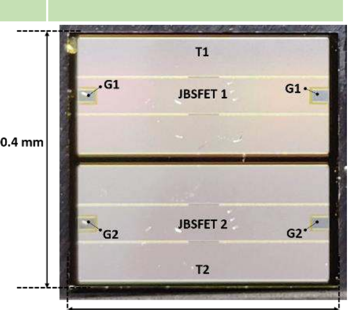
Table I: On-State Voltage Drop vs. Device Count



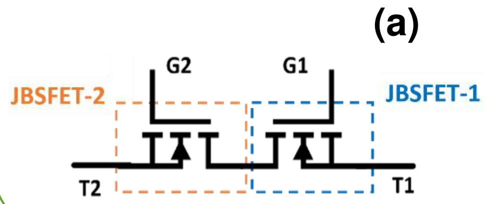
Switch Option	On-Voltage (V)
Diode Bridge + Asym. IGBT **(5 devices)**	3.5
Asym. IGBTs + Flyback diodes **(4 devices)**	2.5
Back-to-Back rev. Blocking IGBTs **(2 devices)**	2.0
Source-Connected SiC MOSFETs + SiC JBS Diodes **(4 devices)**	1.25
Back-to-back SiC MOSFETs + series and rev. blocking SiC JBS Diodes **(6 devices)**	1.25



(a)



(b)



(c)

Fig. 1: (a) BiDFET Cross-Section (b) Fabricated 1.2 kV 10 A BIDFET Chip. and (c) Symbol showing internal JBSFET transistors

BiDFET Static Performance[1]

1. BiDFETs have been packaged as discrete and half-bridge modules, and characterization was conducted using a Keysight B1505A curve tracer and custom DPT boards.
2. Measured Static Characteristics included On-Resistance, Threshold Voltage, Blocking Voltage, Transconductance and Capacitances.
3. The BiDFET exhibits a **lower capacitance compared to its internal JBSFETs**. This indicates a superior switching performance compared to a single internal JBSFET.
4. The BiDFET is implemented by connecting two JBSFETs back-to-back in the **common-drain configuration, which enables easy manufacturing** to create a four-terminal bidirectional switch.

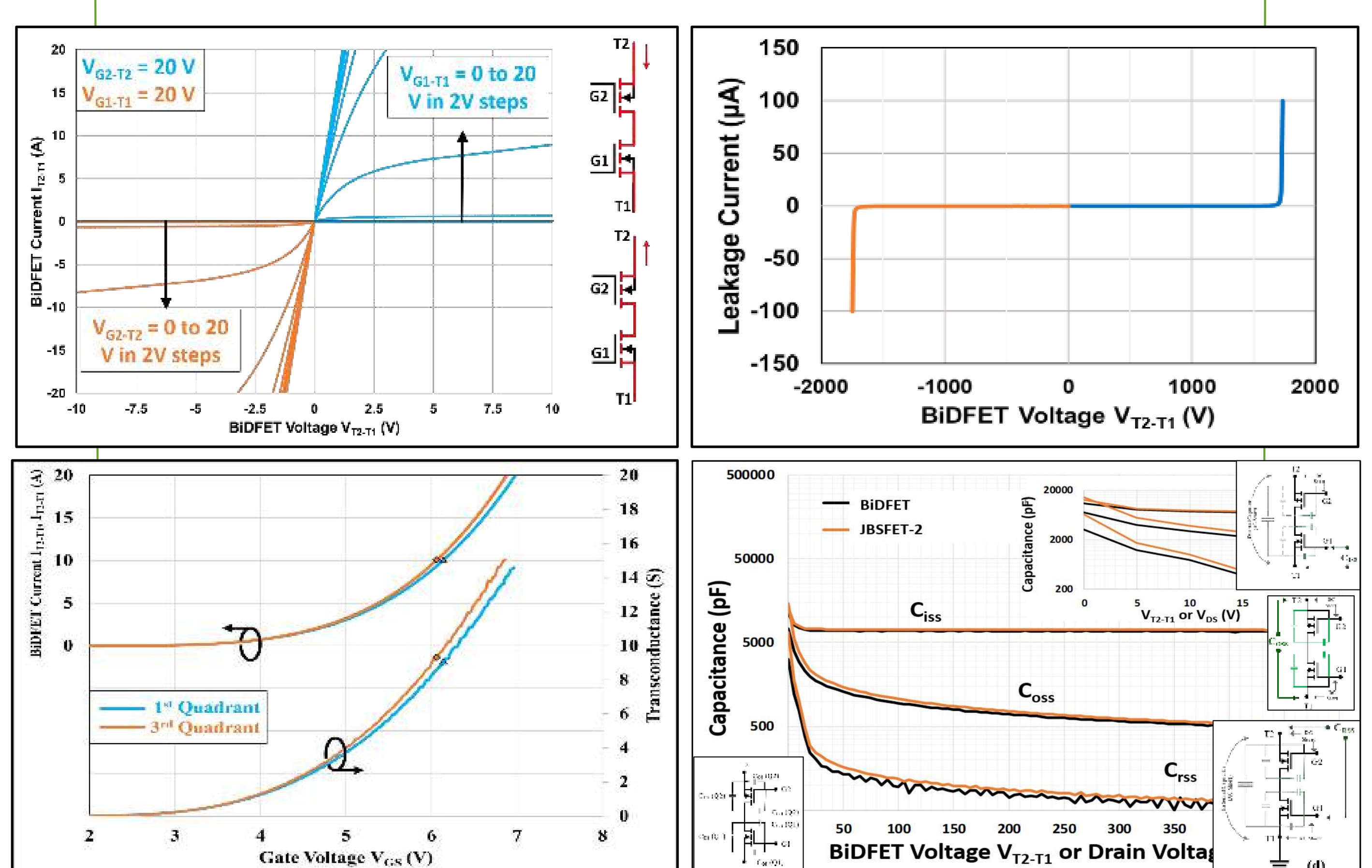
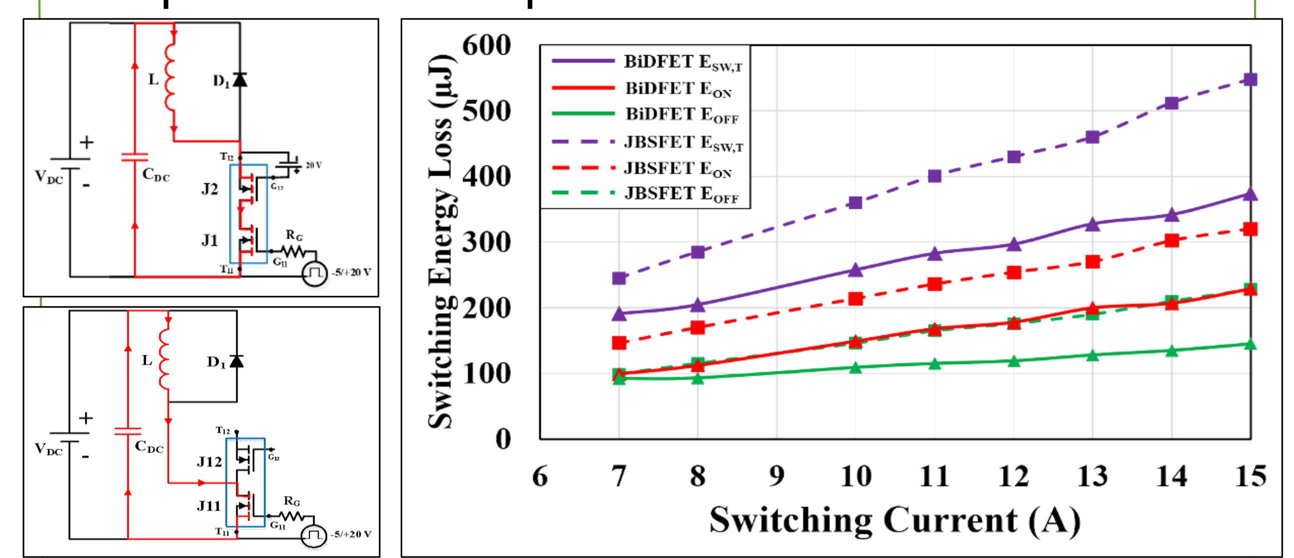


Table II: Static Characteristics of the 1.2 kV SiC BiDFET compared to its internal JBSFETs

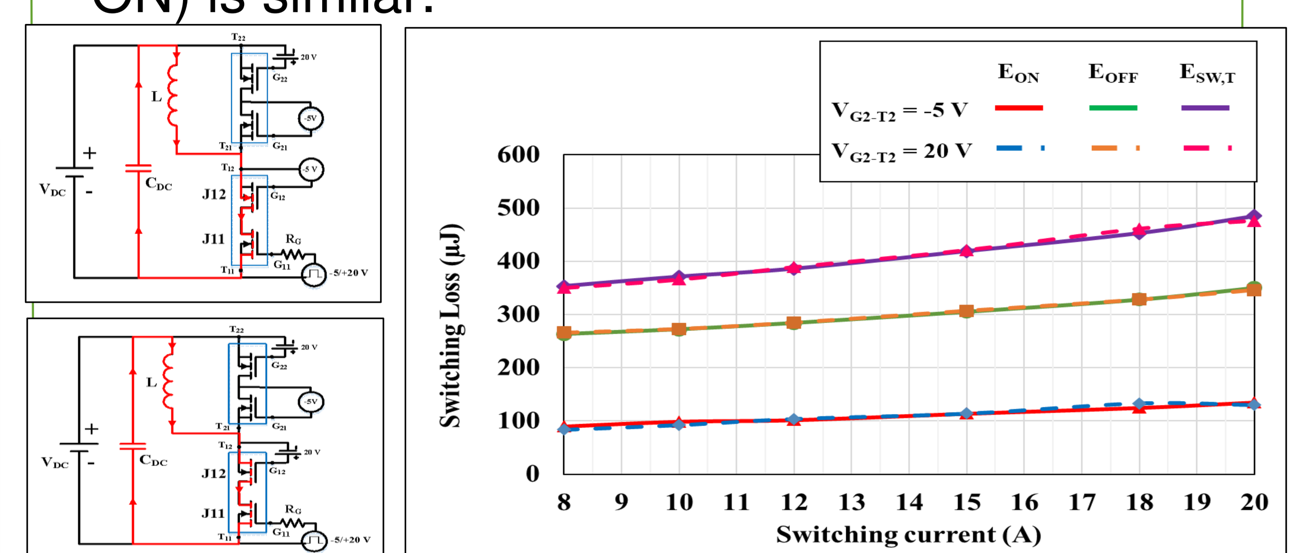
BiDFET		1st Quad.	3rd Quad.	JBSFET
BV_{DSS}, V (I_D = 100 µA)		1731	1750	>1200
$R_{DS,ON}$, mΩ (I_D = 10A, V_{G1-T1} = V_{G2-T2} = 20 V)		59.4	59.4	29
V_{TH} (I_D = 1mA, V_{T2-T1} = 0.1 V)		2.2	2.24	2-4
C_{ISS}, nF	V_{DS} = 500 V	6.9	6.9	7
	V_{DS} = 0 V	11	10.9	12.9
C_{OSS}, nF	V_{DS} = 500 V	0.457	0.46	0.489
	V_{DS} = 0 V	7.2	7.1	14.7
C_{RSS}, nF	V_{DS} = 500 V	0.052	0.055	0.058
	V_{DS} = 0 V	3.2	3.2	6.6

BiDFET Dynamic Performance[3]

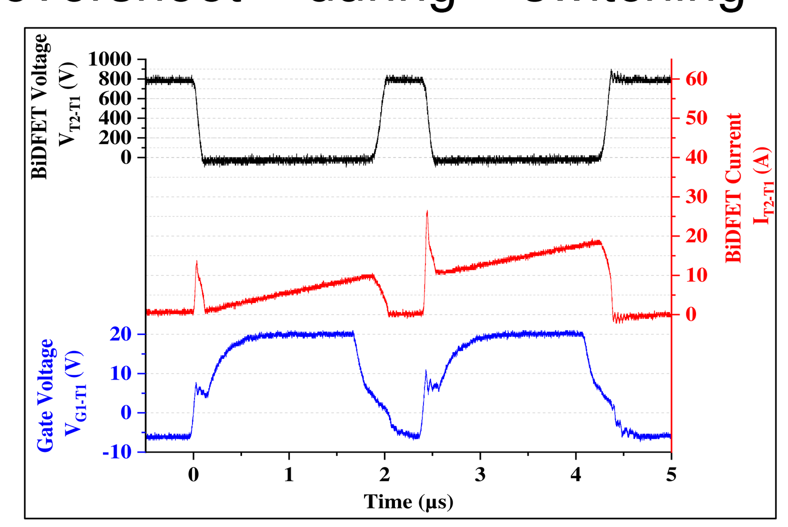
1. The BiDFET has a lower switching loss compared to its internal JBSFETs, as expected from capacitance behavior.



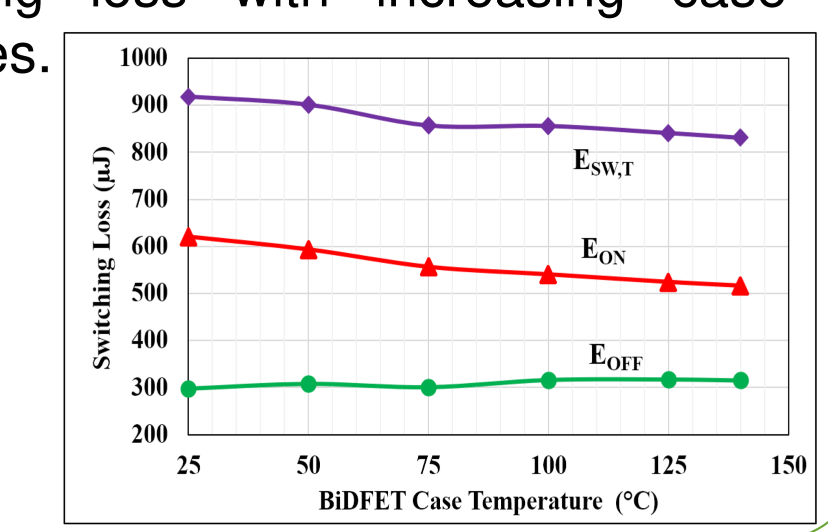
2. The BiDFET switching performance in both operating modes (G2 OFF and G2 ON) is similar.



3. The BiDFET output capacitance causes a current overshoot during switching transients.



4. The BiDFET exhibits a reduction in turn-on switching loss with increasing case temperatures.



References

1. A. Kanale, et. al, “1.2 kV, 10 A 4H-SiC Bi-Directional Field Effect Transistor (BiDFET) with Low On-State Voltage Drop”, Mat. Sci. Forum, vol 1004, pp. 872-81, Jul. 2020
2. K. Han et al., "Monolithic 4-Terminal 1.2 kV/20 A 4H-SiC Bi-Directional Field Effect Transistor (BiDFET) with Integrated JBS Diodes," 2020 32nd International Symposium on Power Semiconductor Devices and ICs (ISPSD), 2020, pp. 242-245.
3. A. Kanale et al., "Switching Characteristics of a 1.2 kV, 50 mΩ SiC Monolithic Bidirectional Field Effect Transistor (BiDFET) with Integrated JBS Diodes," 2021 IEEE Applied Power Electronics Conference and Exposition (APEC), 2021.

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