

# 6.5 KV SILICON CARBIDE ENHANCED MODE JFETS FOR HIGH VOLTAGE DC LINK APPLICATIONS

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## INTRODUCTION

- The excellent material properties of **silicon carbide (SiC)** semiconductors offer great promise for increasing the DC link voltage to well over 1 kV, while maintaining **high efficiency** and also achieving smaller more cost effective power conversion through faster switching.
- The ability to **increase the DC-link voltage up to 4 kV per switch level**, is an application especially attractive for **SiC unipolar devices**, for example, a JFET or MOSFET rated at 6.5 kV, could easily accommodate such operational voltages, while maintaining high switching speeds of 20 kHz.
- Unipolar SiC JFETs** can enable small, lightweight, transformerless topologies for industrial medium voltage grid applications operating in the 3.3 kVAC or 4.16 kVAC regimes.

## 6.5 KV SiC JFET PERFORMANCE

- SiC JFETs have demonstrated robust reliability over that of SiC-MOS technologies.
- SiC JFETs have the added advantage of reliable operation at  $T_{amb} > 300^{\circ}\text{C}$ , limited only by packaging.

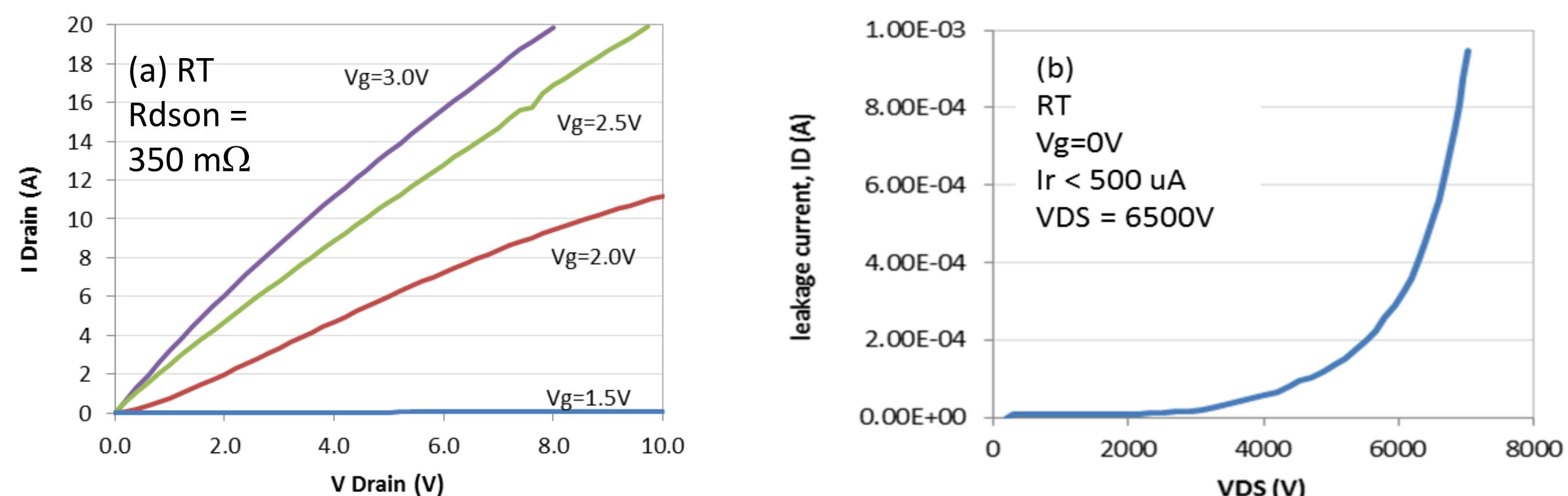


Fig. 1 USCI's Enhanced mode 6.5 kV SiC JFET forward conduction (a), and drain leakage showing ~7 kV blocking (b).

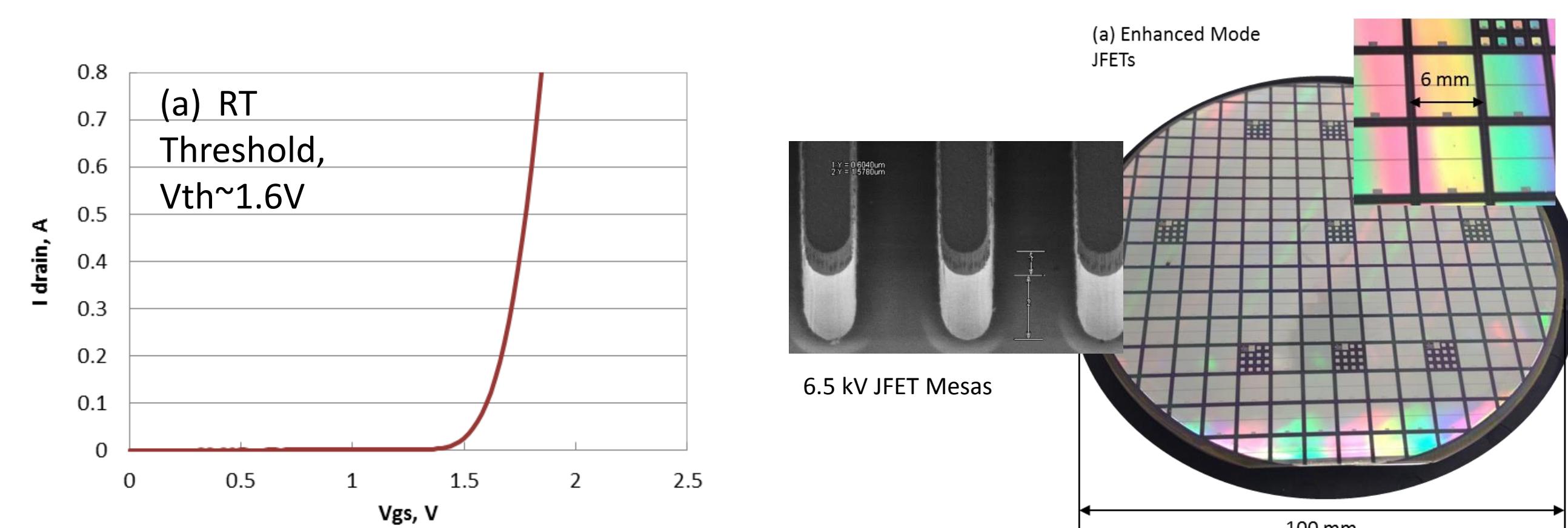


Fig. 2 SiC JFET Drain current vs. Gate-Source Voltage (a), and image of processed wafer showing Source mesas & large 6 x 6 mm die size (b).

## 6.5 KV SiC DIODE PERFORMANCE

- SiC Diodes offer near zero Q<sub>rr</sub>, (reverse recovery losses) and demonstrate excellent high current operation

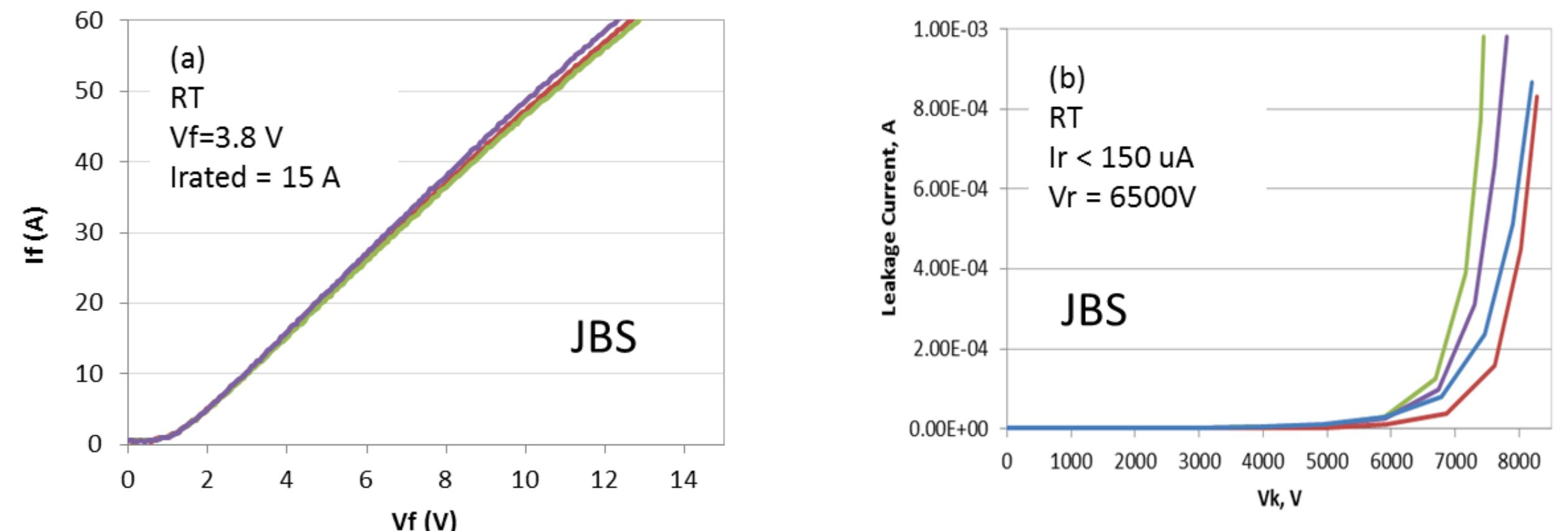


Fig. 3 USCI's 6.5 kV SiC JBS Diode forward conduction (a), and cathode leakage showing >7 kV blocking (b).

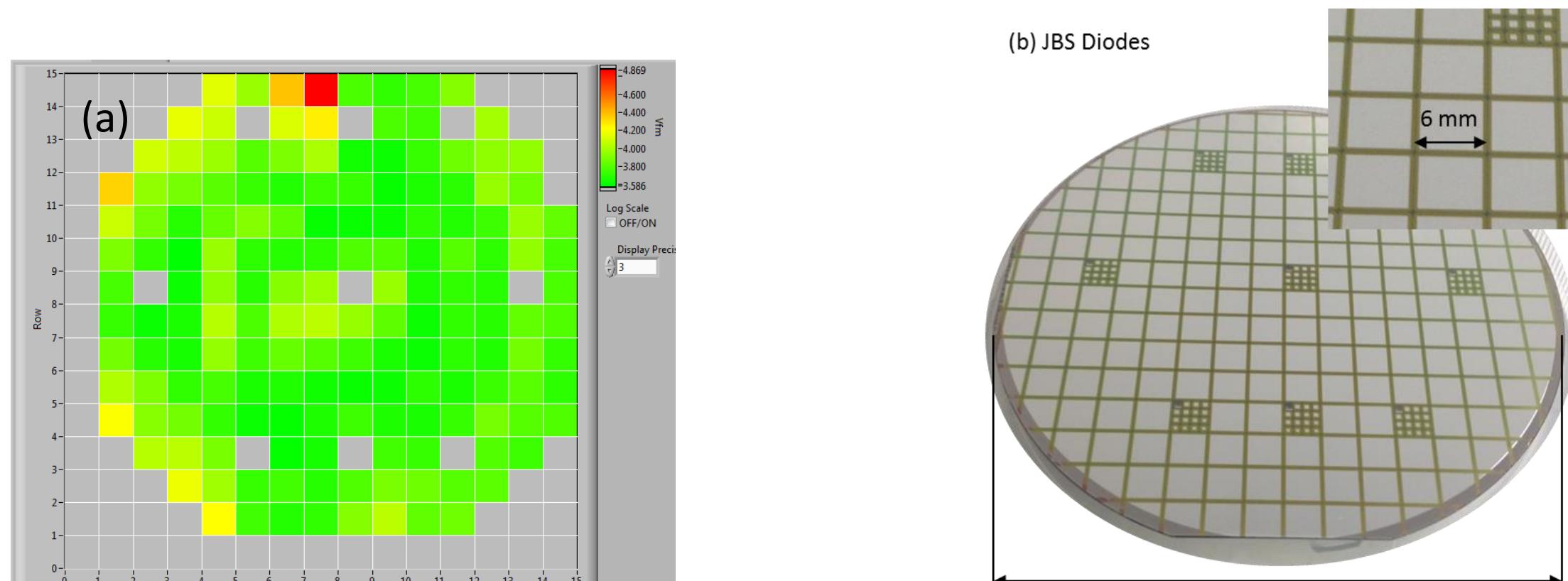


Fig. 4 RDS(on) map showing high yield on 100 mm wafer (a) and image of processed wafer showing large 6 x 6 mm die size (b).

## 6.5 kV JFET POWER HALF-BRIDGE MODULE

- The normally-off 6.5 kV JFETs will be assembled with the 6.5 kV Diodes in antiparallel to form a 20 kHz half-bridge power module rated with the following parameters:

Parameter	Symbol	Value	Units
Drain-Source Voltage	$V_{DS}$	6500	V
Gate-Source Voltage	$V_{GS}$	-20 to 20	V
Continuous Drain Current	$I_D$ , $T=25^{\circ}\text{C}$	60	A
	$I_D$ , $T=125^{\circ}\text{C}$	39	A
Pulsed Drain Current	$I_{D,\text{pulsed}}$	120	A
Max Operation Temperature	$T_j$	200	°C
Isolation Voltage	$V_{ISO}$	10	kV
Drain Source On-Resistance	$R_{DS(on)}$	150	$\text{m}\Omega$

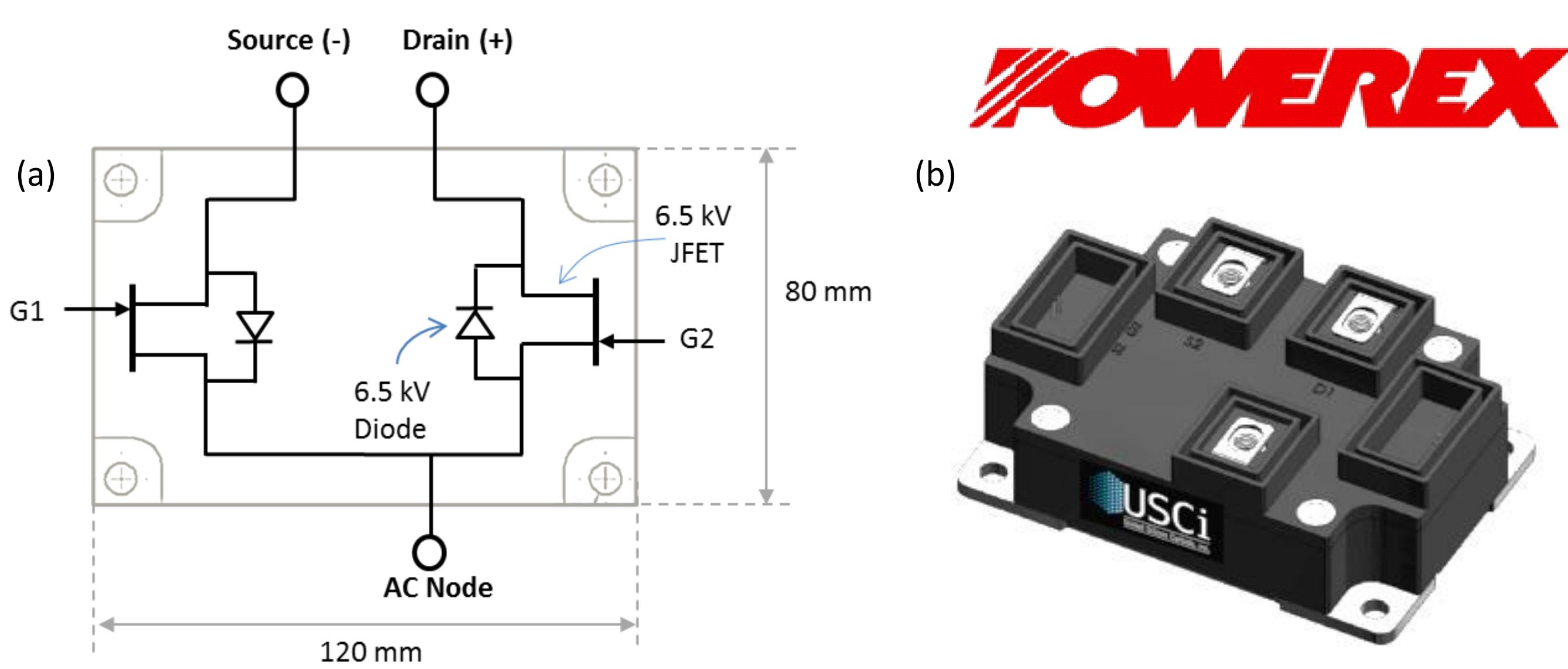


Fig. 5 Schematic of half-bridge power module (a) and final module design (b).

## 6.5 KV JFET MODULE APPLICATION

- CASE STUDY:** Simulation of Neutral Point Clamped (NPC) inverter for transformerless grid-tie to 4.16 kVAC using SiC-JFET half-bridge module.

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### 4 kV DC per switch

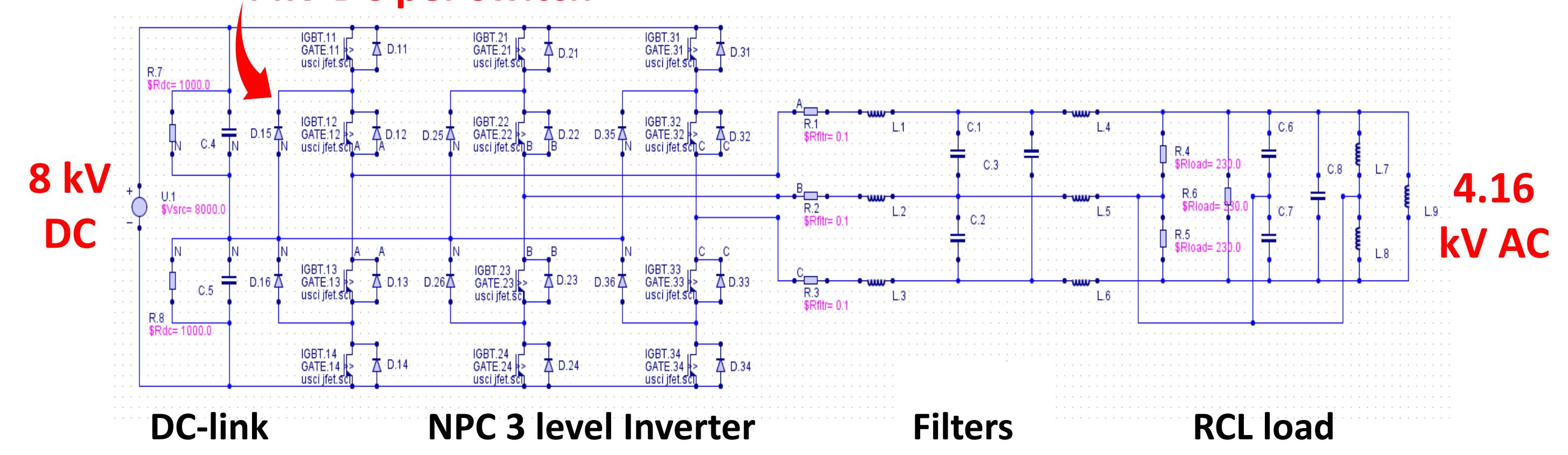
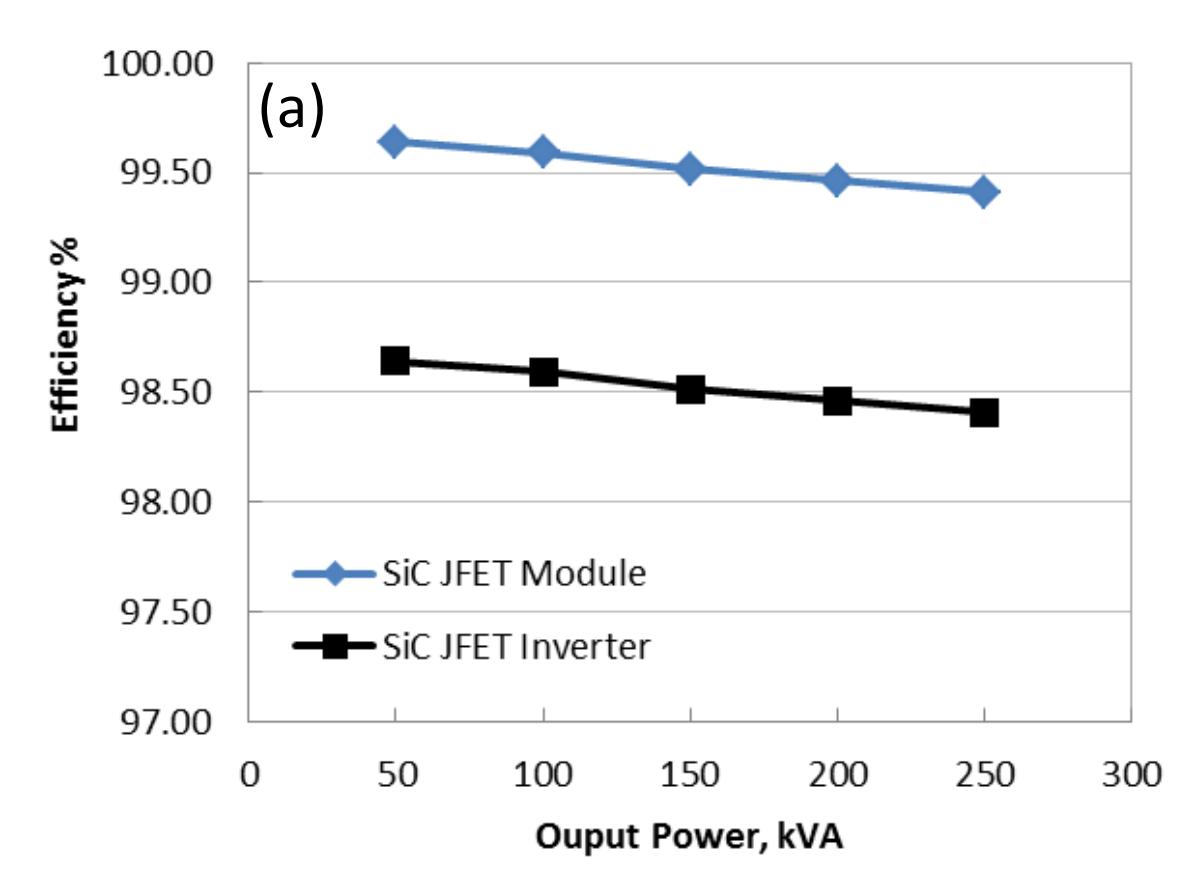


Fig. 6 Three-level neutral point clamped inverter enabling a 8 kV DC link for direct tie into an industrial distribution line at 4.16 kV AC



(a)  
Typical 250 kVA, ~90 ft<sup>3</sup>



6.5 kV JFET  
250 kVA  
~12 ft<sup>3</sup>

Fig. 7 Efficiency simulation of JFET modules and NPC inverter up to 250kVA output (a) and power density and cost benefit estimations on 250kVA inverter (b).

Device Platform	Inverter level	Inverter Output (kVA)	Max Input Voltage (kV)	Typ Freq. (kHz)	Efficiency (%)	Size (ft <sup>3</sup> )	Power Density, (MW/m <sup>3</sup> )	\$/W	Comment
Typical 1.2 kV Si IGBT	2	250	1	10	96.0	90	0.10	\$ 0.40	Transformer included for 4.16 kV grid
NPC 6.5 kV SiC JFET	3	250	8	20	98.5	12	0.75	\$ 0.36	Transformerless to 4.16 kV grid

## Summary

- 6.5 kV SiC JFET and JBS Diode devices** were fabricated for assembly and testing in half-bridge modules rated at 60 A, 20 kHz, and  $T_{amb} = 200^{\circ}\text{C}$  operation.
- Higher DC-link voltage capabilities enable next generation transformerless topologies.
- USCI would like to thank **Dr. Imre Gyuk** of the DOE Energy Storage Program for funding and **Dr. Stan Atcitty** of Sandia National Labs for his technical contribution.
- Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000