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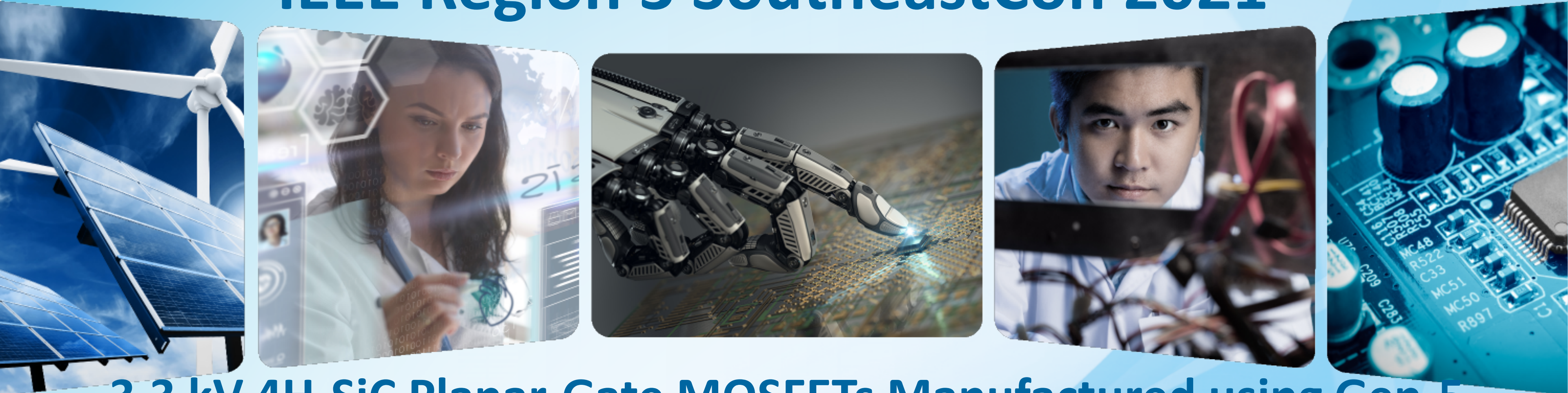

3.3 kV 4H-SiC Planar-Gate MOSFETs Manufactured using Gen-5 PRESiCE^{TM} Technology in a 4-inch Wafer Commercial Foundry

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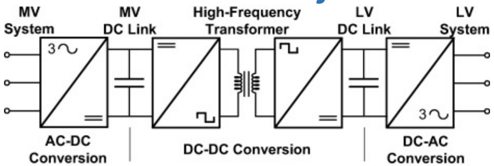
Applications for 3.3 kV Power Devices

Renewable Energy

- Solar String Inverters
- Grid-tied Renewable Energy Conversion
- Energy Storage and Distribution

R. Takayanagi, et al, "3.3 kV All-SiC Module for Electric Distribution Equipment," In *IPEC-Niigata 2018-ECCE Asia*, pp. 3396-3400.

Solid State Transformers



H. Wen, et al, "Characterization and evaluation of 3.3 kv 5 a sic mosfet for solid-state transformer applications," In *2018 IEEE ACEPT*, pp. 1-5.

Transportation

- Railway Traction Systems
- EV Fast Chargers

K. Hamada et al, "3.3 kV/1500 A power modules for the world's first all-SiC traction inverter," *JJAP*, *54*(4S), 04DP07, 2015.

L. Gill, et al, "Medium Voltage Dual Active Bridge Using 3.3kV SiC MOSFETs for EV Charging Application," *2019 ECCE*, USA, pp. 1237-1244.

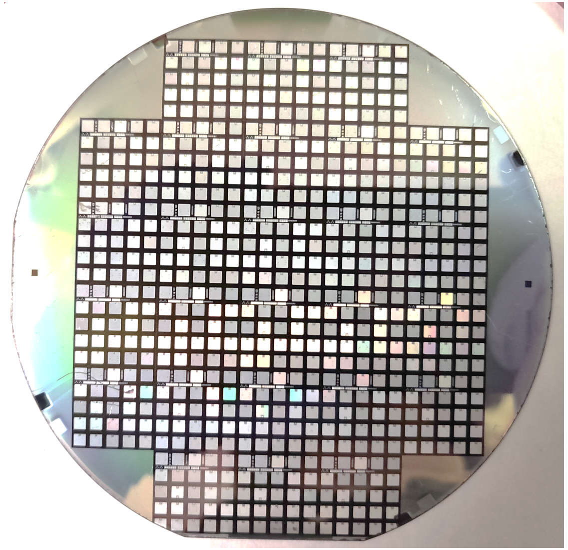
Medium Voltage Industrial Applications

Large industrial converters (cement, mining and minerals, metals, oil and gas etc.)

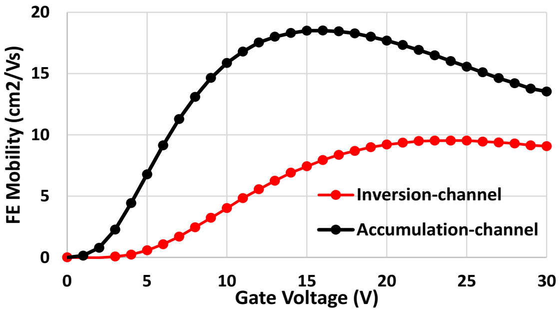
J. Hayes, et al, "Dynamic characterization of next generation medium voltage (3.3 kV, 10 kV) silicon carbide power modules," In *PCIM Europe 2017*, pp. 1-7.

Gen-5 PRESiCE™ Process

Fabricated wafer:



- C-V test structure measurements confirmed gate oxide thickness of 50 nm.
- Field-Effect Mobility was measured using long-channel FATFET test structure.



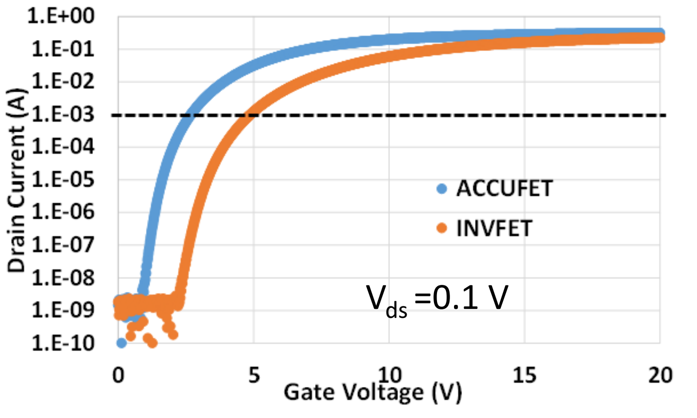
@ Gate voltage of 20 V:

- Accumulation-channel mobility is **~ 17 cm²/Vs**.
- Inversion-channel mobility is **~ 9 cm²/Vs**.

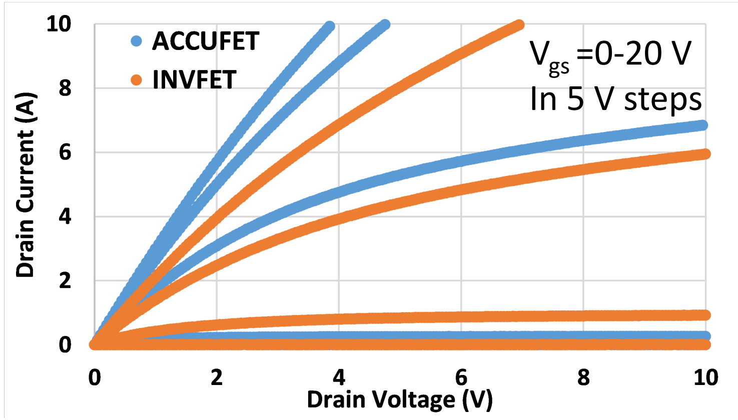
- Accumulation-channel mobility is higher due to reduced charge trapping at the n-Base/SiO_2 interface.

Wafer-level Measurements

Transfer Characteristics



Output Characteristics



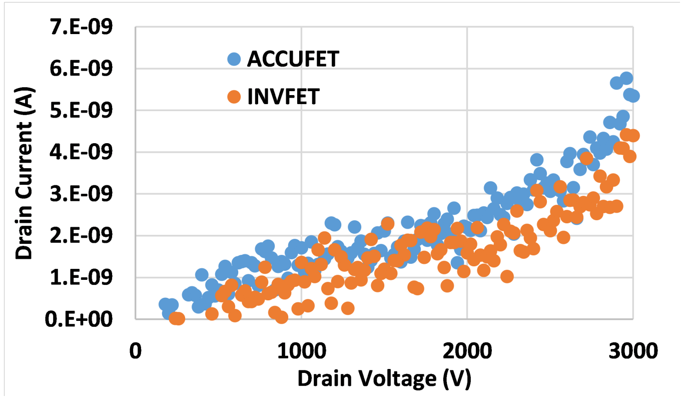
- V_{th} for ACCUFET is lower than that for INVFET because of smaller band bending required to create a channel in case of an n-type base region.
- ACCUFETs have better output characteristics and $R_{on,sp}$ compared to INVFET due to higher channel mobility and lower V_{th}.

$$R_{CH,sp} \downarrow = \frac{L_{CH} W_{cell}}{2\mu_{CH} \uparrow C_{ox} (V_{gs} - V_{th} \downarrow)}$$

	ACCUFET	INVFET
V_{th} @ I_d=1mA	2.7 V	4.9 V
$R_{on,sp}$ @ V_{gs}=20V, I_d=1A	13.8 mΩ-cm^2	19.8 mΩ-cm^2

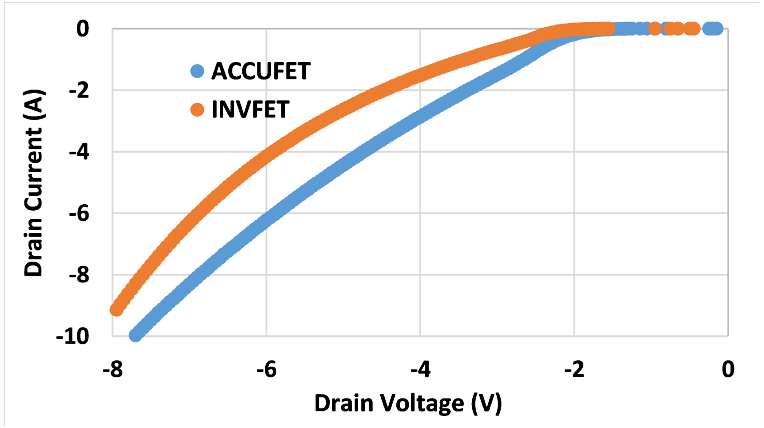
Wafer-level Measurements

Blocking Characteristics



- Both MOSFETs have very low leakage current < 10 nA up to 3 kV.
- Low leakage for ACCUFET implies that channel potential is sufficient to prevent reach-through breakdown.

3rd Quadrant Characteristics

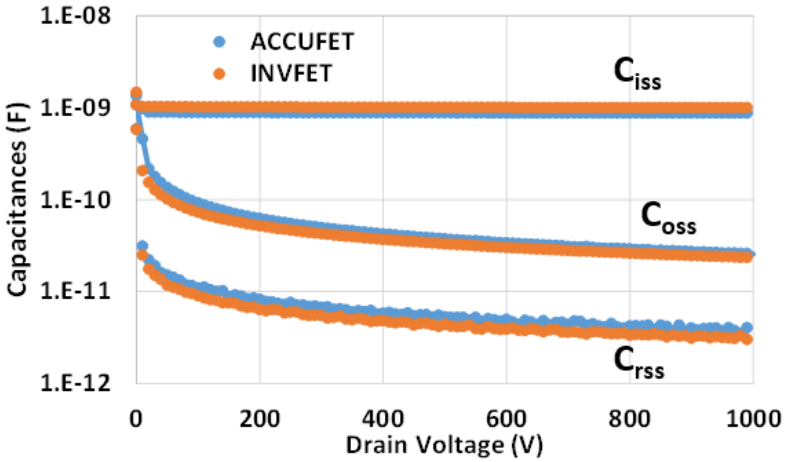


- INVFET has higher voltage drop in the 3rd quadrant at a fixed value of current due to its higher channel potential.

	ACCUFET	INVFET
3rd Quad V_f @ I_d=2.25 A (50 A/cm^2)	3.6 V	4.7 V

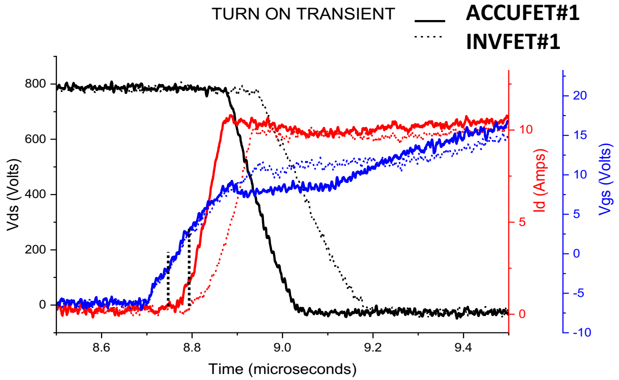
Wafer-level Measurements

Input, Output and Reverse Transfer Capacitances



- Measured C_{iss}, C_{oss} and C_{rss} are very close for both devices due to same basic cell structure.
- Channel type does not affect capacitances.

- However, it has been shown previously that ACCUFETs have better switching performance compared to INVFETs with same device geometry, due to lower V_{th} and higher transconductance.



A. Agarwal, et al, "Experimental Study of Switching and Short-Circuit Performance of 1.2 kV 4H-SiC Accumulation and Inversion Channel Power MOSFETs," ICSCRM 2019.

Summary and Conclusions

Region	ACCUFET	INVFET
$R_{on,sp}$ @ V_{gs}=20V, I_d=1A	13.8 mΩ-cm^2	19.8 mΩ-cm^2
V_{th} @ I_d=1mA	2.7 V	4.9 V
3rd Quad V_f @ I_d=2.25 A	3.6 V	4.7 V
$C_{iss,sp}$ @ V_{ds}=1 kV	19.4 nF/cm^2	22.2 nF/cm^2
$C_{oss,sp}$ @ V_{ds}=1 kV	0.6 nF/cm^2	0.5 nF/cm^2
$C_{rss,sp}$ @ V_{ds}=1 kV	80 pF/cm^2	67 pF/cm^2
HF-FOM (R_{on}*C_{rss})	1104 mΩ-pF	1327 mΩ-pF

- NCSU Gen-5 PRESiCE™ technology was used to establish a SiC power MOSFET manufacturing capability at a 4-inch wafer foundry operated by SiCamore Semi.
- 3.3 kV rated ACCUFETs and INVFETs were fabricated at SiCamore Semi with device performance consistent with state-of-the-art technology.
- Gate-Source Shorts were the yield limiting factor. Most devices had good leakage characteristics indicating robust edge termination.
- Accumulation-channel structure enabled:
    - 1.4 times lower specific on-resistance compared to the INVFET structure.
    - Similar device capacitances as the INVFET structure
    - 1.2 times lower HF-FOM (R_{on}*C_{rss}) compared to the INVFET structure.
- SiCamore Semi can now be used by fabless companies for manufacturing SiC power devices.