ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
ARCES

Silicon Carbide power devices: Status, challenges and future opportunities

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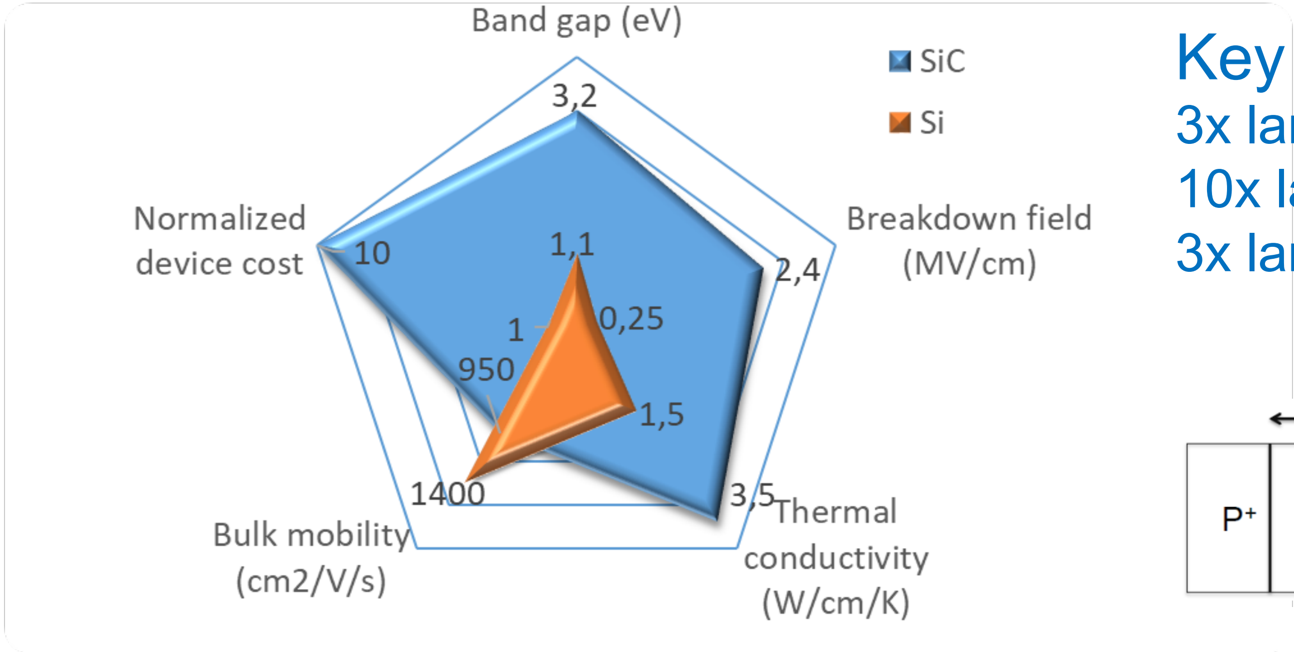
IUNET DAY – September 21, 2017

Outline

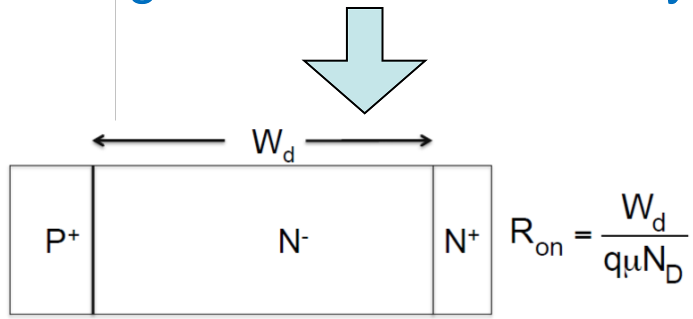
- Material Advantages of SiC vs. Si
- Current status of SiC Devices
- What are the challenges going forward?
- IUNET contributions

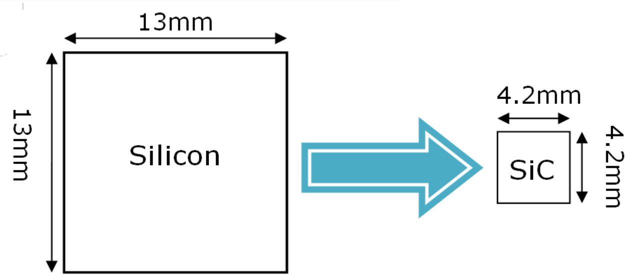
SiC: why?



Key benefits:

3x larger bandgap,
10x larger breakdown field,
3x larger thermal conductivity



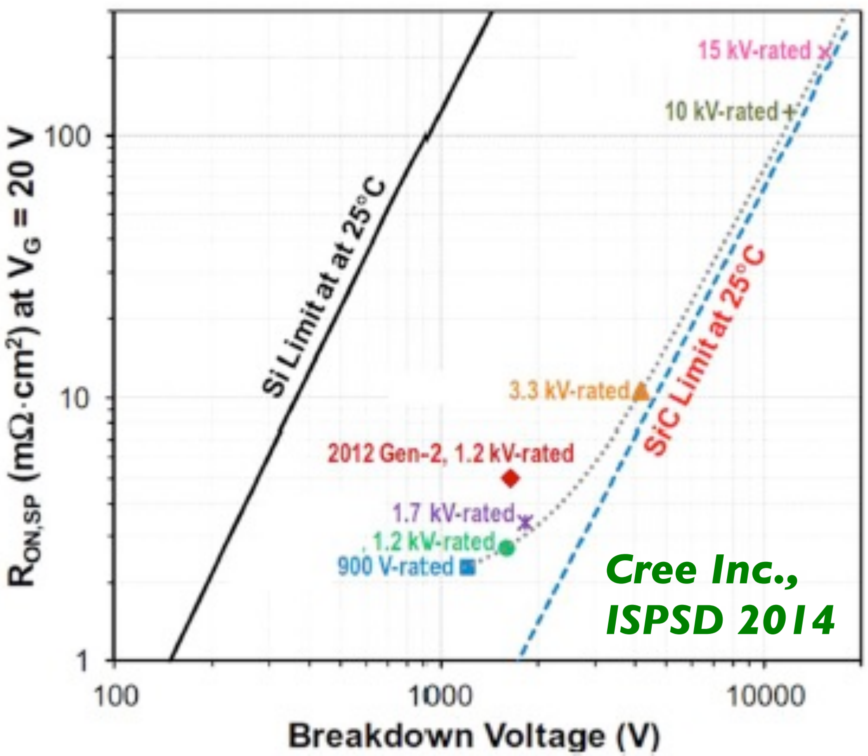


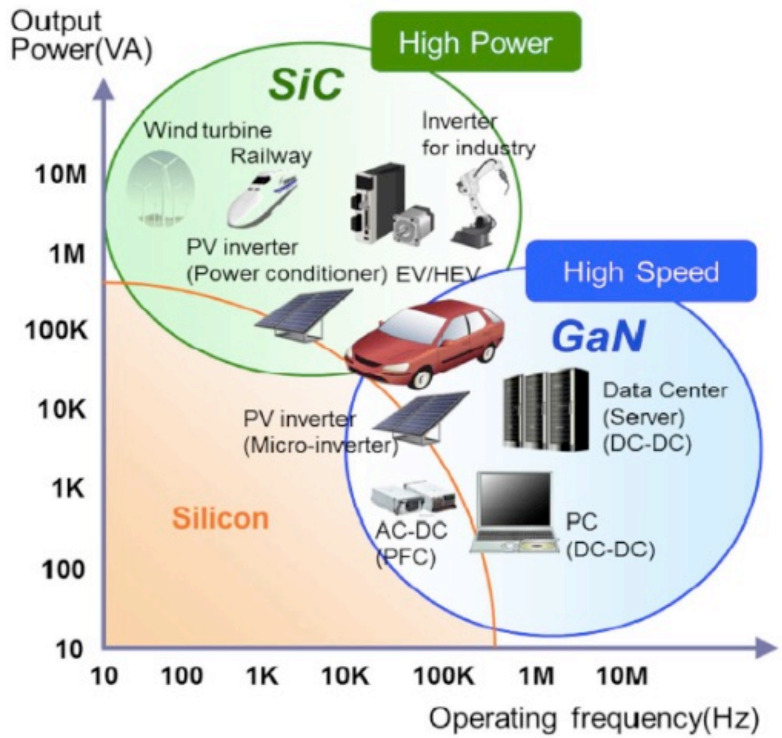
- Smaller size
- Higher efficiency
- Higher working temperature (200°C), present limit is packaging

Drawbacks:

- 10x device cost,
- Low channel mobility (SiC/SiO2 interface)

SiC performance → market opportunities





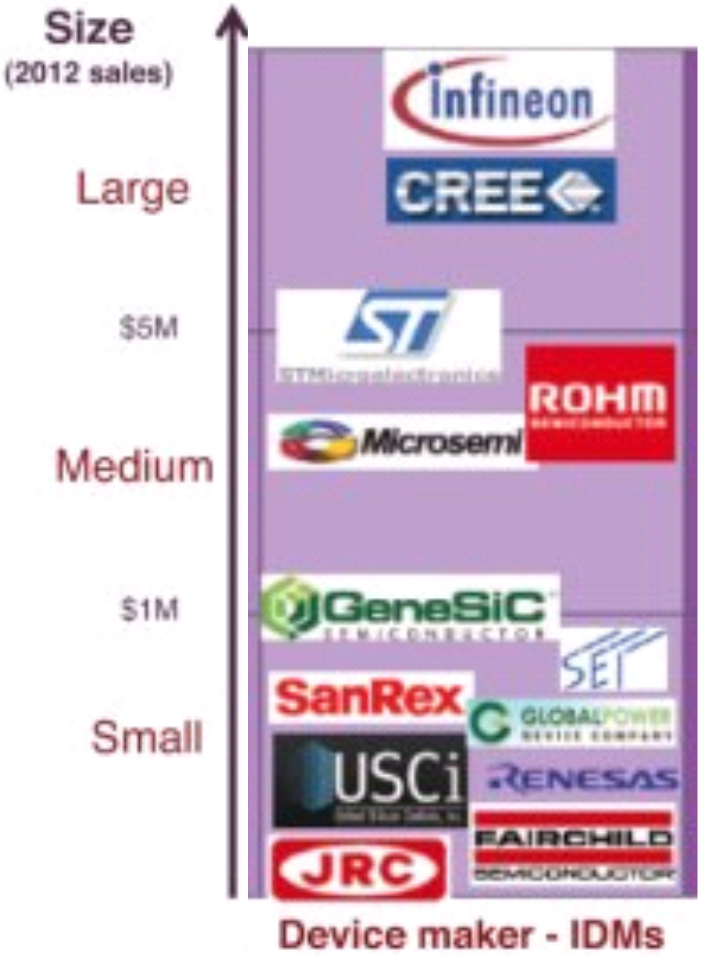
Channel resistance is the primary limitation to the R_{ON} in 4H-SiC MOSFETs with B_V < 1kV

SiC pushes the boundary of unipolar devices for high power voltages (B_V > 1kV)

SiC CAGR 2016-2020: 28%

(Yole Développement, August 2017)

Main players in the SiC device industry



(Yole Développement, May 2013)

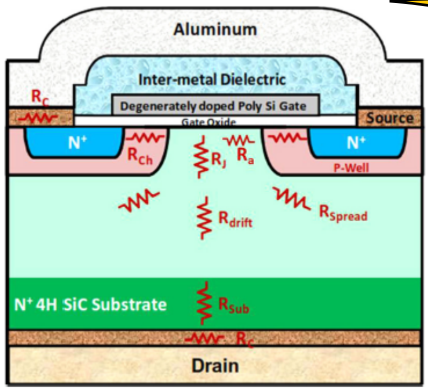
Company	Location	2010 SiC Power Electronics Revenue (M$)
Infineon	**Germany**	27.1
Cree	USA	19.7
STMicro	**Italy**	1.6
ROHM	Japan	1.1
others		3.7

Top 4 suppliers (93% of market)

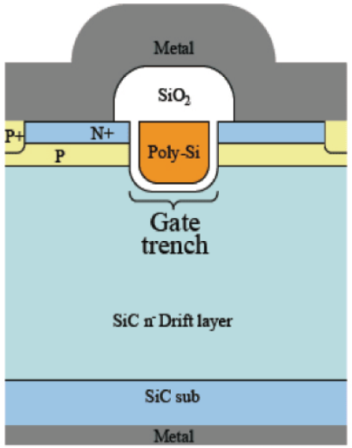
Infineon and STMicroelectronics in Europe with 54% of market

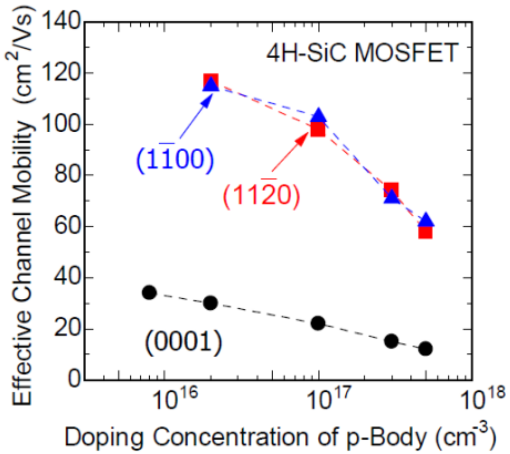
Current status of SiC MOSFETs

Planar MOSFETs



Trench MOSFETs



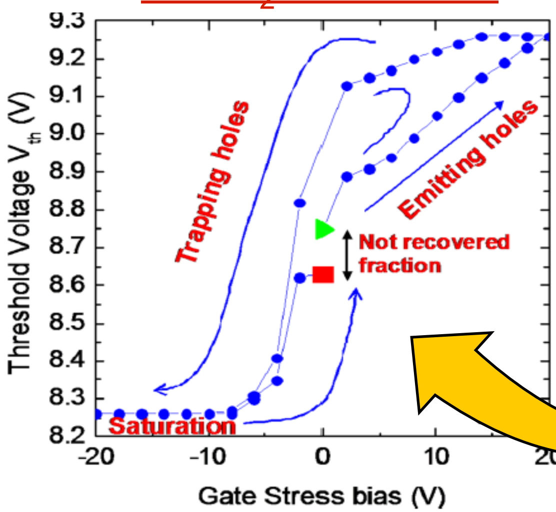


ROHM, IEDM 2011

- No JFET region
- Higher Mobility along the (11-20)

50% lower ON resistance

Lateral MOSFET with N_2O treatment

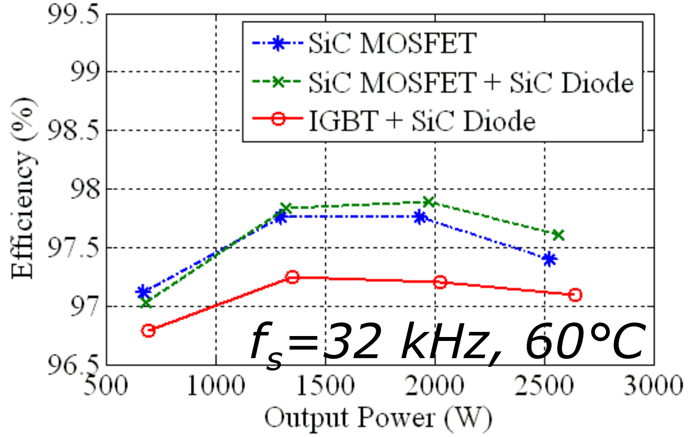


STM, 2017

- Oxide reliability concerns at the trench bottom

P. Fiorenza, G. Greco, F. Giannazzo, F. Iucolano, F. Roccaforte, J. Vac. Sci. Technol. B **35**, 01A101 (2017)

The first 1.2kV SiC MOSFET by ST
The double trench by ROHM
The CoolSiC Trench MOSFET by Infineon



2014

Comparative analysis of driving approach and performance of 1.2 kV SiC MOSFETs, Si IGBTs, and normally-off SiC JFETs

Invited paper

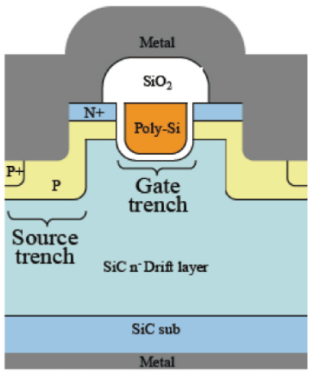
SiC power MOSFETs performance, robustness and technology maturity

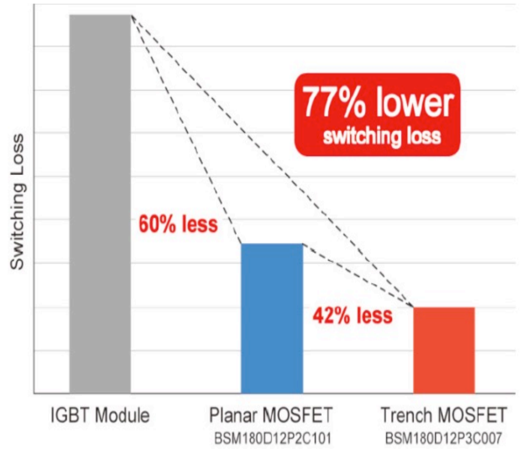
A. Castellazzi et al., Microelectronics Reliability 58 (2016)

2015

The World's First Trench-Type SiC MOSFET -- Significantly reduced ON resistance minimizes size and power consumption in high-power devices including industrial equipment

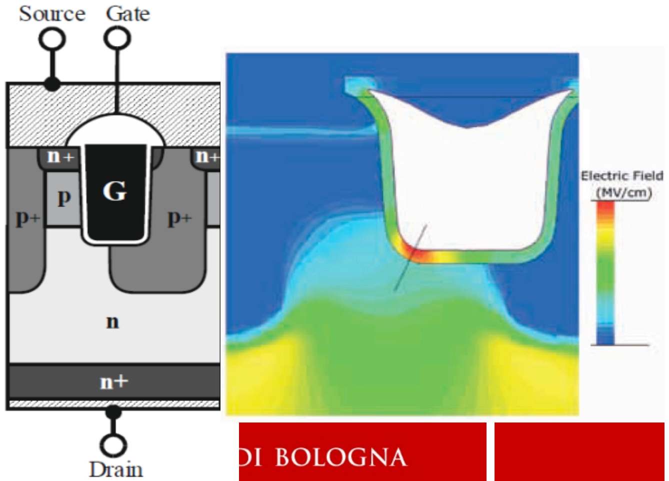
Press Release • Jun 04, 2015 14:00 GMT





2017

CoolSiC Trench MOSFET Combining SiC Performance With Silicon Ruggedness



The most recent news

- ✓ Much progress has been made in reducing SiC crystal defects in substrates
- ✓ The SiC/SiO_2 interface still needs to be improved to reduce interface states (nitridations but also other new treatments)

FUTURE TRENDS IN SIC POWER DEVICE TECHNOLOGY:

- ➢ The wafer diameter increase towards 200mm would reduce the cost of SiC MOSFETs to be competitive with Si devices in 5 years (…and will decrease defect density)
- ➢ Better understanding of the SiC device specific tradeoffs is required
- ➢ Continuous gain in SiC device reliability is needed

"CoolSiC™ and major trends in SiC power device development" Roland Rupp, Infineon, INVITED ESSDERC 2017

IUNET in the NEREID Project

“Nano-Electronics Roadmap for Europe: Identification and Dissemination”
→ Task 4.2 Smart Energy (Gaudenzio Meneghesso – IUNET)

- NEREID will define the **strategy** for a roadmap for those **technologies** that **extend the field of application** of semiconductor technologies by **adding new functionalities or extend application range**.
- Smart-energy technologies, falling under the denomination of “More than Moore”, do not scale simply with geometrical size, and are widely diversified; **therefore new metrics will have to be identified for the roadmap**.

Roadmap and cost/benefit for WBS **2015 — 2018**

- Large wafer sizes, multi-wafer reactors
- New circuit topologies
- Novel device topologies (lateral vs vertical)
- Reliability and stability of WBS

IUNET in the WInSiC4AP Project

2016 ECSEL RIA Call

Wide band gap Innovative SiC for Advanced Power

The major aim is to design and to prototype on
SiC based highly integrated *power converters…*

- **DCDC Converters for Automotive** with half volume and weight of magnetic components, switching frequencies increased from 25 to 150-200Khz, and efficiencies up to 96%
- **Intelligent Power Switches and Inverter for avionics** featuring higher operating temperatures (250 °C) in comparison with the actual150-200°C
- **Compact portable charger for electric vehicles** featuring 50% less overall conversion losses at a10% less volume/weight in comparison with Si-based actual chargers

2017 — 2020

Main role of IUNET

STMicroelectronics - Catania

An innovative trench structure will be developed and adopted to **1.2÷1.7kV** MOSFETs.
Fabricated devices will be assembled in innovative packages able to emphasize device thermal behavior.

IUNET-UNIBO

Use of modeling and simulation to:

- **Understand** breakdown phenomena and **identify** the short and long-time device Safe Operating Area
- **Explore** technology options to improve performance and reliability

IUNET-UNICAL

Measure bias temperature instability (BTI) and low-frequency noise to

- **Evaluate** the material defectiveness and its impact on the device performance.

IUNET-UNIPD

Use of state-of-the-art characterization techniques to

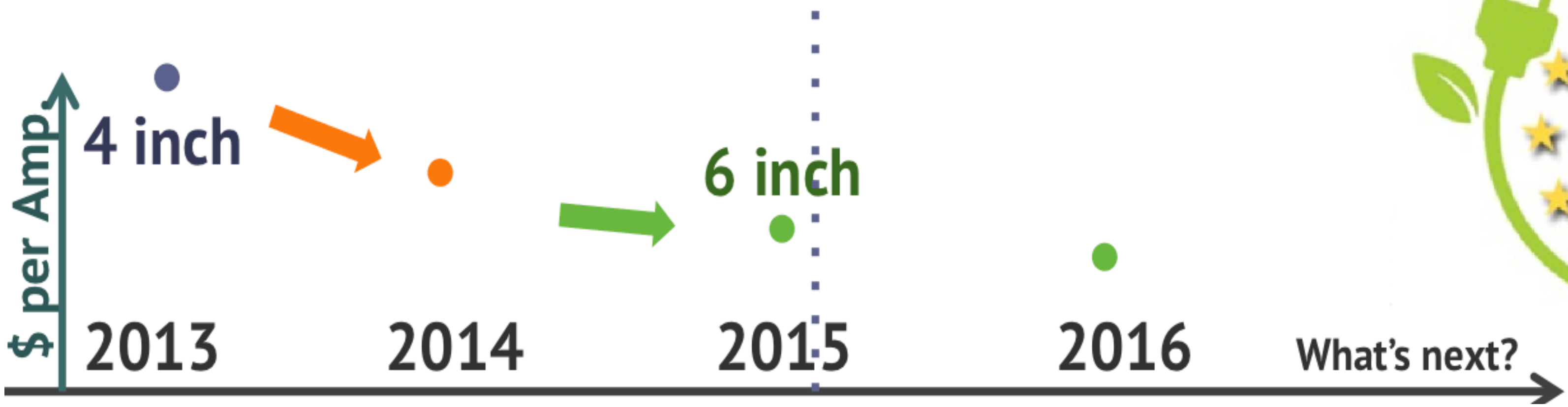
- **Identify** device failure modes and mechanisms and **give in-depth insight** for technological improvements

Realize a test circuit capable of highlighting the device performance in real operating conditions.

IUNET in the REACTION Proposal

2017 ECSEL IA Call

First and European SiC Eigth Inches Pilot line



- Neither SiC nor GaN have a cost advantage with respect to silicon today, largely because of wafer costs.

- REACTION will push through the first worldwide 200mm Silicon Carbide (SiC) Pilot Line Facility for Power technology.
- The 200mm SiC Pilot Line will be located in the ST wafer fab of Catania (Italy), and it will share facilities with the current 6'' line.

Main role of IUNET

IUNET-UNICAL

- *Performance evaluation and understanding of threshold voltage drift during bias temperature instability (BTI) stress;*

IUNET-UNIMORE

- *Evaluation of device stability in switching-mode and comparison of DUTs fabricated with different process options;*

IUNET-UNIPI

- *Ab-initio simulations of defects and traps to identify energy, type of traps and activation mechanisms;*

IUNET-UNIBO

- *TCAD simulations of Power SiC devices aimed at the device structure optimization and accounting for the degradation effects;*

IUNET-UNIPD

- *Identification of device failure modes and mechanisms for the development of a Robust and reliable Power SiC devices.*

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