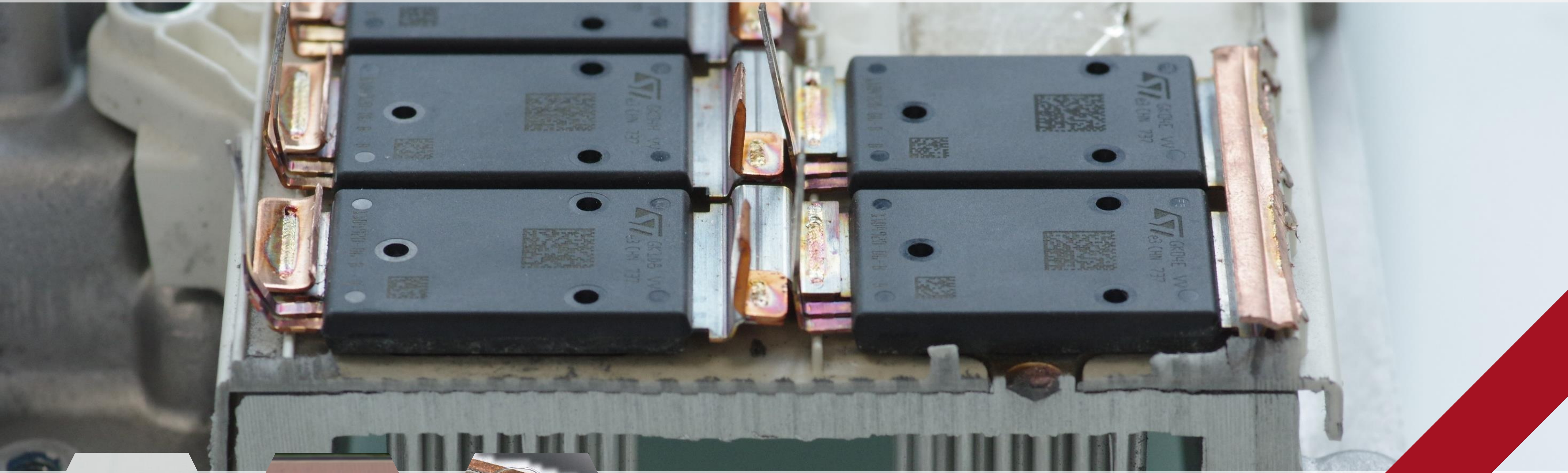
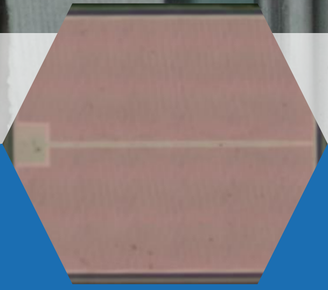
REVERSE COSTING® – STRUCTURAL, PROCESS & COST REPORT





STMicroelectronics SiC Mod

Tesla Model 3 Inverter

Power Semiconductor report by Elena Barbarini

June 2018 – version 1

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SUMMARY

SYSTEM Plus CONSULTING

Executive Summary

Pushed by aggressive legislation, CO_2 reduction is one of the key challenges in the 21st century. The best solution currently available to the automotive industry is the electrification of vehicles, with different levels of electrification depending on the strategies of different car manufacturers. 780,000 battery electric vehicles were shipped in 2017, a number expected to grow to almost 2.8M by 2022. Standard inverter power modules integrate silicon IGBTs, but in electric vehicles the available space in the engine compartment is often so limited that it is difficult to accommodate a power control unit (PCU). Thus, it is necessary that the PCU, which controls electric vehicles' traction motors, has a higher power density and therefore is smaller. Thanks to higher thermal and electrical performance, SiC is the new competitor to silicon at high voltages. Nevertheless, high power densities need high thermal dissipation and thus new packages are needed to improve device performance. To achieve these targets, manufacturers have developed different solutions, such as limiting wire bonding or using overmolded structures to efficiently cool the power semiconductor chips.

Tesla is the first high-class car manufacturer to integrate a full SiC power module, in its Model 3. Thanks to its collaboration with STMicroelectronics the Tesla inverter is composed of 24 1-in-1 power modules assembled on a pin-fin heatsink.

The module contains two SiC MOSFETs with an innovative die attach solution and connected directly on the terminals with copper clips and thermally dissipated by copper baseplates.

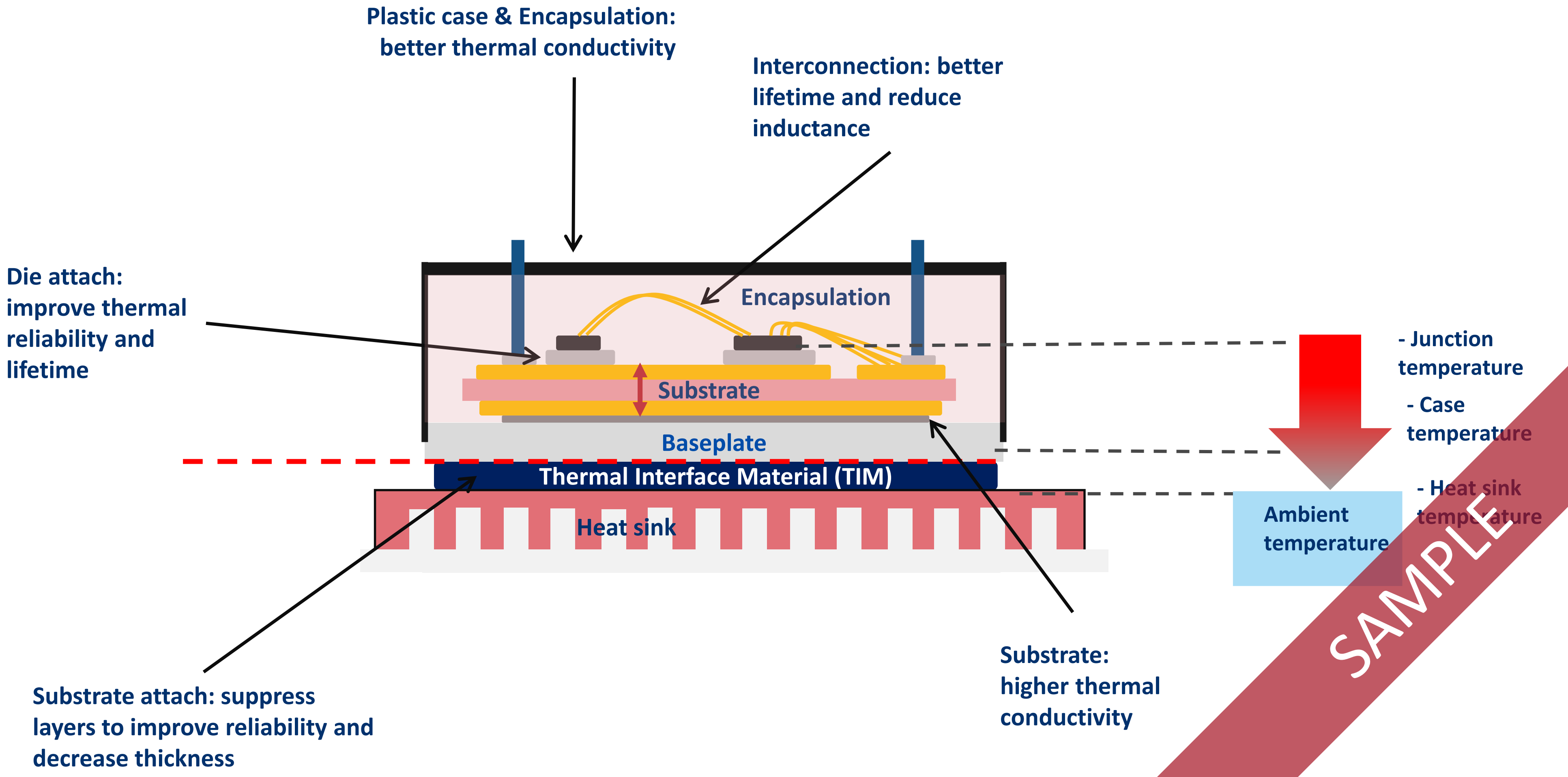
The SiC MOSFET is manufactured with the latest STMicroelectronics technology design, which allows reduction of conduction losses and switching losses. Based on a complete teardown analysis, the report also provides an estimation of the production cost of the SiC MOSFET and package.

Moreover, the report includes a technical and cost comparison with the Mitsubishi J-Series TP-M power module. It highlights the differences in design of the packaging and the material solutions adopted by the two companies.

Power Module Issues

In Si modules , mismatching CTE (coefficient of thermal expansion) makes layers detach from one another.

With the introduction of SiC this problem is much more highligted; in fact the main problem of SiC is thermal dissipation because of material density; thus an adapted package and system integration is needed.



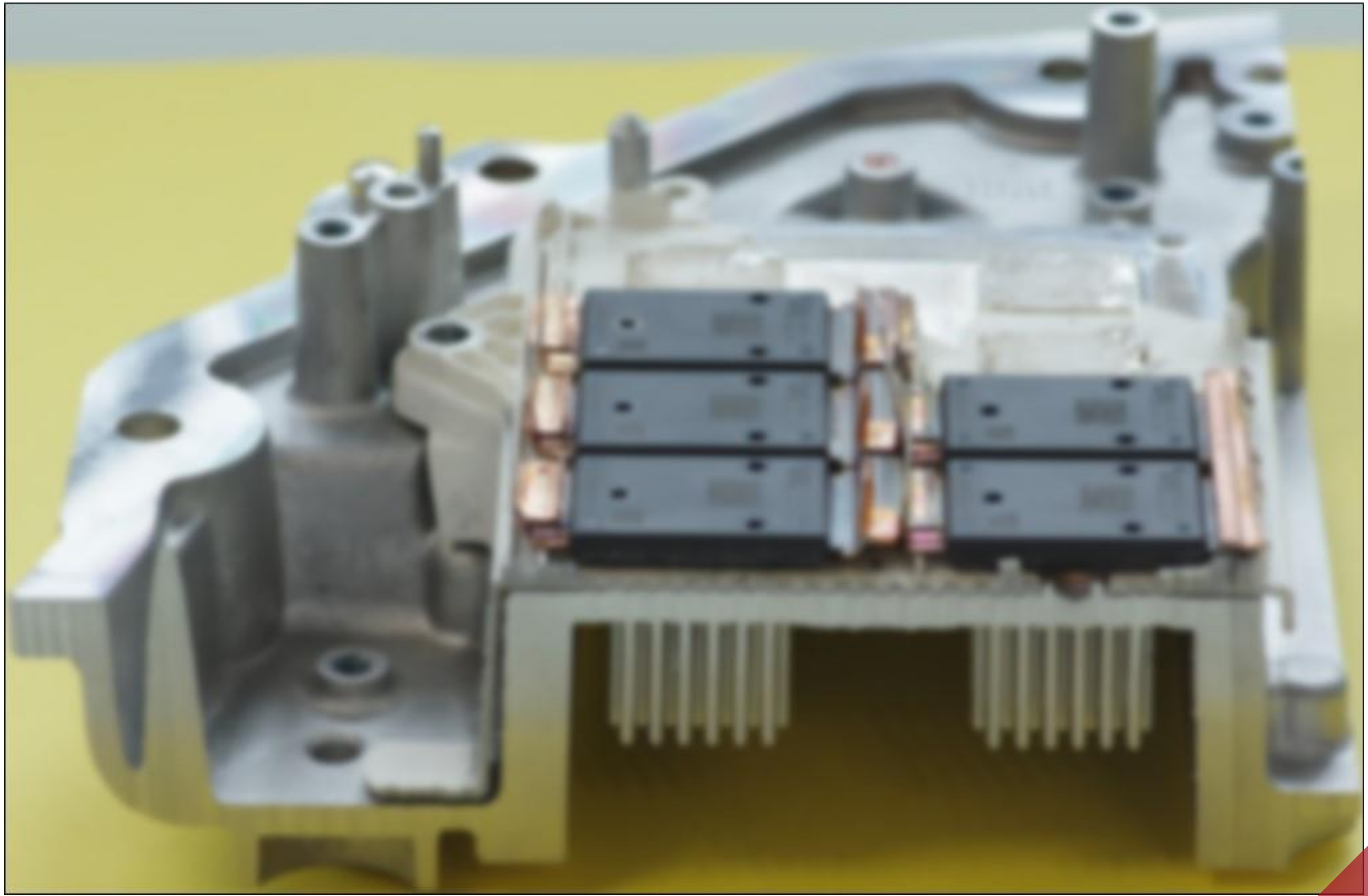
ST SiC products

- ST’s 650 V and 1200 V silicon carbide (SiC) MOSFETs feature very low RDS(on)*area combined with excellent switching performance, translating into more efficient and compact systems. Compared with silicon MOSFETs, SiC MOSFETs exhibit low on-state resistance*area even at high temperatures and excellent switching performances versus the best-in-class IGBTs in all temperature ranges, simplifying the thermal design of power electronic systems.

Part Number	VDSS	Drain Current (Dc) (A)	P_{TOT} (W)	Package	RDS(on) (Ω) (@VGS=20V)
SCT10N120	1200	12	150	HiP247 IN LINE	0.69
SCT20N120	1200	20	175	HiP247 IN LINE	0.239
SCT30N120	1200	45	270	HiP247 IN LINE	0.1
SCT50N120	1200	65	318	HiP247 IN LINE	0.069
SCTWA50N120	1200	65	318	HIP247 LONG LEADS	0.069
SCTW100N65G2AG	650	100	390	HiP247 IN LINE	- ★

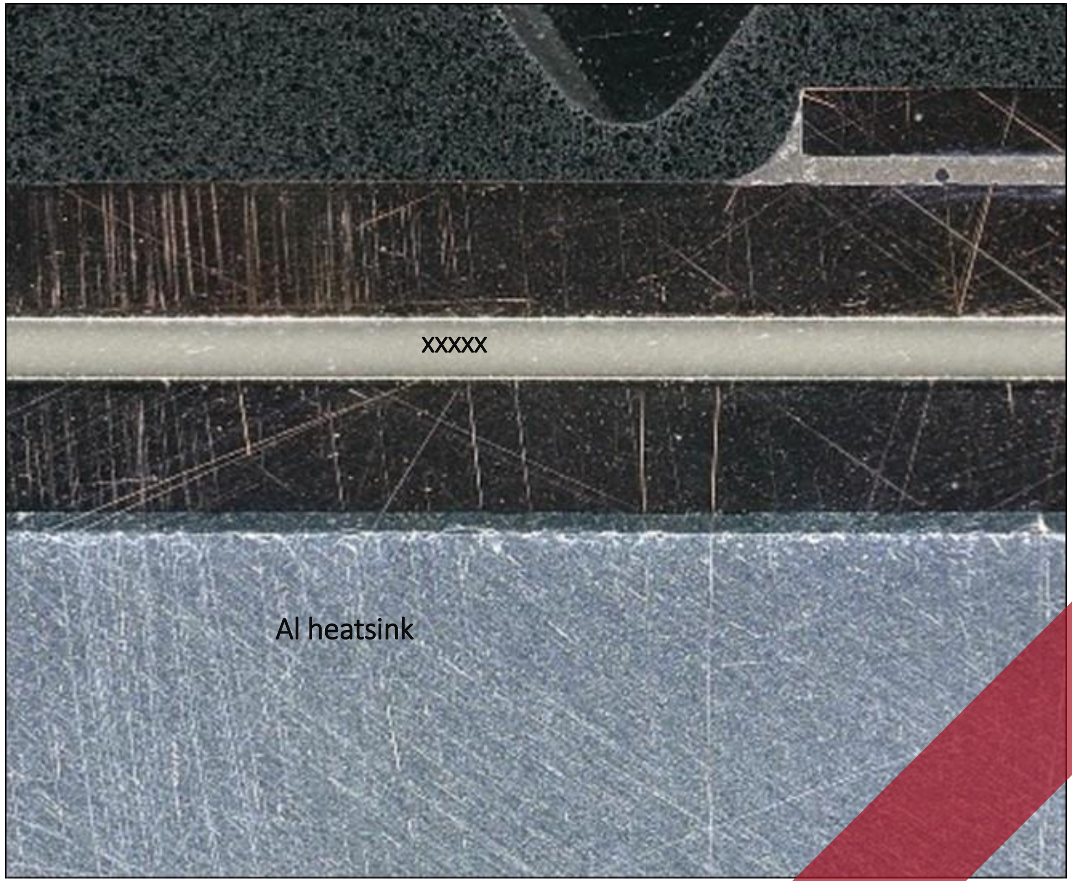
★ Similar to analysed device

Heatsink

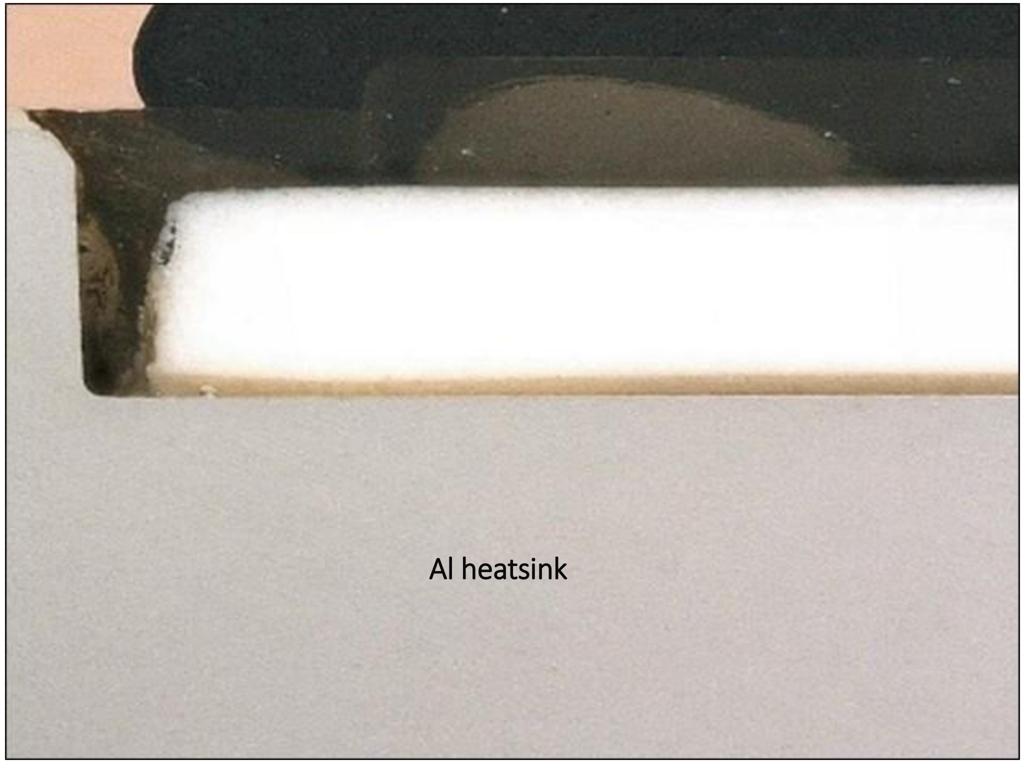


Package Cross section

Heatsink

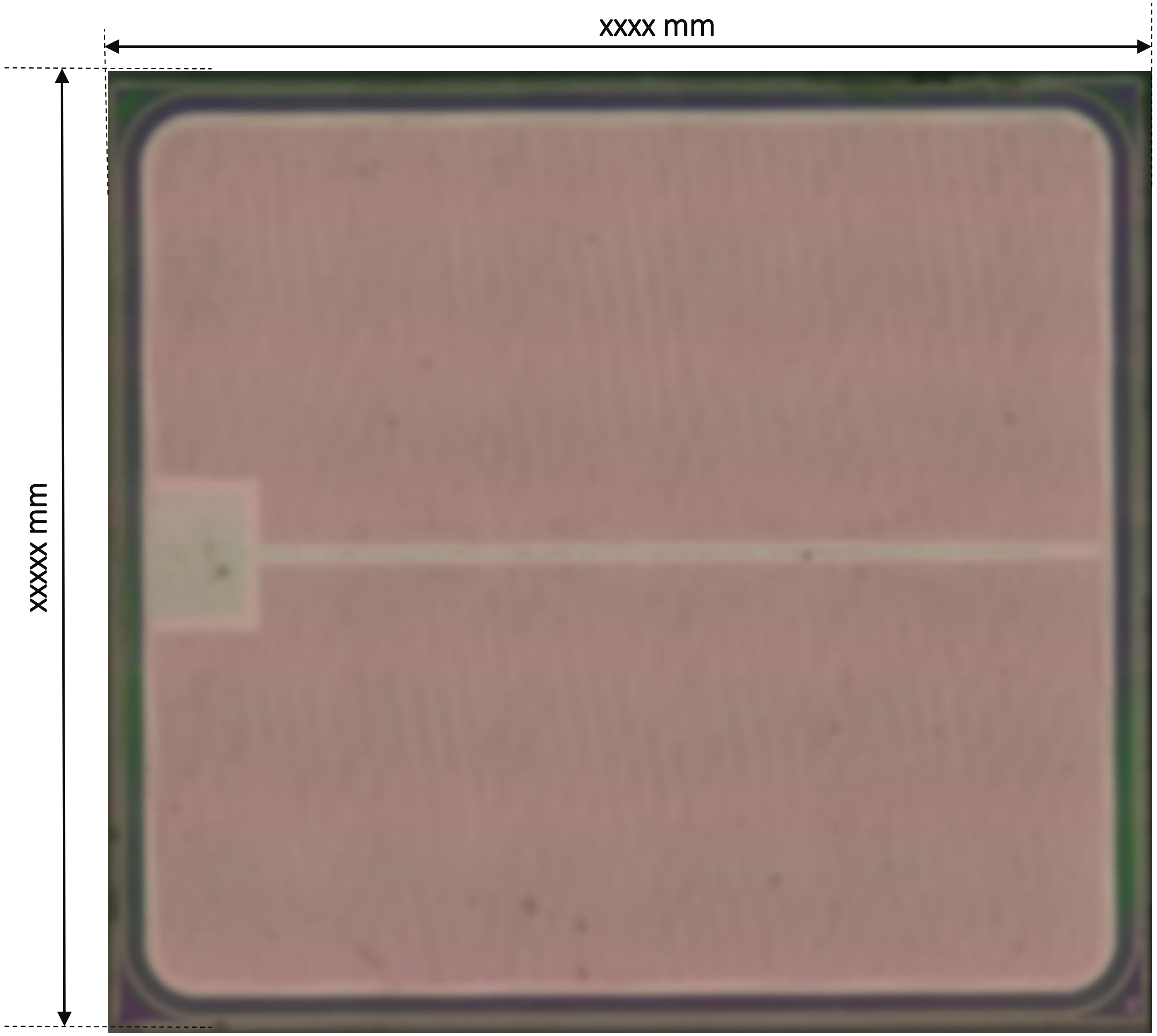


Package Cross section



Package Cross section

MOSFET die dimensions

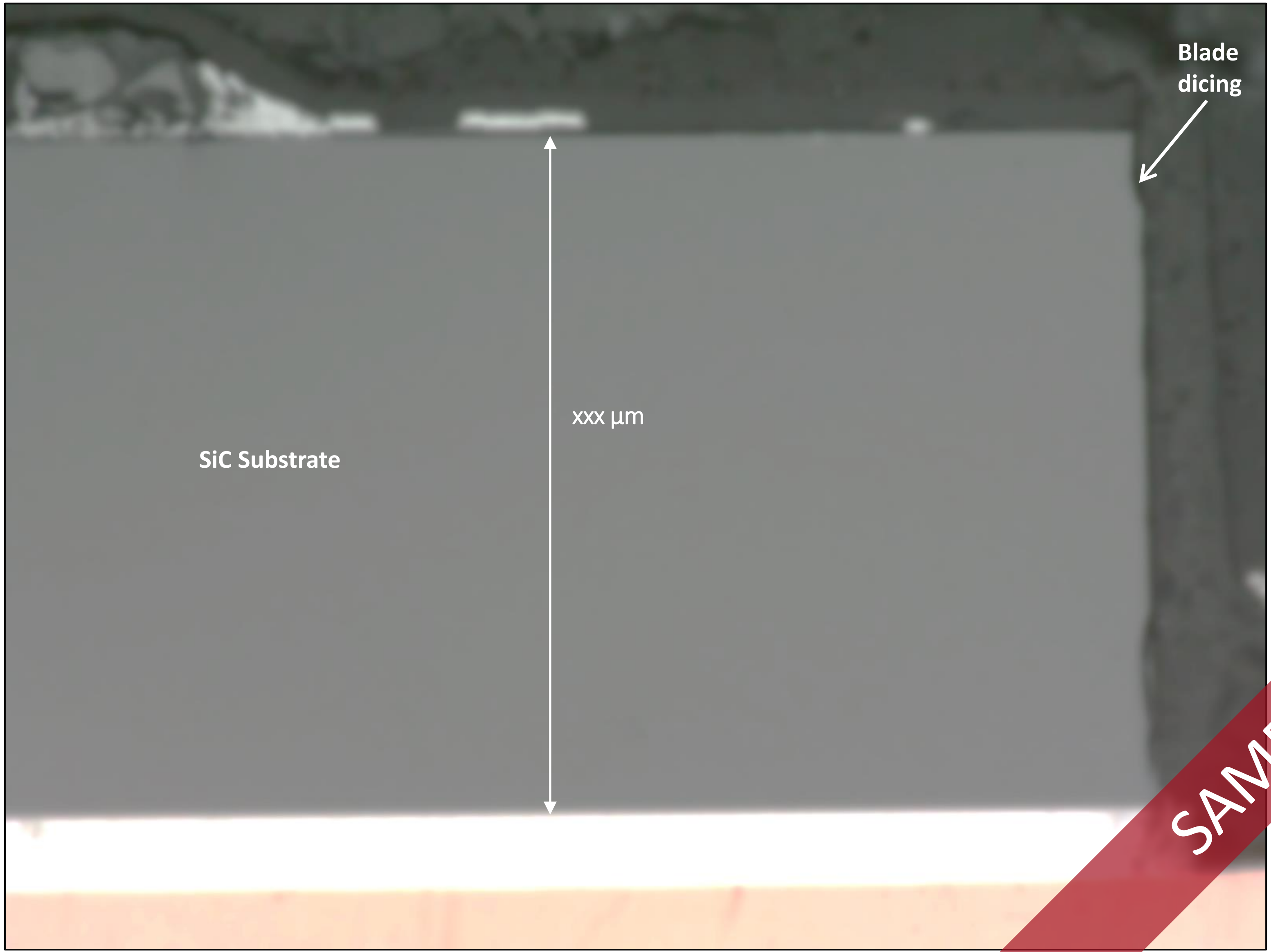


MOSFET Die – Optical view

- Die dimensions:
  xxxx mm² (xxxxmm x xxxxmm)
- There is no marking on the die.

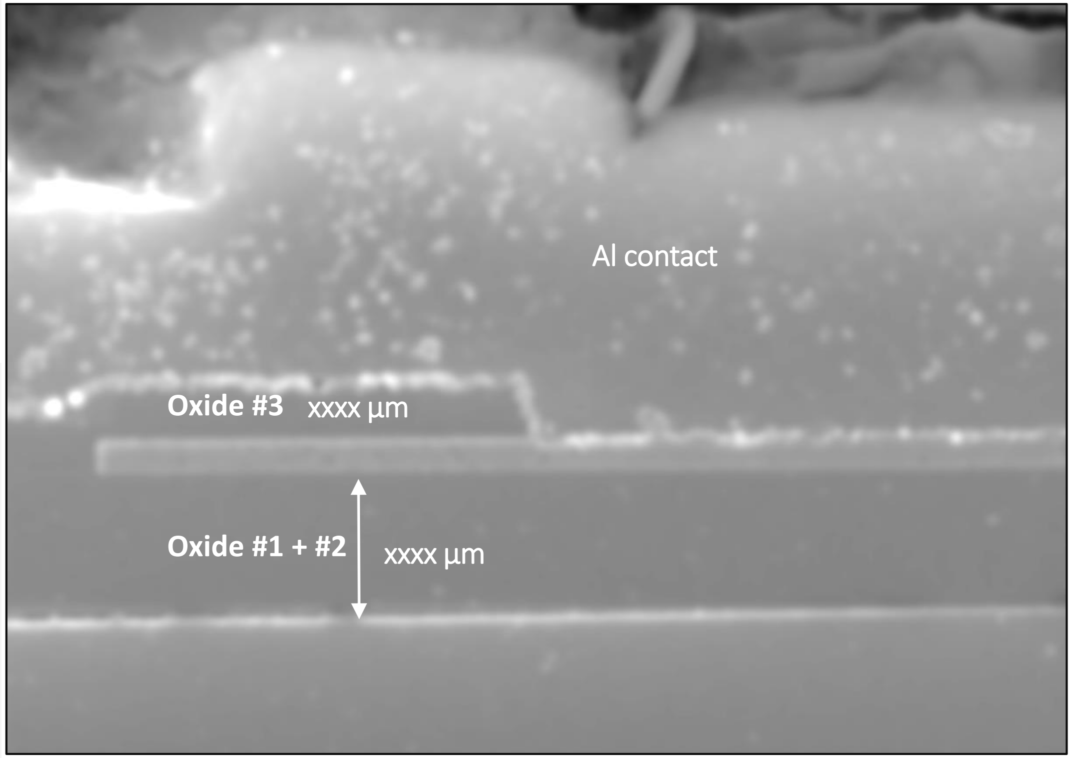
Die cross section

- Substrate thickness: xxxx µm

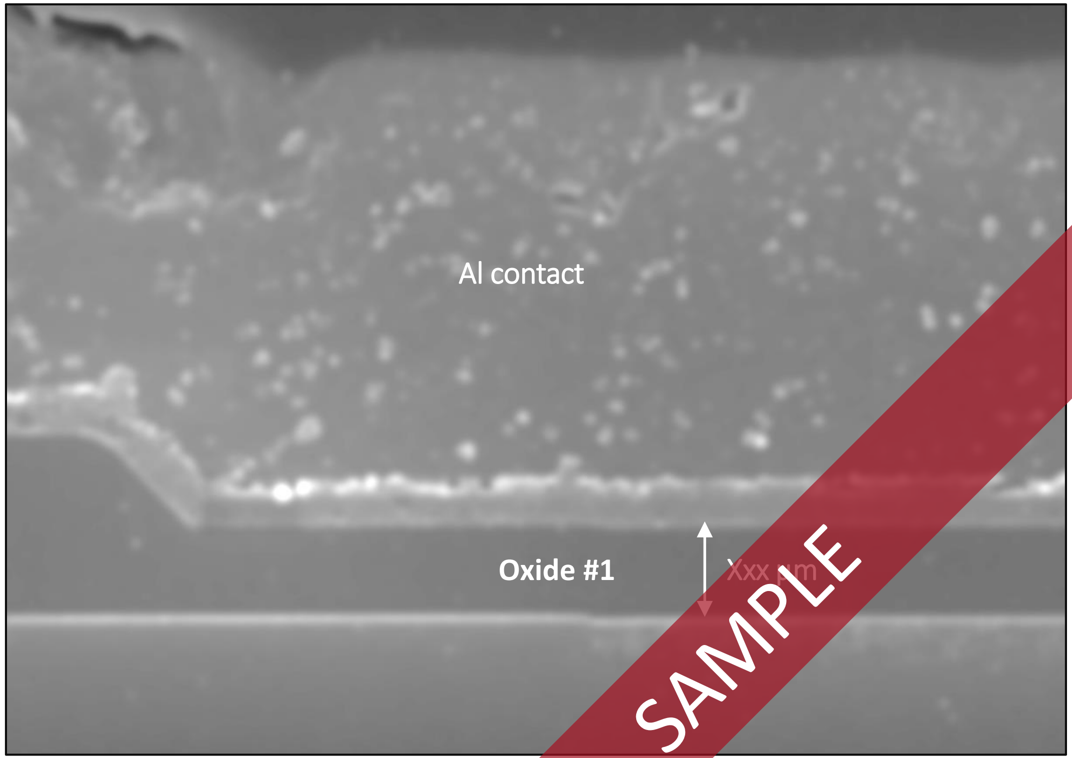


Die cross section – Optical View

Die cross section

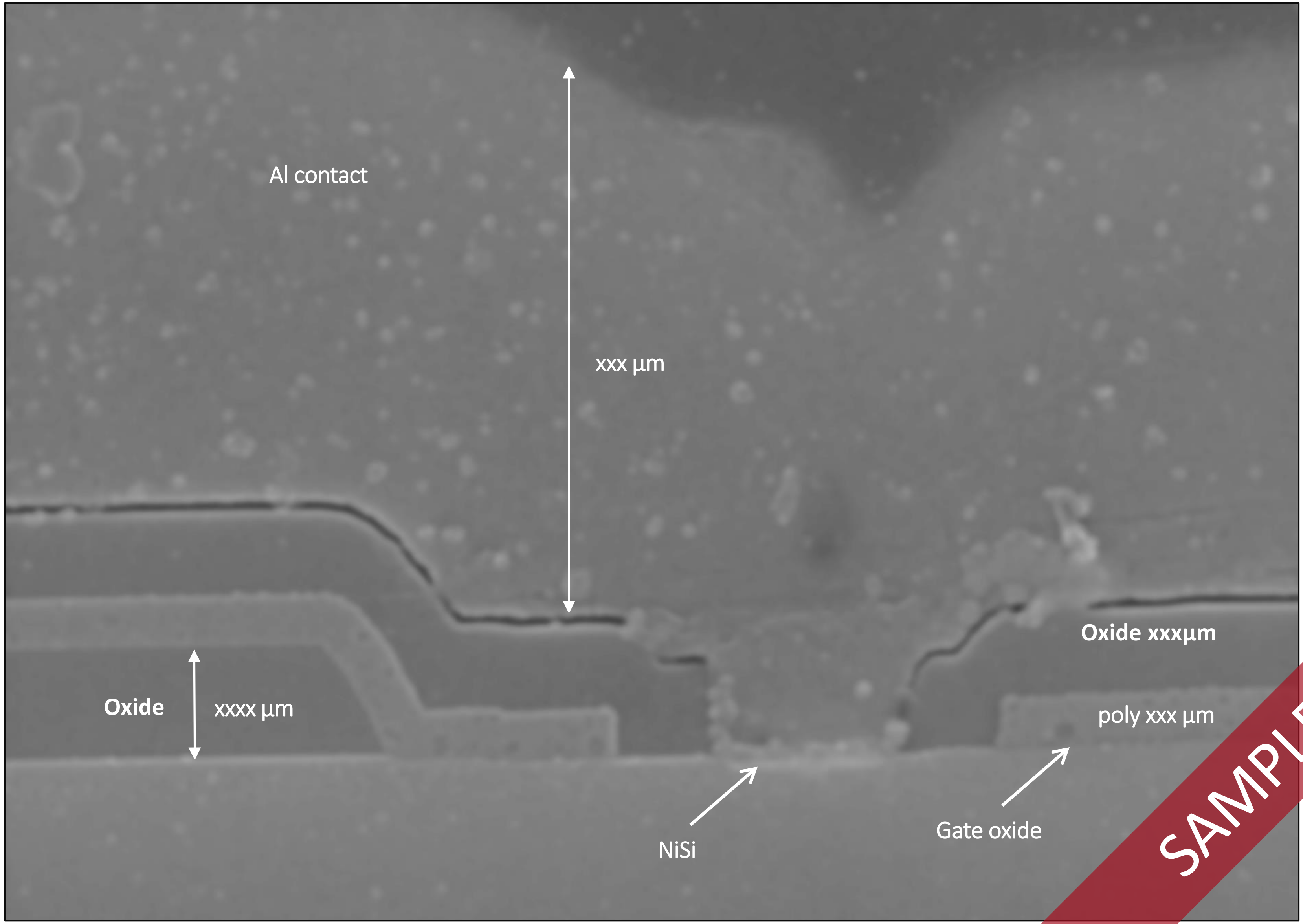


Die cross section –SEM View



Die cross section –SEM View

Die cross section

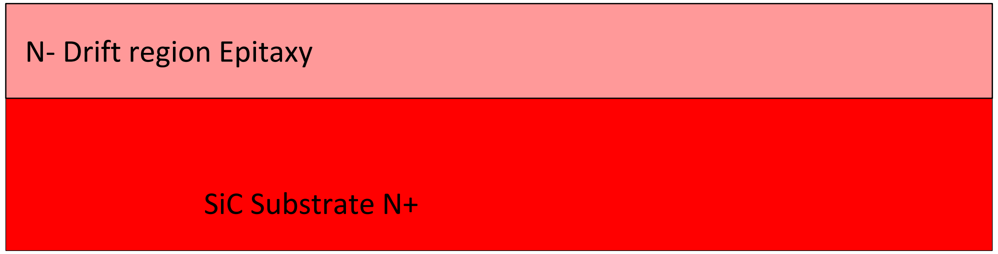


Die cross section – SEM View

MOSFET Process Flow (1/4)

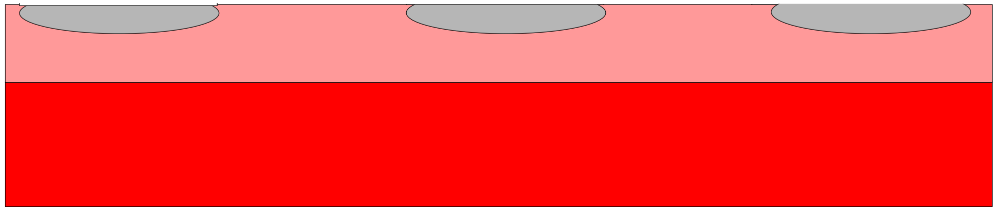
Epitaxy

- Epitaxy



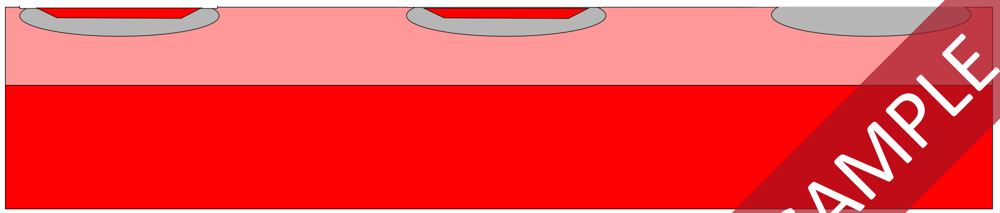
Implantation

- SiO_2 deposition
- Pattern SiO_2
- P well implantation



Implantation

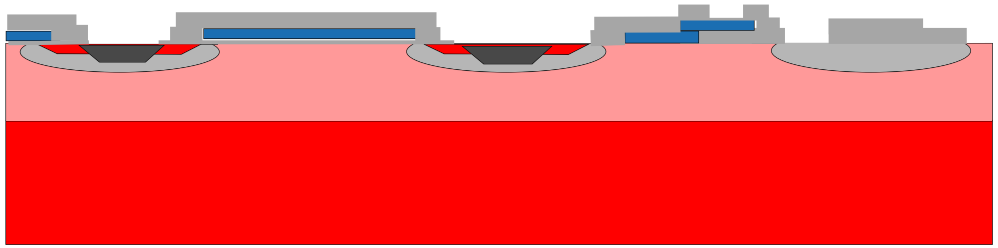
- SiO_2 deposition
- Pattern SiO_2
- N+ source implantation



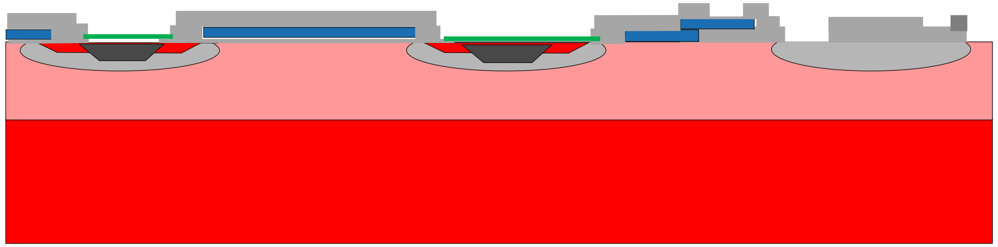
Drawing not to Scale

MOSFET Process Flow (3/4)

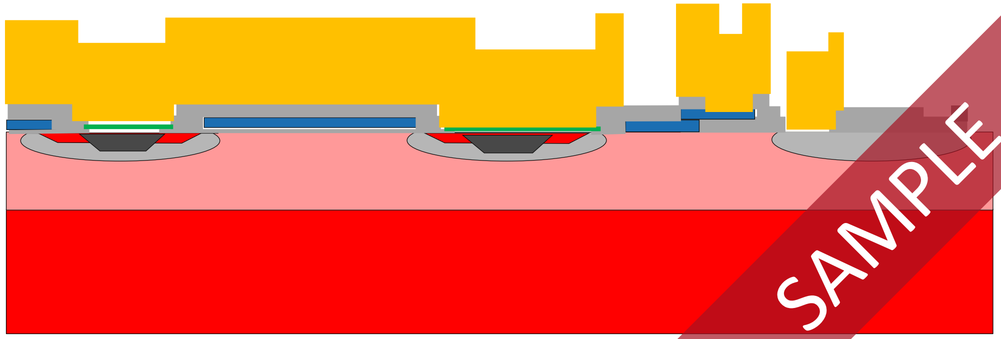
Gate isolation
- Oxide: deposition and pattern



Silicide
- Nickel deposition and pattern
- Silicidation



Metal contact
- Ti and Aluminum deposition and pattern



Drawing not to Scale

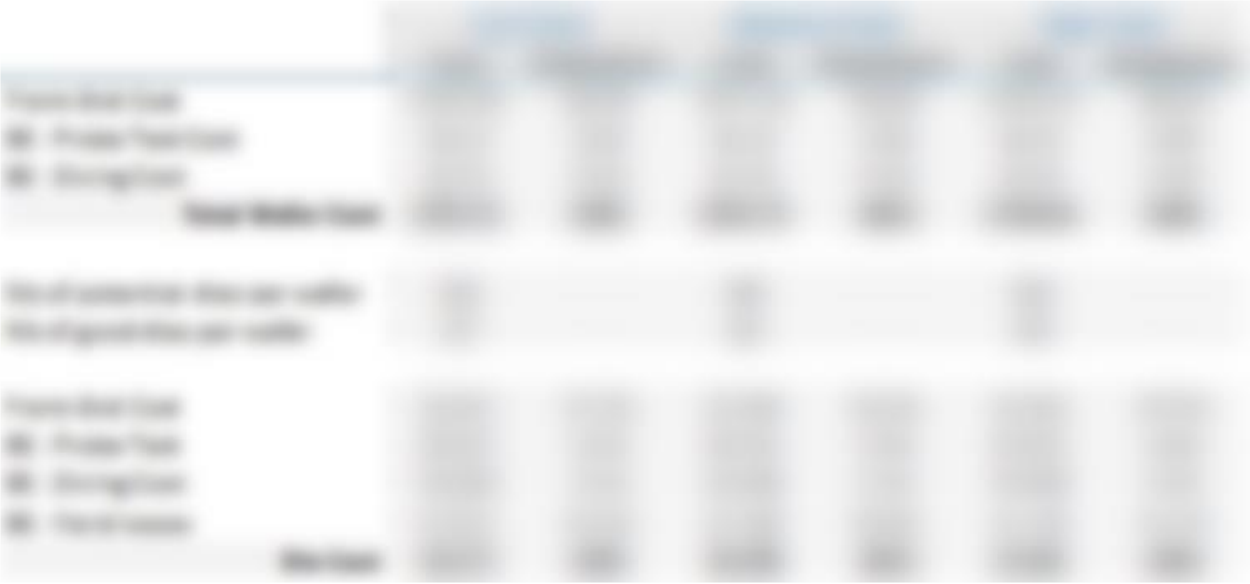
MOSFET Front-End Cost

Front-End	Low Yield		Medium Yield		High Yield	
	Cost	Breakdown	Cost	Breakdown	Cost	Breakdown
Raw wafer Cost (SiC 150mm)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Equipment Cost	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Clean Room Cost	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Labor Cost	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Consumable Cost	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Yield losses Cost	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Front-End Cost	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The front-end cost ranges from $xxxx to $xxx according to years.

The main part of the wafer cost in 2018 is due to the xxxx (xxx%).

MOSFET Die Cost



The MOSFET die cost ranges from $xxxx to $xxxx according to years.

The Front-end manufacturing represents xxxx of the component cost in 2018.

Probe test, dicing and scrap account for xxxx of the component cost.

Final Module Cost

The module cost ranges from $xxx to $xxxx according to years.

The SiC MOSFET dies manufacturing represents xxx% of the component cost.

The packaging represents xx% of the component cost.

Final test and yield losses account for x% of the component cost.

[Overview / Introduction](#)

Company Profile & Supply Chain

Physical Analysis

Manufacturing Process Flow

Cost Analysis

Selling Price Analysis

Comparison

Feedback

About System Plus

Estimated Manufacturer Price

	[illegible]		[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Module cost	[illegible]		[illegible]		[illegible]	
Manufacturer Gross Profit	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Module price	[illegible]		[illegible]		[illegible]	

STMicroelectronics	
Gross Margin	39.0%

The module manufacturing cost ranges from $xxx to $xxx according to years.

By taking into account a gross margin of 39% for ST (2017 results), the module manufacturer price is estimated to range from $xxxx to $xxxxx according to years.

Related Reports

REVERSE COSTING ANALYSES - SYSTEM PLUS CONSULTING

Power Semiconductors & Compound

- Infineon FS600R07A2E3 HybridPACK2 100KW 3-phase
- Infineon EconoPACK4™ 1200V IGBT4 Module
- Semikron SKiM306GD12E4
- ROHM 1200V Trench SiC MOSFET
- Infineon CooliR²Die™ Power Module
- Toyota Prius Power Modules

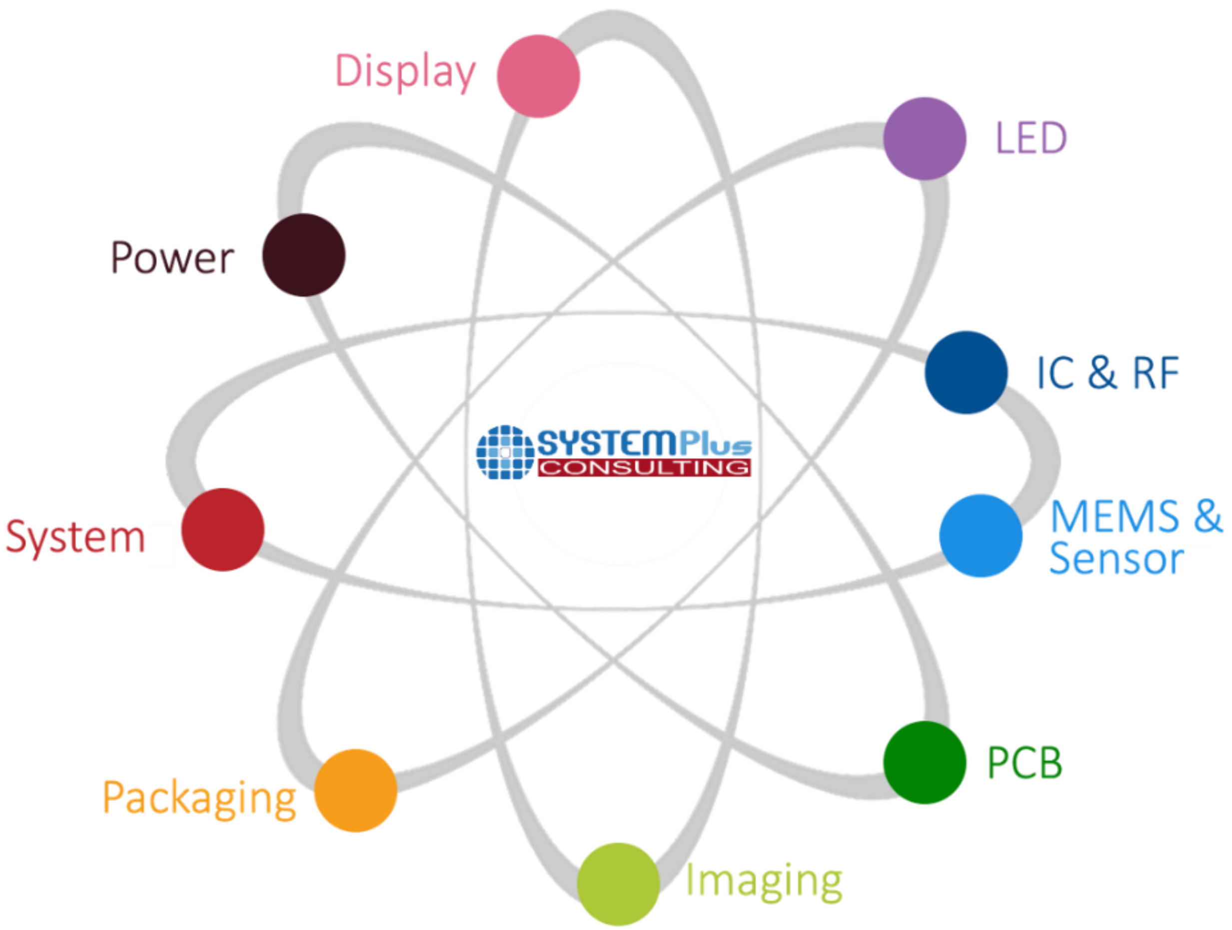
MARKET AND TECHNOLOGY REPORTS - YOLE DÉVELOPPEMENT

Power Electronics & Compound Semiconductors

- Power Electronics for EV/HEV 2018
- Power Module Packaging: Material Market and Technology Trends 2017
- Power SiC 2017: Materials, Devices, Modules, and Applications

COMPANY
SERVICES

Business Models Fields of Expertise



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