Static characterization on-state of an industrial Si Power MOSFET at cryogenic temperature

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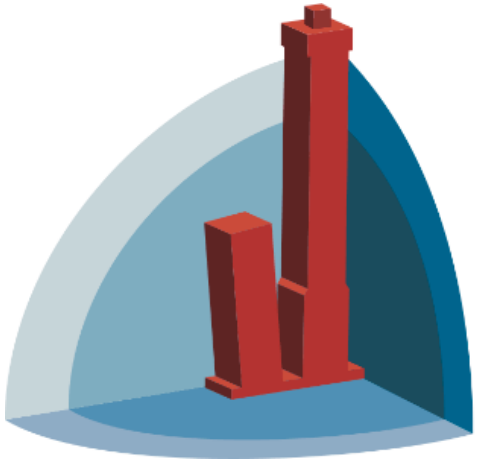

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Presentation outline

I – General introduction

II – Cryogenic system

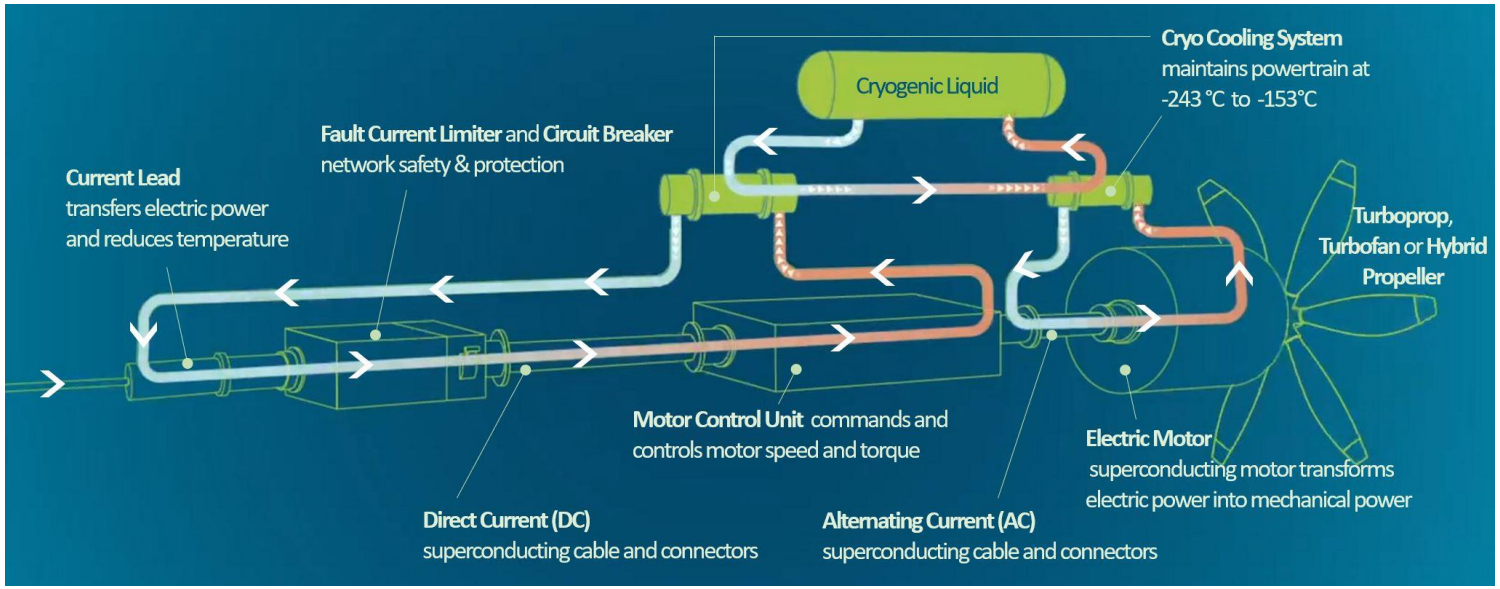
III – Component description and measurements

IV – Conclusion

Introduction

Imothep Project : "Investigation and Maturation of Technologies for Hybrid Electric Propulsion“
H2020 project (“Mobility for Growth” - "towards a hybrid/electric aircraft") Coordinated by ONERA

This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 875006
29 partners - 9 European countries + international partners from Canada - 10.4 M€ EC funding

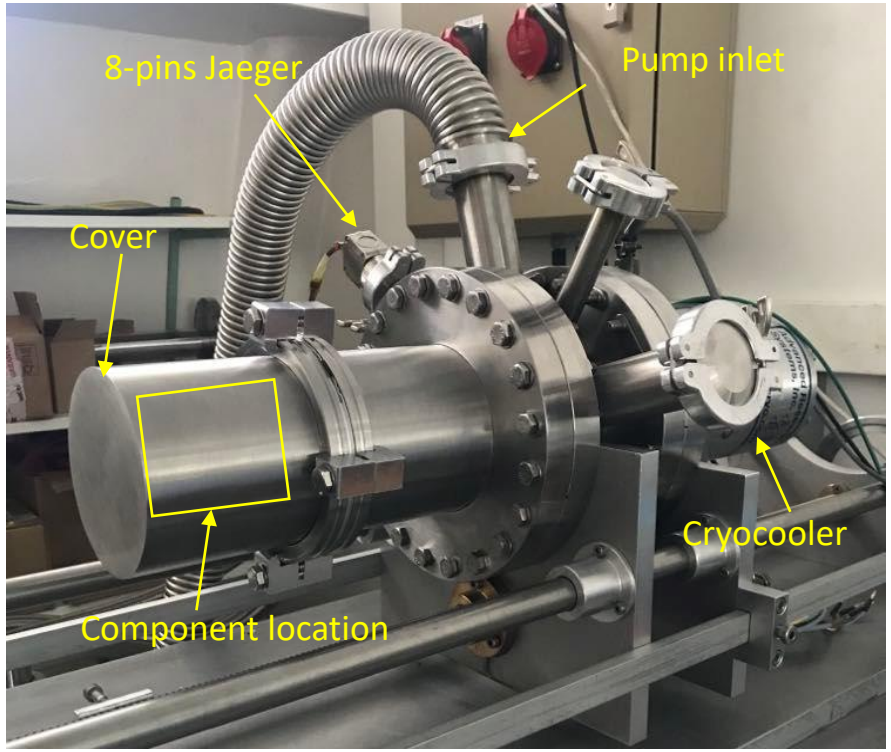


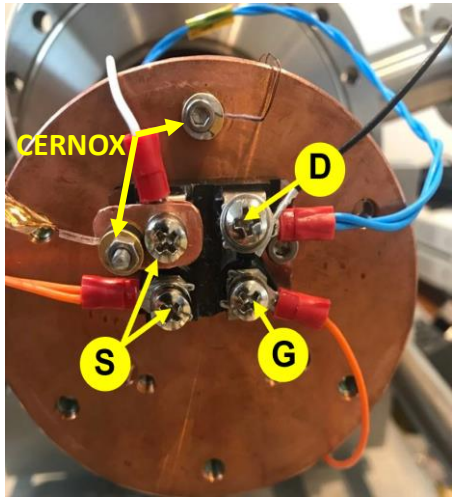
- ASCEND (Advanced Superconducting and Cryogenic Experimental powertraiN Demonstrator)
- SUPERMAN (Superconducting Electrical Machines for Zero Emission Aviation)
- SuperRail (railway network)

How a power electronic component behaves at cryogenic temperature?

“Review of Power Electronics Component at Cryogenic Temperatures”, IEEE Trans Power Electronics, 2020 May ; 35(5) :5144-5156. doi :10.1109/tpel.2019.2944781

Cryogenic system – Temperature management





Equipment used

- Cryocooler ARS 4K model
- LakeShore model temperature control
- Temperature control between 10 K and 320 K
- CERNOX Temperature sensors

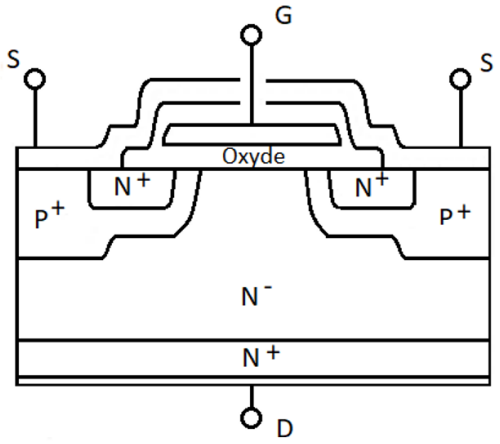
Electrical features

- 300 A pulsed
- 100 A DC
- Electrical breakdown voltage: 1200 V

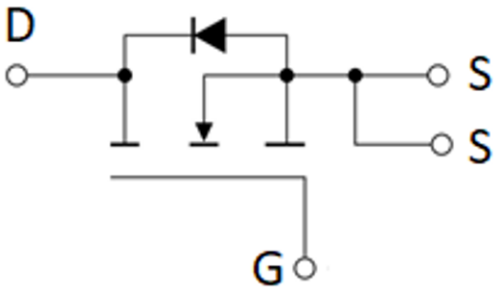
Characterizations

- *I*(*V*) curves
- Resistance measurement
- Voltage/Current Threshold
- Capacity measurement (Coming soon)

Component description – Component selection



power MOSFET structure



Electric schematic of a power MOSFET

2 structures:

- Trench MOSFET (under 100 V)
- Planar MOSFET

Static losses of a MOSFET:

$$P = R_{DSon} \times {I_D}^2$$

To estimate static losses at cryogenic temperature the evolution of resistance R_{DSon} with temperature must be evaluated

The STE180NE10 MOSFET is a 180 A 100 V MOSFET and has been selected

Measurements description – R_{DSON} measurements

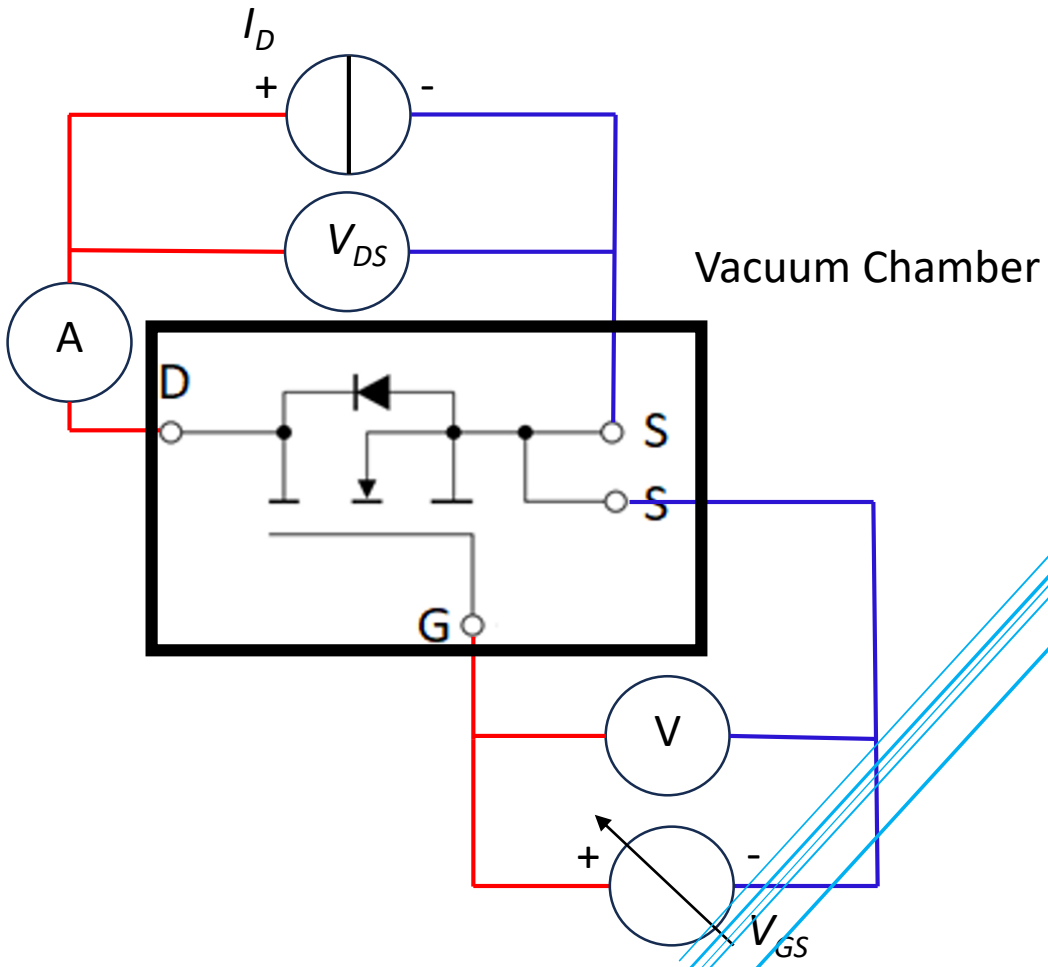
To measure R_{DSON}, a 4 wires measurement technique is used:

A Drain current I_D of 1 A with milliamp accuracy is applied

Then the voltage V_{DS} is measured with microvolt accuracy.

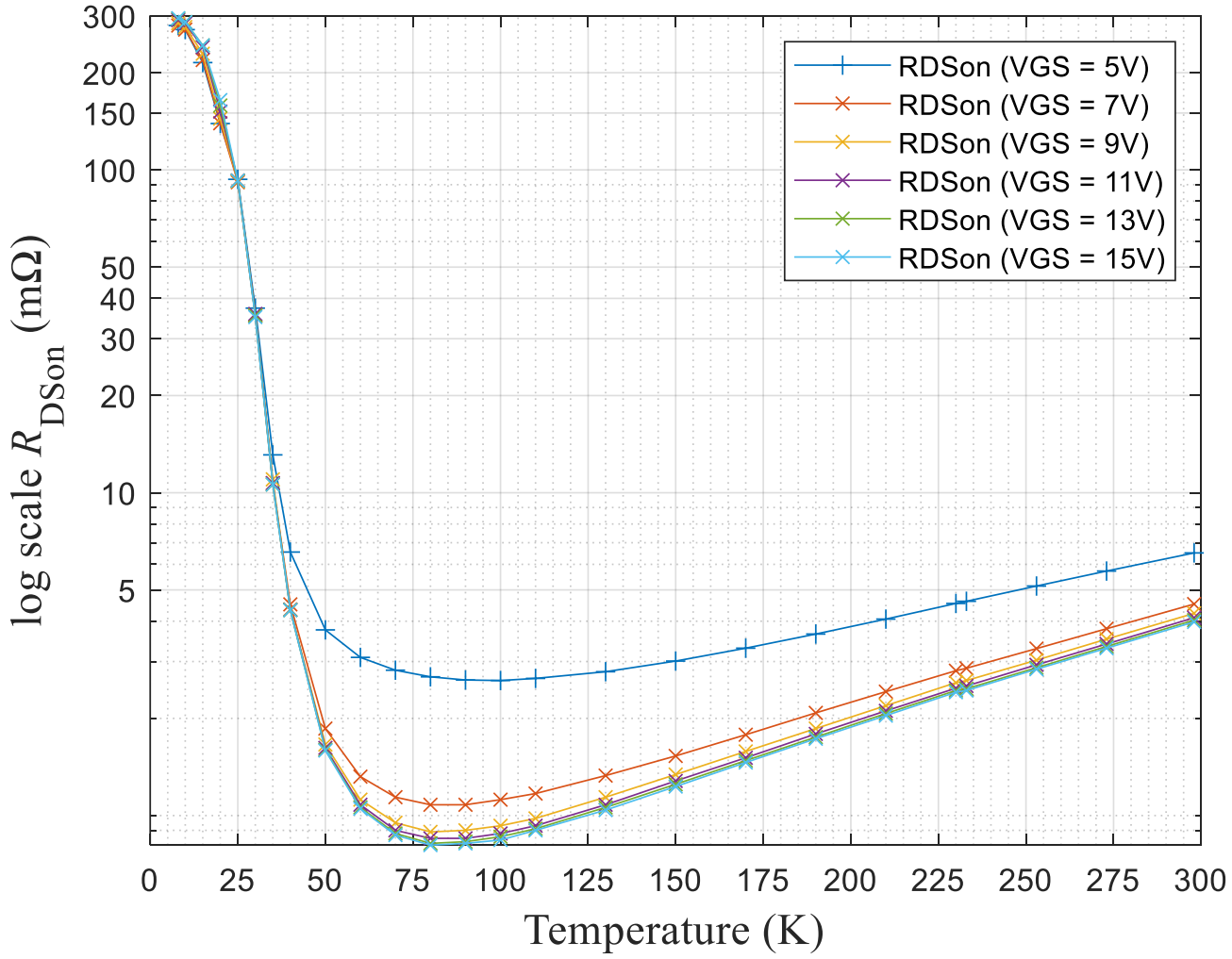
Static measurement:

$$R_{DSON} = \frac{V_{DS}}{I_D}$$



Vacuum Chamber

Measurements description – R_{DSON}



Evolution of R_{DSon} with temperature for I_D = 1 A and different V_{GS}.

Minimum losses at 80 K

Unexpected behavior under 40 K

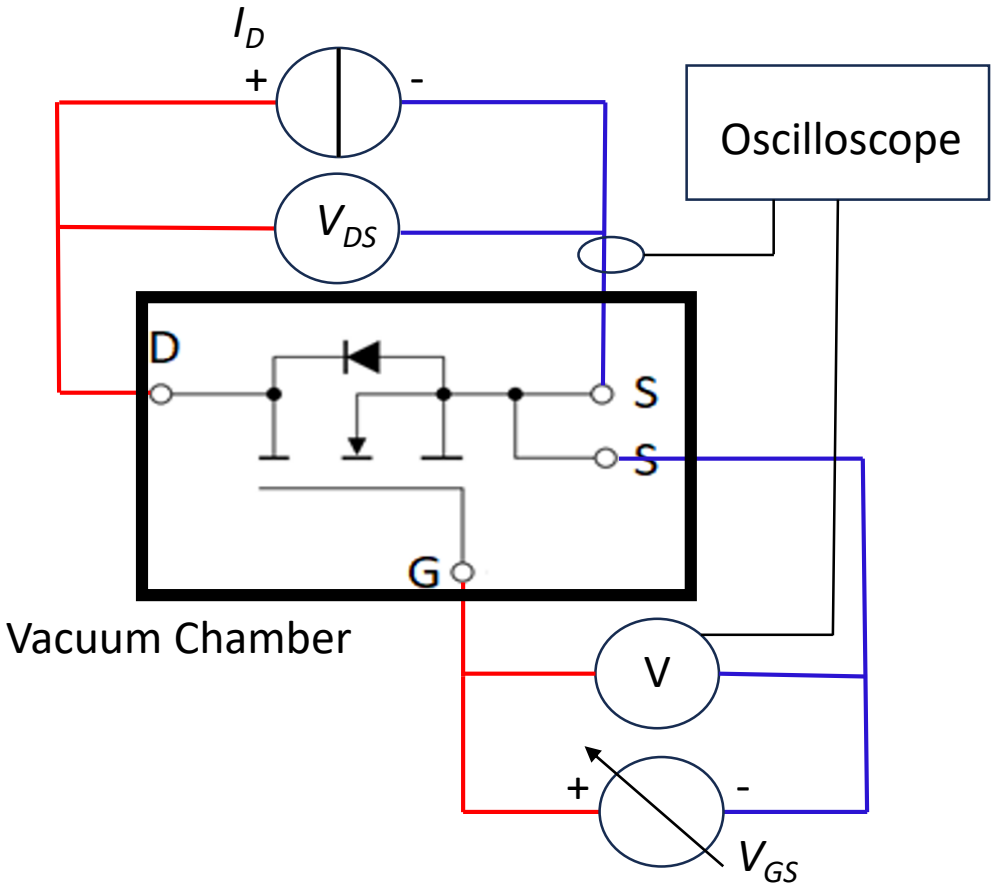
V_{GS}	300 K	80 K	Variation
15	3.98 mΩ	0.81 mΩ	-79.65%
13	4.03 mΩ	0.82 mΩ	-79.65%
11	4.10 mΩ	0.85 mΩ	-79.27%
9	4.23 mΩ	0.89 mΩ	-78.96%
7	4.52 mΩ	1.08 mΩ	-76.11%
5	6.51 mΩ	2.69 mΩ	-58.68%

Measurements description – $I(V)$ Measurement

For each value of V_{GS} a pulsed current of 180 A is applied.

The on-state duration is 0.85 ms

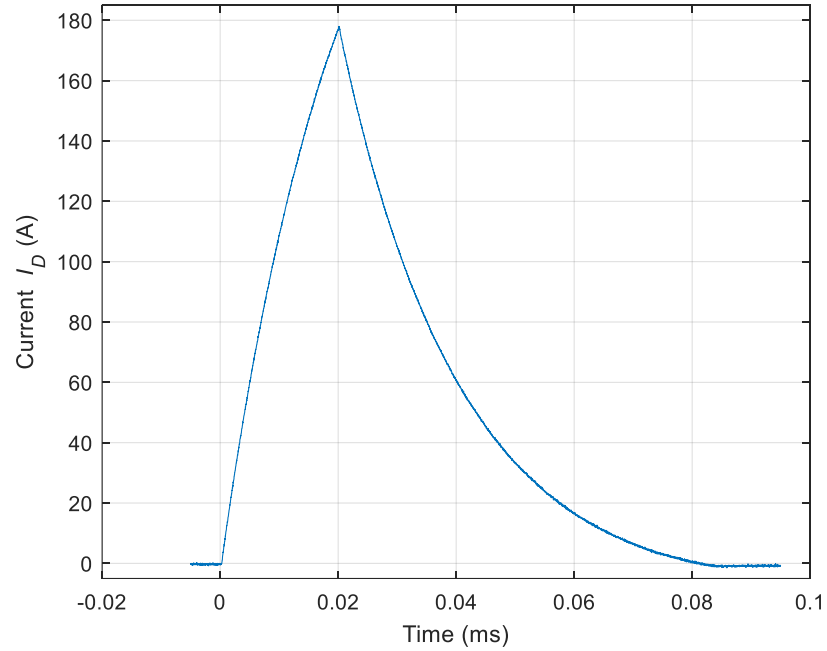
The component is then cooled for 10 seconds



During the pulse:

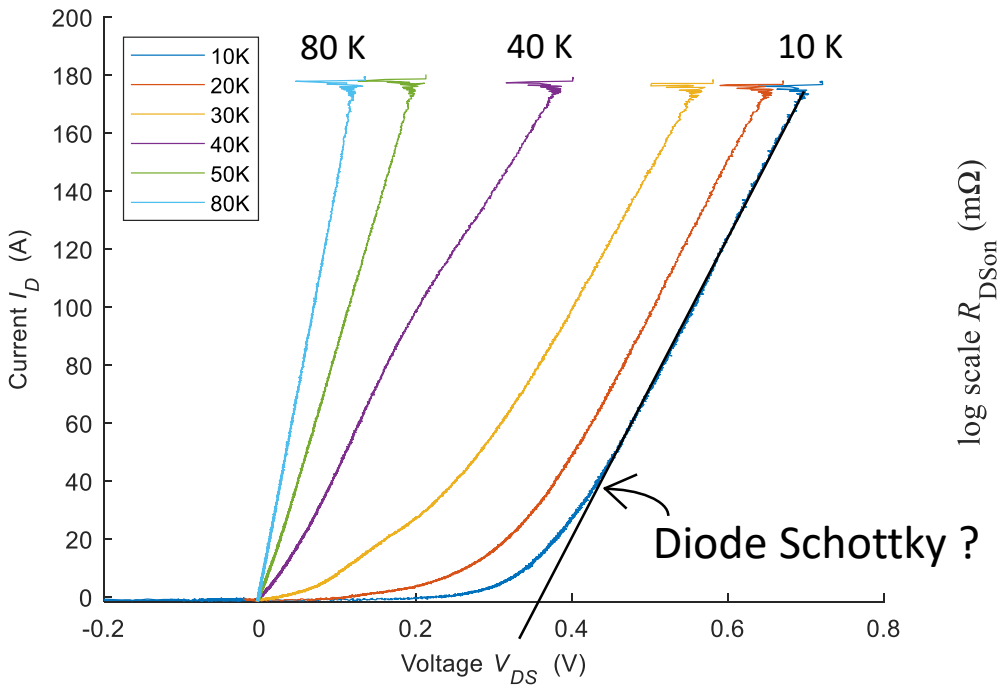
the voltage V_{DS} is measured with an accuracy of 2%
thanks to a Tektronix oscilloscope module for TDS series

the current I_D is measured with an accuracy of 1%
thanks to a current probe for Tektronix oscilloscope

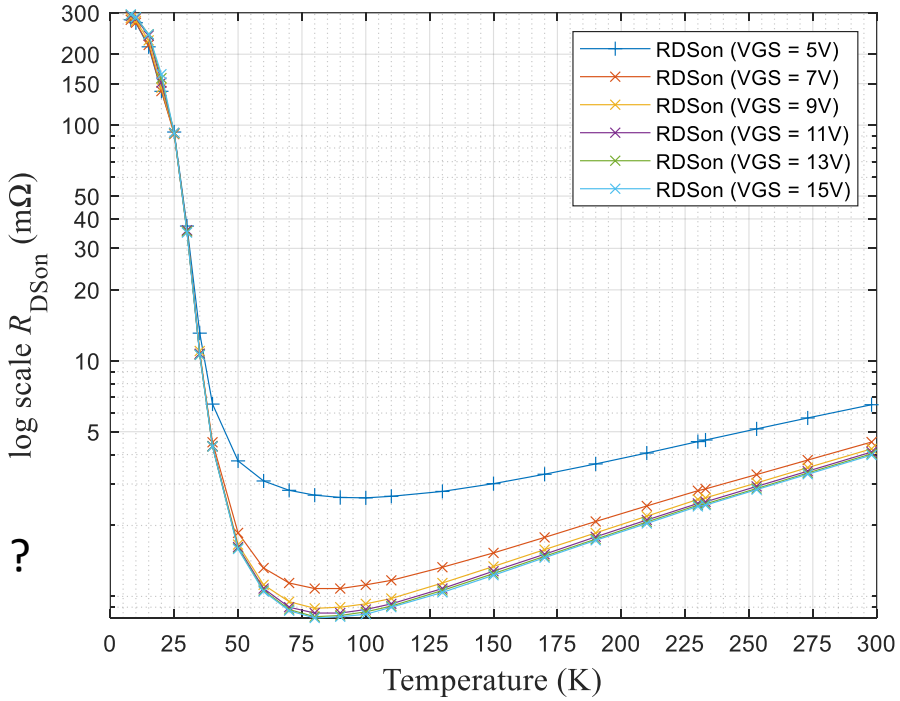


The results are finally obtained by averaging 16 pulses.

Measurements description – *I*(*V*) Measurement

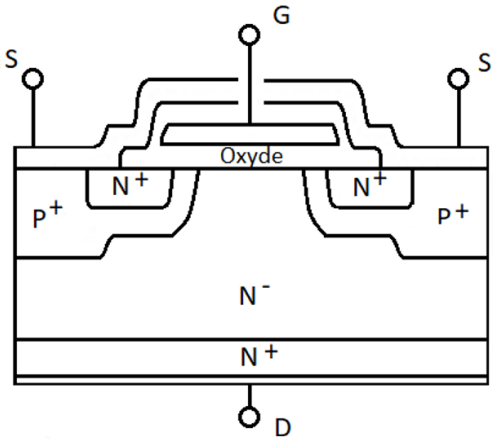


Evolution of $I_D(V_{DS})$ with temperature for V_{GS} = 15 V,



Evolution of R_{DSon} with temperature for I_D = 1 A and different V_{GS}.

Power MOSFET structure



Conclusion

Value	T = 300 K	T = 80 K	Difference between T = 300 K
R_{DSON} @ V_{GS} = 11 V	4.10 mΩ	0.85 mΩ	–79%
V_{TH}	2.90 V	3.90 V	+35%

The rise in threshold voltage, although significant, does not pose a problem in practice.

The Si MOSFET is a good candidate for cryogenic applications @77K, since its static losses are minimal at 80 K.

Thank you for your attention!

- ✓ The same Schottky Diode effect has been observed on other Si MOSFET.
- ✓ Many other *I*(*V*) curves have been carried out:
  - IGBT PT, IGBT NPT, IGBT Trench
  - GaN FET *I*(*V*)
  - Si Diode, Si Fast Recovery Diode
  - SiC Schottky Diode and Si Schottky Diode

The study of a Flyback converter at cryogenic temperature is planned. This includes a study of the behavior of capacitors and magnetic components at cryogenic temperature.