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# What brings diamond compared to wide bandgap materials in power semiconductor devices?

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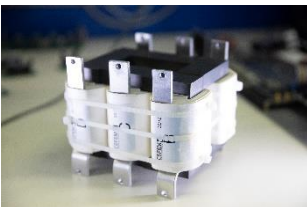
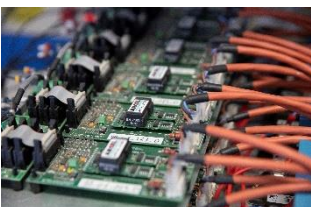
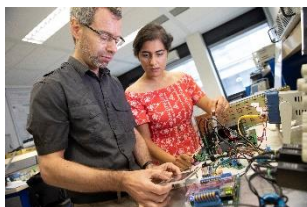
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# What brings diamond compared to wide bandgap materials in power semiconductor devices?

*Session 4A: Diamond Power Devices I*

*\*Invited speaker*

*Sept 11<sup>th</sup> 2023*

Nicolas ROUGER, CNRS Research scientist

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# Outline

## 1. Power semiconductor devices

- A. Specificities and benchmarking
- B. Impact of WBG power devices vs. Silicon

## 2. Diamond for power electronics

- A. Unique properties of diamond
- B. Benefits & benchmark of diamond

## 3. What's next?



This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 101007868. The JU receives support from the European Union's Horizon 2020 research and innovation program and the Clean Sky 2 JU members other than the Union.





Part 1

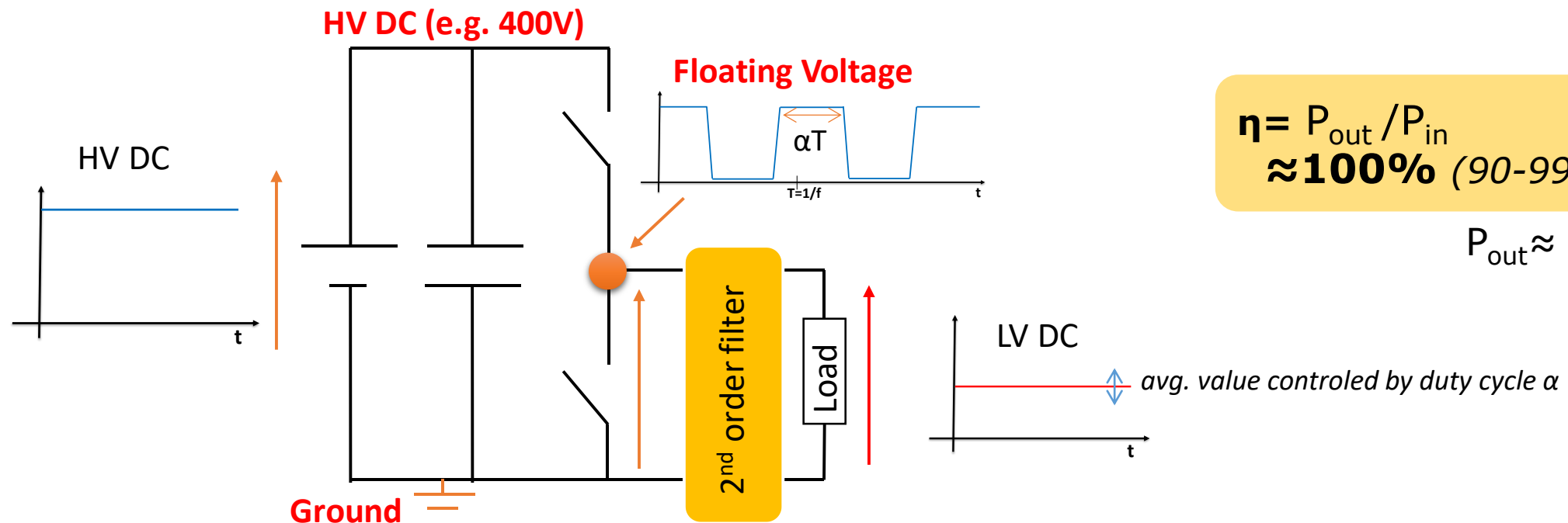
# Power semiconductor devices

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# Power electronics

## e.g. Half bridge / Buck Converter (DC/DC)

- Target 100 % efficiency
- Constraints on weight (volume), safety & reliability, cost, standards, adaptability to operating conditions, ...



$$\eta = P_{out} / P_{in} \approx 100\% \text{ (90-99\%)}$$

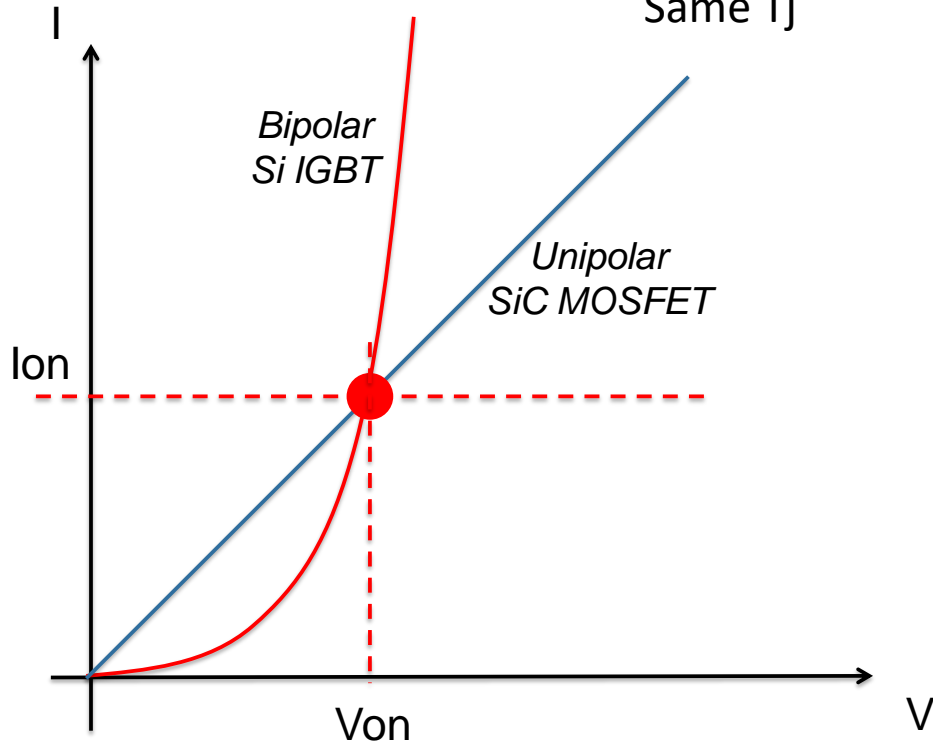
$$P_{out} \approx P_{in}$$

# Power semiconductor devices

How to compare / Benchmark?

e.g. Si vs. SiC (WBG)

Same  $V_{on}$  @  $I_{on}$   $\longrightarrow$  Same conduction losses  
Same Breakdown Voltage  
Same  $T_j$

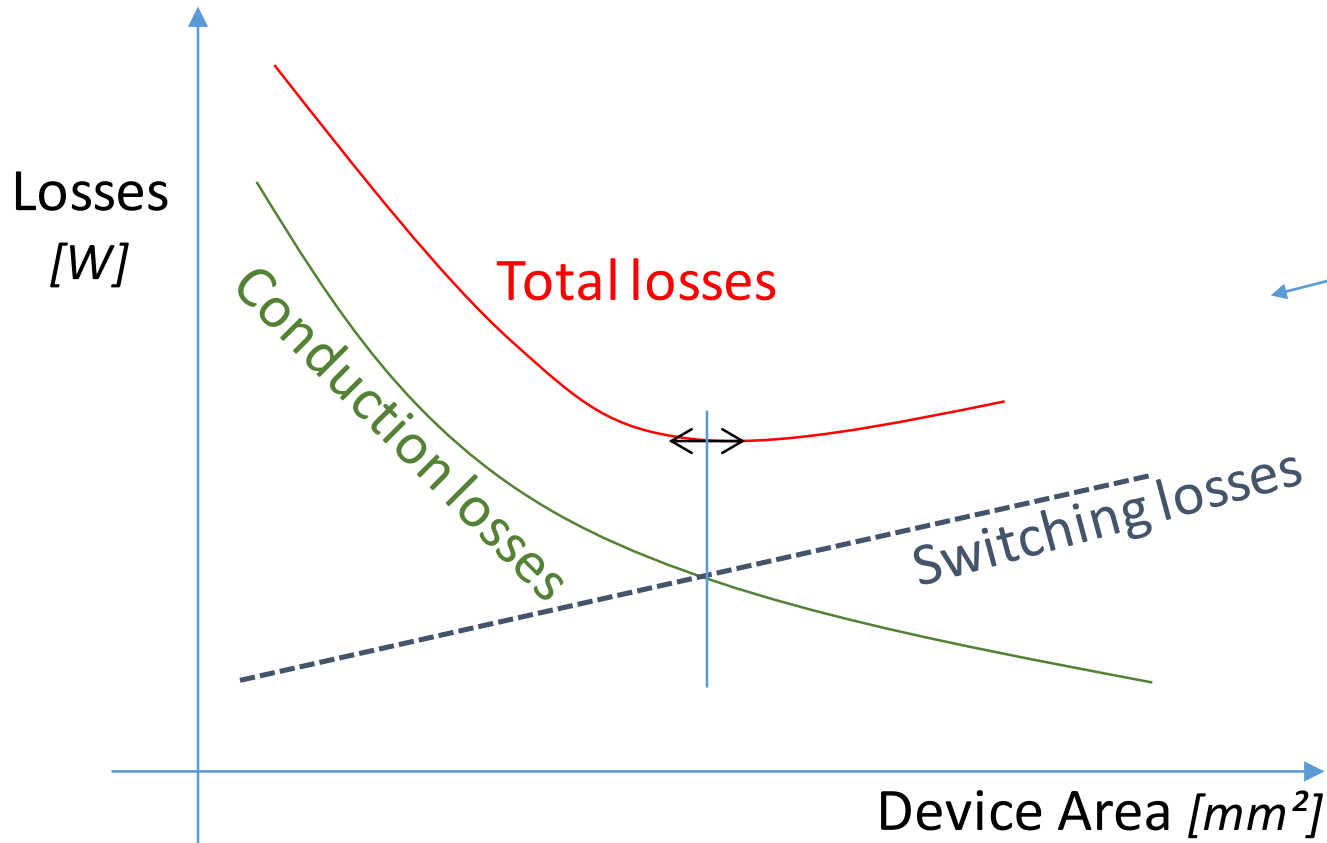


***What are the benefits of (U)WBG vs. Si?***

# Power semiconductor devices

## How to compare / Benchmark?

e.g. Carrier Lifetime Control and optimal area



**Same specifications**  
**Same technology**  
**Same T<sub>j</sub>**  
**Same Carrier Lifetime**



**Trade off and optimization!**  
**Multiple variables**





Part 2

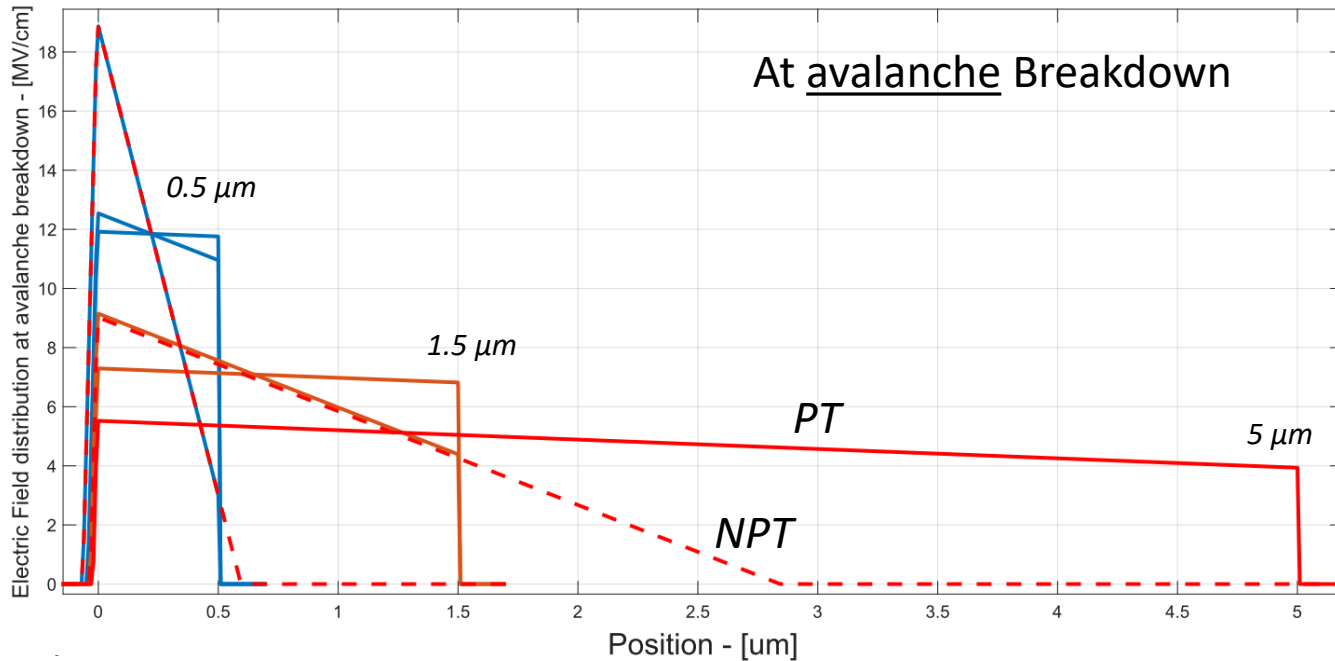
# Diamond for power electronics

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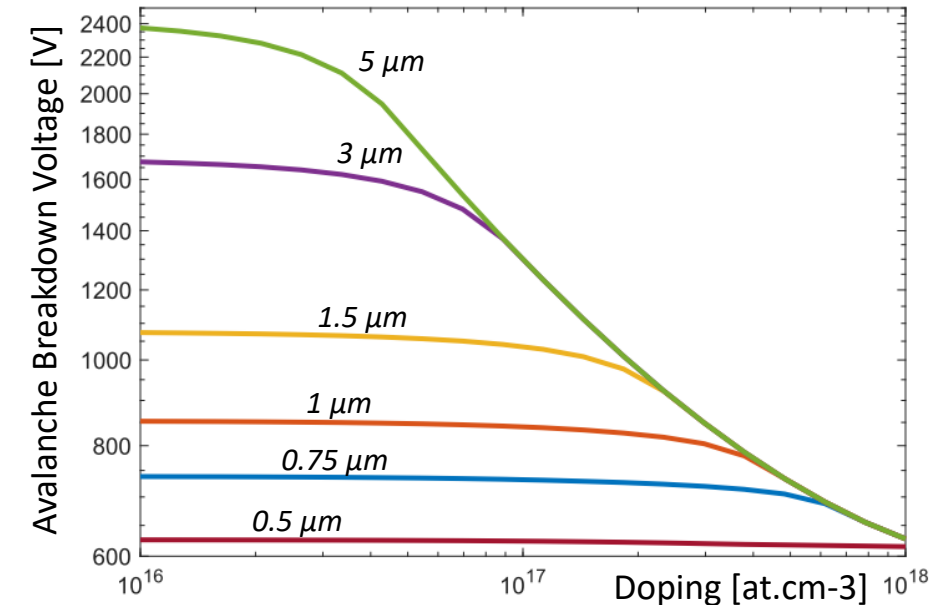
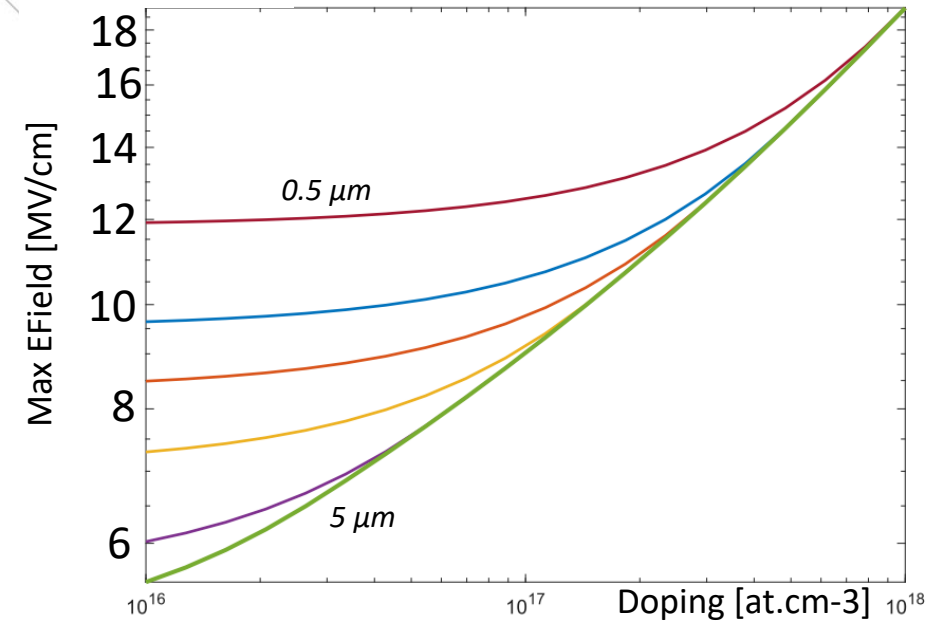
# Benchmark: Diamond

## Critical Electric Field of Diamond?

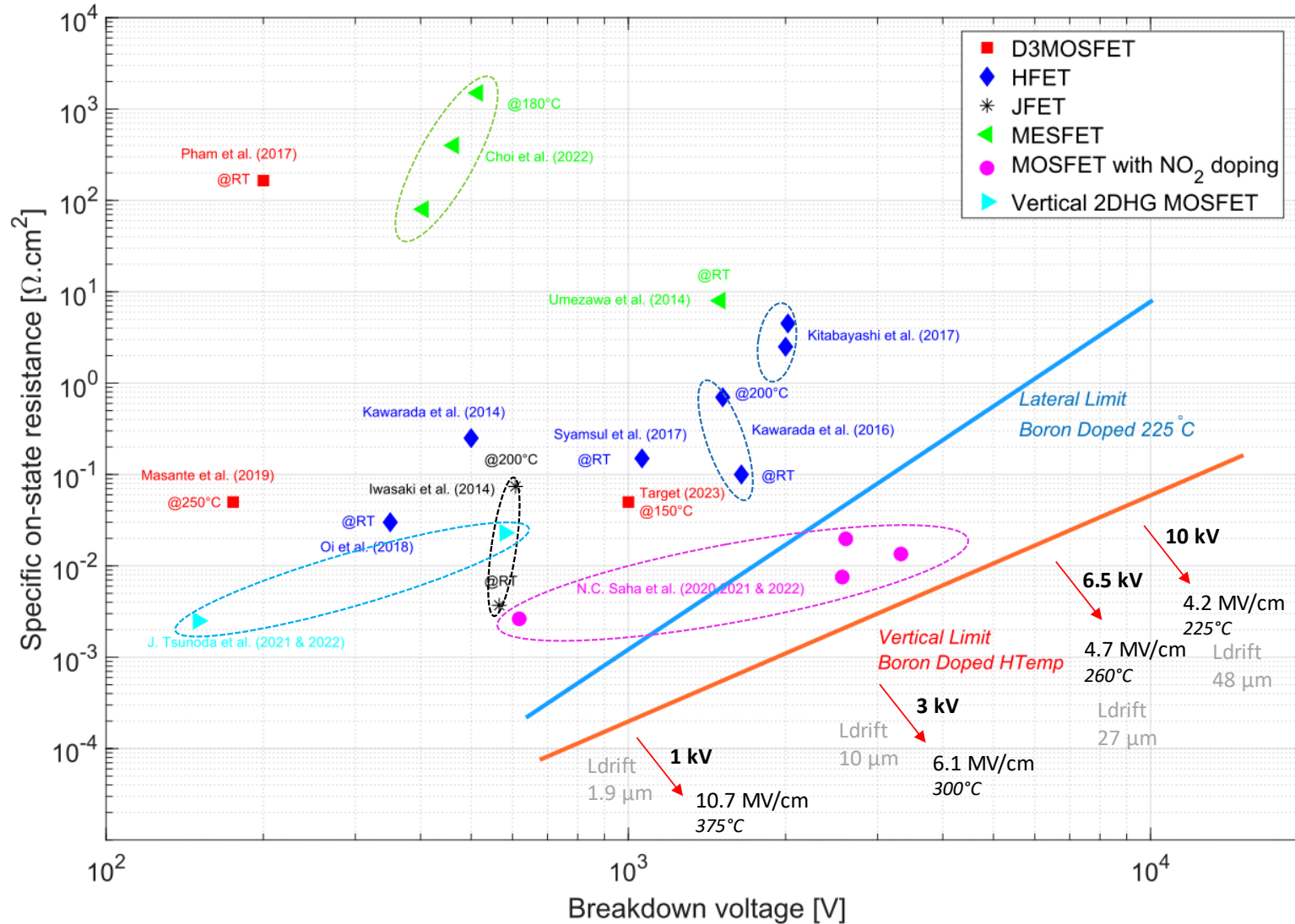


$$\alpha_p = a_p \exp\left(\frac{-b_p}{|E|}\right), \alpha_n = a_n \exp\left(\frac{-b_n}{|E|}\right)$$

[A. Hiraiwa, H. Kawarada, 2013, JAP 114 034506]



# Benchmark: Diamond



Models for diamond limits:

1D Avalanche Breakdown & NPT

Inc. Ionization diamond  
[B] Doped diamond

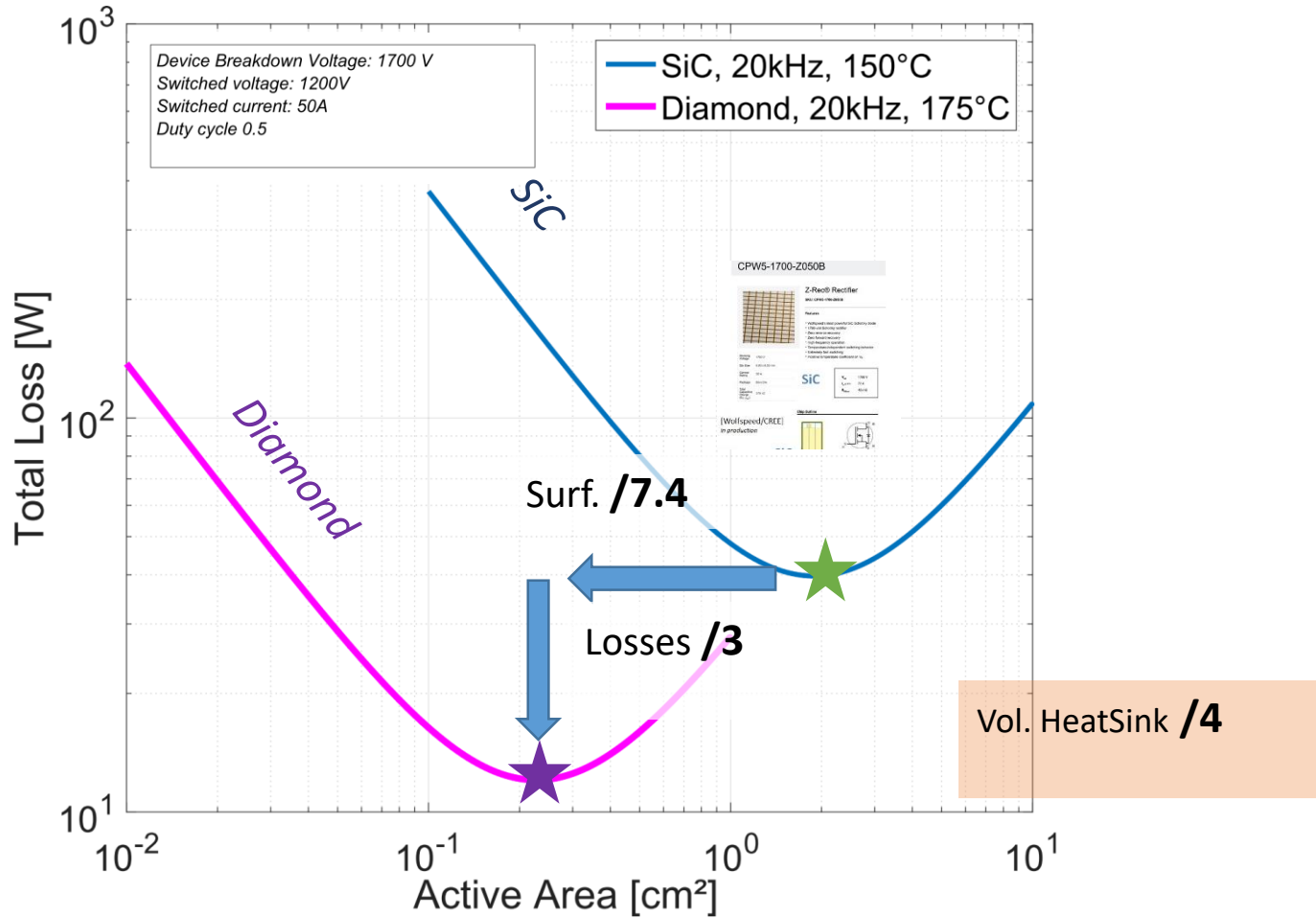
Drift region only

...

[M. Couret et al, 2023, Diamond & Related Materials Vol 135, 109 827, 10.1016/j.diamond.2023.109827]



# Benchmark: Diamond vs. SiC



[N Donato, N. Rouger et al 2020 J. Phys. D: Appl. Phys. 53 093001]

1D Avalanche Breakdown & NPT

Inc. Ionization diamond  
[B] Doped diamond

Non linear Coss for Eon switching energy

$E_{off}=0$

Vertical architecture

Drift region only

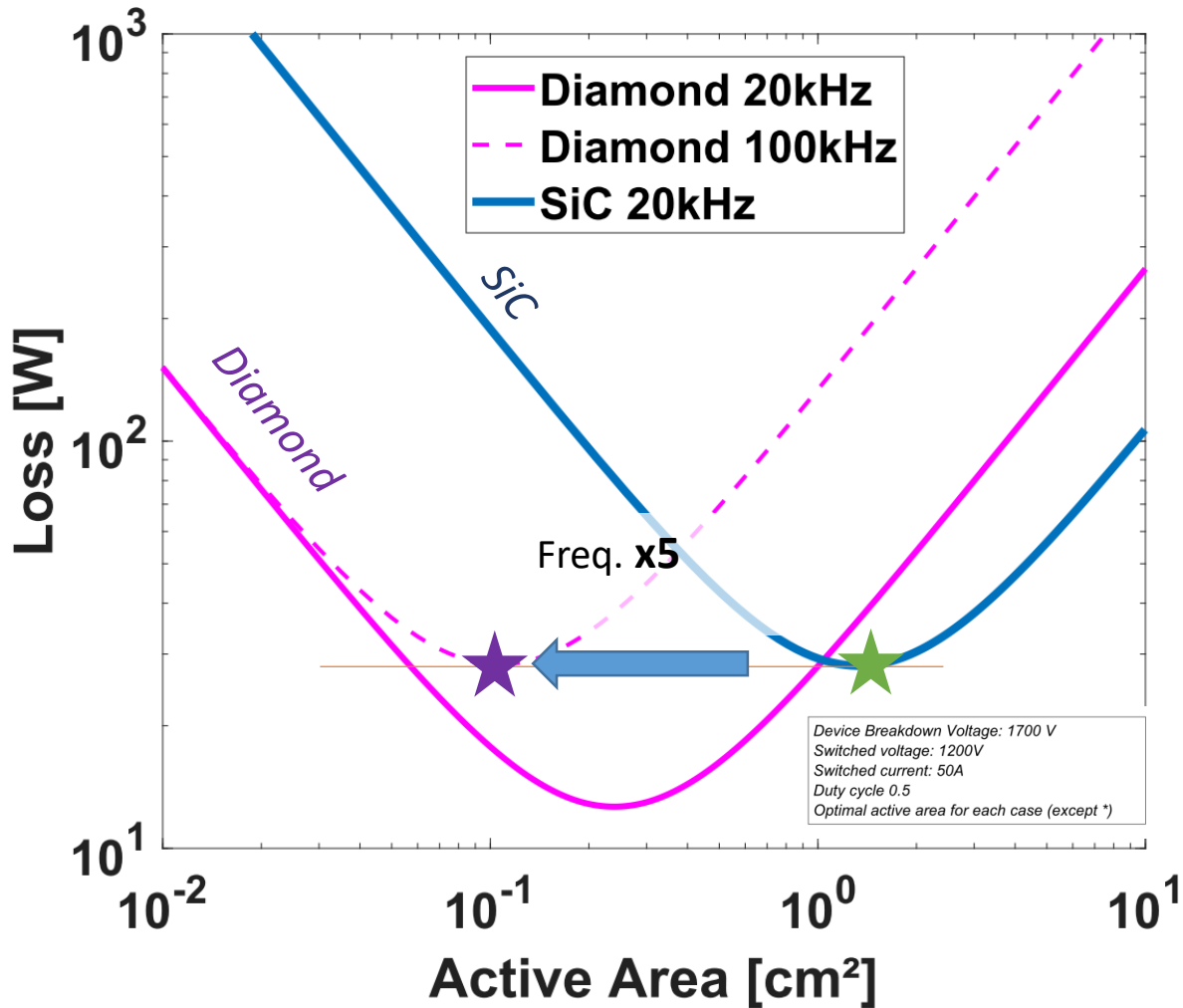
300K Ambient w/ natural convection

...

**Fair but still to be discussed**




# Benchmark: Diamond vs. SiC



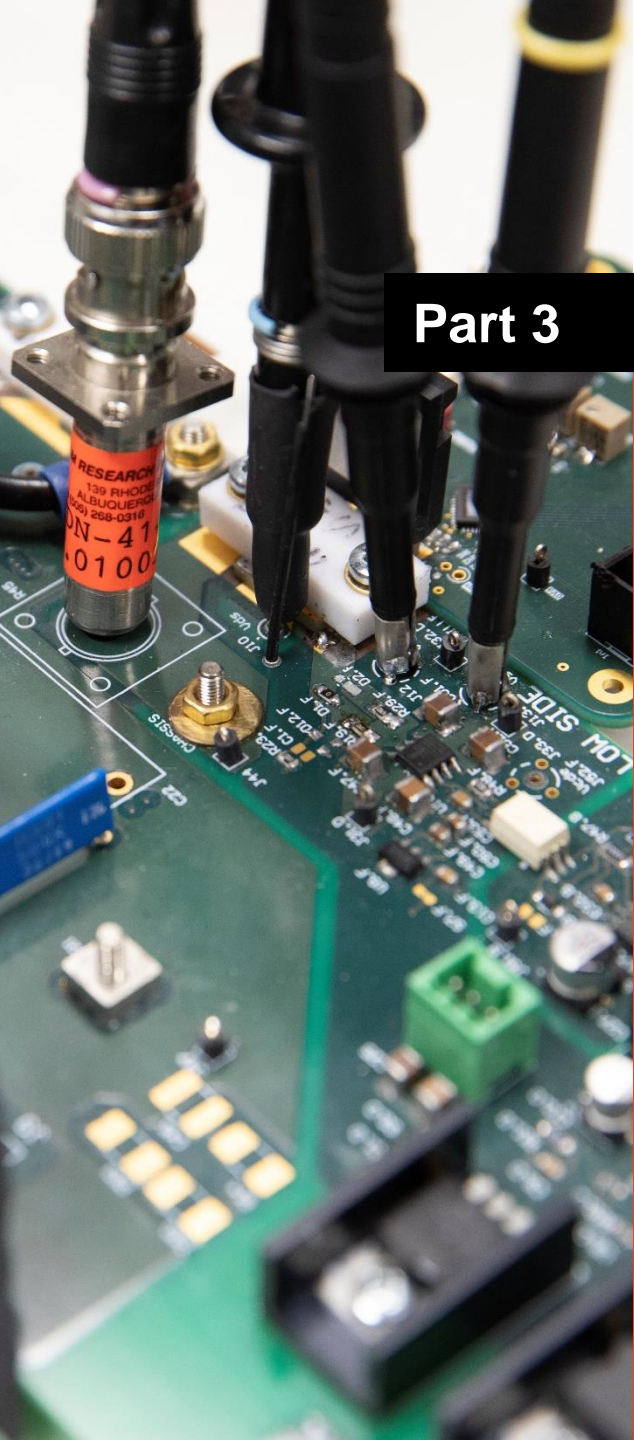
[N Donato, N. Rouger et al 2020 J. Phys. D: Appl. Phys. 53 093001]

Other design:  
 If  $P_{Diam.} = P_{SiC}$  then  
**f x5** => Passive Volume /3 to 5  
 HeatSink Volume **-16% to -30%**



  
 (Losses / Area) x 10!



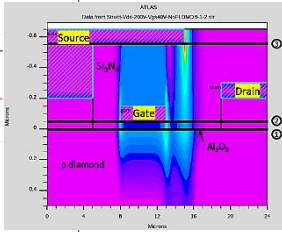
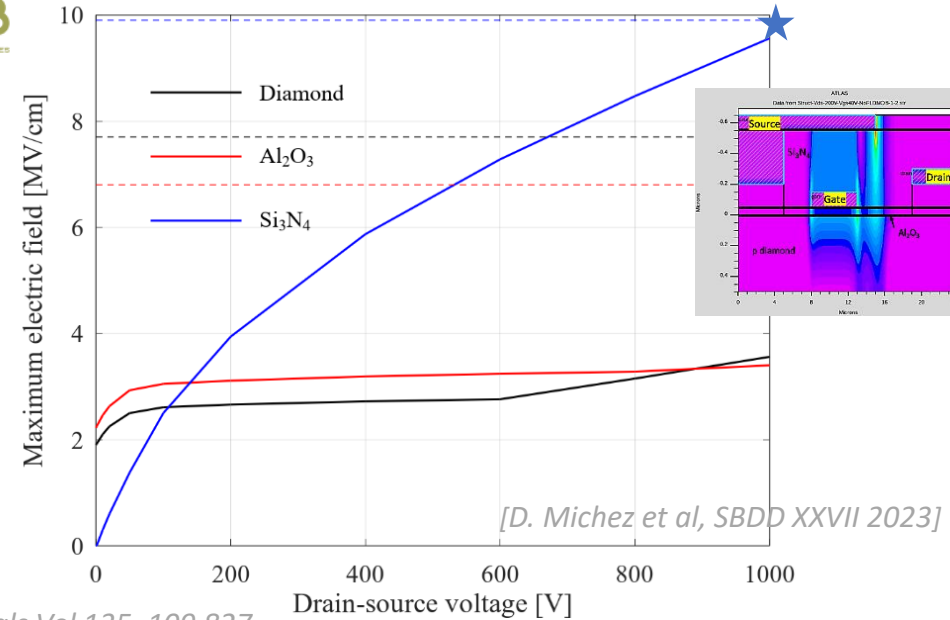
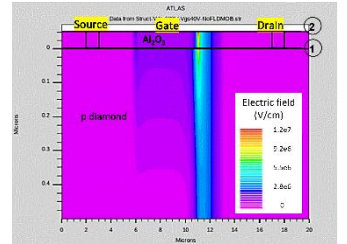
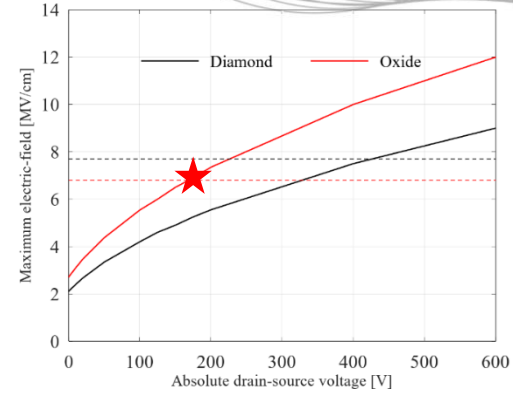
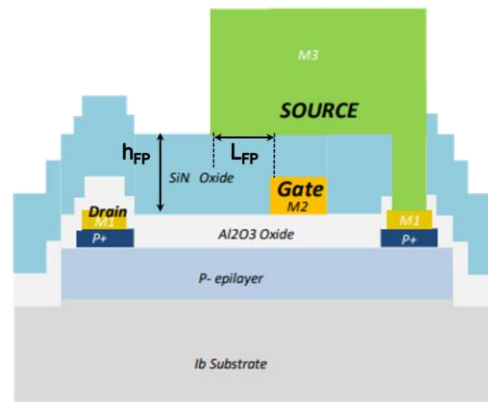
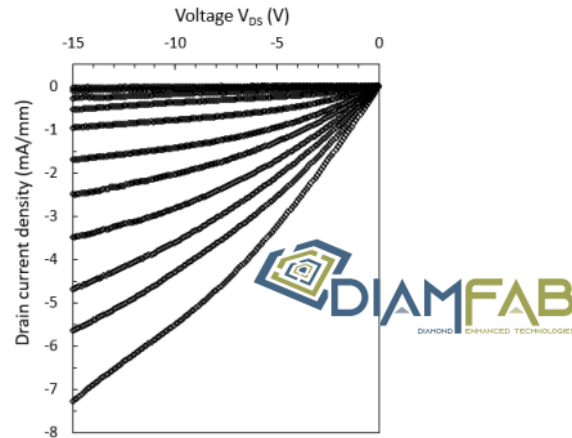
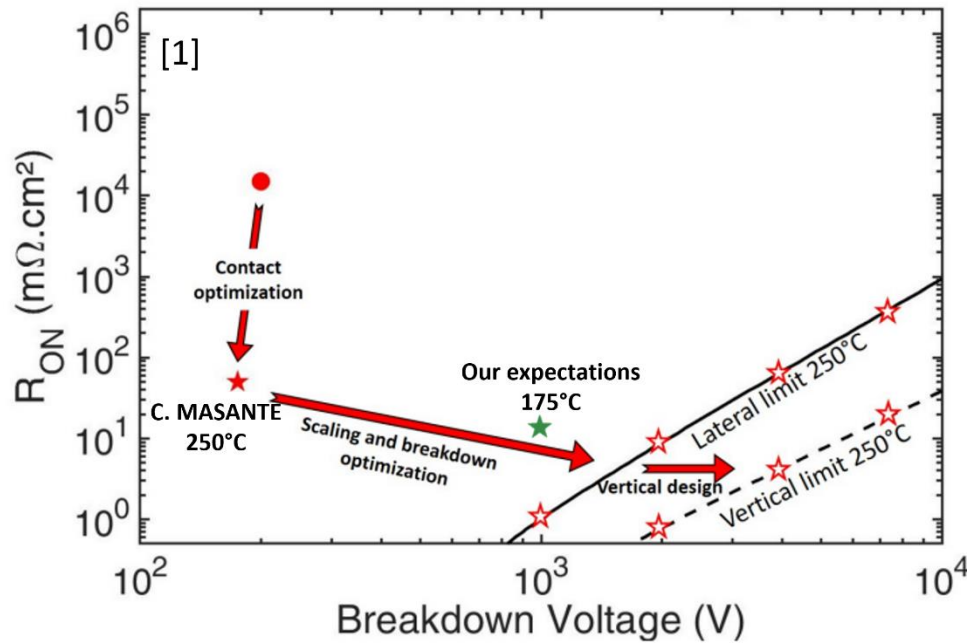


## Part 3

# What's next?

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# Improved FOM *Lateral D3MOSFET* O-term



[M. Couret et al, 2023, Diamond & Related Materials Vol 135, 109 827, 10.1016/j.diamond.2023.109827]

[D. Michez et al, SBDD XXVII 2023]



# Conclusion

## Benefits of Diamond e.g. vs. SiC

- **7 times smaller** die, with **3 times less total losses**
- **4 times smaller heatsink** or **5 times higher switching frequency**



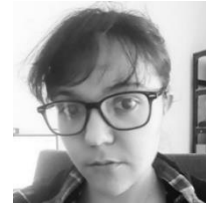
## Challenges

- **Ecrit** for lightly doped and thick diamond?
- How to reach highest 1D **BV** with actual **3D** devices?
- **Large area** diamond devices with good FOM
- High quality & conductive substrate for **vertical** devices?
- **Switching losses** of diamond devices are unknown
- **Power loss density** P/S is expected to increase





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DCADE

2021-2023

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*Dr. D. Eon*



*Pr. E. Gheeraert*



*D. Michez*



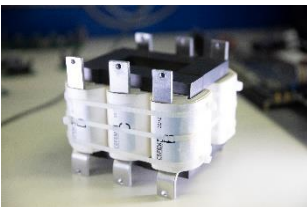
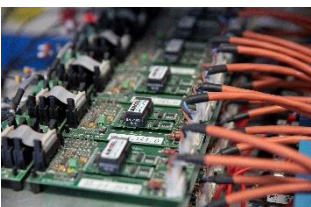
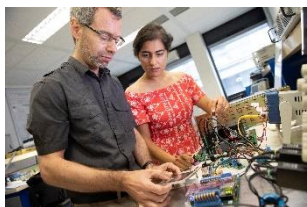
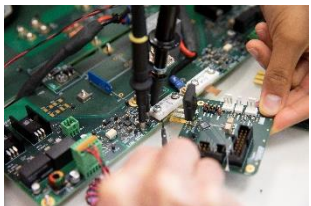
*Dr. J. Letellier*



*Dr. K. Driche & Dr. G. Chicot*







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