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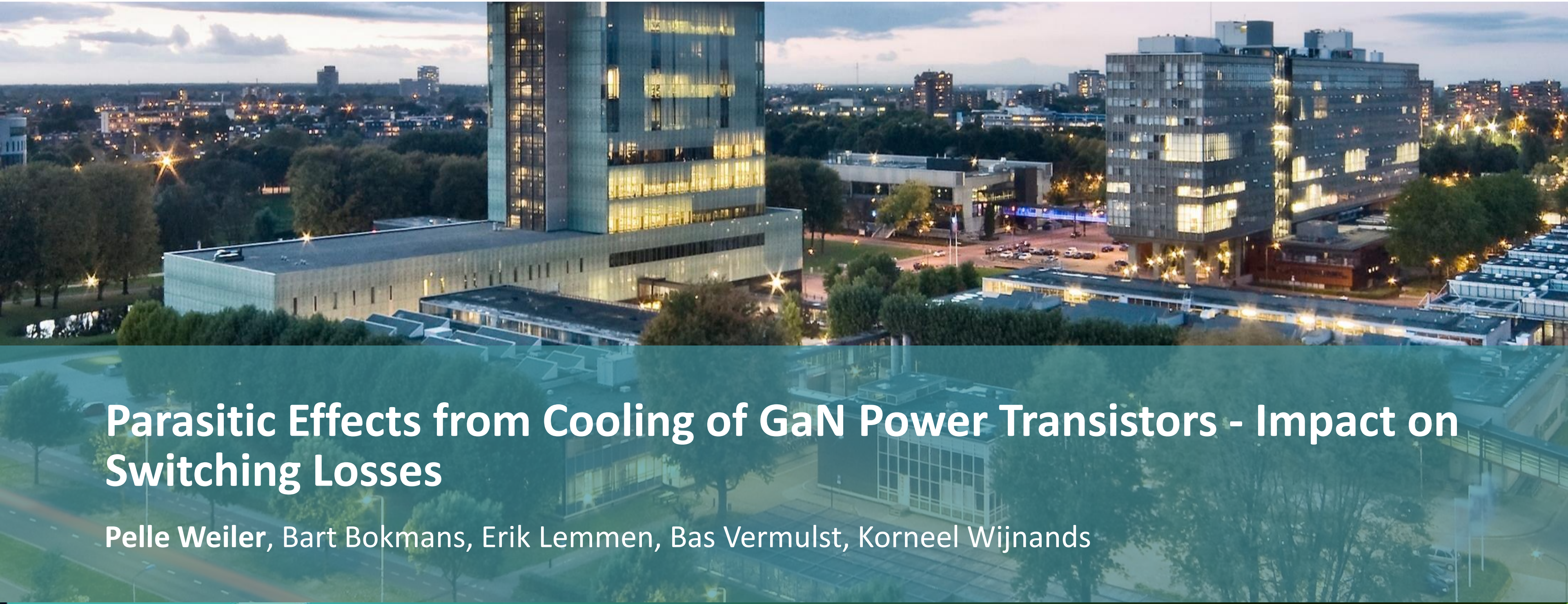

Parasitic Effects from Cooling of GaN Power Transistors - Impact on Switching Losses

Pelle Weiler, Bart Bokmans, Erik Lemmen, Bas Vermulst, Korneel Wijnands

POWER ELECTRONICS 2022
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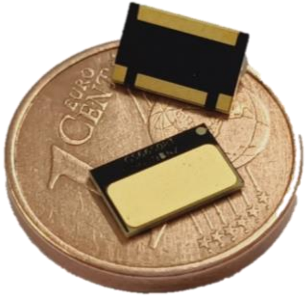
Gallium-Nitride FETs

GaN is becoming a very attractive choice for applications with volume or efficiency restrictions



GaN Systems GS66508T
- 650 V 50 mΩ
- Bottom Side: Drain, Gate, Source
- Top Side: Cooling Pad (Source)

Benefits

Small size → high power density

High dV/dt→ low switching energy

Challenges

Small size → little cooling area

High dv/dt → possible EMI issues

Agenda

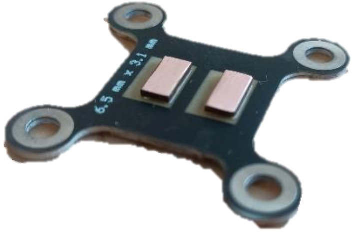
Cooling Solution for GaN devices

- IMS heat-spreaders
- Material limits

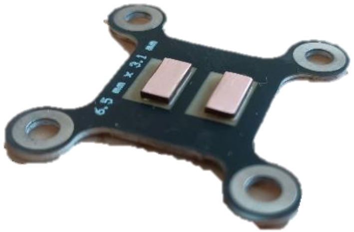
Experimental Verification

- Double pulse setup
- High-bandwidth shunt
- Switching Waveforms
- Switching Losses

Conclusion



IMS Heat-Spreaders



Insulated Metal Substrates

- Aluminium base laminated with insulating polymer and copper
- Ordered same as regular PCB
- Easy custom solutions for non-standard GaN packages

IMS Heat-Spreaders

Copper Layer

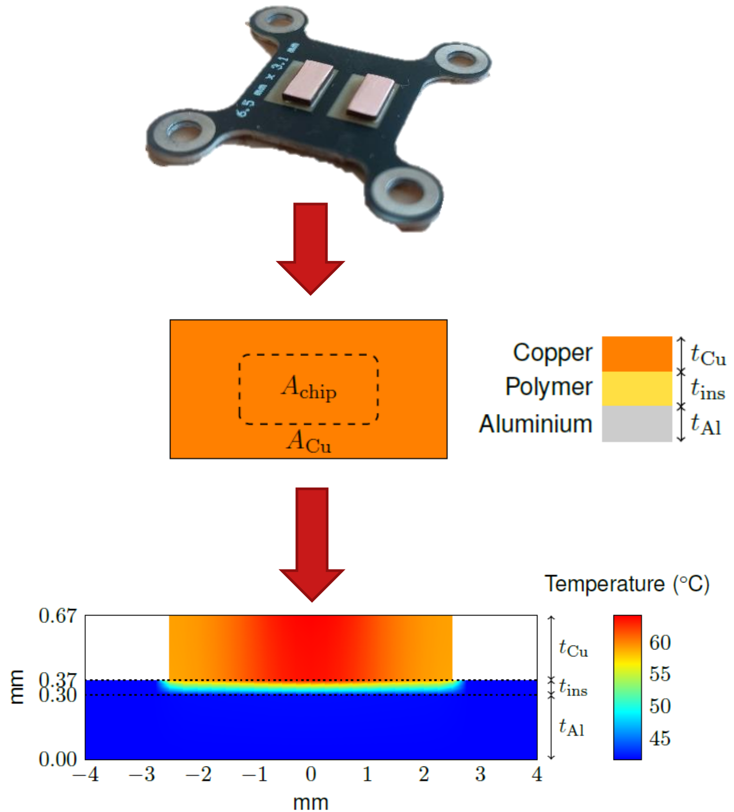
- High thermal conductivity (380 W/m/K)
- Spreads the heat horizontally
- Requires sufficient thickness (> 300 µm)

Insulation Layer

- Low thermal conductivity (1-10 W/m/K)
- As thin as possible (< 100 µm)
- Limits thermal path
- Adds parasitic capacitance

Aluminium Layer

- Structural support (1-1.5 mm)
- Mounted against heat-sink

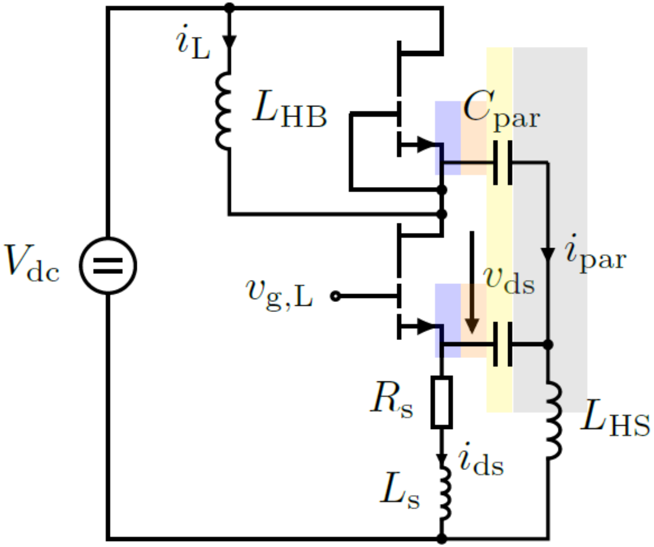


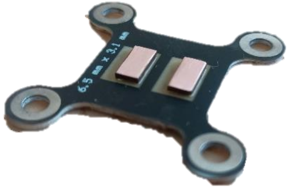
Source: Design Limitations of heat spreaders for gallium-nitride power modules, P. Weiler, PCIM 2020

IMS Heat-Spreaders

Parasitic capacitance

- Connected from switching node to heatsink
- High dv/dt induces current
- Linked to thermal resistance





$$R_{th,ins} = \frac{1}{\kappa_{ins}} \frac{A_{Cu}}{d_{ins}}$$

$$C_{par} = \varepsilon_0 \varepsilon_r \frac{d_{ins}}{A_{Cu}}$$

$$C_{par} = \frac{\varepsilon_0 \varepsilon_r}{\kappa_{ins} R_{th,ins}}$$

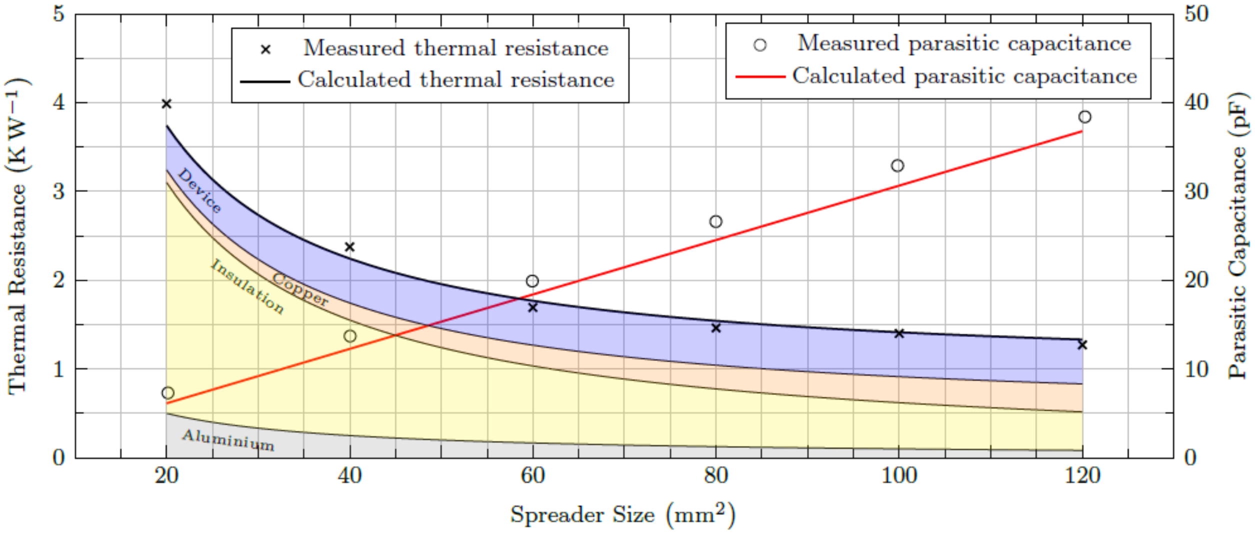
Material	κ $[\frac{W}{m\,K}]$	ϵ_r	$\frac{\kappa}{\epsilon_0 \epsilon_r}$ $[\frac{W}{pF\,K}]$
FR4	0.25	4.5	0.006
VT-4B3	3	4.8	0.07
VT-4B7	7	4.8	0.17
Al2O3	20	9	0.25
AlN	180	9	2.26

IMS Heat-Spreaders

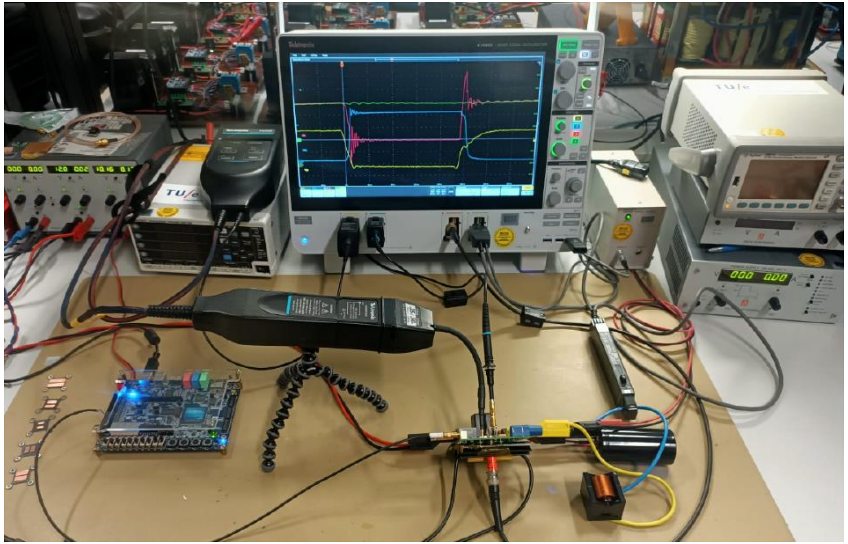
Range of heat-spreaders

- 1-6 x chip area
- Low conductive
  - $\kappa_{ins} = 1$ W/m/K
- Low capacitive
  - $\varepsilon_r = 1.8$
- 1 mm thick copper

→ Investigate effect on switching performance



Experimental Verification



Double Pulse Setup

- 400 V GaN half-bridge
- Calculate switching losses from device voltage and current
- Requires high bandwidth current measurement

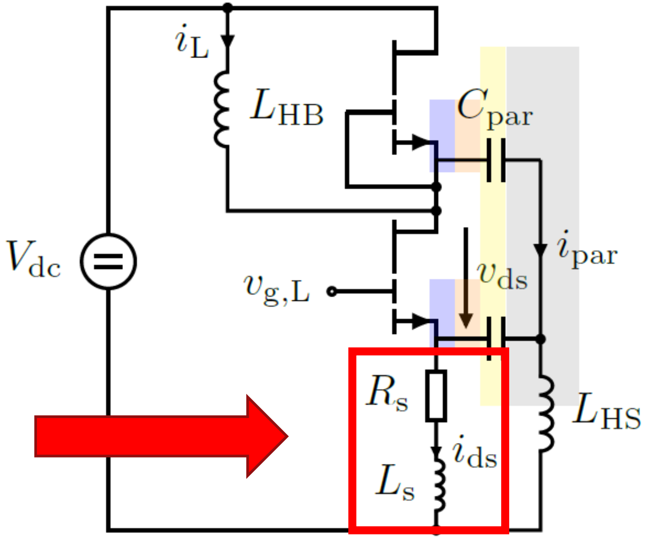
  → Coaxial current shunt

TU/e

Experimental Verification

Coaxial Current Shunt

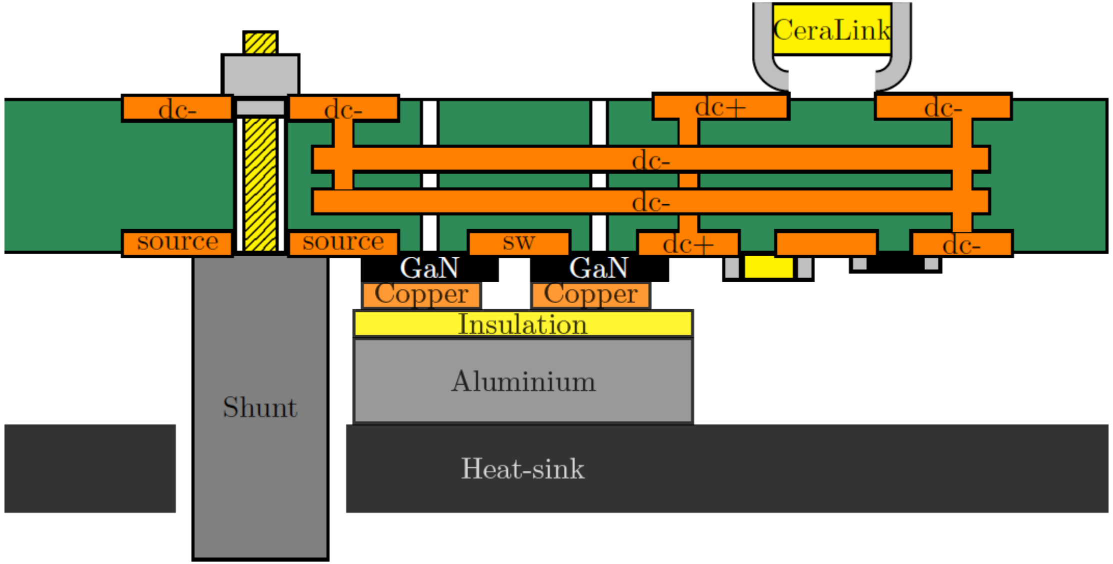
- Passband up to 2 GHz
- 100 mΩ resistance
- Parasitic insertion inductance
  - Dependent on connection
  - In series to power loop inductance



Experimental Verification

Board Design

- Shunt connected with M4 threaded insert
- dc- returned through internal layers for low loop inductance
- GaN devices connected to heat-spreader and heatsink
- RC snubber next to devices
- dc-link capacitor on top



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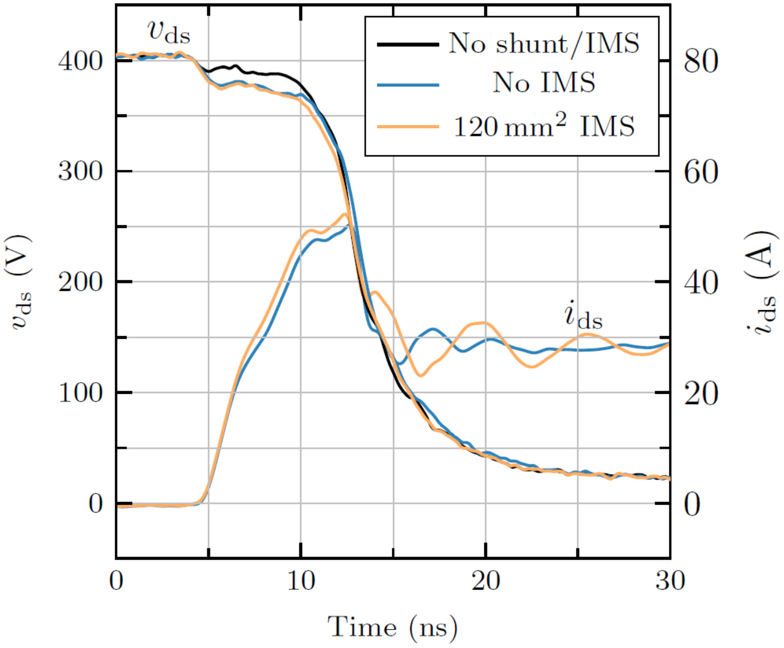
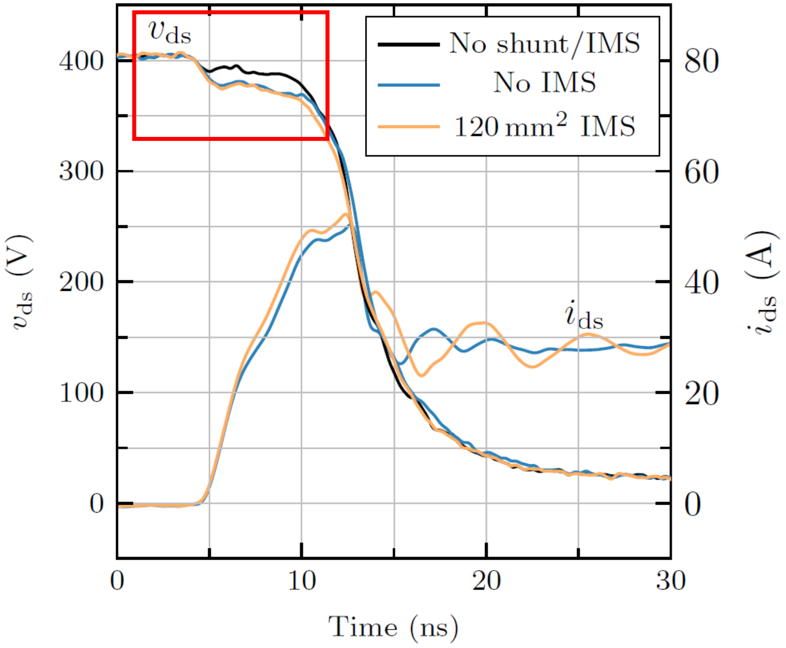


Turn-on

- Shunt has noticeable effect on initial voltage drop
  - Loop inductance resists commutation
- No cooling
  - Lower peak current
  - Less ringing
- 120 mm^2 IMS
  - Increased peak current
  - More ringing

Experimental Verification



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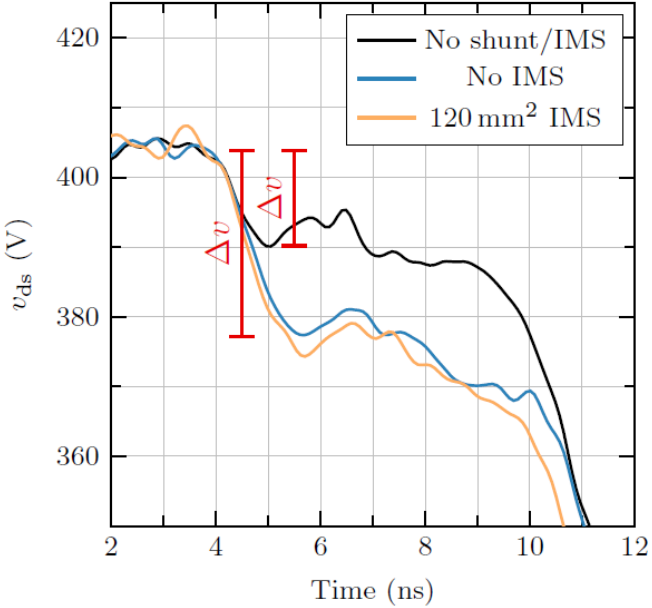
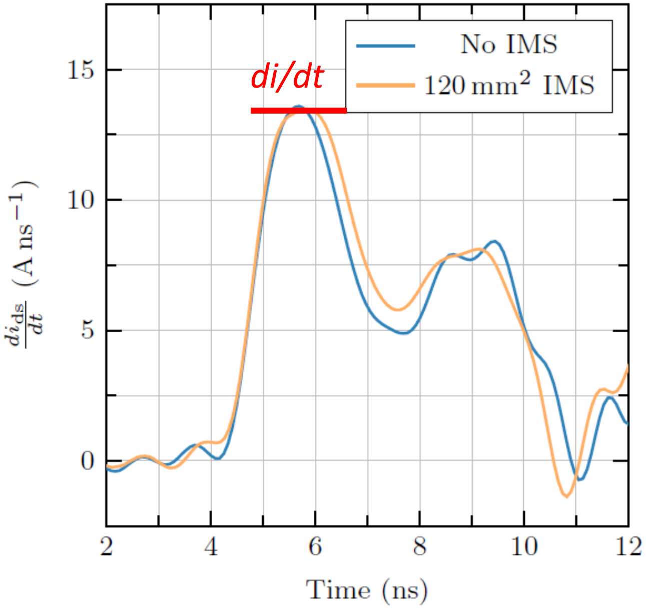


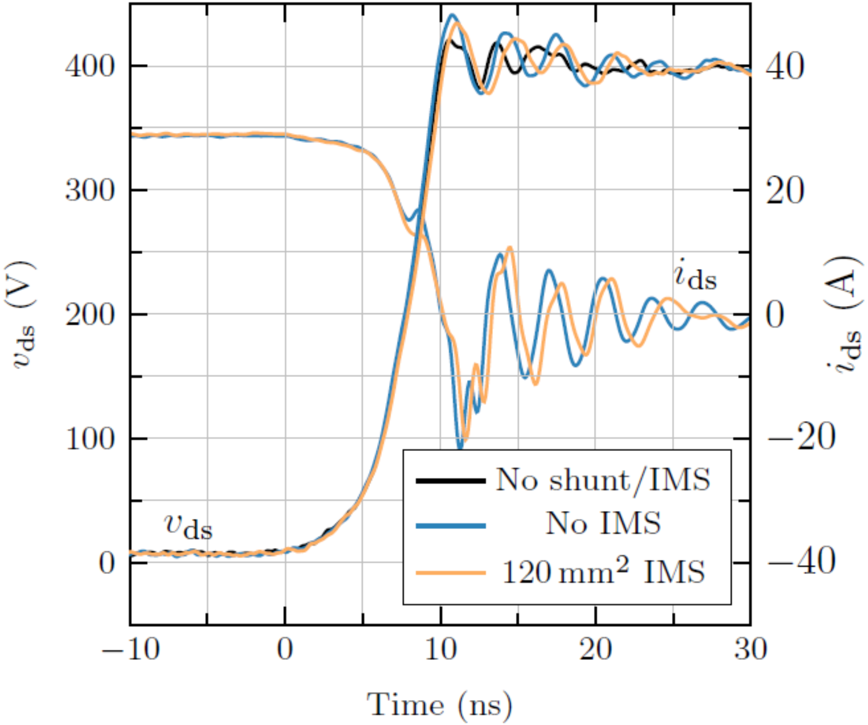


Turn-on

- Voltage drop proportional to loop inductance and di/dt

→ Estimated insertion inductance of shunt ~ 1 nH

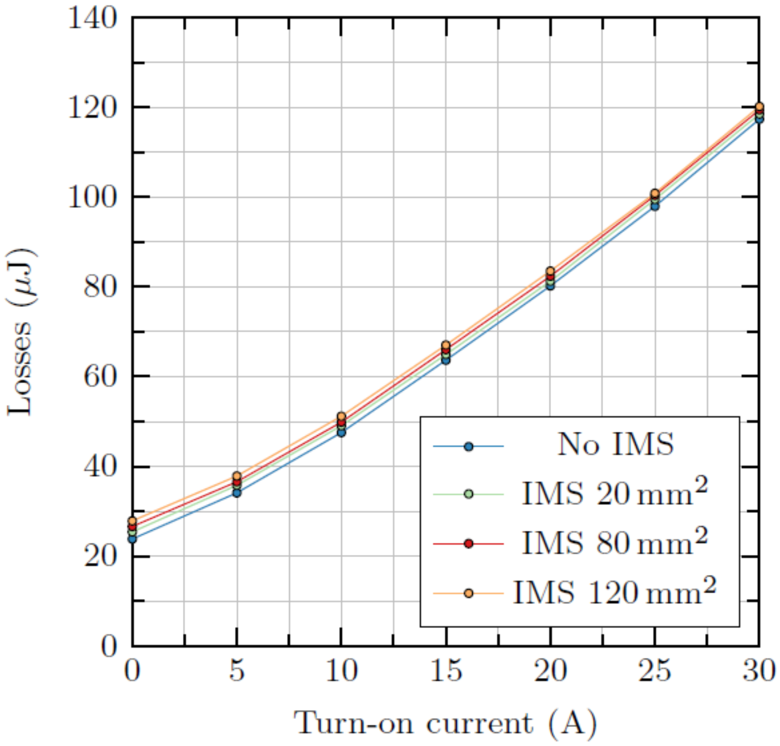
Experimental Verification



Turn-off

- Shunt insertion inductance causes larger overshoot
- Little perceivable difference between no cooling and 120 mm^2 IMS

Experimental Verification



Switching Losses

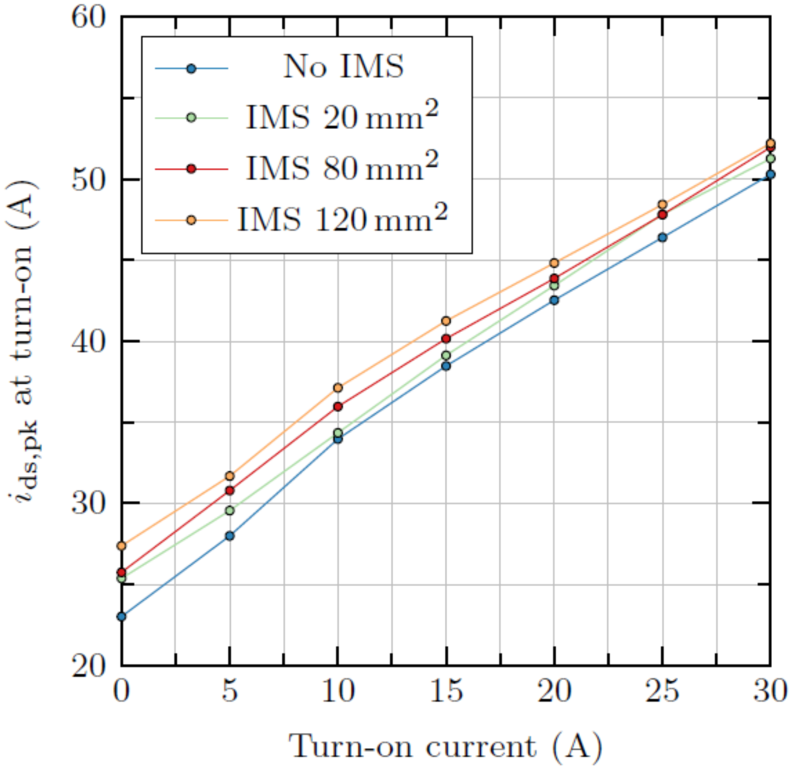
- Increase in losses of up to 4-5 μJ

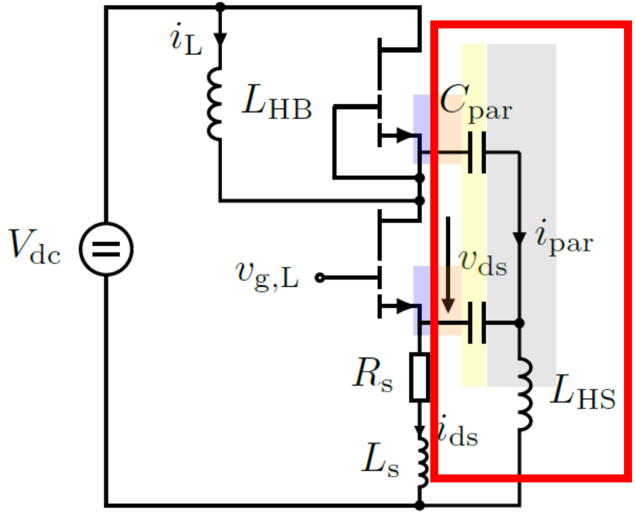
  → 10% relative increase at 10 A

  → Absolute increase in losses is small

However, increased losses come from increased peak current

Experimental Verification





Peak current

- Increased by parasitic heatspreader capacitance
  - Up to 4 A
- Difference between no IMS and flows through heatsink

→ Potential EMI source

Conclusion

Any form of cooling will alter the switching losses of GaN

Parasitic capacitance to heatsink must be included in characterization

- Noticeable impact from 40 pF
- Increased peak current

Excess induced current returns through heatsink

- Source for EMI

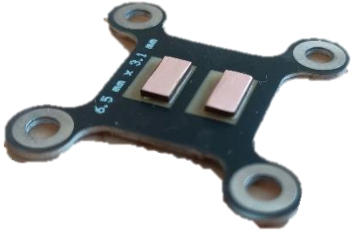
Lower capacitance comes at the cost of larger thermal resistance (using same material)

- Dictated by geometry
- Material coefficient $\kappa_{ins}/(\varepsilon_0 \varepsilon_r)$ determines best case performance for a given material

Conclusion

IMS heat-spreaders

Customizable cooling solution for non-standard packages



Low dielectric constant reduces parasitic impact (ε_r = 1.8)
→ Usually implies lower thermal resistance

Caution with high dielectric constants (ε_r > 4.5)
→ Small areas can already lead to significant parasitic impact

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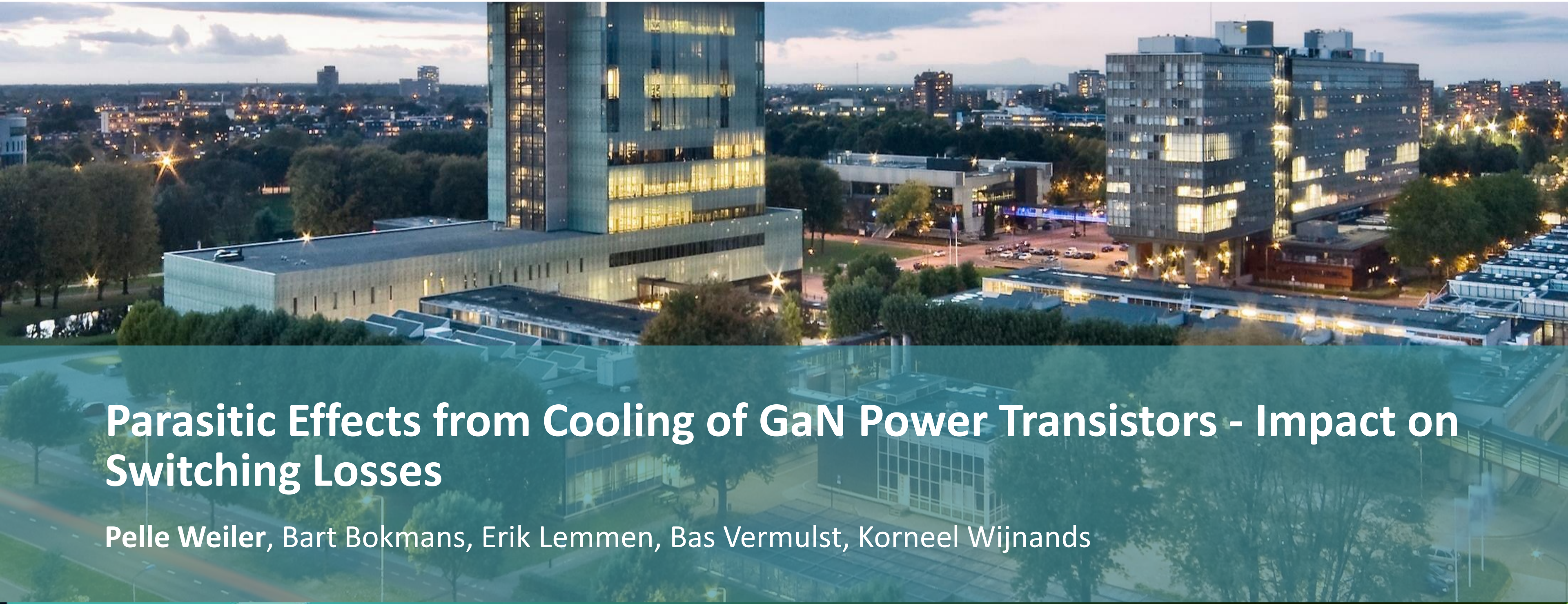

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