Make the world a better place

How can we save…

2300 tons aluminum

17500 tons copper
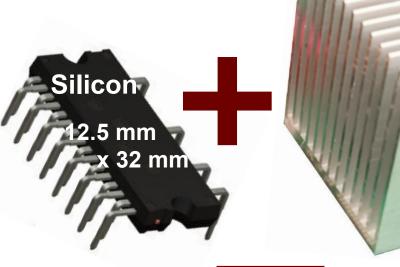
275 GWh energy

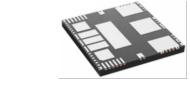**TEXAS INSTRUMENTS**

First 3-phase GaN IPM

GaN IPM

Power Density

65% smaller package than sil...

Efficiency

3x loss reduction no heat sink needed

Slew Rate Control
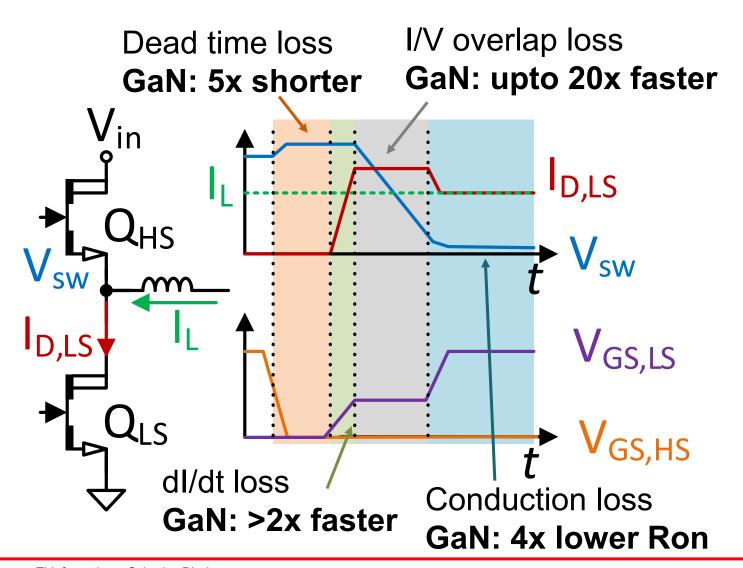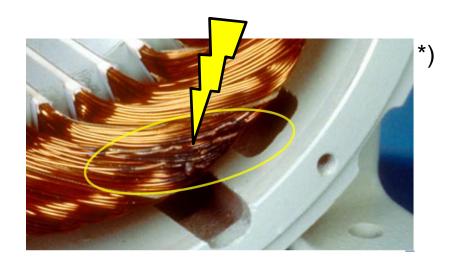
Trade-off: safe operation, EMI, efficiency

Silicon
12.5 mm x 32 mm

+

GaN IPM

GaN:12 mm x 12 mm

3

TEXAS INSTRUMENTS

Maximize efficiency

Dead time loss
GaN: 5x shorter

I/V overlap loss
GaN: upto 20x faster

V_{in}

Q_{HS}

V_{sw}

I_L

$I_{D,LS}$

Q_{LS}

I_L

$I_{D,LS}$

V_{sw}

t

$V_{GS,LS}$

$V_{GS,HS}$

t

dI/dt loss
GaN: >2x faster

Conduction loss
GaN: 4x lower Ron

Isolation break down due to fast dV/dt
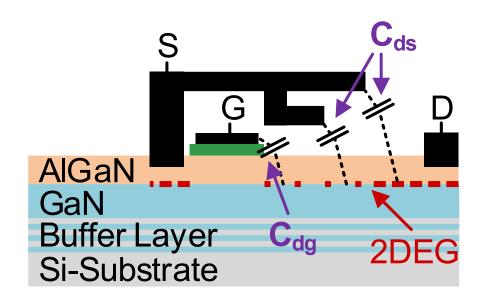
→ *Slew rate control required for GaN*
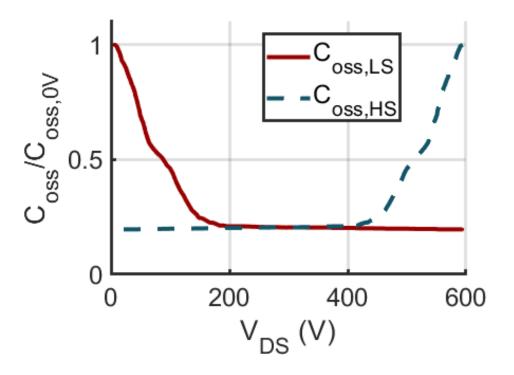
4

TEXAS INSTRUMENTS

Challenges for slew rate control

S   G   D

C_{ds}

AlGaN
GaN
Buffer Layer
Si-Substrate

C_{dg} 2DEG

From: Texas Instruments, LMG2610 Datasheet

https://www.ti.com/lit/ds/symlink/lmg2610.pdf

$C_{oss,LS}$
$C_{oss,HS}$

Lateral Device
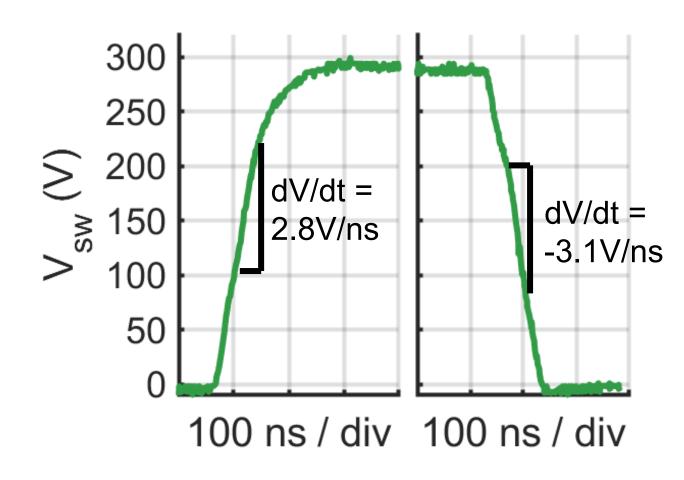
→ Very non-linear capacitances

$$ \rightarrow \frac{dV_{DS}}{dt} \sim I_g \quad \rightarrow \quad \frac{dV_{DS}}{dt} \sim \sqrt{I_g} $$

Derived in Kaufmann et al. APEC 2025
https://ieeexplore.ieee.org/document/10977438
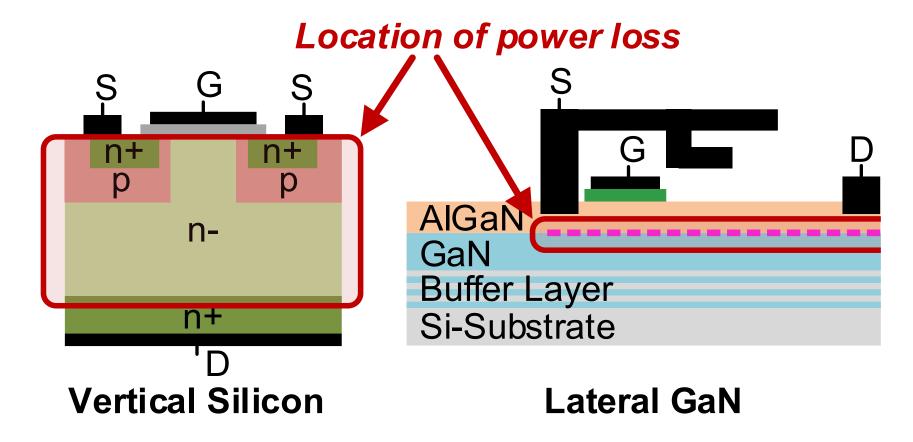
TEXAS INSTRUMENTS

Gate driver: Slew rate control and short delays

- Propagation and turn on delays are proportional to I_{gate}
- Slew rate is propotional to square root of I_{gate}

→ **Implement intelligent gate driver for delay minimization and slew rate control**
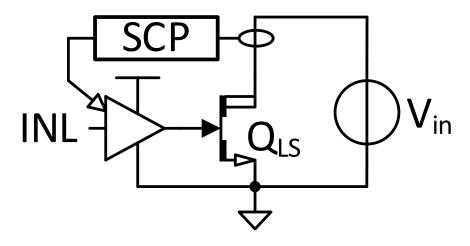

dV/dt = 2.8V/ns

dV/dt = -3.1V/ns

TEXAS INSTRUMENTS

Challenges for short-circuit protection

Location of power loss

Vertical Silicon

Lateral GaN

Surface 2D-channel: High power loss in small volume
→ **Short circuit protection needs to shut-off GaN HEMT in < ~250ns**
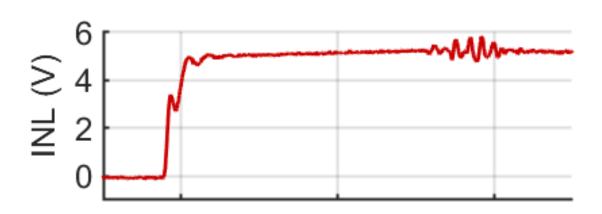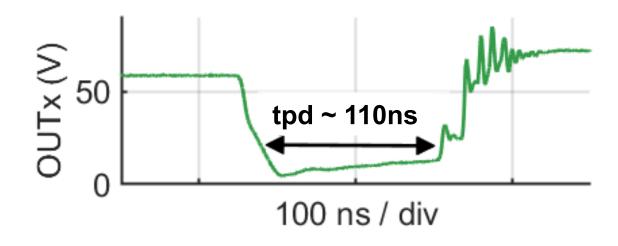
TEXAS INSTRUMENTS

Characterization of short-circuit protection
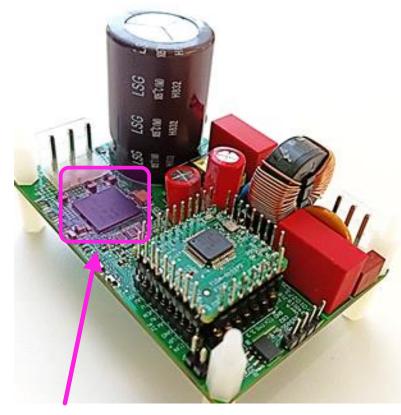

Test: Turn on GaN HEMT in a short circuit Vdrain – Vin

➔ **Short circuit protection (SCP) shuts off GaN FET within less than 150ns**

➔ **Safe operation is ensured by integrated protection**
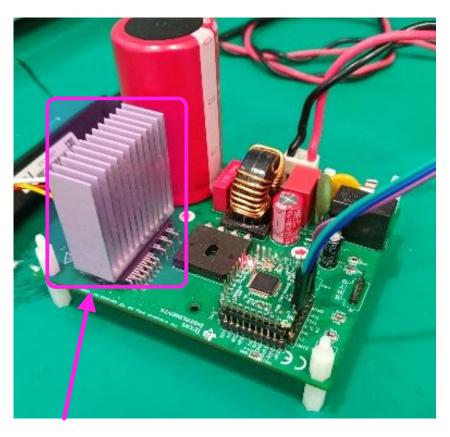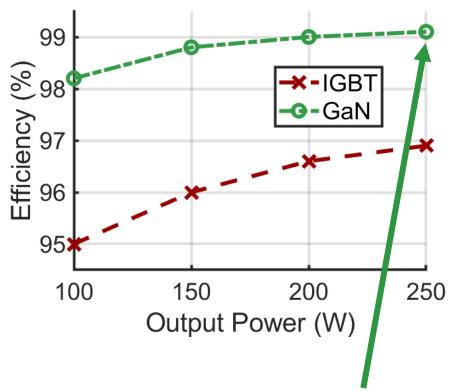
$t_{pd} \sim 110ns$

100 ns / div

Testboard GaN IPM vs. IGBT IPM
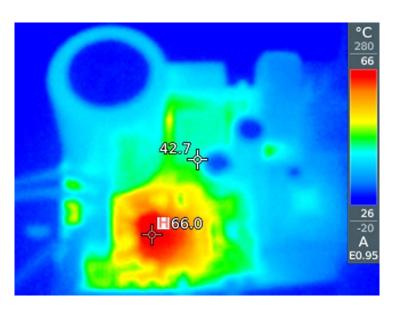
12 * 12mm GaN IPM
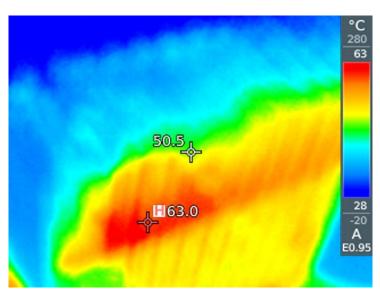
33 * 19mm IGBT IPM
+ 40 * 40 * 15mm heat sink

TEXAS INSTRUMENTS

Measured efficiency and thermal image

GaN IPM without heat sink:
$\Delta T_{case} - T_{amb} = 41°C$

IGBT IPM with heat sink:
$\Delta T_{sink} - T_{amb} = 38°C$

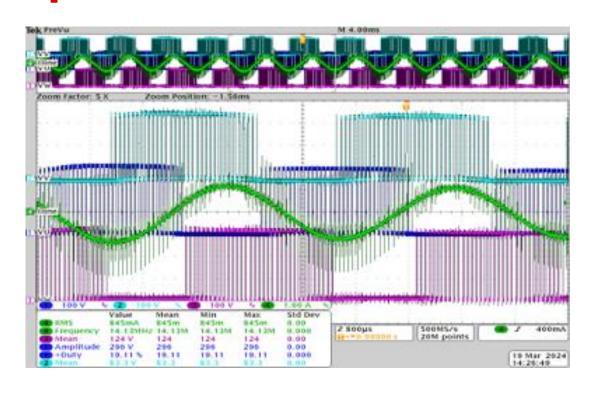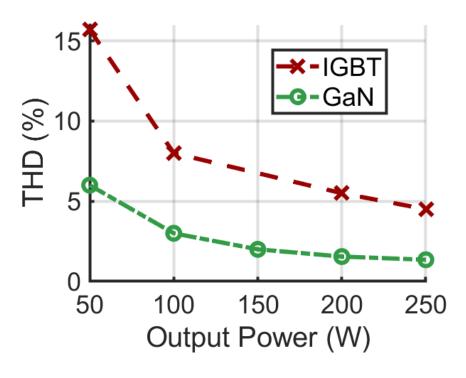*GaN*: upto 99.1% efficiency

Total loss: GaN 2.25W   vs.   IGBT 7.5W

➔ **GaN IPM shows similar temperature increase without heatsink**

Toplevel waveforms and total harmonic distortion

GaN IPM without reverse recovery achieves low dead time and wide duty cycle range

→ **3x lower THD of motor current for quiet operation and longevity of motor bearings**

TEXAS INSTRUMENTS

Comparison to state-of-the-art

Parameter	GaN IPM This Work 2024	Silicon IGBT 2023	Silicon IGBT 2024	Silicon IGBT 2023	Silicon IGBT 2023	Silicon MOSFET 2023	Silicon MOSFET 2024	Silicon MOSFET Half-Bridge 2024
Technology	GaN	IGBT	IGBT	IGBT	IGBT	MOS	MOS	MOS (1/2-H)
Max op. voltage (V)	450	450	450	500	450	500	450	480
Current rating	5A @T_J=125C	4A @TC= 100C	5A @TC= 25C	6A @TC= 25C	5A @TC= 25C	5A	5A @TC= 25C	5.5A
Package (Body size)	12x12 mm (QFN)	36x21mm (DIP)	36.0×14.8 mm (DIP)	32x12.5mm (DIP)	32.8x18.8mm (DIP)	32x12.5mm (DIP)	36.0×14.8 mm (DIP)	(10.8x9.4mm) x3 leaded
Dead time (us)	< 0.2	> 1	1.5	1.5	> 1	1-2	1.5	0.6
Slew rate (V/ns)	5-40	6	~ 2-4	>3	1-3	>3	~ 1-3	2.8-3.4
RDSon (Ω)	0.205	n/a	n/a	n/a	n/a	0.8	0.45	0.83
$V_{DS,1A}$ / $V_{CE,sat}$ (V)	0.205	1.6	1.75	1.6	1.85	0.8	0.45	0.83
Switching Energy 1 cycle, 6 transistors, no reverse recovery (uJ)	50	1170	n/a	870	n/a	582	n/a	n/a
Rth,JunctionCase (°C /W)	5.5	5.3	3.6 (IGBT) 4.2 (Diode)	10 (IGBT) 15 (Diode)	5.4	9.2	3.6	3
Rth,JunctionAmbient (°C /W)	21.2	n/a	25 (IGBT) 29 (Diode)	n/a	n/a	n/a	25	53
OC/SC protection	400ns latch 1-2us comp w/50u retry	Comparator w/ 40 us retry	Comp with 10ms retry	Integrated comparator	Integrated comparator (20us)	Integrated comparator	Comp with 10ms retry	CBC CL, DC bus UV/OV, dual OT
Dead time interlock	adaptive	Yes	No	Yes	No	Yes	No	Yes