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Ultra-Compact and Efficient Powre Supply Enabling AI Computing

Prof Teng Long

Contents

- State-of-the-art Power Supply Architecture for AI datacentres
- Advanced Power Electronics Packaging for for High Integration
- Smart Soft-Switching using Electroluminescence

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Power supply architecture for AI servers

230 Vac

Power tray

400 V

AC-DC

SiC, GaN, Si

DC-DC

SiC, GaN

η>97%

54 V

AI OAM Server tray

IBA DC-DC

Si, GaN

12/6 V

PoL VR DC-DC

Si

<1 V

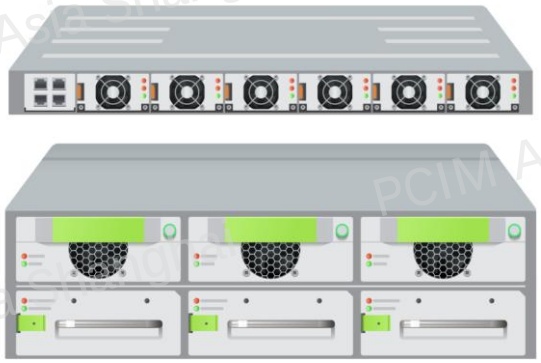
η>88%

Vol < 100x50x50mm

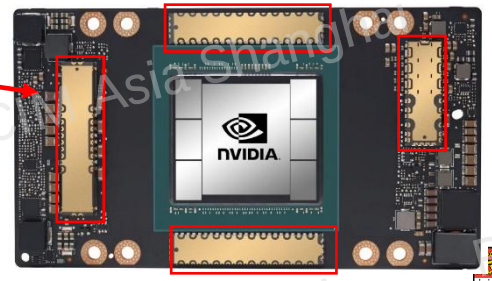
P > 700W

Server tray

Power tray



8x OAM



OAM, >700W

Courtesy to Aytesyn, Nvidia, Inspur, Vicor

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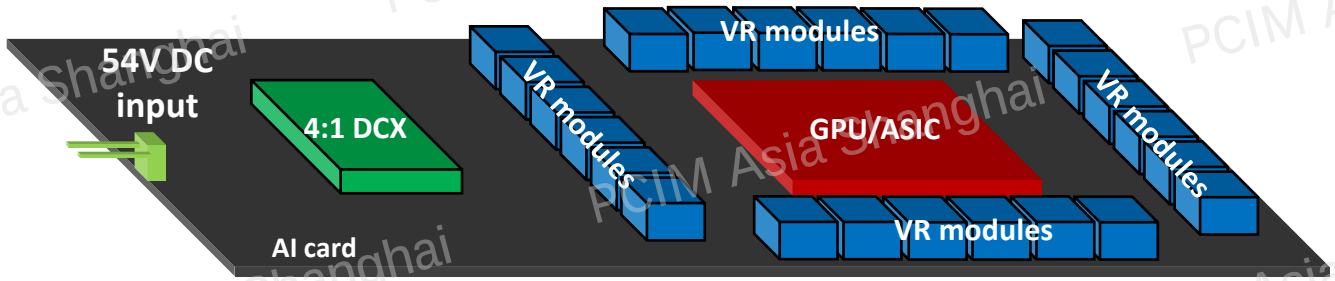
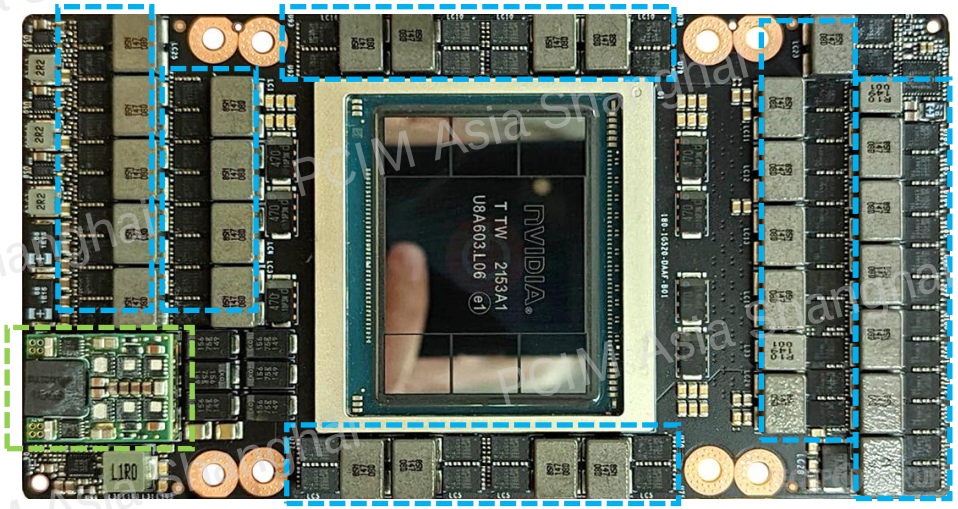
Lateral Two-Stage Architecture: DCX 4:1 ➔ VR



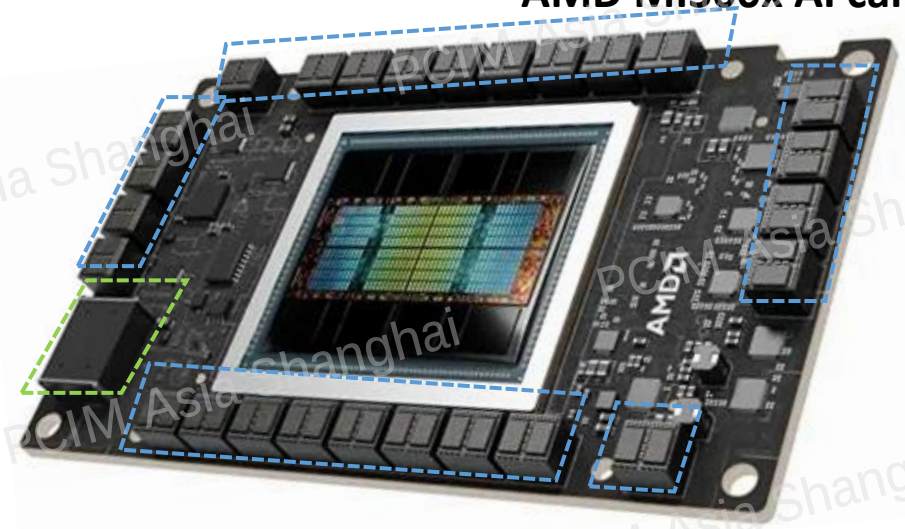
Nvidia H100 AI card

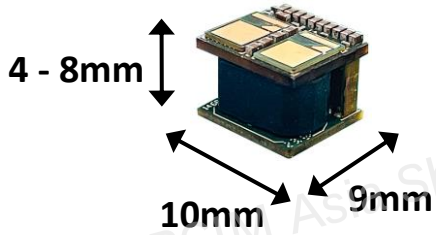


Stage 1: Fixed-Ratio DC transformer (DCX)

- ❑ Fixed ratio voltage conversion, X:1 transfer DC voltage like a transformer (DCX)
- ❑ 4:1 DCX input 40-60V, output 10-15V, typical size: 23mm x 17mm x 8mm (OCP standardized)
- ❑ 5:1, 6:1, 8:1, 10:1, 48:1 are also available
- ❑ Variants of LLC topologies, non-isolated, ZVS soft-switching for high efficiency.

AMD MI300x AI card





Stage 2: Voltage Regulator (VR)

- ❑ High dynamic response requirement: >10A/ns
- ❑ Multi-phase BUCK topology, using coupled or non-coupled inductors
- ❑ DrMOS and multi-phase BUCK controller from the same vendor
- ❑ Trans-Inductor VR (TLVR) BUCK is trending due to better dynamic (but also issues)

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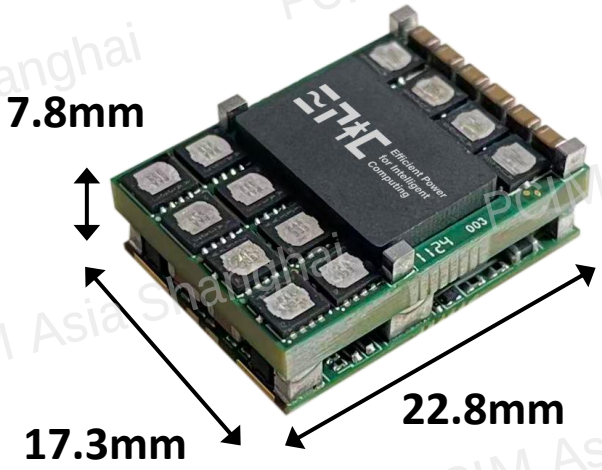
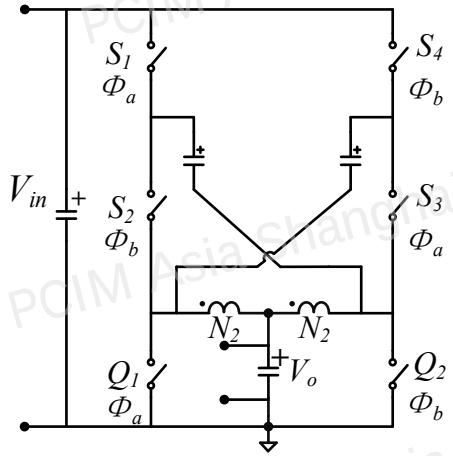
Intermediate Bus Converter (fixed-ratio DCX)

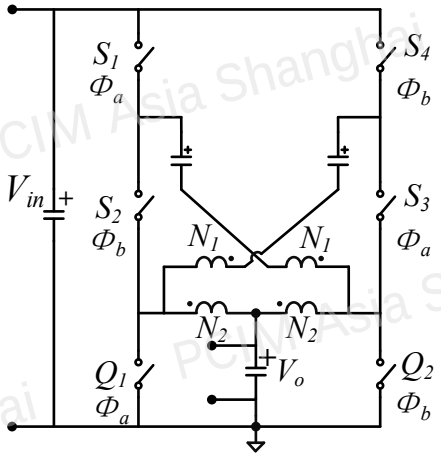


- **1.5kW** high output power
- **98.0%** peak effi and **97.0%** full-load effi.
- **8.1kW/in³** power density
- 1.1% efficiency improvement compared to conventional solutions



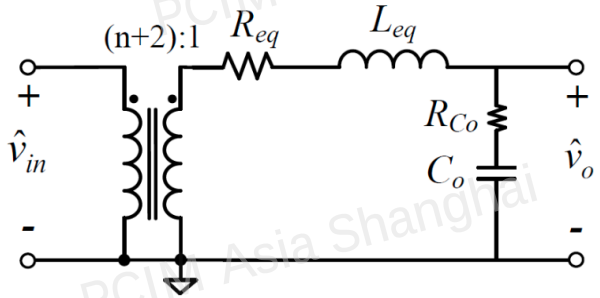
$$\frac{V_o}{V_{in}} = \frac{1}{4}$$

- Delta topology patent
- Fixed 4: 1
- DC bias on Cr



$$\frac{V_o}{V_{in}} = \frac{1}{2(n+2)}$$

- Infineon **HSC** topology patent
- Suitable for 6: 1, 8: 1etc.
- DC bias on Cr
- Complex current loop



$$L_{eq} = \frac{\pi^2 T_s^2}{4(n+2)^2 T_r^2} L_r$$

$$R_{eq} = \frac{\pi^2 T_s}{8(n+2)^2 T_r} R_{LLC}$$

Open-loop LLC variants suits fixed ratio IBA converter

X. Ren, J. Zhang, P. Xu and T. Long, "A Non-isolated Fixed-ratio DC-DC Converter Using Switched Auto-transformer (SATx) for Data Center Applications," *2023 IEEE Energy Conversion Congress and Exposition (ECCE)*, Nashville, TN, USA, 2023

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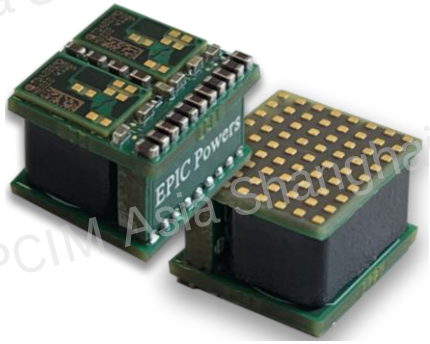
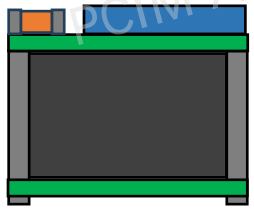
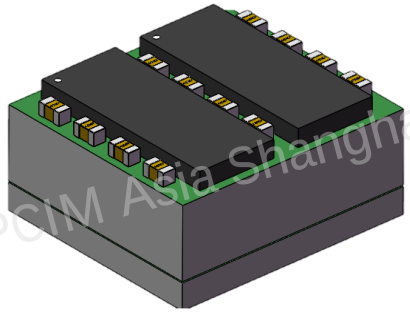
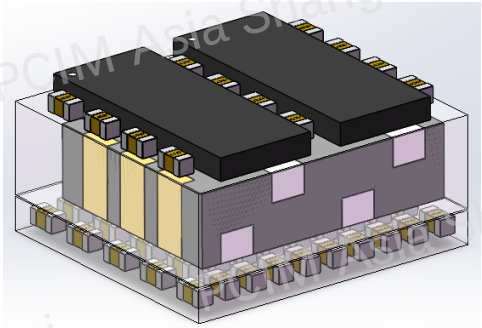
Voltage Regulator (VR) using Buck topology









Top: DrMOS ➔ better cooling
Middle: inductor ➔ low DCR but less coupling

Top: inductor ➔ better coupling
Middle: DrMOS ➔ issue in cooling
B

4-Phase integrated VR Module:

- Customized DrMOS with improved output pins to optimize PCB layout.
- Embedded inductor—reduces copper losses and side plates.
- Embedded output capacitor—uses special 0402 capacitors, with 800uF embedded output capacitance per module.

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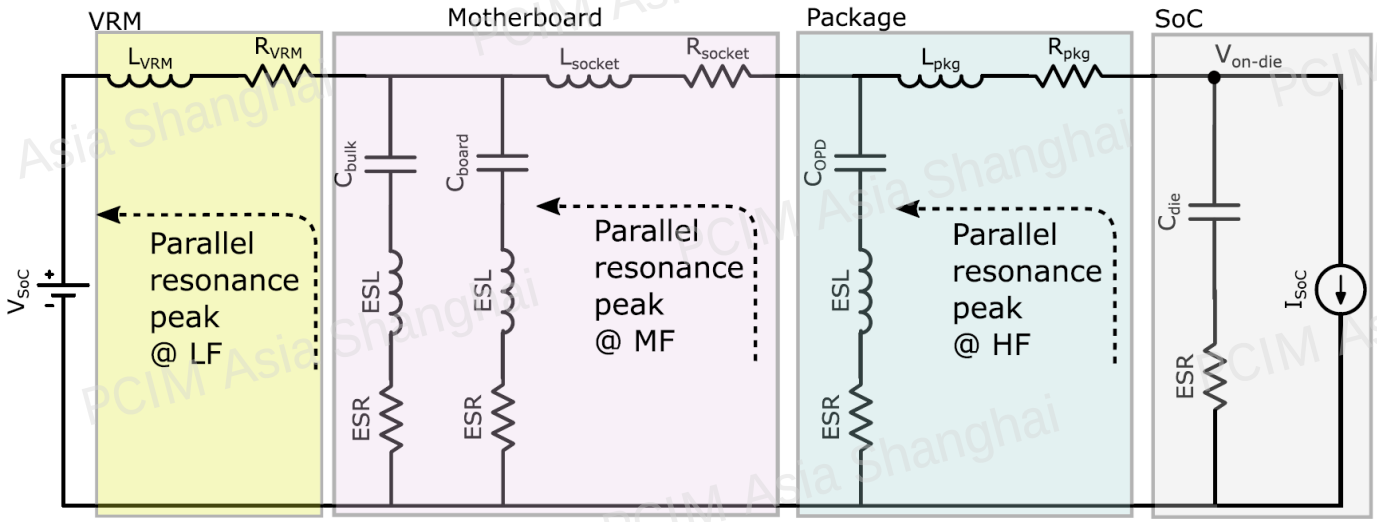
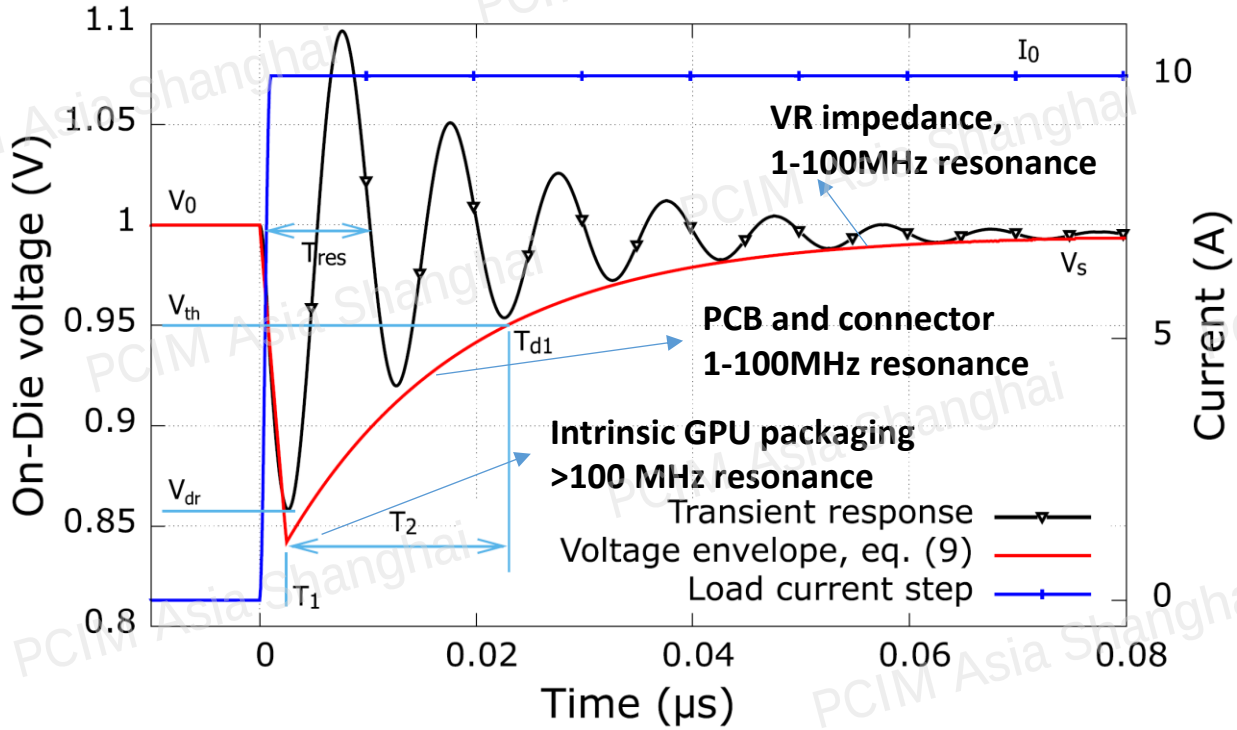
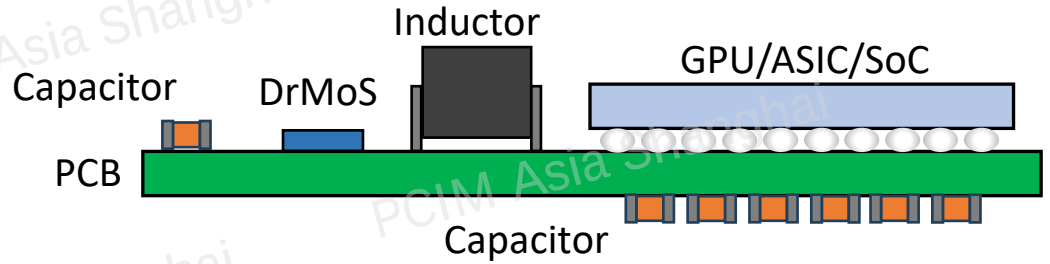
Location, Location, Location ➔ miniaturised power supplies

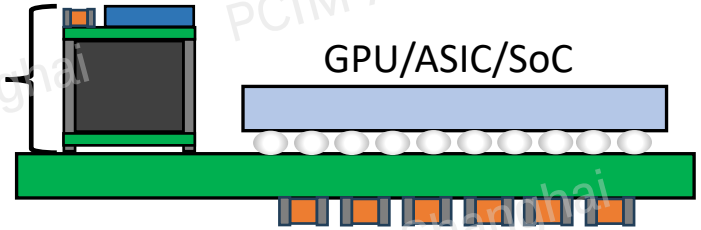


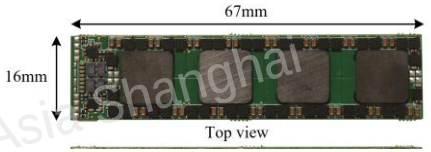




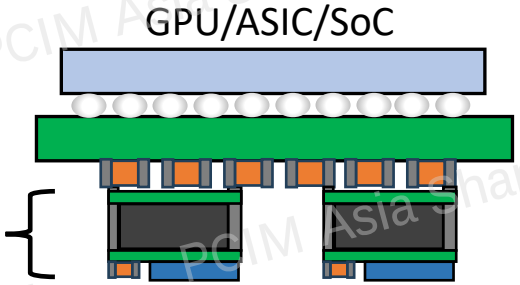
➢ **Reducing distance from VR to GPU ➔ reducing PDN loss and increase dynamics response**

Integrated VR

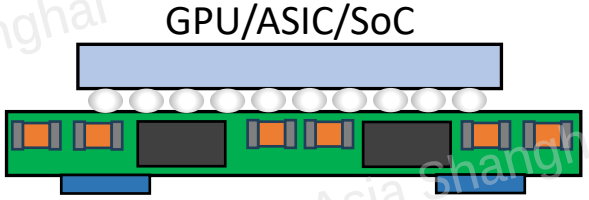




Vertical integrated VR
Height < 4mm



Vertical VR with PCB embedded L&C



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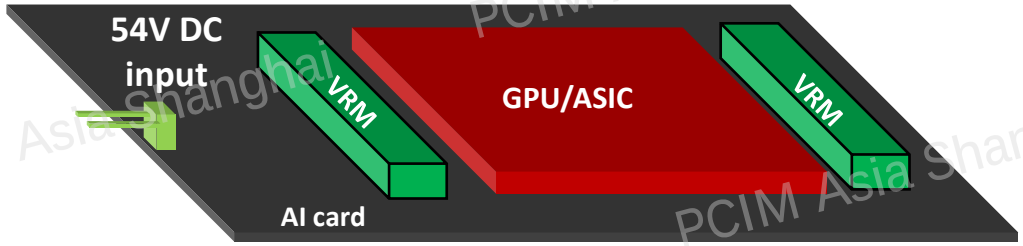
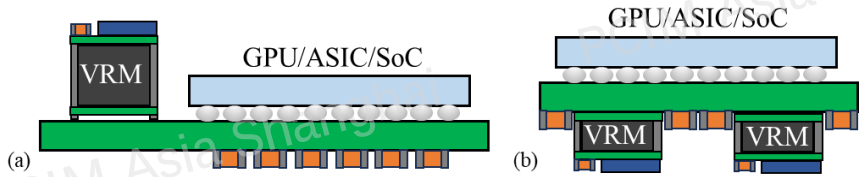
V. Avula, B. Bhattacharyya, V. Smet, Y. Joshi and M. Swaminathan, "Multiphysics Challenges and Opportunities for Integrated Voltage Regulators in Power Delivery Architectures," in IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 12, no. 1, pp. 131-146, Jan. 2022, doi: 10.1109/TCPMT.2021.3124248.

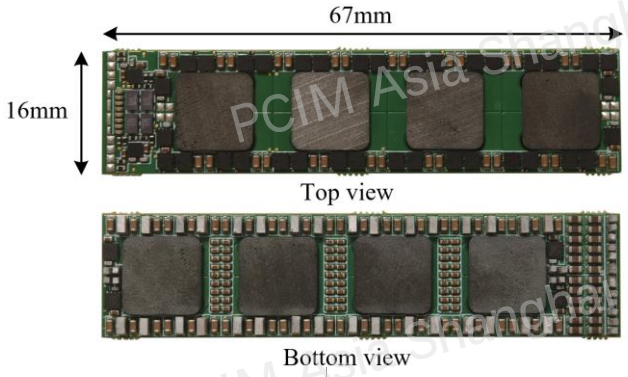
Advanced Single-Stage Regulate VR module (54-0.8V)

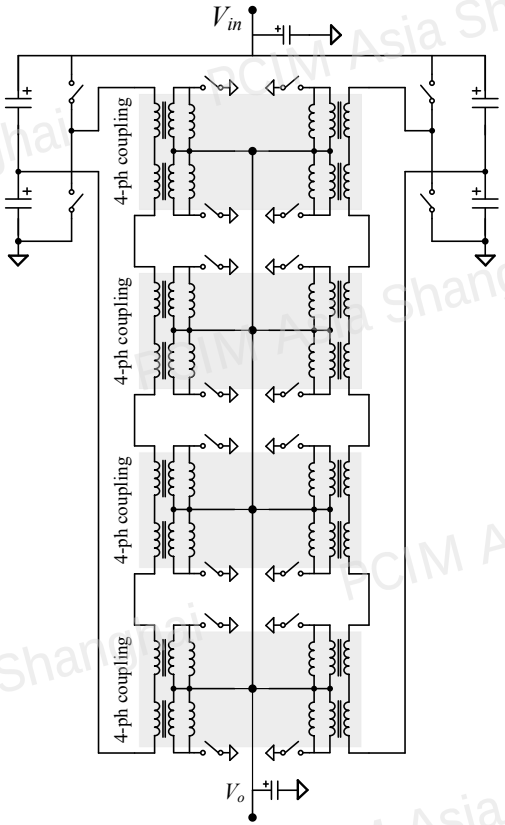


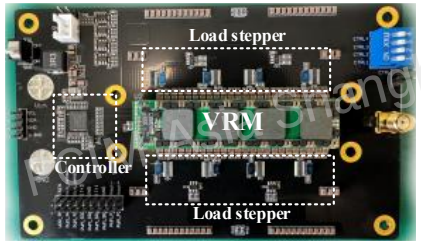
- Direct 54V to PoL regulated GPU voltage (<1V)
- High current module (>400A)
- High dynamic (low transient inductance)
- Miniaturised, smaller than GPU chip



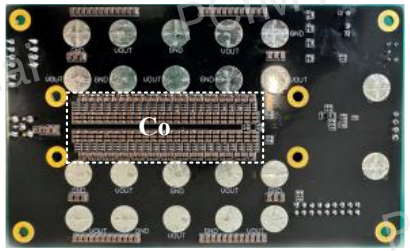
- Vertical and lateral mounting
- Integrated MLCC array (GPU core specific)



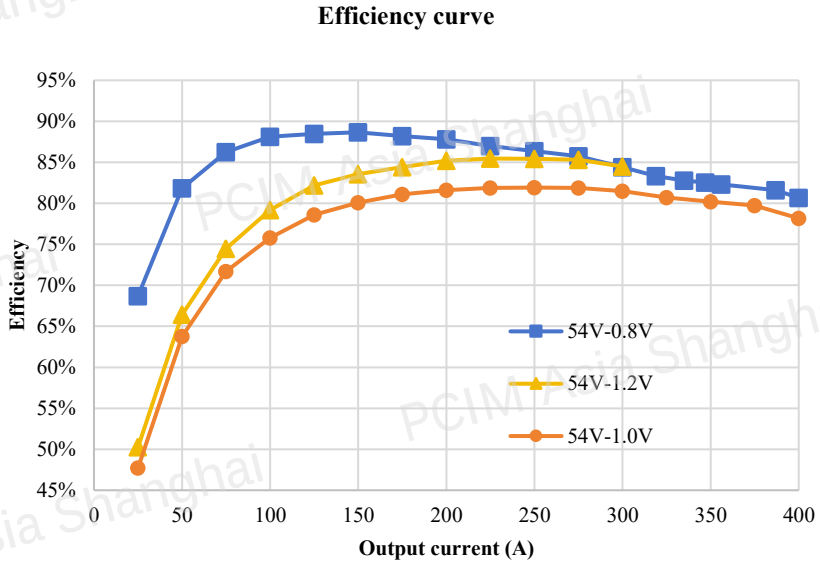


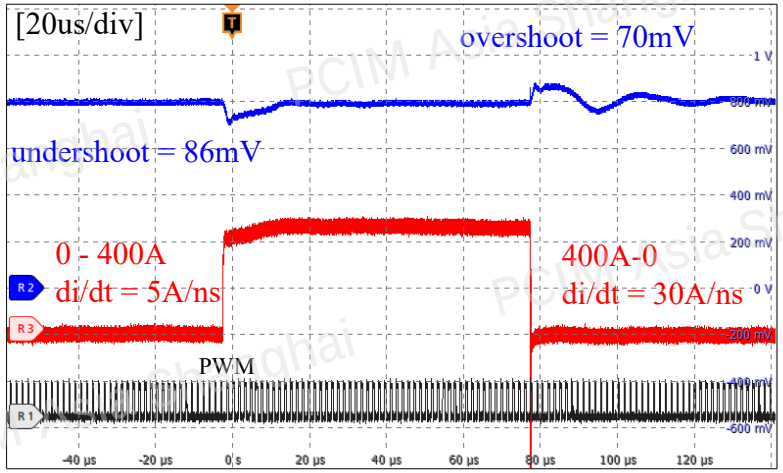


Top view



Bottom view





- **Cambridge prototype**, integrated magnetics, 450A, 54-0.8V, 67 x 16 x 3.9mm
- Dynamic response test di/dt 5A/ns, <80mV voltage transient
- End-to-end peak efficiency 90% @30% load

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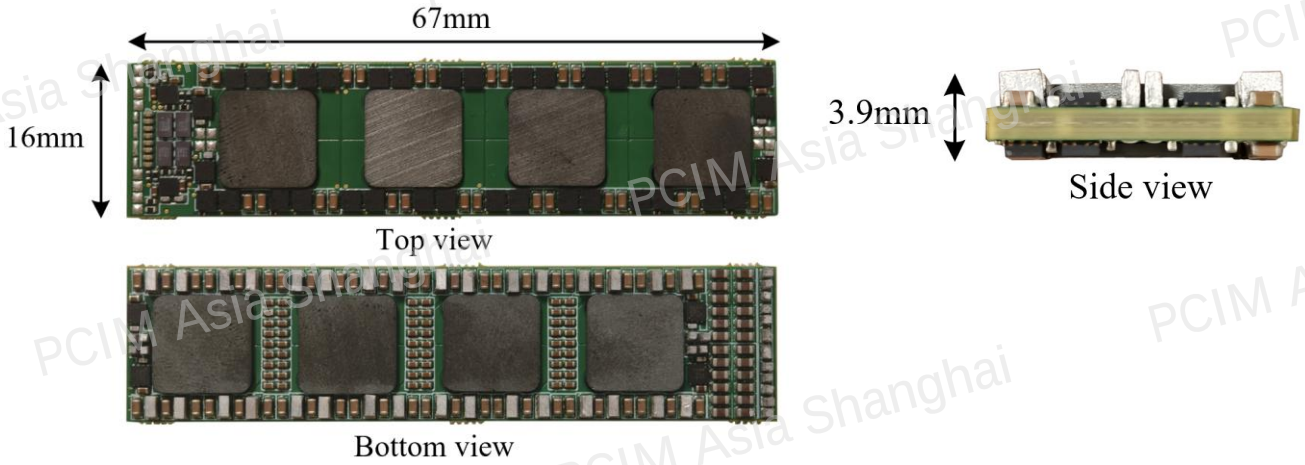
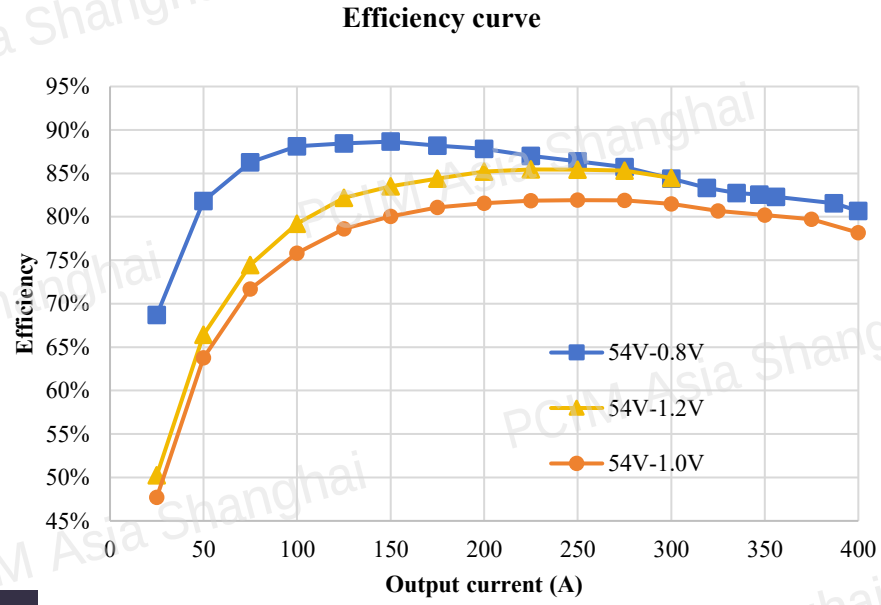
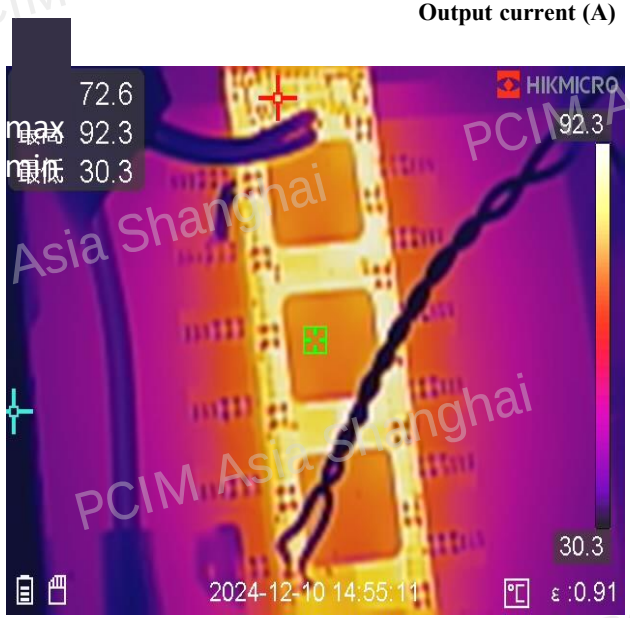
Prototype





Input voltage	40V-60V (typically 54V)
Output voltage	0.8V-1.2V (typically 0.8V)
Output current	400A
Switching frequency	600kHz
Module dimension	67mm/16mm/3.9mm (L/W/H)
Lss per phase	68nH
Ltr per phase	13nH



54V-0.8V
100A-400A
30% duty cycle
Air cooling

- Ultra-low profile (3.9mm thickness) design for VPD
- Output current 400A in 67 x 16 x 3.9mm
- End-to-end peak efficiency 89%, full-load efficiency 81%

X. Ren, J. Zhang, Z. Rong, B. Hu and T. Long, "Ultra-low-profile Single-stage Voltage Regulator Module (VRM) for Next-generation AI Accelerators," *2025 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Atlanta, GA, USA, 2025,

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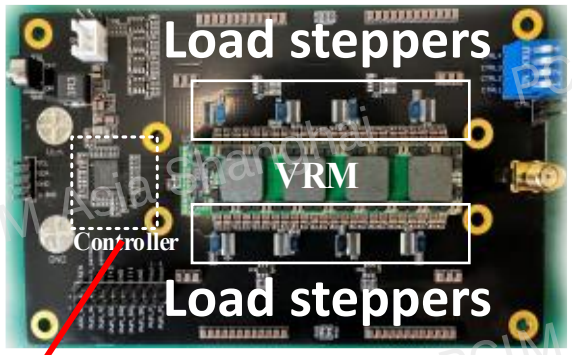
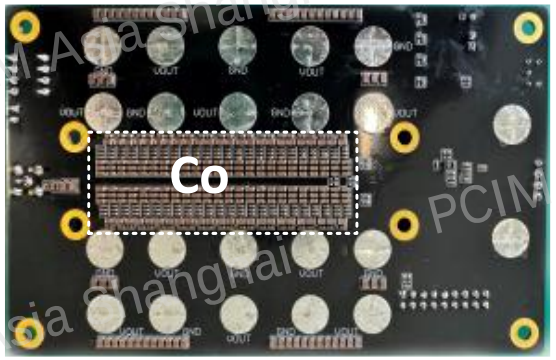
Dynamic testing

Dynamic EVB with load steppers

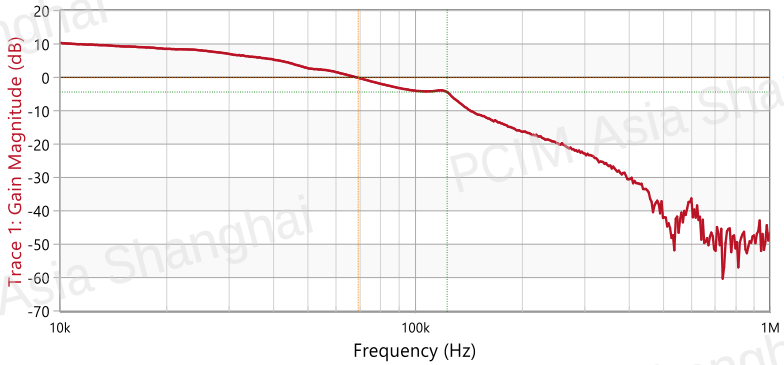


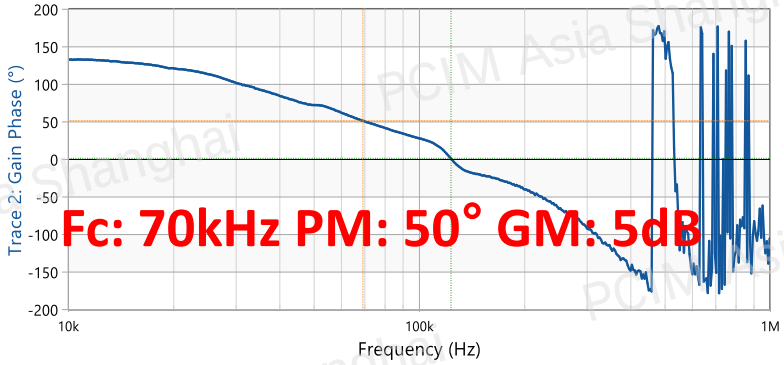
Top view



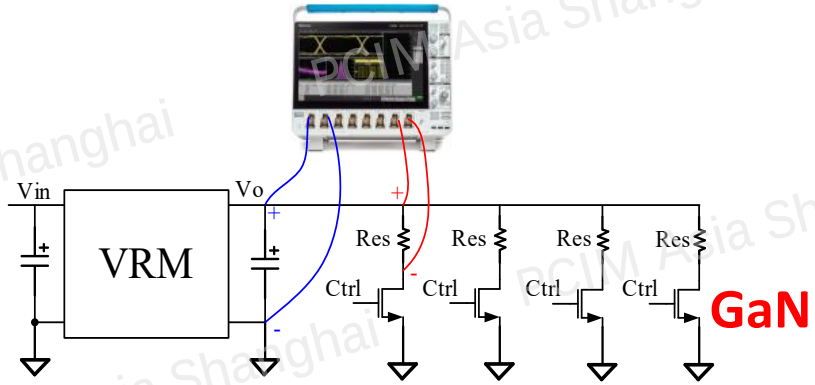
Bottom view

IFX XDPP-1100

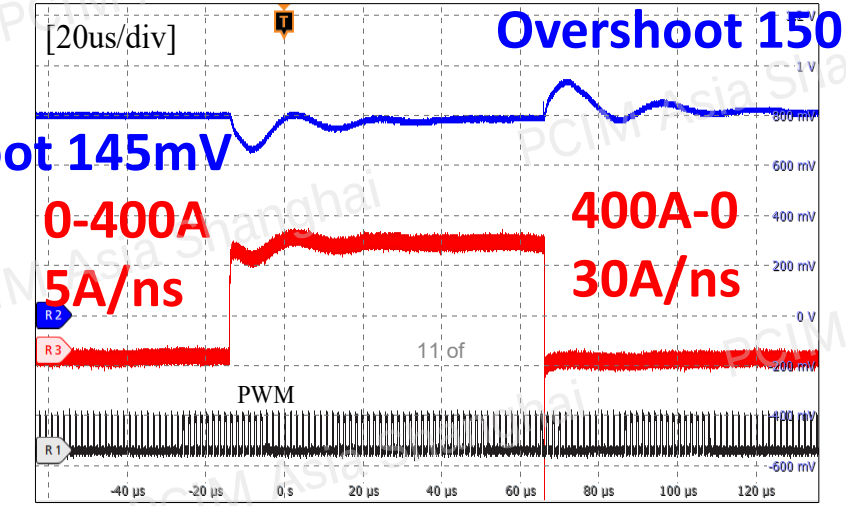




Fc: 70kHz PM: 50° GM: 5dB



GaN



- GaN based dynamic evaluation board
- Ultra-fast transient response (Ltr = 13nH, PID control)

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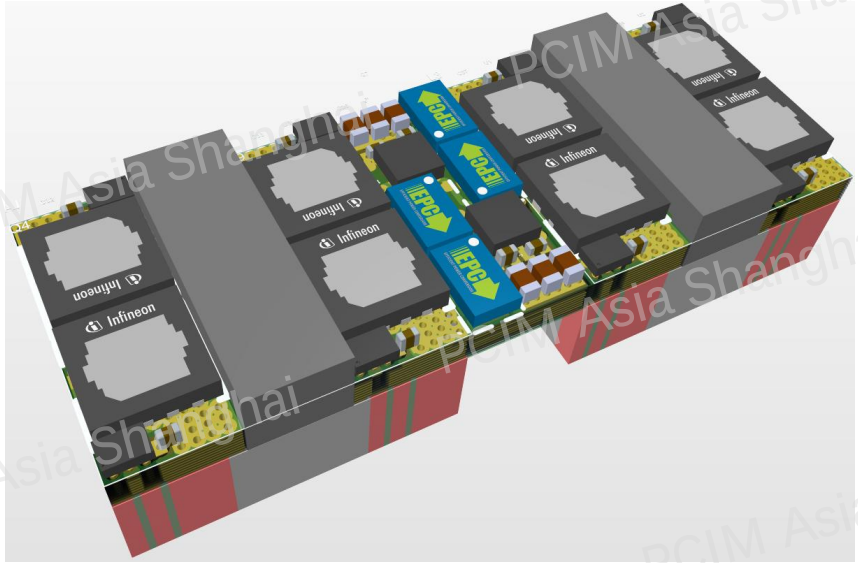
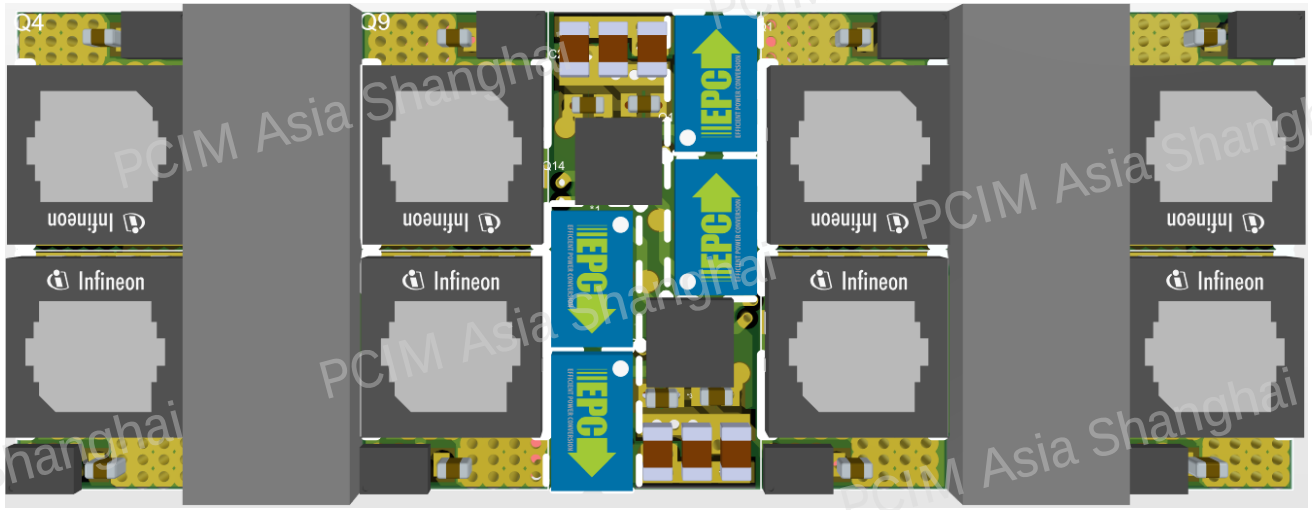
Research Content

Single-Stage Vertical Voltage Regulator



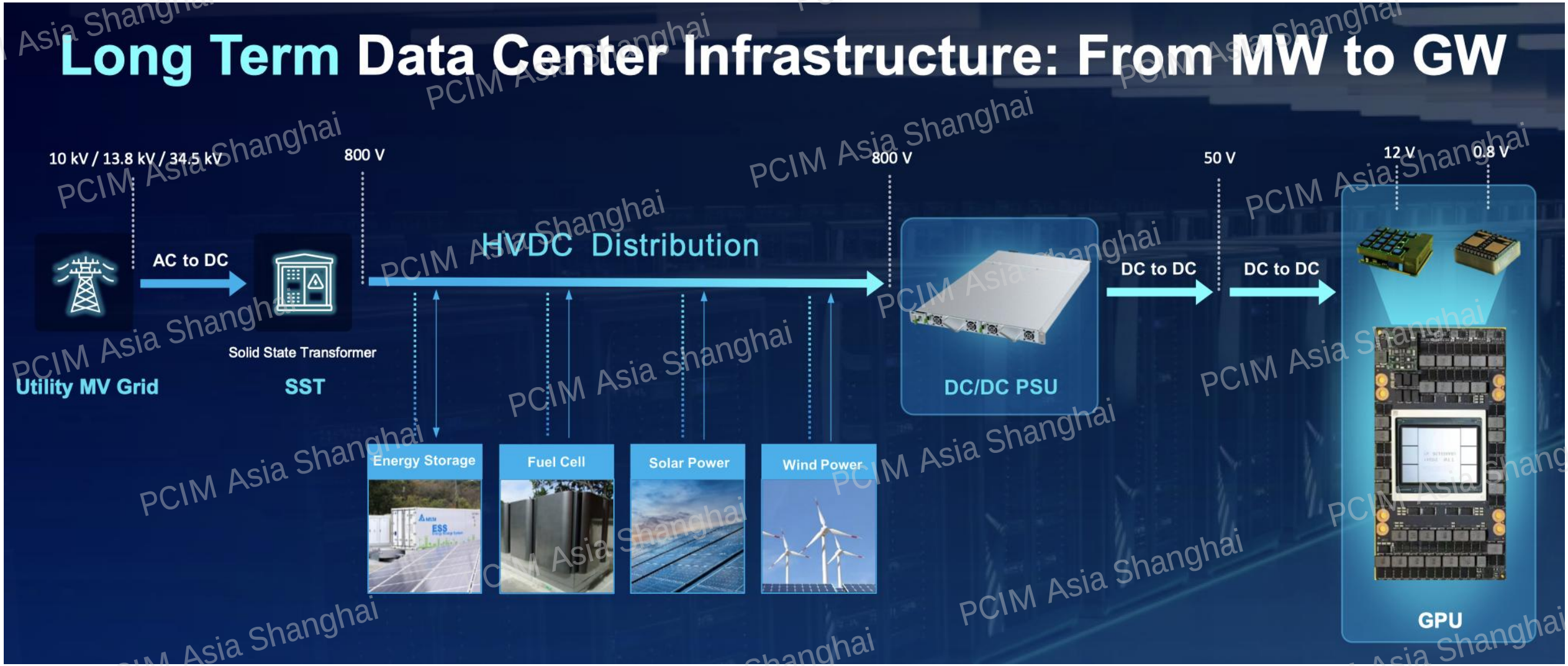


Prototype- 24mm(length) x 9mm (width) x 5.6mm (height)

Current density: 1.48A/mm²

Inductor: 3mm，PCB: 1.2mm，transformer: 1mm，bottom board: 0.4mm(not shown)

Future power architecture for AI datacentre



*Courtesy to **Delta Electronics***

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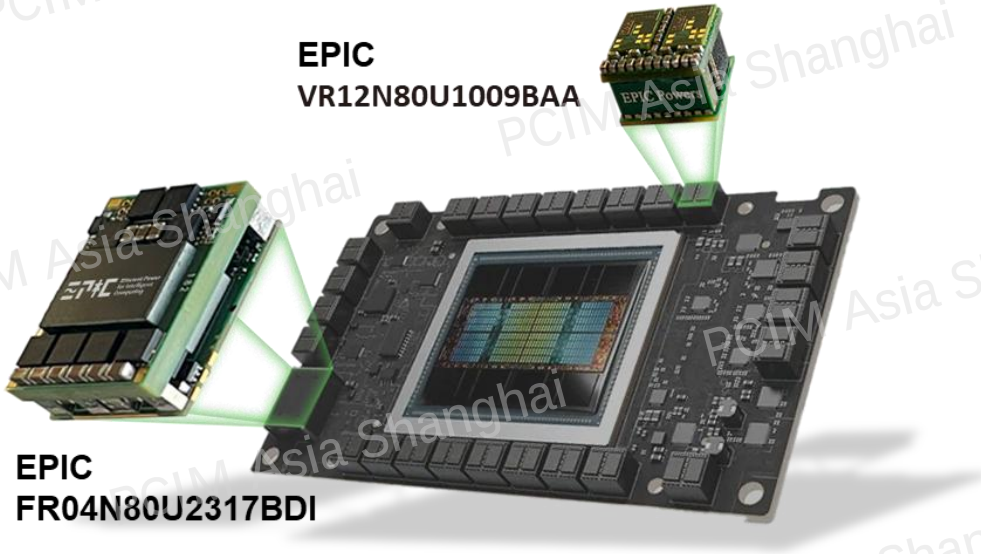
EPIC Tech Ltd

Efficient Power for Intelligent Computing

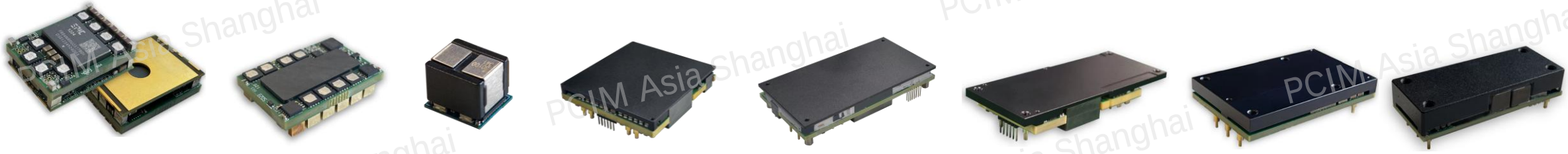


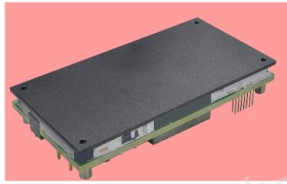
Prof Teng Long
Founder, Chairman

- Tenured Full Professor at the University of Cambridge, world-renowned scholar in power electronics
- Founder and Director of the Cambridge University Advanced Power Electronics Laboratory
- Deputy Director of the Cambridge University Nanjing Centre for Technology Innovation
- Published over 100 SCI journal papers, secured more than £5 million in research funding, holds 15 Chinese patents and 7 international patents
- Formerly with General Electric (GE) UK Power Conversion Division, Chartered Engineer (UK)

Michael Xu
Co-founder, CEO

- Bachelor's and Master's degrees in Power Electronics from Zhejiang University; General Manager Program at China Europe International Business School (CEIBS)
- 2009–2018: Co-founder and R&D Director of Inventronics, major contributor to its A-share IPO
- 2018–2024: Second employee of Navitas China, Head of Application R&D, major contributor to Navitas's NASDAQ IPO
- Zhejiang Province's "151" Talent Program and Hangzhou's "131" Mid-level Talent Program; holder of 18 invention and utility model patents



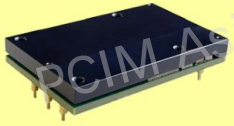


800-48V Regulated
In: 620-950V, Out: 48V
Full-Brick
2.8-3.5 kW, 97.2% peak

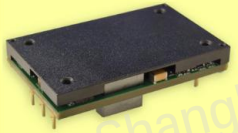
800-50V Fixed-Ratio
In: 650-900V, 16:1,
Half-Brick, Full-Brick
6-10 kW, >98% peak

400-50/25V Fixed-Ratio
In: 250-460V, 16:1, 8:1
1/4-Brick, Isolated
1.8-2kW, 98% peak

300-30V Regulated
In: 220-330V, Out: 30V
Half-Brick, Isolated
1-1.5kW, 95.8% peak

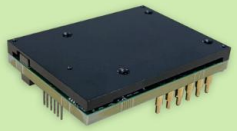


48-12V Regulated
In: 40-60V, Out: 12V
1/4-Brick, Non-Isolated
1.8-2kW, 98.7% peak



48-12V Regulated
In: 48-60V, Out: 12V
1/4-Brick, Isolated
800W, 97.6% peak

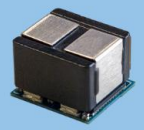
30-12V Regulated
In: 16-40V, Out: 12V
1/8-Brick, Isolated
300-400W, 95.2% peak



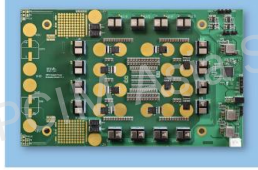
48-3.3V Regulated
In: 25-60V, Out: 3.3V
Half-Brick, Non-isolated
400A@3.3V, 96.5% peak

48-6V Fixed-Ratio
In: 40-60V, 8:1
23x17mm, Non-Isolated
0.5-1kW, >97% peak

48-12V Fixed-Ratio
In: 40-60V, 4:1
23x17mm, Non-Isolated
1-1.5kW, 98.3% peak



12-1V Regulated
In: 4.6-16V, Out:0.23-5V
9x8x10/4.8mm
140A@0.8V, >96% peak



16-Phase 12-1V parallel
In: 48/12V, Out:0.5-2V
1000A continuous
Up to 4000A/µs transient

48-1V Fixed-ratio
In: 40-60V, 48:1
58x115x5.6mm, Non-Iso
450A@0.8V, >93% peak

54-1V Regulated
In: 40-60V, Out:0.75-1.2V
67x16x3.9mm, Non-Iso
450A@0.8V, >90% peak

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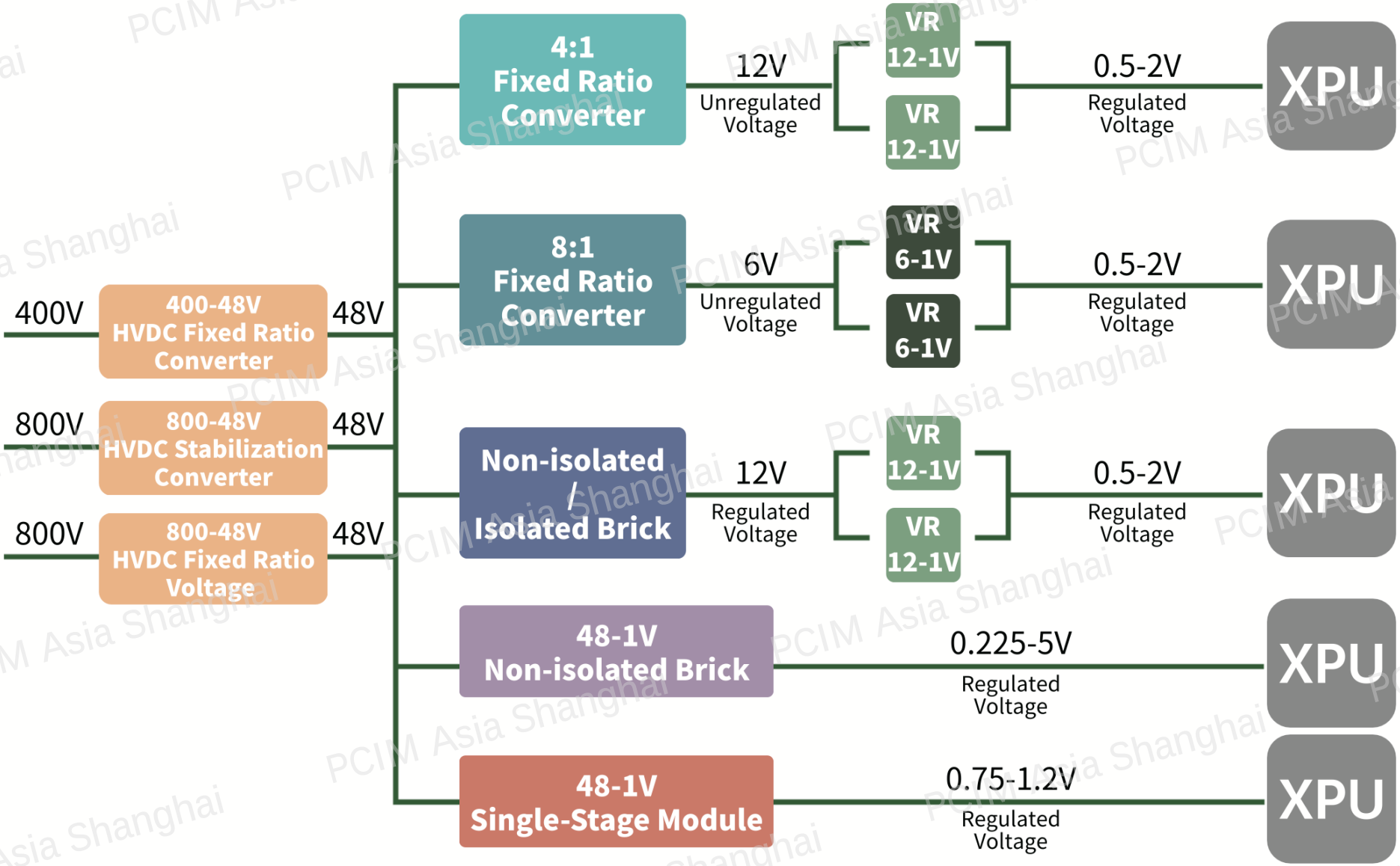
Datacenter Power Delivery Architectures



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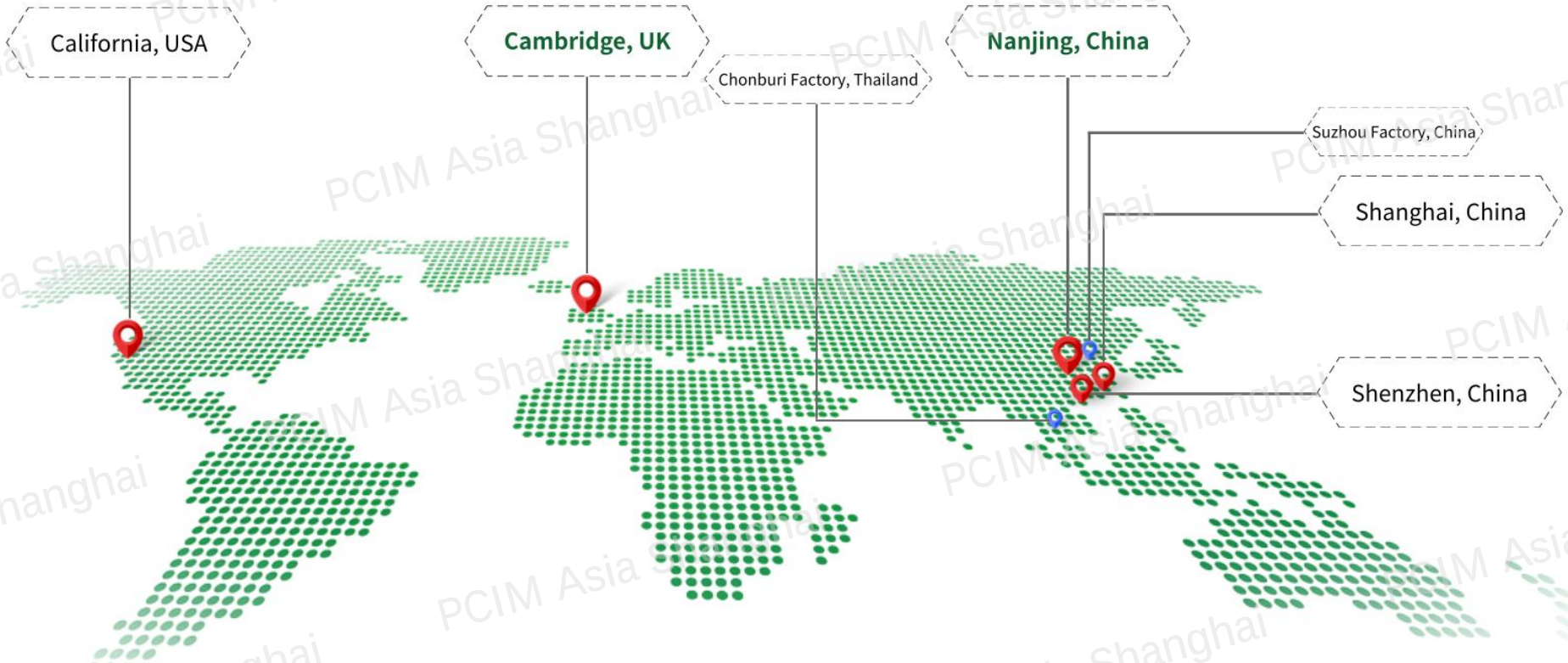

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info@epicpowers.com

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Contents

- State-of-the-art Power Supply Architecture for AI datacentres
- Advanced Power Electronics Packaging for for High Integration
- Smart Soft-Switching using Electroluminescence

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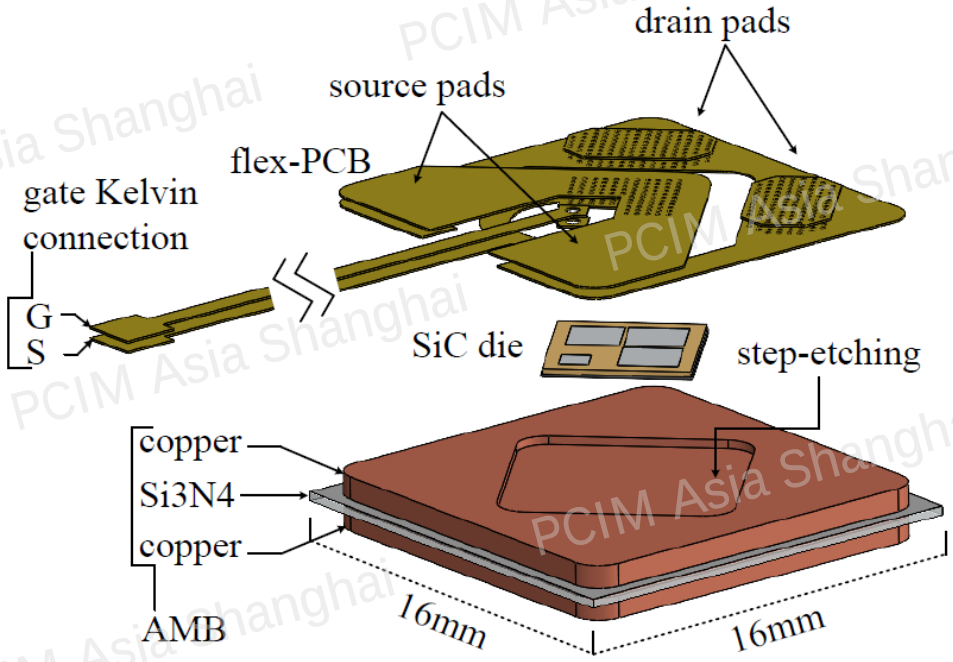
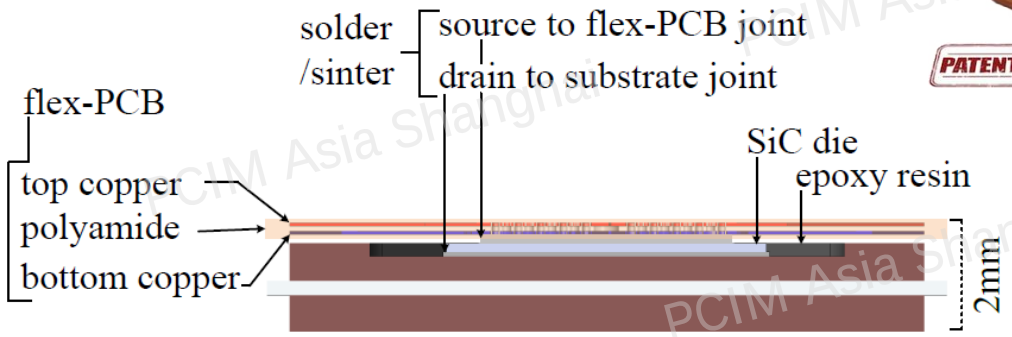
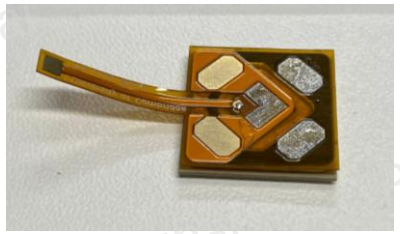
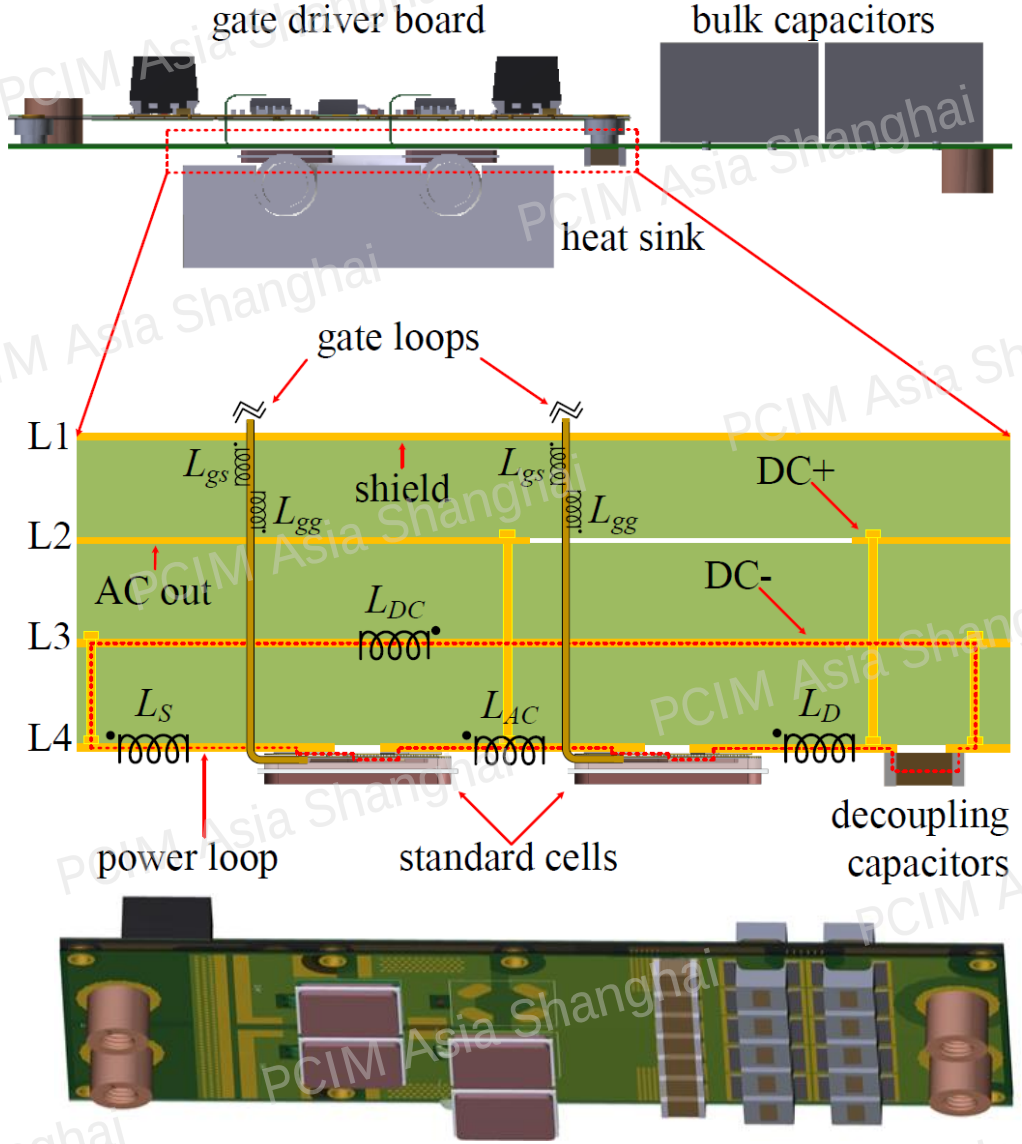
Standard Cell concept and structure









A. Janabi *et al.*, "Substrate Embedded Power Electronics Packaging for Silicon Carbide mosfets," in *IEEE Transactions on Power Electronics*, vol. 39, no. 8, pp. 9614-9628, Aug. 2024

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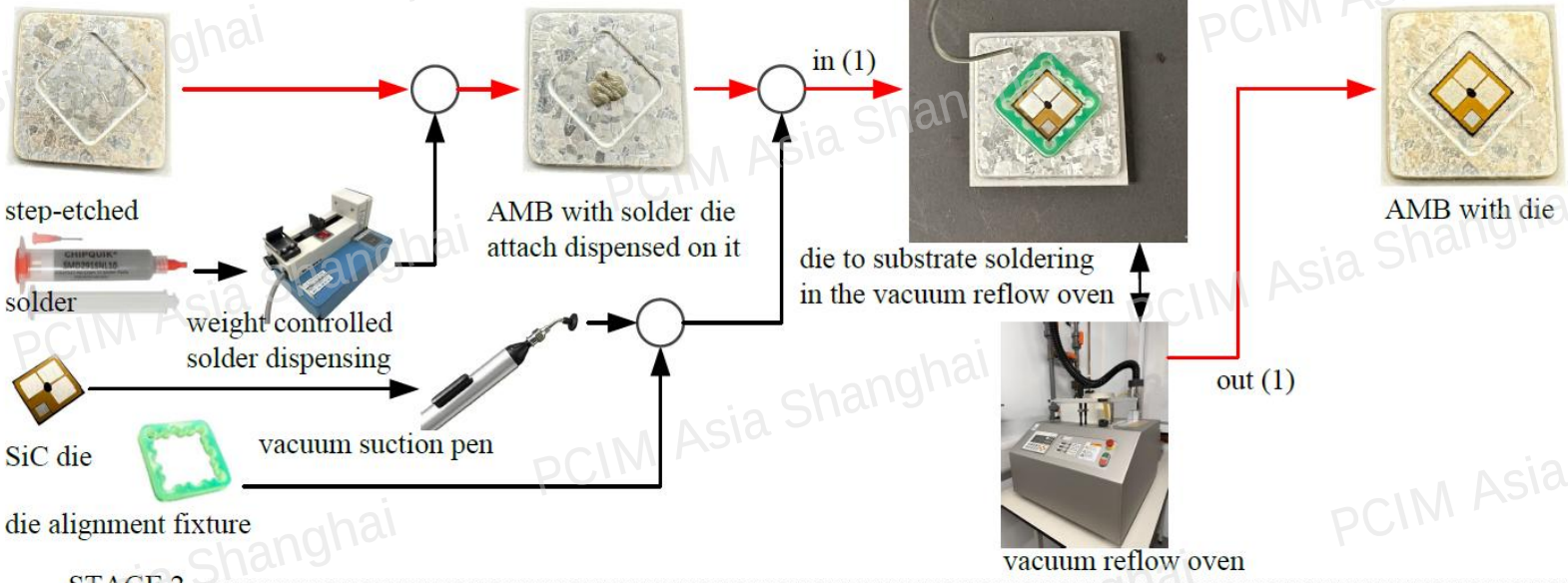
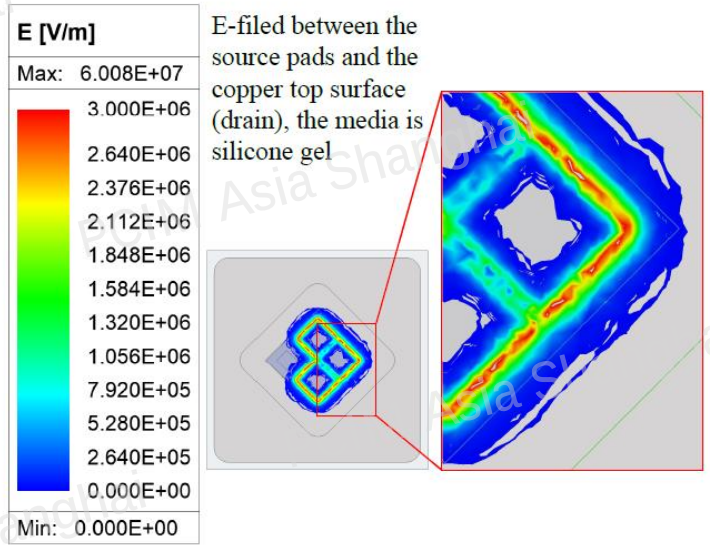
Standard Cell device package assembling

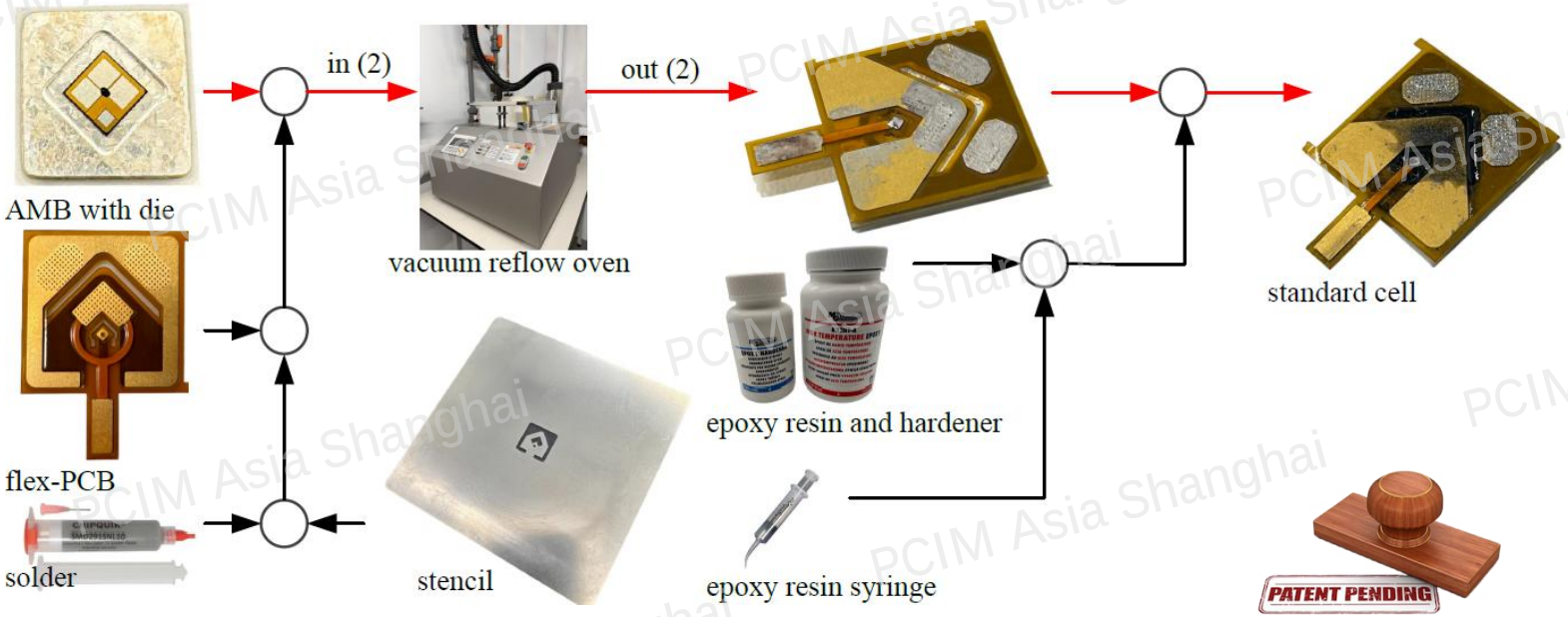
STAGE 1

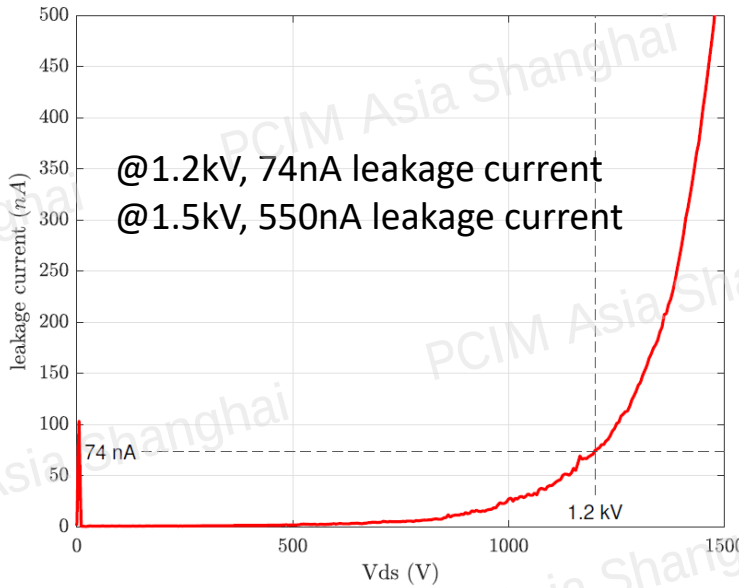




E-filed between the source pads and the copper top surface (drain), the media is silicone gel

STAGE 2





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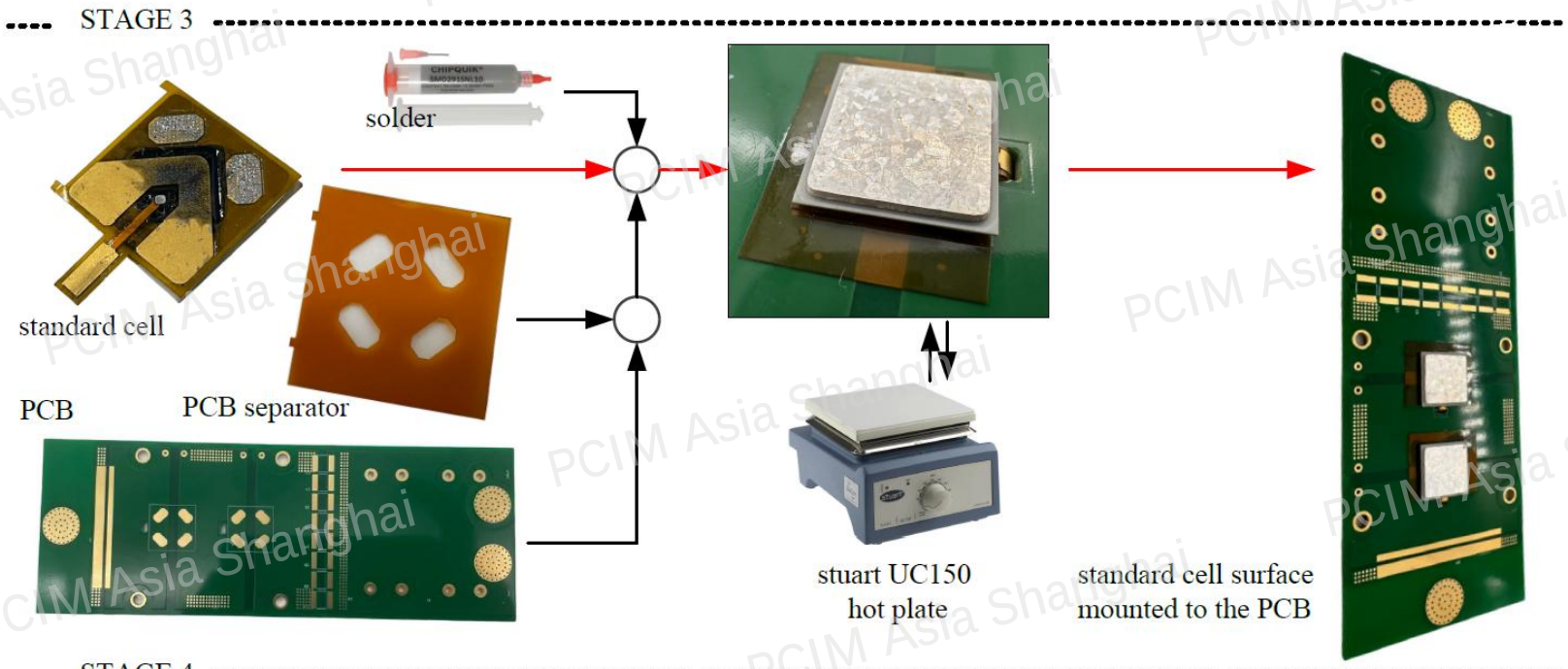
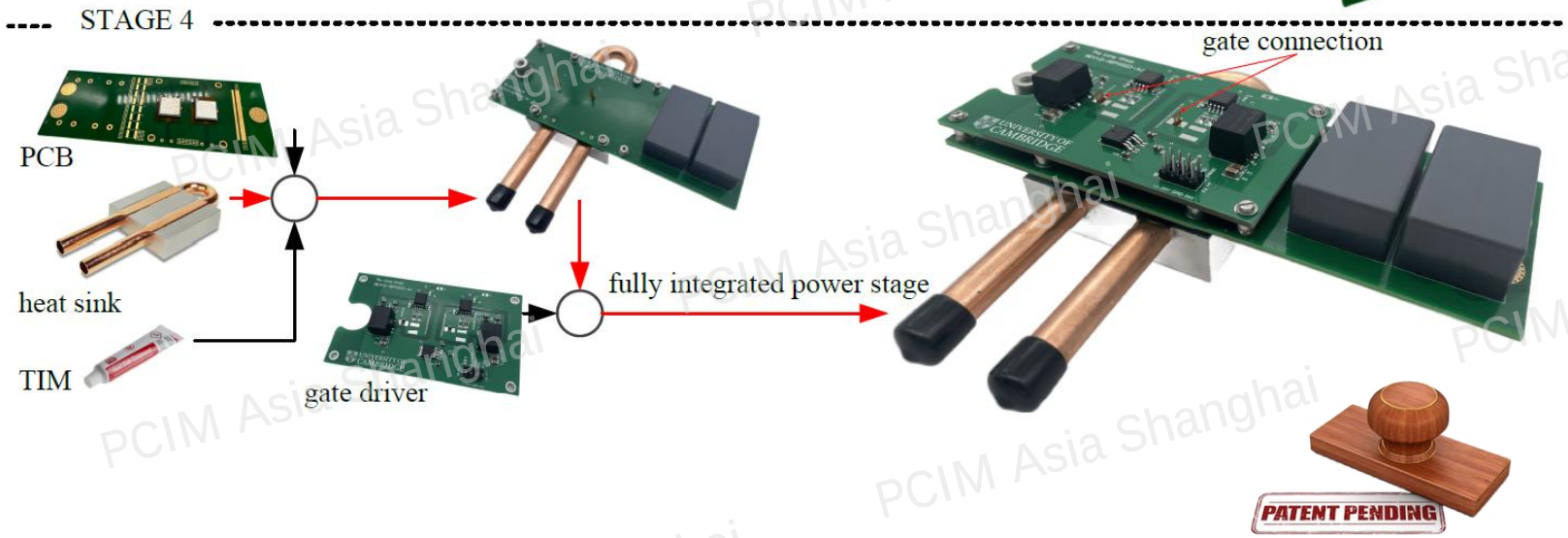
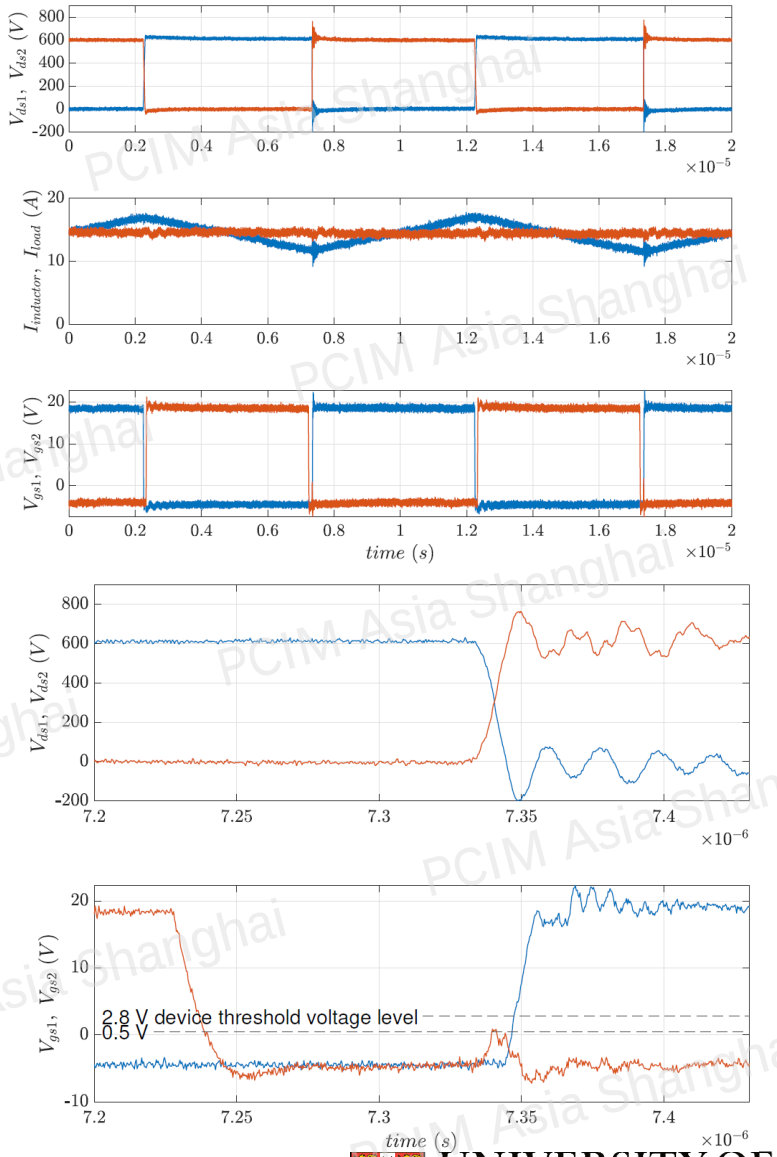
Standard cells in converter systems – surface mounted







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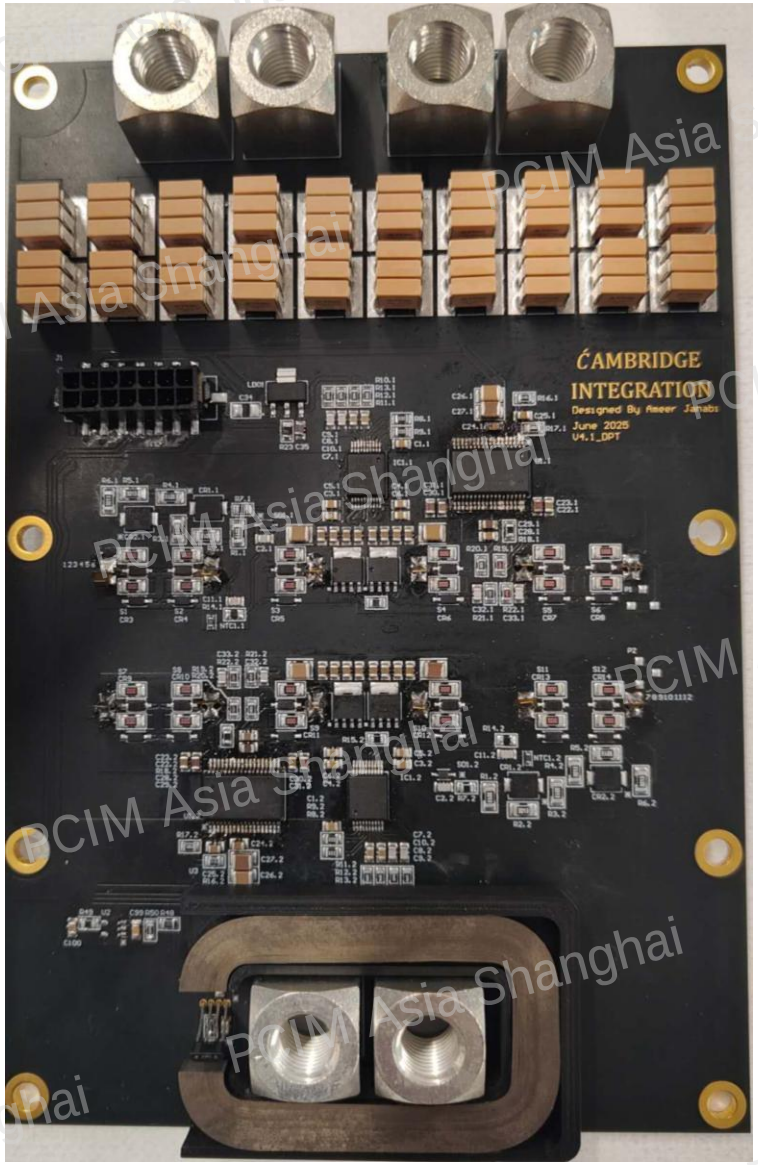
320 kW/L power assembly using 6 Standard Cells in parallel



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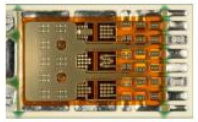
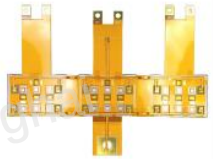
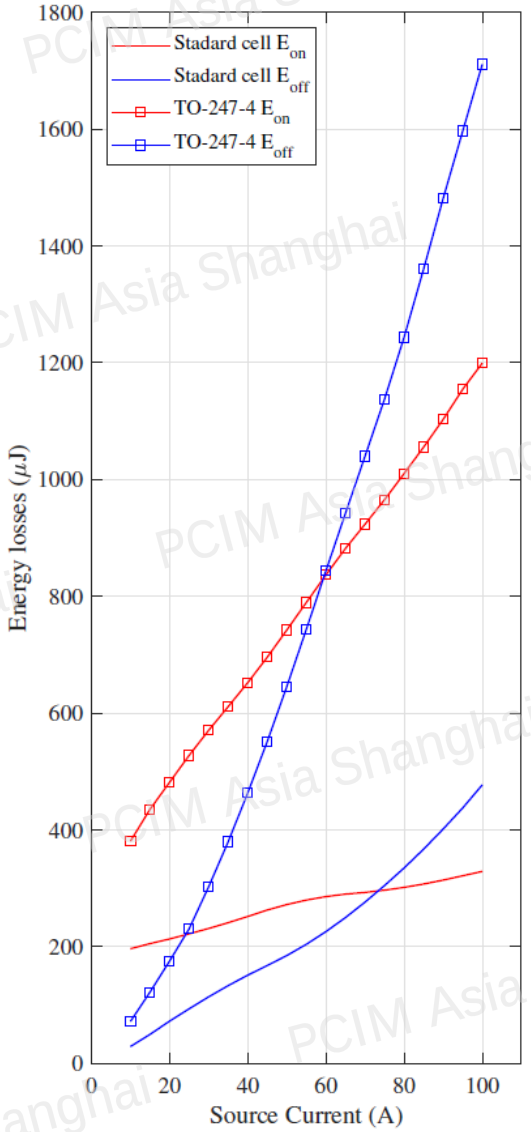
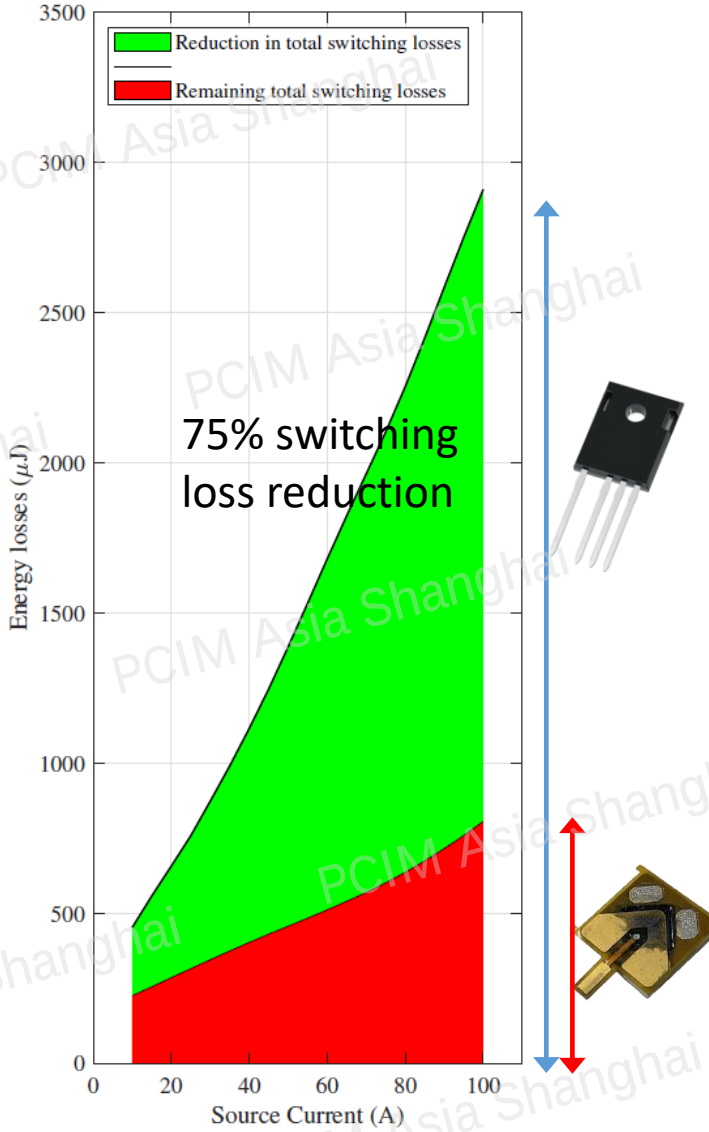
Very low switching energy of standard cell due to low inductance

Package type	Illustration	$L_g(nH)$	$L_p(nH)$
ST P AK/IDPAK		20*	21*
TO-247-4L/TO247plus		20.5*	36.9*
Schweizer p^2 Pack		Low/ layout depen- dent	1.45[22]
AG (AT&S)/CPES		2.2[16]	2.3[16]
GE POL-kW		$(20-30)$*	2.6[36], 5[37]
Semikron eMPack®/SKiN		$(20-30)$*	$(2.5-6)$**
3D-Hybrid package		$(20-30)$*	2.4[35]
Proposed standard cell		1.5*	0.716*,1**





STMicroelectronics SiC die chip:
SCT116N120G3DXAG, 1.2kV, 14. 6mOhm, 130A

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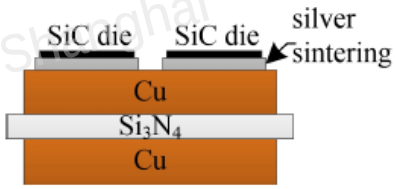
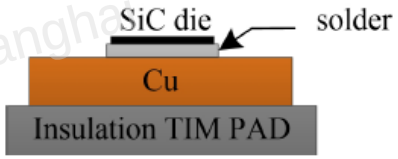
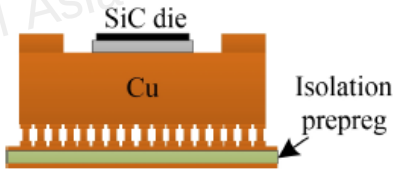
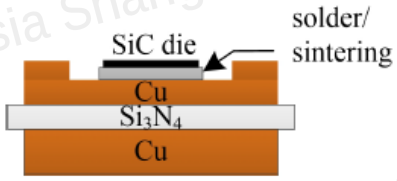
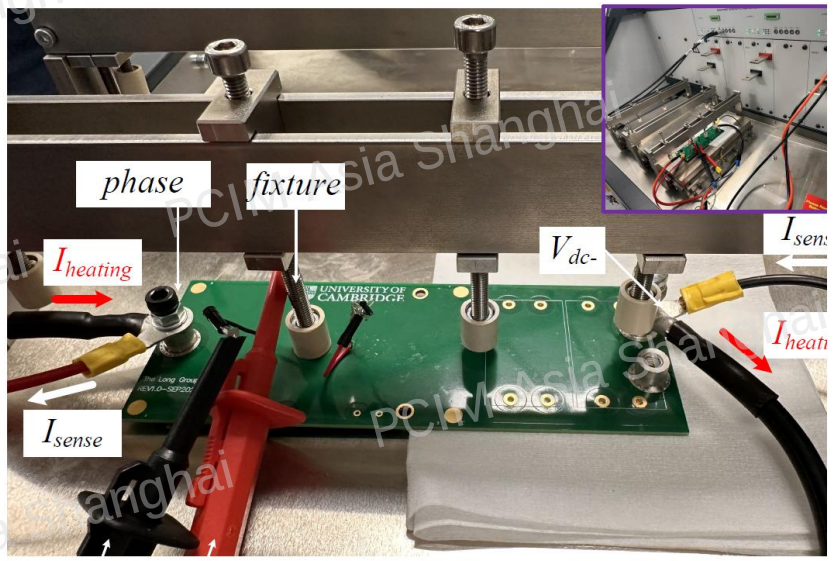
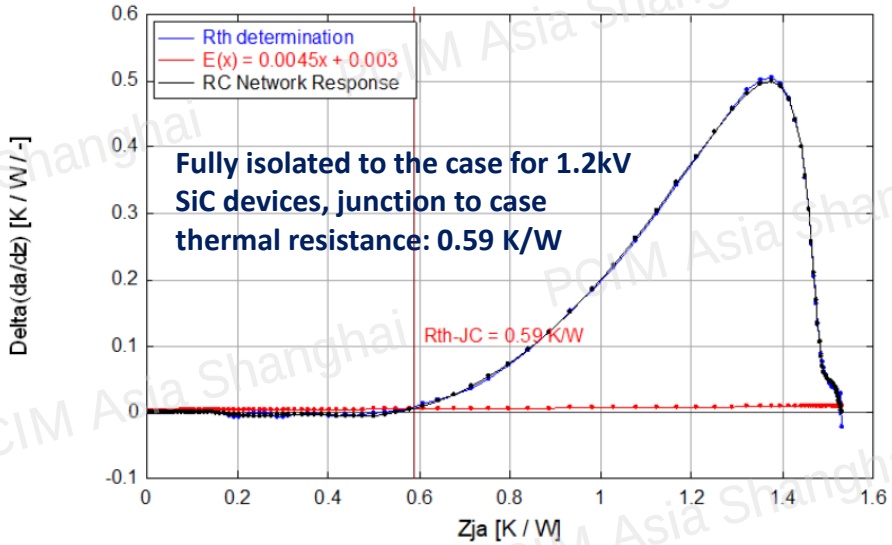
Low thermal resistance of standard cell

Package type	Illustration	Layers stack	R_{th-JC}
ST PAK/IDPAK			$0.6^{[45]}$
TO-247-4L/TO247plus			1.3
Embedding/p^2 Pack, ABB			**Only for 48V system!** 0.58, $0.5^{[47]}$
Proposed standard cell			0.59



T3Ster Master: Difference of the derivatives



A. Janabi *et al.*, "Substrate Embedded Power Electronics Packaging for Silicon Carbide mosfets," in *IEEE Transactions on Power Electronics*, vol. 39, no. 8, pp. 9614-9628, Aug. 2024

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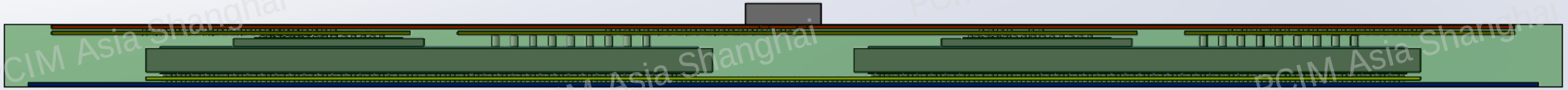
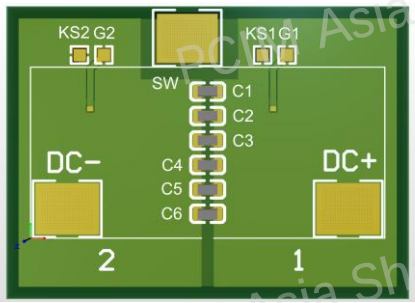
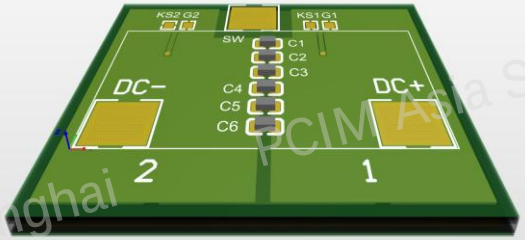
Beyond Standarc Cell: PCB embedded SiC/diamond substrates







- Insulation for 1.2kV applications
- Mucher higher thermal conductivity
- Less than 300pH half-bridge stray inductance

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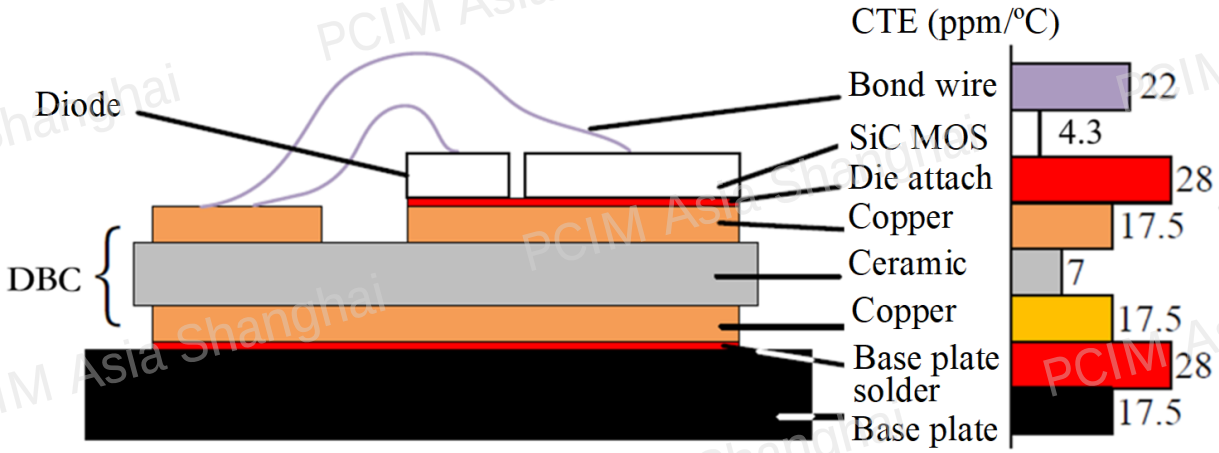
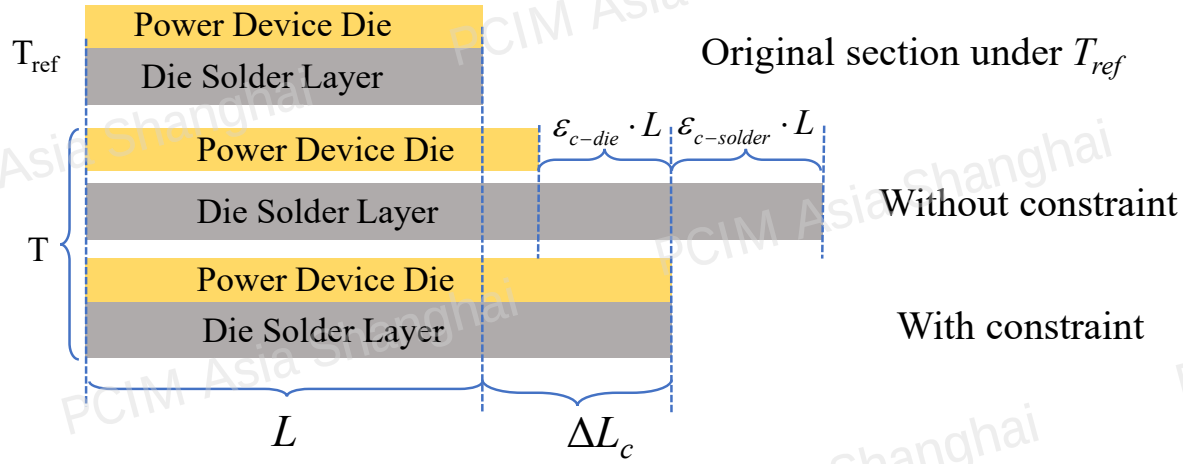
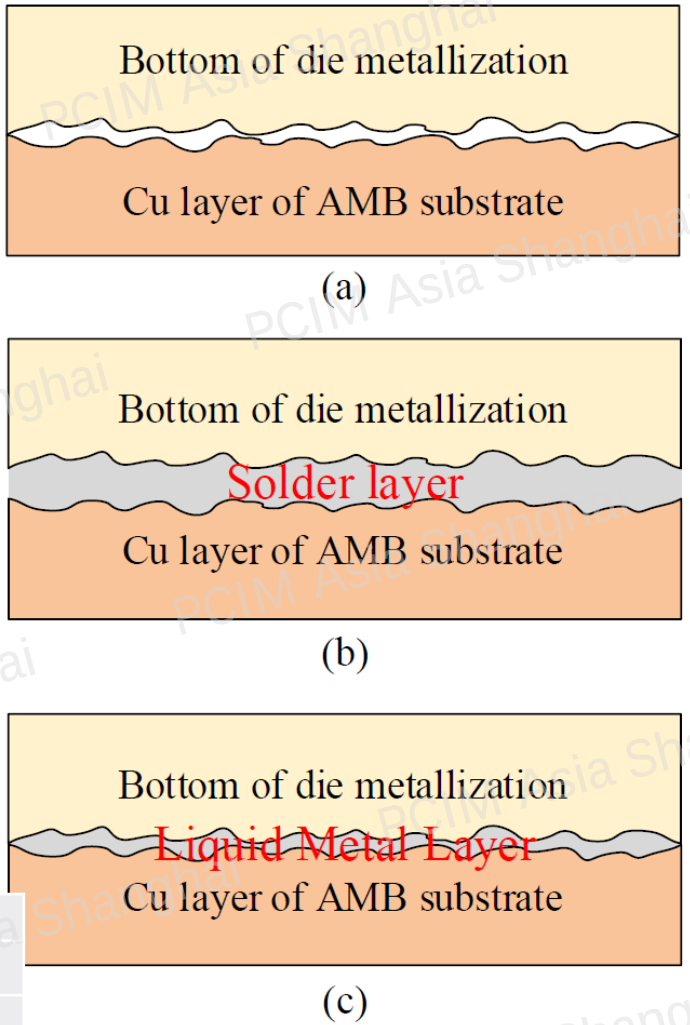
Basics of thermomechanical stress of power electronics package







Material	Key material properties		
	(°C)	(S/m)	(W/(m•K))
GaInAg	8	5.0×10^6	75
$Ga_{68}In_{22}Sn_{10}$	-17	3.46×10^6	16.5
$In_{51}Bi_{32.5}Sn_{16.5}$	53	4.9×10^6	70
Solder (SAC305)	217	7.6×10^6	58.7

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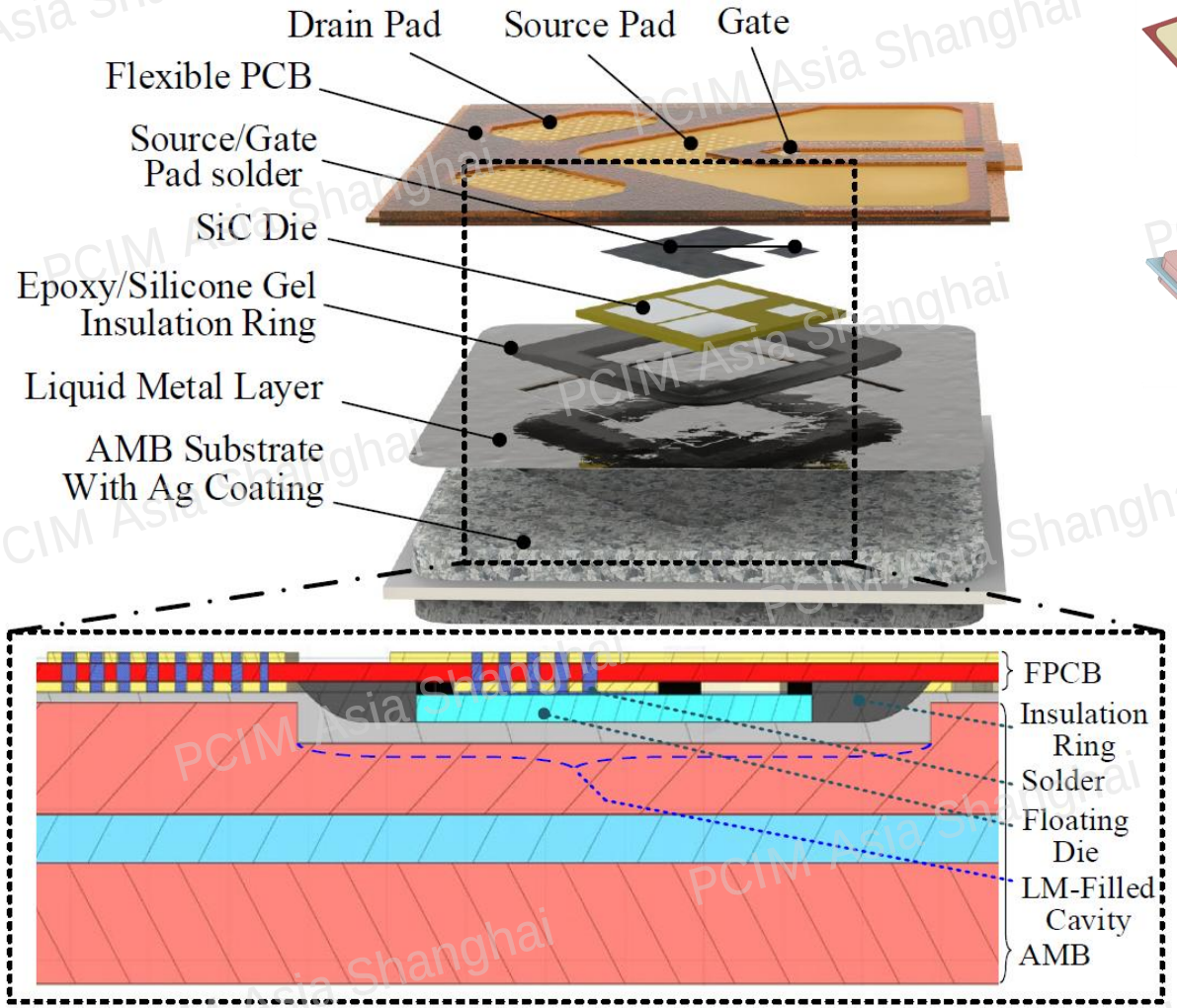
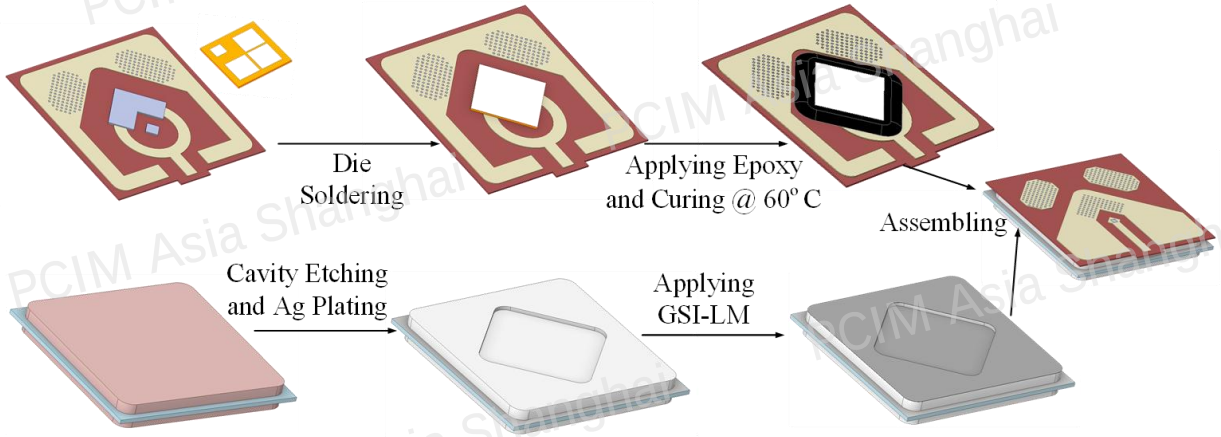
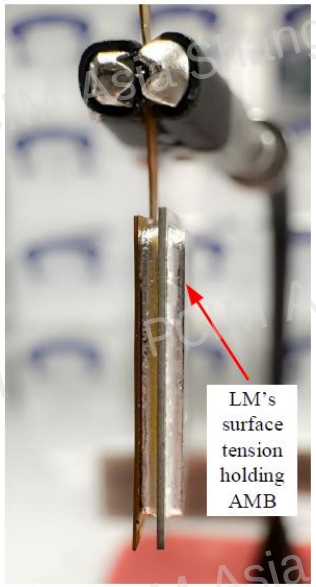
Using GaInAg LM for die touch joint







W. Mu, A. Janabi, B. Hu, L. Shillaber and T. Long, "Liquid Metal Fluidic Connection and Floating Die Structure for Ultralow Thermomechanical Stress of SiC Power Electronics Packaging," in *IEEE Transactions on Power Electronics*, vol. 39, no. 7, pp. 7808-7814, July 2024,

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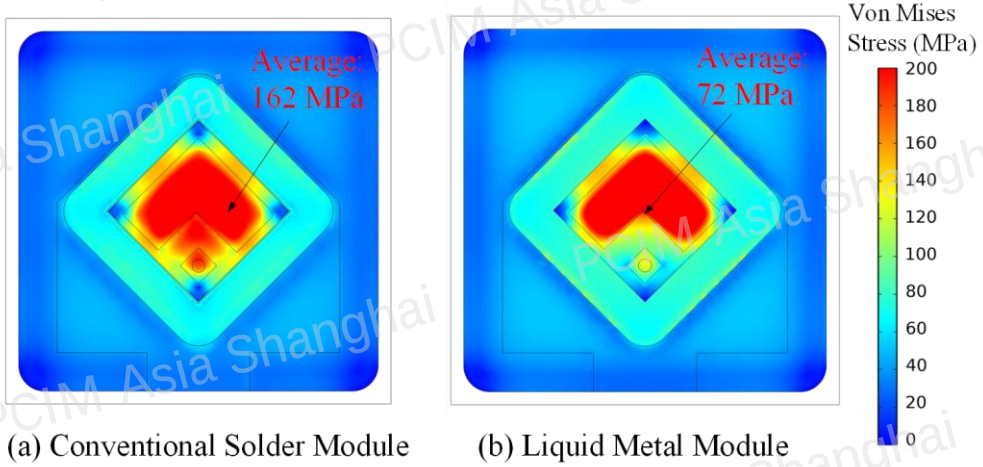
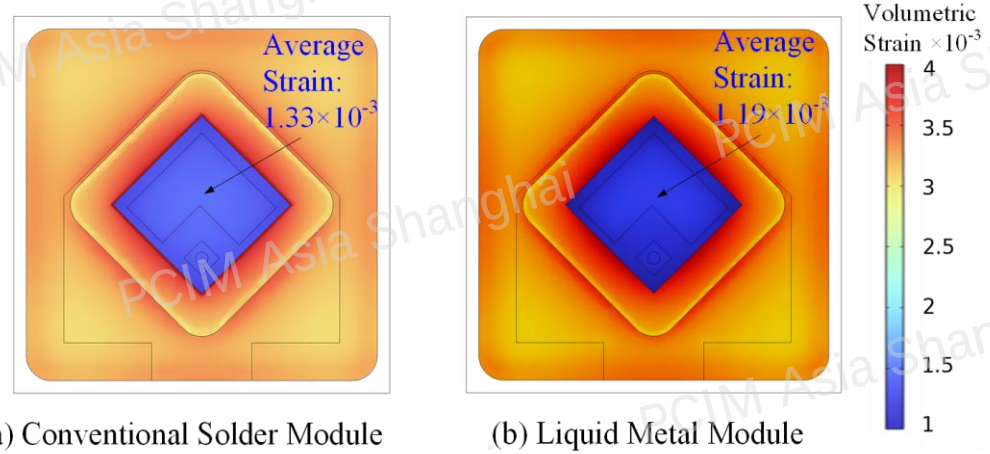
Large reduction of stress due to floating die structure using LM



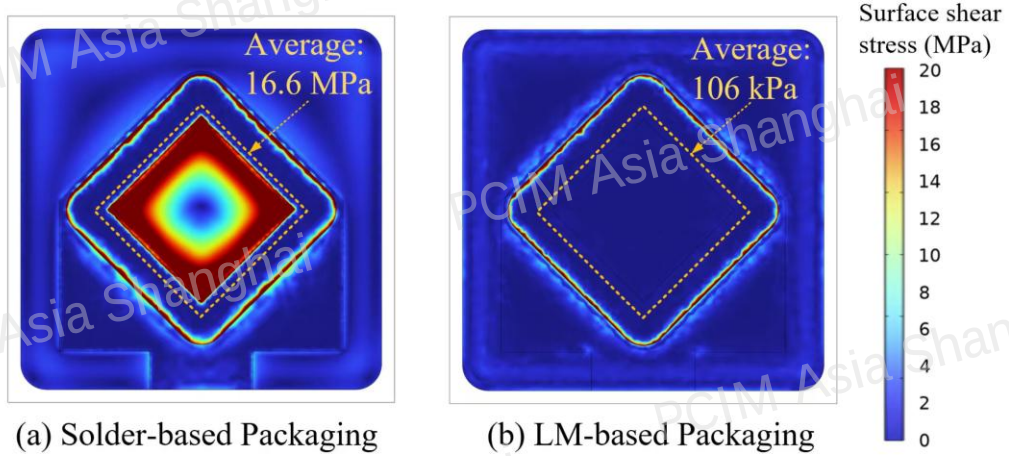
(a) Conventional Solder Module (b) Liquid Metal Module

- ❖ Von-Mises stress comparison
- 55% reduction on the SiC MOSFET



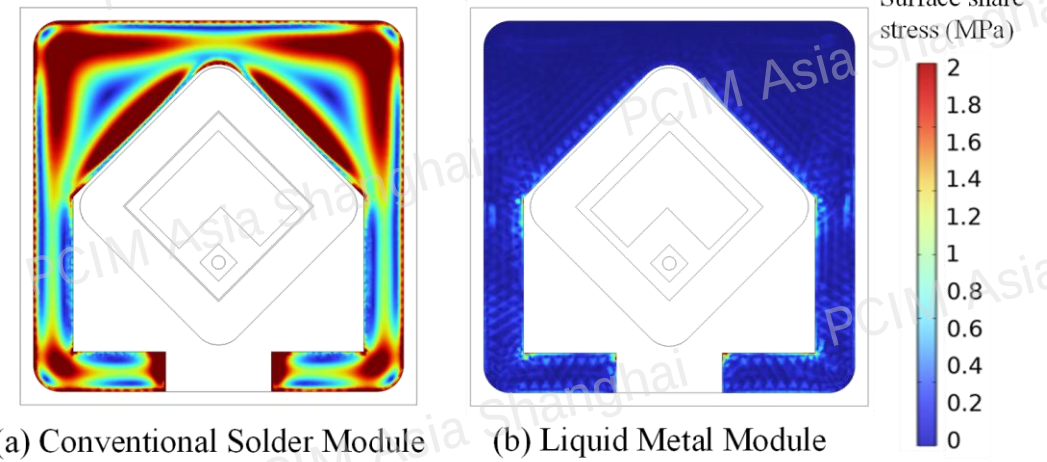
(a) Conventional Solder Module (b) Liquid Metal Module

- ❖ Volumetric thermal strain comparison
- Strain is decoupled by the LM layer so the die is under less tension.



(a) Solder-based Packaging (b) LM-based Packaging

- ❖ Shear stress comparison of the AMB
- 99% reduction of surface share stress.



(a) Conventional Solder Module (b) Liquid Metal Module

- ❖ Shear stress comparison of the FPCB
- Improved reliability for FPCB

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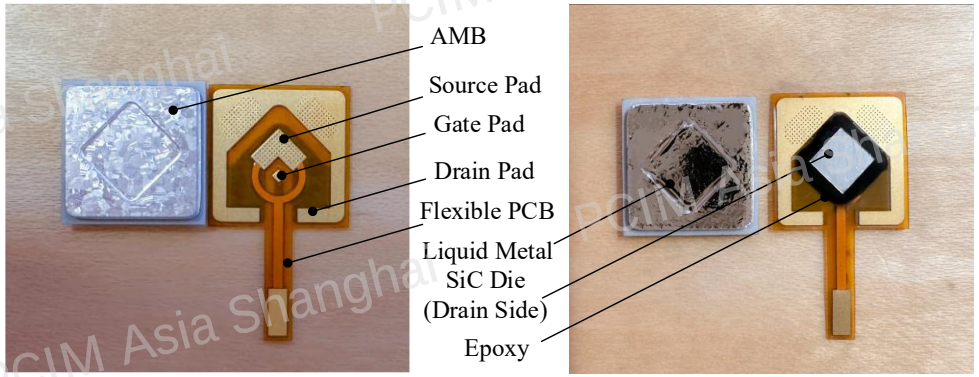
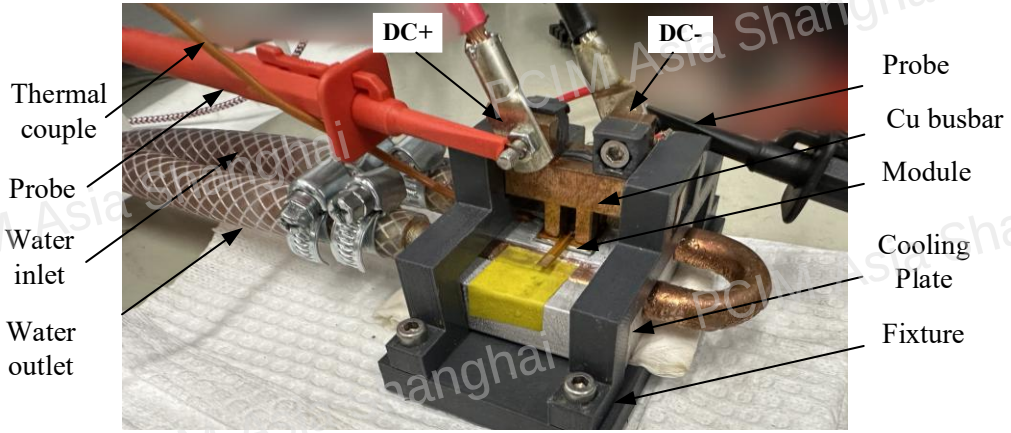
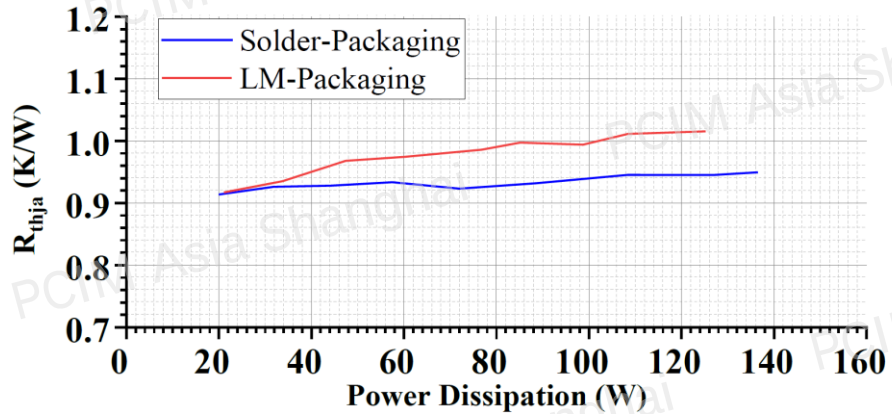
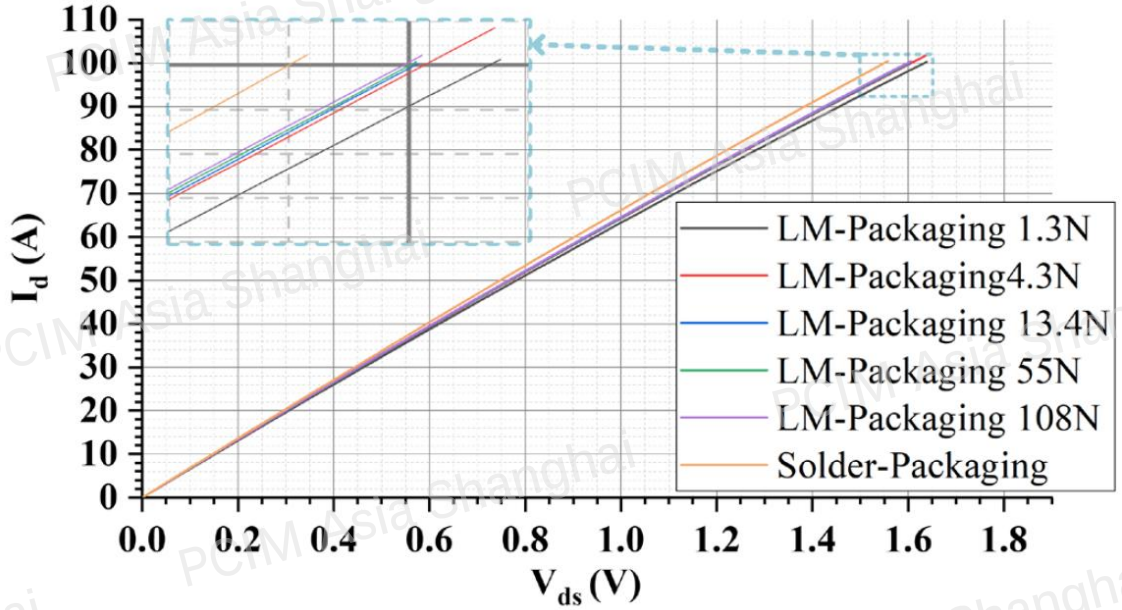
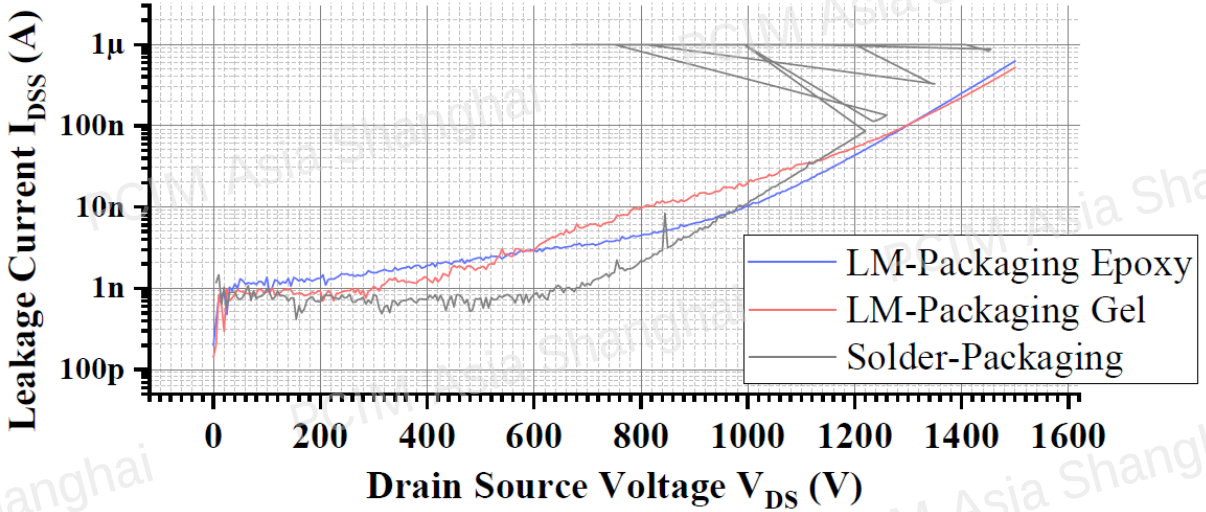
Excellent thermal and electrical conduction using LM in packaging











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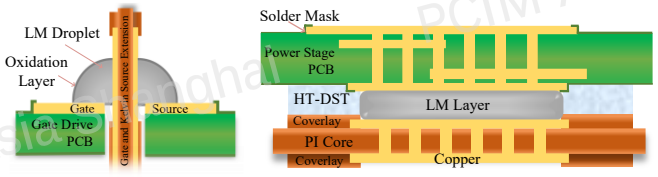
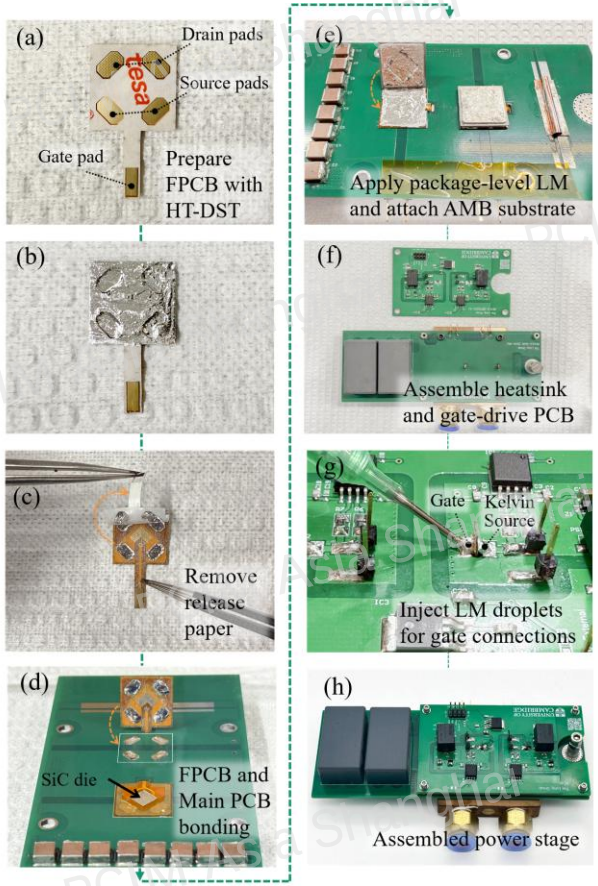
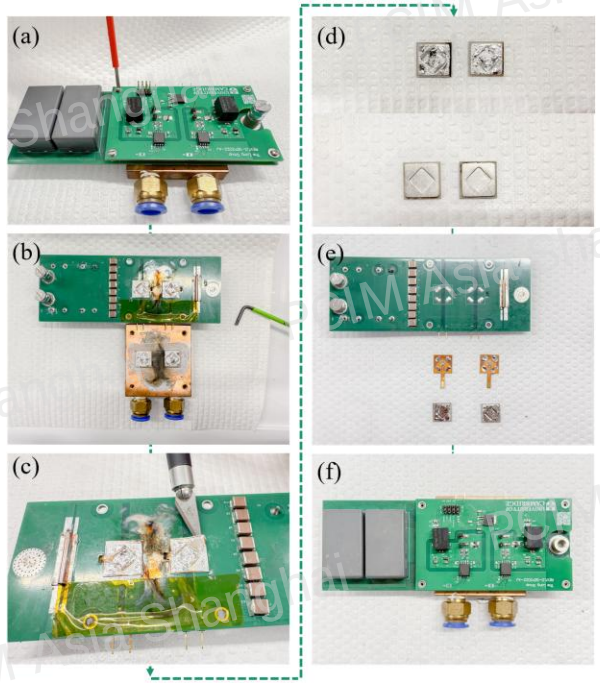
Repairable, Recyclable, and Reliable Power Electronics



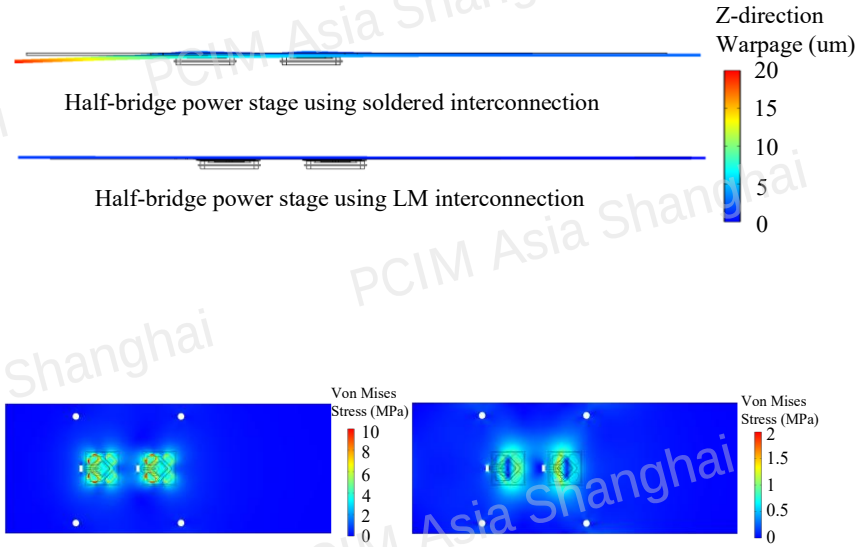
Using Liquid Metal (LM) for components' connection to PCBs



Process of LM based PCB assembling



Straight forward Repairing/Replacing failed SiC device package enabled by LM converter PCB assembly design



Significant thermomechanical stress reduction increasing reliability of the converter PCB assembly

Working progress:

- Corrosion of LM (GaInAg) to copper and silver needs to be investigated, particularly with power device metallization (12 month).
- Power cycling tests of entire PCB assembly will be conducted (9 month).
- One paper submitted to IEEE Trans on Power Electronics (under review).

W. Mu, A. Janabi, B. Hu, L. Shillaber and T. Long, "Liquid Metal Fluidic Connection and Floating Die Structure for Ultralow Thermomechani of SiC Power Electronics Packaging," in *IEEE Transactions on Power Electronics*, vol. 39, no. 7, pp. 7808-7814, July 2024,

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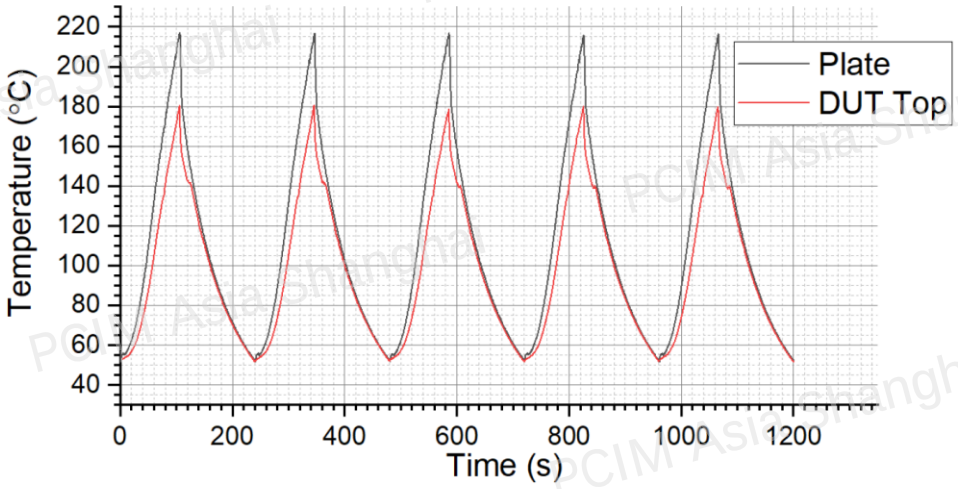
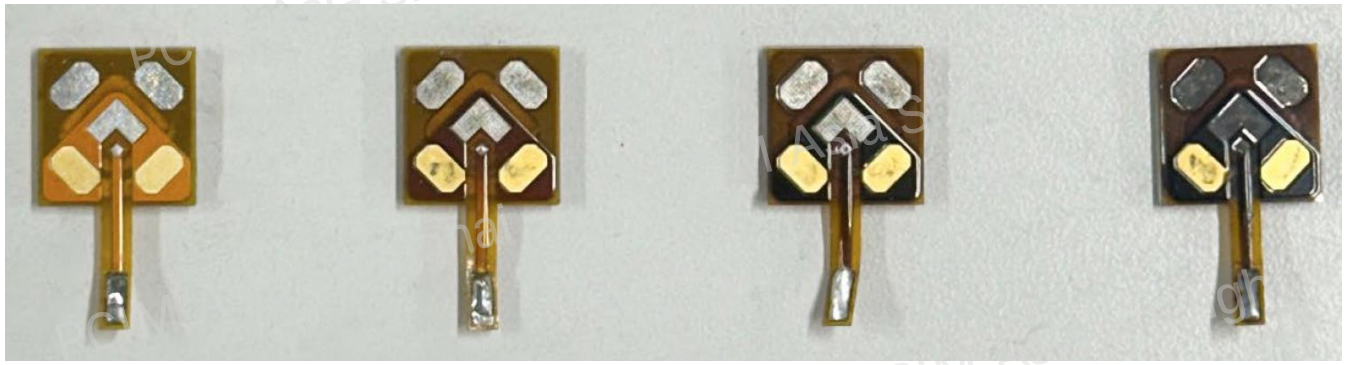
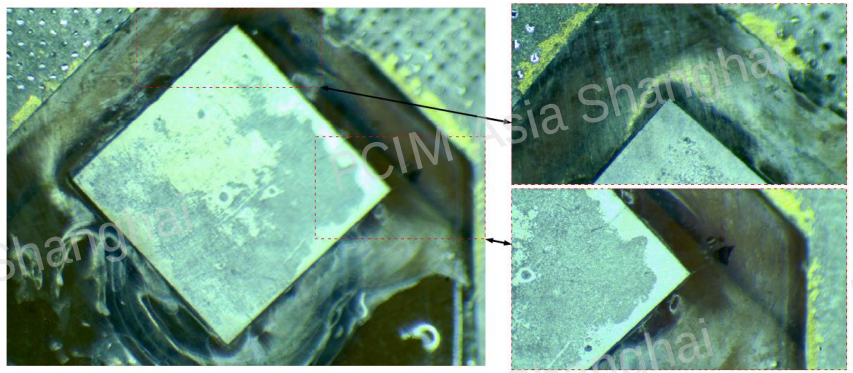
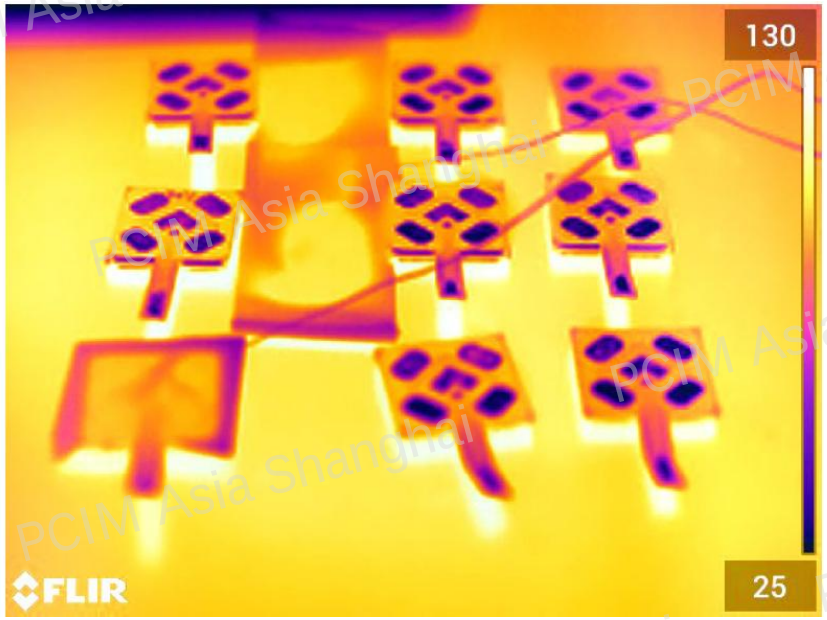
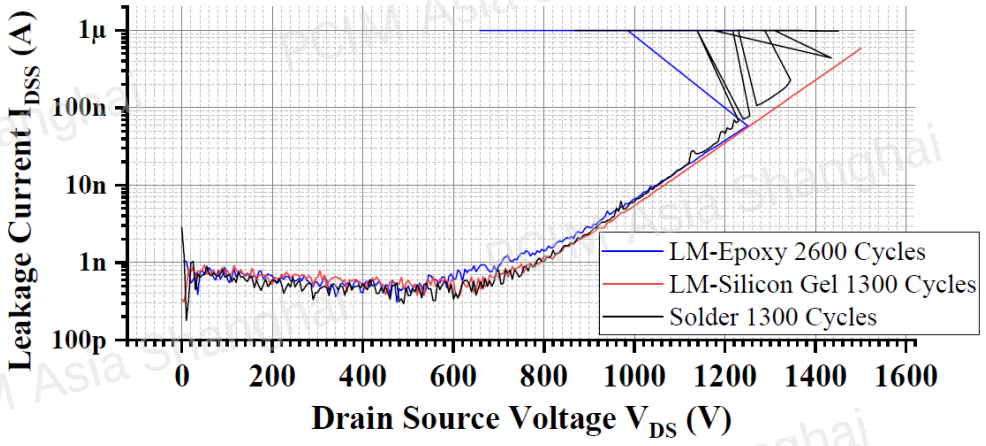
Temperature cycling shows consistence of LM and damming











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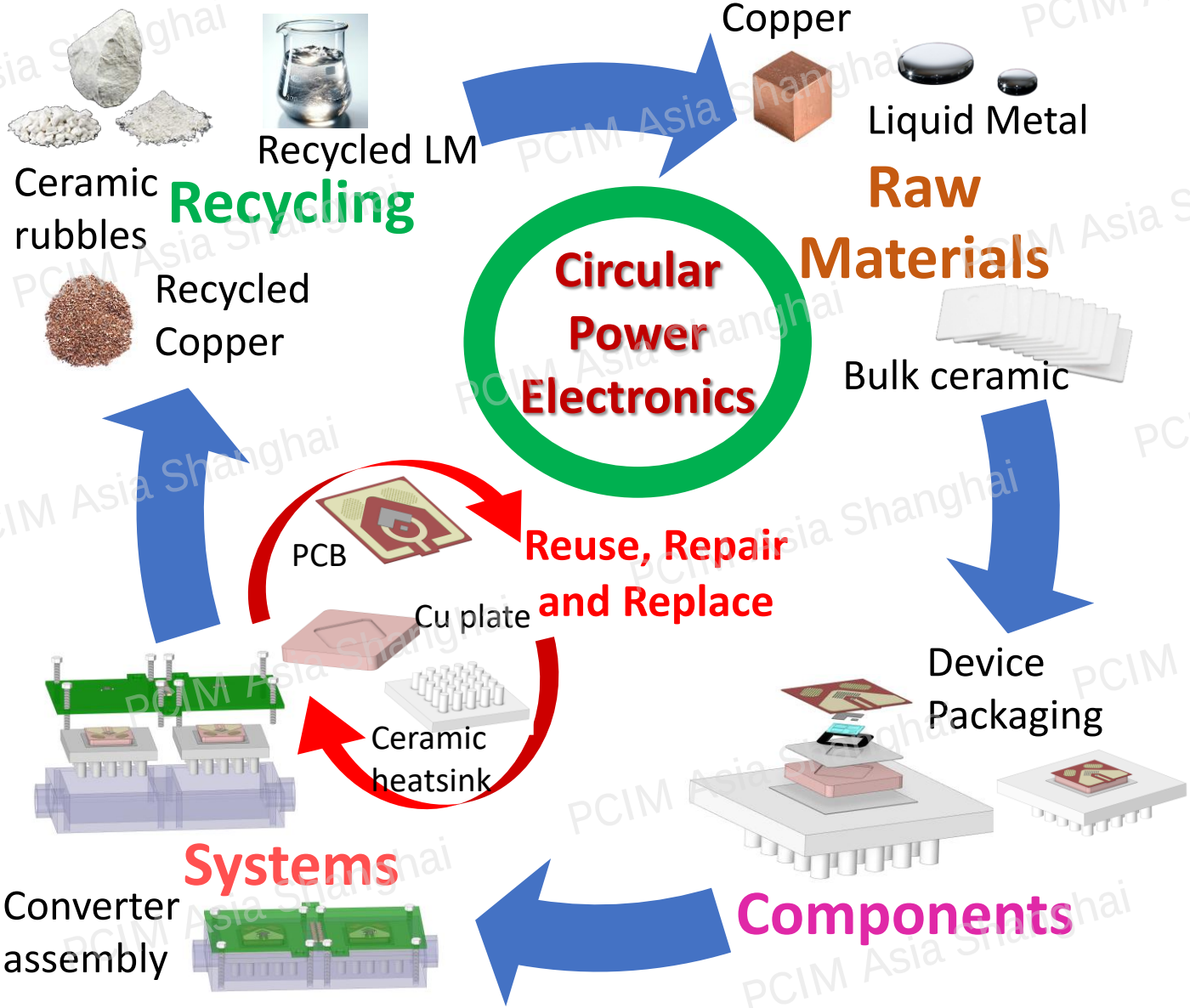
Circular Power Electronics



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APP32215: Advanced Device Packaging Enabling High Performance and Circular Power Electronics (CircularPE)

Resources and costs

Total full economic cost (fEC)	Total funding applied for	Total contribution from applying organisations
£1,339,731	£1,071,784.80	£267,946.20

Add resources and costs for each organisation

Organisation	Full economic cost (fEC)	
University of Cambridge	£841,277	Complete ✔
Compound Semiconductor Applications Catapult	£498,454	Complete ✔

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Contents

- State-of-the-art Power Supply Architecture for AI datacentres
- Advanced Power Electronics Packaging for for High Integration
- Smart Soft-Switching using Electroluminescence

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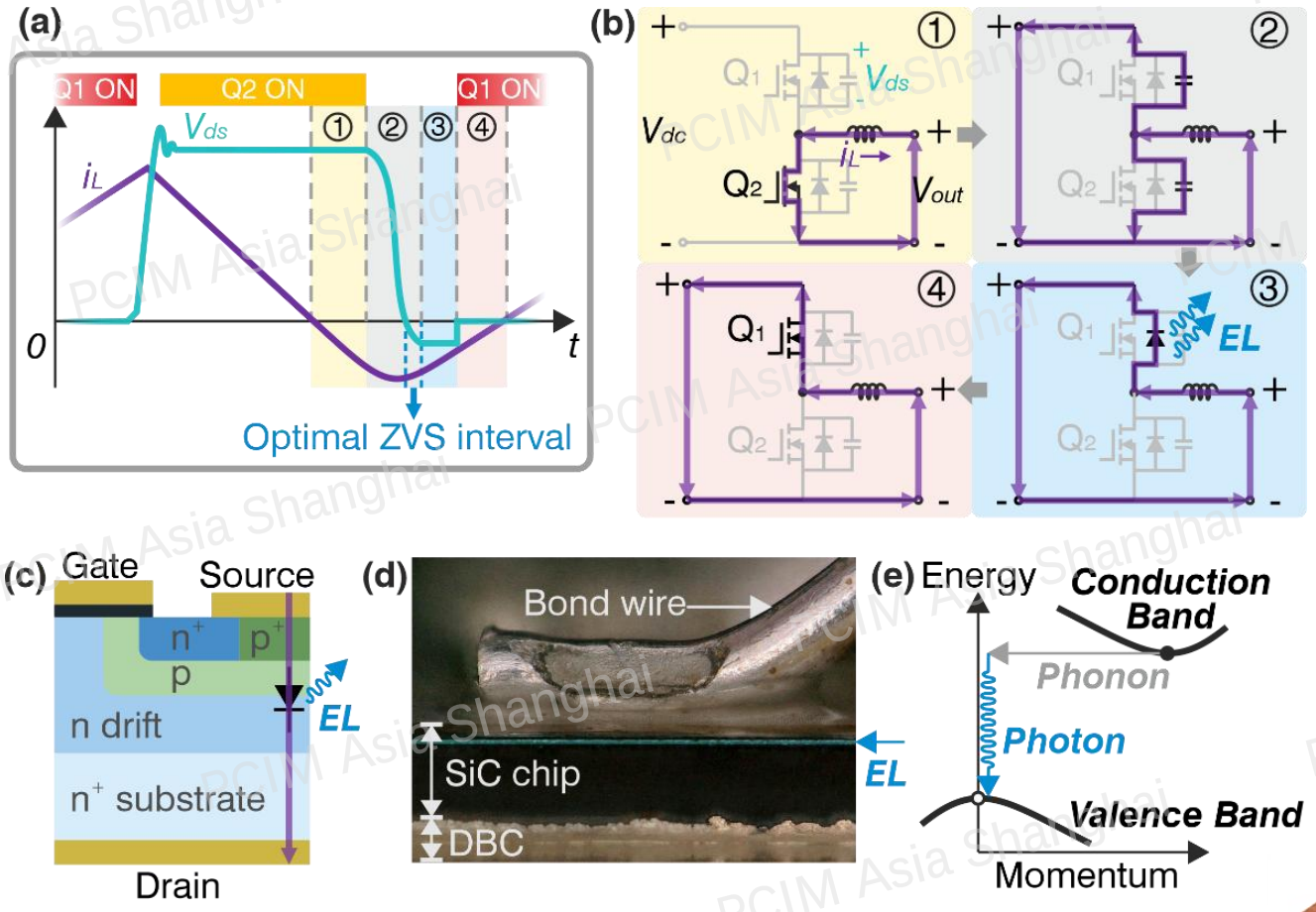
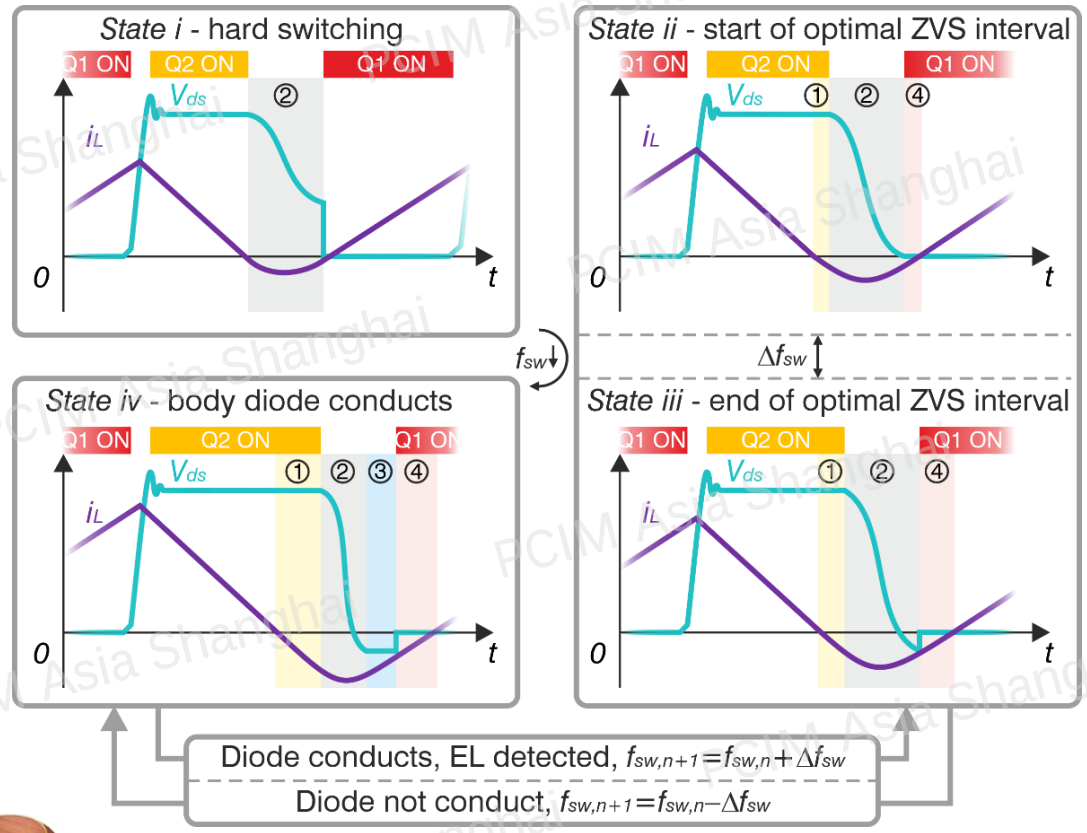
Optically Triggered Self-Adaptive ZVS





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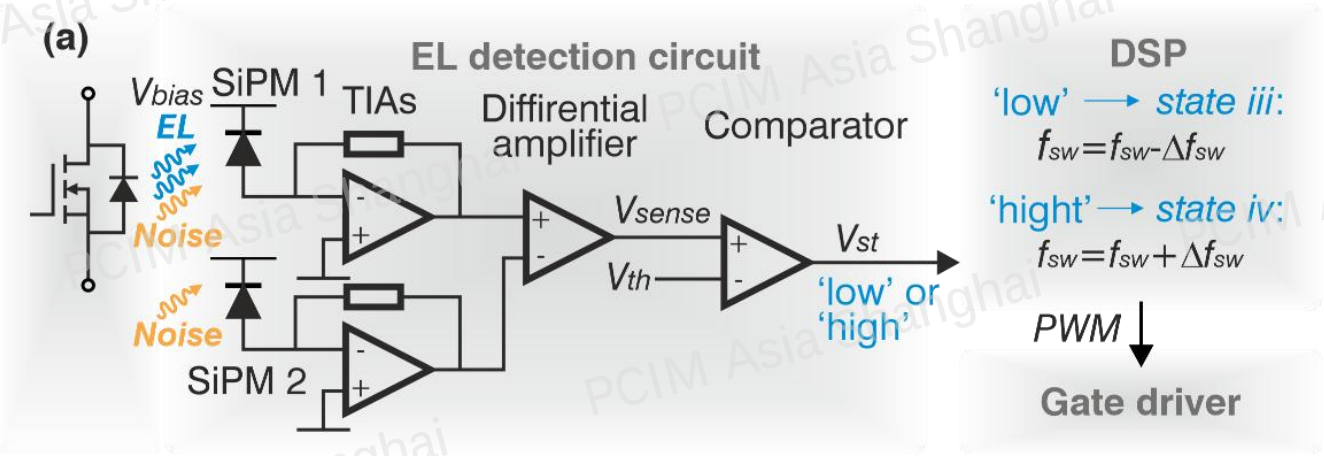
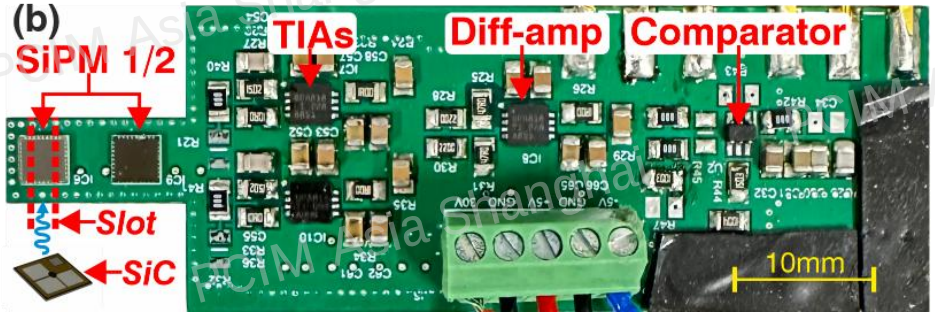
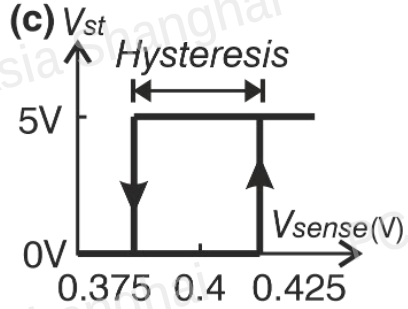
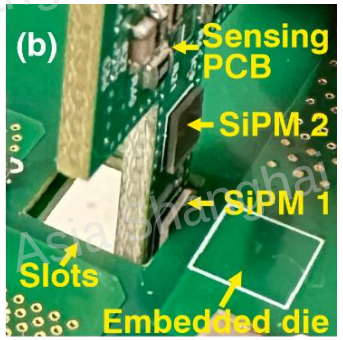
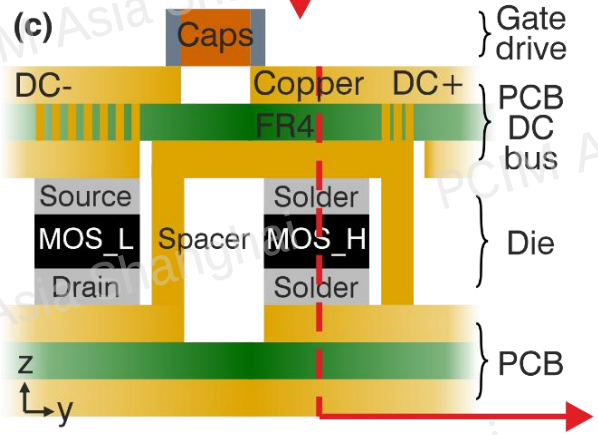
Experimental validation

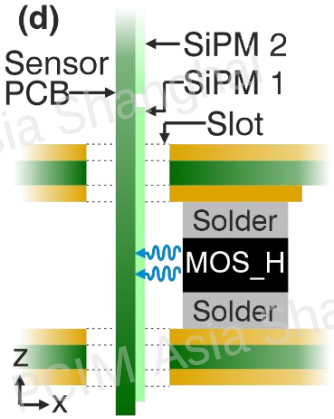












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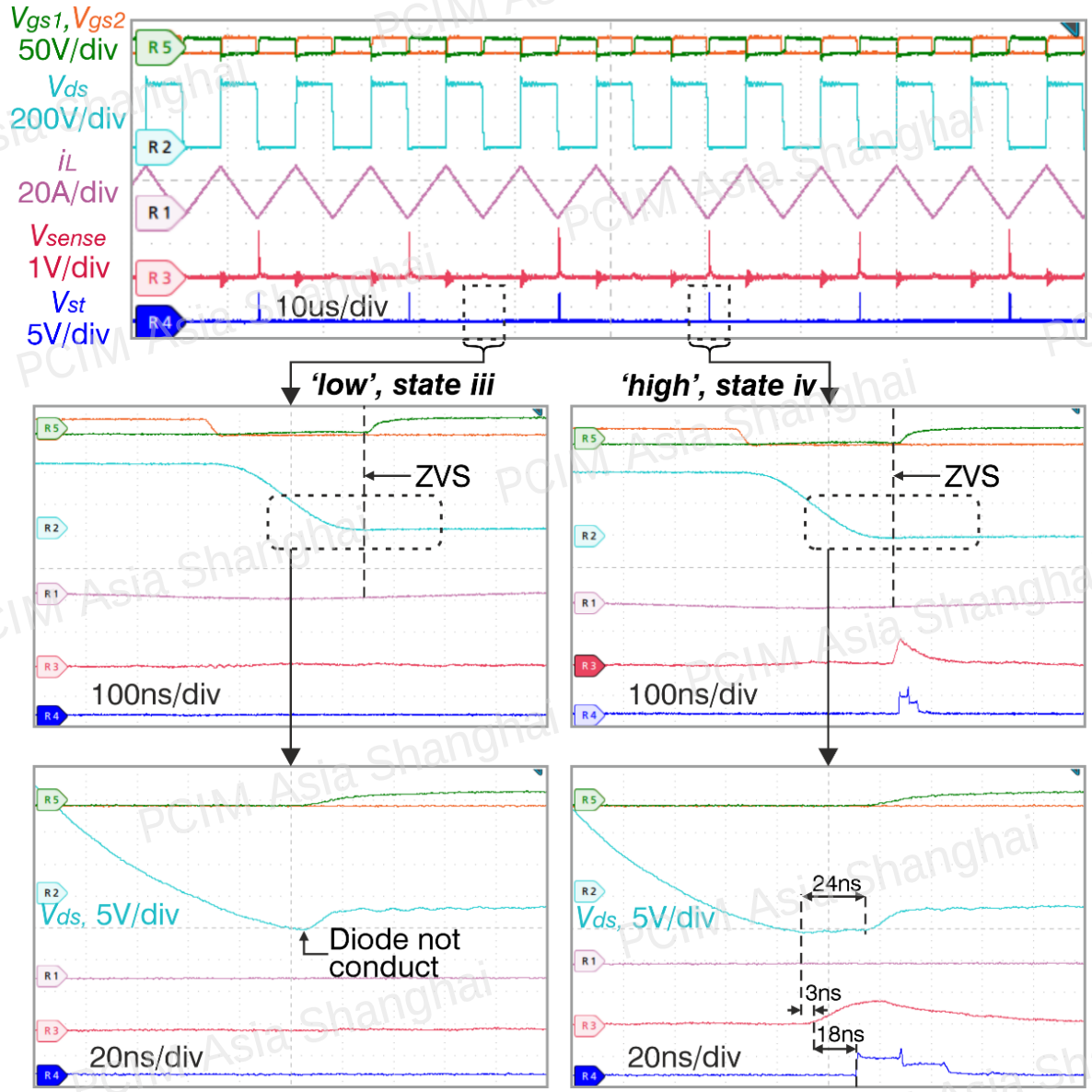
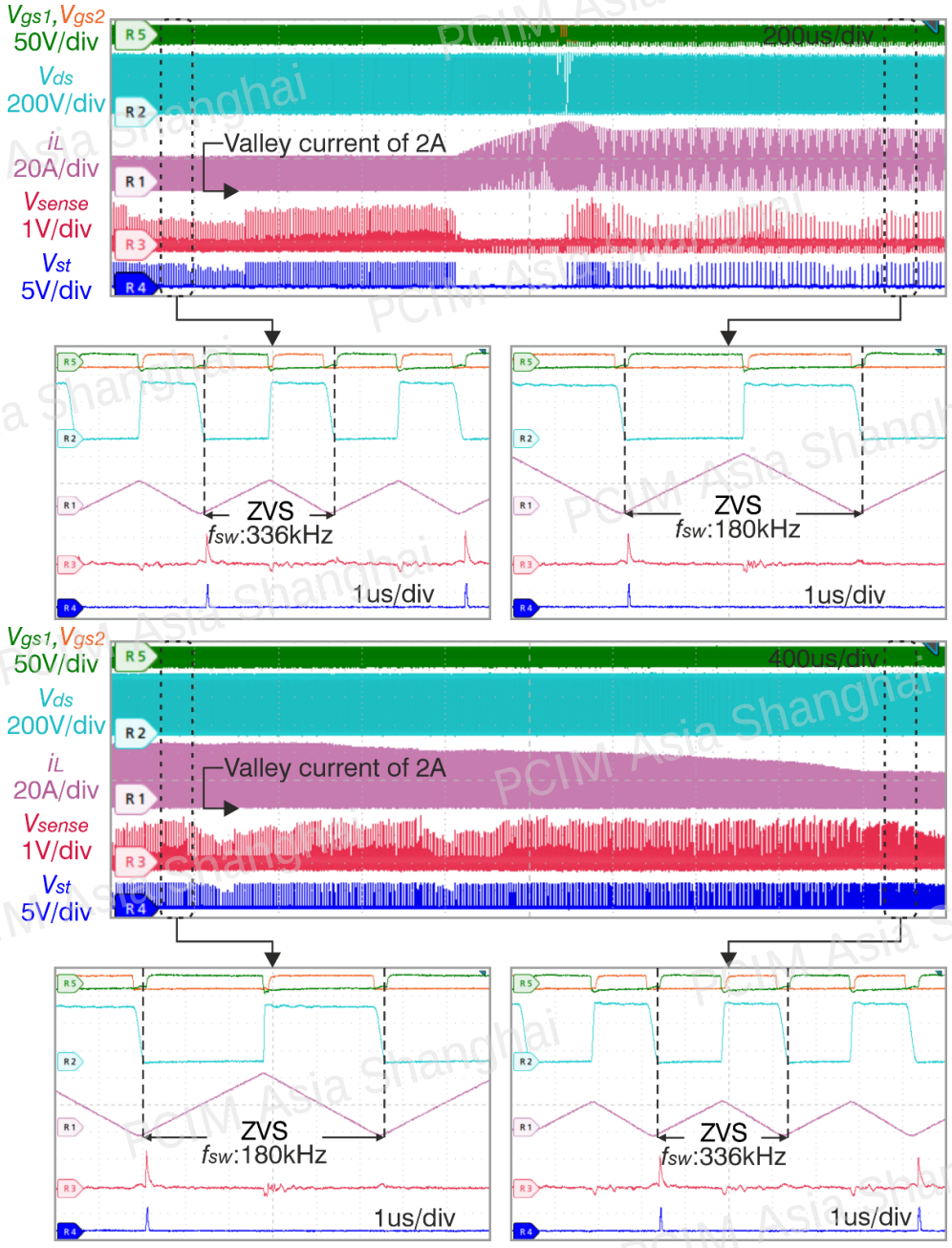
Results





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Cambridge Power Electronics Laboratory
(The Long Group)

Prof Teng Long
Chair of Power Electronics

The Long Group

Packaging	Converter	System
Embedding & Integration	AC-DC DC-DC	Transport Electrification
Packaging Materials	Switching & Soft Switching	Server/Datacenter Power Supplies
Modelling & Reliability	Magnetics & Inductive Device	Sustainable Power Electronics

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