WARWICK

UK competitiveness in power and microelectronic semiconductors

Phil Mawby

29/03/2023 – Centre for Power Electronics

Reminder of some basic facts about semiconductors

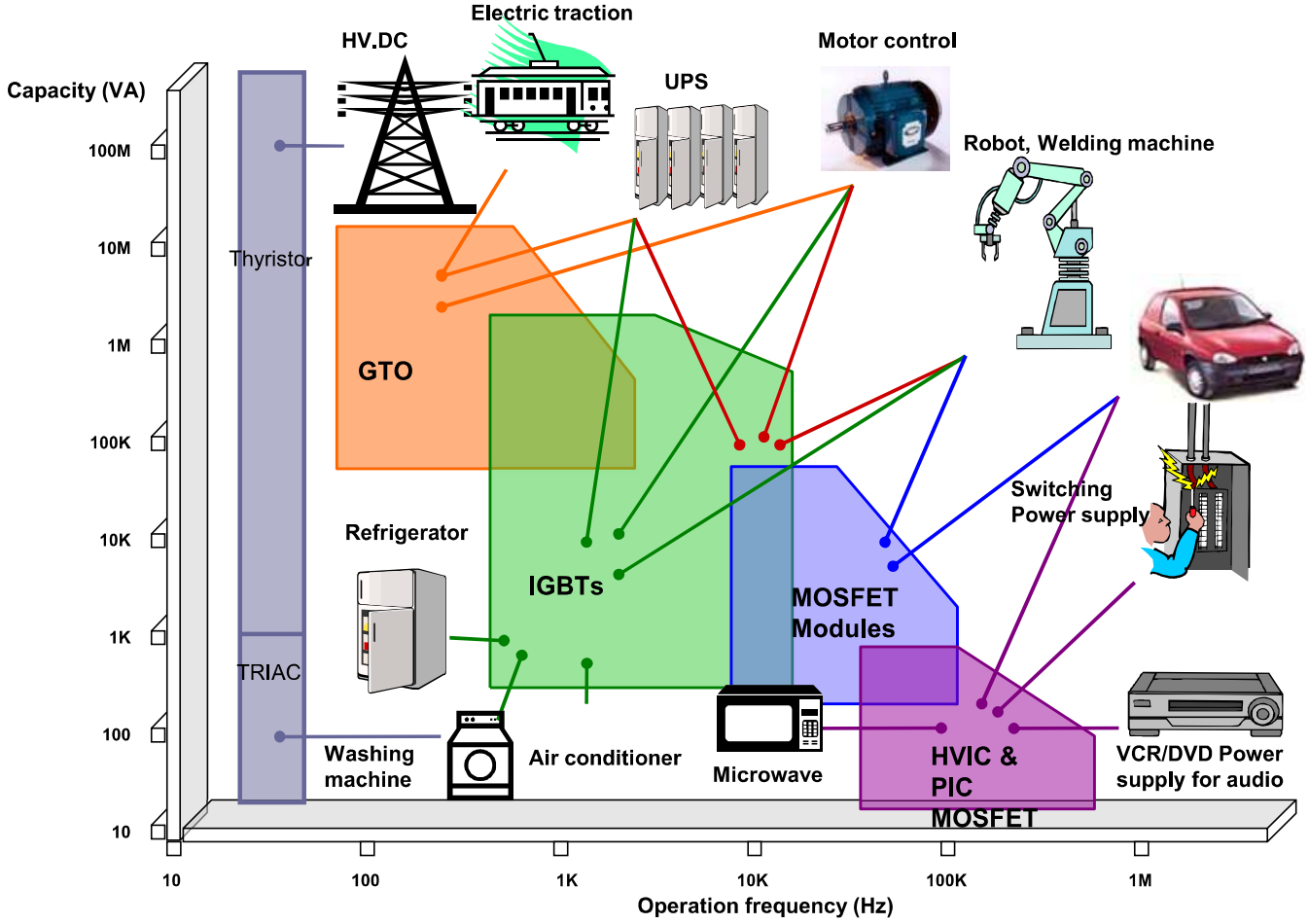
WARWICK

- Semiconductor Industry is the 4th largest industry in the world
- Almost $1trillion pa
- Power semiconductor market is approximately 10% of this - £100b pa
- Big, but it underpins so much of modern society – every thing that processes electrical energy
- Systems and products at least 10 times this so over $1trillion

What is Power Electronics?

WARWICK

- Power Electronics is based on the use of high power transistors.
- The drive is to continuously increase efficiency, whilst at the same time increase power density
- Power devices switch at high speeds in converting electrical power
- mW- GW


Capacity (VA)
100M
10M
1M
100K
10K
1K
100
10
Thyristor
TRIAC
HV.DC
Electric traction
UPS
Motor control
Robot, Welding machine
GTO
IGBTs
MOSFET
Modules
Refrigerator
Switching
Power supply
Washing
machine
Air conditioner
Microwave
HVIC &
PIC
MOSFET
VCR/DVD Power
supply for audio
10
100
1K
10K
100K
1M
Operation frequency (Hz)

WARWICK

What is different about Power Devices?

WARWICK

- The device features are bigger than for current generation leading edge IC technology
  - Can use earlier generation processing equipment

- Long drift region needed for blocking voltage requirements
  - Need thicker epitaxy layers (depending on voltage)
  - Different for lateral devices

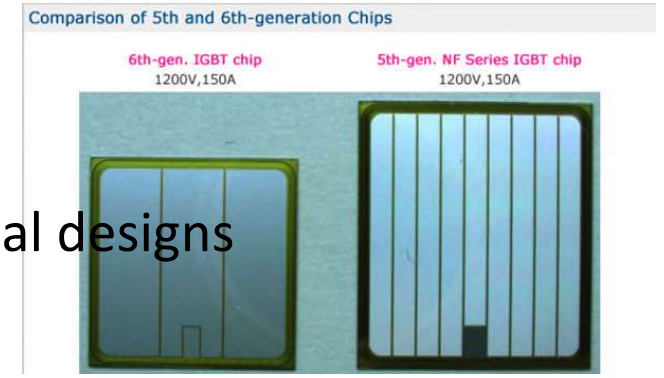
- Physically larger area – to handle current - proportional

- Use fewer masking steps (which dictates the processing cost)
  - 7/8 masking layers as opposed to 30+ layers for processor chips

What is different about Power Devices? ….

WARWICK

- Most high power devices are vertical in structure
- Most modern devices come as chips – some traditional designs are full wafers (4”-8”)
- Special structures are needed to terminate the high electric field
- Ion Implantations can be considerably deeper



Power Semiconductor Fab locations in UK

WARWICK

Semefab

Clas-SiC WAFER FAB

DIODES INCORPORATED

DYNEX SEMICONDUCTOR

CGD CAMBRIDGE GaN DEVICES

nexperia

IXYS

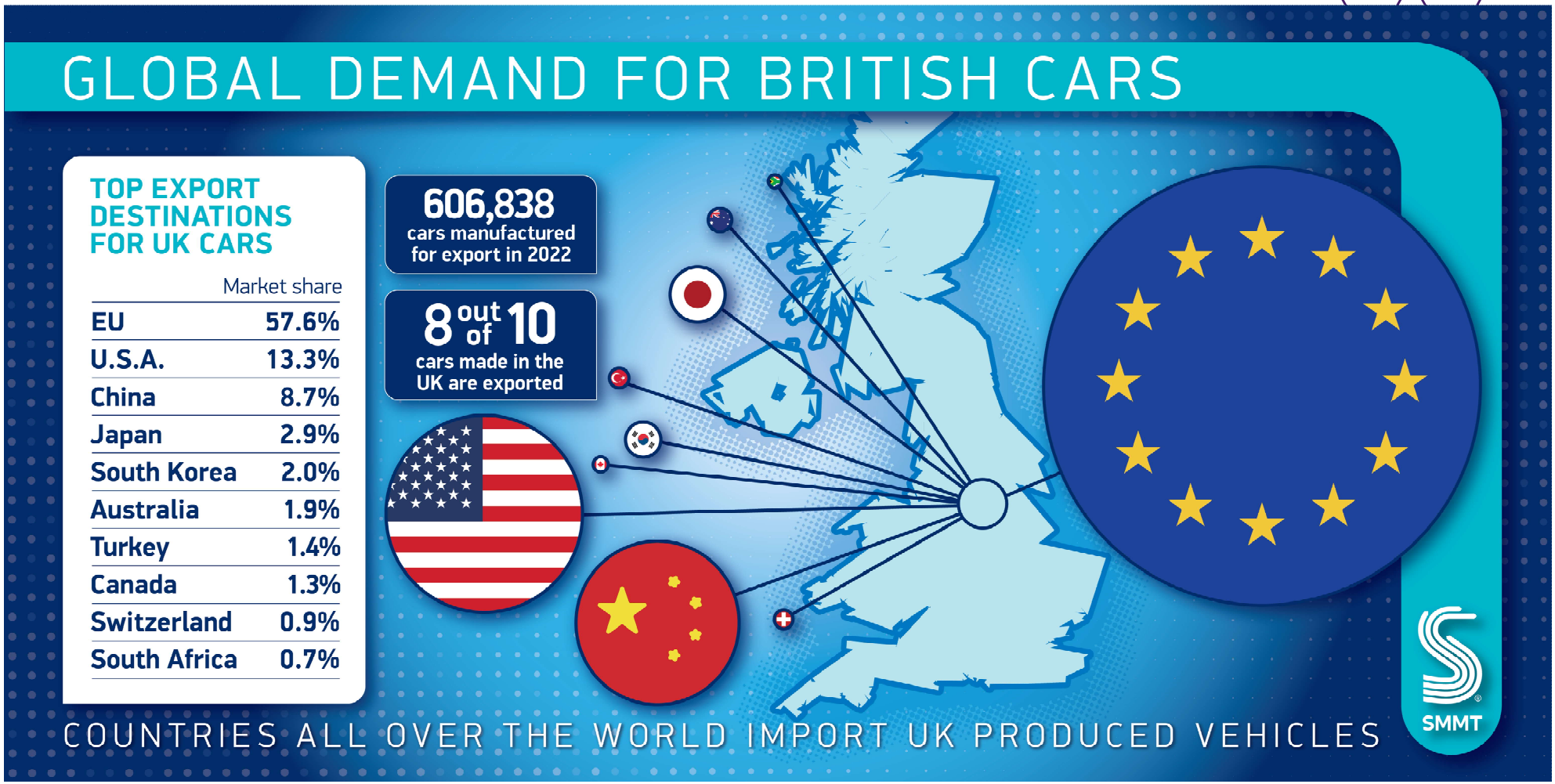
So from this one Market – EV drivetrains what does this mean

WARWICK

- These little relatively small devices are at the heart of electrifying everything
  - Almost anything that moves – road, rail, marine, aviation
  - And everything that doesn't – new electricity grid and power infrastructure
  - Including renewable energy


GY65 NRJ


A3XX-100


GLOBAL DEMAND FOR BRITISH CARS
TOP EXPORT DESTINATIONS FOR UK CARS
Market share
EU 57.6%
U.S.A. 13.3%
China 8.7%
Japan 2.9%
South Korea 2.0%
Australia 1.9%
Turkey 1.4%
Canada 1.3%
Switzerland 0.9%
South Africa 0.7%
606,838 cars manufactured for export in 2022
8 out of 10 cars made in the UK are exported
SMMT
COUNTRIES ALL OVER THE WORLD IMPORT UK PRODUCED VEHICLES

Source : SMMT

Why is power becoming so important?

WARWICK

- 600,000 cars per year
  - If all electrified with an average of 80kW – 200A 800V dc voltage
  - Each inverter will probably need 8 IGBTs 75A and 8 Diodes per phase ~ 1cm2 of silicon each – say 50cm2
  - 20cm wafer – 300cm2
  - The means 1 wafer – 6 or so cars
  - 100k wafers per year just for this one market in the UK
  - This assumes very high yield and conservative power rating
  - module value £300 x 600000 = £180m pa

Device Structures for modern Power Devices

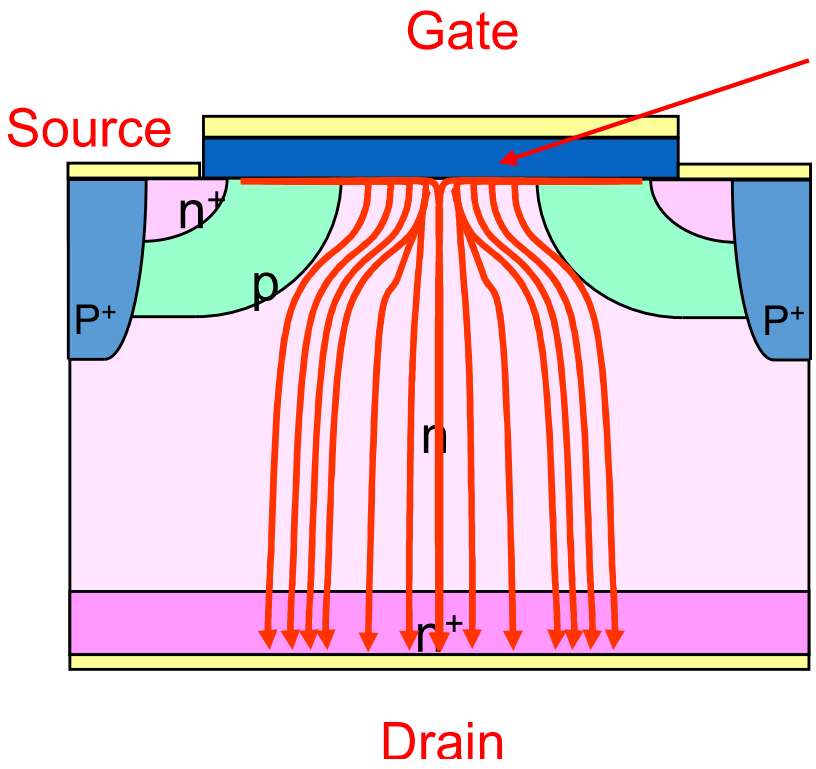
WARWICK

- Chip manufacture as opposed to full-wafer devices (HV thyristors and diodes)
- MOSFETs and IGBTs are the modern workhorses for power switches
- The top of the wafer is very similar for both devices
- For IGBTs, the backside of the device varies with successive generations

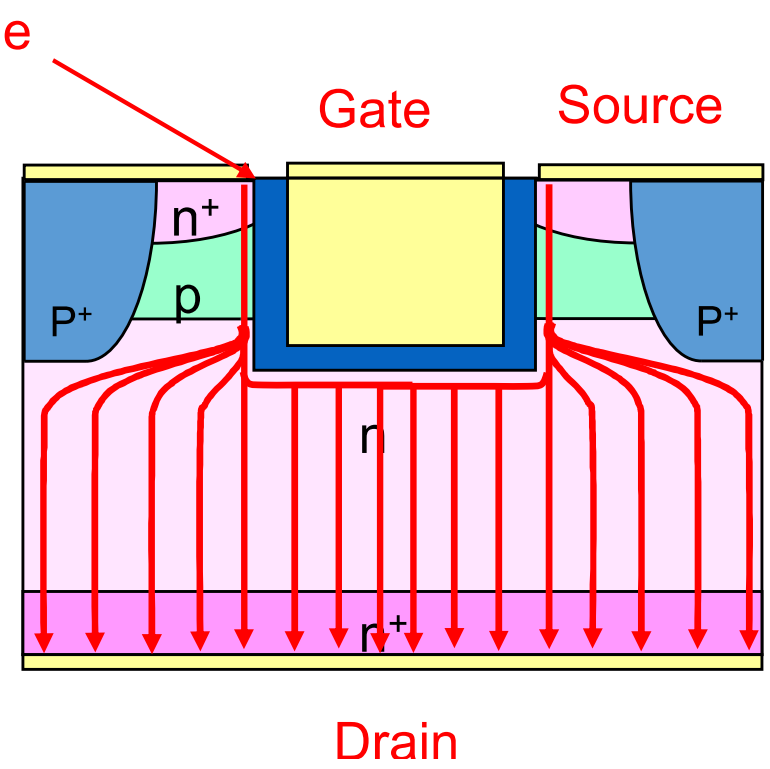
Comparison of top-side MOSFET Structures

WARWICK

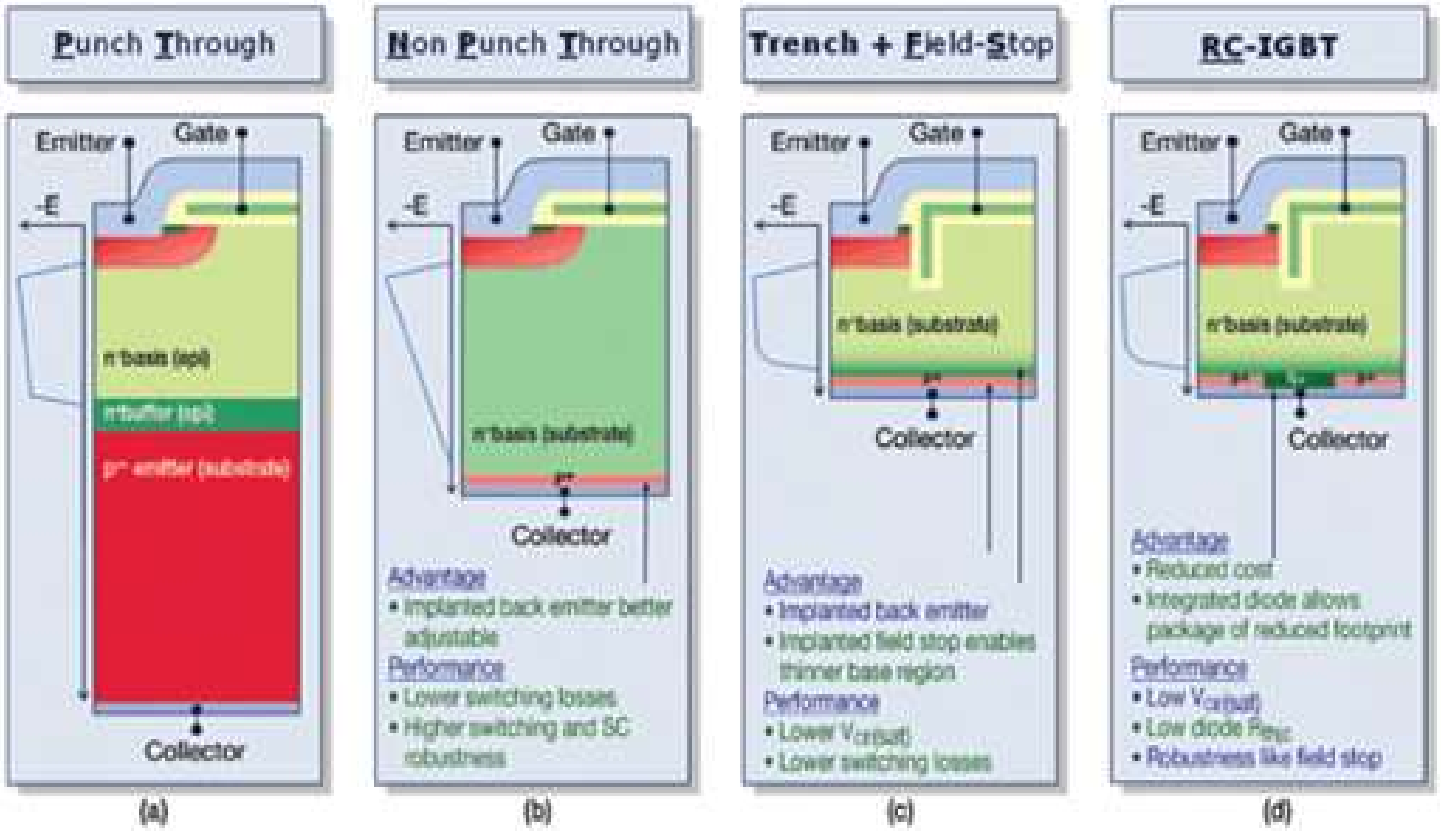
DMOS Structure



Trench Structure

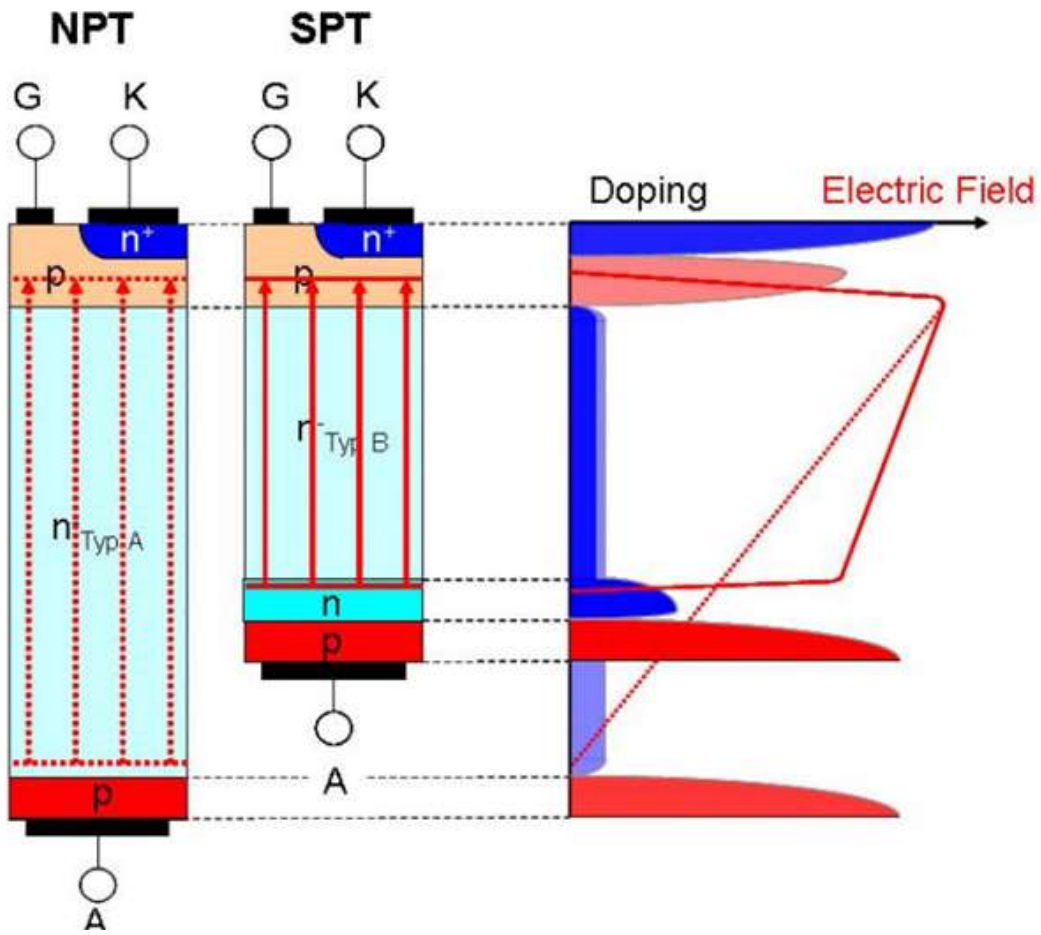


Comparison of IGBT Structure Evolution



Ref:https://www.electronicproducts.com/igbts-for-embedded-systems/

- Comparison of punch through and non-punch through



Ref: ABB – Munaf Rahimo

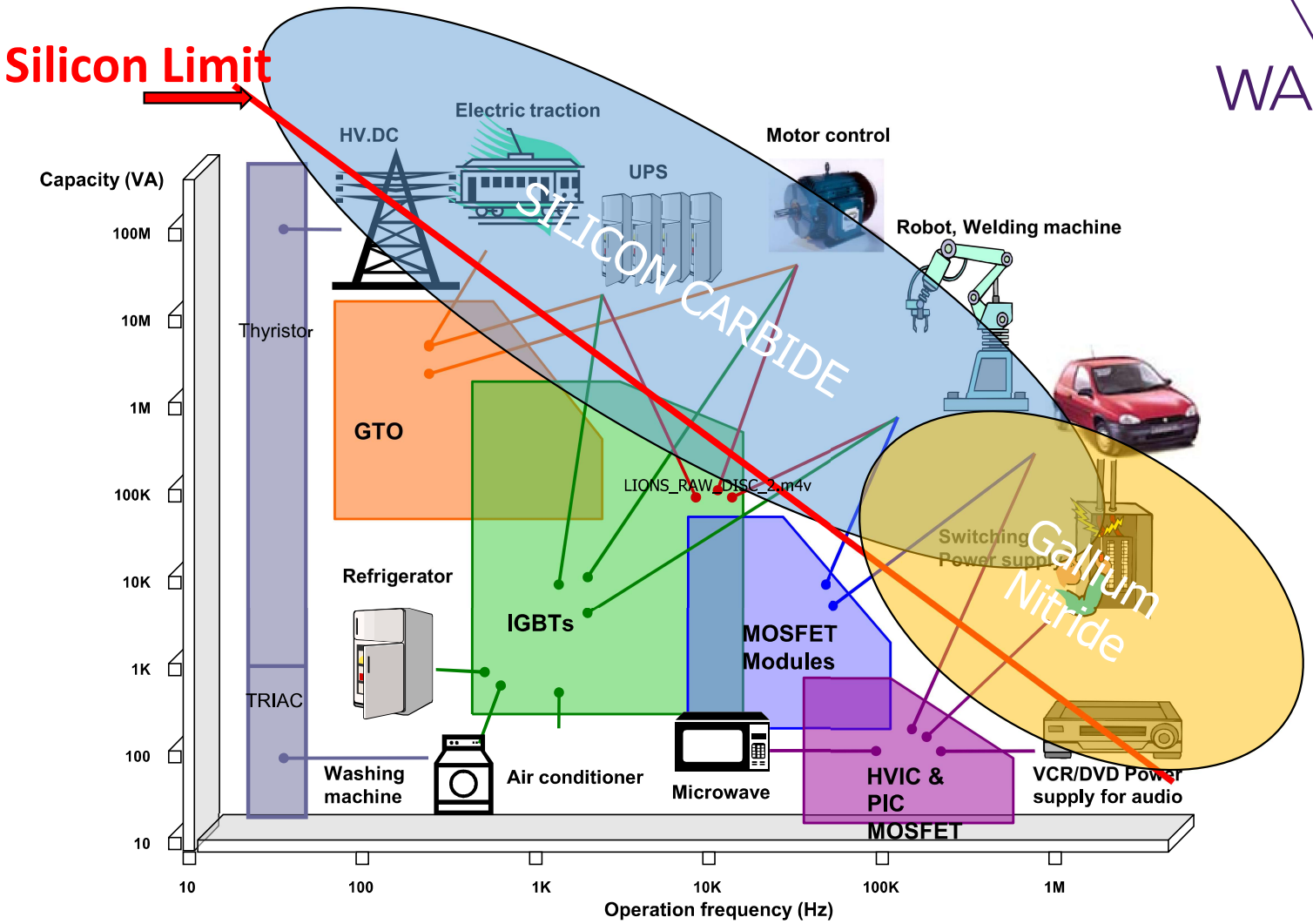
New Materials

WARWICK

- WBG materials – silicon carbide (SiC) and gallium nitride (GaN)

- SiC is very similar to silicon in structures and main process flow
  - Oxidation and implantation anneals are done at higher temperature
  - Must use RIE etching
  - No appreciable dopant diffusion

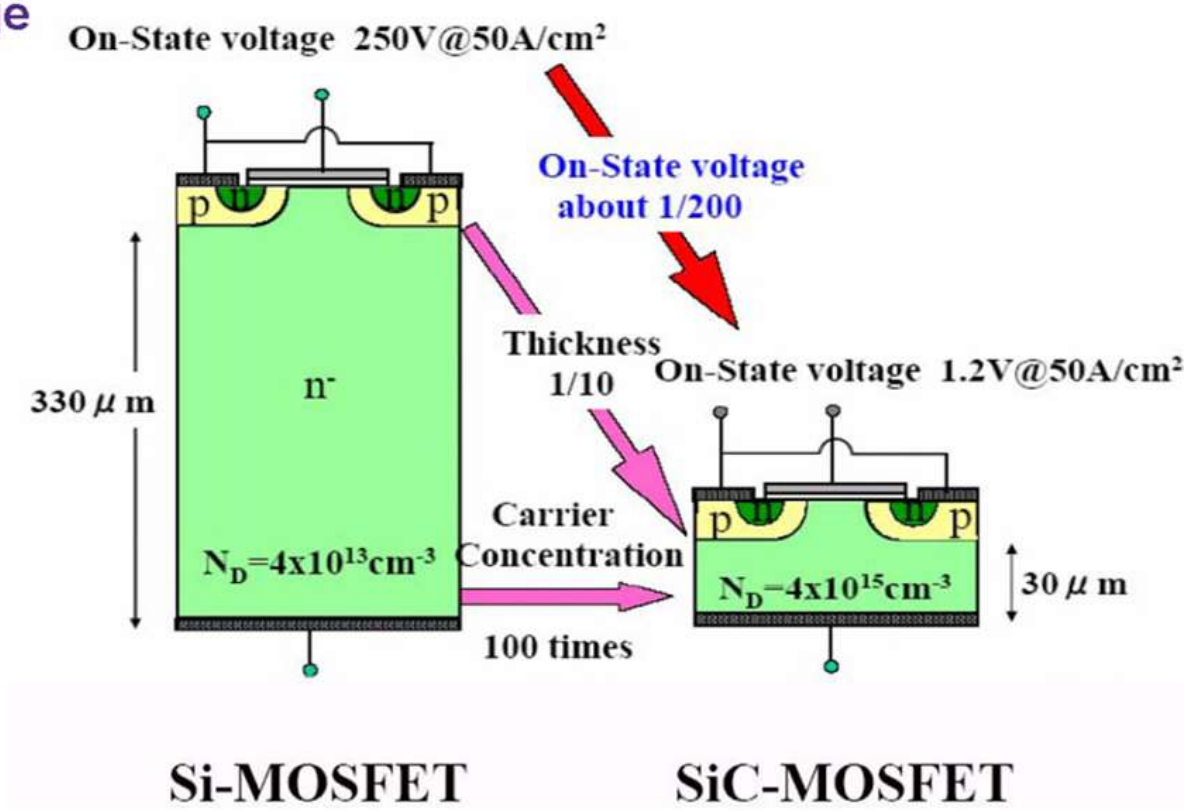
- GaN is very different
  - No GaN substrates – needs to be grown on another material
  - Generally lateral devices – area increase with voltage
  - Use a 2-DEG for channel – very fast
  - Material is very defective – a good thing?


Silicon Limit
Capacity (VA)
100M
10M
1M
100K
10K
1K
100
10
HV.DC
Electric traction
UPS
Motor control
Robot, Welding machine
SILICON CARBIDE
Thyristor
GTO
LIONS_RAW_DISC_2.m4v
Switching Power supply
Gallium Nitride
Refrigerator
IGBTs
MOSFET Modules
TRIAC
Washing machine
Air conditioner
Microwave
HVIC & PIC MOSFET
VCR/DVD Power supply for audio
10
100
1K
10K
100K
1M
Operation frequency (Hz)

WARWICK

SiC MOSFET drift region

- Higher carrier concentration
- Lower on-state voltage
- Thinner devices



Sources: SatCon Technology Corp

- New Packaging required

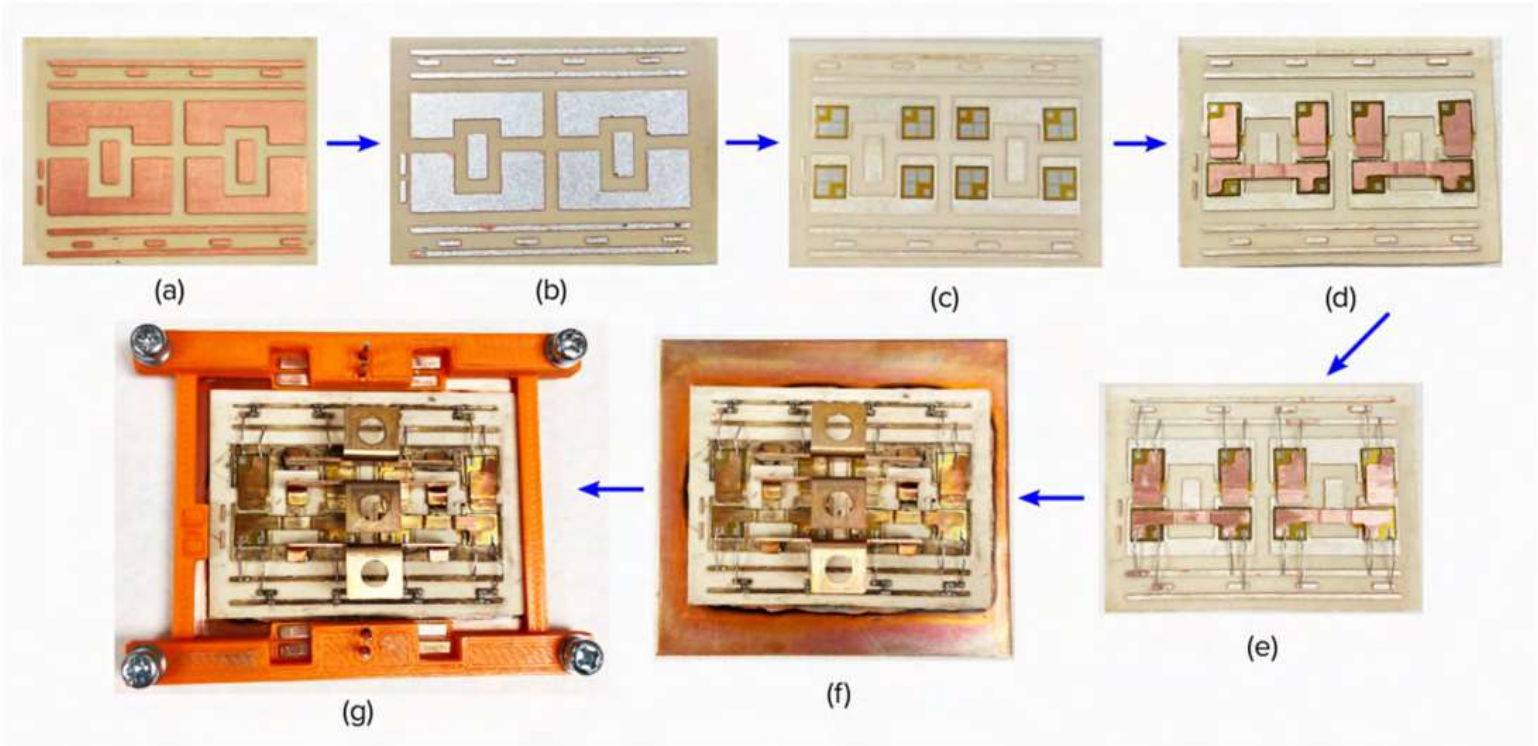


Fig. 5. Power module assembly process: (a) custom-made wet etched DBC board, (b) silver coated DBC board, (c) die attachment silver sintering, (d) copper clip silver sintering, (e) Kelvin connection wire bonding, f) gate resistor, terminal, baseplate soldering, (g) 3D printed case for silicone gel filling.

Ref: Haiyong Wan - Warwick

The UK has supply chain capability in power modules and inverter systems but is exposed to upstream material supply shortages

ADVANCED PROPULSION CENTRE UK

	Wafer	Epi-wafer	Die	Discrete / Power module		Inverter system
UK supply capability (example of UK companies)	**None (imported)**	**Limited (small scale, R&D)**	**Medium (vol constrained)**	**Medium (limited volume)**	**Good (could scale up)**	**Good (low-volume mfg)**
		iQE, Advanced Epi, Icemos (non-auto)	Nexperia, Clas-SiC, Dynex, Diodes Inc, Inex	Nexperia, Microchip, TT Electronics, Bourns, Filtronic	Nexperia, Microchip, TT Electronics, CIL	McLaren Applied, Turntide, Equipmake, Empel, Lyra, Viritech, hofer powertrain, etc.

SiC inverter value stack* High-volume automotive

The UK has good capability in ~80% of the value-stack but exposed to upstream supply chain shortages in wafers and die

Production equipment and design capability in the UK

The UK has leading process and measurement equipment suppliers for semiconductor manufacturing, e.g., Oxford instruments.
KLA and SPTS.

SPTS, based in Newport, supply precision equipment for semiconductor manufacturing:
- Wafer level defect mapping, plasma etching, dicing, vapour deposition
- £367m turnover in 2021 worldwide

The UK hosts world-class fabless companies that provide chip architecture design, and integration services internationally, e.g., 'ARM', 'Imagination' and 'Graphcore'.

* **Credits to:** Exawatt SiC and GaN inverter cost-stack study for the APC, Dec 2022.
** Inverter system includes: circuit board, ICs, microcontroller, sensors, resistors, capacitors, magnetic devices, DC-link capacitor, terminals, HV and LV connectors, bus bars, plastic injection moulding parts, cooling system, cabling, environmental management, aluminium die-cast case, sealing, electronic manufacturing, housing assembly, validation testing.

NB: mfg refers to manufacturing

The APC is funding strategic projects to build and strengthen power electronics manufacturing in the UK

ADVANCED PROPULSION CENTRE UK

APC 12: McLaren Applied – ESCAPE

- Building a secure UK end-to-end power electronic supply chain capable of competing globally
- Aligning the UK SiC supply chain to be capable of the end-to-end supply of materials and parts to support UK power electronics manufacturing
- Total project value £19.5 million, with £9.7 million funded through the APC

Project consortium

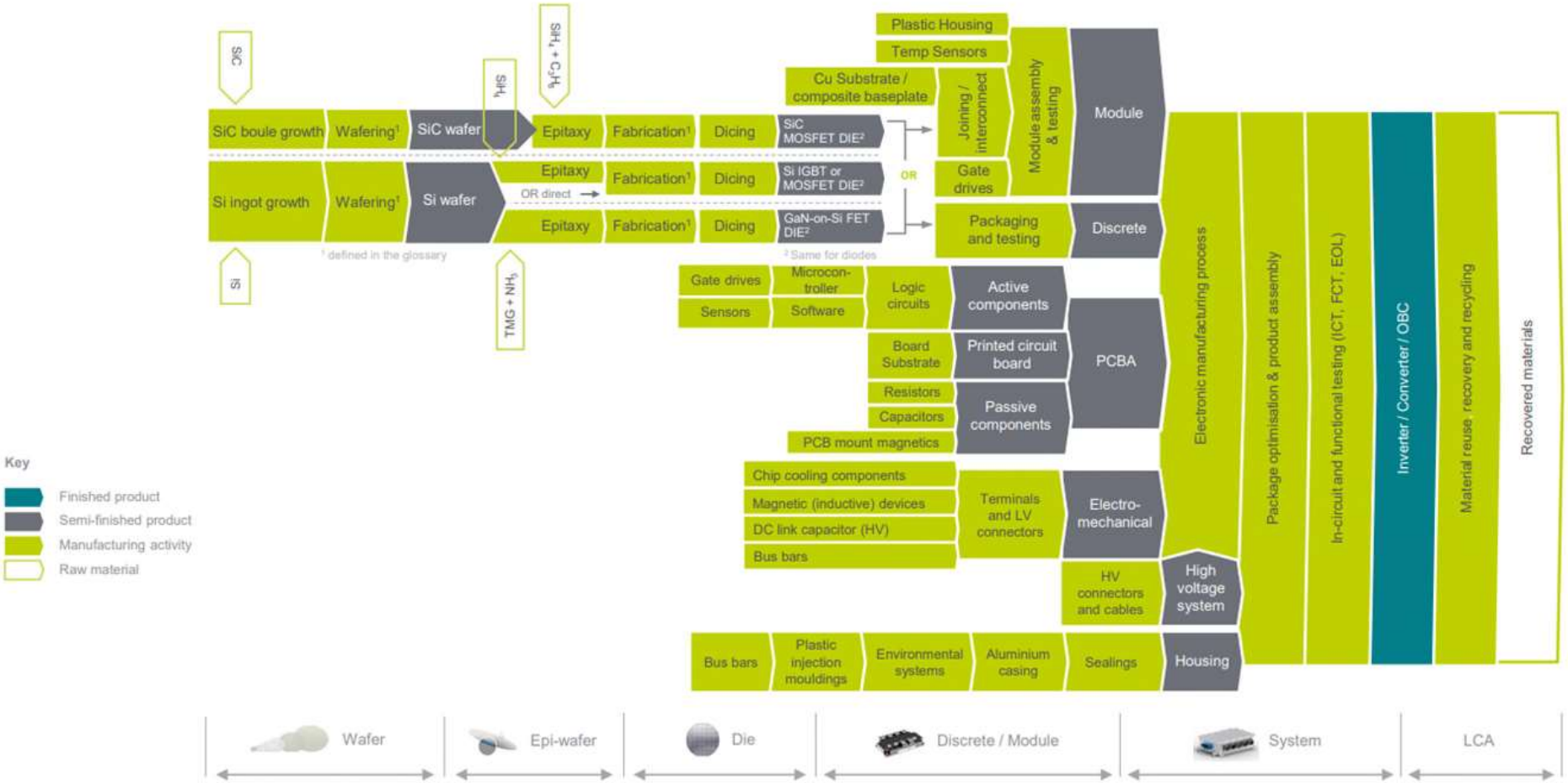
McLaren Applied (lead partner)
University of Warwick
Clas-sic Wafer Fab
Compound Semiconductor Centre
Lyra Electronics
Microchip Technology
MaxPower Semiconductor
Techworkshub
Tribus-D
Turbo Power Systems
Exawatt
Compound Semiconductor Applications Catapult

APC 15: BMW – @FutureBEV

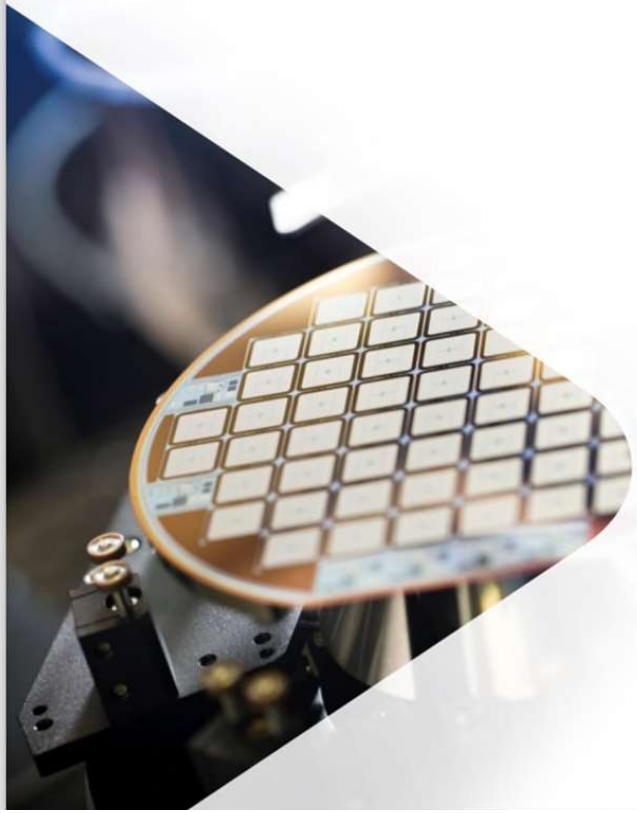
- New standardised inverter utilising 800 V SiC power modules
- Improving efficiency
- Fast charging capability
- Developing UK 800 V battery supply chain
- Total project value £30 million, with £15 million funded through the APC

Project consortium

BMW (lead partner)
Compound Semi-conductor Applications - Catapult
Custom Interconnect Ltd
Lyra Electronics
University of Warwick


SiC
SiH4
SiH4 + C3H8
SiC boule growth
Wafering1
SiC wafer
Epitaxy
Fabrication1
Dicing
SiC MOSFET DIE2
Si ingot growth
Wafering1
Si wafer
Epitaxy
OR direct
Fabrication1
Dicing
Si IGBT or MOSFET DIE2
Epitaxy
Fabrication1
Dicing
GaN-on-Si FET DIE2
OR
1 defined in the glossary
2 Same for diodes
Si
TMG + NH3
Plastic Housing
Temp Sensors
Cu Substrate / composite baseplate
Joining / interconnect
Gate drives
Module assembly & testing
Module
Packaging and testing
Discrete
Gate drives
Sensors
Microcon-troller
Software
Logic circuits
Active components
Board Substrate
Printed circuit board
Resistors
Capacitors
Passive components
PCB mount magnetics
PCBA
Chip cooling components
Magnetic (inductive) devices
DC link capacitor (HV)
Bus bars
Terminals and LV connectors
Electro-mechanical
HV connectors and cables
High voltage system
Bus bars
Plastic injection mouldings
Environmental systems
Aluminium casing
Sealings
Housing
Electronic manufacturing process
Package optimisation & product assembly
In-circuit and functional testing (ICT, FCT, EOL)
Inverter / Converter / OBC
Material reuse, recovery and recycling
Recovered materials
Key
Finished product
Semi-finished product
Manufacturing activity
Raw material
Wafer
Epi-wafer
Die
Discrete / Module
System
LCA

Key recommendations



Building the UK's compound semiconductor supply chain

- The UK should focus on strengthening its SiC compound semiconductor supply chains for locally-produced high-performance and high-power vehicles
- Industrialising advanced die packaging can give the UK the edge in accessing high-value markets in discrete and power module devices
- Assembly and manufacturing inverters and converter systems hold 30-50% of the total power electronics value in the supply chain. UK Tier 1s can leverage strengths in differentiated products to increase local production for domestic and export markets
- Encouraging foreign direct investments in SiC and GaN technologies will allow the UK to consolidate and expand its significant footprint in vehicle manufacturing
- A lack of upstream wafer substrate manufacturing exposes the UK to supply shocks and downstream production constraints. More emphasis should be given to R&D projects that can create viable technologies for semiconductor material growth in the UK

So what is going on around the world

- USA - $280b Chips Act
- EU - €43b Chips Act
- China - $143b (1 trillion Yuan)
- South Korea - $450b
- Japan - $7b
- UK - Thinking about a possible strategy?

Can we be successful in the UK in Power semiconductors

WARWICK

- USA - $280b Chips Act
- EU - €43b Chips Act
- China - $143b (1 trillion Yuan)
- South Korea - $450b
- Japan - $7b
- UK - Thinking about a possible strategy?

So What can we do?

WARWICK

- World Class University Research is attractive to industry
- We can't compete to attract major wafer fabs (even power ~ £1b)
- We can compete in device packaging and module manufacture
- The skills shortage is acute
- UK has many power electronics design and manufactures
- These are the building blocks of modern society – can we afford not to produce these?

Thank You