Power through Innovation

UK and China Joint R&D
&
Wide Band Gap Semiconductors: UK operating in global market

Yangang Wang

Company Profile

CRRC is a world leading rail transportation equipment manufacturer
Develops and manufactures high power semiconductor devices and assemblies…

R&D Centre, Dynex, UK

Manufacturing
Dynex UK – 6” wafer fabrication

TEIC, Birmingham, UK
Opening Q3 2018

- CRRC China
- Line 3 Established 2009
- Line 4 opened 2015, capacity: 120 k IGBT wafers, 1 million pcs modules
- 8” wafer fab, 6,000 m2, class 10

- Inverter Assembly Line – CRRC China
- 13 converter product lines
- Annual output of 10 GW converters

- CRRC, China SiC
- Now in operation

株洲中车时代电气股份有限公司
ZHUZHOU CRRC TIMES ELECTRIC CO.,LTD.

Locomotive

- 1700V, 3300V, 4500V 6500V IGBT modules

Urban Rail - Metro

- 3300V and 1700V IGBT

HEV/EV

- 750V, 1200V IGBT modules
- All Silicon and hybrid Si/SiC for higher frequency applications

Wind Power

- 2.5MW IGBT power stack

PV

- 1200V hybrid SiC inverter

Power distribution

- HVDC – IGBT 3kv+
- Grid
- Electric vehicle network

Power Quality

- SVC

Drive Industry

- HV soft starter

Collaboration between Dynex and CRRC

1. UK/China Joint R&D Power Semiconductors

- CRRC acquired 75% Dynex Semiconductor share in 2008
- CRRC set up Power Semiconductor R&D Centre in 2010 in Lincoln
- R&D activities on Si and WBG gap power semiconductor chip, module technology, high power bipolar, EV assembly technology
- ~70 R&D Engineers in total
- Extensive collaborative R&D activities with CRRC and China Universities and Companies

1. UK/China Joint R&D Power Semiconductors

- CRRC funded University of Nottingham projects on IGBT reliability and health monitoring for locomotive application
- RD centre works with Nottingham on power module technology, failure analysis, power cycling test and results analysis
- RD centre collaborating with Nottingham on government, EU and ECPE founding projects from 2010, the topics were advanced power module packaging technology, HEV power train system, integrated cooling, reliability etc.
- CRRC is supporting Nottingham on EPSRC doctoral centre program
- CRRC and Nottingham are looking for wide collaboration in power electronics, motor control, reliability etc: CRRC show case in Notting on 11th Jun

1. UK/China Joint R&D Power Semiconductors

- CRRC working with University of Cambridge on IGBT and FRD die development since 2014
- CRRC has the state-of-the-art 8" chip manufacture line for full voltage (600-6500V) IGBT and FRD wafer processing
- Collaboration is on advanced IGBT and FRD design, simulation and manufacture
- 4th generation trench field stop IGBT was developed
- Smart IGBT and RC-IGBT are being developed

UNIVERSITY OF
CAMBRIDGE

1. UK/China Joint R&D Power Semiconductors

- Through Innovate UK-China bridge collaborative project, University of Cambridge is working with CRRC, Hunan University and Dynex on RC-IGBT development
- RC-IGBT is an advanced power semiconductor device with great advantages over conventional trench field stop IGBT
- CRRC has a 6” SiC wafer line and is looking for collaborations with UK Universities and companies.
- University of Cambridge and CRRC started discussing on SiC device collaboration and projects.

1. UK/China Joint R&D Power Semiconductors

- Through Innovate UK collaborative project, University of Warwick, Cambridge are working with CRRC on SiC device development
- CRRC collaborated with Warwick on SiC devices design and manufacture, Warwick trained CRRC engineers on SiC devices processing
- University of Warwick working with Chinese Universities and companies on SiC device development and applications
- CRRC supports Warwick on EPSRC doctoral centre program

THE UNIVERSITY OF WARWICK

中国中车 CRRC

1. UK/China Joint R&D Power Semiconductors

- Through Innovate UK collaborative project, University of Sheffield works with CRRC on integrated EV power system and motor development
- Through EU project, Sheffield and RD centre work on advanced planar power module development for More-Electric Aircraft
- CRRC is working with Cambridge University on EV power system
- CRRC is keen to participate in KTP projects with Sheffield

The University Of Sheffield.

UNIVERSITY OF CAMBRIDGE

中国中车
CRRC

1. UK/China Joint R&D Power Semiconductors

- By UK and EU collaborative projects, CRRC works with UK universities and companies on R&D of power electronics devices, systems, wide band gap semiconductor and applications

1. Dynex R&D sponsored projects

Innovate UK

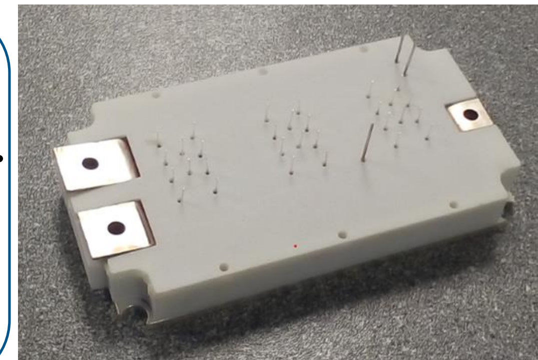
NOVAE – Integrated PMs for hybrid electric vehicles.
SiCER - SiC Power Electronics packaging. 3.3 kV+
DiSOHM – Copper wire bonding.
Intellithermod - Thermal Management. LCV's.

University of Nottingham, University of Warwick, University of Newcastle. Many industrial partners.

Innovate UK/Advanced Propulsion Centre

FIRST - **F**requent, **I**ntegrated, **R**obust, **St**op/Start **T**echnology. Dynex developed new packaging for SiC MOSFETs, no diodes. Hybrid Electric bus application.

Cummins, University of Nottingham, Castlet.

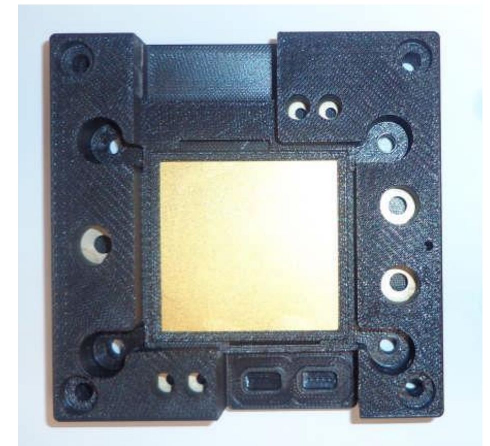


European Commission

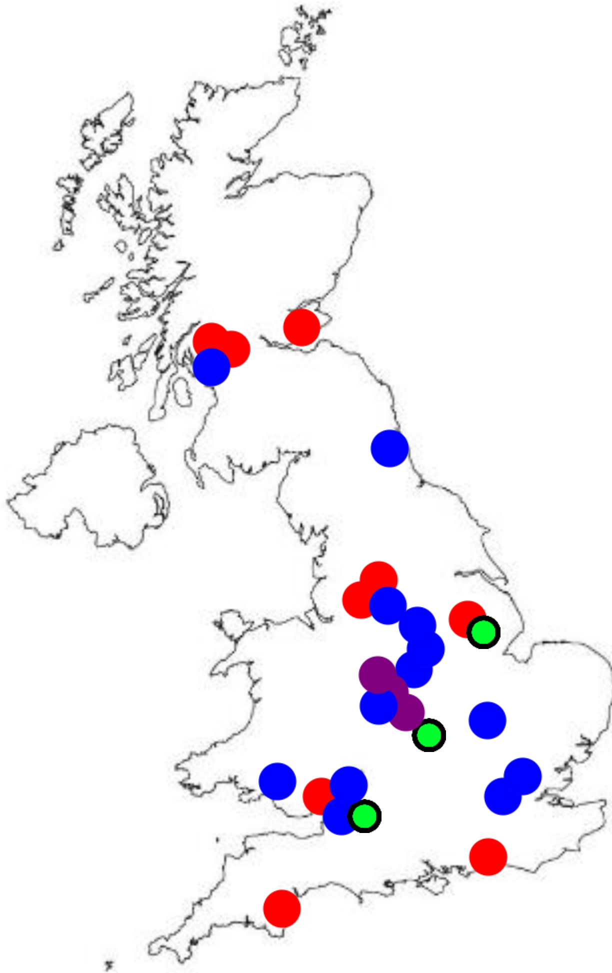
I2MPECT - **I**ntegrated, **I**ntelligent **M**odular **P**ower **E**lectronic **C**onver**T**er Wire bond free. All SiC. Aerospace application.

Siemens, Airbus, INSA, ETHZ, Safran, Uni. of Sheffield

MATPLAN – All SiC. Wire bond free. Double side cooled.



2. UK's semiconductor skills and capabilities



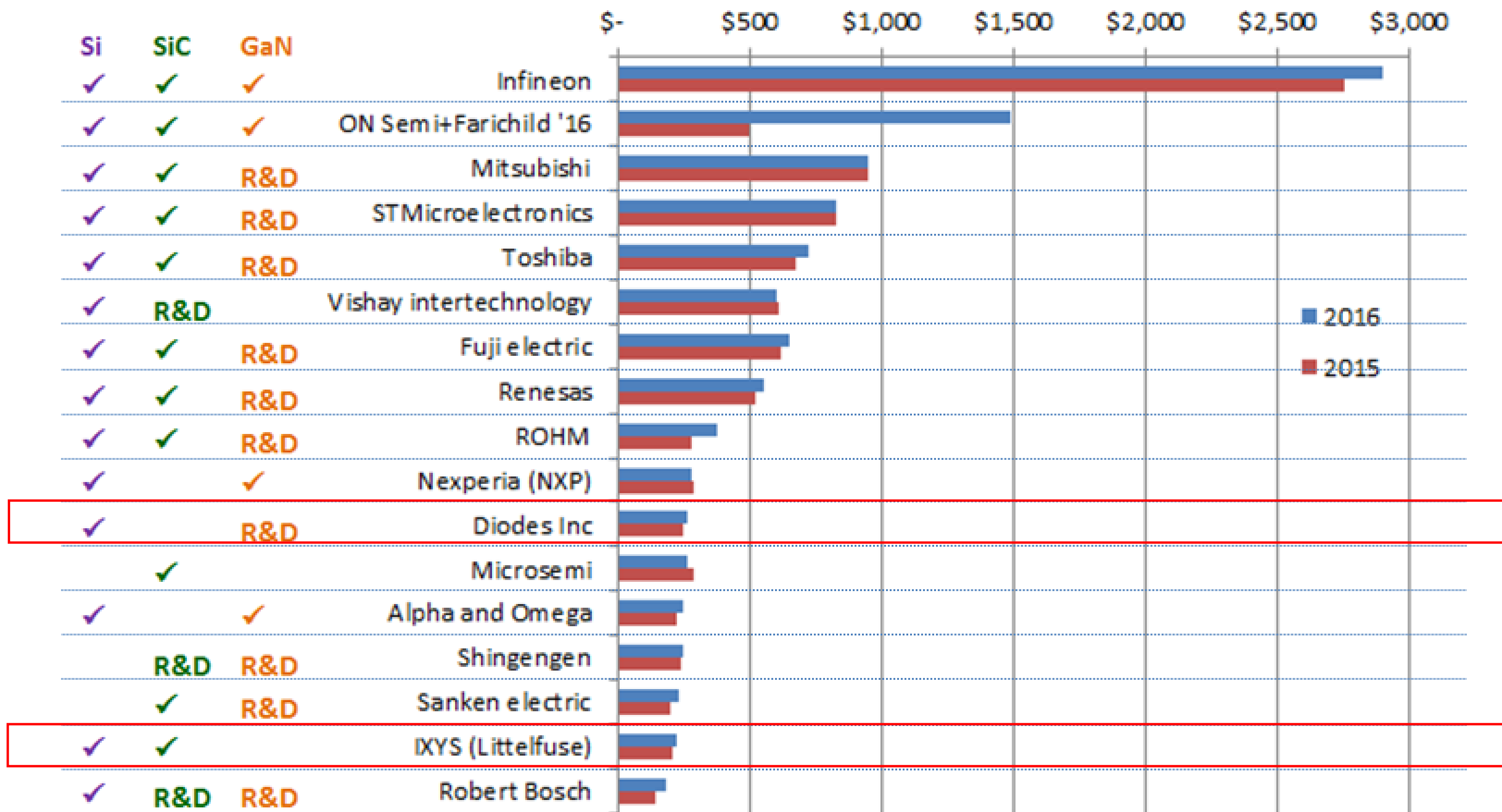
- Semiconductor wafer and/or Epitaxy fabrication facilities (Mainly Si, includes WBG and other)
- **Universities (R&D: Si & WBG)**
- Power electronics packaging (Si & WBG)
- Other R&D/product development (WBG)

- UK wide support partners and organisations
  - PEUK, EPSRC, Innovate UK, APC, Catapults, Knowledge Transfer, Techworks, NMI, IMAPS

- UK has good skills pool and resources in Si fabrication
- Strong R&D in chip development, device packaging including Si and WBG.

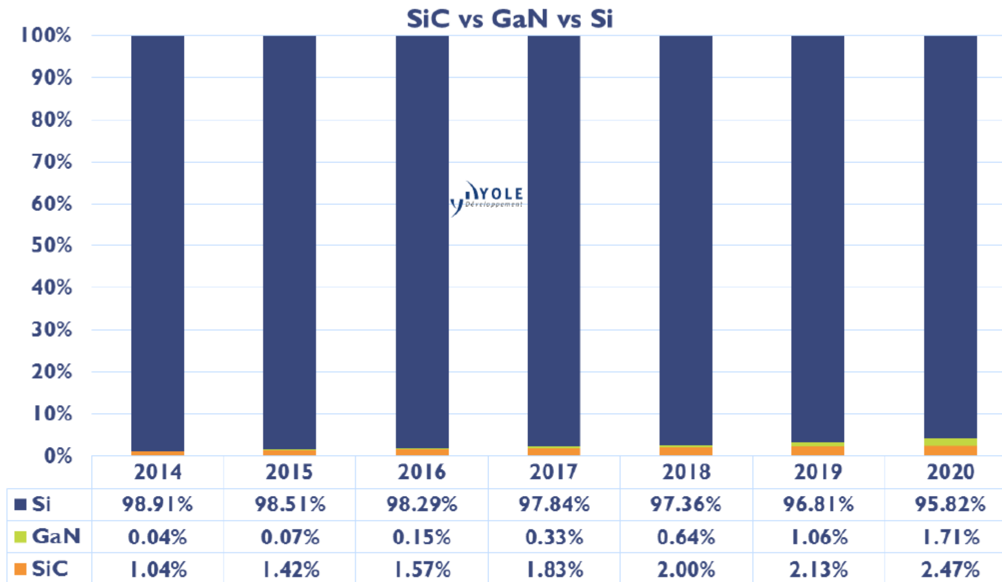
- Currently, UK relies heavily on imports for WBG wafer fabrication, chip manufacture, power modules.

2. Global Market Power Modules, IPM & IGBT



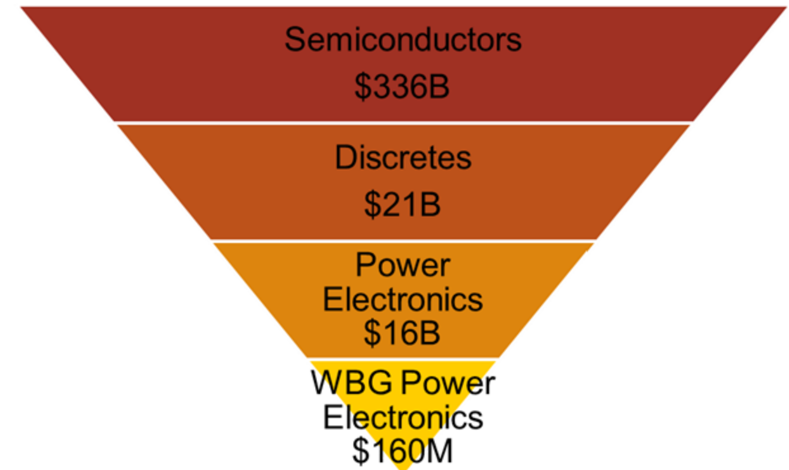
- UK based Diodes Inc. and IXYS among top 18 suppliers.
- Strong competition from Europe, Asia, USA.

2. Global market share by technology



	2014	2015	2016	2017	2018	2019	2020
Si	98.91%	98.51%	98.29%	97.84%	97.36%	96.81%	95.82%
GaN	0.04%	0.07%	0.15%	0.33%	0.64%	1.06%	1.71%
SiC	1.04%	1.42%	1.57%	1.83%	2.00%	2.13%	2.47%

* GaN nominal Scenario is considered.



- Strong demand for Si devices, WBG share is small but increasing.
- WBG PE is a very small segment of PE, PE is a very small share of total semiconductors.
- Growth of WBG devices is driven by smaller packaging, high power density and higher efficiency in Auto and industrial.
- WBG opportunities are also from growing energy demand and efficiency, environmental awareness, increase in regulations, renewable energy generation, reduction in power converter size and deduction of system cost.

2. Applications driving the WBG market

SiC power application market share

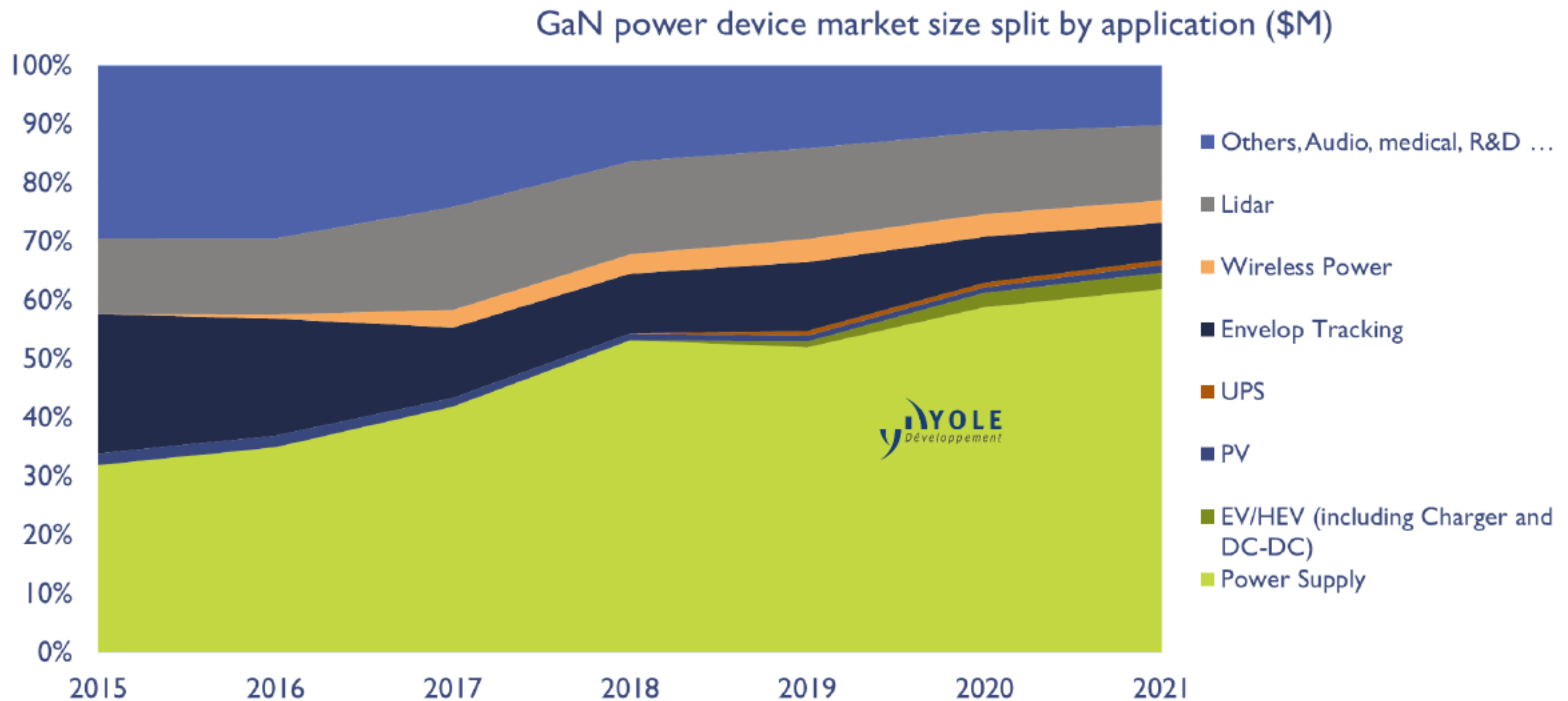
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

2016 2017 2018 2019 2020 2021 2022

- Others (Oil and Gas, Military, Medical, R&D…)
- UPS
- Motor drive (including air conditioning)
- PV
- xEV charging infrastructure
- Wind
- xEV (including on-board charger)
- PFC/power supply
- Rail (including auxillary power)

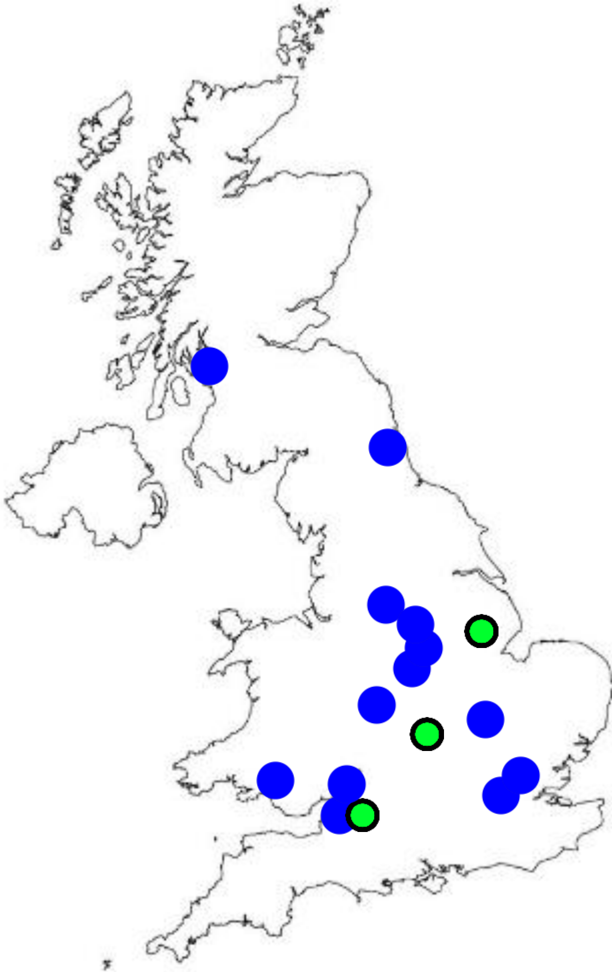
- Clean energy and EV is driving the market for SiC technology.
- WBG in H/EV will surpass power supplies.
- PV inverters and industrial motor drives significantly increases.
- SiC based power device market grows steadily, reaching $1B in 2022 with a +28% CAGR. WBG device will comprise over 12% of the PE market by 2025.

2. Applications driving the WBG market



- Smaller/LV power supplies are driving market for GaN.
- GaN based power device market to reach $280M in 2021 with a 86% CAGR.

2. UK's WBG skills and capabilities

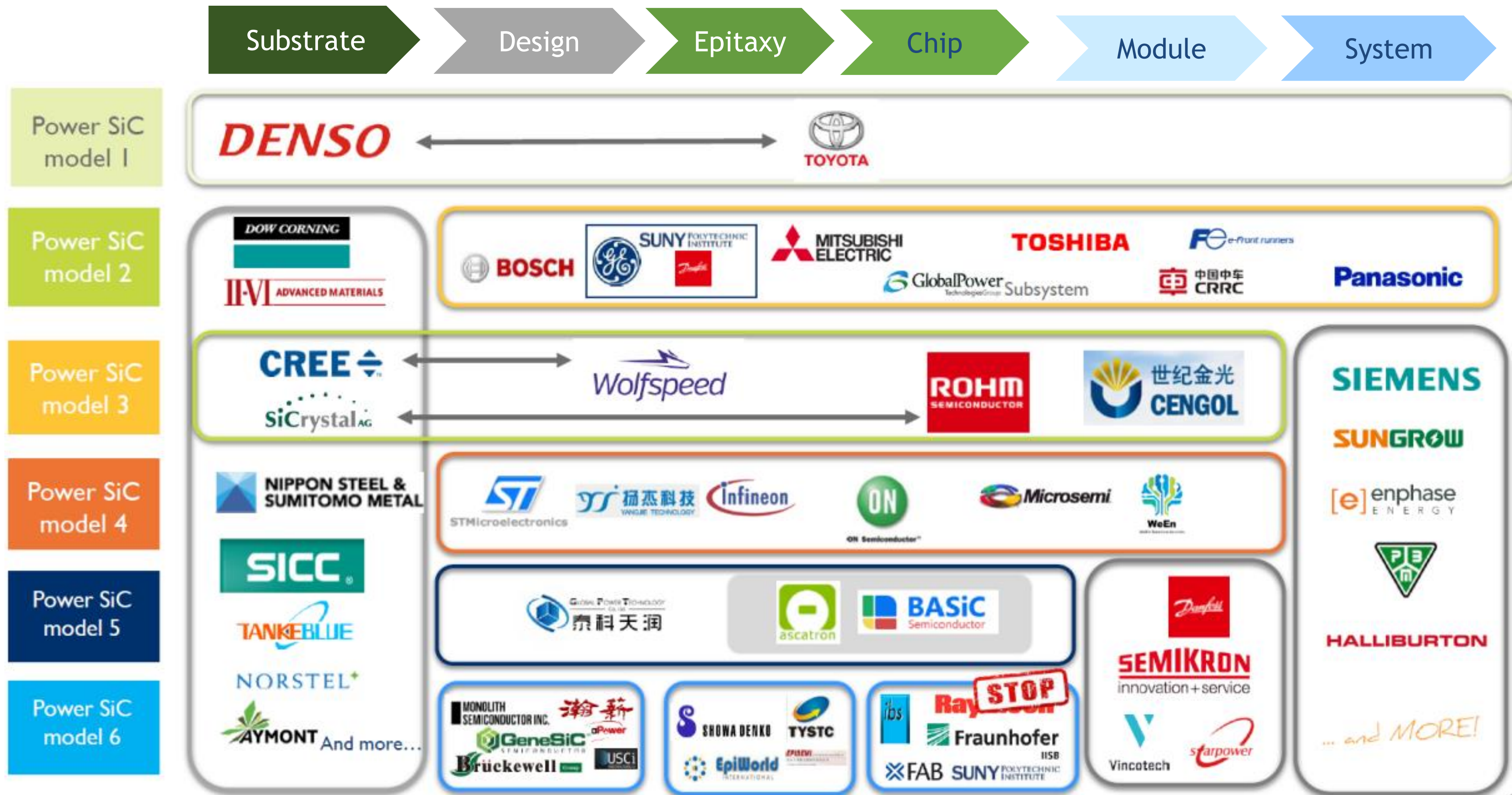


- **Universities (R&D: Si & WBG)**
- Power electronics packaging (Si & WBG)

- UK has various R&D activities in WBG device, packaging and applications.
- Universities and industries are doing RD on SiC/GaN/Diamond device and module design, simulation and prototype manufacture.
- SiC fabs were set up in Wales and Scotland
- WBG packaging are being investigated widely in university and industry
- WBG device/modules are being applied in automotive, racing and sport car, industrial and aerospace

2. SiC material and device supply chain

➢ UK WBG/SiC industry is not on the high level of the world



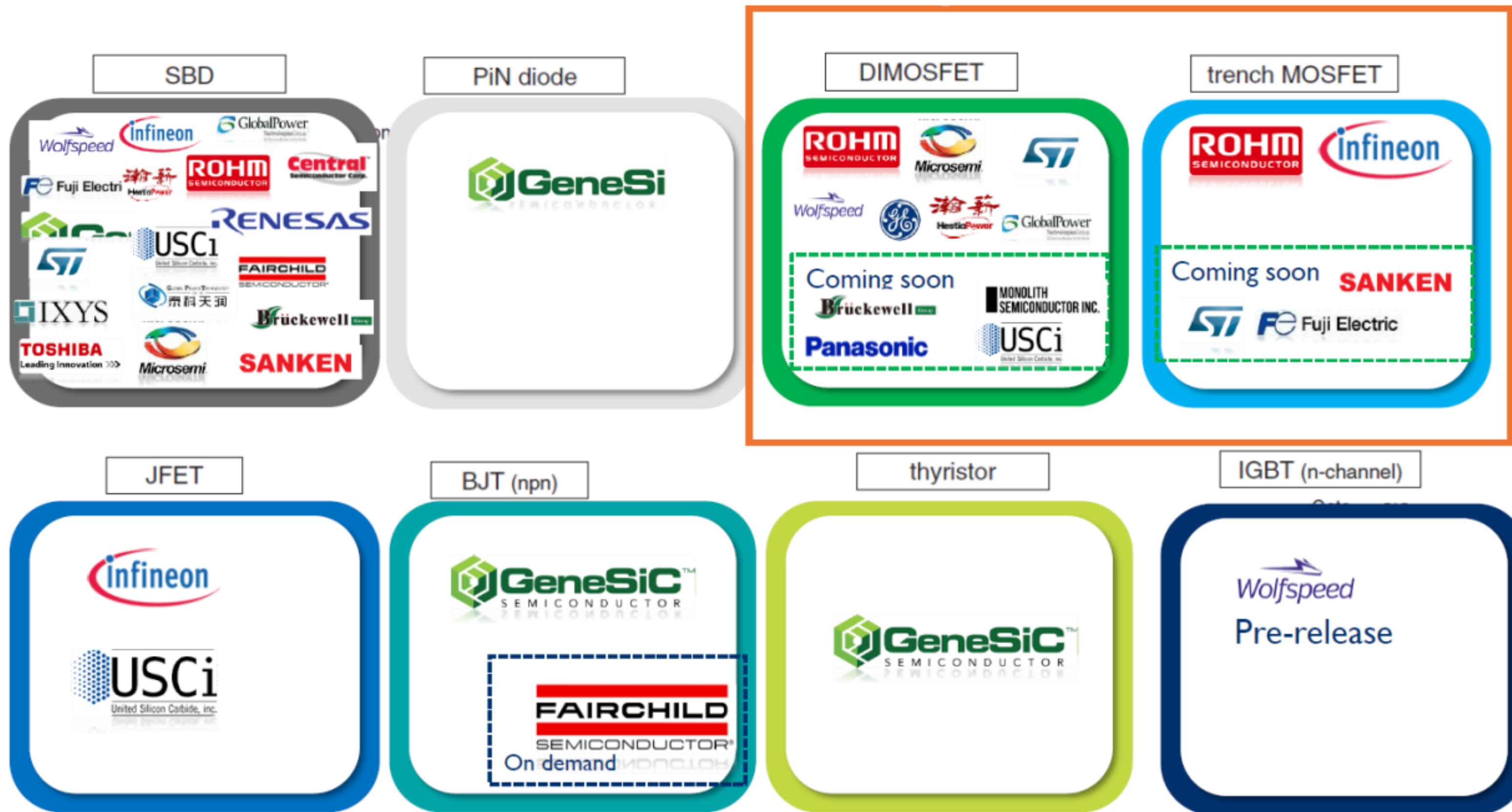
2. Opportunities of WBG material and device

- SiC wafer suppliers mainly from US, JPN, EU and China, UK is blank
- Processing of WBG wafers is comprehensive
- China is growing in SiC wafer manufacture
- Cost and defect density are key issues for improvement
- Gate oxide reliability is to be enhanced

	4H n-type	4H S.I.	6H n-type	6H S.I.	Epiwafers
CREE (US)	X (6") 8" demonstrated	X (4")			X
Denso (J)	X (4")				
Dow Corning (US)	X (6")				X
Hebei Tongguang	X (4")				
SiCrystal (D) (Now Rohm)	X (6")		X (3")		X (ROHM)
II-VI (US)	X (6") 8" demonstrated		X (6")	X (6")	
Nippon Steel (J)	X (6")				X
Norstel (SW)	X (4")	X (4")			X
POSCO (Kr)	5"demonstrated				
Nitride Crystals (Ru)	X (3")				
SKC (form. Crysband) (Kr):	X (4")				
SICC (CN)	X (4")	X (4")			X
TankeBlue (CN)	X (4") 6" demonstrated	X (4")	X (4")	X (3")	
Gengol(CN)	X(4")	X(4")	X(4")	X(4")	X
CETC 2	X (4")	X (4")			X
CETC 46	X (4")	4" demonstrated			

2. Opportunities of WBG material and device

- SiC devices are mainly Diode, JFET, MOSFET, SCR, RF devices.
- JBS, SBD, HMET are in production, Trench MOSFET is being optimized, SiC IGBT is in research stage.
- UK has broad experience in designing, the fabs can help device processing
- UK can lead the HV SiC Diode, MOSFET and IGBT development



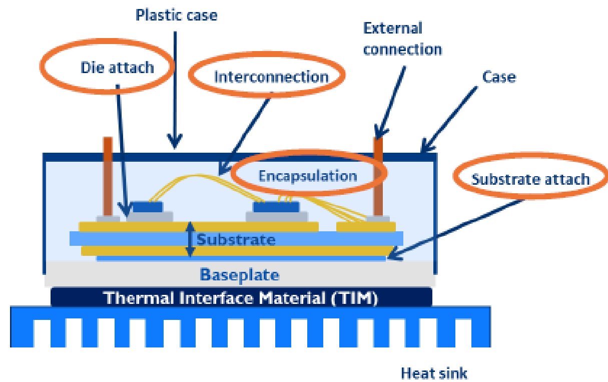
2. Opportunities of WBG packaging

- Challenges of SiC packaging:

Cooling for high power density
High temperature material and technology
Voltage/Current oscillation by High stray inductance
Current imbalance by mismatch parameters

Impact of SiC chips on choice of packaging materials

Full SiC modules require a new design and thus new packaging materials.



Structure of a wire-bonded power module on a heat sink.
Yole Développement

Old design

Substrate
High thermal conductivity ceramics such as AlN and Si3N4.

Encapsulation
High-temperature epoxy or silicone gel.

SiC chips:
High Tj and high frequency.

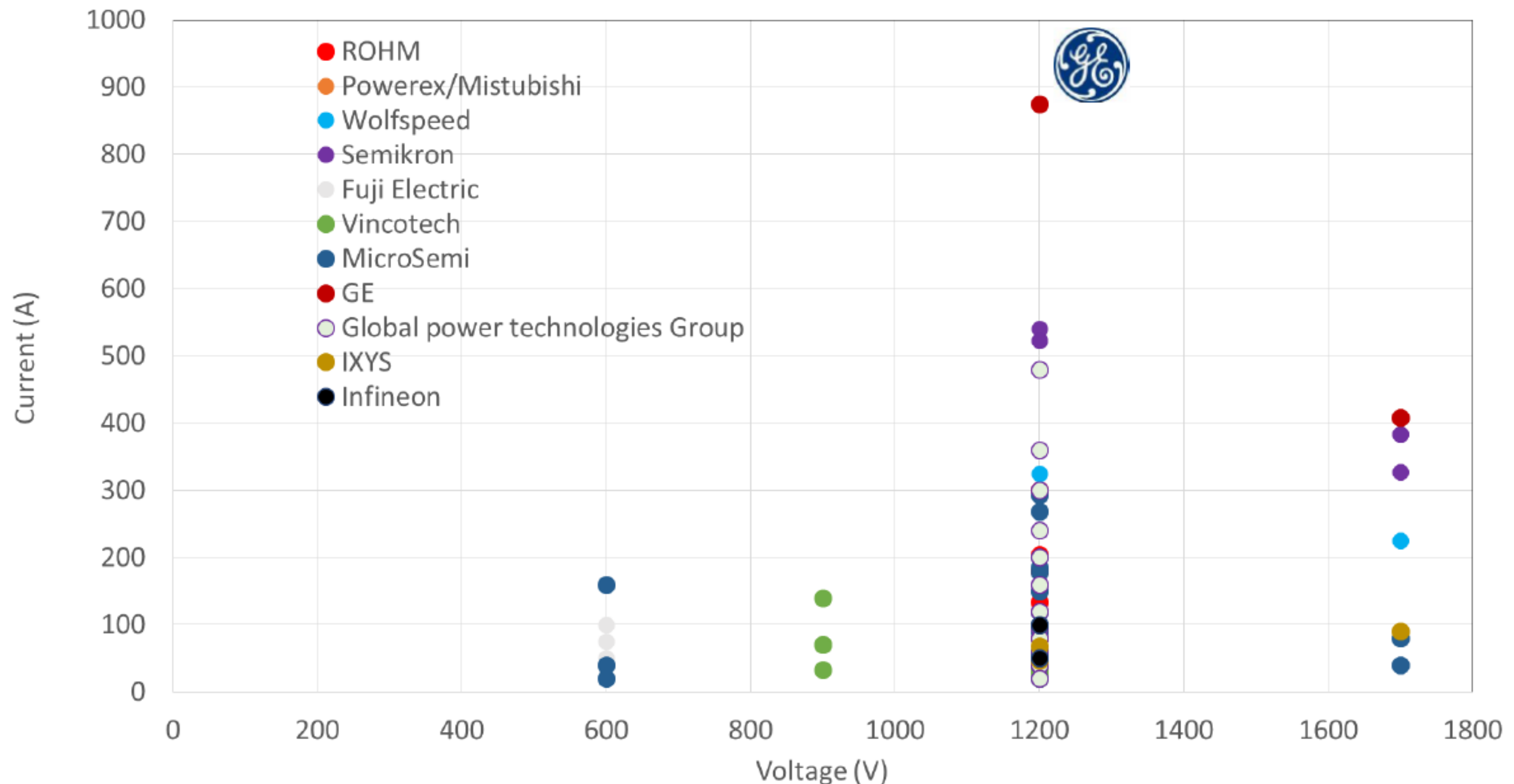
Die attach
Silver sintering is expected to become the preferred choice.

Interconnections
Low-inductance interconnections.

New designs and new materials are needed.

2. Opportunities of WBG packaging

- Key SiC and GaN module products are supplied by US, Japan and Germany
- UK has done research and prototype packaging for WBG power module
- UK has investigated advanced packaging structure, technology for WBG
- Custom and standard WBG module assembly could be contributed by UK university and industry



2. Opportunities of WBG application

- SiC device are being widely used in new energy (solar and wind power)
- EV Charger is another application field for SiC device
- SiC device are tried in locomotive by Japanese companies
- HEV/EV drive, locomotive, smart grid and aerospace will use SiC soon
- LED, RF, Communication, radar/lidar are key areas for GaN devices
- WBG market in the UK is increasing accordingly
- EV, Power generation and transmission, High speed trains are driving factors
- UK WBG device end users have opportunity to compete with worldwide

3. Summary

- CRRC WBG RD activities and collaboration with UK are widely
- WBG industrial chains are formed in US, Japan and EU
- WBG wafer is limiting device performance and industry development
- China is setting up own industrial chain, and start to play roles in all stages
- UK has seen opportunities in WBG device design, manufacture and applications