UK-Taiwan Technology Showcase for Compound Semiconductors: Power Electronics for Net Zero

Virtual event
Monday 19th October 2020
9:00 – 11:00 UK time
16:00 – 18:00 Taiwan time

Cambridge Microelectronics Ltd (Camutronics)

Dr. Tanya Trajkovic, Founder and CEO

www.camutronics.com

Cambridge Microelectronics Ltd (Camutronics)

- **Camutronics is a spin-off from Cambridge University,** formed in 2012
- Extensive experience and know-how **with all High Voltage Technologies in Si, SiC, GaN and Diamond**
- Camutronics is focused on product development and IP generation for customers
- Fields of expertise include:
  - Si, SiC, GaN, Diamond, Ga_2O_3
  - Lateral and Vertical devices
  - Power ICs
  - Trench and Planar MOS Gate devices
  - Voltages from 20V to >10kV
  - IGBTs, MOSFETs and Diodes
  - Reverse-conducting IGBTs (RC-IGBTs)
  - Superjunction (MOSFETs and IGBTs)
  - Ultra-fast lateral Si IGBTs for Power ICs up to 20W
  - Gate drivers and integration for reduced losses and size reduction

Founding Team

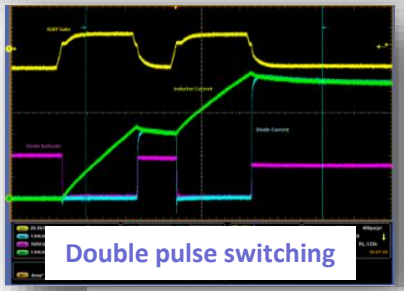
- The founders are world-renowned leaders in high voltage technologies with more than 20 years of experience **in academia and industry:**
  - **Dr Tanya Trajkovic,** CEO (PhD from Cambridge in Trench IGBTs)
  - **Prof Florin Udrea,** CTO (Prof at the University of Cambridge and Fellow of the Royal Academy of Engineering)
  - **Dr Nishad Udugampola** (PhD from Cambridge in Power Electronics)
  - **Dr Vasantha Pathirana** (PhD from Cambridge in RF Power Devices)
  - **Prof Gehan Amaratunga** (Prof at the University of Cambridge and Fellow of the Royal Academy of Engineering)
- Jointly inventors of **more than 150 granted patents** (30 owned by Camutronics) and more than 500 published papers
- Developed and helped deploy **novel products** for power electronics applications in consumer electronics, lighting, traction, medical, industrial and automotive applications

Camutronics' Customers and Partners

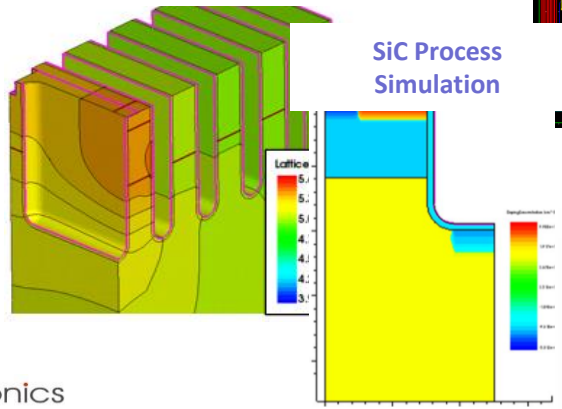
- **Camutronics** has a proven track record in transferring research to industry. We have successfully worked on long-term projects with major multinational companies:
  - Texas Instruments
  - Cambridge Silicon Radio - CSR (acquired by Qualcomm)
  - China Railway Stock Corp. (CRRC)
  - International Rectifier (acquired by Infineon)
  - Infineon
  - NXP
  - Vishay
  - Dynex Semiconductor
  - ABB
  - Fuji Electric
  - Denso Corporation
  - Cypress Semiconductor
  - Microsemi Semiconductor
  - Fairchild Semiconductor (acquired by OnSemi)
  - On Semiconductor

Device Physics, Testing and System Expertise

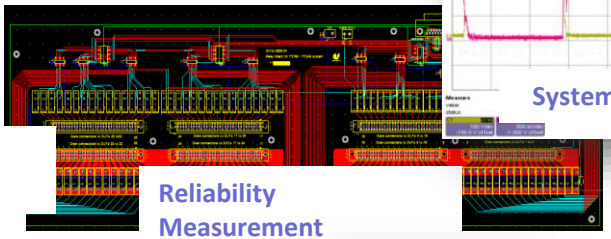
- 2D and 3D process, device and mixed-mode simulations
- Testing at wafer-level and in packages up to 10kV
- Reliability testing (HTRB, HTGB, TDDB, etc.)
- System performance evaluation by combining testing and simulations
- Packaging optimisation: layout and material selection for lowest cost, reduced parasitics, highest efficiency and improved reliability



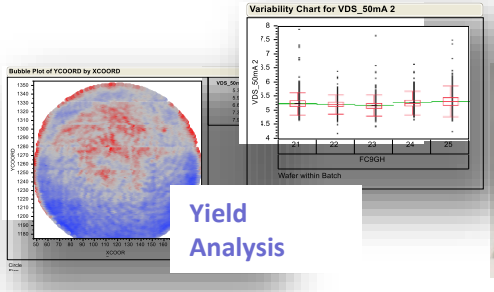
IGBT short Circuit Simulation in 3D



SiC Process Simulation

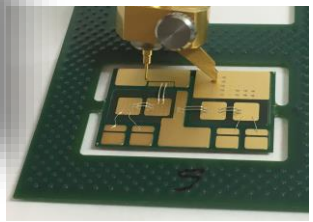


Reliability Measurement



Yield Analysis

Inductance Measurement



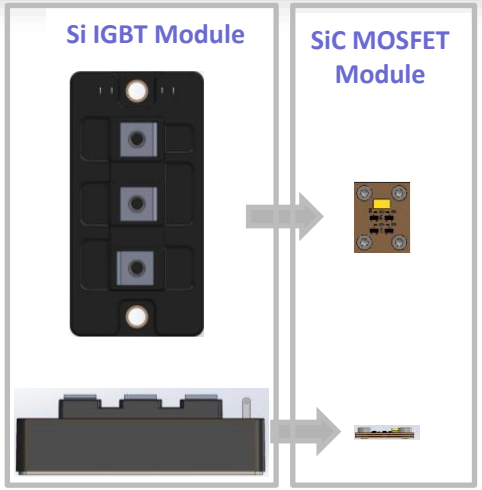
Designing Power Electronics for Net Zero

Objectives:

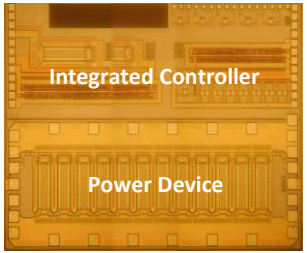
- Reduce size, weight and energy losses
- Reduce wiring, parasitics and related losses
- Improve reliability

Methods:

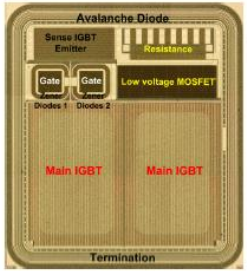
1. Replace traditional Power Devices with more energy efficient versions
2. Reduce module size and weight
3. Increase integration within the chip and within the package



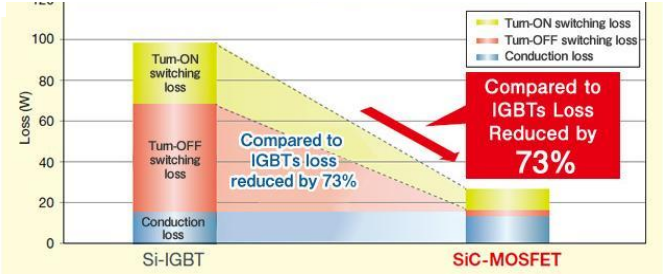
Monolithic Power IC



Smart Power Device with integrated sensing



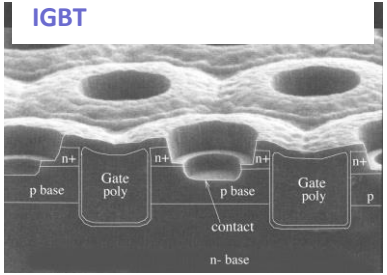
Loss reduction when SI IGBT is replaced with SiC MOSFET



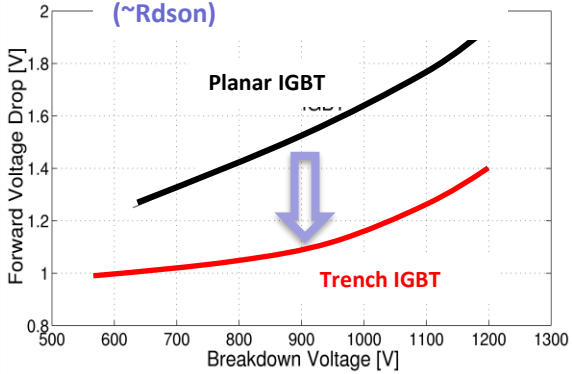
Replace Planar IGBTs with Trench IGBTs

- Trench Gate technology offers lower losses and higher power density
- Minimal changes to existing processing is needed to implement Trench Gate
- Trench gate design will reduce losses for all voltage ranges (600V – 10kV)

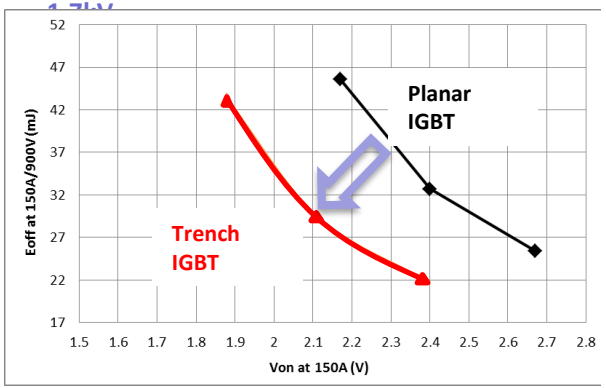
SEM picture of Trench IGBT



IGBT Conduction losses (~Rdson)



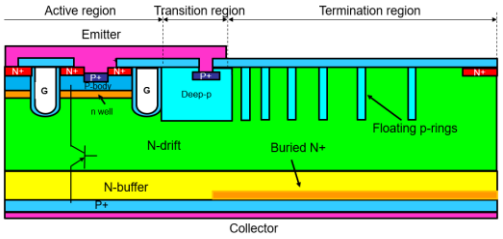
Eoff vs Von for Planar and Trench IGBTs,



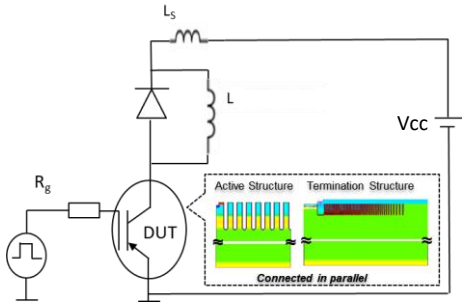
Camutronics' Expertise in Trench IGBTs

- More than 20 years of experience designing and optimising trench IGBTs
- Camutronics designed first trench IGBTs in China which are currently in high volume production (650V, 1200V, 1700V and 3300V)

Simulated Trench IGBT Cross-Section

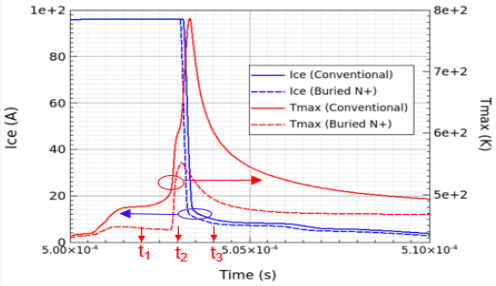


Simplified RBSOA Test Circuit

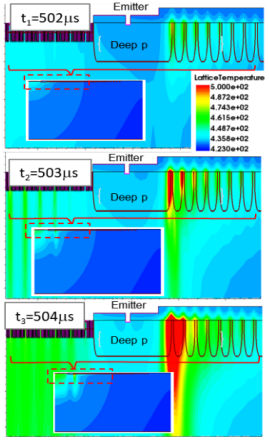


- Advanced simulations allow insight into weakest point of the design
- Based on simulations, device or system circuit can be improved to enhance robustness

Current and temperature inside the IGBT during the RBSOA Test



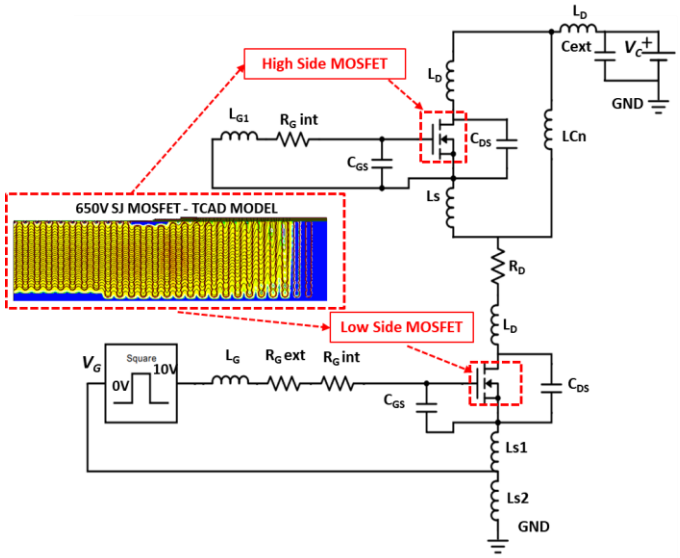
Temperature inside the IGBT during the RBSOA



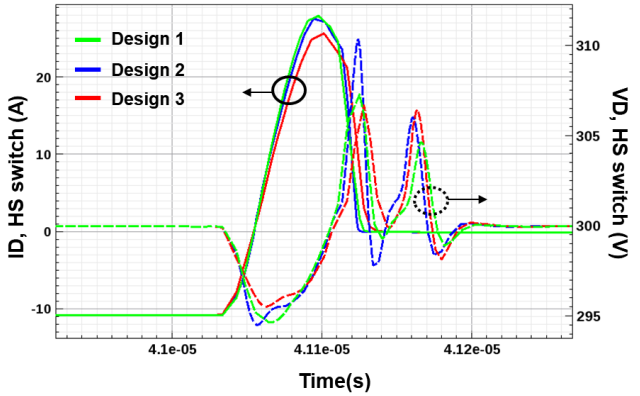
Use of Super-Junction Devices

- Super-Junction (SJ) devices have a specially designed voltage-blocking region which allows them to deliver lower losses than standard devices
- Super-Junction design is effective for both MOSFETs and IGBTs, for Si and SiC
- Camutronics have designed 650V SJ MOSFETs which are now in production

Reverse Recovery simulation for 650V SJ MOSFET

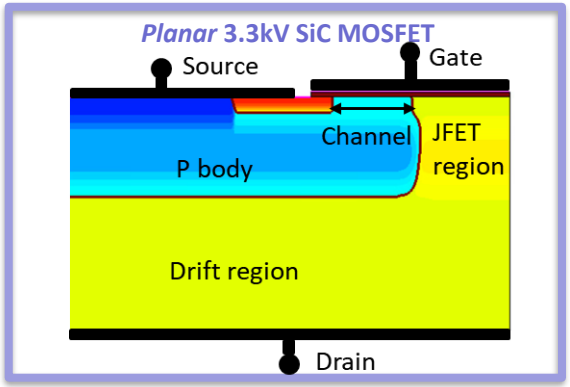


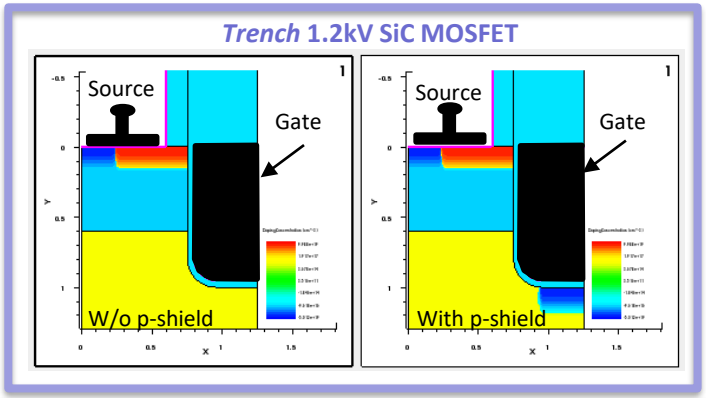
- SJ MOSFET TCAD model generated using layout, process and device simulations
- TCAD model with parasitic package and circuit components used in mixed-mode (SPICE) simulation
- This allows detailed analysis of device and circuit behaviour and best approach for optimisation

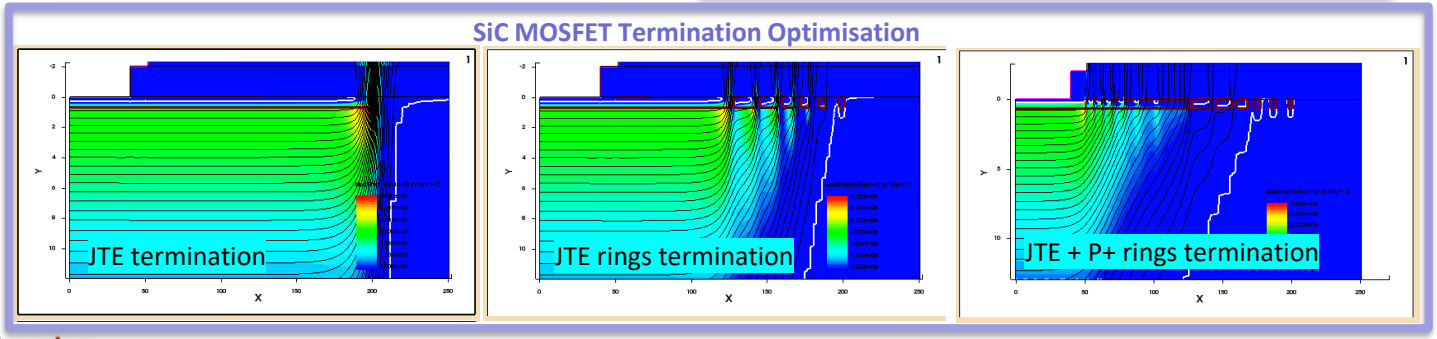


SiC Devices

- Use of SiC MOSFETs instead of Si IGBTs can significantly reduce system losses. Trench SiC MOSFET offers lowest Rdson
- Camutronics have designed 1.2kV and 3.3kV trench and planar SiC MOSFETs

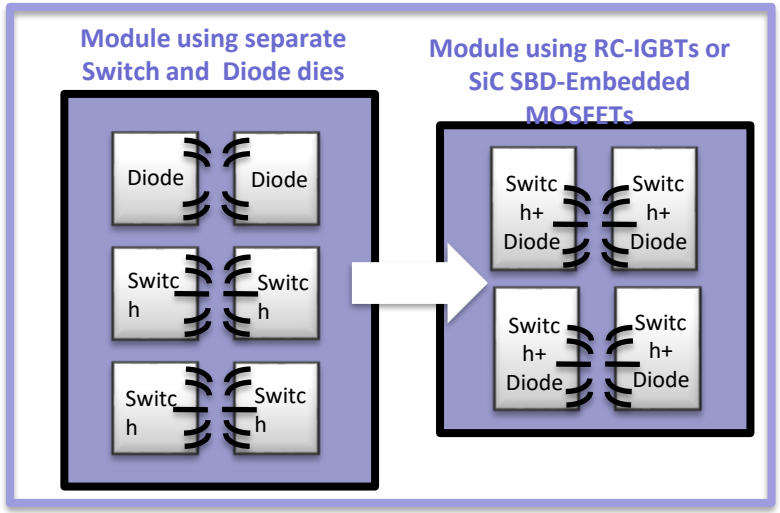






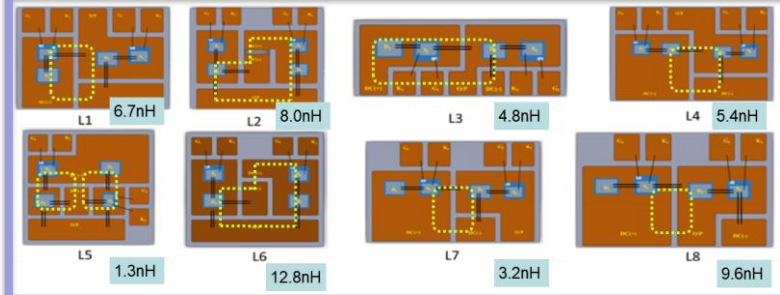
Integration for Reduced Losses, Size and Weight

- Combining High Voltage Switch and Diode on the same die can have many advantages:
  - Smaller module size and fewer bondwires
  - Lower thermal resistance and lower total losses
  - Improved reliability and lower assembly and wafer-testing cost
- Reverse Conducting IGBTs (RC-IGBTs) are IGBTs with the Diode integrated on the same die
- SiC SBD-Embedded MOSFETs have fast SiC Schottky Diode integrated within the SiC MOSFET die
- Camutronics has designed both Si RC-IGBTs and SiC SBD-embedded MOSFET



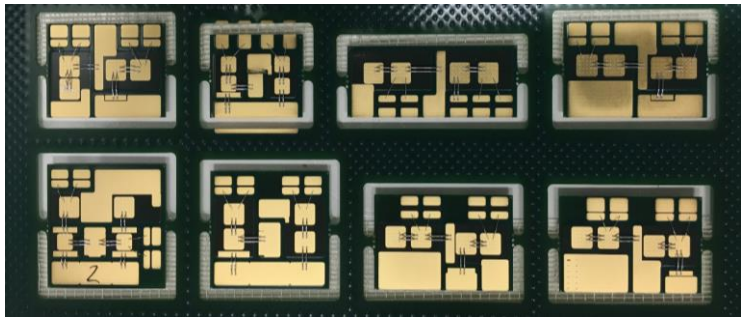
Module Layout Optimisation

- Objective: design customised SiC module layout to minimise parasitics
- Solution: Investigate several layouts, fabricate samples and measure inductances to find the best design!

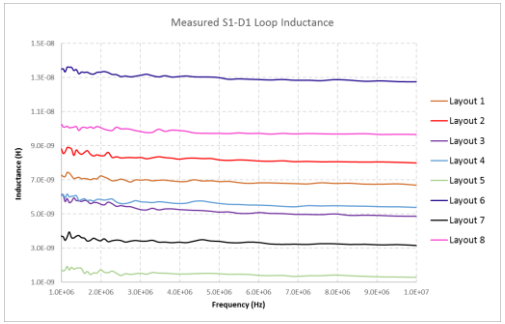


Investigate various layout Design options (8 different layouts considered)

Fabricate proposed layouts (without dies placed)



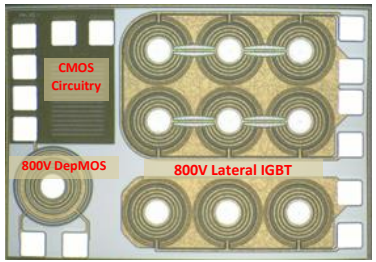
Inductance measurements



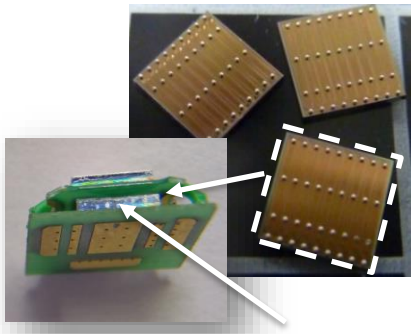
Power ICs

- Integrating external circuit components and sensing blocks (current sensor, temperature sensor, etc.) onto the same die with the High Voltage switch
- Lateral Si devices for full monolithic integration or lateral GaN devices for co-packing
- Camutronics has developed proprietary Lateral 800V IGBT technology in Si which is a cheaper option to GaN for power applications up to 20W
- Ultra-fast IGBTs (up to 200kHz) can be made on the same die as controllers, current/temperature sensors, start-up devices and offer a much smaller product solution than using lateral MOSFETs or vertical devices

Lateral 800V IGBT integrated with the Gate Driver and Start-up Device

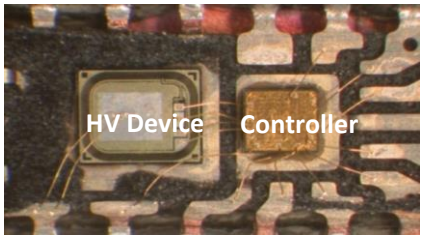


10A, 1kV Lateral IGBTs with solder balls for ultra-compact Chip-on-Board Assembly



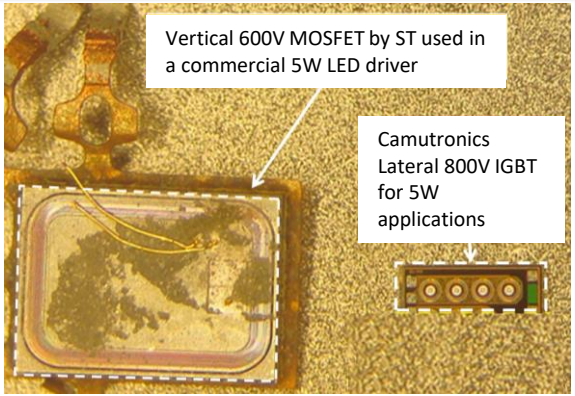
1.2kV Lateral IGBT embedded into PCB

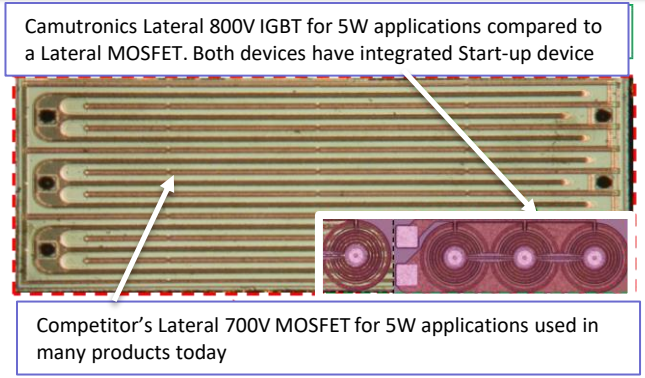
Co-packed HV device + controller



Camutronics Lateral IGBTs vs Competitive Solutions

- Lateral IGBTs allow monolithic integration and use of smaller packages as their area is 5X smaller than lateral MOSFET and 10X smaller than a vertical MOSFET used for the same low-power application





- Smallest lateral IGBT available, >5X smaller than a lateral MOSFET
- >800V blocking with avalanche capability
- Extremely low capacitances (<20pF)
- Ultra-low leakage current (<1nA)
- Soft switching waveforms result in very low EMI
- Suitable for flip-chip assembly

THANK YOU!

Cambridge Microelectronics Ltd – Camutronics

www.camutronics.com

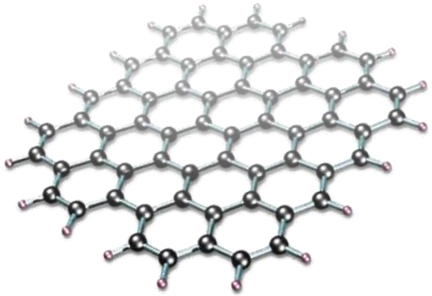
tanya.trajkovic@camutronics.com

Manufacturing Graphene Electronic Devices

UK-Taiwan Technology Showcase for Compound Semiconductors

Simon Thomas, Ivor Guiney and Colin Humphreys

19 October 2020

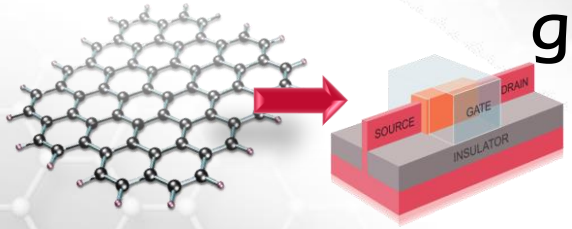


Graphene Innovation

Realising two-dimensional materials technologies

Paragraf

UNIVERSITY OF CAMBRIDGE



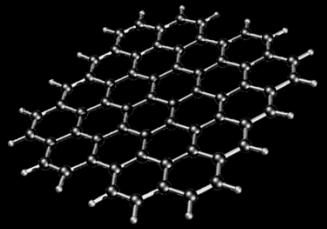
Delivering transformative graphene-based electronic devices at commercial quality & scale

Paragraf's goal is to deliver the long speculated graphene-based electronic devices enabling next generation electronics technologies

Graphene the Wonder Material

This extraordinary material is unique in the world

GRAPHENE



BSI/ISO definition:
one to ten layers of carbon atoms
arranged in a hexagonal lattice structure

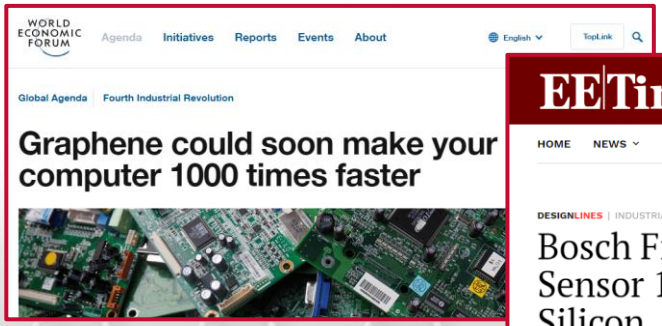
- **Extremely conductive (>1000x better than copper)**
  Delivering much higher speed electronics
- **Ultra low resistivity (lowest known material)**
  Significantly decreasing device power consumption
- **Very High Flexibility**
  Enabling bendable and curved electronics
- **Super High Strength (200x strength of steel)**
  Vastly increasing device stability and robustness
- **High Thermal Conductivity & Stability**
  Increasing device performance and thermal immunity
- **Almost Complete Chemical Stability**
  Allowing new, harsh environment electronic technologies
- **High Optical Transparency (>97%)**
  Providing non-intrusive device contacting

Other beneficial electronic properties include; very high electronic breakdown potential, high radiation resistance, very high magnetic field immunity

The only existing material with multiple world beating properties in a single package

Graphene the Game Changer

Graphene has already proven step change technology advancements



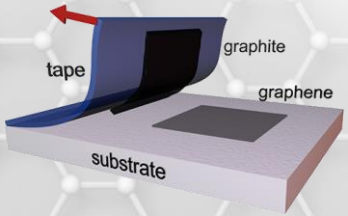
However, these amazing results continue to remain at the laboratory level

The challenge: to produce commercial scale, high quality graphene to enable these technologies to be manufactured at high volume

Graphene Production Limitations

Significant volume graphene is available, in several forms:

- Exfoliated: High quality, but very small (< 5mm^2)
- CVD: Good size but contaminated with poor quality & reproducibly
- Dispersions: Versatile but contaminated and needs 'reforming' in a matrix



However, these current materials are not suitable for large-scale production of high-tech graphene devices

The Graphene Solution

Paragraf graphene by MOCVD

- Large area → up to 8″ currently
- High quality → 100% substrate coverage
- Direct on substrate → contamination free
  → no transfer required
- Semi compatible → Si, SiO_2, AlO_2, GaN, SiC
- Functionalised → tuneable properties

Wafer scale, electronic device processing compatible graphene now available

Graphene Magnetic Field Sensors

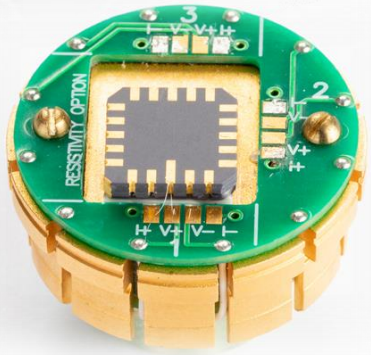
Graphene has unique properties ideal for magnetic sensing

- 2D material → higher directional field sensitivity
- High electron mobility → magnetic sensitivity proportional to mobility
- Doping can tailor carrier concentration → tuneable device performance
- Material robustness → impervious to electrostatic discharge (ESD)
- Low resistivity → high frequency operation capability
- No planar Hall Effect → stray field insensitivity

Graphene Hall Sensor Overview

Paragraf graphene Hall Effect Sensors introduce step change:

- High sensitivity → >1400 V/AT, ppm resolution
- Very wide operating field range → -9T to +9T
- Wide temperature operation window → <1K to >450K
- High frequency operation → 100MHz
- High voltage capability → >2000V
- Low power operation capability → < 1µW



Paragraf GHS 02-AT sensor on test assembly

Graphene Hall Sensor Comparison

Graphene provides unique magnetic field measurement performance

	Types of Magnetic Field Sensors					
Critical Sensor Properties	Hall Sensor	Specialist Hall Sensor	Magnetoresistive Sensor	Flux Gates	Nuclear Magnetic Resonance Sensors	Paragraf GHS
Sensitivity	✓	✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓
Field Range	✓	✓	✓	✓	✓	✓✓✓✓✓
No Planar Effect	✓✓	✓✓	✓	✓	✓	✓✓✓✓✓
Low Temperature	✓✓	✓✓	✓✓	✓✓✓✓	✓✓	✓✓✓✓✓
High Frequency	✓✓✓	✓✓✓	✓✓✓	✓	✓	✓✓✓✓✓
Low Power Use	✓✓	✓✓	✓✓	✓	✓	✓✓✓✓✓
Overall Performance	11	12	12	13	11	29

Graphene Hall Sensor Applications

- Precision field mapping in battery packs – ensure long lifetime in electric cars
- Precise current sensing – save large amounts of energy: towards net zero
- High frequency & transient power measurement

Engine monitoring & optimisation

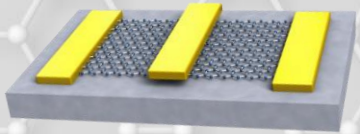
Motor speed & position control

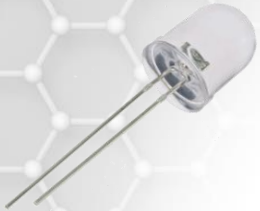
Energy cell & bank analysis

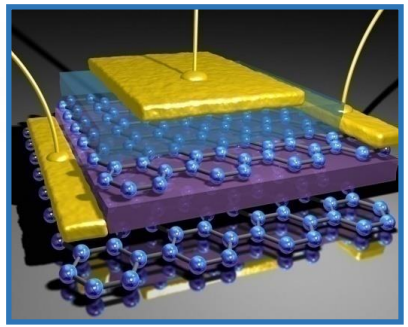
Paragraf graphene electronic devices

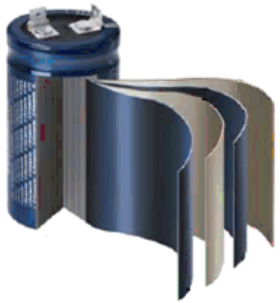
Hall sensors are just the beginning: our first product

- No catalysts, no transfer process = Si compatibility, GaN/GaAs/SiC compatibility
- High power, high frequency device operation proven
- High efficiency devices: towards net zero









paragraf

enquiries@paragraf.com

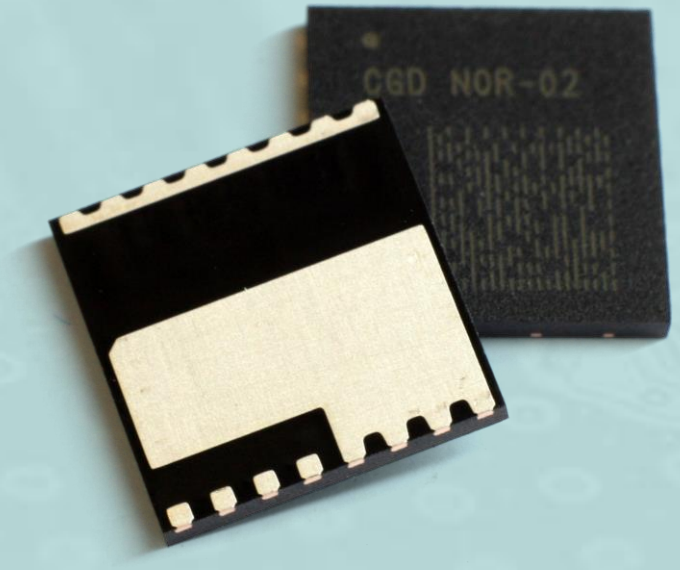
paragraf.com

+44 (0)1487 842 117

Cambridge GaN Devices

Shaping the Future of Power Electronics

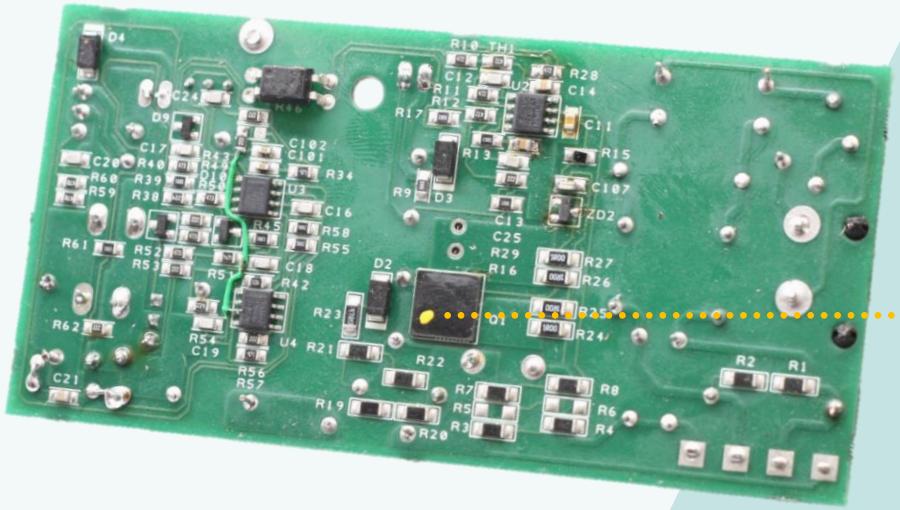
By delivering the Most Efficient Easy-to-use transistor

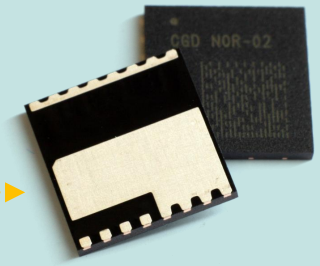


Power devices at the heart

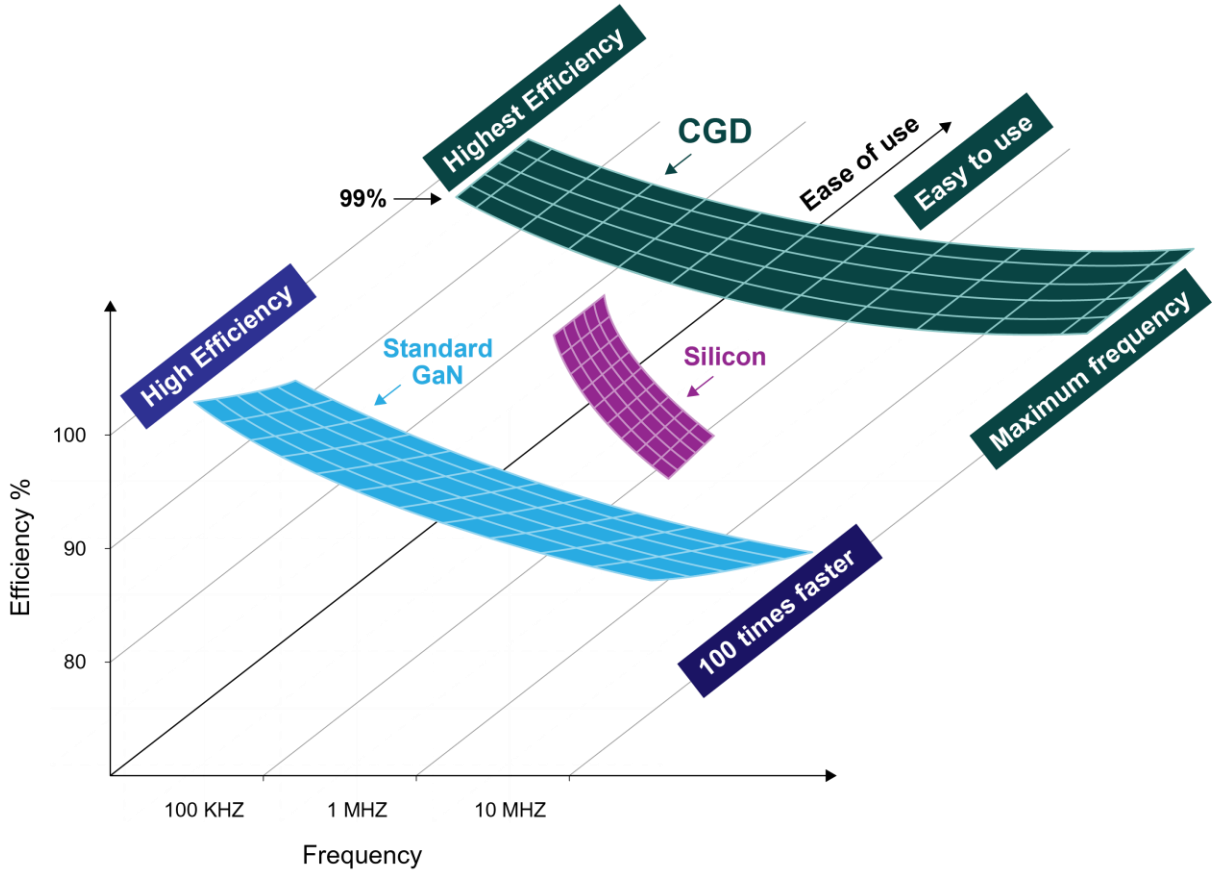
>80% of the world's electricity passes through a Power Electronics circuit…

…and is controlled by Power Devices





What if…CGD?

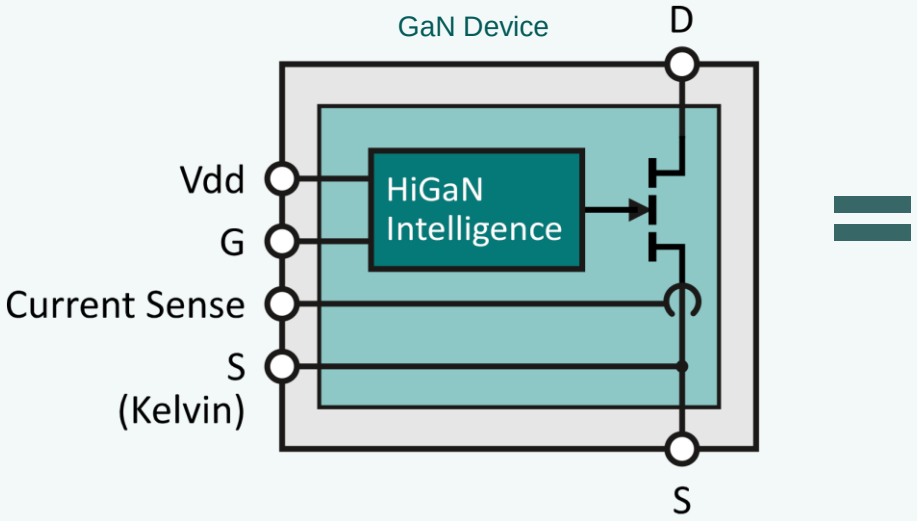


CGD technology:
The best of silicon with the performance of GaN

- Reliable
- Safe
- Freedom of design
- Not as hot, more reliable, no cooling components
- Hundreds of TWh per year saved
- Billions of Energy bills saved
- Millions of tons of CO_2 saved
- Smaller, more compact circuit
- More power for the same volume
- Maximum Efficiency

Our solution

Cambridge GaN Devices



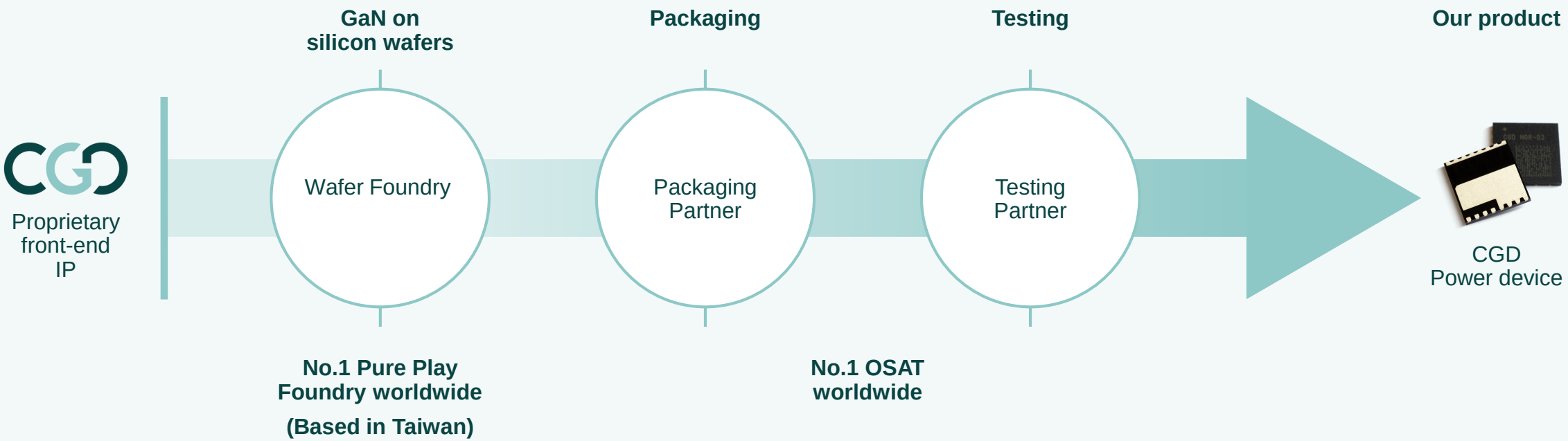
On-chip integrated solution

- **Safe:** Integrated protection functionalities
- **Reliable:** Integrated control features
- **Freedom to design application board:** No limitation on gate driver and space savings on board
- **Maximum Efficiency:** IP that enables GaN maximum efficiency

Strong IP Portfolio

Business model and supply chain

CGD's devices are manufactured into a standard fabless semiconductor supply chain, leveraging the scalability and capabilities of the industry's #1 suppliers



We have leveraged CGD teams' experience of shipping billions of power devices to the market to secure #1 suppliers that could deliver the best performance at the lowest cost

The markets we operate in

Consumer electronics: Power supplies

Reduced weight

More efficient

All applications - *Transistors TAM 2018: 1BUSD*

Industrial: LED drivers and power supplies

Volume reduction

More efficient

Lighting only - *Transistors TAM 2018: 0.3BUSD*

Data centres: Power supplies

OPEX reduction by 10%

CAPEX reduction by 4%

All PSUs - *Transistors TAM 2018: 0.3BUSD*

Automotive, electric vehicles: On-Board-Chargers (OBC)

Faster charging

50% smaller OBCs and DCDC converters

All applications - *Transistors TAM 2018: 2BUSD*

WHY NOW?

A compact and green solution

Hi-tech horticulture for national supply chain.

More and more connected

Huge demand for audio/video streaming and online services

Towards a green world

Electrifications of cars is happening

GaNext

CGD is leading the European funded project aimed at developing GaN-based modules for low and high power applications

GaNext

13 partners

3 countries

10.2 million €

Cambridge GaN Devices

advICo
Si IC

Besi (NL)
Packaging Technology

CSA Catapult (UK)
Application testing

TU Eindhoven (NL)
Power Electronics

Fraunhofer IMS
(DE) Si IC

Maccon (DE)
Motor Drive

Infineon Technologies (DE)
Gate Driver

Lyra Electronics (UK)
On-Board Charger

Neways Technologies (NL)
PV inverter

Signify (NL)
LED driver

Sumida (DE)
Magnetic components

TU Dortmund (DE)
Power Electronics

CGD core team

Dr. Giorgia Longobardi
Founder and CEO

- 11 years experience in Gallium Nitride Power devices.
- Product-oriented research project manager with top semiconductor companies: NXP (2010-2013), Infineon (2014-2017), Vishay (2014-2017).
- Leader of the GaN Power devices team at the Engineering Department of University of Cambridge.
- Inventor of 12 patent applications.

Prof. Florin Udrea
Founder and CTO

- Professor of Power semiconductor devices at University of Cambridge (Si, SiC, GaN, Diamond).
- Inventor of more than 150 patent applications.
- Consultant for: Toyota, Denso, NXP, Infineon, Vishay, On Semi, ABB.
- Founder of CamSemi (Si power ICs) sold to Power Integration.
- Founder of Cambridge CCS (Sensors) sold to AMS.
- Founder of Camutronix (Si power devices).

Zahid Ansari
VP of Operations

- VP of Operations, Director of Product Engineering and Acting VP of Business Development at CamSemi.
- Responsible for enabling CamSemi's supply chain to deliver over 500,000 IC's per day and over 1 billion IC's in total.
- 14 years of experience in technical and operations roles in Power Electronics.

Andrea Bricconi
VP of Business development

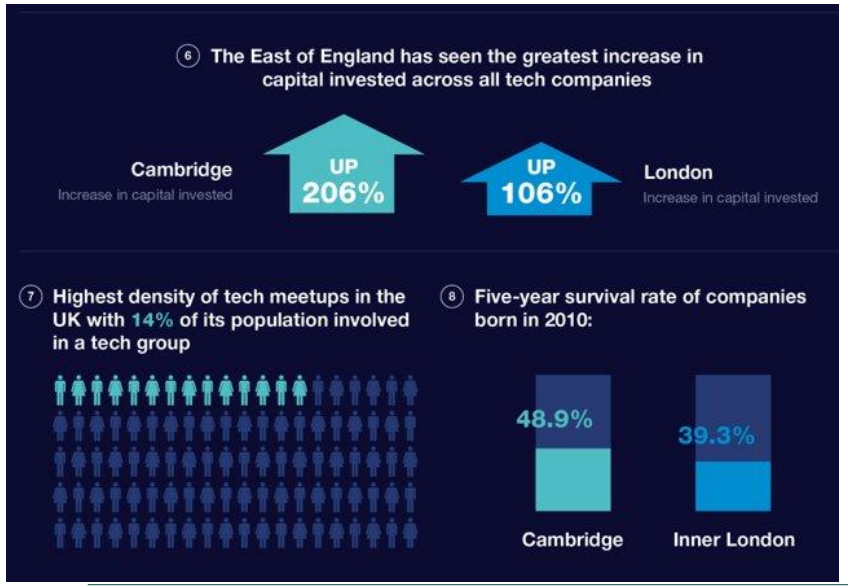
- 20+ years experience in power semiconductors industry.
- Led product engineering, product development and marketing groups in International Rectifier and Vishay.
- Co-started and managed the GaN program at Infineon with focus on business development for consumer, industrial and automotive markets.
- Focus on customers and on bringing new technologies to the market.

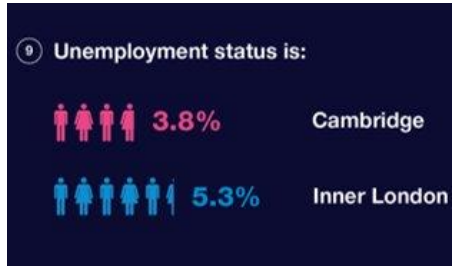
At the heart of the Cambridge Cluster

Cambridge GaN Devices CGD is a **spin-off company from Engineering Department** at **Cambridge University incorporated in October 2016.**

We are located at the heart of the **Cambridge Cluster**

CAMBRIDGE CLUSTER– EUROPE'S MOST SUCESSFUL TECHNOLOGY CENTER





Our facilities

Deanaland House, 160, Cowley Road, Cambridge CB4 0DL

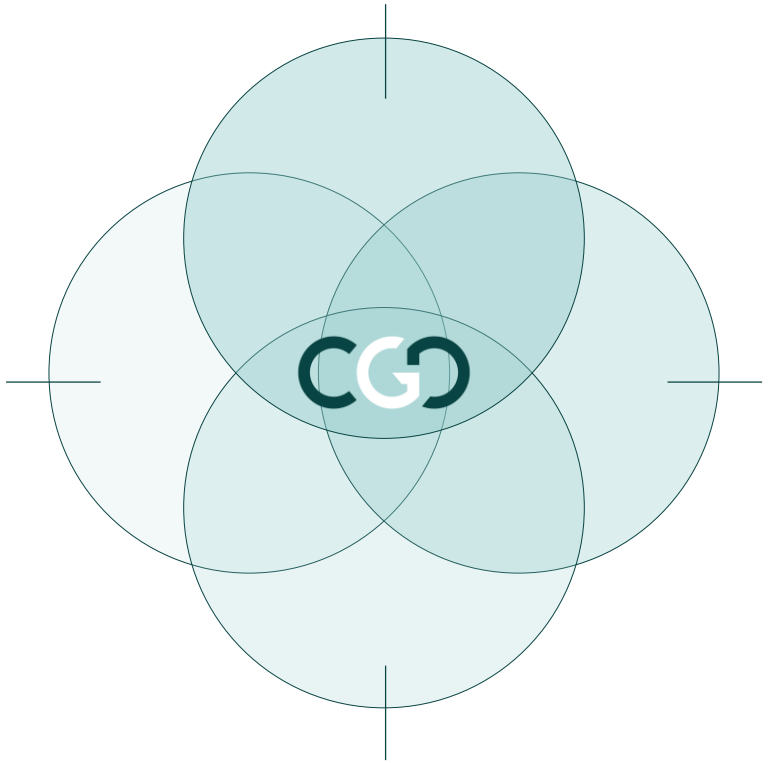
Doubling our size in the next 1 year!

Why CGD?

Where innovation, unique proposition, market readiness and experience meet

Unique proposition

Experienced team with track record in power and fabless semiconductor business



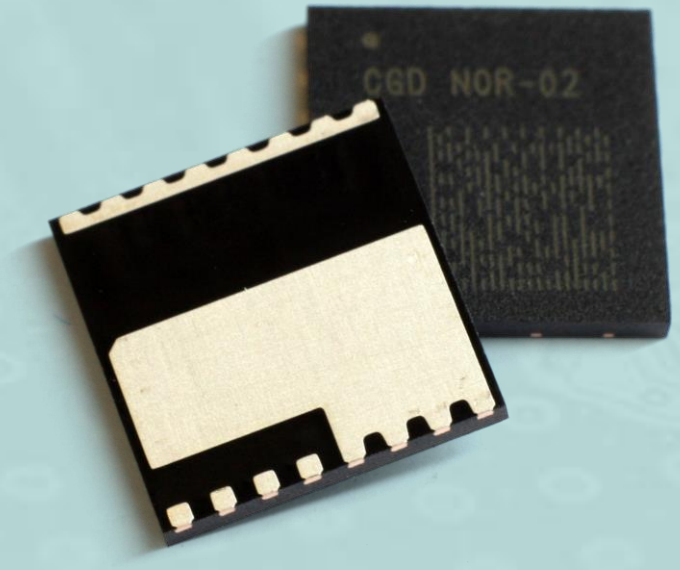
University of Cambridge
Brand Cutting-edge research
Pool of talents

Market readiness

Cambridge GaN Devices

Shaping the Future of Power Electronics

By delivering the Most Efficient Easy-to-use transistor



We welcome your feedback. Let us know your thoughts at events@csa.catapult.org.uk

If you have any questions on webinar content, would like to suggest a webinar topic, or to discuss working with us, please email collaboration@csa.catapult.org.uk

Keep your eye on our website and social media channels for more information on future webinars.

https://csa.catapult.org.uk/events/

Follow us @CSACatapult

Tel: 01633 373121

Email: info@csa.catapult.org.uk

Twitter: @CSACatapult

Website: www.csa.catapult.org.uk

The CSA Catapult is a member of CS-Connected – the South Wales compound semiconductor cluster

www.csconnected.com