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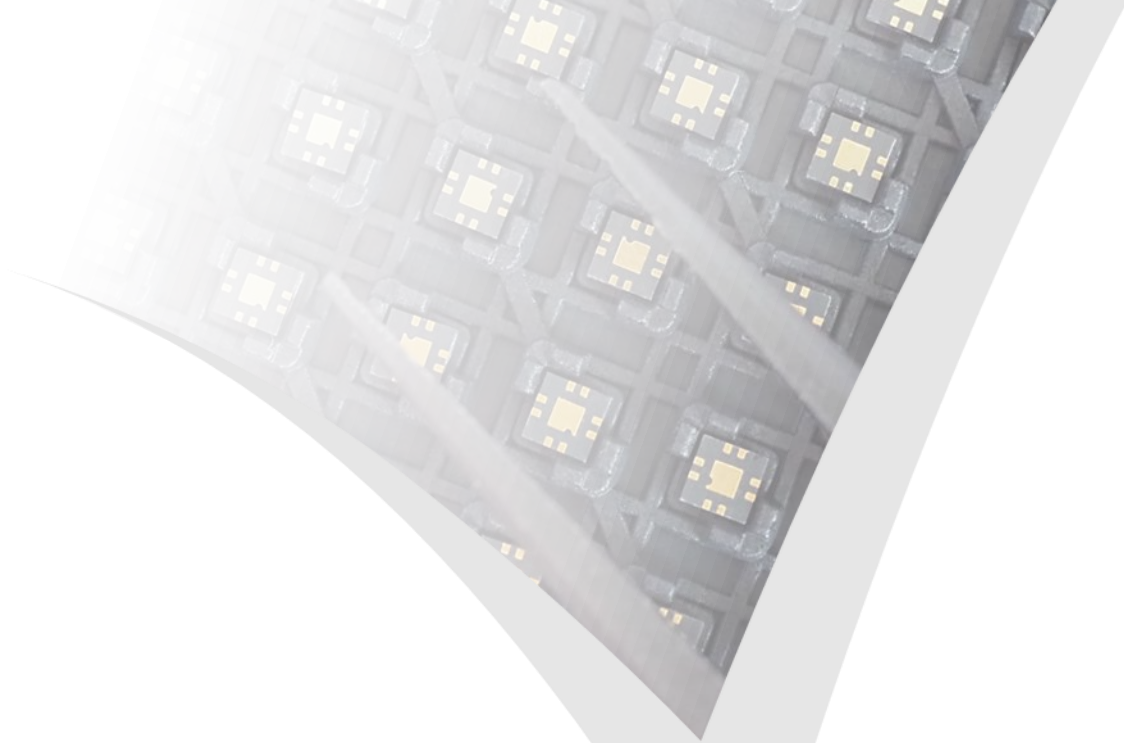
LEADING THE WAY
IN GRAPHENE ELECTRONICS



Creating and scaling a new materials business in the UK

5th June 2024 – NMI Conference, Liverpool.

New materials – what's wrong with the old ones?

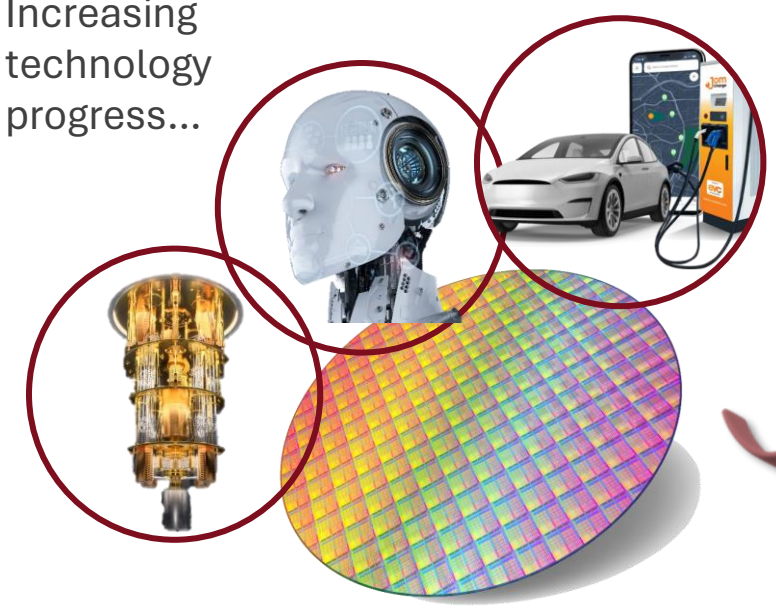
More More than Moore's Law Law?

"Number of presentations discussing the end of Moore's Law doubles every two years"

There is no doubt we have an unsatiable demand for more performance in our devices,

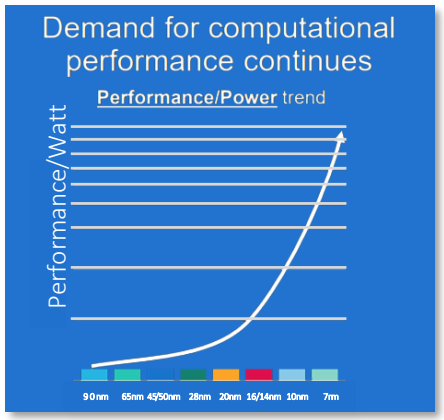
but today's more pressing reason for change is **energy**.

Increasing technology progress...

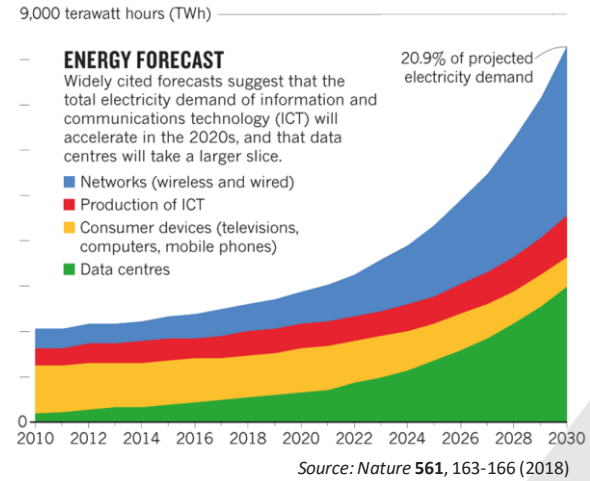


...requires increasingly advanced chips...

...with increasingly higher performance



Source: International Business Strategies Inc.



Source: Nature **561**, 163-166 (2018)

"There's no way to get ***AI*** there without an ***energy*** breakthrough,"

Sam Altman OpenAI, 2023

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The Sign of Our Times
A sustainability challenge

By 2030 it is conservatively estimated that more than 20% of the world's energy will be consumed by computing.

In 2020 datacenters used more energy than the whole of the UK.

A simple ChatGPT query uses over 5 times the energy of a standard search engine.

Sources: Frontier Group, IBM, IEA,

The healthcare sector is responsible for almost 5% of global greenhouse gas emissions and has a carbon footprint equivalent to 514 coal-fired power plants.

If the sector were a country, it would be the fifth largest polluter on Earth. Under a 'business as usual' scenario, emissions from healthcare could triple between now and 2050.

The two largest challenges are Overdiagnosis & Ecosystem Transportation (Patient, Samples, Laboratories)

Sources: The Lancet VOLUME 397, ISSUE 10269, P129-170, JANUARY 09, 2021, Health Care Without Harm, 2019, 2021, BMJ 2021

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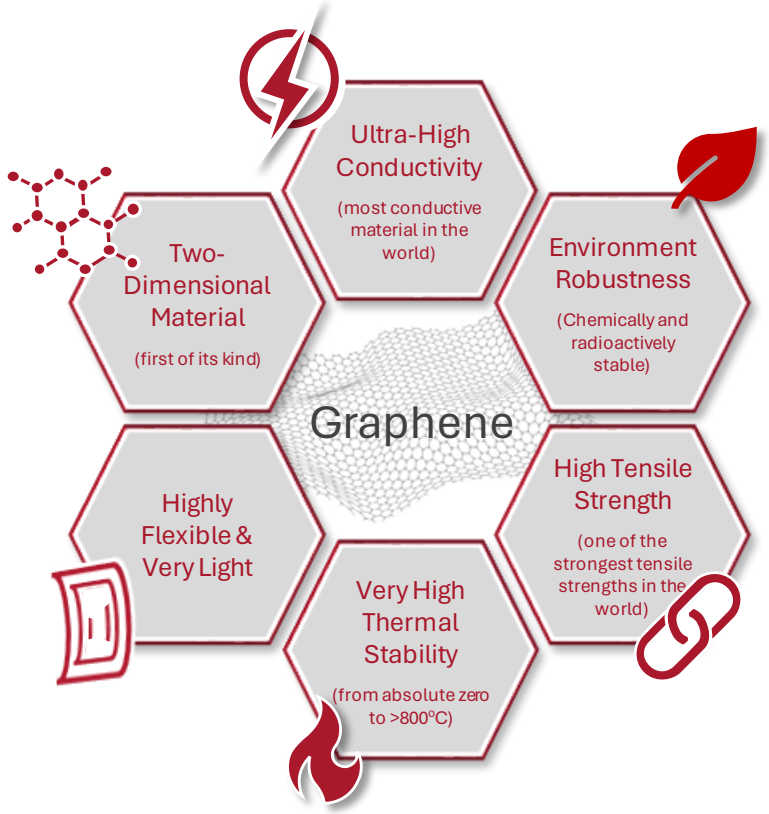
A Solution… 2D Materials with Superpowers

Transformative 2D Materials, take Graphene

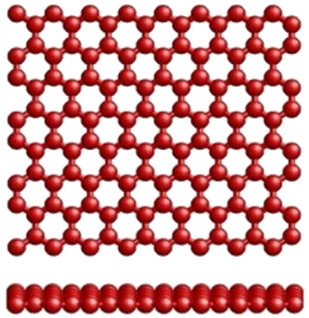


At >150x more conductive than Silicon, it is a revolutionary electronic material

Confinement of a material to a single atomic layer brings extraordinary properties…

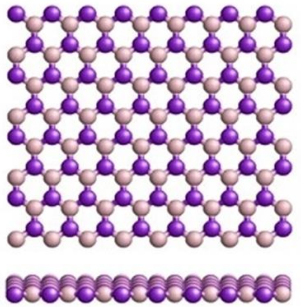
Two-Dimensional Materials

Elemental 2D



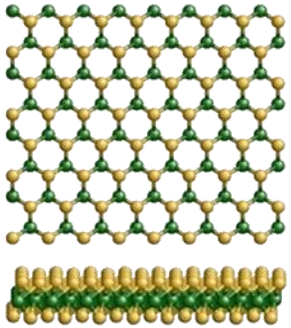
Graphene

Binary 2D



Hexagonal Boron Nitride

Multiplane 2D



Transition metal dichalcogenide (TMD)

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Graphene technologies have great potential to reduce the environmental impact of materials used in electronics devices and products

As a single layer of carbon atoms, graphene requires significantly less materials to produce than standard semiconductors. But further, the process for manufacturing graphene has many environmental benefits compared to today's standard semiconductor materials.

	Product Material	
Manufacturing Inputs	**Graphene**	**Semiconductors**
Raw Materials	✓ Common chemicals, no requirement for intensive mining to source vs. semiconductor elements	✗ Use of rare earths which requires complex mining. Many materials concentrated in single regions so supply chain sensitive to geo-political conditions. **some materials on the EU critical materials list*
Produced Materials	✓ Low cost, readily available, non-toxic chemicals that can be manufactured locally so no global transport impact	✗ Highly energy intensive processes to extract and refine materials required for manufacture. Produced in specific global locations requiring long haul transport. **source materials are also heavy*
Implications	✓ Production of graphene by MOCVD has no highly toxic or hazardous materials in the manufacturing process, and uses very small amounts of chemicals so little production waste and any waste is inert and safe to dispose	✗ Health, safety and environmental implications related to semiconductor substrates(1) and semiconductor epitaxy generation, transportation, use and disposal of resulting waste streams are very complex, costly and toxic
By-Products	✓ Lack of hazardous materials in final product means product can be recycled within the standard electronics recycling flow	✗ Extremely toxic and hazardous by-products are formed and released into the environment; are very hard to dispose of in a safe and non-hazardous way

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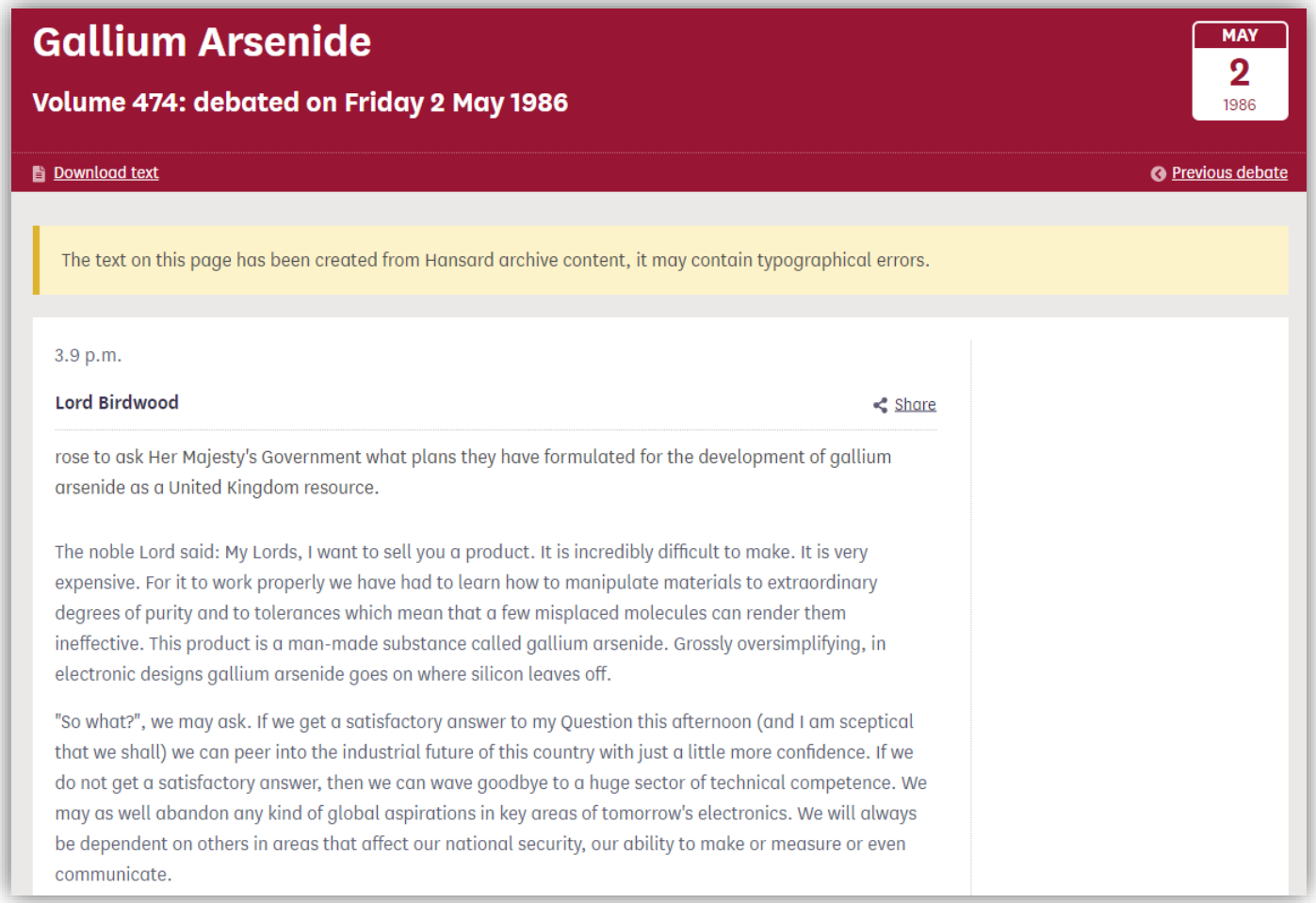
Bringing New Materials to the industry takes time

Hansard, House of Lords



Gallium Arsenide

Volume 474: debated on Friday 2 May 1986

MAY 2 1986

Download text | Previous debate

The text on this page has been created from Hansard archive content, it may contain typographical errors.

3.9 p.m.

Lord Birdwood Share

rose to ask Her Majesty's Government what plans they have formulated for the development of gallium arsenide as a United Kingdom resource.

The noble Lord said: My Lords, I want to sell you a product. It is incredibly difficult to make. It is very expensive. For it to work properly we have had to learn how to manipulate materials to extraordinary degrees of purity and to tolerances which mean that a few misplaced molecules can render them ineffective. This product is a man-made substance called gallium arsenide. Grossly oversimplifying, in electronic designs gallium arsenide goes on where silicon leaves off.

"So what?", we may ask. If we get a satisfactory answer to my Question this afternoon (and I am sceptical that we shall) we can peer into the industrial future of this country with just a little more confidence. If we do not get a satisfactory answer, then we can wave goodbye to a huge sector of technical competence. We may as well abandon any kind of global aspirations in key areas of tomorrow's electronics. We will always be dependent on others in areas that affect our national security, our ability to make or measure or even communicate.

Creating and scaling a business based on new materials technology in the semiconductor industry requires work on many fronts...

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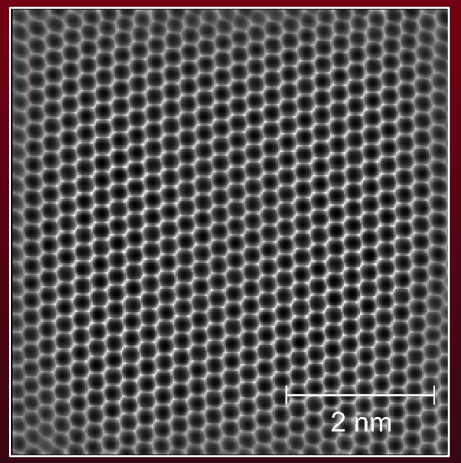
New materials – multiple challenges

- Pioneer the technology
- Prove its manufacturability
- Develop device technology
- Communicate to the industry
- Conceptualise future roadmap
- Develop partnerships
- …and build a factory or two



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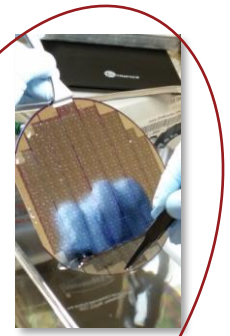
A Disruptive New Material Technology

Exfoliated Graphene

Sticky tape method

Graphene harvested from sticky tape pulled from graphite

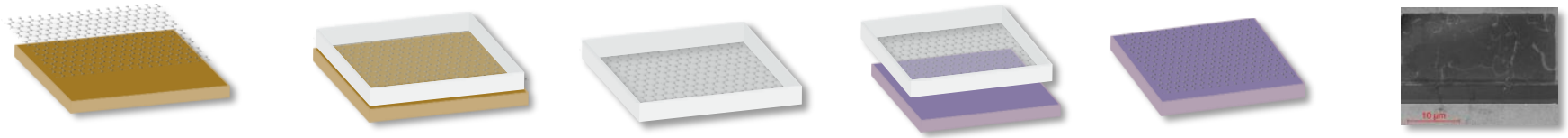
Good for Nobel prizes, less so for manufacturing



CVD Graphene

Also Known as Transferred Graphene

Graphene Growth on Copper → **Add Coating** → **Etch Away Copper** → **Transfer to Silicon** → **Dissolve Coating** = **processed graphene on substrate**



Complex, Low quality, High Cost, Difficult to scale

Paragraf Graphene

Direct to Substrate

Graphene growth direct on substrate using MOCVD = **Graphene on target substrate with no processing**

Very high-quality device ready graphene, low cost, Easy to scale

Paragraf's single step process for graphene direct on substrate

- No contamination
- No Damage
- High Quality
- Cost Effective
- Scalable

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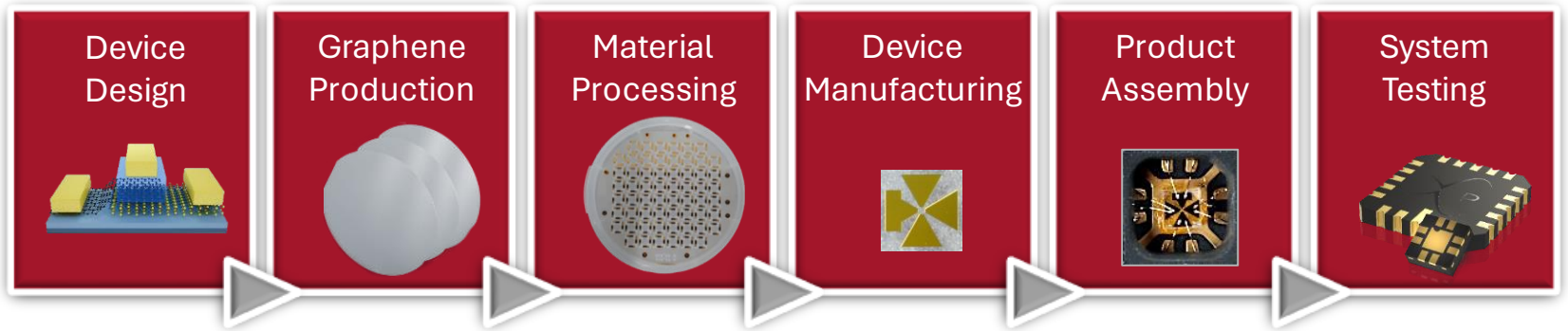
Graphene Deposited Direct to Substrate

Development doesn't stop with the new material...

Over 5 years Paragraf has developed **all** steps of the graphene device manufacturing process from material synthesis through to final device delivery

End to End Capability



Full IP Ownership
Protected

Steep Learning Curve
Difficult to Follow

Supply Chain Control
Expensive to Copy

Paragraf now owns one of the largest and most rapidly growing graphene electronics IP portfolios in the world, built on the core capability of being able to produce graphene layers on substrate, also a globally protected, proprietary process

Full Ownership of the Underlying Platform of Graphene Technology

137	60	121	Huge Platform of Trade Secrets
Granted Patents	Patent Families	Pending Patents	

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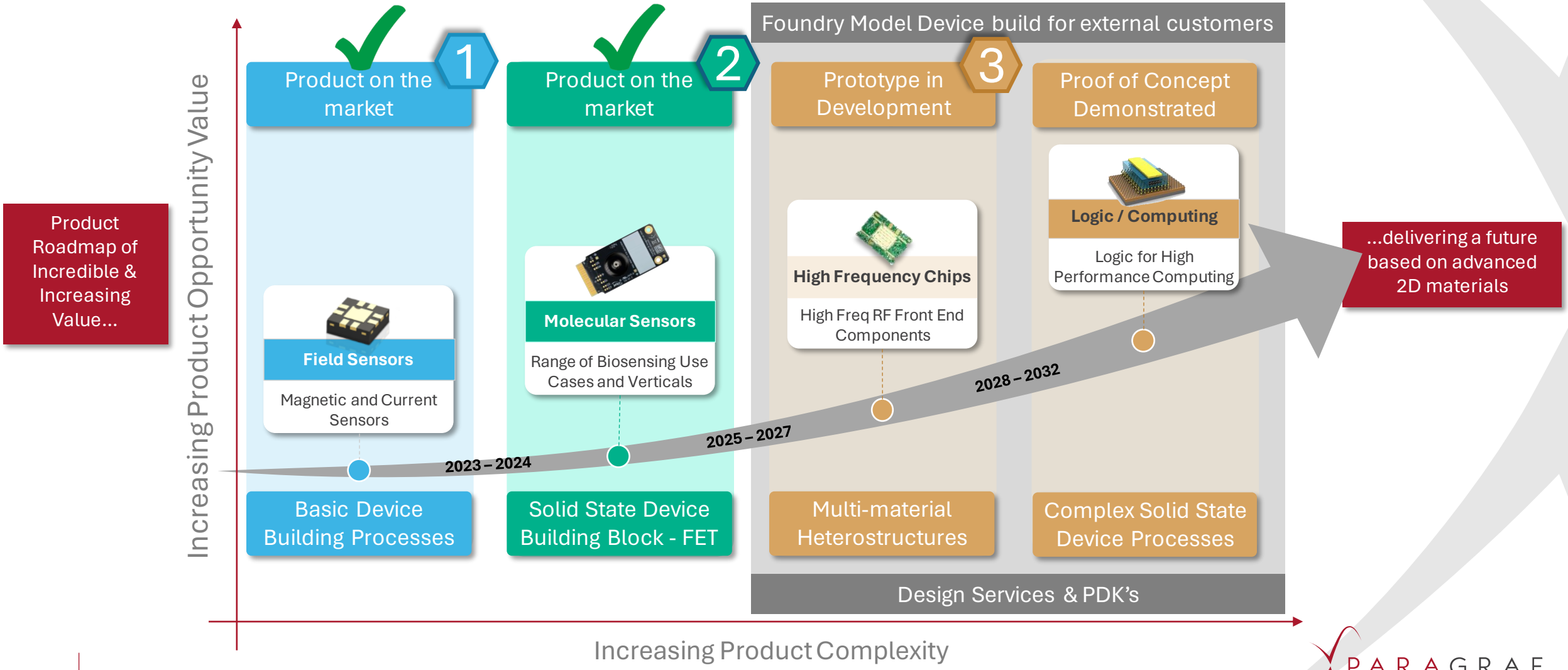
Building blocks of process development required to introduce a new material technology to the industry, with products released along the way…



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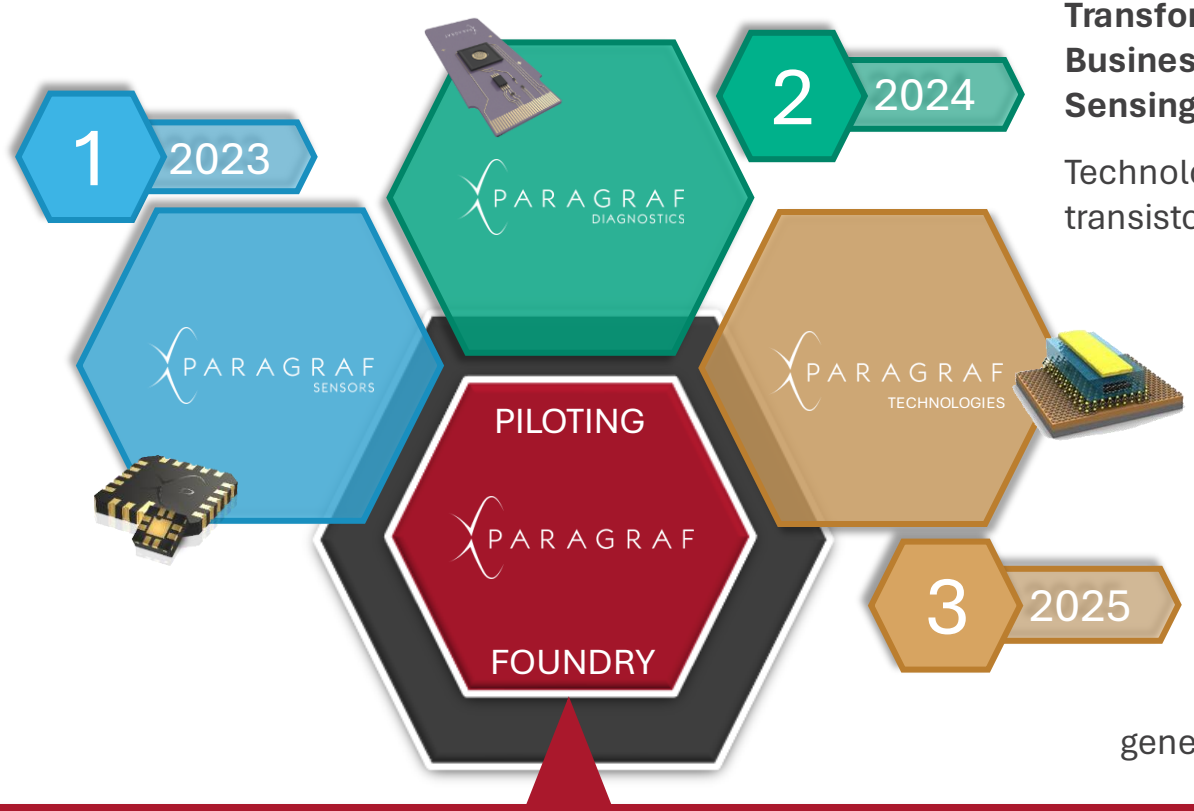
Paragraf's Foundry model

The core foundry builds the process know-how and volume capability to support a growing number technologies and markets.

Validation Technology Business Unit | Magnetic Sensing

The first technology that demonstrates graphene can be manufactured, incorporated into devices and provide higher performance, lower power, cost effective products



Transformational Technology Business Unit | Chemical & Biomolecular Sensing

Technology that demonstrates a graphene transistor, benefiting a new market segment.

Industry Defining Technology Business Unit | Technologies

Technology that gives industries access to graphene as a next generation material in their products

The Paragraf foundry will offer customers the ability to pilot graphene-based devices to a significant volume. Beyond this scale the production will be licensed to partners and high volume fabs to supply the device customer

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The route from “Lab to Fab”: first steps out of University of Cambridge

- Moving from the Department of Material Science at the University of Cambridge, the ongoing development of a new material technology, with MOCVD, needed much more space.
- Staying close to Cambridge, but on a Seed budget, facilities came from the ground up – and from a pretty basic ground!

- Paragraf’s first location in Somersham, Cambridgeshire, is now full to the brim and is now supporting ongoing research and development, to plot production capability.

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Paragraf Foundry, Huntingdon UK.

- In 2023, Paragraf's second site took shape and the first phase of manufacturing cleanroom is due for completion in August this year.

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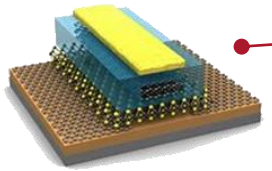
Business Snapshot 2024

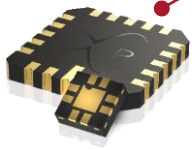
Most extensive global propriety IP portfolio in graphene materials & device production



Array of next generation electronics, including graphene logic, in development

130+ Granted Patents

Products on the Market



First graphene sensing technologies being manufactured at commercial scale

Revenue Generating & $90m VC raised

Significant Commercial Partners & Customers Engaged

3 Facilities & APAC Presence

Cambridgeshire, UK
R&D + Small Volume Production

Cambridgeshire, UK
Volume Manufacturing

San Diego, USA
Sales & Specialist Dev.
result of an acquisition in 2023

2017 — Paragraf spins out from University of Cambridge

2018 — Paragraf is established; Seed funding

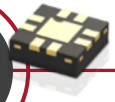
2019 — Prototype graphene Hall sensors delivered; Series A funding

2020 — Major industry partnerships

2021 — Biosensor proof of concept delivered

2022 — Series B funding

2023 — GHS products and data acquisition unit available; 2nd manufacturing site, USA-business acquired



2024 — Graphene field-effect transistor (GFET) launched

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Paragraf now a new, new material business in the UK

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LEADING THE WAY
IN GRAPHENE ELECTRONICS

Tony Pearce CEng FIMMM
Chief Operating Officer, Paragraf Ltd

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