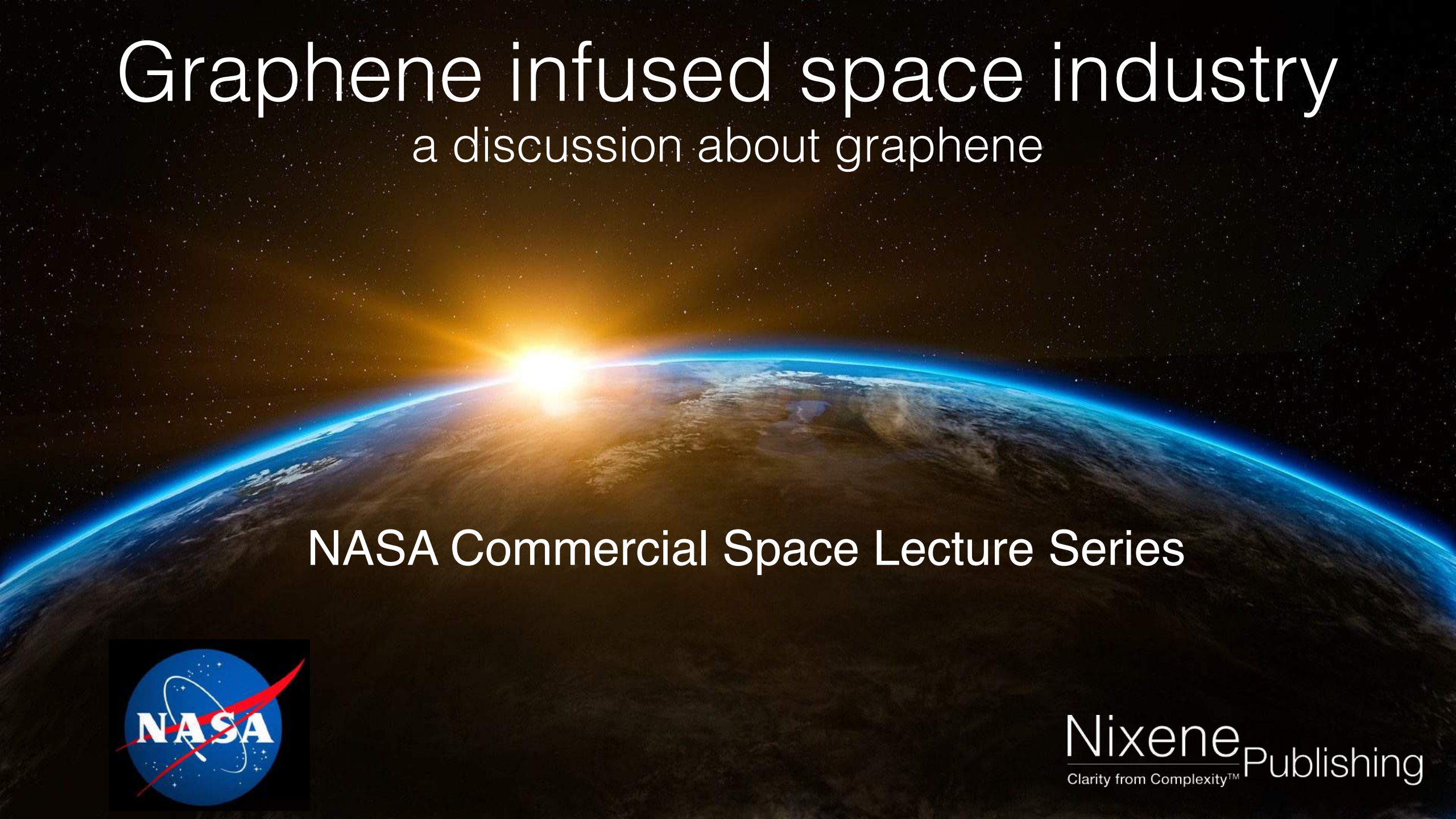
Graphene infused space industry

a discussion about graphene



NASA Commercial Space Lecture Series

Nixene Publishing
Clarity from Complexity™

Our agenda today

Nixene Publishing
Clarity from Complexity™

Debbie Nelson
The Nixene Journal

Rob Whieldon
Introduction to graphene and
Powder applications

Adrian Nixon
State of the art sheet graphene
manufacturing technology

Interactive session:
Ask anything you like

Rob Whieldon Adrian Nixon Debbie Nelson

American Graphene Summit Washington D.C. 2019

https://www.nixenepublishing.com/nixene-publishing-team/

Who we are

Debbie Nelson

Debbie has over two decades experience in both face-forward and online networking. She is active with ongoing NASA Social activities, and enjoyed covering the Orion capsule water test and Apollo 50th anniversary events at Marshall Space Center. Debbie serves as Contributing Editor and Project manager for Nixene Publishing and manages the US office.

Rob Whieldon

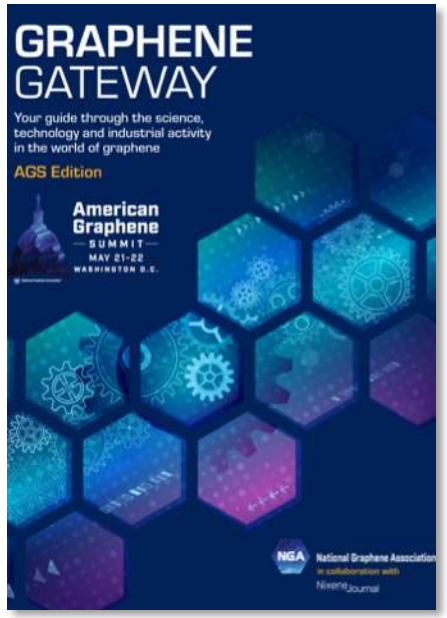
Rob Whieldon is Operations Director for Nixene Publishing having spent over 20 years supporting businesses in the SME community in the UK. He was the Executive Director of the prestigious Goldman Sachs 10,000 Small Businesses programme in Yorkshire and Humber and is the former Director of Small Business Programmes at Leeds University Business School. He is a Gold Award winner from the UK Government Small Business Charter initiative and a holder of the EFMD (European Framework for Management Development) Excellence in Practice Award. More recently he was a judge for the worlds first Graphene Hackathon and tutors PhD students on commercialisation at the NowNano Centre for Doctoral Training at the University of Manchester

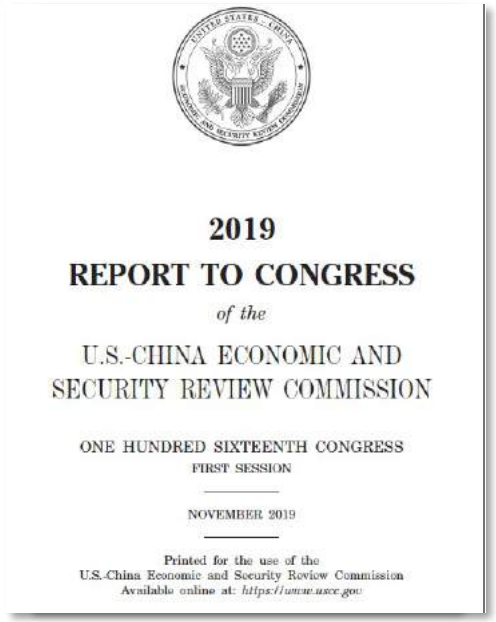
Adrian Nixon

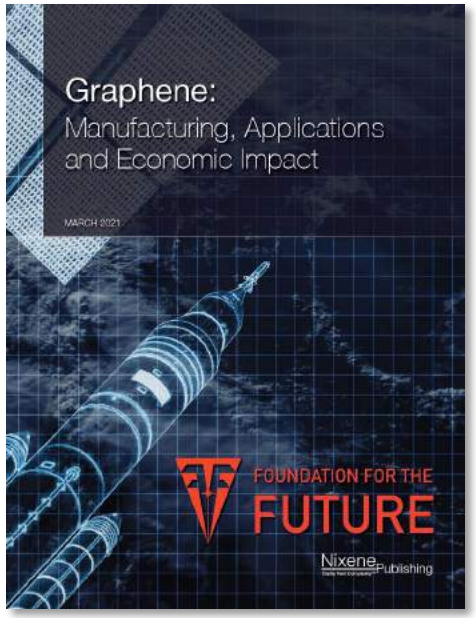
Adrian began his career as a scientist and is a Chartered Chemist and Member of the Royal Society of Chemistry. He has over 20 years experience in industry working at Allied Colloids plc, an international chemicals company (now part of BASF). Adrian is the CEO and Editor in Chief of Nixene Publishing, which he established in the UK in 2017. Adrian is a board member of the International Space Elevator Consortium (ISEC)

The Nixene Journal is dedicated to graphene and 2D materials

We operate a subscription model and do not take advertising
This means we have a completely independent view of this rapidly emerging field
Each issue explains the technology and commercial activity taking place







Since 2017, each month we report developments in the world of graphene and 2D materials with the Nixene Journal™
We also create special editions

Nixene Publishing
Clarity from Complexity™

We are based at the home of graphene and in the USA

Graphene Engineering Innovation Centre (GEIC) Manchester, UK

A world-class, multi-million pound centre for industry-led development in graphene applications in partnership with academics.

The GEIC specialises in the rapid development and scale up of graphene and other 2D materials applications

Nixene Publishing is an affiliate partner at the GEIC

Nixene Publishing
Clarity from Complexity™

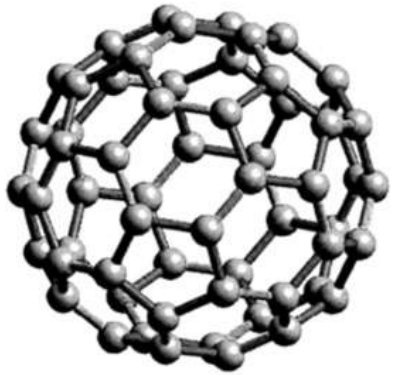
The content

Two short presentations follow, summarising:

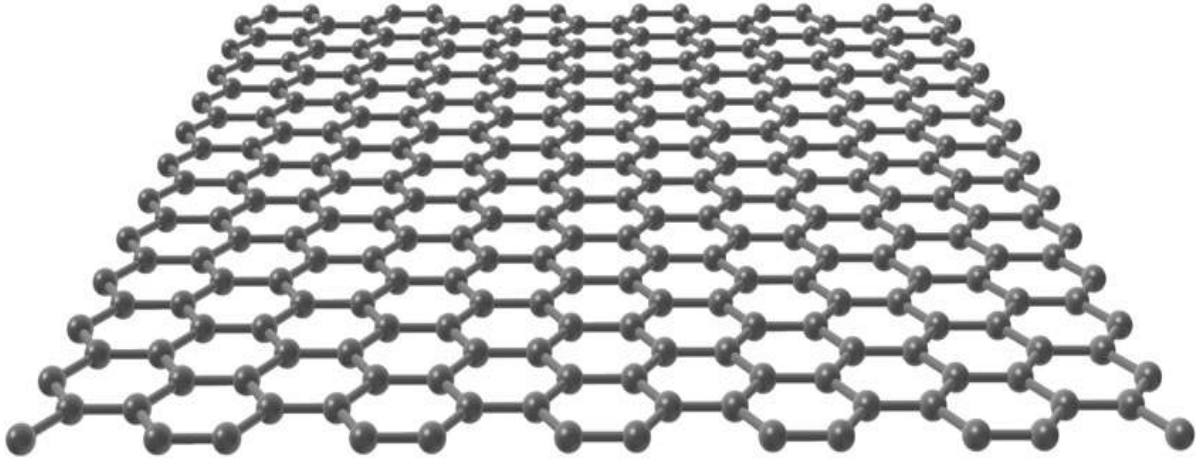
- Graphene and 2D materials by Rob Whieldon
- Large scale sheet graphene by Adrian Nixon

Graphene and 2D materials technology and applications

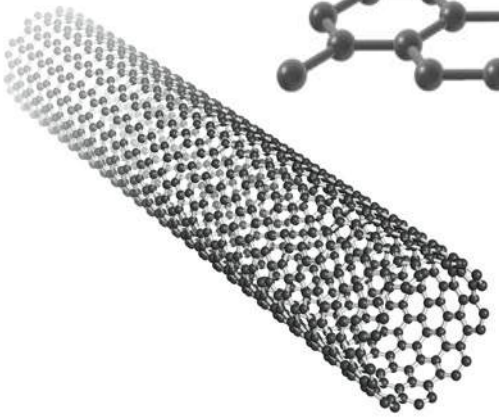
Carbon: Dimensions



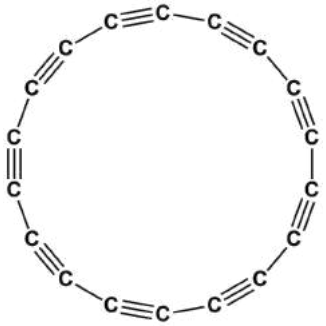
Fullerenes:
0D material



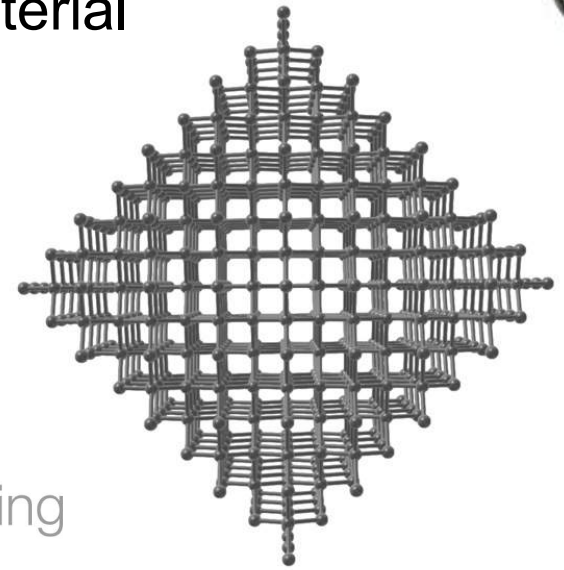
Graphene:
2D material



Carbon nanotubes:
1D material



Cyclocarbon:
0D material



Diamond,
Amorphous Carbon:
3D material

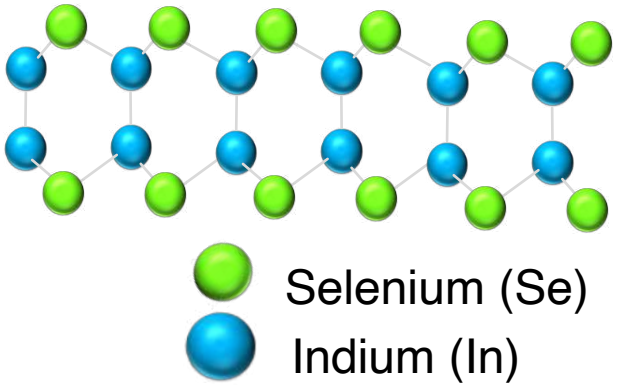
Examples of other two dimensional (2D) materials: The ‘Graphenes’ landscape

There are thousands of potential 2D materials [1]

Examples:

- Hexagonal Boron Nitride (hBN)
- Molybdenum Disulphide (MoS_2)
- Molybdenum Diselenide ($MoSe_2$)
- Tungsten Disulphide (WS_2)

Indium selenide: Side view

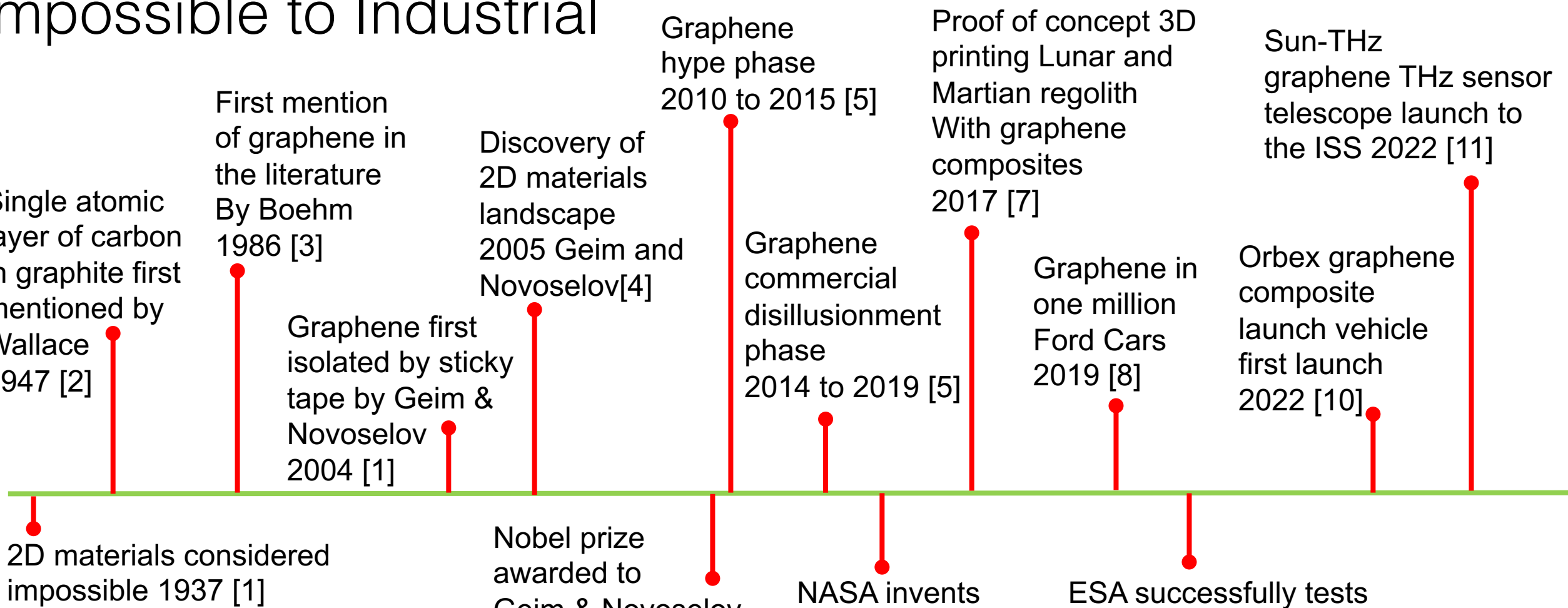


These materials can be used on their own
or layered with one another, or graphene, like a club sandwich

These are called Van der Waals heterostructures and they have the potential to create ‘designer’ materials with new properties

Source:
1 https://www.chemistryworld.com/news/thousands-of-2d-materials-are-just-waiting-to-be-discovered/3008661.article

Impossible to Industrial



Sources:

1. https://arxiv.org/pdf/cond-mat/0702595.pdf
2. https://doi.org/10.1088/0031-8949/2012/T146/014003
3. https://www.sciencedirect.com/science/article/abs/pii/0008622386901260?via%3Dihub
4. https://doi.org/10.1073/pnas.0502848102
5. https://www.youtube.com/watch?v=nkmAVAa6LqM&t=187s
6. https://www.nasa.gov/langley/business/feature/nasa-langley-s-technology-further-enhances-graphene-functions
7. https://www.nature.com/articles/srep44931
8. https://www.youtube.com/watch?v=tnBDYIicQQE
9. https://www.esa.int/ESA_Multimedia/Images/2020/05/Graphene_sail_in_microgravity
10. https://orbex.space/news
11. https://www.graphene-info.com/newly-designed-telescope-graphene-sensors-be-used-space-near-future

Nixene Publishing
Clarity from Complexity™

Nobel Prize in Physics 2010: Graphene

Prior to 2004

Graphene and other 2D materials were considered impossible to exist

2004
Graphene isolated as world's first 2D material at the University of Manchester, UK

2010
Andre Geim & Konstantin Novoselov Win Nobel Prize For preparing and characterising graphene

Source: https://www.nobelprize.org/uploads/2018/06/advanced-physicsprize2010.pdf

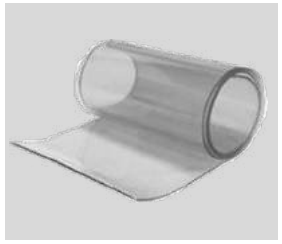
Graphene is a Frontier Material

200 times
stronger than steel

World's best
conductor of electricity

Very stable material
Non-toxic

Flexible and
transparent

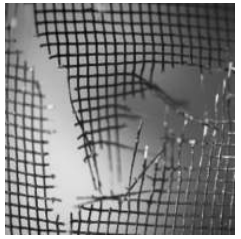


Highest melting point of any
material in a vacuum

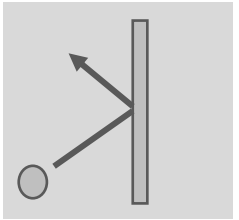
100 times more
tear resistant than steel

World's best
conductor of heat

World's most
fatigue resistant material



World's most
impermeable material



Source: https://www.nobelprize.org/uploads/2018/06/advanced-physicsprize2010.pdf

Graphene: The hype

Innovation Trigger: Graphene Isolated

Disillusionment over graphene powders leads to reaction against the hype

Mainstream commercial adoption of graphene powders Driven by standard

Multiple market Disruption by manufacture of large scale sheet single crystal graphene

Graphene Powder and Sheet / Film

Two types of graphene manufacturing

Graphene currently manufactured as powders

Commercial applications starting to evolve

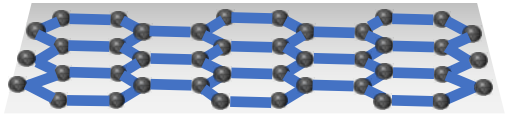
Sheet or Film graphene is a far higher value market

Defect free sheet graphene is the ideal graphene film and is called Single Crystal Graphene

Graphene Powder

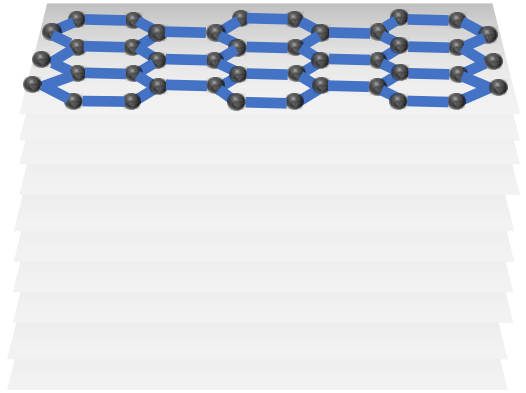
Graphene powders can be made from graphite

Sri Lankan flake graphite. Image credit: Adrian Nixon



1 Layer

Graphene



3 to 10 Layers

Few layer Graphene

Graphene is to graphite as a playing card is to a pack of cards

Methods for manufacturing graphene as powders and dispersions

Graphite

Exfoliation

Mechanical
Chemical
Electrical

Tonnes scale graphene

Crop waste biochar

High temperature pyrolysis

Tonnes scale graphene

Waste plastic Carbon source in

200 V electric pulse heats the carbon to 3000°C forming graphene

Lab scale Flash graphene

Source: Tour. J, et al. (2020) Gram-scale bottom-up flash graphene synthesis
https://www.nature.com/articles/s41586-020-1938-0

Nixene Publishing
Clarity from Complexity™

Graphene Powder Applications: Examples

Graphene and Ford Motor company

Global CO_2 reduction Graphene – concrete composites

Holey graphene

Sustainable graphene-rubber composites SpaceBlue

Graphene enhanced propellant

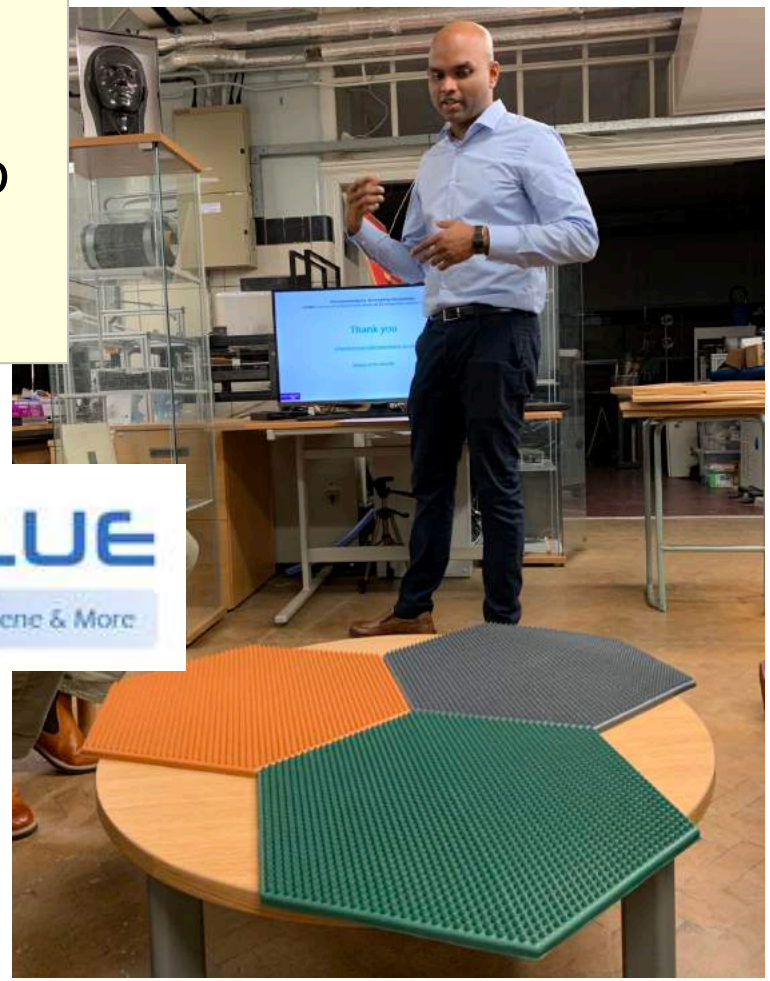
Graphene – lunar & Martian regolith composites

Graphene composites lightweighting launch vehicles

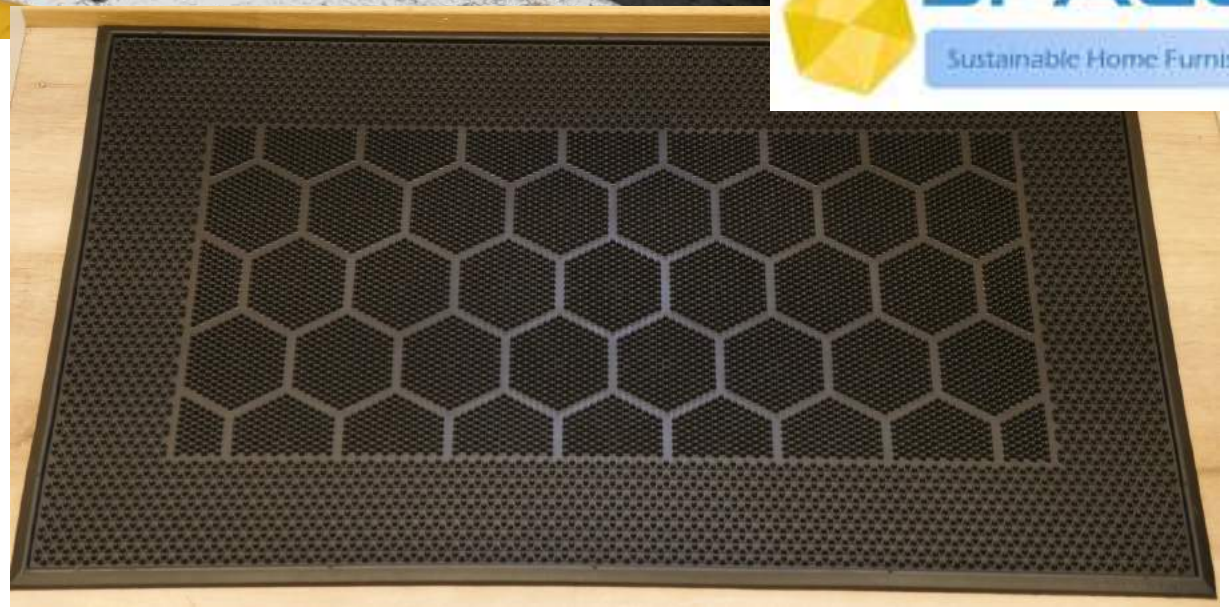
Graphene ink sensors

Sustainable graphene-rubber polymer composites
Graphene recycling waste car and truck tyres

SpaceMat ™
Enables tyre recycling
Making rubber mats that do not disintegrate like normal recycled rubber



SPACEBLUE
Sustainable Home Furnishing - Graphene & More



Source:
https://spaceblue.co.uk/products/spacemat-graphene-enhanced-recycled-sustainable-rubber-doormat

Nixene Publishing
Clarity from Complexity™

Graphene-Concrete composites

Graphene enhanced concrete used in the construction of the Siglo XXI Yucatan Convention Center

0.03% Graphene oxide by weight increases compressive strength of concrete by at least 25% [1]

If adopted globally This means 2% reduction in global CO_2 emissions [2]

[1] https://www.sciencedirect.com/science/article/abs/pii/S0950061818316088

[2] https://www.sciencedirect.com/science/article/abs/pii/S0950061818316088

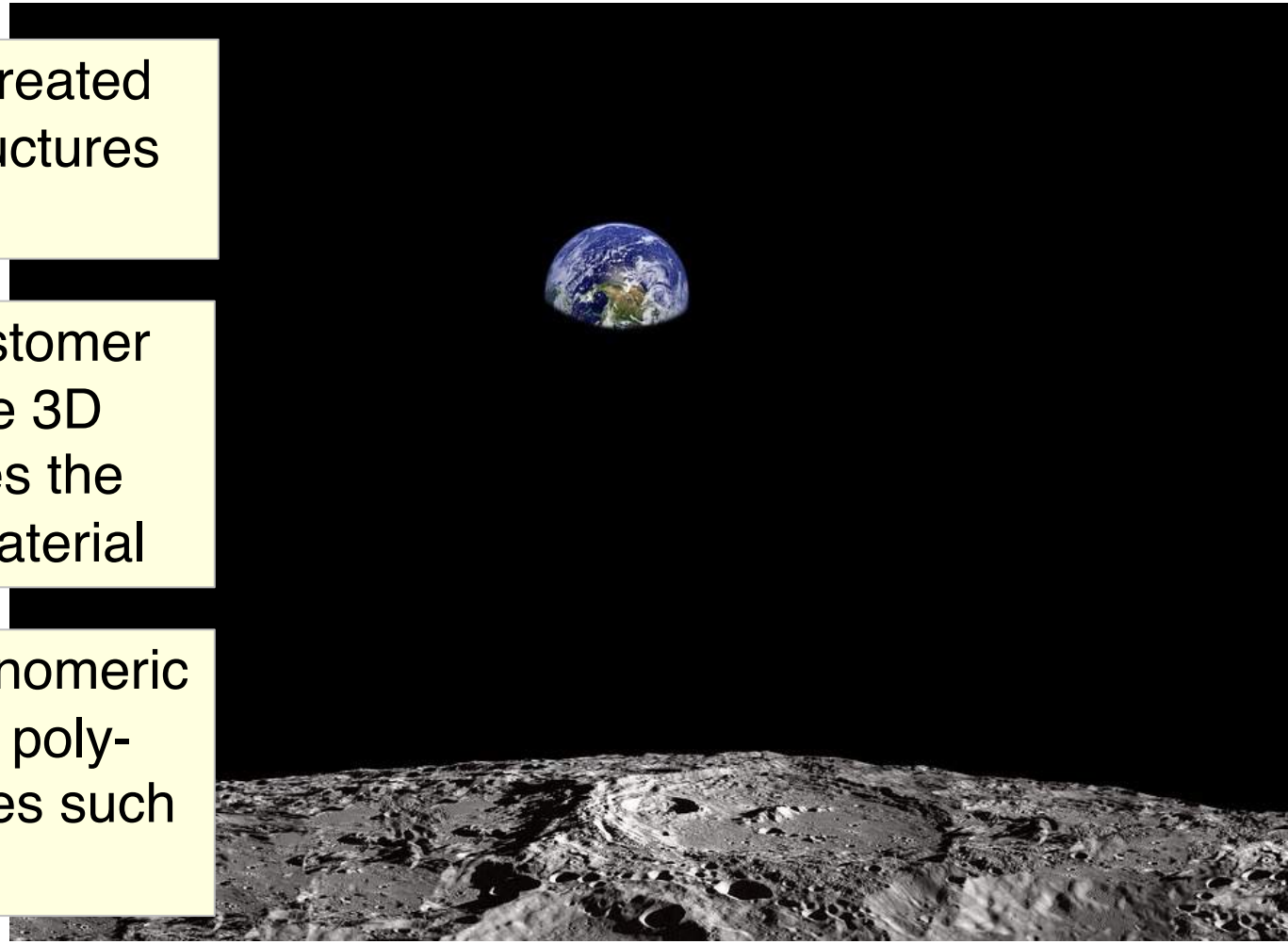
Image credit: https://www.theyucatantimes.com/2020/02/the-siglo-xxi-yucatan-convention-center-enters-mexicos-top-ten/

3D printing Martian and Lunar regolith

Researchers at Northwestern University created Robust and Elastic Lunar and Martian Structures from 3D-Printed Regolith Inks

The inks were made from a graphene-elastomer composite that bonded the regolith in the 3D printing process. The graphene enhances the strength and elasticity of the 3D printed material

The elastomer can be synthesized from monomeric components, such as poly-lactic acid and poly-glycolic acid, isolated from biological sources such as compost and human urine



Source:
https://www.nature.com/articles/srep44931

Image credit: Pixabay

Graphene enhanced propellant

Purdue University have developed a graphene foam.

They developed methods of making and using compositions with solid fuel loaded on highly conductive, highly porous graphene foams for enhanced burn rates for the loaded solid fuel.

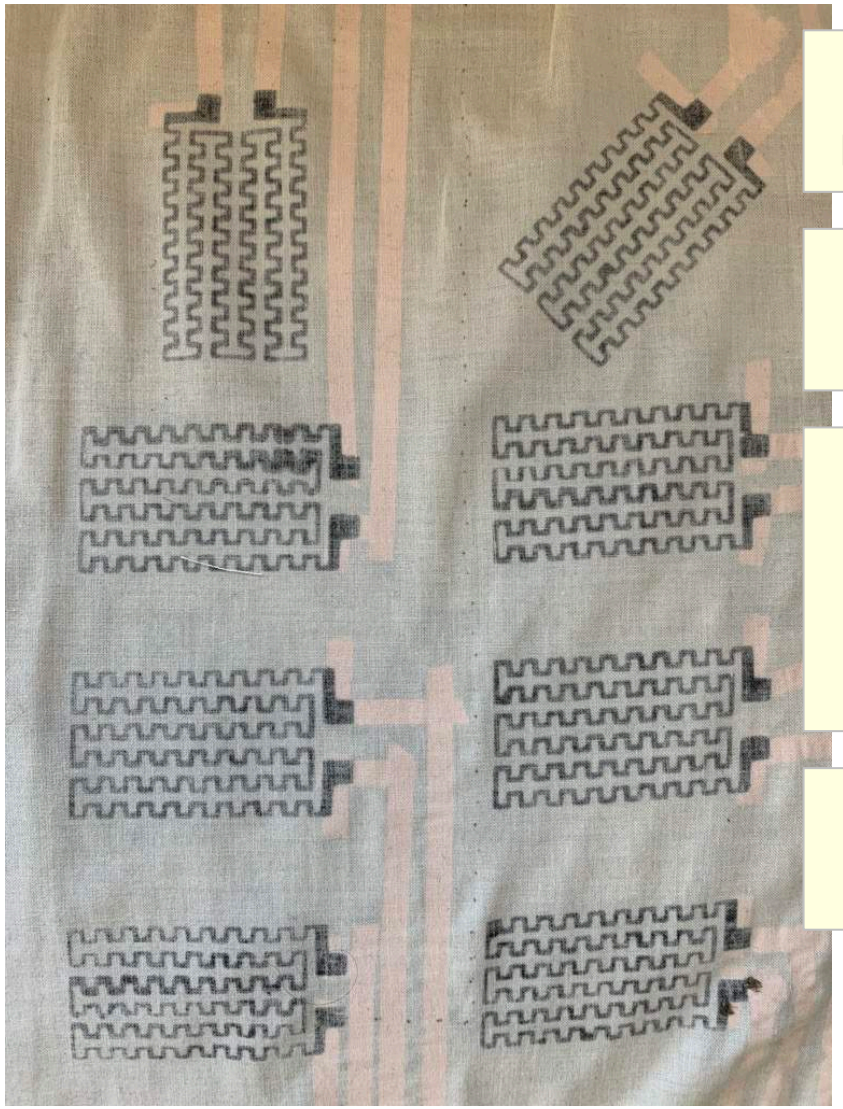
The graphene foam structures are:

- High temperature thermally stable,
- Super lightweight
- Reusable

Source:
https://www.purdue.edu/newsroom/releases/2019/Q2/new-hybrid-energy-method-could-fuel-the-future-of-rockets,-spacecraft-for-exploration.html

Image credit: Unsplash

Screen printed graphene sensors at the graphene hackathon



Graphene conductive ink made from graphene powder

Sensor patterns printed directly onto fabric

When person sits in the seat the pressure sensitive sensors give information about posture

Feedback given to person to help them improve posture

Image credit: Adrian Nixon

Orbex launch vehicle made with graphene polymer composites

Orbex is a UK-based private, low-cost orbital launch services company. Due to commence operations in 2022

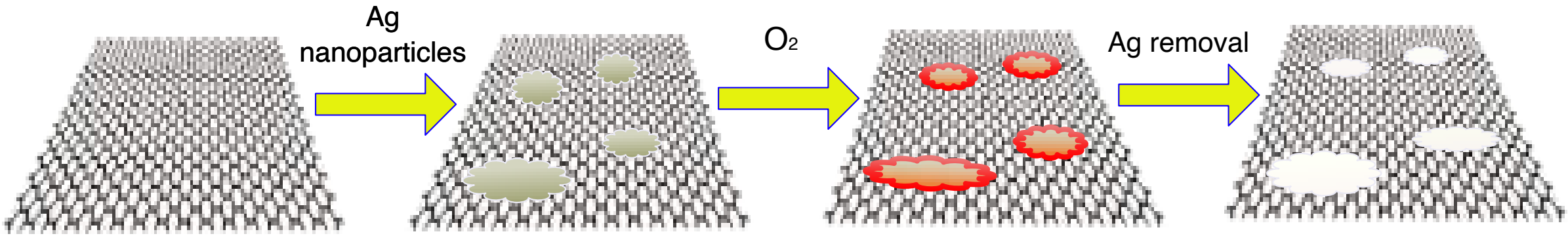
Orbex prime is a two-stage rocket designed to carry up to 150 kilograms of payload, contained within a 1.3-metre fairing, into a sun synchronous orbit.

Orbex prime is built with 3D-printed engines and a carbon fibre and graphene body

Source:
https://orbex.space/news

NASA Holey Graphene

NASA Langley have invented a new technique that can create holes in graphene sheet with precision



Start with graphene nanoplatelets usually made from graphite

Dust the surface with silver nanoparticles

Oxidise the graphene around each nanoparticle to create the holes

Remove remaining Ag nanoparticles with acid to leave the holes

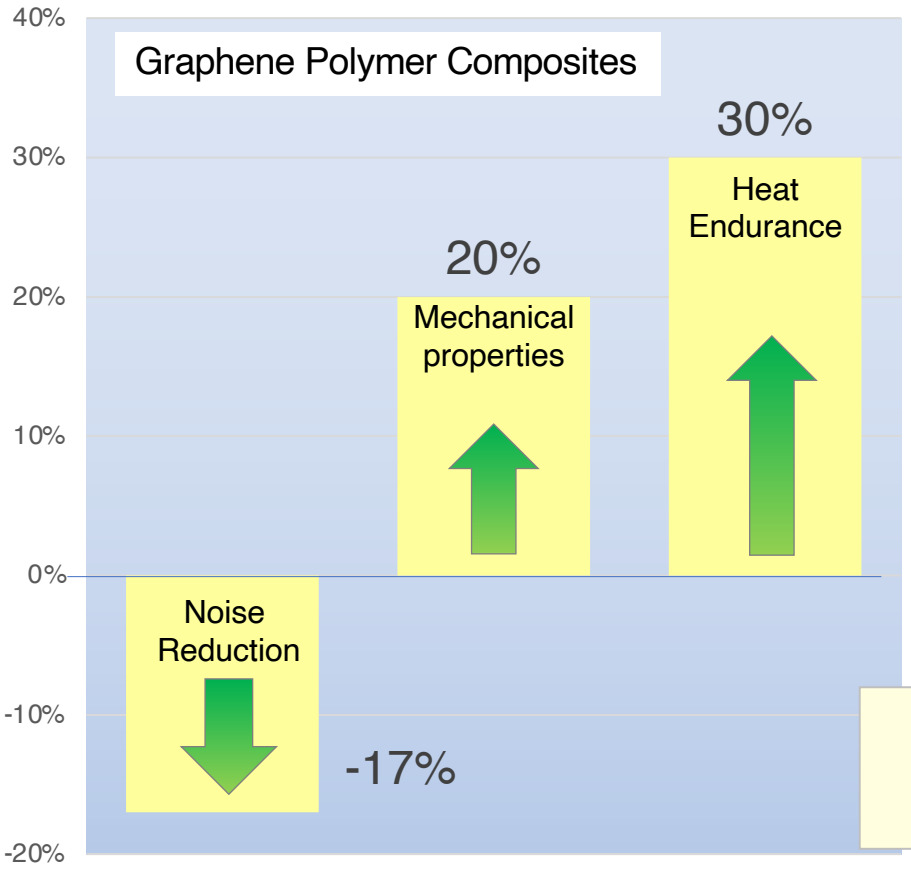
This could be used to make size selective membranes for gas / liquid separation

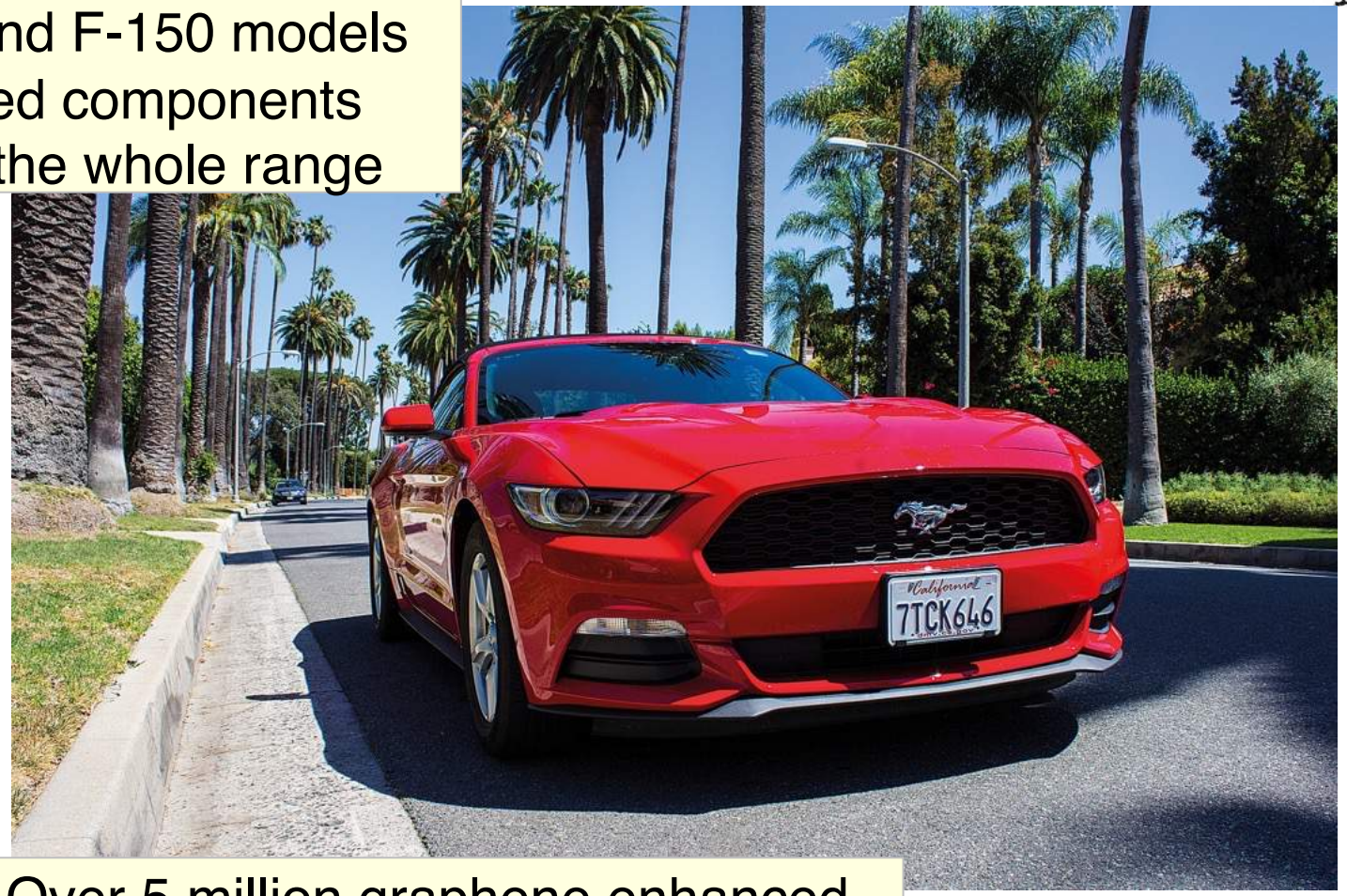
https://www.nasa.gov/langley/business/feature/nasa-langley-s-technology-further-enhances-graphene-functions

Graphene composites in Ford vehicles – Acoustic damping

Quieter, more refined cars = competitive advantage

From 2019 all Ford Mustang and F-150 models contained graphene enhanced components
This is now extended across the whole range





Over 5 million graphene enhanced automobiles manufactured

Nixene Publishing
Clarity from Complexity™

[1] https://media.ford.com/content/fordmedia/feu/en/news/2018/10/09/ford-innovates-with-miracle-material-powerful-graphene-for-vehicle-parts.html

Sheet Graphene

Large scale sheet graphene

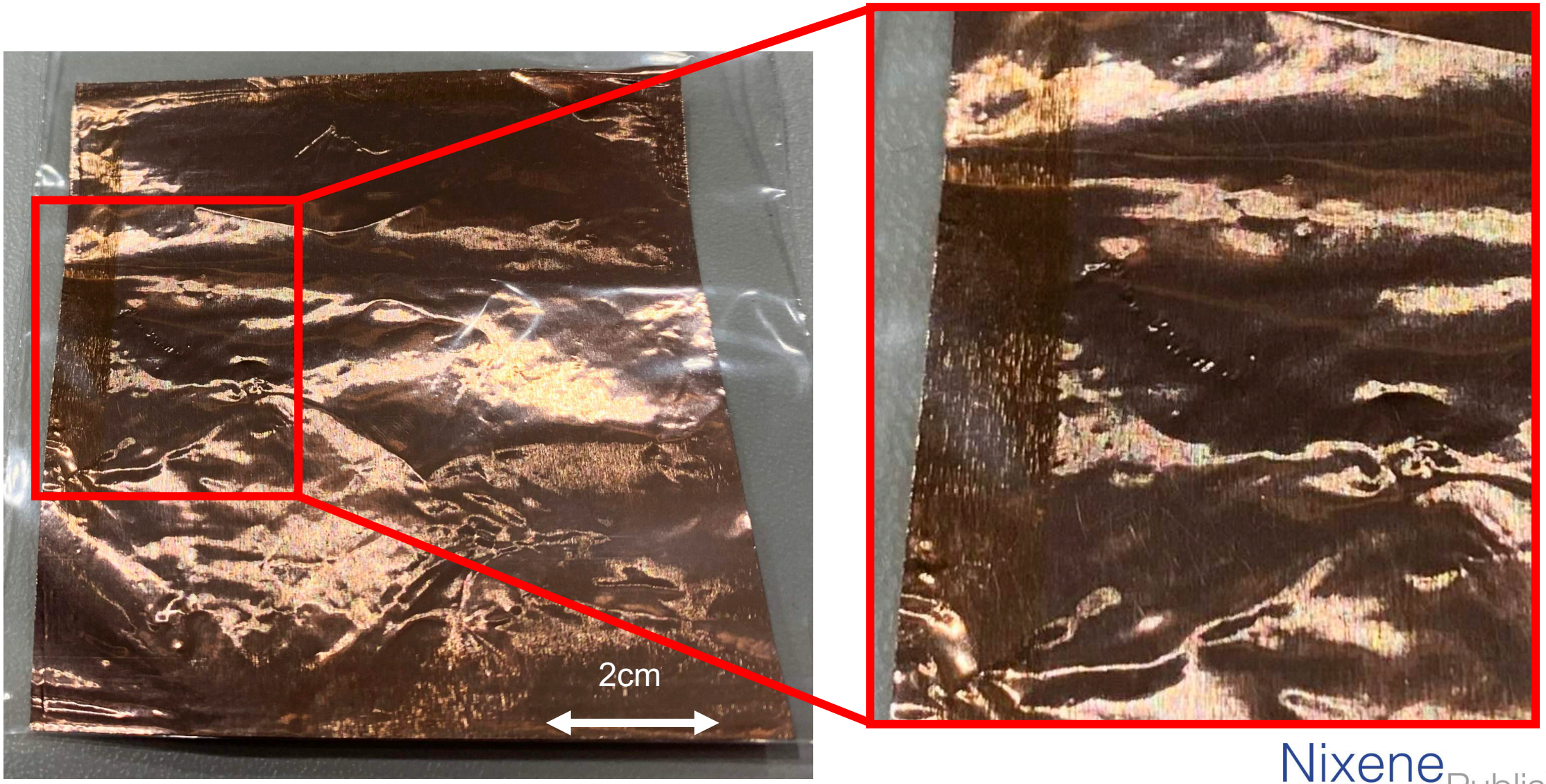
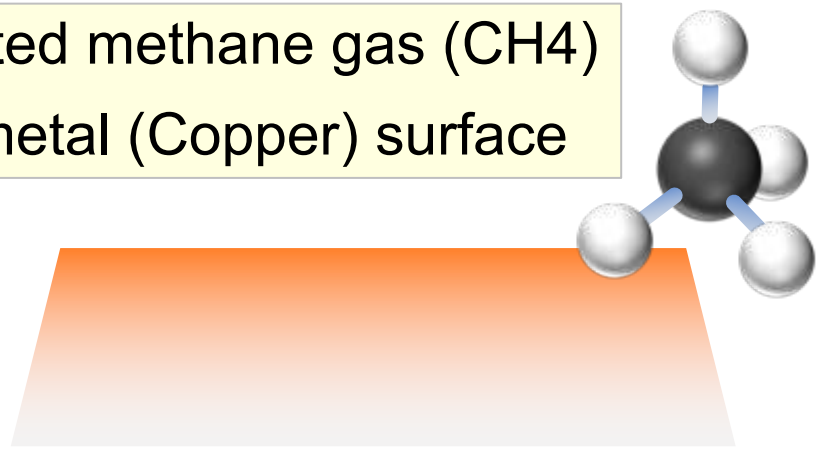


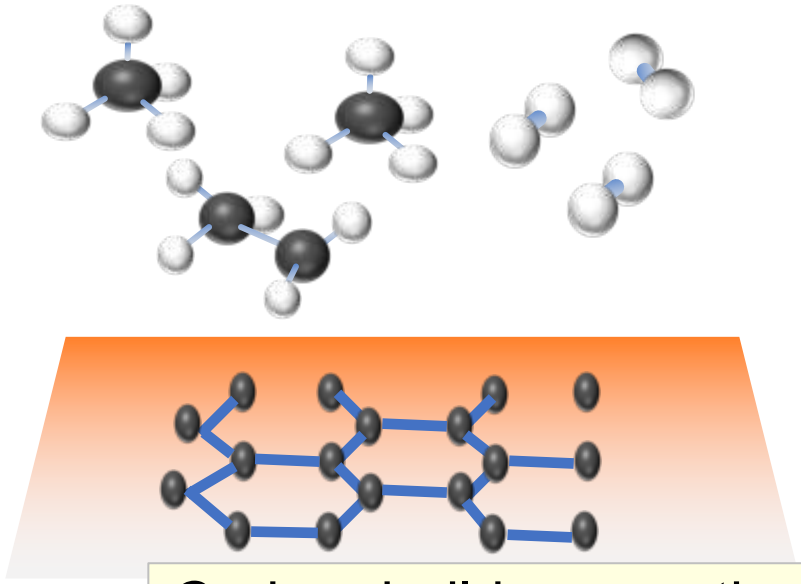
Image Credit: Adrian Nixon

Making graphene from the ‘bottom up’ by Chemical Vapour Deposition (CVD)

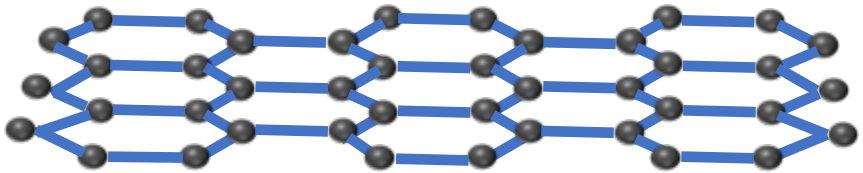
Pass heated methane gas (CH4)
Over a metal (Copper) surface



The copper helps carbon and hydrogen separate from the methane



Carbon builds up on the copper as a hexagonal graphene layer



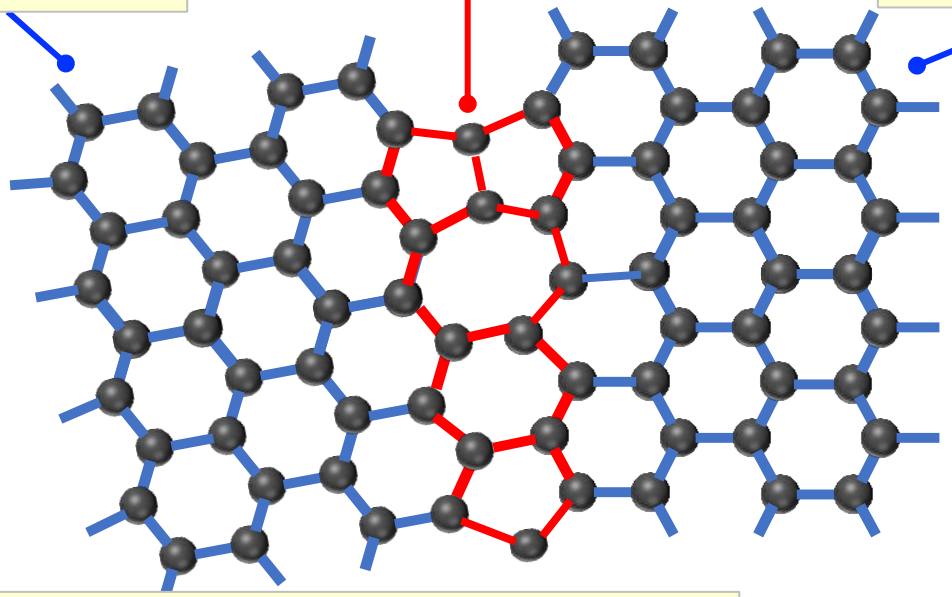
Remove the copper to leave the one atom thick graphene sheet

Understanding Polycrystalline and Single Crystal Graphene

Single Crystal Graphene domain A

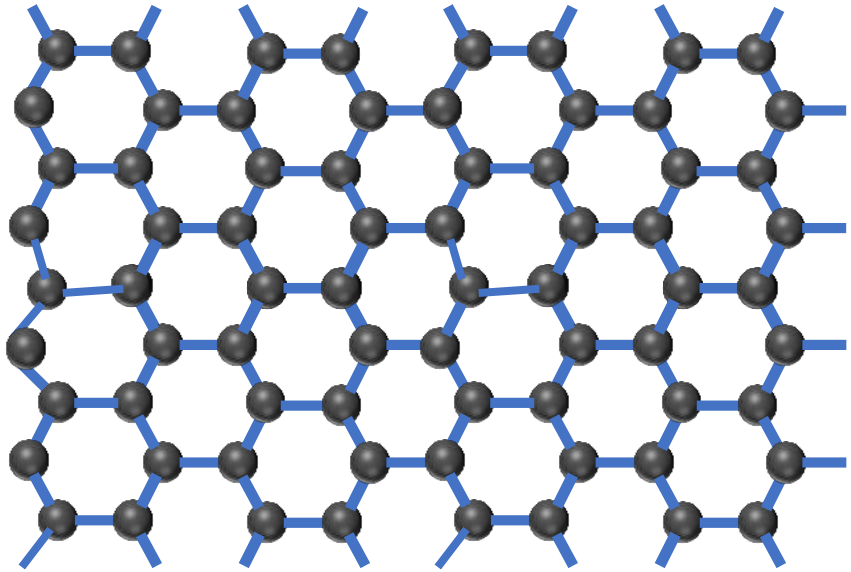
Grain boundary Formed of 5,6,7,8 membered rings

Single Crystal Graphene domain B



The grain boundaries introduce vacancies and defects that make graphene polycrystalline
This is close to the current state of the art of graphene film manufacturing

Single Crystal Graphene continuous repeating pattern with no defects



This is the ultimate material
200 times stronger than steel and best material for electronics and many other applications.
It will take time and resources to perfect and be a longer term product

Is it even possible to make single crystal graphene?

Single crystal means a single molecule at macro-scale

Single crystal means a single two dimensional molecule at scales of centimetres, metres and kilometres

Single Crystal Graphene has already been made in the lab in 2017 and 2018

A team at Peking University started by annealing a copper shape from the point to create a single crystal of metal with no grain boundaries

Single Crystal graphene (a single molecule) Has already been made half a metre long – in China [1]

Then they arranged the growing conditions to form hexagon domains
These domains aligned and joined up rather than form discontinuities

This produced a sheet of continuous graphene that contained
99% ultra highly orientated grains forming a single crystal 50mm x 500mm [1]

Oak Ridge National Laboratory has also shown that single crystal graphene can be made in the lab [2]

Sources: X. Xu et al. (2017) Ultrafast epitaxial growth of metre-sized single-crystal graphene on industrial Cu foil, Science Bulletin 62. 1074-1080
[1] https://arxiv.org/abs/1707.02512
[2] https://www.ornl.gov/news/method-grow-large-single-crystal-graphene-could-advance-scalable-2d-materials

Is it possible to make graphene at industrial scale and speeds?

Economic manufacture will require metres per second speeds

Graphene is only 17 years old, how fast could it be made right now?

Note: The following examples are continuous industrial processes aimed at electronics markets and other commercial applications

Europe: Continuous industrial manufacture of graphene

Aixtron is a Graphene Flagship partner based in Germany. It makes a graphene production machine called the Neutron

This is a roll to roll (R2R) process

Vertical tube furnace making polycrystalline graphene for consumer electronics, sensors and photonic applications.

Speed not disclosed

Production capacity: 20,000 square metres of graphene per year

The graphene is made on metal foil and a separation process yet to be developed

Aixtron Neutron at the Graphene Engineering Innovation Centre (GEIC) in Manchester, UK Image credit: Rob Whieldon

https://phys.org/news/2019-06-cost-effective-large-scale-graphene-aixtron.html

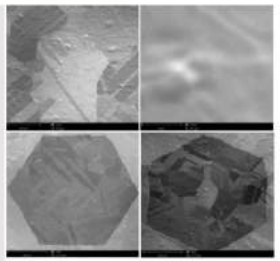
USA: Continuous industrial manufacture of graphene

Example of Graphene Measurements	(Single layer)
Crystal size	40 µm - > than 1 mm
Coverage	>98%
Multilayer coverage	Down to <5%
2D width average (Graphene on Si/SiO_2)	33 cm^{-1}
2D/G Intensity ratio (Graphene on Si/SiO_2)	2.1 – 3
D/G Intensity ratio (Graphene on Si/SiO_2)	<0.3

	PET Ref	PET/1 Layer	PET/5 Layers	PET/10 Layers
Transmittance @550 nm		97.3%	87.2%	76%
Sheet resistance Ω/sq	O.L. (∞)	630	120	55
Barrier WVTR g/m²/day	5.1	-	1.3	-

High coverage

Large crystals



Large sheets (300mm x length)

Consistent properties

Effective Barrier | Excellent Conductor | Transparency | Bio Compatible | Lubricant

General Graphene in the USA announced they have a roll to roll process for making graphene on copper foil

Horizontal tube furnace making polycrystalline graphene for electronics

Speed unknown

Production capacity 100,000 m^2 / year

They have had some success transferring the graphene from the copper foil on to Polyethylene terephthalate (PET) film.
1 – 10 layer graphene has been made at square centimetre scale

Image credit: General Graphene

Korea: Continuous industrial manufacture of graphene

LG in Korea announced they have developed a continuous graphene production line

This is a roll to roll (R2R) process

Vertical tube furnace making polycrystalline graphene for electronics

This is capable of making graphene by the kilometre

It is a high speed process 1m / minute

However, the graphene is stuck on the copper foil and a separation process yet to be developed

Large Area & High Speed 400 mm R2R System for Mass Production

Specifications

- Configuration : 3300(H) x 2000(D) x 2000(W)
- Pressure : ~ 10^{-3} Torr
- Temperature : Max. 1,100 ℃ (± 1 %Deviations)
- Roll Speed : ~ 60m/hr
- Roll Width : 400 mm width (double roll)

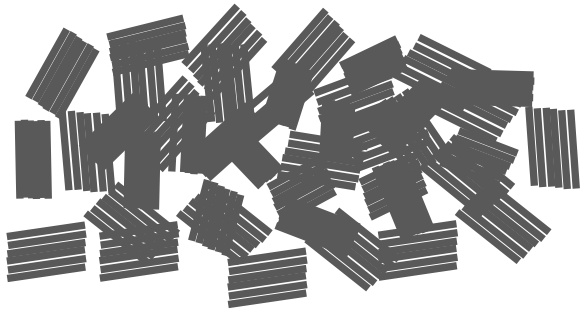
Image credit: LG Electronics

LG are making graphene for electronics markets

This announcement shows that graphene can be made at high speed by a continuous process

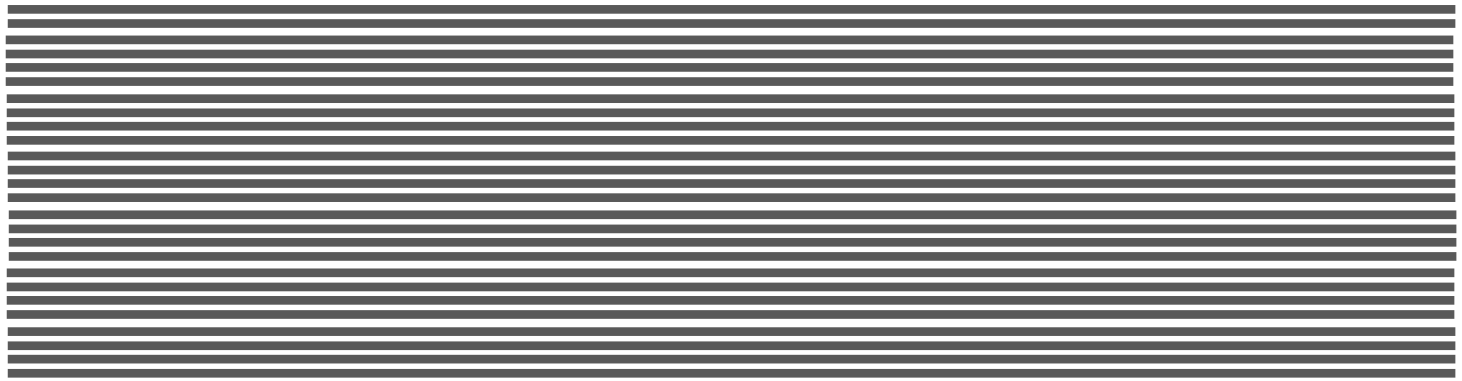
Graphene is not just an advanced material, it is a frontier material. This is disruptive technology

Graphite
Multi-layered graphene nanoplates



Multilayer graphene exists in nature as graphite
The bulk material is made of jumbled stacks of nanoplates

Nixene® : Multi-layered sheet graphene



Multilayer sheet single crystal graphene is an entirely new material that is not found in nature
The bulk material is made of highly coherent layered sheets of single molecules of graphene
on the scale of centimetres, metres, kilometres

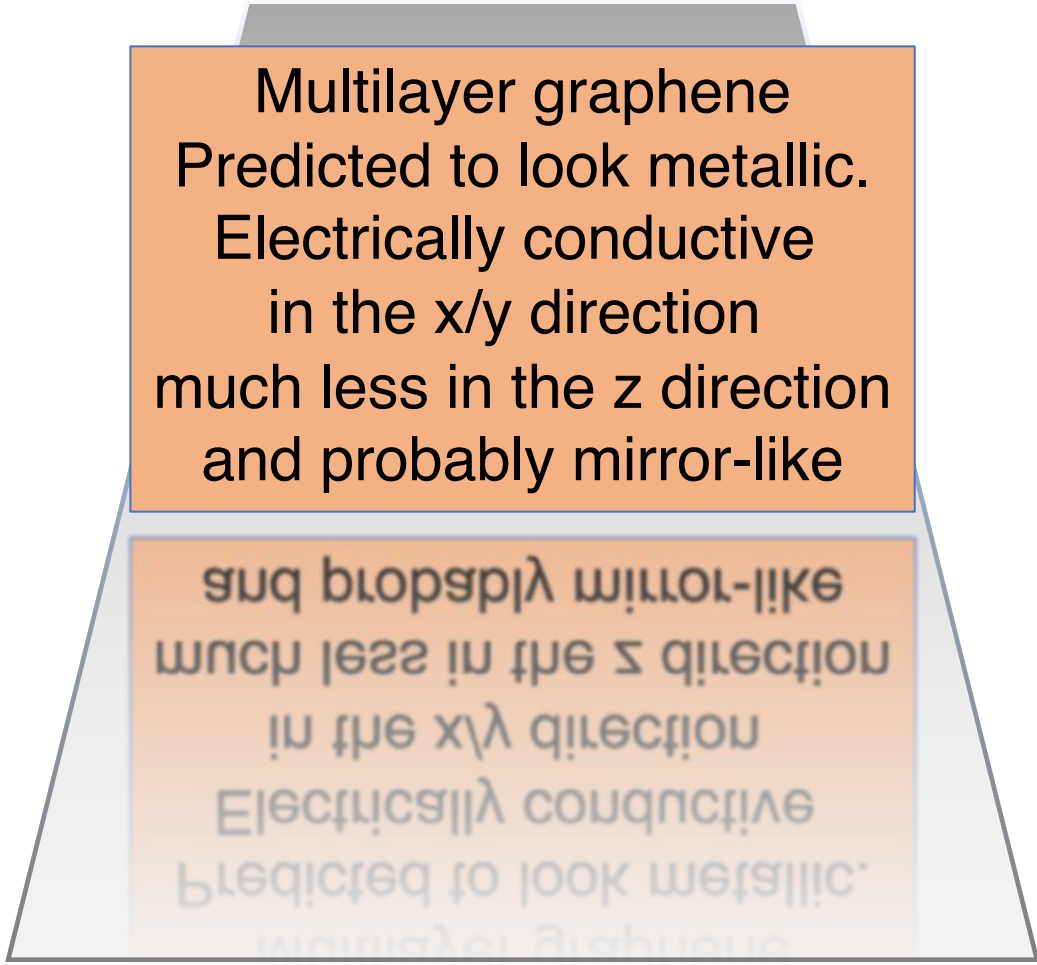
Nixene Publishing
Clarity from Complexity™

The Frontier material
Multi-layered sheet single crystal graphene (Nixene)

Nixene has yet to be made at scale:

Predicted properties

- 200 times stronger than steel
- Extremely high melting point
- Chemically stable surface
- As hard as diamond
- Extremely thin, probably inflexible,
- Anisotropic electrical and thermal conductivity
- Impermeable to all gases
- Untearable
- Unbreakable



Predicted properties by Nixene Publishing based on published literature

Nixene Publishing
Clarity from Complexity™

Sheet Graphene Applications: Examples

Graphene solar sails

Space Elevator

Ultra-lightweight bullet proof armour

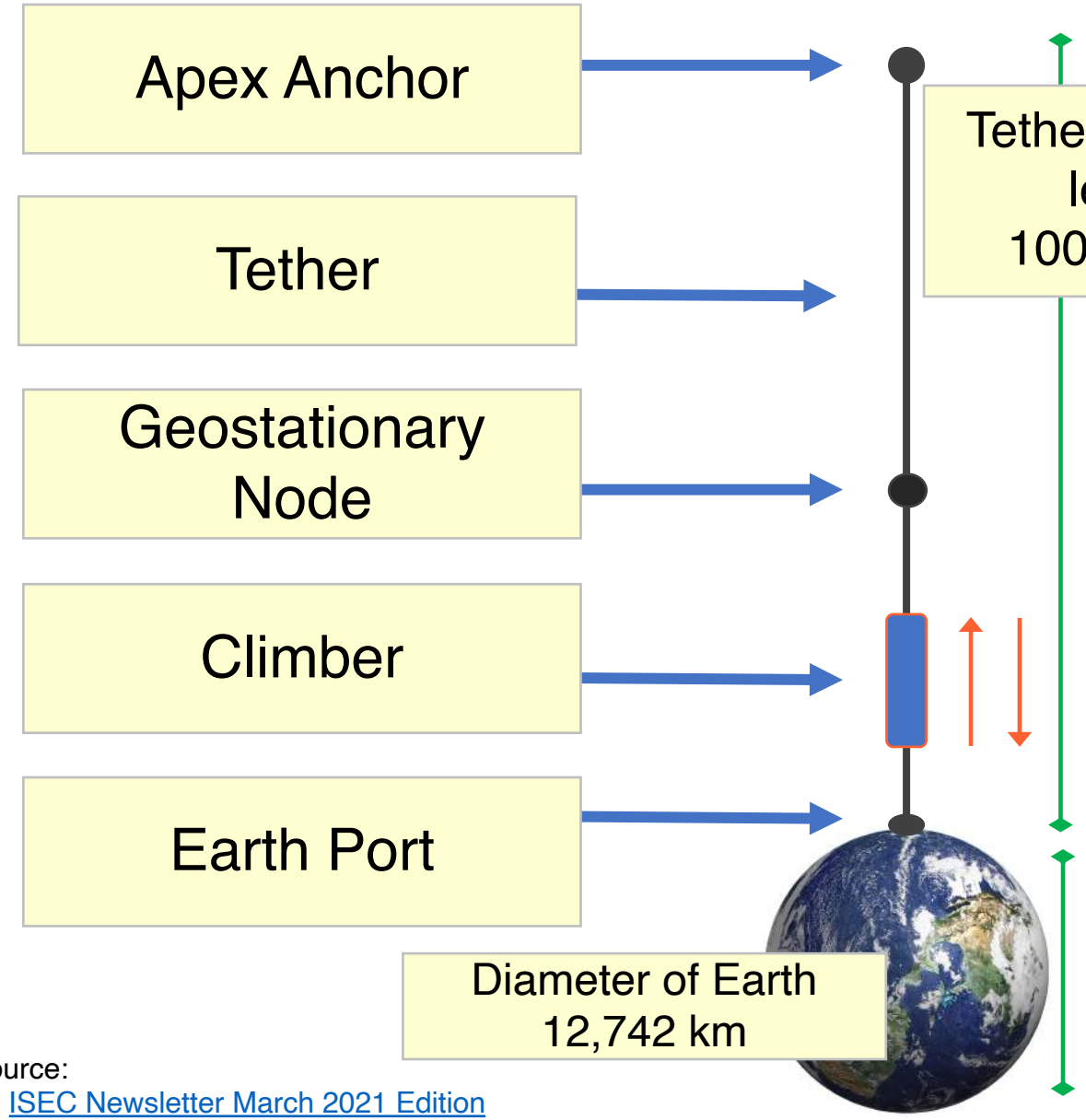
Radiation proof Hall sensors

Ultra-lightweight and flexible touchscreens

Lab on a chip SARS-CoV-2 sensors

Impossible to industrial

Graphene Sheet / Film and the Space Elevator



Jerome Pearson is considered the co-inventor of the Space Elevator. He conceived the idea of the space elevator in 1969 while working at the NASA Ames Research Center [1]

NASA Institute of Advanced Concepts (NIAC) Feasibility study reported in 2003.

"We have defined a complete space elevator that can be constructed, deployed and operated using current or near-term technology"

"The ribbon, being the only component of the space elevator not commercially available, is the last hurdle prior to construction of the space elevator "

Source:
[1] ISEC Newsletter March 2021 Edition
[2] http://images.spaceref.com/docs/spaceelevator/521Edwards.pdf

Nixene Publishing
Clarity from Complexity™

Graphene Sheet / Film a candidate tether material for the Space Elevator

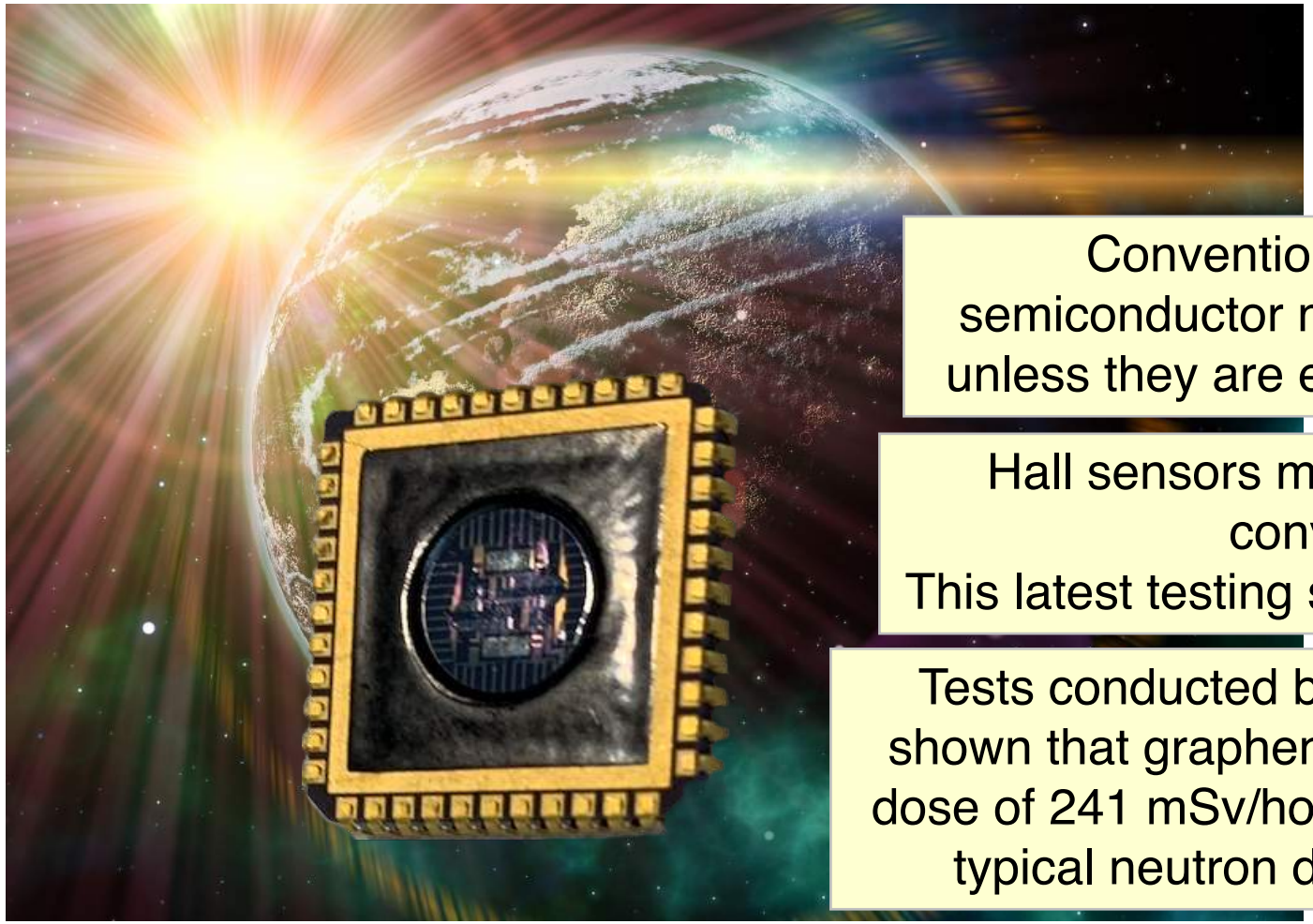
Single Crystal Graphene has a tensile strength of 130 GPa

It also is very lightweight one square metre weighs just 0.77 milligrams

So, single crystal graphene is strong enough and light enough to be a tether candidate material

Can graphene be made at the industrial scales needed?

Graphene Hall Effect sensors are ready for high-radiation applications in space and beyond



Hall Effect sensors are a critical electronic component in a variety of applications, from proximity sensing and speed detection through to current sensing

Conventional sensors made from silicon and other semiconductor materials react adversely to neutron radiation, unless they are encapsulated in radiation-hardened packaging

Hall sensors made from graphene are more sensitive than conventional silicon based sensors.
This latest testing shows they are also more resistant to radiation

Tests conducted by the UK National Physical Laboratory have shown that graphene Hall sensors survive exposure to a neutron dose of 241 mSv/hour – which is about 30,000 times the expected typical neutron dose rate in the International Space Station

Image credit: Pixabay and Adrian Nixon

Source:
https://www.eejournal.com/industry_news/paragraf-and-npl-demonstrate-that-paragrafs-graphene-hall-effect-sensors-are-ready-for-high-radiation-applications-in-space-and-beyond-2/

Graphene Field Effect transistors – lab on a chip

CVD Graphene can now be used to make reliable field effect transistors that can detect biochemicals in body fluids

The technology is progressing rapidly and multiple sensors can be embedded on one chip

The this means multiple results can be read out rapidly from just one sample. Useful for diagnostics in remote locations

The graphene Field Effect Transistor (FET) Sensor: a lab on a chip for Covid-19 (SARS-CoV-2) detection

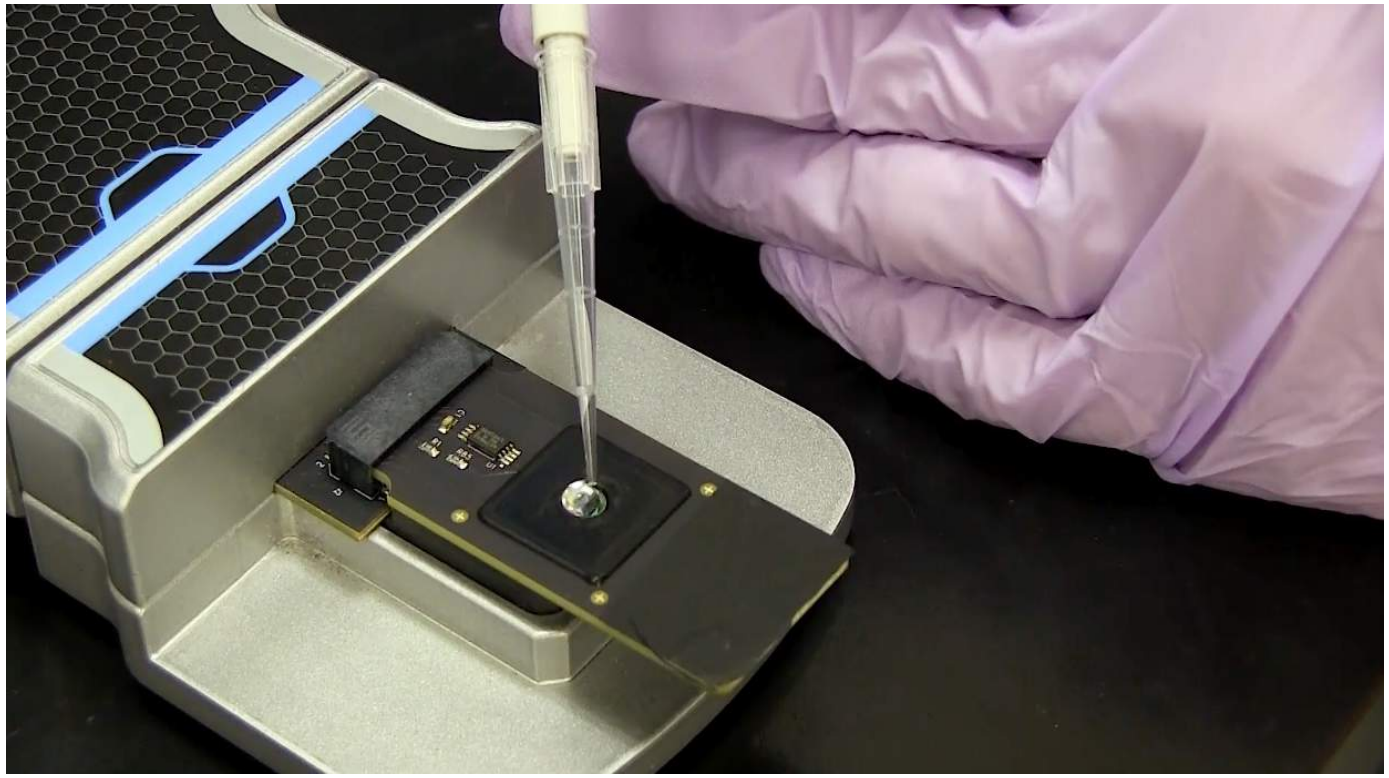


Image Credit: Cardea Bio

Cardea and The University of Berkeley California have a designed a graphene FET sensor with CRISPR technology

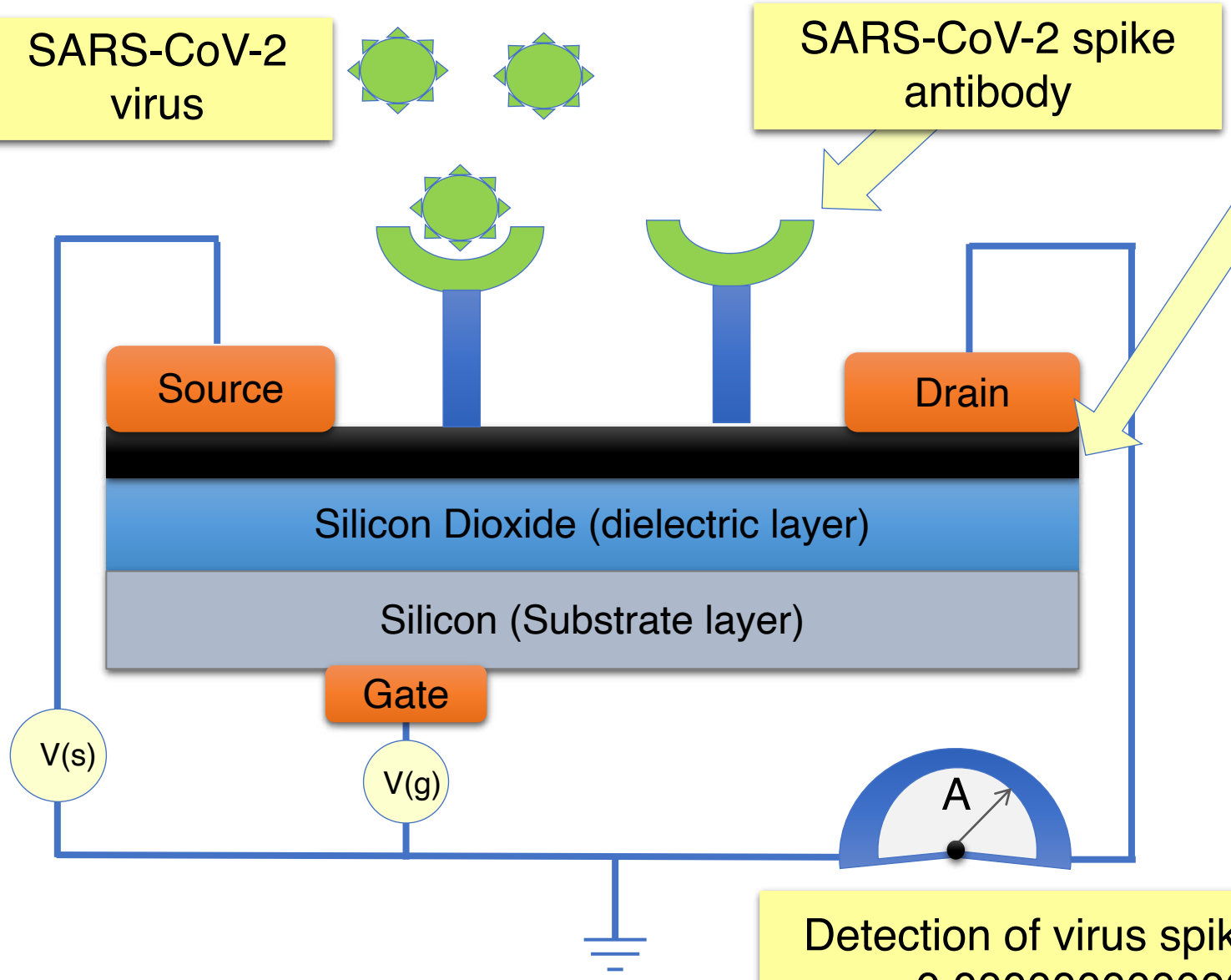
The company is now working on the detection of SARS-CoV-2 virus RNA to give results in minutes

CRISPR: clustered regularly interspaced short palindromic repeats

Source:
https://www.nature.com/articles/s41587-020-0597-x
https://cardeabio.com/crispr-chip/

Nixene Publishing
Clarity from Complexity™

Korean Graphene Field Effect Transistor detects SARS-CoV-2 virus



Graphene is functionalized with spike antibody groups to make it sensitive to the SARS-CoV-2 virus

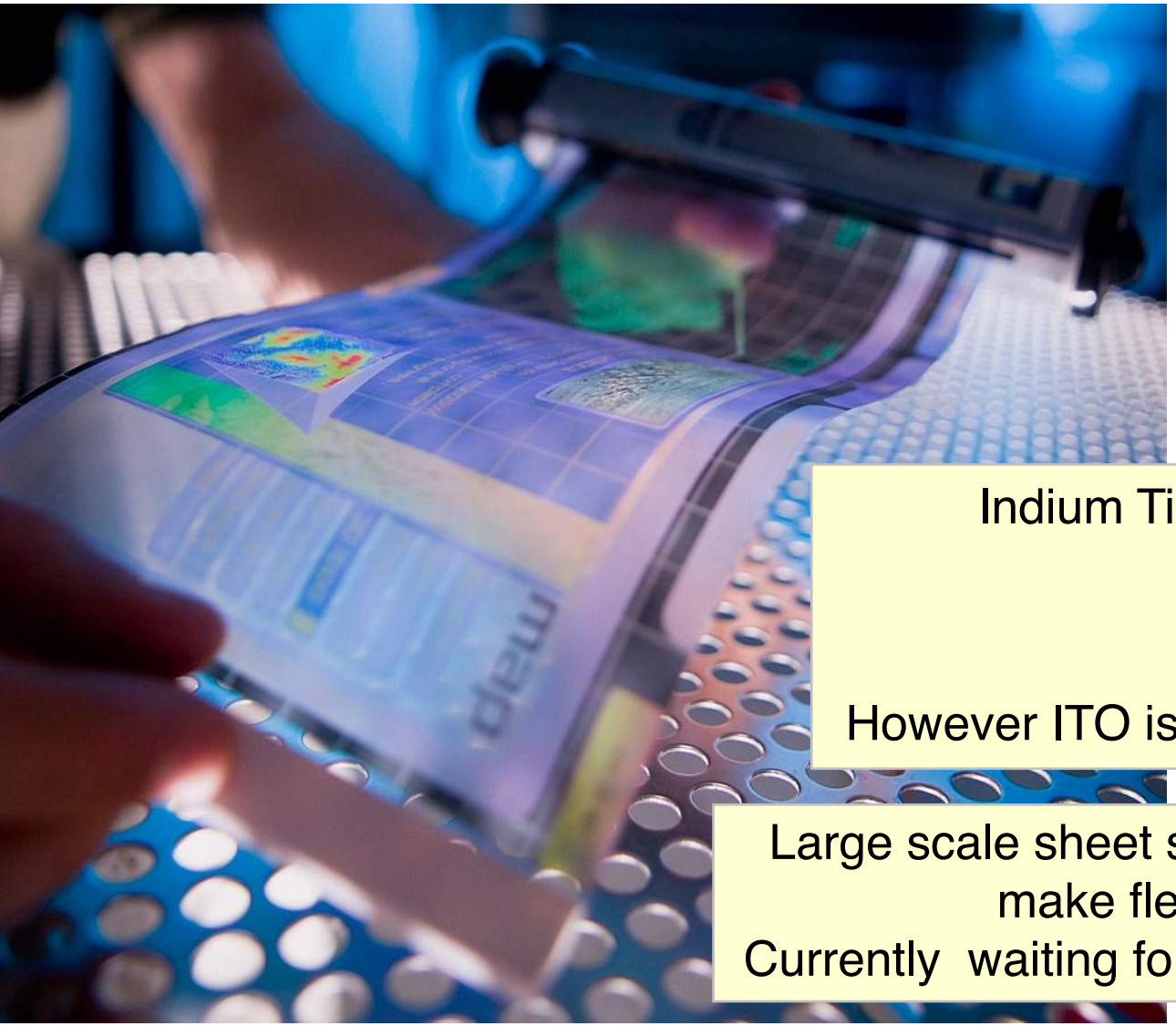
When a virus engages with the antibody this changes the electric field in the local region

This change in electric field alters the conductivity of the graphene and the change in current measured with an ammeter (A) with high sensitivity

Detection of virus spike protein 1fg/ml
0.000000000000001g / ml

Source https://pubs.acs.org/doi/10.1021/acsnano.0c02823

Sheet Graphene: Lightweight Flexible touchscreens



Flexible display technology developed by Arizona State University, as funded by the U.S. Army

The flexible display works well
However the flexible touchscreen overlayer has not yet been developed

Indium Tin oxide (ITO) is the best touchscreen material
Cheap
Transparent
Electrically conductive
However ITO is brittle and cannot be used for flexible touchscreens

Large scale sheet single crystal graphene has already been proved to make flexible touchscreens by Samsung in 2013
Currently waiting for industrial production of sheet graphene to catch up

Nixene Publishing
Clarity from Complexity™

Multi layered sheet graphene: Lightweight armour

Lightweight armour is another market that will be disrupted by Single Crystal Graphene

Current lightweight armour market is based on liquid armour technology

Layered (1000s) Single Crystal Graphene (nixene) thin as plastic film and as lightweight will stop a bullet

Source
https://www.businesswire.com/news/home/20170726005685/en/Top-3-Emerging-Trends-Impacting-Global-Military

Graphene Solar Sails

CENTER OF APPLIED SPACE TECHNOLOGY AND MICROGRAVITY

ZARM

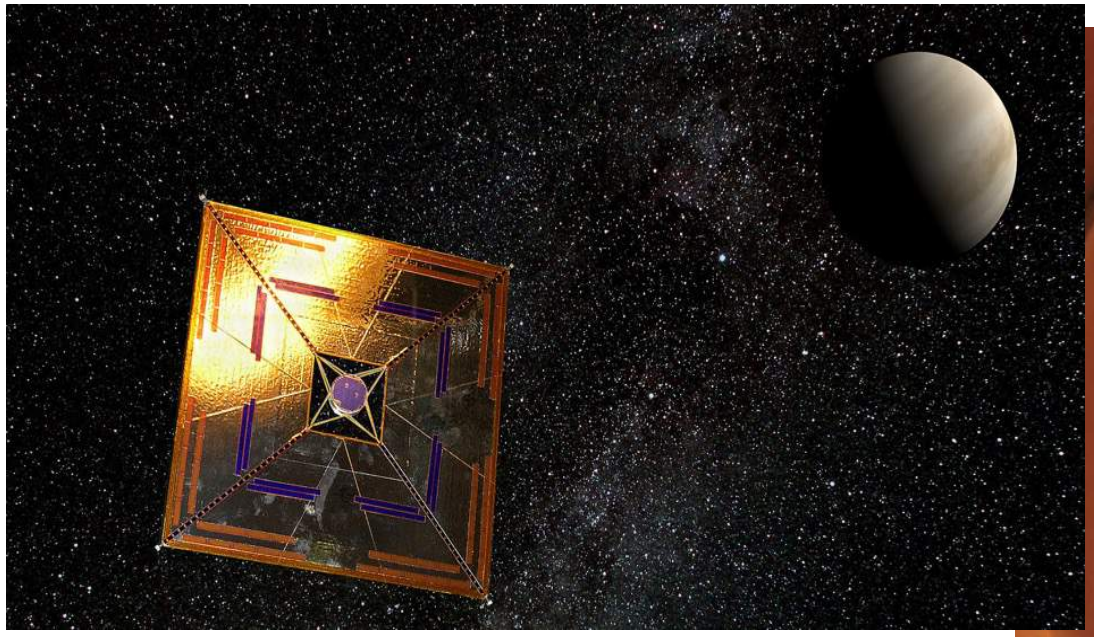
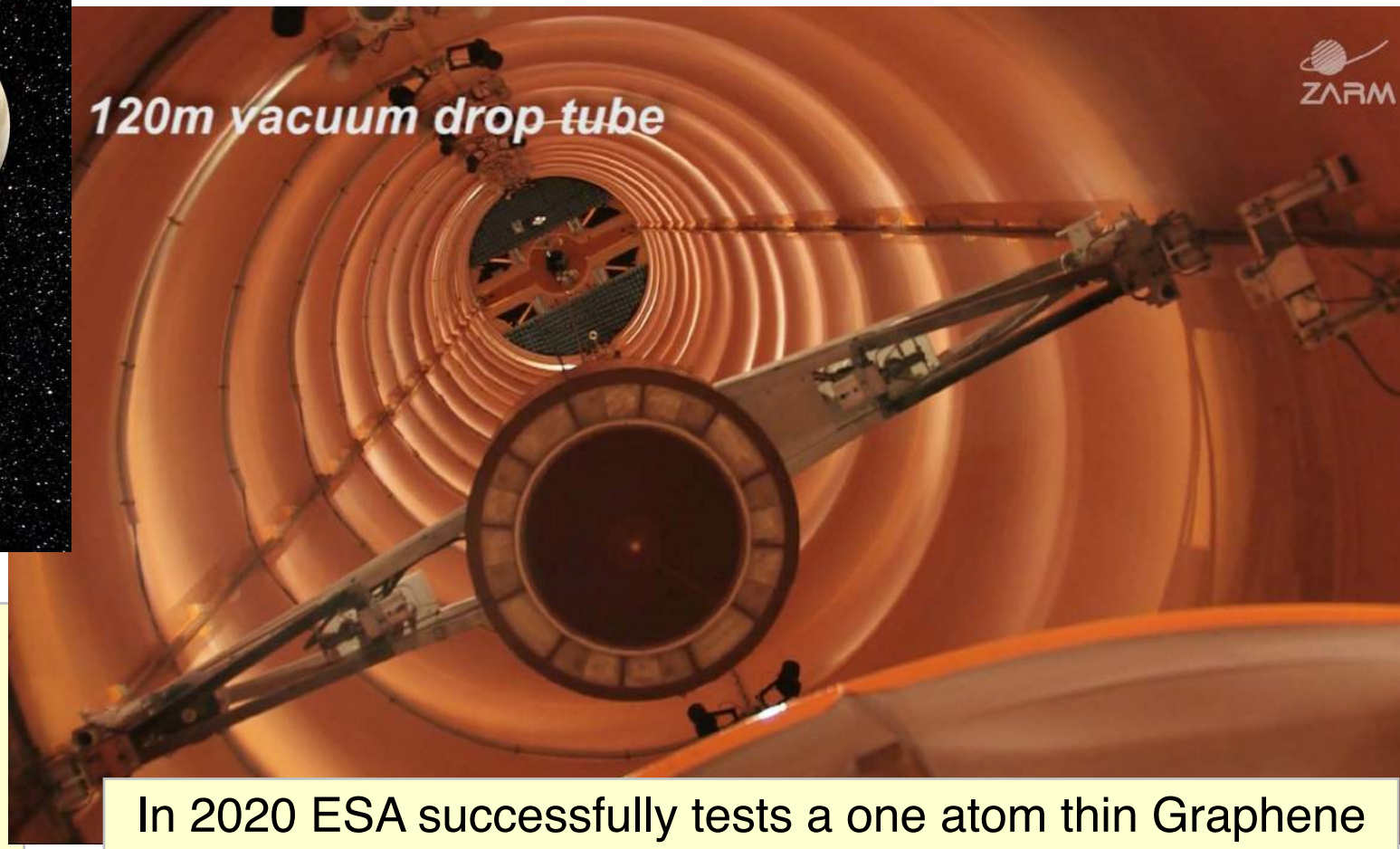


Image credit: Pixabay

In 2018 the China Academy of Launch Vehicle Technology (CALT), the rocket development arm of the Chinese space programme, revealed that it has designed a graphene composite film suitable for use in light-propelled spacecraft. [1]



In 2020 ESA successfully tests a one atom thin Graphene solar sail at the ZARM drop tower in Bremen, Germany and achieved 1ms^{-2} with a 1W laser [2]

Image credit: ZARM

Sources:
1. http://www.spacetechasia.com/china-designs-graphene-composite-film-for-light-propulsion/
2. https://www.esa.int/ESA_Multimedia/Images/2020/05/Graphene_sail_in_microgravity

Nixene Publishing
Clarity from Complexity™

Graphene: Current reality - Impossible to Industrial in 17 years

If you think graphene is overhyped - think again

We are seeing proven double-digit performance improvements in multiple applications of graphene powders and dispersions

CVD (sheet) graphene is starting to make an appearance in sensors and actively considered for the Space Elevator tether

Graphene is the swiss army knife of advanced materials

Source:
https://pubs.acs.org/doi/10.1021/acsanm.0c02055

Image credit: Pixabay

Interactive session

What applications come to mind for graphene?

(Thinking aloud, and allowed)

Ask anything you like…

(see how long it takes to get us to say ‘we don’t know’)

The Nixene Publishing Team

Adrian Nixon
Editor

Rob Whieldon
Operations

Nigel Cliffe
Marketing

Neil Moon
Commercial

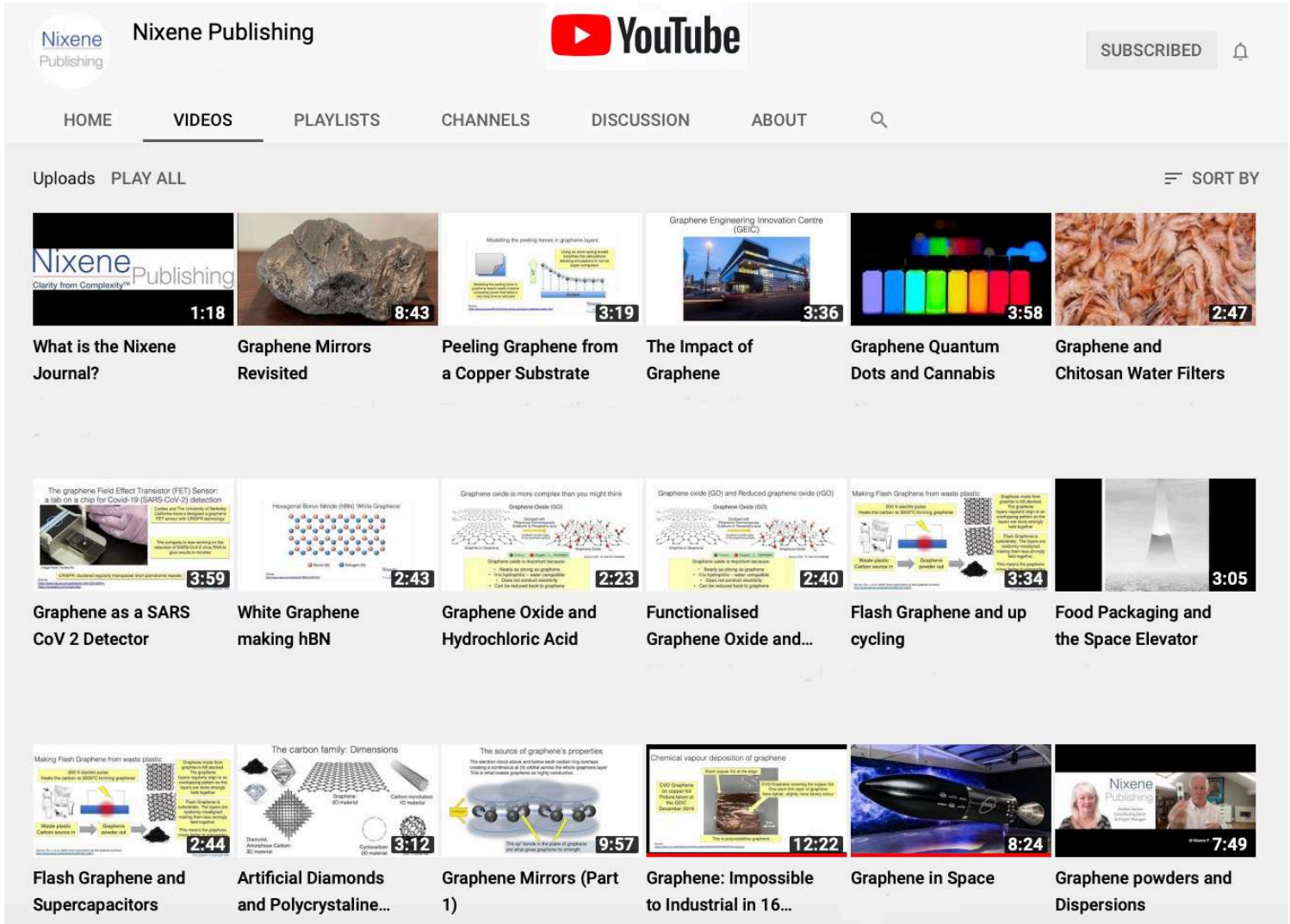
Debbie Nelson
Contributing Editor
& Project Manager

Joanna Whitehead
Graphic Design &
Print Management

Nixene Publishing Ltd
3B Lockheed Cl | Preston Farm Industrial Estate | Stockton-on-Tees | TS18 3SH | United Kingdom
Nixene Publishing (USA)
2953 Bienville Blvd | #158 Ocean Springs | MS 39564 | USA
www.nixenepublishing.com

Nixene Publishing
Clarity from Complexity™

More free content about graphene and 2D materials
The Nixene Publishing YouTube channel



Over 70 short videos

Concise content

Latest technology

Commercial applications

Constantly updated

https://www.youtube.com/c/NixenePublishing/videos

Nixene Publishing
Clarity from Complexity™

To find out more

We operate a subscription model and do not take advertising.
If you want to take out a subscription, please contact either Debbie or Rob directly or email info@nixenepublishing.com

Nixene Publishing Ltd

3B Lockheed Cl I Preston Farm Industrial Estate I Stockton-on-Tees I TS18 3SH I United Kingdom

Nixene Publishing (USA)

2953 Bienville Blvd I #158 Ocean Springs I MS 39564 I USA

www.nixenepublishing.com

Nixene Journal

Nixene Publishing
Clarity from Complexity™

Nixene Publishing

Unbiased and independent information in the world of graphene

www.nixenepublishing.com

Follow us on:

#clarityfromcomplexity