



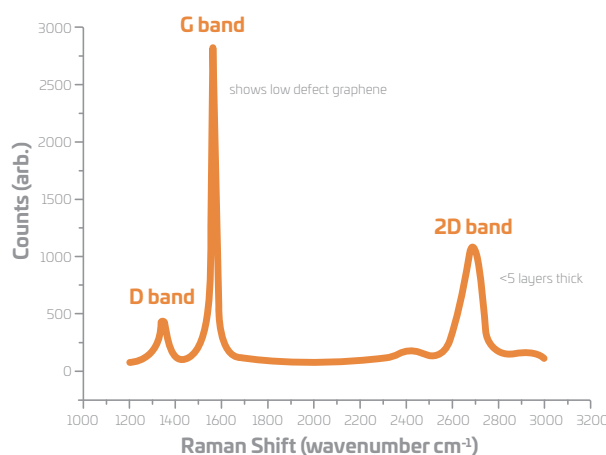
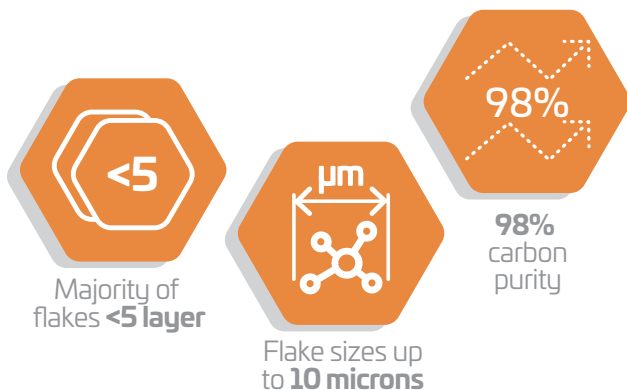
## High Purity, Low Defect Graphene

*“Establishing global benchmarks in few-layer graphene production is important as disruptive technology works best when standards have clarity”*

Neill Ricketts, CEO

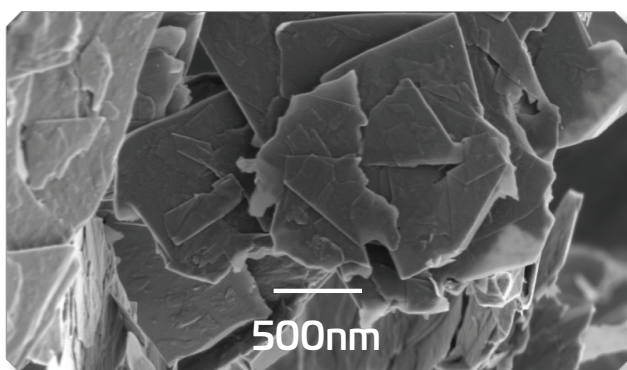
### Nanene™ offers limitless opportunities

Nanene™ is a high quality few-layer graphene powder. The high graphene purity and low defect ratio establish Nanene™ as an outstanding commercially available product that enables true leverage of graphene's unique properties.



Versarien's® patented production processes leave graphene flakes relatively pristine and undamaged. With an impressive D/G peak intensity ratio of ~0.3\*, studies confirm Nanene™ has a high proportion of few-layer graphene flakes less than 3.5 nanometres / 10 layers thick.

\*The lower this number the better, with alternative products having a D/G peak ratio of up to ~2.0.



SEM [1kV] image of bulk Nanene™ showing large flakes



The Graphene Council

### Verified Graphene Producer 2019-2020

Versarien® has successfully passed the Verified Graphene Producer program as administered by The Graphene Council. The Verified Graphene Producer program is an independent, third party verification system that involves a physical inspection of our production facilities, a review of our processes, a random sample of product material and rigorous characterization and testing by a first class, international materials laboratory. For further information, please contact The Graphene Council directly at [tbarkan@thegraphenecouncil.org](mailto:tbarkan@thegraphenecouncil.org)

Versarien® uses two separate patented and scalable manufacturing processes to produce 2D materials.

by **Versarien**®

# What is Graphene?

First isolated in 2004 by two researchers at the University of Manchester, pure graphene is a single atom thick and is referred to as a 2D material.

It is incredibly strong (200 times stronger than steel) and has some very impressive new properties over and above it's 'parent' graphite.

Bi-layer and few-layer graphene has properties

that measure in the same ranges as mono-layer graphene. As the number of layers increases these properties start to significantly reduce.

That is why we only sell powder with high proportions of few-layer flakes.

See below for graphene properties as measured in pristine mono-layer flakes:

Thermal Stability	Thermal Conductivity	Electrical Conductivity	Light Absorption	Gas Permeability	Chemical Stability	Mechanical Strength
						
Stable to decomposition at high temperatures	The perfect conductor >5,000 W/(m·K)	The fastest & most efficient conductor	Absorbs all light frequencies 2.3% per layer	Impermeable to gases. Prevents oxygen ingress	Inert material, so increases chemical resistance	Tensile strength 1.30GPa Young's Modulus > 1TPa



## Technical Specifications

Property	Measurement	Method
Layers ≤5, ≤10, >10	60%, 90%, 10%	Raman [1]
Apparent Thickness	<3.5 nm / 10 layers	AFM [2]
Defect ratio	0.3AV <sub>i</sub> /I <sub>G</sub>	Raman
Lateral Dim.	<10µm	SEM

## Concentration (At.%)

Carbon	Oxygen	Flourine	Sulphur	Nitrogen
98 ± 1.0	2.0 ± 1.0	0.5 ± 0.5	0.5 ± 0.5	0.3 ± 0.3

[1] Raman - bulk powder measurements - layer thickness estimated from 2D lineshape analysis based on A.C. Ferrari, Solid State Communications 143 (2007) 47–57.

[2] AFM - Nanene powder dispersed according to NPL's "Good Practice Guide: Characterisation of the structure of graphene, GPG 145" using N-methyl-2-pyrrolidone (NMP) solvent, with 30 minute sonication at each dilution step.

## Why is Nanene™ so Special?

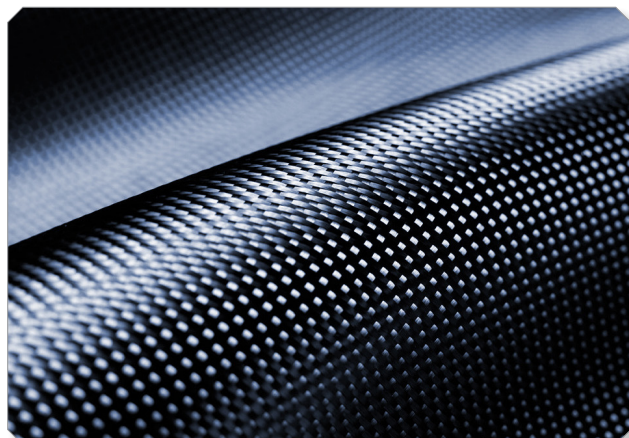
We produce graphene powder with significant few-layer flakes. We then take that powder and put it through further processing in order to isolate only the very best quality graphene. This is Nanene™. With 60% ≤5 layers and 90% ≤10 layers, estimated by Raman, and 98% purity, Nanene™ is an outstanding graphene powder and is available today for commercial supply.

## Potential Applications:

Graphene has the potential to revolutionise a wide range of industries.

Being electrically conductive, thermally conductive and a highly effective mechanical reinforcer there are numerous potential applications for graphene such as:

 Composites  Energy  Biomedical  Membranes  Coatings  Sensors  Electronics



Graphene adds strength and flexibility to composite materials



Graphene is being used to develop biomedical sensors



## Graphene Powders: Solutions for Diverse Graphene Applications

We use two different patented processes to produce our graphene and are partnered with both the University of Manchester and the University of Cambridge. Versarien® has four graphene facilities in the UK.

### +GNP-HP

Versarien

#### Technical Specifications

Property	Measurement	Method
Layers $\leq 5$	18%	Raman
Layers $\leq 10$	73%	Raman
Layers 10-100	27%	Raman
Defect ratio	0.3AV. $I_D/I_G$	Raman
Lateral Dim.	<26.5 $\mu$ m	SEM

#### Concentration (At.%)

Carbon	Oxygen	Flourine	Sulphur	Nitrogen
96 $\pm$ 3.0	3.0 $\pm$ 2.0	1.0 $\pm$ 1.0	1.0 $\pm$ 1.0	0.3 $\pm$ 0.3



Majority of flakes  
<10 layer

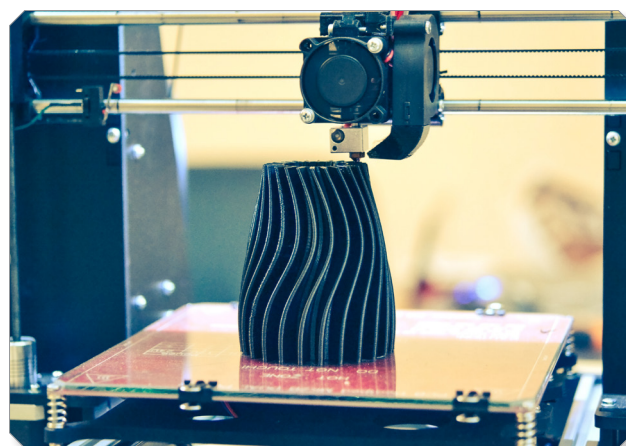


Particle sizes up  
to 26.5 microns



Very Low  
defect ratio

**GNP-HP** is a few-layer graphene powder with large lateral dimensions. With a defect ratio to match Nanene™, GNP-HP is suitable for a wide range of applications and has shown significant improvements in tensile strength, Young's modulus, uniform elongation and elongation at break.



Graphene is being used in 3D printing applications

## Graphene Oxide Powders: Oxygen Bonding Benefits

In addition to our high quality, low defect graphene powders, we also supply graphene oxide and reduced graphene oxide. With a higher defect ratio, these products are suitable for different applications where the high proportion of oxygen would be beneficial.

### +GO

Versarien

#### Technical Specifications

Property	Measurement	Method
Layers	Majority $\leq 2$	AFM
Defect Ratio	>1 AV. $I_D/I_G$	Raman
Lateral Dim.	<4 $\mu$ m	SEM/AFM
Colour	Brown	

#### Concentration (At.%)

Carbon	Oxygen	Sulphur	Nitrogen	Mn
60 $\pm$ 5.0	33 $\pm$ 5.0	2.5 $\pm$ 2.5	1.5 $\pm$ 1.5	1.5 $\pm$ 1.5



Majority <2 layer  
flakes



Lateral dimensions  
up to 4 microns



60% Carbon  
33% Oxygen

### +RGO

Versarien

#### Technical Specifications

Property	Measurement	Method
Layers	<100	AFM
Defect Ratio	1.5 AV. $I_D/I_G$	Raman
Lateral Dim.	<20 $\mu$ m	SEM/AFM
Colour	Black	

#### Concentration (At.%)

Carbon	Oxygen	Sulphur	Nitrogen	Mn
85 $\pm$ 7.5	12 $\pm$ 7.5	1.5 $\pm$ 1.5	2.5 $\pm$ 2.5	1.5 $\pm$ 1.5



<100 layer  
flakes



Lateral dimensions  
up to 20 microns



85% Carbon  
12% Oxygen

### Potential Applications:

Li-ion batteries and fuel cells, battery electrodes, solar PV cells, electrically conductive inks, thermally conductive films and coatings, thermal interface materials, lightweight composites, concrete, metal-matrix composites, corrosion protection, improved barrier properties, permeation and mechanical performance.



# GRAPHINKS

## Conductive Ink Technology

Our own graphene inks are produced via a patented micro-fluidisation process. Printable conductive inks for flexible electronics can be both cheaper and more flexible than traditional circuit board solutions. We have two different inks suitable for different deposition methods. Both are environmentally friendly, non-toxic, aqueous and can be stored at room temperature (20°C). We also formulate graphene inks for specific customer requirements.

	GRAPHINK 1	GRAPHINK 2
Typical Ink Characteristics	<b>Solvent</b>	Water
	<b>Viscosity (@ 100 s<sup>-1</sup>)</b>	3-4cP
	<b>Total solids content</b>	~0.1 wt%
Typical graphene Characteristics	<b>Flake type</b>	Few-layer graphene
	<b>Lateral size</b>	80-500 nm
	<b>Thickness</b>	Few-layer, <3 nm
	<b>Graphene Content</b>	0.2-0.5 mg/mL
Typical Film Properties	<b>Deposition method</b>	Ink Jet Printing/ Vacuum Filtration/ Meyer Bar Coating
	<b>Drying conditions</b>	Flexo/ Gravure/ Screen Printing/ Blade/ Meyer Bar Coating
	<b>Sheet resistance @ thickness</b>	100°C for 10 min
	<b>Transparent films</b>	~4 kΩ/□@80nm, 30 Ω/□@2μm
	<b>Transparent substrates</b>	~10 Ω/□@25μm



Graphene Ink Closeup - Photo Credit to James Macleod

## Versarien® Tomorrow's Materials Available Today

Versarien® PLC is at the cutting edge of 2D material development. Founded in 2010, Versarien® is a specialist materials producer that delivers engineering advantage through innovation to a broad variety of industry sectors. With over 100 staff in five different locations across the United Kingdom, Versarien® is leading 2D materials development and manufacturing, with patented processes scaled up for commercial supply. In addition, research collaborations with leading institutions and strategic commercial partnerships are enabling this disruptive technology to become a reality.

Want to know more?  
Get in touch today  
[www.versarien.com](http://www.versarien.com)  
[info@versarien.com](mailto:info@versarien.com)  
+44 (0) 1242 269 122

We'd love to talk to you about research collaboration, partnerships and commercial 2D material supply.

Our current partners:



**The Graphene Council**  
Research, Development and Application

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by **Versarien®**