Versarien®

NANOMATERIALS **PORTFOLIO**

MARCH 2023

ABOUT VERSARIEN

Versarien plc (AIM: VRS) is an IP-led advanced engineering materials group that utilises proprietary technology to create innovative engineering solutions. Versarien holds more than 120 patents covering areas including the manufacture and use of graphene and related materials (GRMs) in diverse applications. We develop and manufacture advanced materials and products globally through a number of subsidiaries, and have the widest portfolio of high-quality verified products.

UNITED KINGDOM SUBSIDIARIES

Versarien GRAPHENE

2-DTECH

CAMBRIDGE GRAPHENE

GLOBAL SUBSIDIARIES

Gnanomat

Gnanomat S.L. (Spain)

Versarien 버자리언 코리아

Versarien Korea (South Korea)

Want to know more? Get in touch today

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VERIFIED GRAPHENE PRODUCER

The Graphene Council administers the Verified Graphene Producer® and the Verified Functionalized Graphene™ programs, the only credentials that include independent 3rd party in-person inspections of graphene production facilities, verification of production methods, volumes and quality control processes.

The Verified Graphene Producer® and Verified Functionalized Graphene™ programs also include independent expert testing of graphene materials by internationally recognised and qualified labs, such as the National Physical Laboratory (NPL) in the UK, according to the Graphene Classification Framework.

Versarien uses proprietary materials technology to create innovative engineering solutions that are capable of having game-changing impact in a broad variety of industry sectors.
Versarien was the first company in the world to pass the rigorous Verified Graphene Producer® program in 2019, and has been re-certified in 2022.

Neill Ricketts, CEO of Versarien: "We are delighted that Versarien is the first graphene producer to successfully gain recertification under the Graphene Council's Verified Graphene Producer programme following the scale-up of our graphene production facilities. This validation of our technology will enable our partners and potential customers to have confidence that the graphene we produce meets globally accepted standards."

Terrance Barkan, Executive Director of The Graphene Council: "We congratulate the Versarien team on obtaining a successful re-certification as a Verified Graphene Producer®, which we believe is the most stringent validation programme available for the Graphene sector. Versarien has proven itself to be a true leader in the production and application of graphene materials and we are proud to have them as a member of the Graphene Council."

Find out more about the Verified Graphene Producer program

VERIFIED GRAPHENE® PRODUCER
THE GRAPHENE COUNCIL

CONTENTS

GRAPHENE & GRAPHENE OXIDES

Chemical vapour deposition (CVD) is the process to manufacture truly single-layer graphene (SLG). Versarien subsidiary Versarien Korea Ltd. (South Korea), manufactures SLG using a rapid thermal CVD process (RT-CVD) in a clean room environment. Graphene synthesis and lamination, transfer and stacking are performed in Class 1000 (ISO 6) laboratories, whilst wet chemical etching and all graphene characterisation takes place in Class 10000 (ISO 7) laboratories. Our standard products include SLG on copper foil (**CVD-101**) up to 200 x 200 mm in size, SLG transferred on to SiO_2/Si wafers (**CVD-201**), or SLG transferred on to PET substrates (**CVD-301**). We also offer services to produce multiple stacked layers of graphene and transfer graphene on to other substrates of the customer's choice.

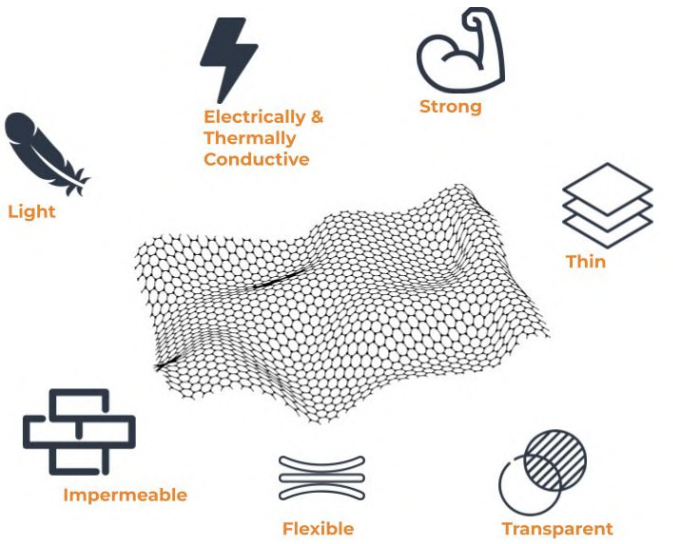
Potential applications of CVD graphene include sensors, membranes, transparent conductive electrodes, resistive heaters and use in high-frequency electronic, (opto)electronic and semi-conductor applications.

Versarien Graphene Ltd. (Gloucestershire, UK) manufactures graphene powders. **Nanene-001** is a high quality few-layer graphene (FLG) powder, independently tested and passing the Graphene Council's Verified Graphene Producer® program. 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.

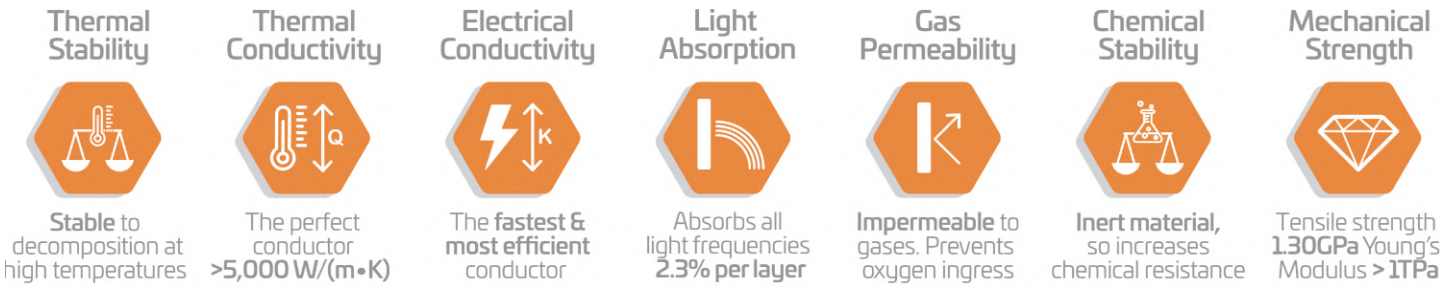
Nanene-002 is a graphene nanoplatelet (GNP) powder with large lateral dimensions and is suitable for a wide range of applications showing significant improvements in tensile strength, Young's modulus, uniform elongation and elongation at break in polymer composite applications.

Nanene™ applications include use as an additive for thermoset, thermoplastic and rubber based composite materials, electrodes in lithium-ion batteries and fuel cells, solar PV cells, electrically conductive inks, thermal interface materials, concrete, metal-matrix composites, paints and coatings (corrosion protection, anti-fouling, UV resistant, barrier films, etc.).

In addition to our high quality, low defect graphene powders, we also supply graphene oxides **GO-001** and **GO-002** (in development) with different flake sizes (small and large, respectively). With a higher level of oxygen content ratio, these products are suitable for different applications where high aspect ratio and processability are key.



The impressive array of graphene properties



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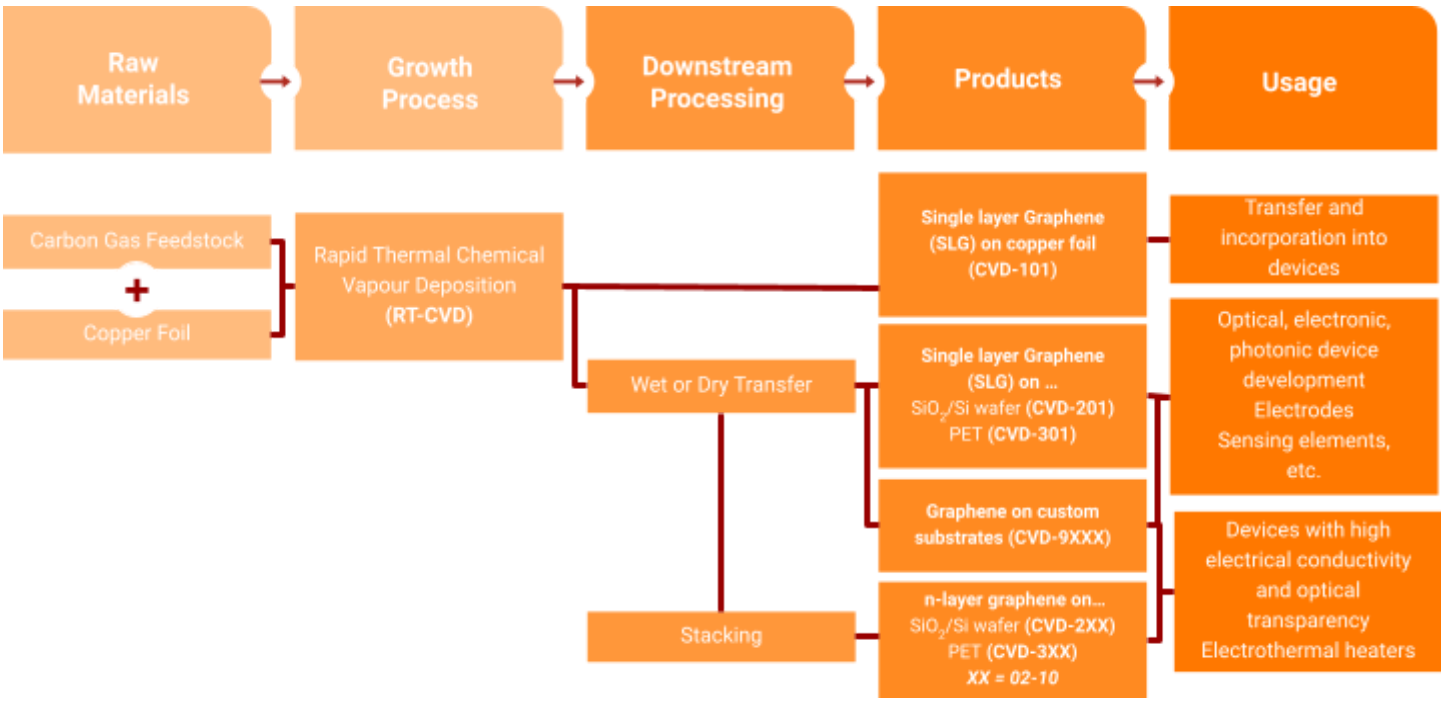
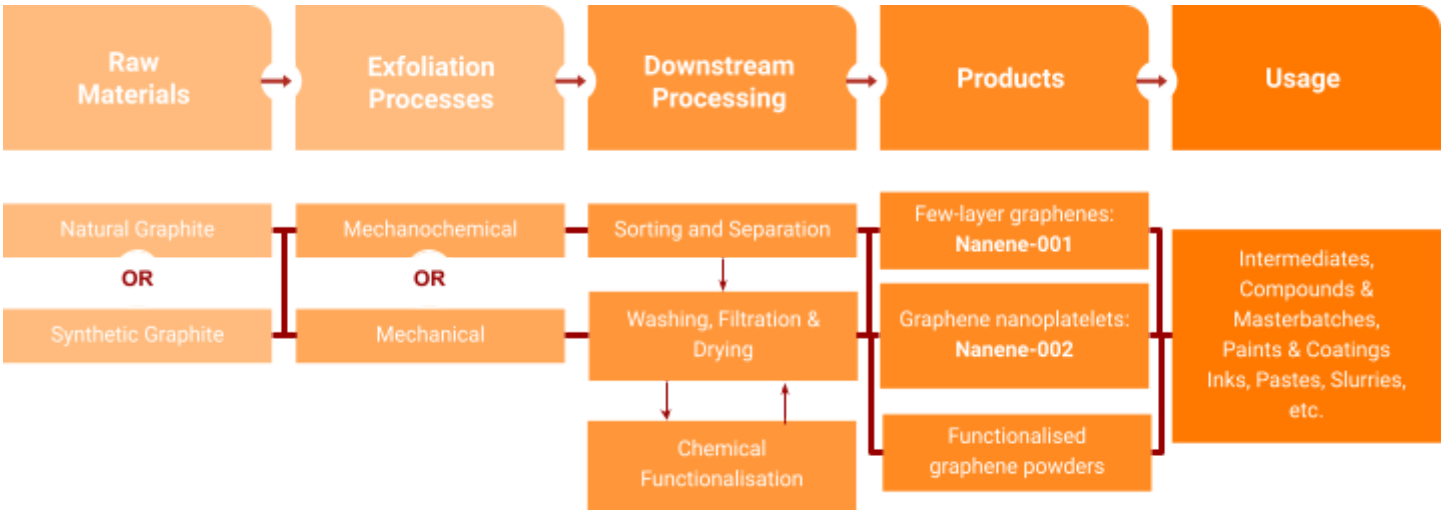


Process flow for the manufacture and uses of CVD graphene materials



Process flow for the manufacture and uses of Versarien's graphene powder materials (Nanene™)

PRODUCT CODE	GENERAL INFORMATION	MOQ
	CVD GRAPHENE	
CVD-101	Single-layer graphene (SLG) on copper foil	Up to 200 x 200 mm
CVD-201	Single-layer graphene (SLG) on SiO_2/Si wafer	2, 4, 6 ,8”
CVD-301	Single-layer graphene (SLG) on PET substrate	Up to 200 x 200 mm
CVD-2XX (XX = 02-10)	N-layer graphene stacked on SiO_2/Si wafer	Enquire
CVD-3XX (XX = 02-10)	N-layer graphene stacked on PET substrate	Enquire
CVD-9XXX	Custom CVD graphene. Please specify your requirements. Alternative substrates include quartz, sapphire, PEN, other polymers	Enquire
	GRAPHENE POWDERS	
Nanene-001	Few-layer graphene, non-functionalised, produced by mechano-chemical exfoliation of natural graphite	0.1 kg
Nanene-002	Graphene nanoplatelets, non-functionalised, produced by mechano-chemical exfoliation of natural graphite	0.1 kg
Nanene-003	Graphene nanoplatelets (in development, enquire for more details)	Enquire
	GRAPHENE OXIDE DISPERSIONS	
GO-001	Graphene oxide, platelet shaped, oxygen-functionalised, produced by chemical oxidation of recycled graphene powder feedstock	0.1 kg
GO-002	Larger lateral size (~40 µm) graphene oxide (in development, enquire for more details)	Enquire

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CVD Graphenes

PRODUCT INFORMATION

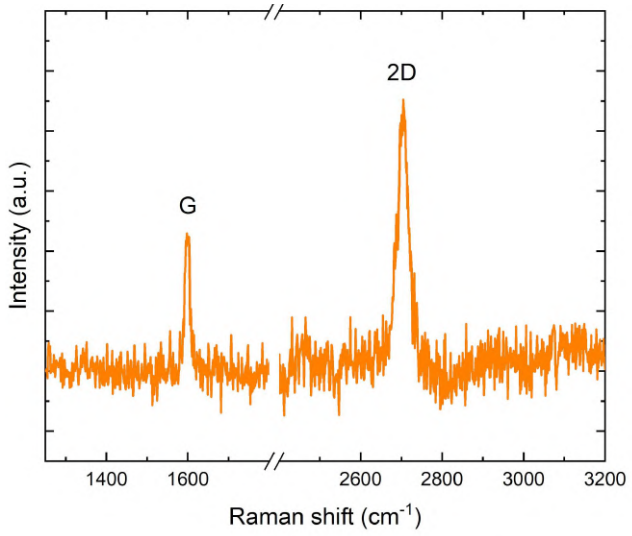
Description	Single-layer graphene (SLG) on copper foil
Graphene Type	Single-layer graphene (SLG)
Form	Film
Substrates	**CVD-101:** Copper foil (35 µm thickness) **CVD-201:** SiO_2/Si wafer, **CVD-301:** PET film **CVD-9XXX:** Customer substrate
Manufacturing Method	Rapid Thermal Chemical Vapour Deposition (RT-CVD)
Transfer Method	Wet or dry transfer possible (Enquire)

GRAPHENE CHARACTERISTICS

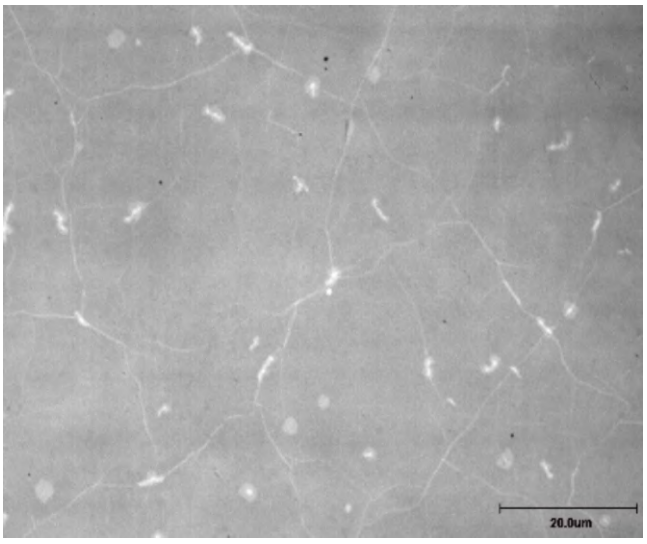
Colour	Transparent
Transparency	>97 % (measured on PET)
sp^2 Bonded Carbon	~1580 cm^{-1}
Structural Defects (I_D/I_G)	<0.1
I_{2D}/I_G	~1.8 ± 0.2
FWHM (G) cm^{-1}	~15 ± 2
FWHM (2D) cm^{-1}	~35 ± 4
Coverage	> 95 %
Number of Layers	1 (some bilayer islands)
Grain size (µm)	20-50 µm
Electron Mobility on SiO_2/Si	Dependent on transfer process and encapsulation
Sheet Resistance on SiO_2/Si (CVD-20X)	1L (CVD-201): ~280 Ω/square 2L (CVD-202): ~150 Ω/square
Sheet Resistance on PET (CVD-30X)	1L (CVD-501): ~200 Ω/square 2L (CVD-502): ~110 Ω/square

TYPICAL CHARACTERISATION DATA

RAMAN SPECTROSCOPY (on PET substrate)



CONFOCAL MICROSCOPY (on PET substrate)



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Nanene-001

PRODUCT INFORMATION

Description	Few-layer graphene, non-functionalised, produced by mechano-chemical exfoliation of natural graphite
Graphene Type	Few-layer graphene (FLG)
Form	Powder
Manufacturing Method	Mechano-chemical exfoliation
Raw Material	Natural graphite
CAS Number	1034343-98-0
EC Number	801-282-5

GRAPHENE CHARACTERISTICS

		Graphene Council "Verified Producer" Program
Colour		-
sp^2 Bonded Carbon (cm^{-1})		Detected
Structural Defects (I_D/I_G)		Low defect density
Number of Layers	**D10**	3.7
	D50	7
	D90	30.8
Z-Axis Dimensions (nm)	**D10**	~1.2
	D50	~2.3
	D90	~10.3
Primary Particle Shape		Flake
Lateral Dimensions (µm)	**D10**	x : 0.91 y : 0.66
	D50	x : 1.32 y : 0.90
	D90	x : 3.15 y : 1.46
Aspect Ratio (lateral size/thickness)	**Min**	-
	Max	
Bulk Density (untapped) (g/cm^3)		0.271 (Tapped)
Carbon Content (at.%)		97.5 ±0.2 wt.%
Oxygen Content (at.%)		2.5 ±0.3 wt.%
C/O ratio		38.7
Impurities (at.%)		None detected
Functionalisation (type and wt.%)		None detected
Surface Particle Charge (mV)		-41.1 (±1.2)
Graphene Orientation		-
Specific Surface Area (m^2/g)		46.48 (±0.78)
Crystallite Size (nm)		27.2
Interlayer Spacing (d spacing) (nm)		0.335
Crystallinity (%)		Highly crystalline
FWHM (002) Peak (°)		-
Dispersibility		-

Nanene™
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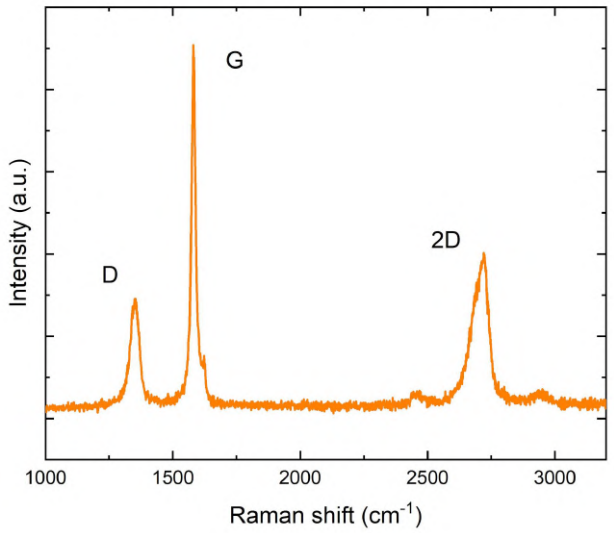
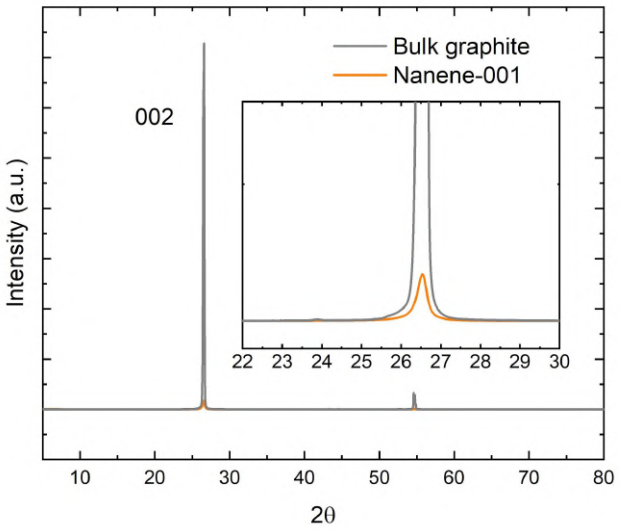
TYPICAL CHARACTERISATION DATA

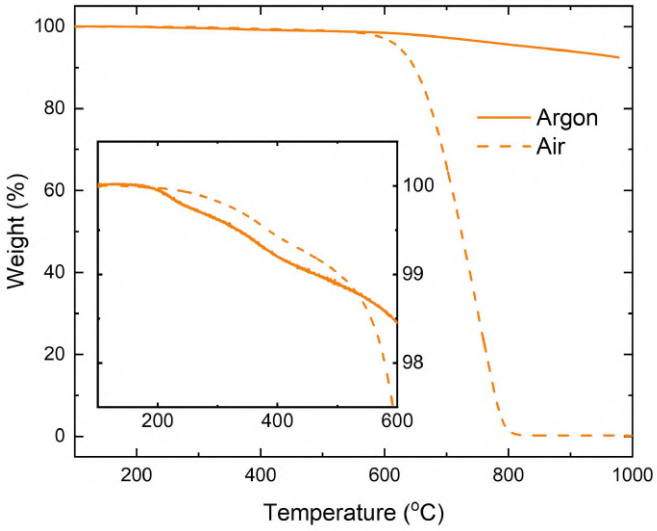
RAMAN SPECTROSCOPY



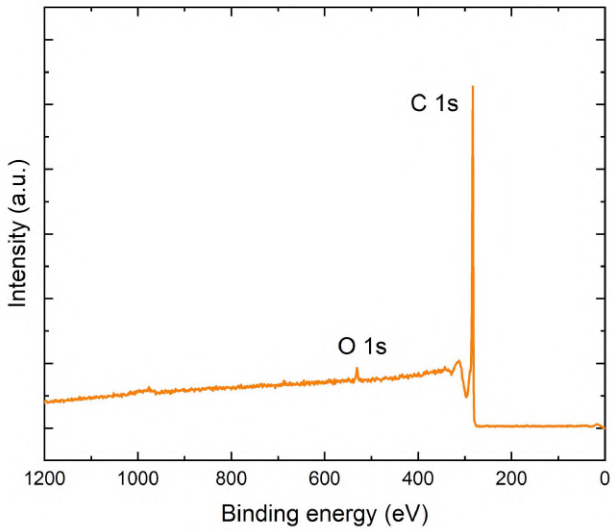
X-RAY DIFFRACTION



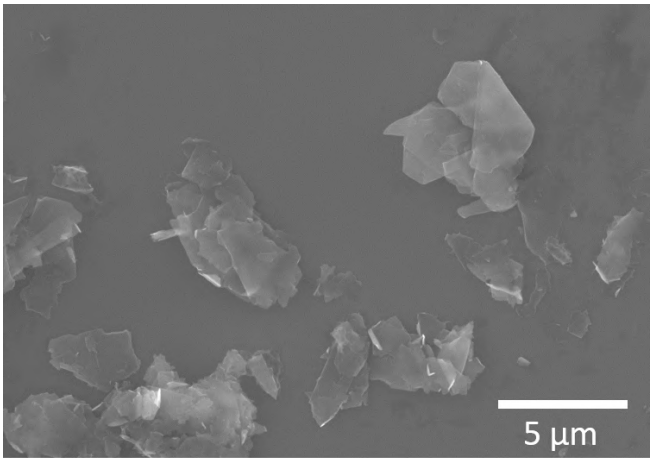
THERMOGRAVIMETRIC ANALYSIS



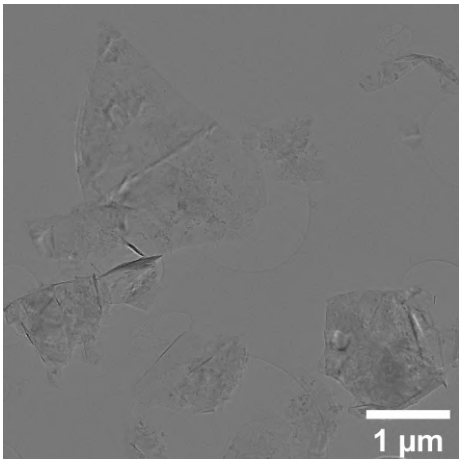
X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



TRANSMISSION ELECTRON MICROSCOPY



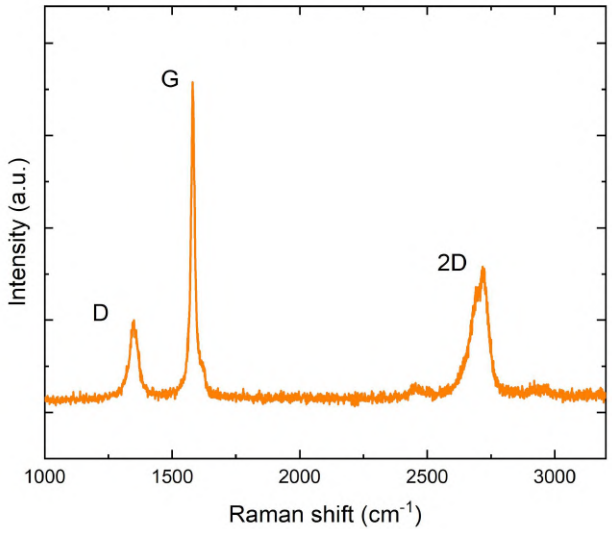
Nanene-002

PRODUCT INFORMATION		
Description		Graphene nanoplatelets, non-functionalised, produced by mechano-chemical exfoliation of natural graphite
Graphene Type		Graphene nanoplatelets (GNP)
Form		Powder
Manufacturing Method		Mechano-chemical exfoliation
Raw Material		Natural graphite
CAS Number		1034343-98-0
EC Number		801-282-5
GRAPHENE CHARACTERISTICS		
Colour		Black / Dark grey
sp^2 Bonded Carbon (cm^{-1})		~1580
Structural Defects (I_D/I_G)		~0.3
Number of Layers	**D10**	4-5
	D50	12-13
	D90	~48
Z-Axis Dimensions (nm)	**D10**	~1.4
	D50	~4.2
	D90	~16.3
Primary Particle Shape		Platelets, Plate
Lateral Dimensions (µm)	**D10**	x : 0.97 y : 0.89
	D50	x : 2.16 y : 1.78
	D90	x : 4.01 y : 3.06
Aspect Ratio (lateral size/thickness)	**Min**	~50
	Max	~4230
Bulk Density (untapped) (g/cm^3)		<0.25
Carbon Content (at.%)		>96
Oxygen Content (at.%)		~2.5
C/O ratio		~48
Impurities (at.%)		<1 (F, S, N)
Functionalisation (type and wt.%)		N/A
Surface Particle Charge (mV)		-16.3
Graphene Orientation		Turbostratic
Specific Surface Area (m^2/g)		~25
Crystallite Size (nm)		37.7
Interlayer Spacing (d spacing) (nm)		0.336
Crystallinity (%)		~66
FWHM (002) Peak (°)		0.23
Dispersibility		Organic solvents: IPA, DMF, NMP, DMSO

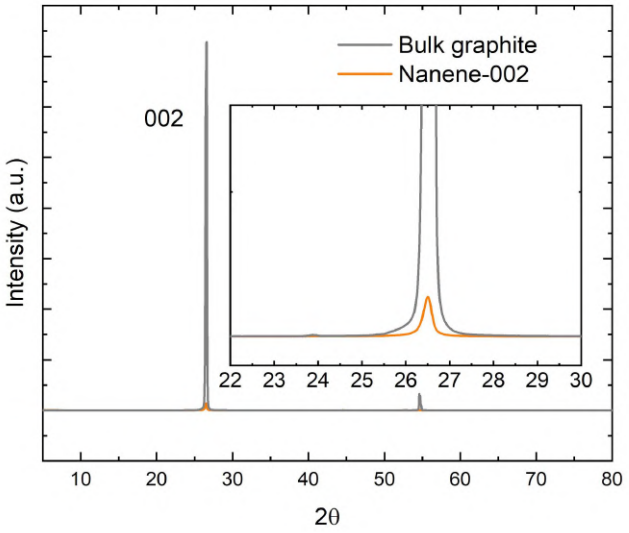
Nanene™ Versarien

TYPICAL CHARACTERISATION DATA

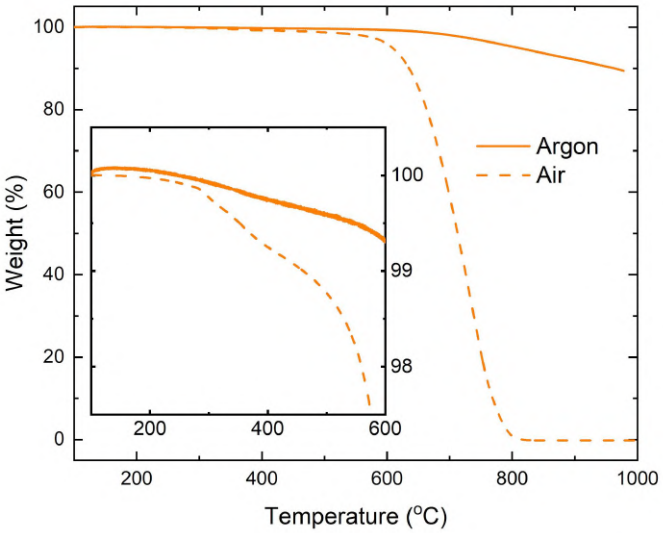
RAMAN SPECTROSCOPY



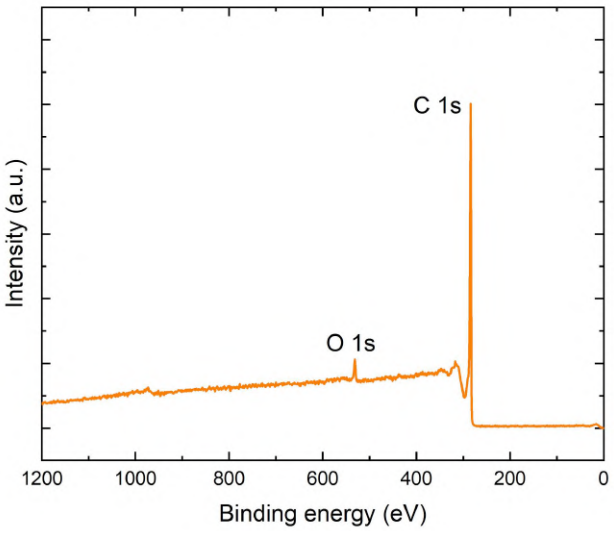
X-RAY DIFFRACTION



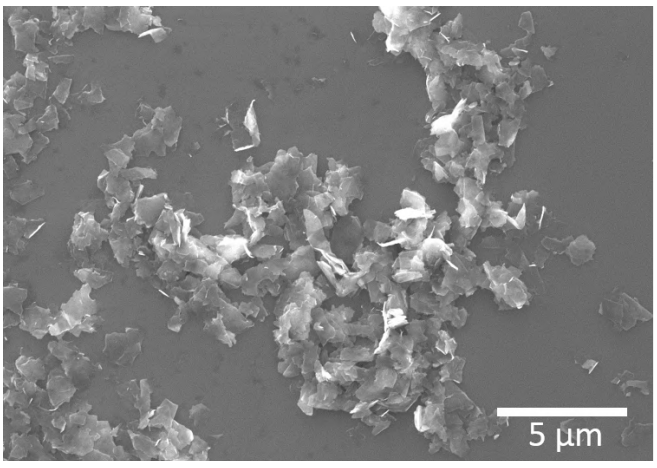
THERMOGRAVIMETRIC ANALYSIS



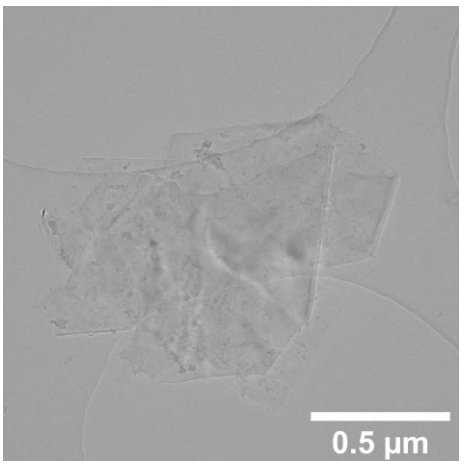
X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



TRANSMISSION ELECTRON MICROSCOPY



GO-001

PRODUCT INFORMATION

Description	Graphene oxide, platelet shaped, oxygen-functionalised, produced by chemical oxidation of recycled graphene powder feedstock
Graphene Type	Graphene Oxide (GO) - small flake size
Form	Dispersion (water)
Manufacturing Method	Chemical oxidation
Raw Material	Recycled feedstock from graphene powder processes
Dispersants / Surfactants	No
Typical Concentration (wt.%)	~5
Solvent Content (wt.%)	~95
CAS Number	-
EC Number	-

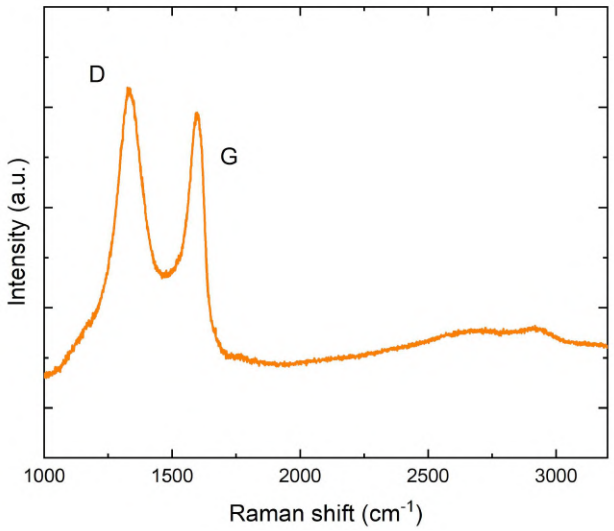
GRAPHENE CHARACTERISTICS

Colour		Brown
sp^2 Bonded Carbon (cm^{-1})		~1580
Structural Defects (I_D/I_G)		~1.3
Number of Layers	**D10**	1
	D50	2
	D90	<3
Z-Axis Dimensions (nm)	**D10**	~0.8
	D50	~1.6
	D90	~2.5
Primary Particle Shape		Platelet, Plate
Lateral Dimensions (µm)	**D10**	x : 0.95 y : 0.57
	D50	x : 1.94 y : 1.31
	D90	x : 3.53 y : 2.25
Aspect Ratio (lateral size/thickness)	**Min**	~268
	Max	~4280
Bulk Density (untapped) (g/cm^3)		–
Carbon Content (at.%)		~57
Oxygen Content (at.%)		~40
C/O Ratio		1.38
Impurities (at.%)		S ~3
Functionalisation (type and wt.%)		Oxygen functionalisation
Surface Particle Charge (mV)		-36.9
Graphene Orientation		N/A
Specific Surface Area (SSA)		–
Crystallite Size (nm)		4.7
Interlayer Spacing (d spacing) (nm)		0.778
FWHM (002) Peak (°)		~1.7
Dispersibility		Water and organic solvents

GO Versarien

TYPICAL CHARACTERISATION DATA

RAMAN SPECTROSCOPY



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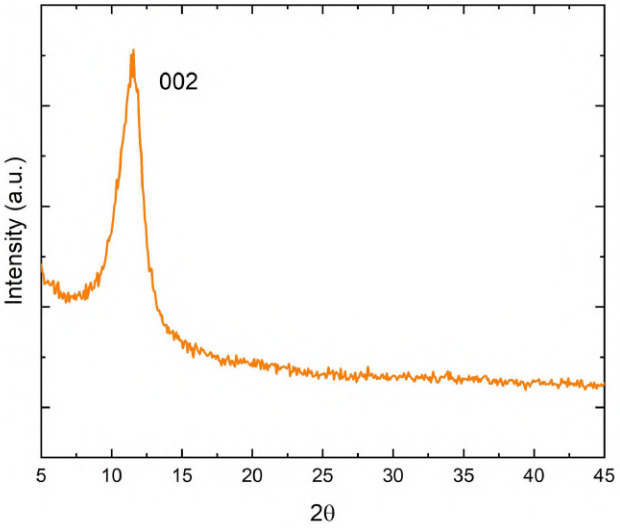
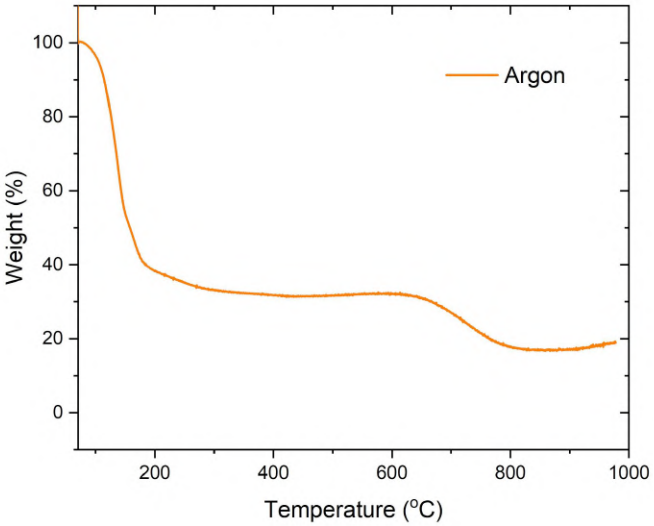
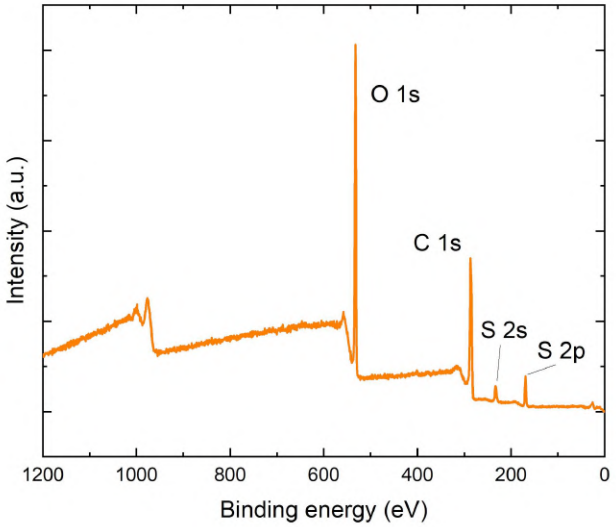


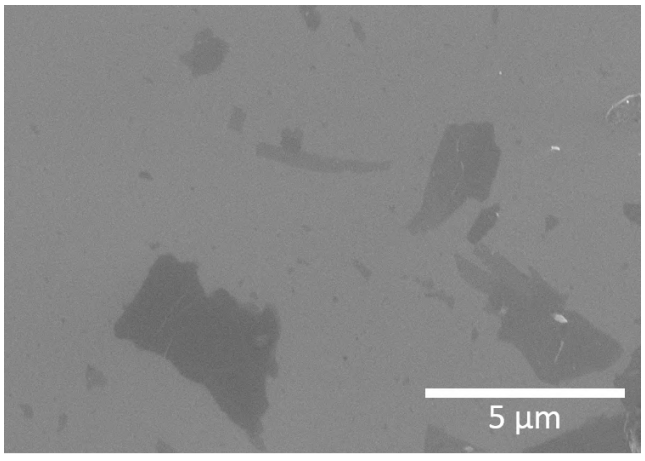
THERMOGRAVIMETRIC ANALYSIS



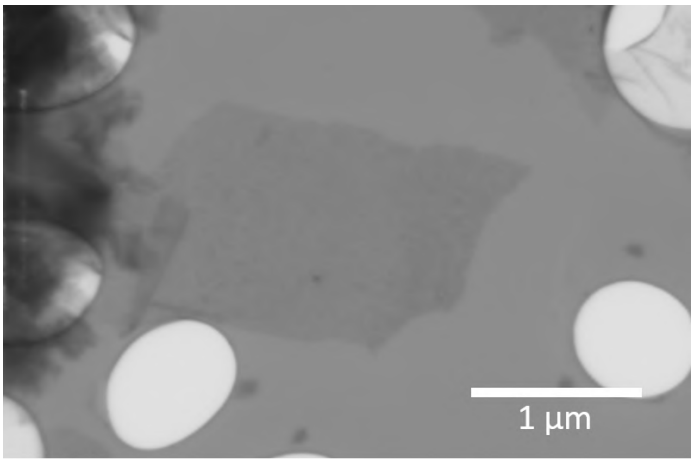
X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



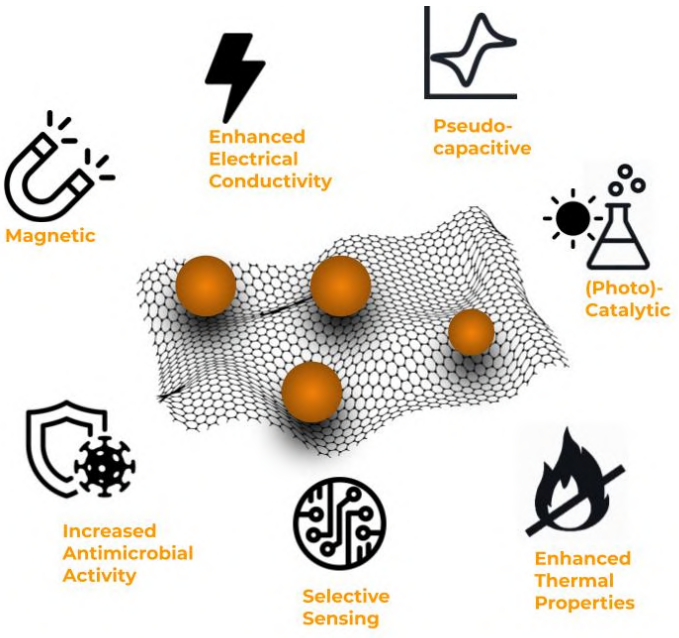
SCANNING TRANSMISSION ELECTRON MICROSCOPY



HYBRID NANOMATERIALS

Versarien subsidiary Gnanomat S.L. (Madrid, Spain), develops novel hybrid nanomaterials combining graphene with metal (oxide) nanoparticles. Graphene-supported metal (oxide) nanoparticles form a very large family of materials whereby graphene provides a high surface area substrate that makes metal (oxide) nanoparticles accessible to the environment, allowing them to better perform their functions. Graphene adds electrical conductivity to oxides, which are usually poor conductors; electron injection from graphene into oxides increases the concentration of holes in graphene and may increase the conductivity of the entire hybrid material. Synergistic benefits are observed in a number of applications such as battery and supercapacitor electrodes, as well as in electrocatalysis.

The current methods for production of graphene-based hybrid materials require multi reactor chemical transformations, making their industrial production challenging and expensive. Gnanomat has patented an environmentally friendly, safer (no need for hazardous or toxic chemical reagents or solvents) and straightforward method for the production of hybrid materials in a one-pot synthesis procedure, which lends itself to low cost industrial production. Thanks to the unique features of our technology, it has the potential to become the gold-standard method for industrial production of hybrid nanomaterials, offering a solution to overcome the critical barriers in actually exploiting the benefits of these materials in energy storage devices and beyond.



Dual/multi-functional properties and applications that can be realised following surface functionalisation of graphene with metal (oxide) nanoparticles

Click here to read more about **Hybrid Nanomaterials** or visit **www.versarien.com/media-centre**

PRODUCT CODE	GENERAL INFORMATION	MOQ (kg)
	GRAPHENE/METAL (OXIDE) NANOPARTICLE HYBRID MATERIAL POWDERS	
Nanene-003-Ag	Hybrid nanomaterial synthesised by the formation of nanoparticles of silver on the surface of graphene nanoplatelets	0.01
Nanene-003-MnOx	Hybrid nanomaterial synthesised by the formation of manganese oxide nanoparticles on the surface of graphene nanoplatelets	0.01
Nanene-003-CuOx	Hybrid nanomaterial synthesised by the formation of copper oxide nanoparticles on the surface of graphene nanoplatelets	0.01
Nanene-003-ZnO	Hybrid nanomaterial synthesised by the formation of zinc oxide nanoparticles on the surface of graphene nanoplatelets	0.01
Nanene-003-Superparamagnetic	Hybrid nanomaterial synthesised by the formation of manganese oxide and iron oxide nanoparticles on the surface of graphene nanoplatelets	0.01

Nanene-003-Ag

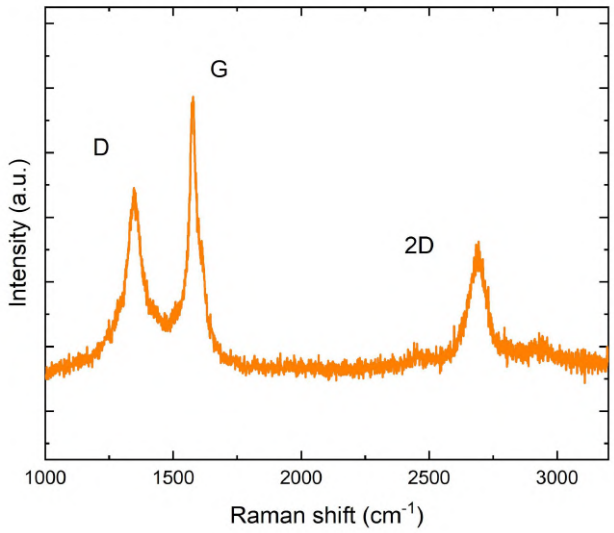
PRODUCT INFORMATION	
Description	Hybrid nanomaterial synthesised by the formation of nanoparticles of silver on the surface of graphene nanoplatelets
Graphene Product	Nanene-003
Form	Powder
Manufacturing Method	Chemical
CAS Number	-
EC Number	-

GRAPHENE CHARACTERISTICS
Enquire

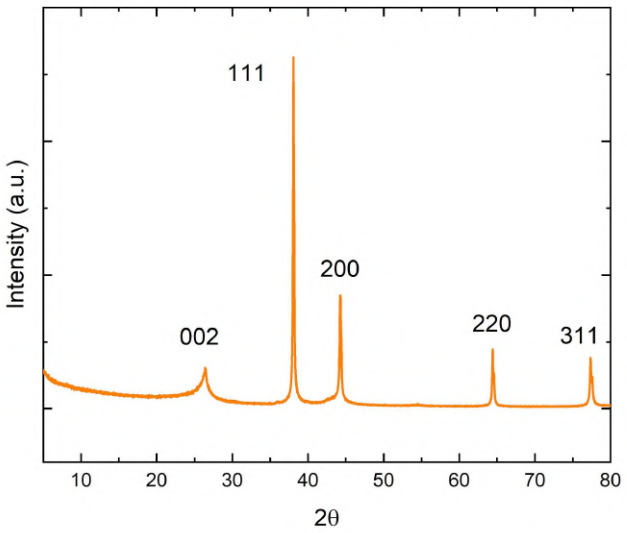
HYBRID MATERIAL CHARACTERISTICS	
Structural Defects (I_D/I_G)	~0.8
Bulk Density (untapped) (g/cm^3)	0.46
Chemical/Elemental Composition (at.%)	C ~90.5, Ag ~1 , O ~7
Impurities (at.%)	Na ~1.5
Functionalisation (type and wt.%)	Silver nanoparticles, 20
Surface Particle Charge (mV)	-31.2
Specific Surface Area (SSA) (m^2/g)	402
Crystallite Size (nm)	11.5
Interlayer Spacing (d spacing) (nm)	0.337
Crystallinity (%)	30
FWHM (002) Peak (°)	~0.7
Dispersibility	Organic solvents

TYPICAL CHARACTERISATION DATA

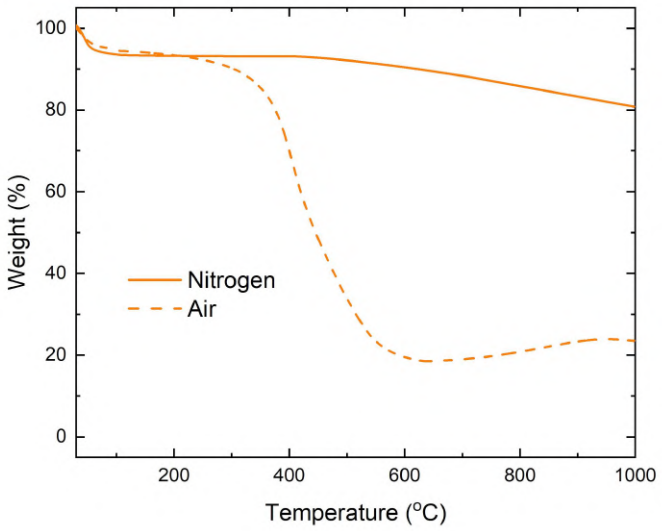
RAMAN SPECTROSCOPY



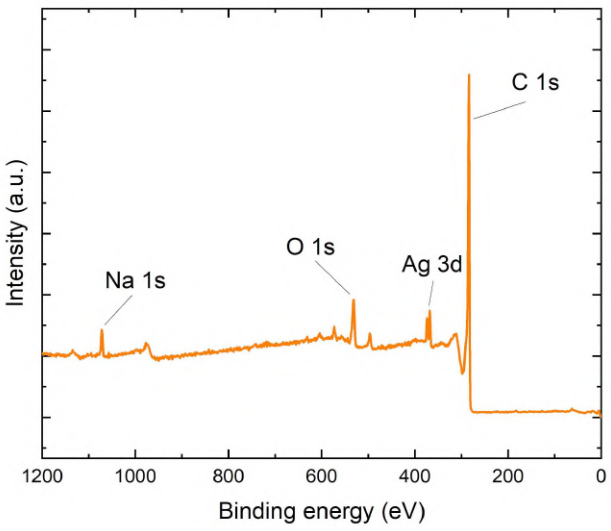
X-RAY DIFFRACTION



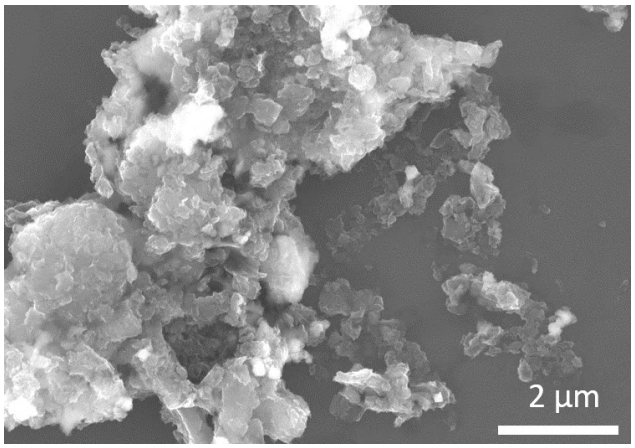
THERMOGRAVIMETRIC ANALYSIS



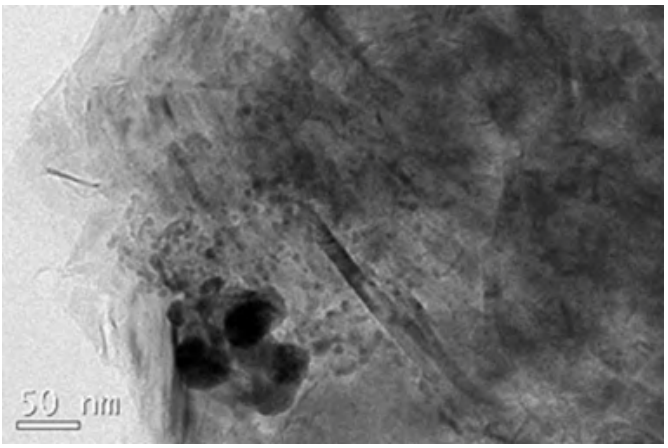
X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



TRANSMISSION ELECTRON MICROSCOPY



Nanene-003-MnOx

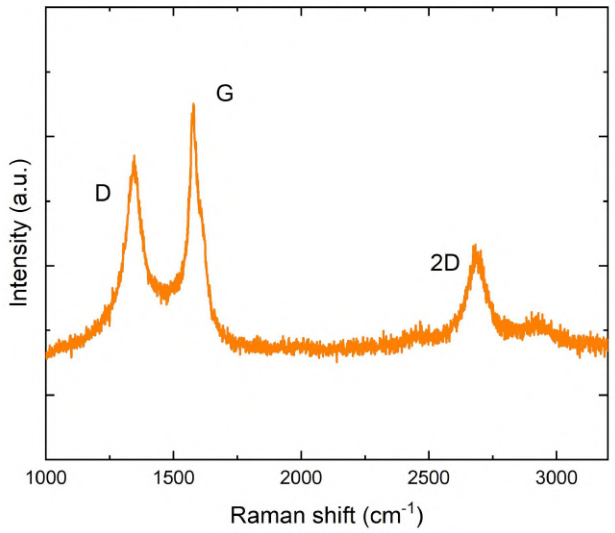
PRODUCT INFORMATION	
Description	Hybrid nanomaterial synthesised by the formation of manganese oxide nanoparticles on the surface of graphene nanoplatelets
Graphene Product	Nanene-003
Form	Powder
Manufacturing Method	Chemical
CAS Number	-
EC Number	-

GRAPHENE CHARACTERISTICS
Enquire

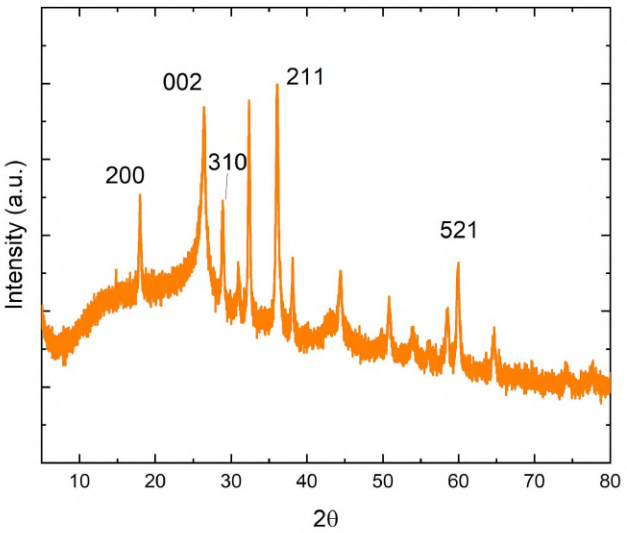
HYBRID MATERIAL CHARACTERISTICS	
Structural Defects (I_D/I_G)	~0.8
Bulk Density (untapped) (g/cm^3)	0.40
Chemical/Elemental Composition (at.%)	C ~78, Mn ~6 , O ~14.5
Impurities (at.%)	Na ~1.5
Functionalisation (type and wt.%)	Manganese oxide nanoparticles (20)
Surface Particle Charge (mV)	-29.8
Graphene Orientation	Turbostratic
Specific Surface Area (SSA) (m^2/g)	365
Crystallite Size (nm)	14.7
Interlayer Spacing (d spacing) (nm)	0.337
Crystallinity (%)	52
FWHM (002) Peak (°)	~0.55
Dispersibility	Organic solvents

TYPICAL CHARACTERISATION DATA

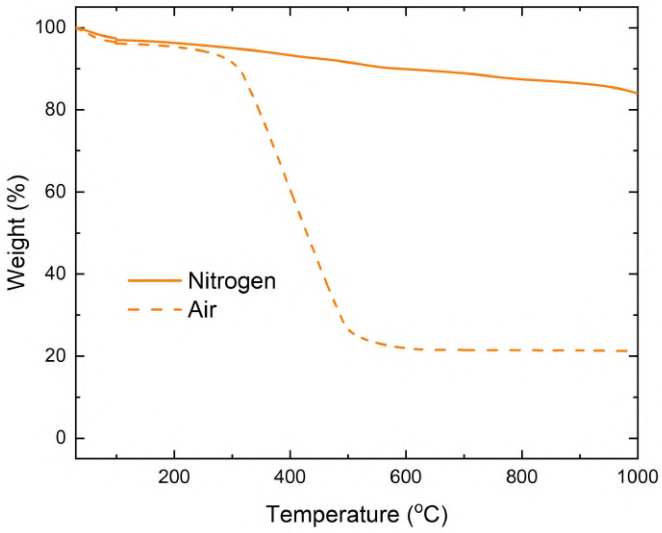
RAMAN SPECTROSCOPY



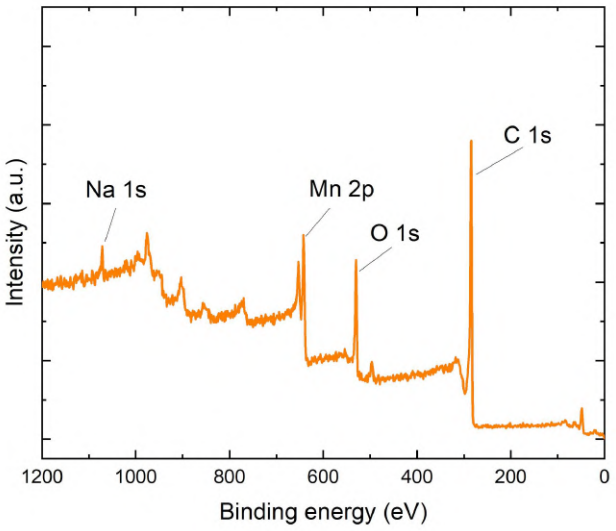
X-RAY DIFFRACTION



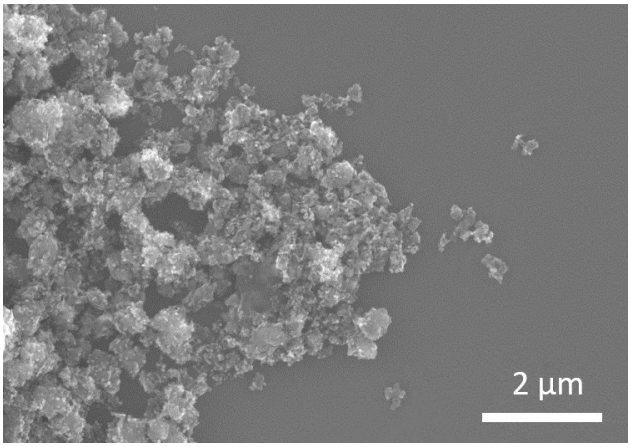
THERMOGRAVIMETRIC ANALYSIS



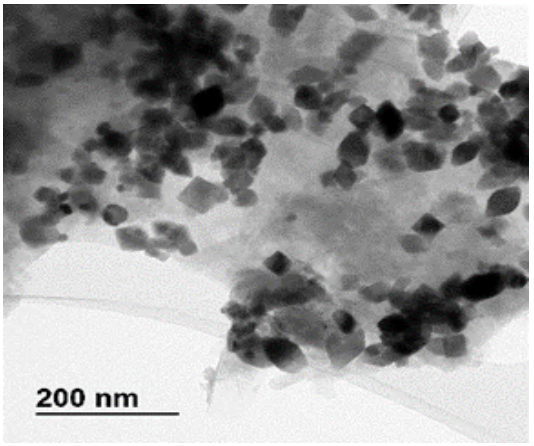
X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



TRANSMISSION ELECTRON MICROSCOPY



Nanene-003-CuOx

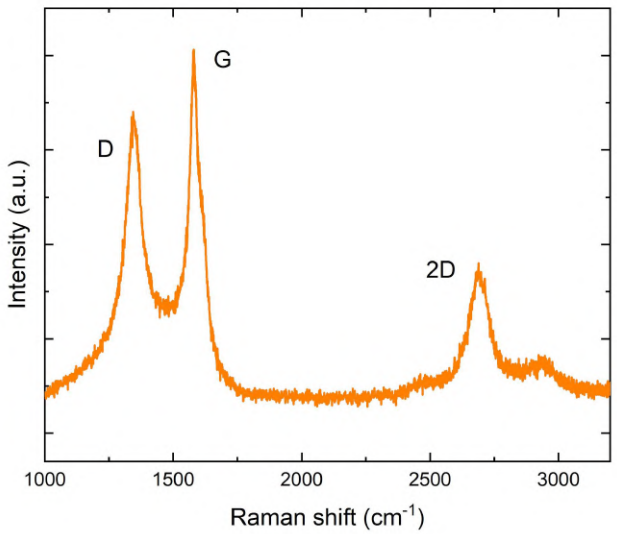
PRODUCT INFORMATION	
Description	Hybrid nanomaterial synthesised by the formation of copper oxide nanoparticles on the surface of graphene nanoplatelets
Graphene Product	Nanene-003
Form	Powder
Manufacturing Method	Chemical
CAS Number	-
EC Number	-

GRAPHENE CHARACTERISTICS
Enquire

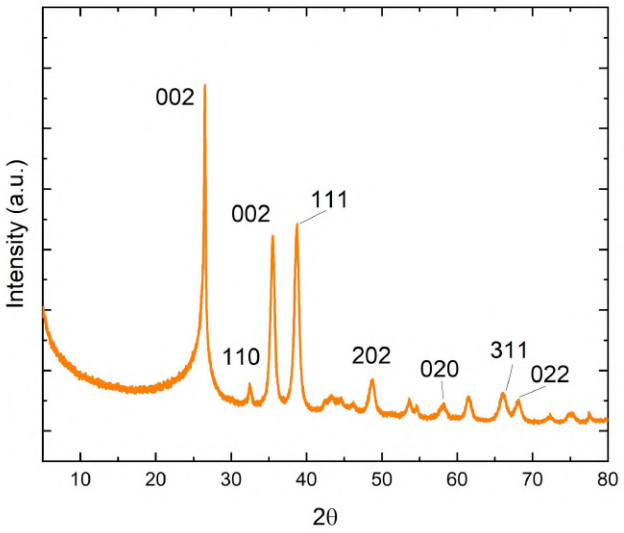
HYBRID MATERIAL CHARACTERISTICS	
Structural Defects (I_D/I_G)	~0.8
Bulk Density (untapped) (g/cm^3)	0.50
Chemical/Elemental Composition (at.%)	C ~84, Cu ~5 , O ~9
Impurities (at.%)	Na ~2
Functionalisation (type and wt.%)	Copper oxide nanoparticles (20)
Surface Particle Charge (mV)	-28
Graphene Orientation	Turbostratic
Specific Surface Area (SSA) (m^2/g)	260
Crystallite Size (nm)	23
Interlayer Spacing (d spacing) (nm)	0.336
Crystallinity (%)	86
FWHM (002) Peak (°)	~0.35
Dispersibility	Organic solvents

TYPICAL CHARACTERISATION DATA

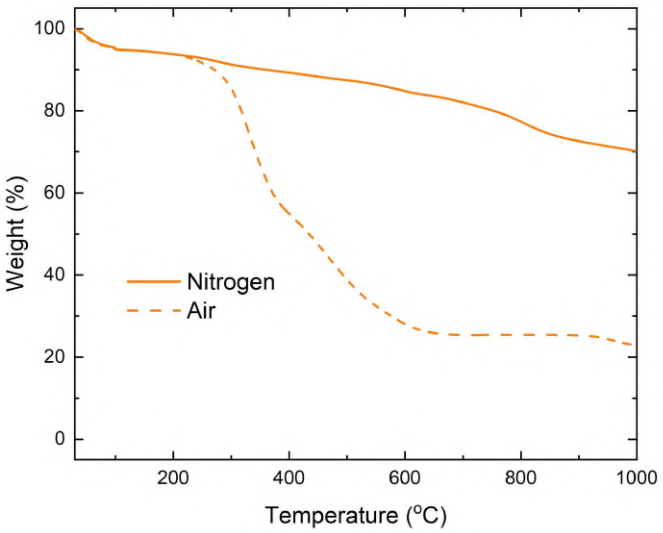
RAMAN SPECTROSCOPY



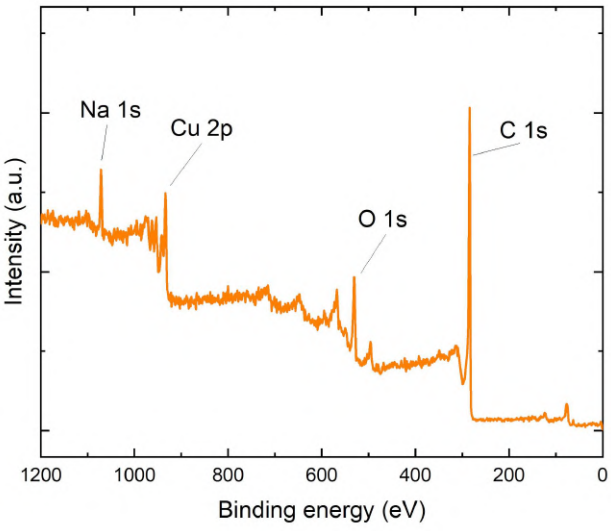
X-RAY DIFFRACTION



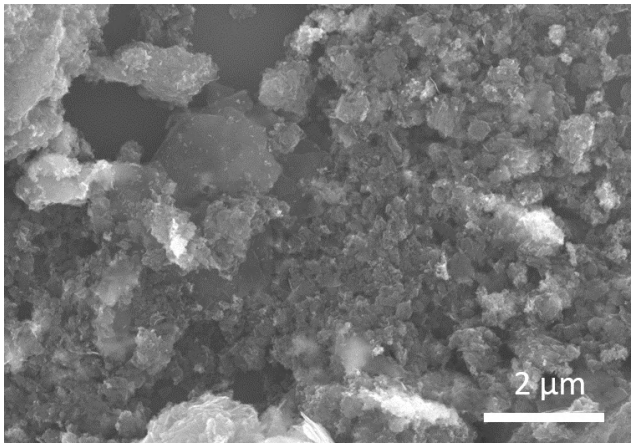
THERMOGRAVIMETRIC ANALYSIS



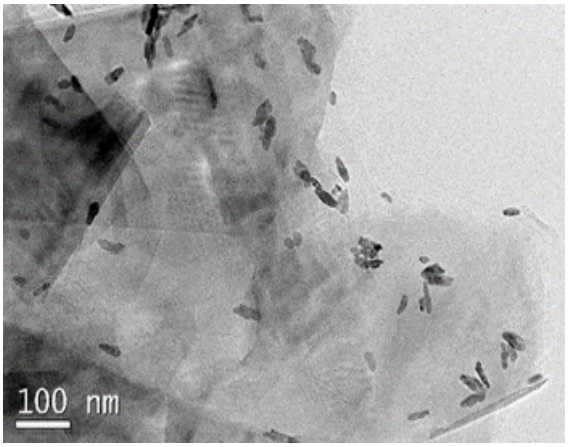
X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



TRANSMISSION ELECTRON MICROSCOPY



Nanene-003-ZnO

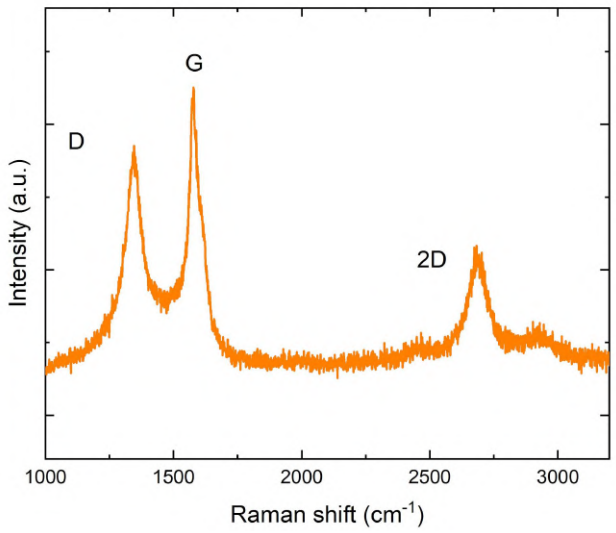
PRODUCT INFORMATION	
Description	Hybrid nanomaterial synthesised by the formation of zinc oxide nanoparticles on the surface of graphene nanoplatelets
Graphene Product	Nanene-003
Form	Powder
Manufacturing Method	Chemical
CAS Number	-
EC Number	-

GRAPHENE CHARACTERISTICS
Enquire

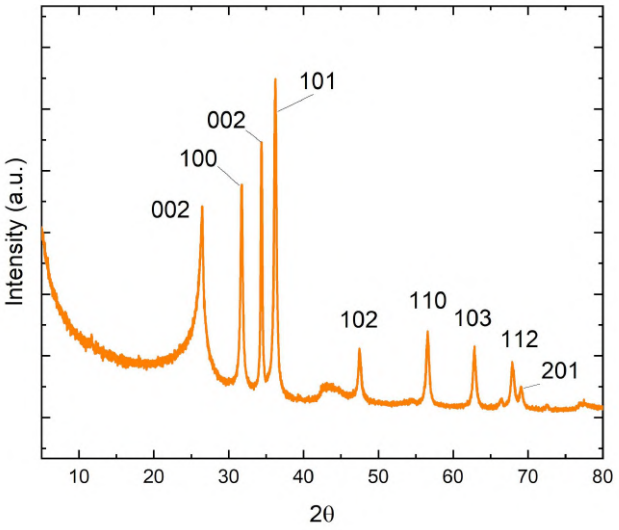
HYBRID MATERIAL CHARACTERISTICS	
Structural Defects (I_D/I_G)	~0.8
Bulk Density (untapped) (g/cm^3)	0.40
Chemical/Elemental Composition (at.%)	C ~77, Zn ~8.7 , O ~11
Impurities (at.%)	Na ~1.5, Cr ~1.8
Functionalisation (type and wt.%)	Zinc oxide nanoparticles (20)
Surface Particle Charge (mV)	-25.5
Graphene Orientation	Turbostratic
Specific Surface Area (SSA) (m^2/g)	377
Crystallite Size (nm)	12.4
Interlayer Spacing (d spacing) (nm)	0.337
Crystallinity (%)	72
FWHM (002) Peak (°)	~0.65
Dispersibility	Organic solvents

TYPICAL CHARACTERISATION DATA

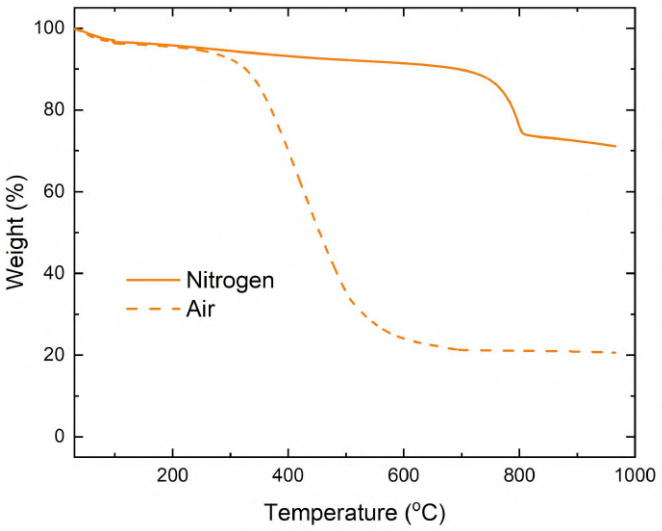
RAMAN SPECTROSCOPY



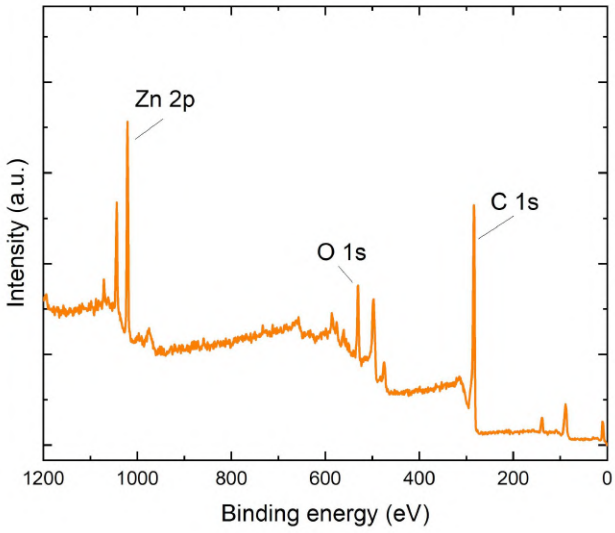
X-RAY DIFFRACTION



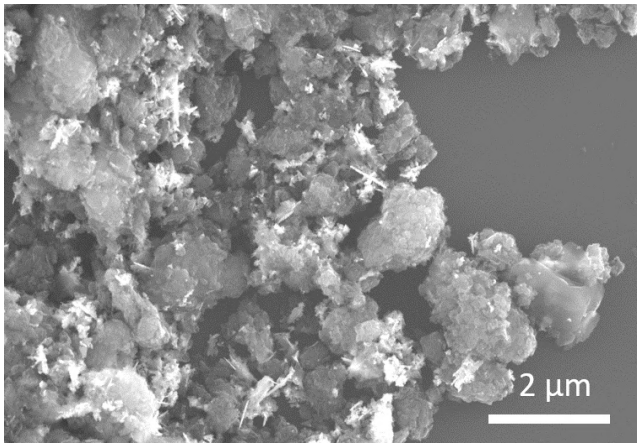
THERMOGRAVIMETRIC ANALYSIS



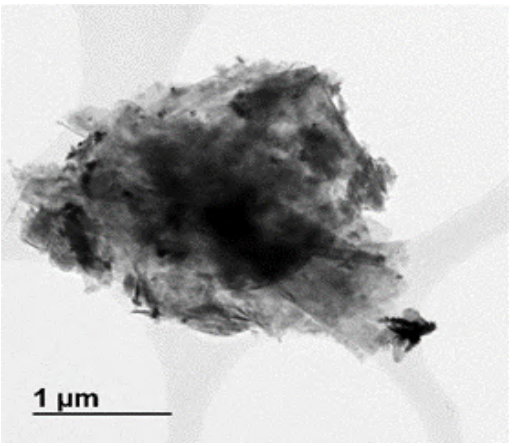
X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



TRANSMISSION ELECTRON MICROSCOPY



Nanene-003-Superparamagnetic

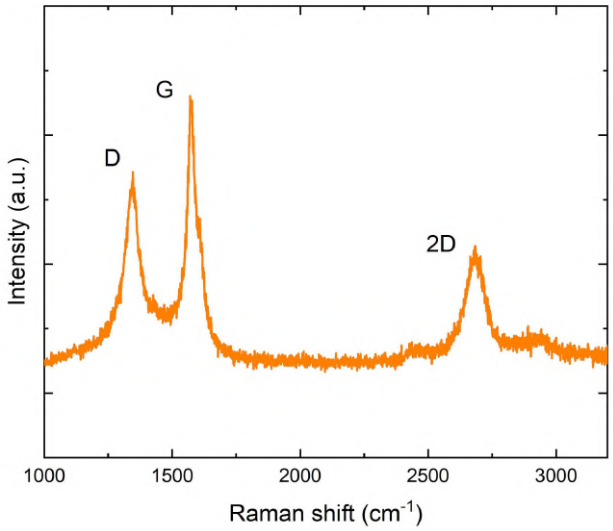
PRODUCT INFORMATION	
Description	Hybrid nanomaterial synthesised by the formation of manganese oxide and iron oxide nanoparticles on the surface of graphene nanoplatelets
Graphene Product	Nanene-003
Form	Powder
Manufacturing Method	Chemical
CAS Number	-
EC Number	-

GRAPHENE CHARACTERISTICS
Enquire

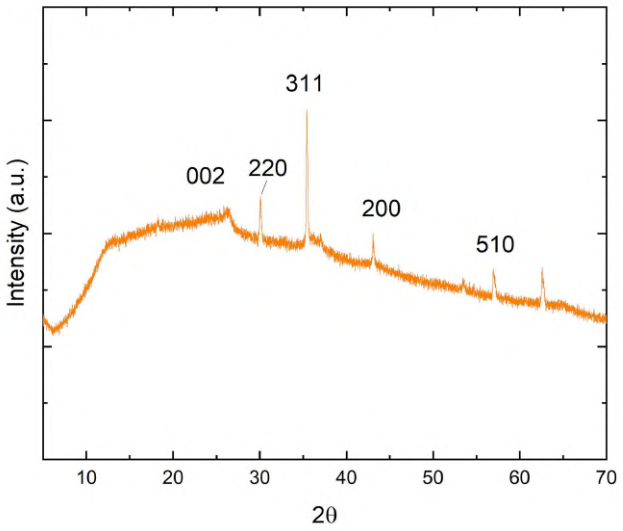
HYBRID MATERIAL CHARACTERISTICS	
Structural Defects (I_D/I_G)	~0.75
Bulk Density (untapped) (g/cm^3)	0.53
Chemical/Elemental Composition (at.%)	C ~80, Fe~2, Mn~2 , O ~15
Impurities (at.%)	Na ~1,
Functionalisation (type and wt.%)	MnO and Fe (20)
Surface Particle Charge (mV)	-10.8
Graphene Orientation	Turbostratic
Specific Surface Area (SSA) (m^2/g)	-
Crystallite Size (nm)	~81
Interlayer Spacing (d spacing) (nm)	0.340
Crystallinity (%)	~81
FWHM (002) Peak (°)	0.1
Dispersibility	Organic solvents

TYPICAL CHARACTERISATION DATA

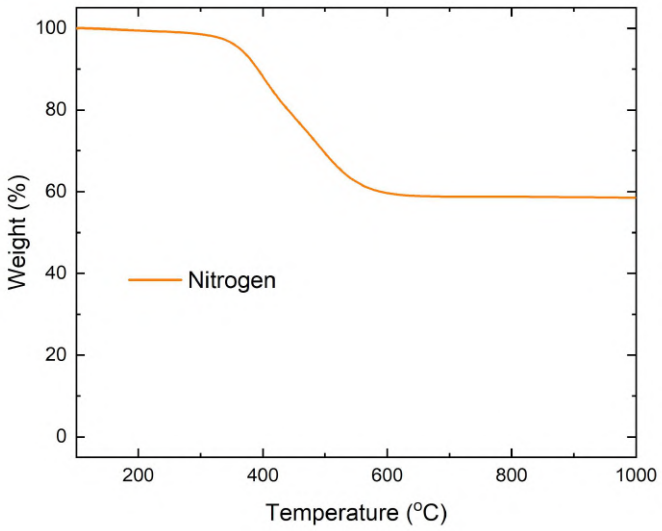
RAMAN SPECTROSCOPY



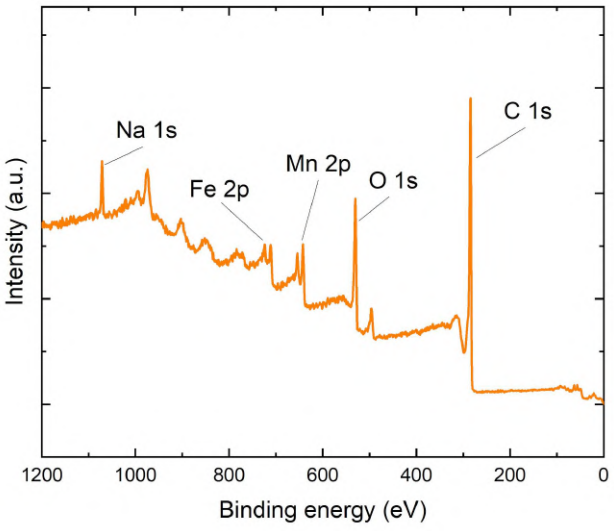
X-RAY DIFFRACTION



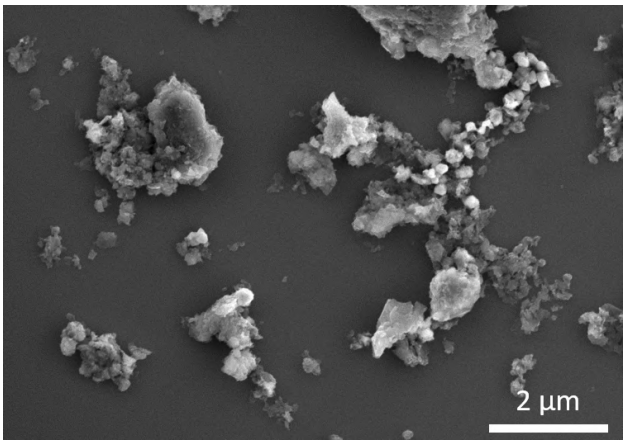
THERMOGRAVIMETRIC ANALYSIS



X-RAY PHOTOELECTRON SPECTROSCOPY



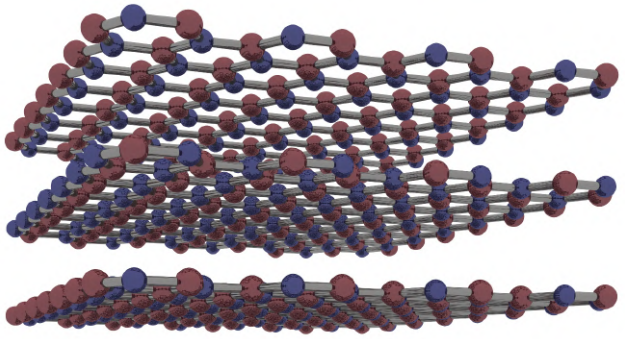
SCANNING ELECTRON MICROSCOPY

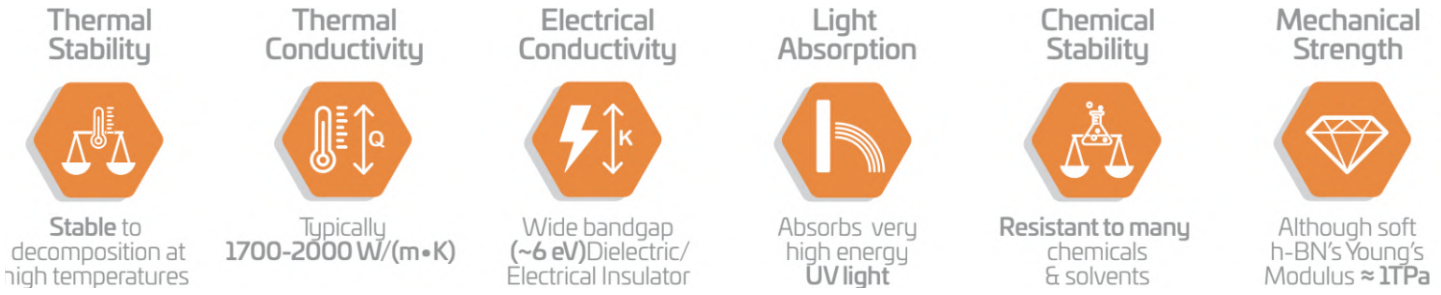


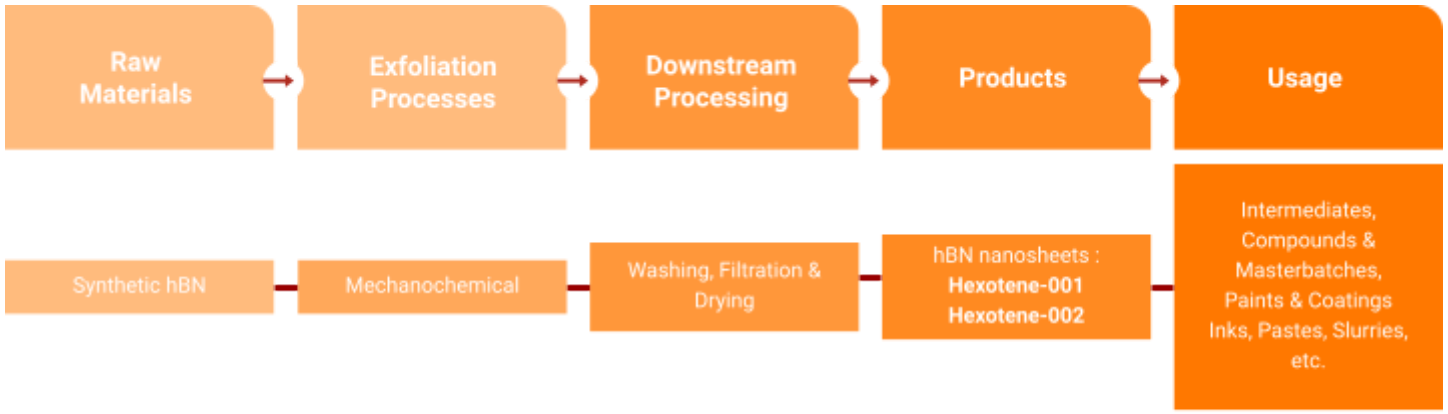
HEXAGONAL BORON NITRIDE

Hexotene™ is our family of high quality hexagonal boron nitride (hBN) nanosheet powders. We offer two grades: **Hexotene-001** and **Hexotene-002**, derived from different bulk hBN raw materials, with other functionalised forms in development.

hBN consists of covalently bonded, alternating boron and nitrogen atoms within a hexagonal honeycomb arrangement, similar to the structure of graphene. However, it holds some uniquely different characteristics: hBN is white in colour and a wide electronic bandgap of ~6 eV has been observed for hBN which gives rise to highly insulating electrical properties. This makes **Hexotene™** particularly useful for products where electrical conductivity is not desired, but many other features such as thermal conductivity and mechanical strength can be harnessed. The ability to allow for incorporation of other colours into consumer products, for example, is also a key advantage over graphene.







Process flow for the manufacture and uses of Versarien's hBN powder materials (Hexotene™)

Versarien®

PRODUCT CODE	GENERAL INFORMATION	MOQ (kg)
	HEXAGONAL BORON NITRIDE (HBN) POWDERS	
Hexotene-001	hBN nanosheets (BNNS), platelet shaped, non-functionalised, produced by mechano-chemical exfoliation of synthetic hBN	0.1
Hexotene-002	hBN nanosheets (BNNS), platelet shaped, non-functionalised, produced by mechano-chemical exfoliation of synthetic hBN	0.1
Hexotene-003	hBN nanosheets (BNNS), platelet shaped, functionalised (in development, enquire for more details)	Enquire

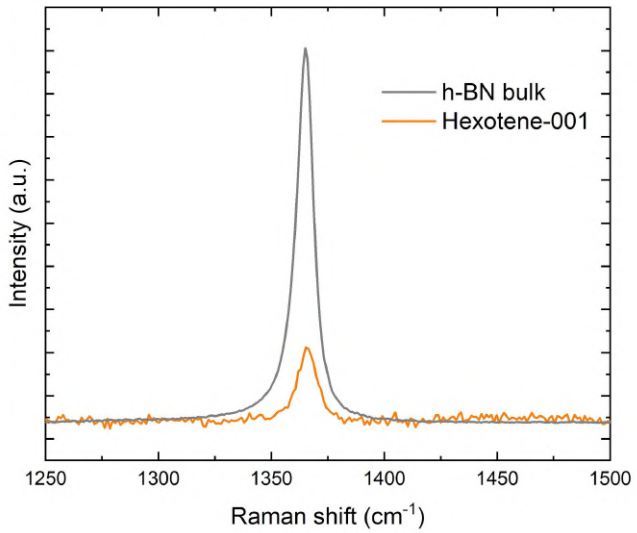
Hexotene-001

PRODUCT INFORMATION		
Description		hBN nanosheets, platelet shaped, non-functionalised, produced by mechano-chemical exfoliation of synthetic hBN
hBN Type		hBN nanosheets (BNNS)
Form		Powder
Manufacturing Method		Mechano-chemical exfoliation
Raw Material		Synthetic hBN
CAS Number		10043-11-5
EC Number		233-136-6
HBN CHARACTERISTICS		
Colour		White
Raman Peak Position (cm^{-1})		1366
Primary Particle Shape		Platelet, Plate
Lateral Dimensions (µm)	**D10**	x : 1.32 y : 1.01
	D50	x : 2.29 y : 2.01
	D90	x : 4.33 y : 3.91
Bulk Density (untapped) (g/cm^3)		<0.25
Chemical/Elemental Composition (at.%)		B ~42, N ~45
Impurities (at.%)		C ~7, O ~5, F/S, <1
Functionalisation (type and wt.%)		None
Surface Particle Charge (mV)		-38.9
Specific Surface Area (SSA) (m^2/g)		~40
Crystallite Size (nm)		41.5
Interlayer Spacing (d spacing) (nm)		0.333
Crystallinity (%)		~76
FWHM (002) Peak (°)		0.27
Dispersibility		Not measured

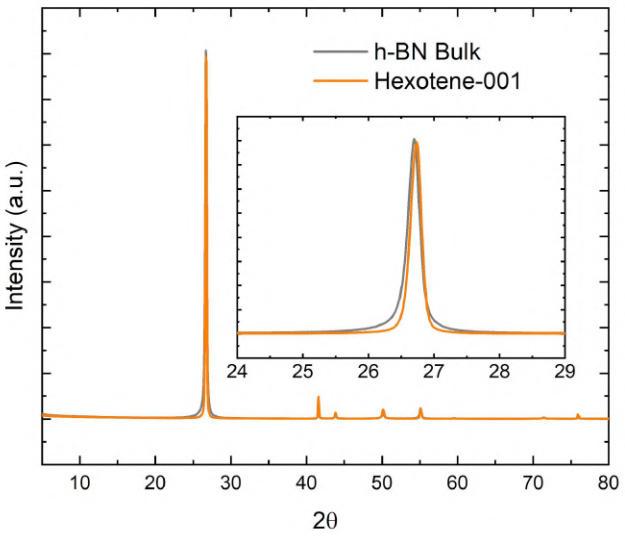
Hexotene

TYPICAL CHARACTERISATION DATA

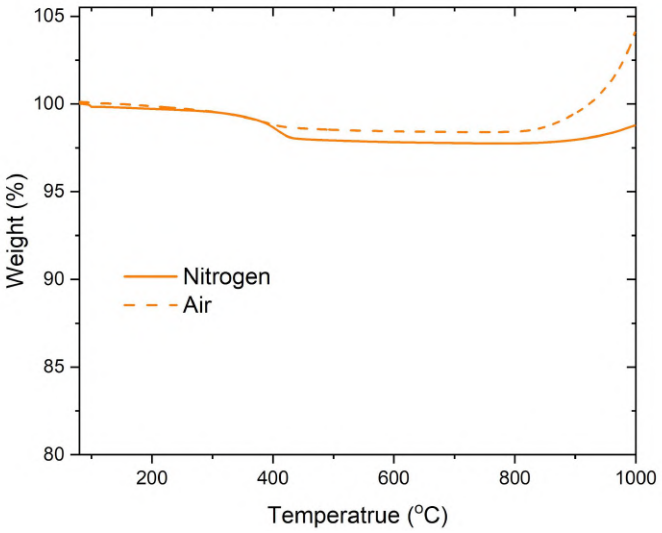
RAMAN SPECTROSCOPY



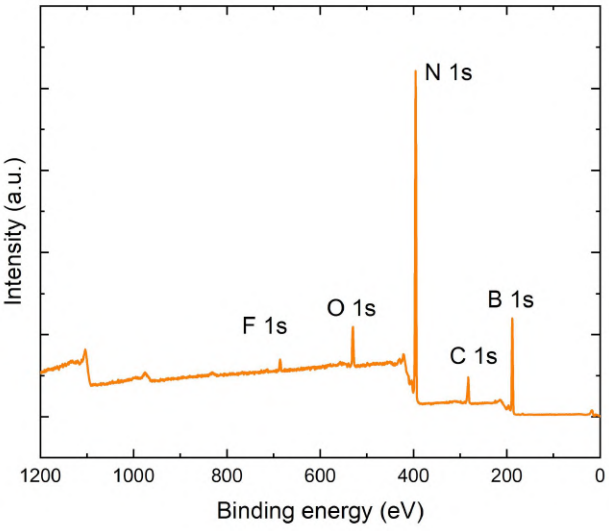
X-RAY DIFFRACTION



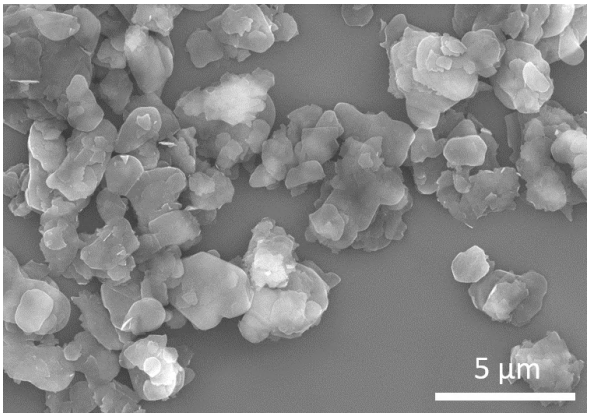
THERMOGRAVIMETRIC ANALYSIS



X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



Versarien

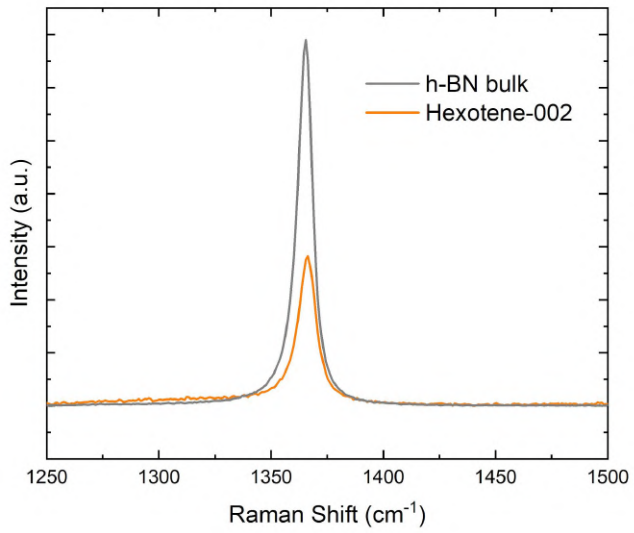
Hexotene-002

PRODUCT INFORMATION		
Description		hBN nanosheets (BNNS), platelet shaped, non-functionalised, produced by mechano-chemical exfoliation of synthetic hBN
hBN Type		hBN nanosheets (BNNS)
Form		Powder
Manufacturing Method		Mechano-chemical exfoliation
Raw Material		Synthetic hBN
CAS Number		10043-11-5
EC Number		233-136-6
HBN CHARACTERISTICS		
Colour		White
Raman Peak Position (cm^{-1})		1366
Primary Particle Shape		Platelet, Plate
Lateral Dimensions (µm)	**D10**	x : 0.85 y : 0.81
	D50	x : 2.98 y :2.11
	D90	x : 3.96 y : 3.10
Bulk Density (untapped) (g/cm^3)		<0.25
Chemical/Elemental Composition (at.%)		B ~42, N ~45
Impurities (at.%)		C ~6, O ~4, F/S <1
Functionalisation (type and wt.%)		None
Surface Particle Charge (mV)		-33.8
Specific Surface Area (SSA) (m^2/g)		~40
Crystallite Size (nm)		28.7
Interlayer Spacing (d spacing) (nm)		0.333
Crystallinity (%)		~77
FWHM (002) Peak (°)		0.28
Dispersibility		Not measured

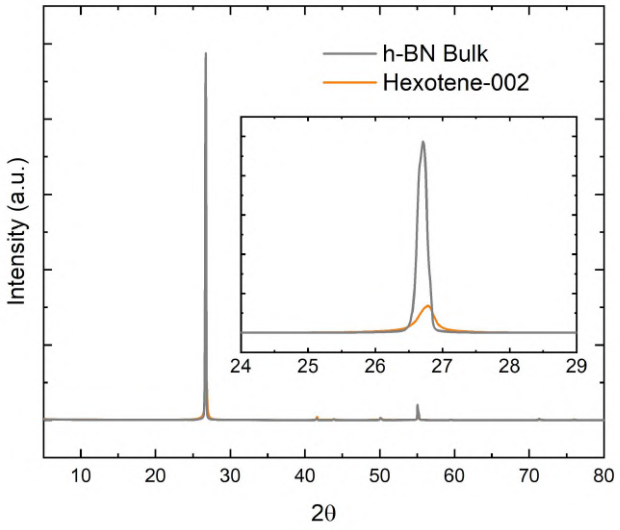
Hexotene

TYPICAL CHARACTERISATION DATA

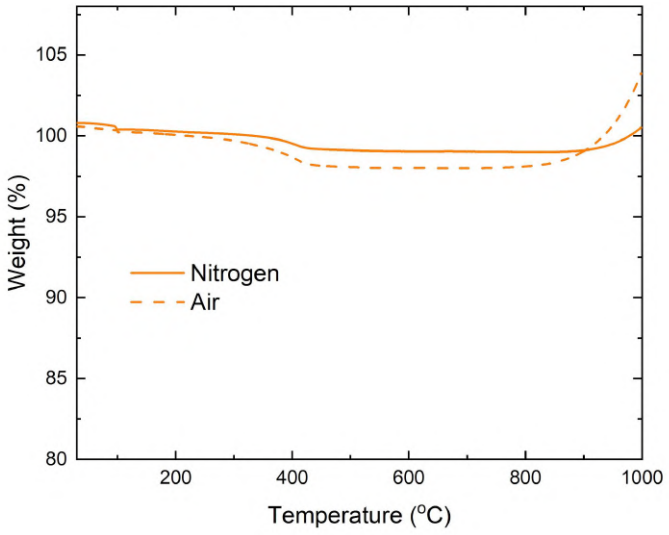
RAMAN SPECTROSCOPY



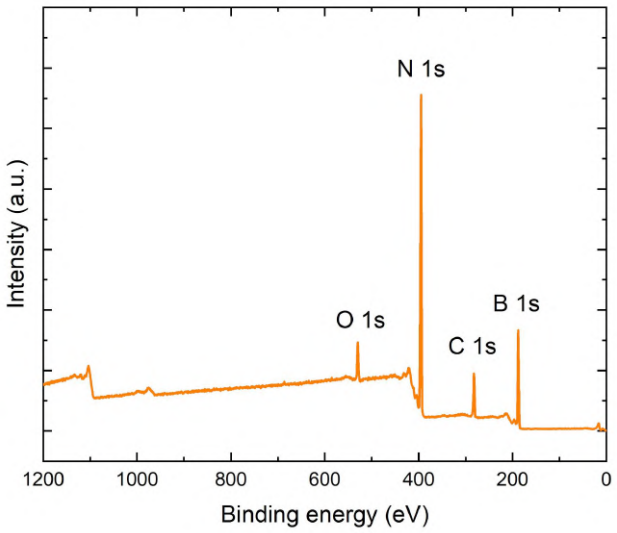
X-RAY DIFFRACTION



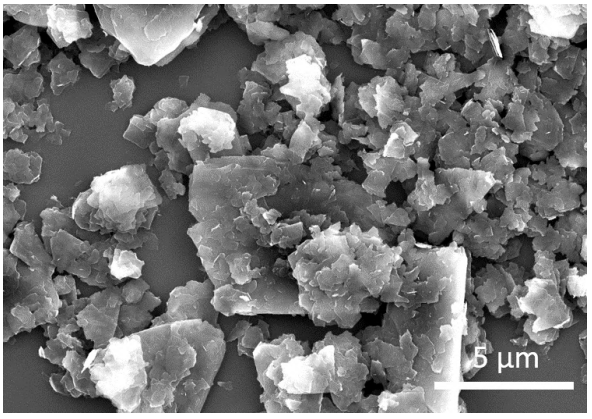
THERMOGRAVIMETRIC ANALYSIS



X-RAY PHOTOELECTRON SPECTROSCOPY



SCANNING ELECTRON MICROSCOPY



Versarien

GRM INKS & DISPERSIONS

Graphinks™ are graphene and related material (GRM) inks and dispersions that bring multi-functionality (high electrical and thermal conductivity, fire retardation, UV protection, etc.), produced via a high pressure homogenisation process that offers high yield and uniform size distribution. We have 'standard' **Graphinks™** for different deposition methods from inkjet to screen printing and developmental formulations (DF) with different nanomaterials and solvent combinations.

GRAPHINKS FORMULATION & PRINTING GUIDANCE

Graphink-101 was developed using a Drop-on-Demand (DoD) Dimatix Materials Printer, DMP-2800 (FUJIFILM Dimatix Inc., USA) using Dimatix Materials Cartridges. Jetting profiles and cleaning procedure files can be sent electronically following purchase of the ink. This does not guarantee successful printing and will require optimisation at the customer's end.

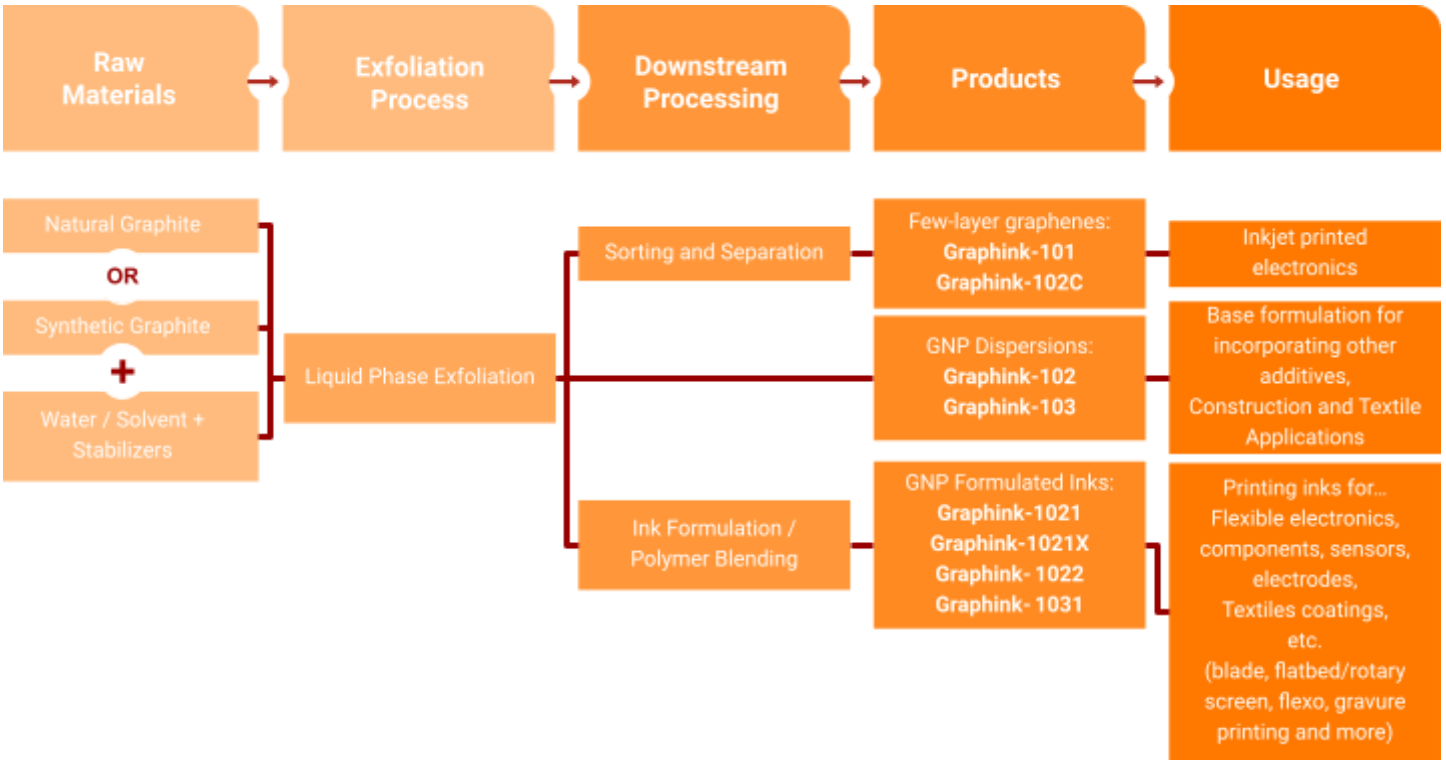
Graphink-102 and **Graphink-103** are water-based graphene dispersions with no binders or rheology modifiers added. They provide you the freedom to formulate a water-based graphene ink suitable for application with their binder or additives of choice. In order to increase their viscosities for different printing methods we developed **Graphink-1021** and **Graphink-1022** contain cellulose rheology modifiers and binders. The rheological behaviour of these inks is thixotropic, which means they are highly viscous when in storage. The viscosity will drop significantly as shear is applied during printing processes and the viscosity will rebuild after printing which is important to maintain high-resolution printing patterns. These inks can be printed on paper, glass, plastics and textile substrates. Good coatings can provide sheet resistances of <5 Ω/□ (@25 µm print thickness). Because these inks are water soluble, we have developed a cross-linked version that can be used in aqueous environments - **Graphink-1021X**, for example, in biosensor electrode applications.

Graphink-1021 and **Graphink-1022** were developed using a flatbed screen printing machine using screens with a waterproofed and hardened polyester mesh with mesh size ranging from 15 to 120. Depending on the printing technique and the machine, the viscosity of the inks may need to be reduced using deionised water only.

Cleaning: Reclaim excess ink from the screen using a spatula, use disposable cleaning wipes followed by rinsing and washing processes with detergent and water. Scrub the screen lightly with a brush, then wash out the screen with water and leave to air dry. Repeated cleaning processes may be necessary.

Other printing/coating techniques include but are not limited to:

- Doctor blade / Meyer bar coating
- Spray coating
- Slot die coating
- Dip coating
- Curtain coating
- Flexographic Printing
- Gravure Printing



Process flow for the manufacture and uses of Versarien's graphene-based inks and dispersions (Graphinks™)

GRAPHENE-WEAR PRINTING GUIDANCE

Versarien have developed water-based ink formulations for textiles coating: **Graphink-1031** (Graphene) is part of Versarien's **Graphene-Wear™** product range with **Graphink-DF-2002** (hBN) in development. **Graphink-1031** is a certified product according to OEKO-TEX® ECO PASSPORT.

Fabric specifications

We have tested a wide range of fabric compositions, weights and colours. The below examples are suggested fabrics types. Please enquire with Versarien if you want to print on to something different.

- Fabric types: polyamide/elastane blends (knitted - interlock), polyester/elastane blends (knitted - interlock), polyester/cotton blends (woven - plain weave), 100% polyester (pique, jersey)
- Fabric colour: Any
- Fabric GSM: ~80-200

Ink specifications

All ingredients comply with ZDHC MRSL. Safety data sheets (SDS) are supplied with the inks.

- Ink viscosity: 850-1100 cP at 100 s^{-1} shear rate.
- Resulting pattern colours:
  Graphink-1031: Black/grey (may show through light-coloured fabrics)
  Graphink-DF-2002: White (dyes can be added to give colour)

Screen specifications

- Mesh type: Enquire

Print conditions

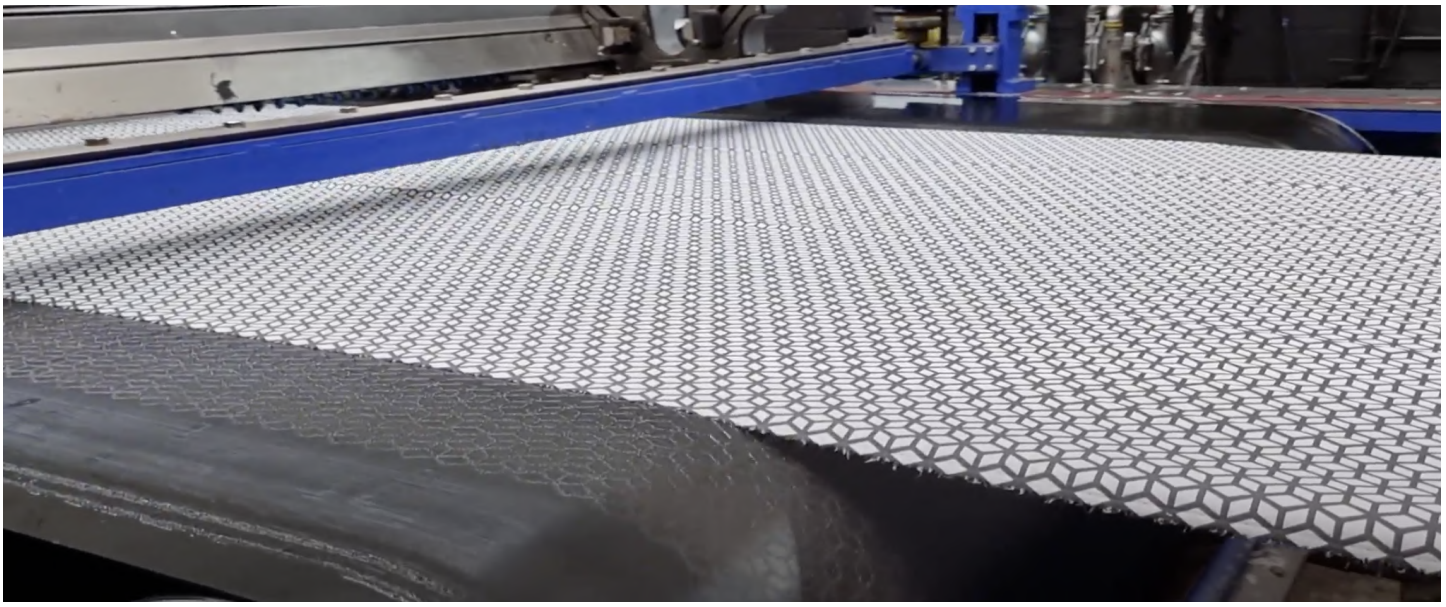
- Printing speed: ideally > 10 m/min
- Drying temperature: 150 °C, (minimum 1 min/maximum 3 min)
- Curing temperature: 150 °C, (minimum 5 min/maximum 10 min)

Additional notes

- Stir inks well before printing.
- Do not dilute inks with water, solvents or add any other ingredients.
- Keep enough volume of ink in the rotary screen to cover the whole printing width.
- If the printing needs to be stopped in the middle of the process for any adjustments etc. keep the screen rotating to avoid ink getting dried on the screen
- Depending on the stretchiness of the fabric, change the tension under which the fabric is during the printing process. Drying under too much tension may cause the printed fabric to wrinkle.
- Stretchy fabrics may need to be fixed at the edges during printing to stop curling.
- Clean up: Use water

OEKO TEX®
ECO PASSPORT
EP 60720
Shirley

This certificate EP 60720 is valid until 31.01.2024.



Click here to find out more about Graphene-Wear™

Versarien®

Versarien are happy to help develop the ink for your printing/coating needs

We can increase nanomaterial concentrations or add rheology modifiers and other additives in line with your requirements

Contact us at **info@versarien.com**

Versarien®

PRODUCT CODE	GENERAL INFORMATION	MOQ (kg)
	GRAPHENE DISPERSIONS	
Graphink-101	Low viscosity inkjet printing ink: Coatings, printed electronics, antennas, sensors, energy storage devices, etc.	0.1
Graphink-102	Base dispersion for clients who want to blend with their own binders/polymers/inks. Suited to printed electronics applications.	1
Graphink-102C	Low viscosity ink, printing ink for laser sintering processes (enquire for more details).	0.1
Graphink-103	Base dispersion for clients who want to blend with their own binders/polymers/inks. Suited to construction and textile applications.	25
	FORMULATED GRAPHENE INKS	
Graphink-1021	Moderate viscosity flexo and screen printable ink: Coatings, printed electronics, antennas, sensors, energy storage devices, etc.	1
Graphink-1021X	Moderate viscosity flexo and screen printable ink: For coatings that are going to be exposed to aqueous environments, suitable for electrodes and biosensors. Contains cross-linker.	1
Graphink-1022	High viscosity screen printable ink: Coatings, printed electronics, antennas, sensors, energy storage devices, etc.	1
Graphink-1031	Screen printable ink for textiles coatings (thermal management, wicking). Contains cross-linker.	25
	DEVELOPMENTAL 2D MATERIAL INKS & DISPERSIONS (enquire for more details)	
	GRAPHENE INKS (DF-1XXX)	
Graphink-DF-1001	Low viscosity solvent-based ink in isopropyl alcohol (IPA) suitable for spray coating or inkjet printing.	Enquire
Graphink-DF-1002	Low viscosity based dispersion (dispersed with an anionic surfactant), 30% graphene loading.	Enquire
Graphink-DF-1002C	Low viscosity inkjet printing ink: Coatings, printed electronics, antennas, sensors, energy storage devices, etc. Can also be used for dip coating of textiles.	Enquire
Graphink-DF-1003	Low viscosity graphene based ink without any binder (dispersed with a non-ionic surfactant), 30% graphene loading.	Enquire
Graphink-DF-1004	Formulated with polyamide imide (PAI) for anti-corrosion and abrasion resistant coatings. Anti-static and conductive formulations available.	Enquire
	HEXAGONAL BORON NITRIDE (HBN) INKS (DF-2XXX)	
Graphink-DF-2001	Low viscosity hBN based ink without any binder (dispersed with a non-ionic surfactant), 20% hBN loading.	Enquire
Graphink-DF-2001C	Low viscosity hBN based ink suitable for spray coating or inkjet printing. Can also be used for dip coating of textiles.	Enquire
Graphink-DF-2002	Screen printable ink for textiles coatings (thermal management, wicking). Contains cross-linker.	Enquire
	MOLYBDENUM DISULFIDE (MoS_2) INKS (DF-3XXX)	
Graphink-DF-3001	Low viscosity MoS_2 based ink without any binder (dispersed with an anionic surfactant), 10% MoS_2.	Enquire
Graphink-DF-3002	Low viscosity MoS_2 based ink without any binder (dispersed with an non-ionic surfactant), 30% MoS_2.	Enquire
Graphink-DF-3002C	Low viscosity MoS_2 ink suitable for spray coating or inkjet printing. Can also be used for dip coating or film casting through vacuum filtration.	Enquire

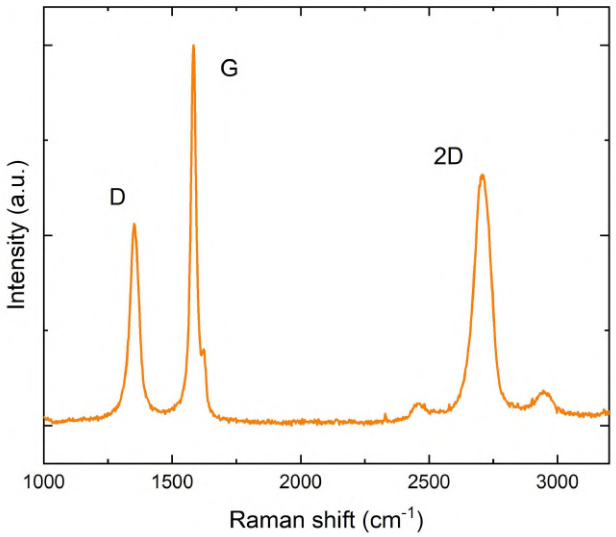
Graphink-101 (Graphene)

PRODUCT INFORMATION		
Description		Few-layer graphene in water, non-functionalised, platelet shaped, produced by liquid phase exfoliation of synthetic graphite
Graphene Type		Few-layer graphene (FLG)
Form		Dispersion (water)
Manufacturing Method		Liquid phase exfoliation
Raw Material		Synthetic graphite
Dispersants / Surfactants		Yes, see safety data sheet (SDS) for more information
Graphene Concentration (wt.%)		0.02-0.05
Total Solid Content (wt.%)		0.07-0.10
Solvent Content (wt.%)		~99.9
GRAPHENE CHARACTERISTICS		
Colour		Black / Dark grey
sp^2 Bonded Carbon (cm^{-1})		~1580
Structural Defects (I_D/I_G)		~0.5
Number of Layers	**D10**	2
	D50	6
	D90	22
Z-Axis Dimensions (nm)	**D10**	~0.7
	D50	~2
	D90	~7.4
Primary Particle Shape		Platelet, Plate
Lateral Dimensions (nm)	**D10**	70
	D50	90
	D90	130
Aspect Ratio (lateral size/thickness)	**Min**	~9.5
	Max	~186
Chemical/Elemental Composition (at.%)		C ~88.5
Oxygen Content (at.%)		~9.5
C/O ratio		~9.3
Impurities (at.%)		Na ~2 (unwashed)
Functionalisation (type and wt.%)		N/A
INK CHARACTERISTICS		
Viscosity (cP)	**100 s^{-1}**	~2
Rheological Behaviour		Newtonian
Surface Tension (mN/m)		~62
Surface Particle Charge (mV)		-34
PRINT CHARACTERISTICS		
Printing Techniques		Inkjet Printing, Spray Coating, Mayer Bar Coating, Vacuum Filtration
Substrates		Glass, Paper, Plastics (surface treatment may be required first)
Drying Conditions		100°C for 10 minutes (no sintering required)
Sheet resistance (@ thickness)		~4 kΩ/□ @ 80 nm; ~30 Ω/□ @ 2 µm (vacuum filtered films)

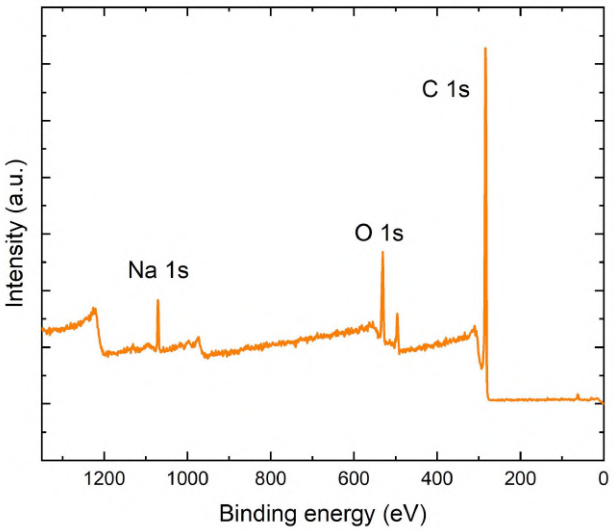
GRAPHINKS

TYPICAL GRAPHENE CHARACTERISATION DATA

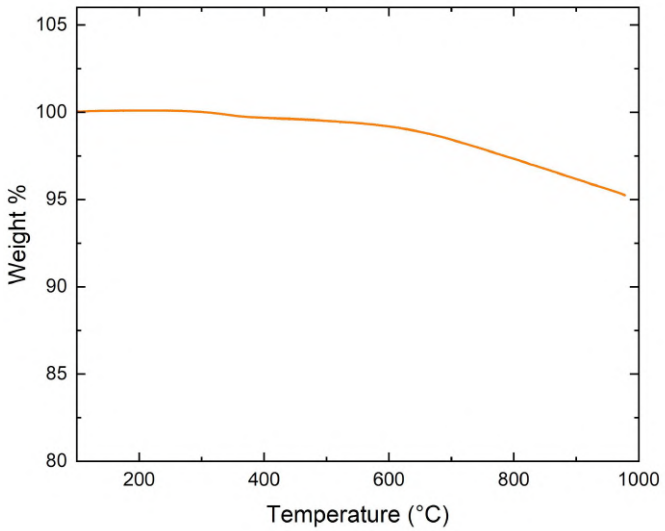
RAMAN SPECTROSCOPY



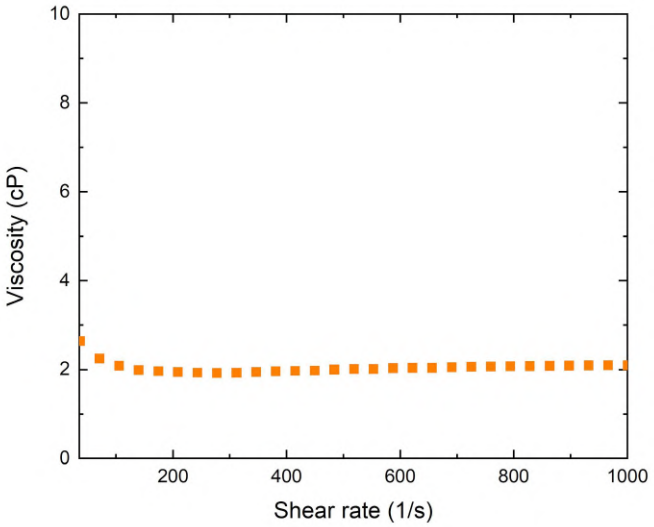
X-RAY PHOTOELECTRON SPECTROSCOPY



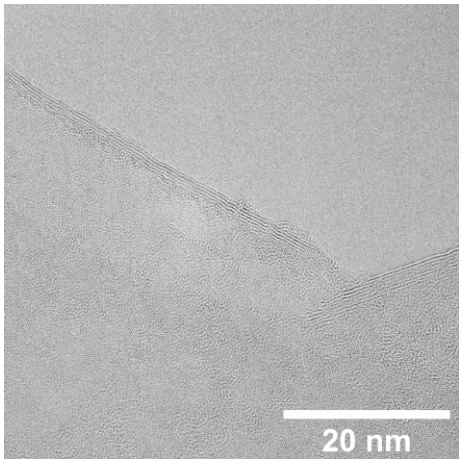
THERMOGRAVIMETRIC ANALYSIS (ARGON)



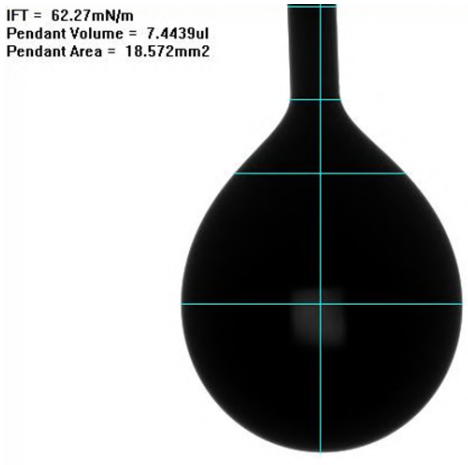
OSCILLATORY RHEOLOGY



TRANSMISSION ELECTRON MICROSCOPY



SURFACE TENSION



Versarien

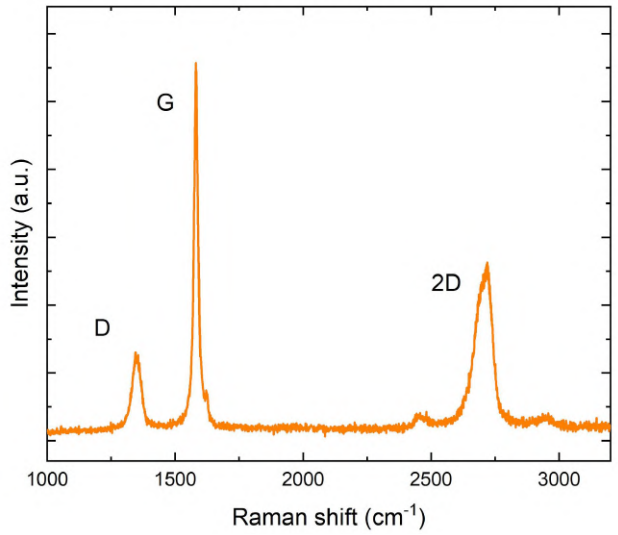
Graphink-102 (Graphene)

PRODUCT INFORMATION		
Description		Graphene nanoplatelets in water, non-functionalised, platelet shaped, produced by liquid phase exfoliation of synthetic graphite
Graphene Type		Graphene nanoplatelets (GNP)
Form		Dispersion (water)
Manufacturing Method		Liquid phase exfoliation
Raw Material		Synthetic graphite
Dispersants / Surfactants		Yes, see safety data sheet (SDS) for more information
Graphene Concentration (wt.%)		10
Total Solid Content (wt.%)		10.5
Solvent Content (wt.%)		89.5
GRAPHENE CHARACTERISTICS		
Colour		Black / Dark grey
sp^2 Bonded Carbon (cm^{-1})		~1580
Structural Defects (I_D/I_G)		~0.3
Z-Axis Dimensions (nm)	**D10**	1
	D50	6
	D90	22
Primary Particle Shape		Platelet, Plate
Lateral Dimensions (µm)	**D10**	~0.3
	D50	~2
	D90	~7.4
Aspect Ratio (lateral size/thickness)	**Min**	~13.6
	Max	~7400
Chemical/Elemental Composition (at.%)		C ~98.4
Oxygen Content (at.%)		~1.6
C/O ratio		~61.5
Impurities (at.%)		N/A
Functionalisation (type and wt.%)		N/A
Specific Surface Area (SSA) (m^2/g)		N/A
Surface Particle Charge (mV)		-35.7
DISPERSION CHARACTERISTICS		
Viscosity (cP)	**100 s^{-1}**	~1-2
Rheological Behaviour		Newtonian
Contact Angle on Glass (°)		73.93

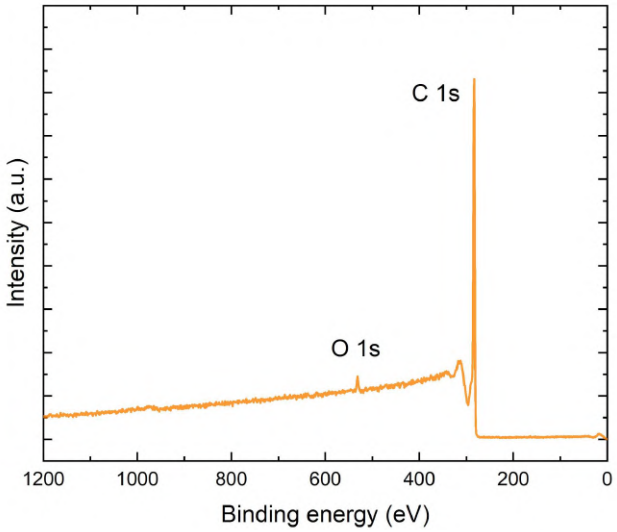
GRAPHINKS

TYPICAL GRAPHENE CHARACTERISATION DATA

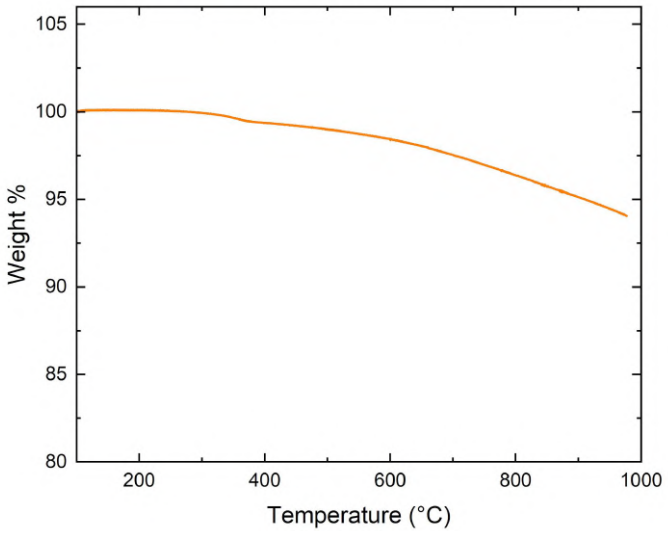
RAMAN SPECTROSCOPY



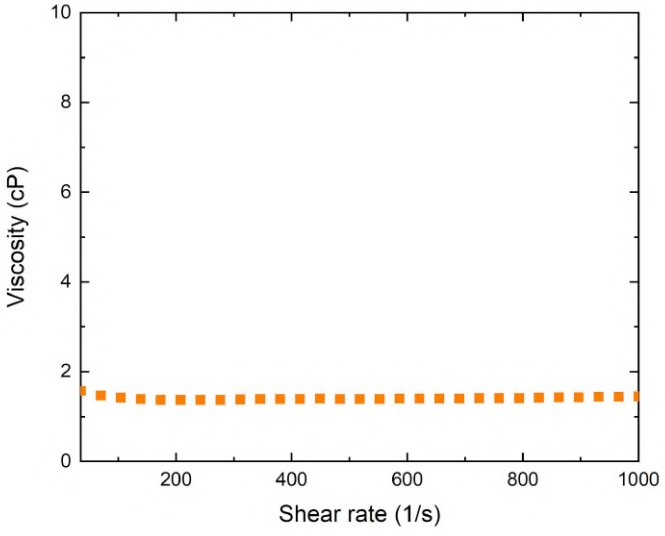
X-RAY PHOTOELECTRON SPECTROSCOPY



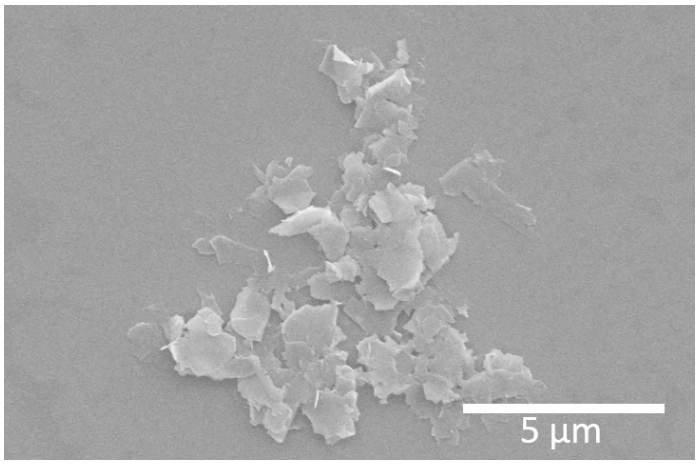
THERMOGRAVIMETRIC ANALYSIS (Argon)



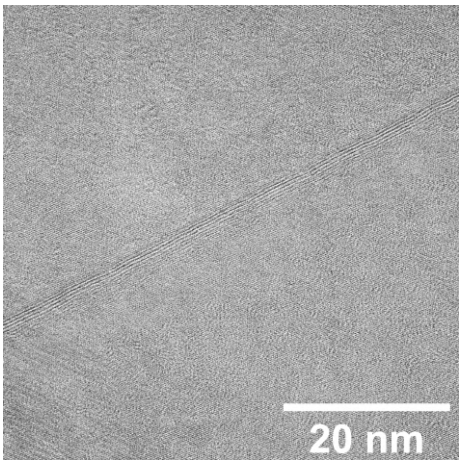
OSCILLATORY RHEOLOGY



SCANNING ELECTRON MICROSCOPY



SCANNING TRANSMISSION ELECTRON MICROSCOPY



Versarien®

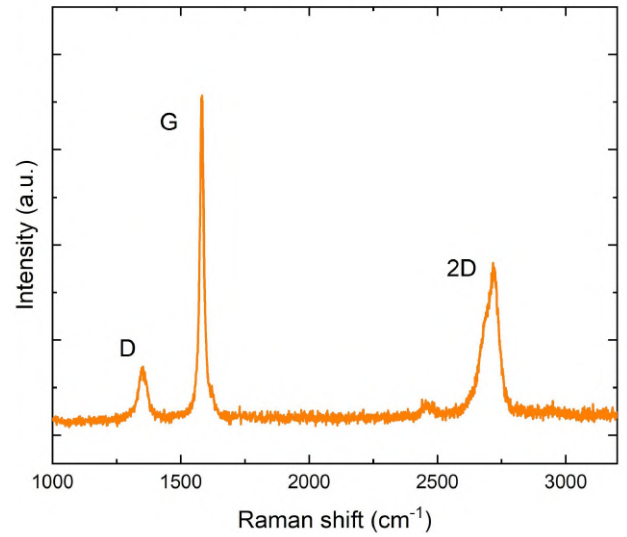
Graphink-103 (Graphene)

PRODUCT INFORMATION		
Description		Graphene nanoplatelets in water, platelet shaped, produced by liquid phase exfoliation of synthetic graphite
Graphene Type		Graphene nanoplatelets (GNP)
Form		Dispersion (water)
Manufacturing Method		Liquid phase exfoliation
Raw Material		Synthetic graphite
Dispersants / Surfactants		Yes, proprietary information
Graphene Concentration (wt.%)		20
Total Solid Content (wt.%)		22
Solvent Content (wt.%)		78
GRAPHENE CHARACTERISTICS		
Colour		Black / Dark grey
sp^2 Bonded Carbon (cm^{-1})		~1580
Structural Defects (I_D/I_G)		~0.1
Z-Axis Dimensions (nm)	**D10**	4
	D50	17
	D90	32
Primary Particle Shape		Platelet, Plate
Lateral Dimensions (µm)	**D10**	~1.3
	D50	~5.7
	D90	~10.7
Aspect Ratio (lateral size/thickness)	**Min**	~40.6
	Max	~2675
Chemical/Elemental Composition (at.%)		C ~95
Oxygen Content (at.%)		~5
C/O ratio		~19
Impurities (at.%)		N/A
Functionalisation (type and wt.%)		N/A
Specific Surface Area (SSA) (m^2/g)		N/A
Surface Particle Charge (mV)		-30.4
DISPERSION CHARACTERISTICS		
Viscosity (cP)	**100 s^{-1}**	~3
Rheological Behaviour		Newtonian

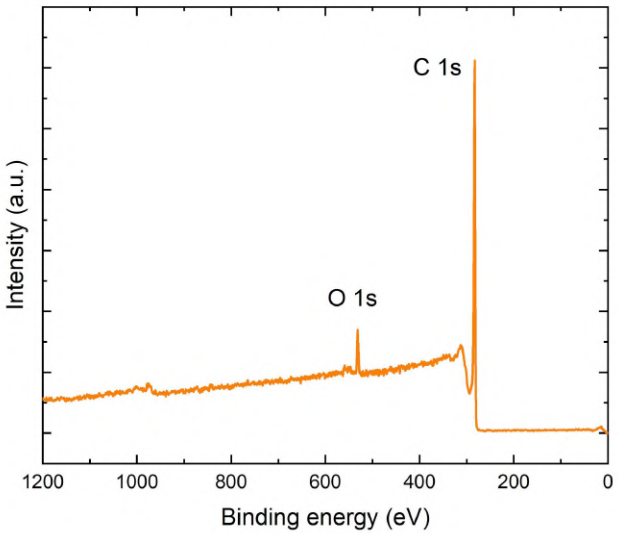
GRAPHINKS

TYPICAL CHARACTERISATION DATA

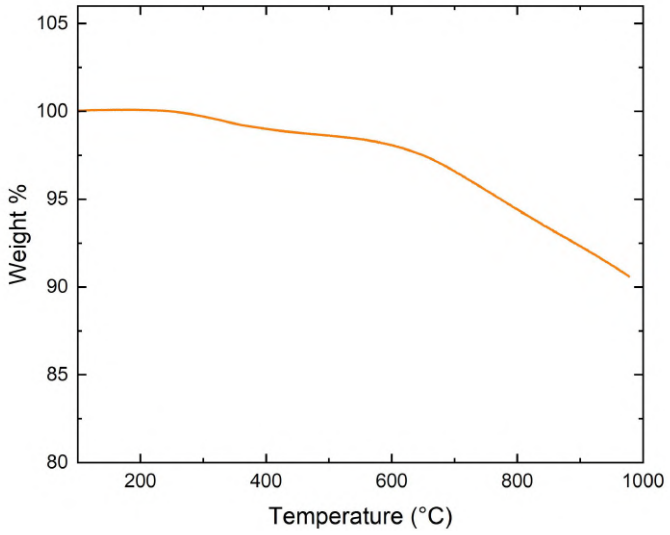
RAMAN SPECTROSCOPY



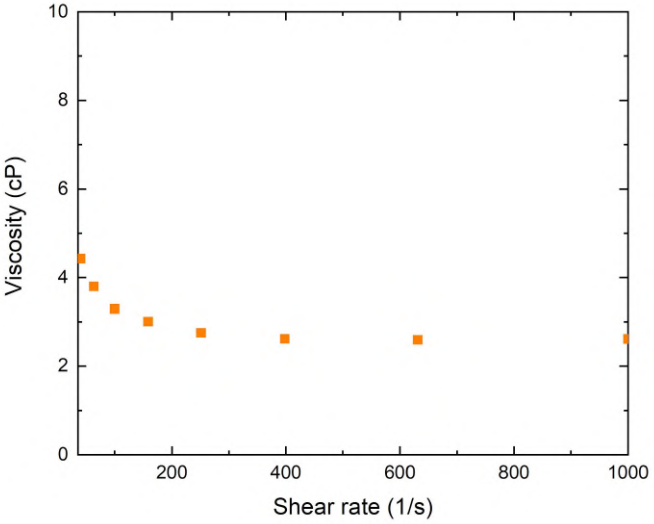
X-RAY PHOTOELECTRON SPECTROSCOPY



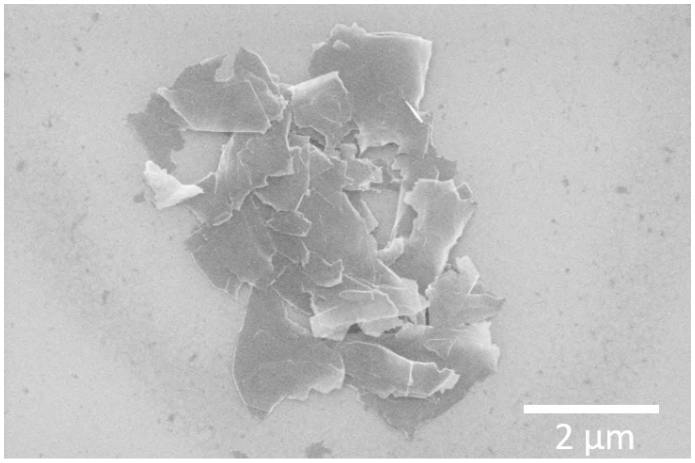
THERMOGRAVIMETRIC ANALYSIS (Argon)



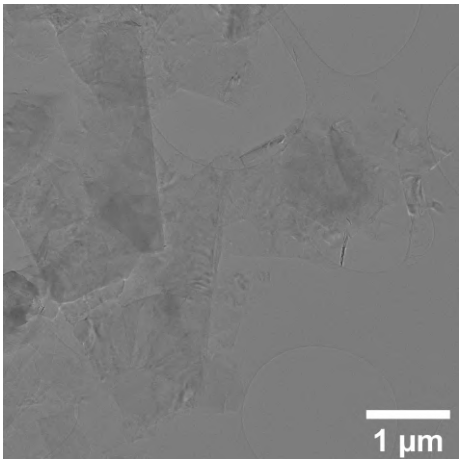
OSCILLATORY RHEOLOGY



SCANNING ELECTRON MICROSCOPY



TRANSMISSION ELECTRON MICROSCOPY



Versarien®

GRAPHINKS

Graphink-1021 (Graphene)

PRODUCT INFORMATION		
Description		Water-based graphene nanoplatelet ink with sodium carboxymethylcellulose
Graphene Type		Graphene nanoplatelets (GNP)
Form		Formulated ink
Manufacturing Method		Liquid phase exfoliation
Raw Material		Synthetic graphite
Solvent		Water
Dispersants / Surfactants		Yes, see safety data sheet (SDS) for more information
Graphene Concentration (wt.%)		10
Total Solid Content (wt.%)		11.5
Solvent Content (wt.%)		89.5
GRAPHENE CHARACTERISTICS		
See Graphink-102 TDS		
INK CHARACTERISTICS		
Viscosity (cP)	**$2s^{-1}$**	5000-10000
	100 s^{-1}	650-950
Rheological Behaviour		Non-Newtonian (Thixotropic)
PRINT CHARACTERISTICS		
Printing Techniques		Mayer bar, Screen printing, Blade/knife coating, Slot die, Flexo/gravure coating
Substrates		Glass, Paper, Plastics, Textile Graphink 1021 is compatible with DuPont™ Intexar™ for use in clothing manufacturing processes
Drying Conditions		@100 ^{0}C for 10-30 min
Sheet resistance (ohms/square)		≤5 Ω/□ @ 25 µm

This product is also available containing a proprietary chemical cross-linker for use in aqueous environments once dried - **Graphink-1021X**

Versarien®

GRAPHINKS

Graphink-1022 (Graphene)

PRODUCT INFORMATION		
Description		Water-based graphene nanoplatelet ink with sodium carboxymethylcellulose
Graphene Type		Graphene nanoplatelets (GNP)
Form		Formulated ink
Manufacturing Method		Liquid phase exfoliation
Raw Material		Synthetic graphite
Solvent		Water
Dispersants / Surfactants		Yes, see safety data sheet (SDS) for more information
Graphene Concentration (wt.%)		10
Total Solid Content (wt.%)		12
Solvent Content (wt.%)		88
GRAPHENE CHARACTERISTICS		
See Graphink-102 TDS		
INK CHARACTERISTICS		
Viscosity (cP)	**2 s^{-1}**	10000 - 30000
	100 s^{-1}	1500 - 1900
Rheological Behaviour		Non-Newtonian (Thixotropic)
PRINT CHARACTERISTICS		
Printing Techniques		Mayer bar, Screen printing, Blade/knife coating, Slot die, Flexo/gravure coating
Substrates		Glass, Paper, Plastics, Textile Graphink 1022 is compatible with DuPont™ Intexar™ for use in clothing manufacturing processes
Drying Conditions		@100 ^{0}C for 10-30 min
Sheet Resistance (ohms/square)		≤5 Ω/□ @25 µm

GRAPHINKS

Graphink-1031 (Graphene)

PRODUCT INFORMATION		
Description		Water-based graphene nanoplatelet ink formulated with proprietary binders and thickeners for rotary-screen printing on textiles
Graphene Type		Graphene nanoplatelets (GNP)
Form		Formulated ink
Manufacturing Method		Liquid phase exfoliation
Raw Material		Synthetic graphite
Solvent		Water
Dispersants / Surfactants		Yes, see safety data sheet (SDS) for more information
Total Solid Content (wt.%)		~9.5%
Solvent Content (wt.%)		90.5%
GRAPHENE CHARACTERISTICS		
See Graphink-103 TDS		
INK CHARACTERISTICS		
Viscosity (cP)	**2 s^{-1}**	~6000-10000
	100 s^{-1}	650-1100
Rheological Behaviour		Non-Newtonian (Thixotropic)
PRINT CHARACTERISTICS		
Printing Techniques		Screen Printing (Flatbed, Rotary)
Substrates		Textiles: Polyester, Nylon and their blends with Elastane, bio-based, (use ready-to-print fabric) GSM range ~80-200 GSM
Drying and Curing Conditions		Drying temperature: 150 ^{0}C, (minimum 1 min/maximum 3 min) Curing temperature: 150 ^{0}C, (minimum 5 min/maximum 10 min)

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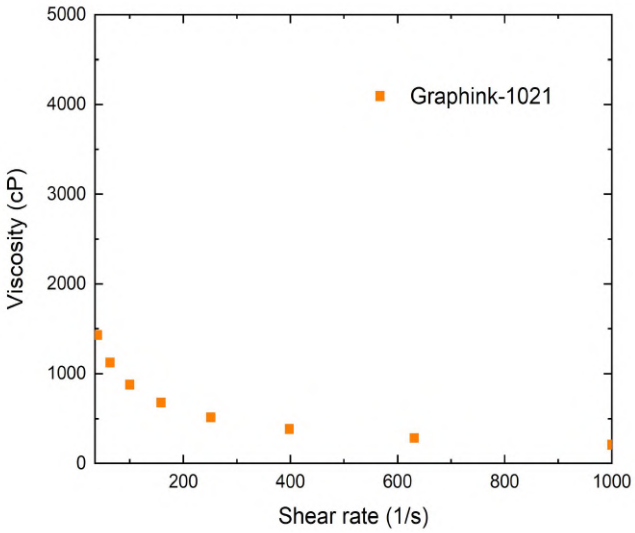
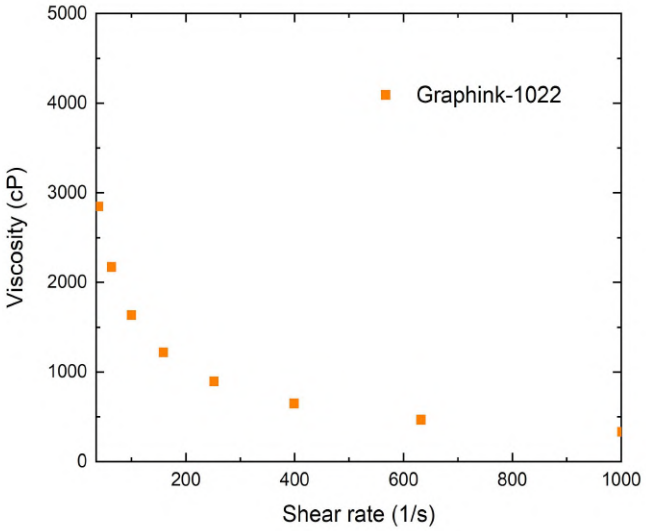
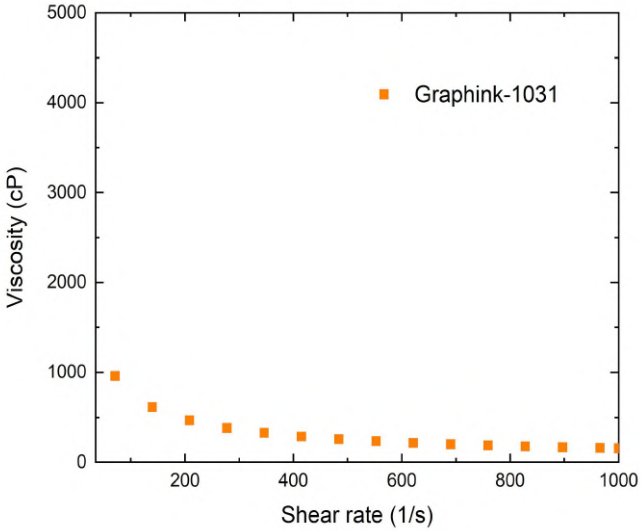
GRAPHINKS

TYPICAL INK CHARACTERISATION DATA

OSCILLATORY RHEOLOGY







SCIENTIFIC LITERATURE

Graphene Powders

- "A primary study into graphene/polyether ether ketone (PEEK) nanocomposite for laser sintering," **Applied Surface Science**, 428, 15 (2018)
- "Ethylene methyl acrylate copolymer (EMA) assisted dispersion of few-layer graphene nanoplatelets (GNP) in poly(ethylene terephthalate) (PET)," **Polymer**, 205, 122836 (2020)
- "Realizing the theoretical stiffness of graphene in composites through confinement between carbon fibers," **Composites Part A**, 113 (2018)
- "Preparation and characteristics evaluation of mono and hybrid nano-enhanced phase change materials (NePCMs) for thermal management of microelectronics," **Energy Conversion and Management**, 205, 112444 (2020)
- "Determining the level and location of functional groups on few-layer graphene and their effect on mechanical properties of nanocomposites," **ACS Appl. Mater. Interfaces.** 12, (2020)
- "High-performance nanoporous aramid films reinforced with functionalized carbon nanocharges using ionic liquid," **Polymer**, 202, 122629 (2020)
- "Thermal Interface Materials with Hexagonal Boron Nitride and Graphene Fillers in PDMS Matrix: Thermal and Mechanical Properties," **Energies** 16, 2522 (2023)

Graphene Oxides

- Speciality product featuring a particle range ~100 nm in biosensing applications: "Activation of human natural killer cells by graphene oxide-Templated antibody nanoclusters," **Nano Lett.**, 18, 5, 3283-3289 (2018)
- "Paper-based electrochemical biosensors for voltammetric detection of miRNA biomarkers using reduced graphene oxide or MoS_2 nanosheets decorated with gold nanoparticle electrodes," **Biosensors**, 11, 7, 236 (2021)
- "Thermophysical characteristics and enhancement analysis of carbon-additives phase change mono and hybrid materials for thermal management of electronic devices," **Journal of Energy Storage**, 34, 102231 (2021)
- "Fresh and hardened state properties of hybrid graphene oxide/nanosilica cement composites," **Construction and Building Materials**, 221 (2019)
- "Electroresponsive silk-based biohybrid composites for electrochemically controlled growth factor delivery," **Pharmaceutics**, 12, 742 (2020)
- "Graphene oxide and electroactive reduced graphene oxide-based composite fibrous scaffolds for engineering excitable nerve tissue," **Materials Science and Engineering C**, 119, 111632, (2021)
- **PHD thesis** "Lime-based construction materials: effects of novel additives on physical and chemical properties" University of Bath, Department of Architecture & Civil Engineering (2020)

Hybrid Nanomaterials

- "Toxicology assessment of manganese oxide nanomaterials with enhanced electrochemical properties using human in vitro models representing different exposure routes" **Sci Rep**, 12, 20991 (2022)

Graphinks™

Formulation:
- p52-57 of: "Production and processing of graphene and related materials," **2D Materials**, 7, 022001 (2020)

Graphink-101:
- 57-59 of: "Production and processing of graphene and related materials," **2D Materials**, 7, 022001 (2020)

Graphink-1021:
- "Microfluidization of Graphite and Formulation of Graphene-Based Conductive Inks," **ACS Nano**, 11, 2742-2755 (2017)
- p59-61 of: "Production and processing of graphene and related materials," **2D Materials**, 7, 022001 (2020)
- Application of our Graphink 1021 in RFID applications: "Screen-printed and spray coated graphene-based RFID transponders," **2D Materials**, 7, 015019 (2020)

CVD graphene

- "Vibrational fingerprints of residual polymer on transferred CVD-graphene," **Carbon**, 117 (2017)
- "Graphene-enabled electrodes for electrocardiogram monitoring," **Nanomaterials**, 6, 9, (2016)
- "Characterisation, coverage, and orientation of functionalised graphene using sum-frequency generation spectroscopy," **Phys. Chem. Chem. Phys.**, 20 (2018)
- "A versatile route to edge-specific modifications to pristine graphene by electrophilic aromatic substitution," **J Mater. Sci.**, 55 (2020)
- "Quantitative super-resolution microscopy to assess adhesion of neuronal cells on single-layer graphene substrates," **Membranes**, 11, 878 (2021)
- "Dynamic modulation of the fermi energy in suspended graphene backgated devices," **Science and Technology of Advanced Materials**, 20, 1 (2019)

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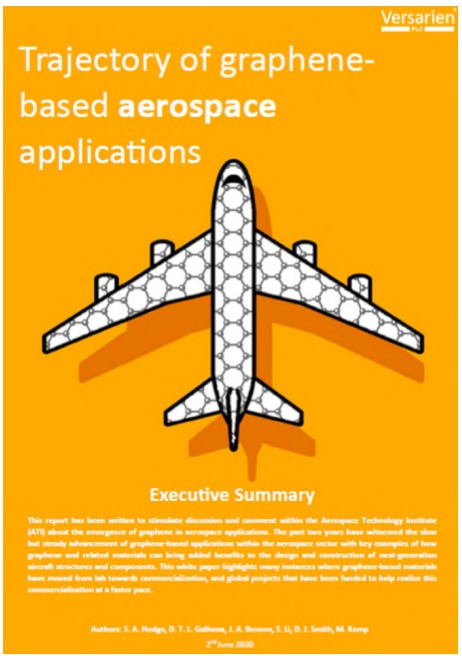

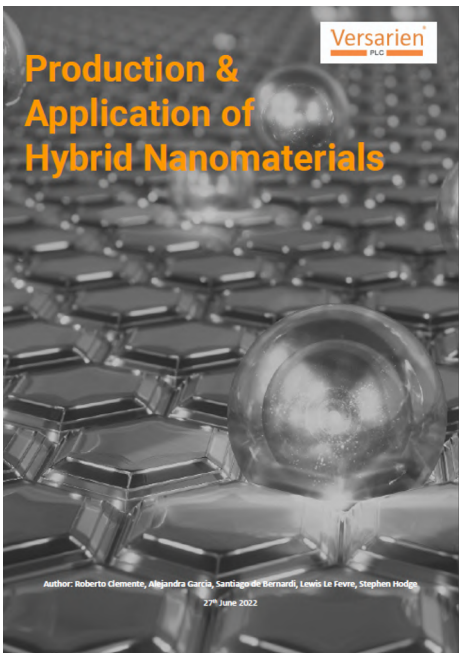

APPENDIX

Test Methods

CHARACTERISTIC	TEST METHOD	STANDARD(S) FOLLOWED	MEASURED QUANTITY or UNITS
sp^2 Bonded Carbon (graphene only)	Raman spectroscopy	ISO/TS 21356-1	Presence of graphene E2g mode (G Peak) ~1580 cm^{-1}
Presence of hBN (hBN only)	Raman spectroscopy	-	Presence of hBN E2g mode ~1366-1370 cm^{-1}
Presence of MoS_2 (MoS_2 only)	Raman spectroscopy	-	Presence of MoS_2 E2g and A1g mode ~380-405 cm^{-1}
Structural Defects (graphene only)	Raman spectroscopy	ISO/TS 21356-1	Intensity ratio of D and G peaks (I_D/I_G)
Number of Layers	Raman spectroscopy or TEM	ISO/TS 21356-1	D10, D50, D90
Z-Axis Dimensions	AFM	ISO/TS 21356-1	Apparent Thickness (nm) based on >20 measured particles
Primary Particle Shape	Microscopy methods (AFM, SEM, TEM)	-	Observation
Lateral Dimensions	SEM, TEM or AFM	ISO/TS 21356-1 / ISO 19749	D10, D50, D90 (µm) based on >200 measured particles
Aspect Ratio	TEM or AFM	-	Minimum and Maximum values based on >20 particles
Bulk Density	Mass measurements	ASTM D7481-18	g/cm^3
Chemical/Elemental Composition	XPS	ISO/PWI 23359	Atomic % composition (at.%)
Oxygen Content	XPS	ISO/PWI 23359	Atomic % composition (at.%)
Impurities at%	XPS	ISO/PWI 23359	Atomic % composition (at.%)
functionalisation (type and %w)	XPS and TGA	ISO/PWI 23359 / ASTM E1131-20	weight loss by TGA
Surface Particle Charge	Zeta potential measurements	ISO 9276-1 / ISO 9276-2	mV
Specific Surface Area (SSA)	BET	ISO/TS 21356-1	m^2/g
Crystallinity	XRD	ASTM-D5187-21	% of crystalline features
Viscosity	Parallel Plate Rheometer	-	Viscosity (cP) at RT
Surface Tension & Contact Angle	Goniometer	ISO 19403-2:2017	Surface contact angle
Sheet Resistance	4-Point Probe Method	-	Ω/□

Acronyms: Atomic force microscopy (AFM), transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), thermogravimetric analysis (TGA), Brunauer–Emmett–Teller (BET), X-ray diffraction (XRD)

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