Innovating at the Nanoscale

GENERAL GRAPHENE

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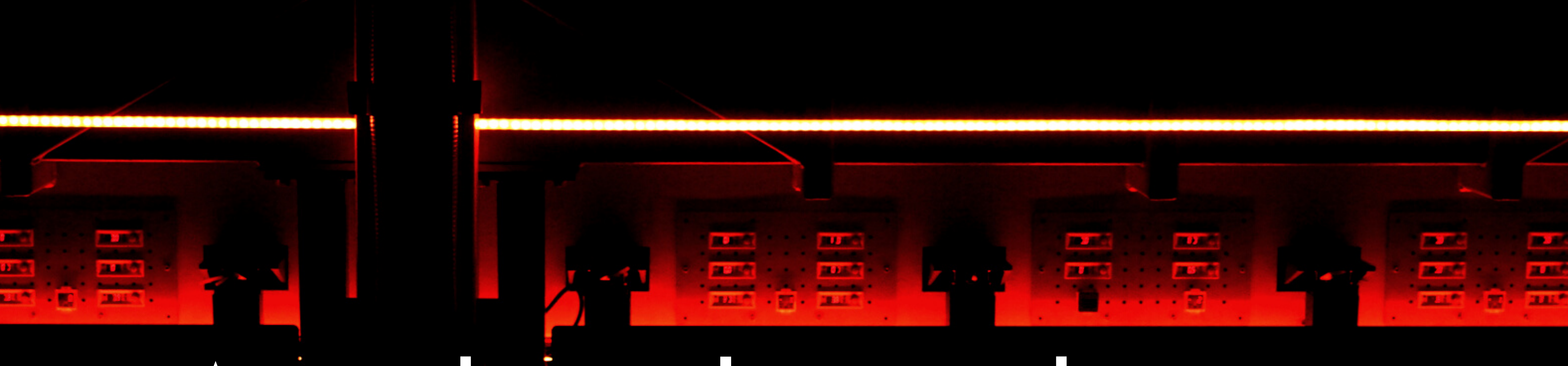
"Making graphene was a science problem.



We developed an *engineering* solution."

General Graphene is a world leader in the low-cost mass production of graphene films and uses a proprietary atmospheric pressure chemical vapor deposition (APCVD) process.

Founded in 2014, General Graphene has overcome the biggest barrier to graphene commercialization - scalable mass production.

Graphene in the real world

General Graphene started with a singular vision – to develop the technology which would allow large-area CVD graphene films to be:

- mass produced;
- in industrial volumes;
- at an affordable price.

Only once this vision was realised would graphene become a commercially viable material.

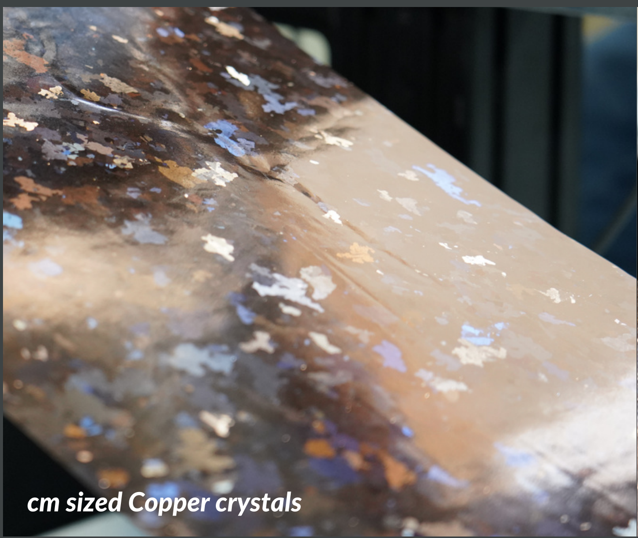
This was the motivation behind GG 3.0, our state-of-the-art CVD graphene film production system. GG 3.0 does precisely what we set out to do.

GG 3.0 is only the beginning. As we continue to optimize the graphene production and graphene transfer processes, we are confident that we can drive costs lower and our quality and quantities higher.

Innovating at the Nanoscale

Graphene – the wonder material

Ultra-thin (.345 nm)
Young's modulus of 1 Tpa - Flexible
Intrinsic tensile strength of 130 GPa (>200x stronger than steel)
Thermal conductivity > 3,000 WmK (graphite is 2,000 WmK)
Optical absorption of exactly πα≈2.3% (i.e., transparent)
Impermeable barrier to all gases
Room temperature electron mobility of 200,000cm2/V·s (silicon is 1,400 cm2/V·s)
Breakdown current density of 107 A/mm-2 (copper is 1,000 A/mm-2)
Biocompatible
Chemically inert
Grown typically on copper or nickel and then transferred onto various substrates


cm sized Copper crystals


mm sized Copper crystals

GG 3.0 – Pioneering industrial-scale graphene growth

Our latest CVD graphene film production line – named GG 3.0 – is an iterative edition of our proprietary atmospheric pressure roll-to-roll chemical vapor deposition system. Currently, it is the only system in the world capable of synthesizing industrial scale volumes of CVD graphene films at a low cost and consistent quality.

Roll to roll production

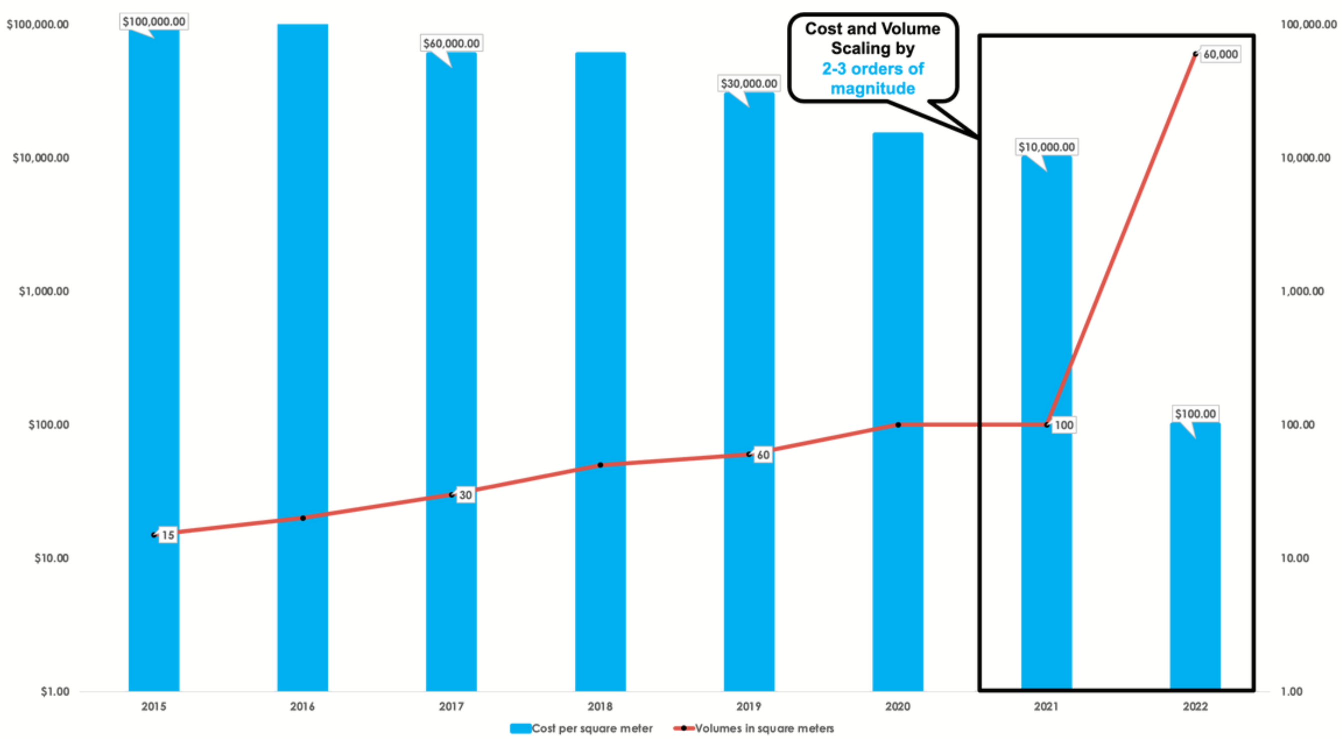
Modular furnace design

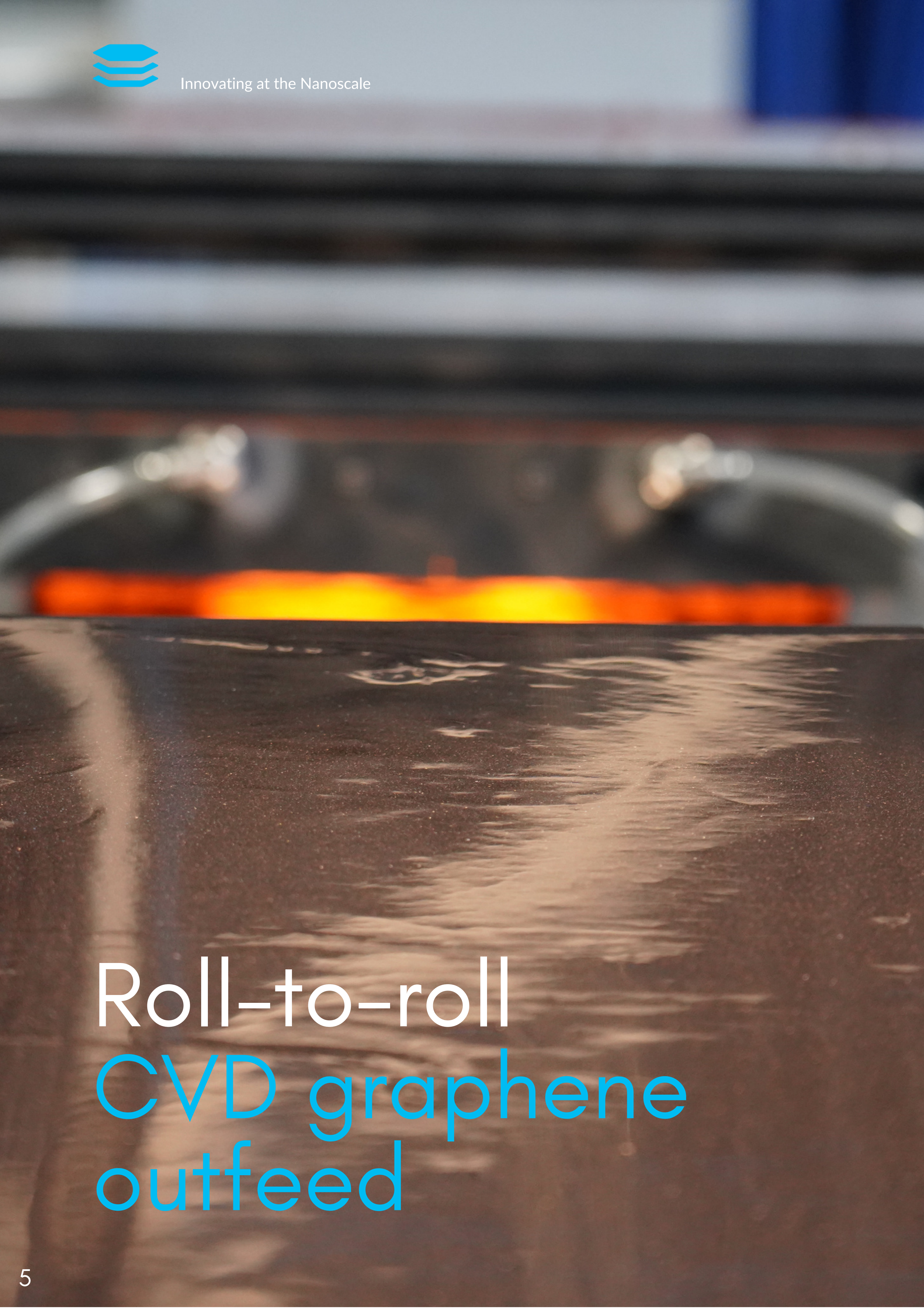
Scalable production

Consistent and reproducible quality

100,000 m2/yr
High capacity

Tailor properties to fit applications





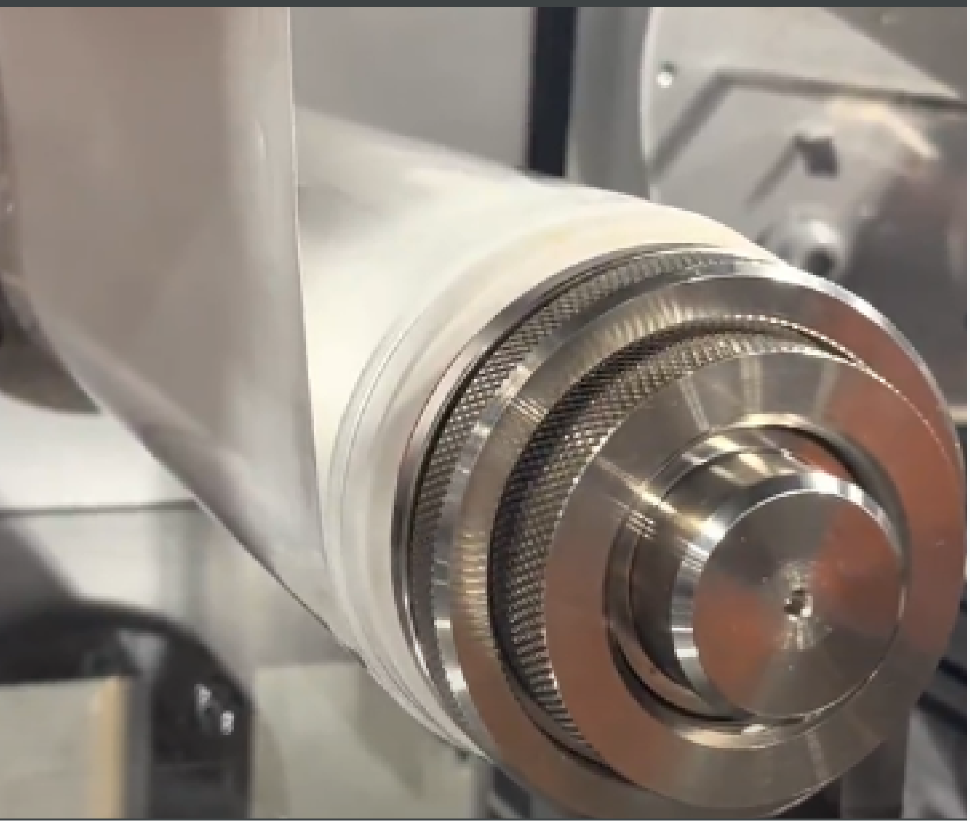
Roll-to-roll CVD graphene outfeed

Optimising graphene transfer

CVD graphene is grown on a catalytic metal substrate. After the growth process, the graphene is typically transferred onto a target substrate.

Graphene transfer is a complicated process that requires specialised methods. General Graphene has developed several graphene transfer techniques to facilitate both batch and roll-to-roll graphene transfer and applies the transfer method most suitable to the application.

Human beings were never meant to handle nanoscale materials, as they are too delicate to withstand the stresses induced during a manual transfer process. If damaged during the transfer process, the graphene often fails to perform as expected. Yet, manual transfer remains the industry standard.



General Graphene has developed prototypes that
automate the transfer of graphene to a wide array of substrates.

Ultimately, we believe the industry's requirements for graphene will be a function of two factors:

1) Does it meet the performance requirements of the application? And

2) Is it priced appropriately to be used in the application?

Automated graphene transfer is critical to achieving both and has long represented a core focus of the company.

Graphene on PVA generated by roll-to-roll transfer

Innovating at the Nanoscale

Bring on the heat

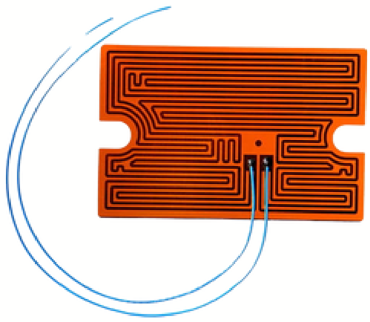
General Graphene is developing CVD graphene films for use in ultra-thin, lightweight (virtually weightless) and flexible heating solutions.

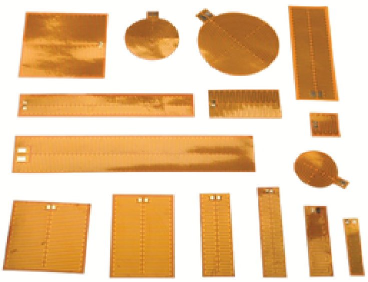
There are many thin lightweight and flexible heating solutions available on the market today that are used in a variety of applications such as seat warmers and heating pads, protection from freezing of outdoor devices, condensation prevention, battery heating, and many more.

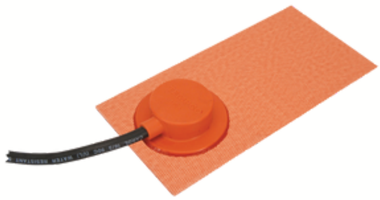
However, existing thin and flexible heating solutions are neither light enough nor thin enough to keep up with the shrinking size of electronics, components, and appliances. To maintain power and energy efficiency, it is essential for electronics and appliances to make lightweight products a strategic product initiative.

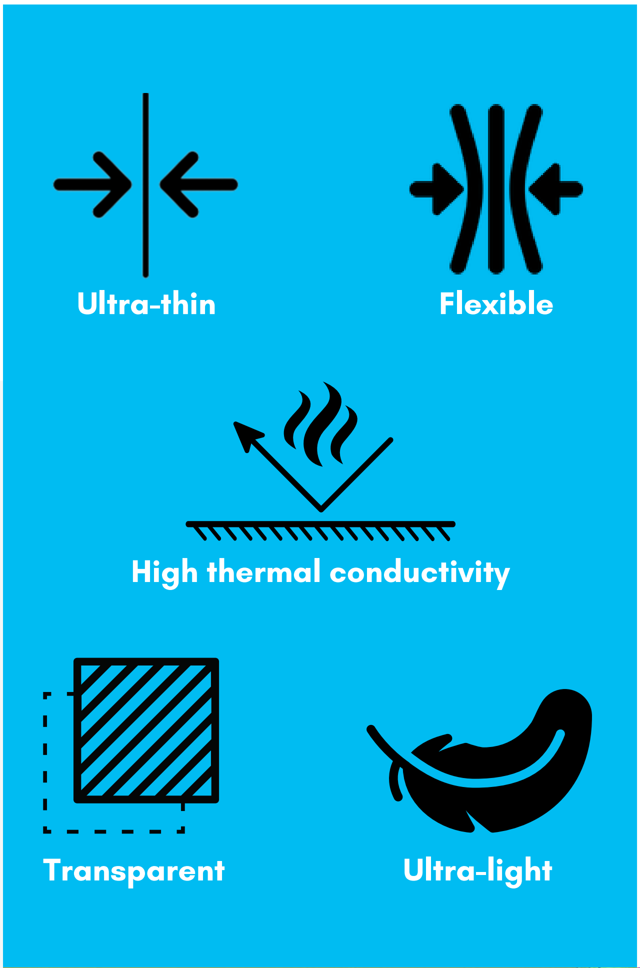
We are exploring the use of CVD graphene in a variety of heating solutions – each tailored for very specific end industries and applications. We plan to collaborate with the companies currently manufacturing thin film flexible heaters to deliver improved, graphene-enabled heating solutions.

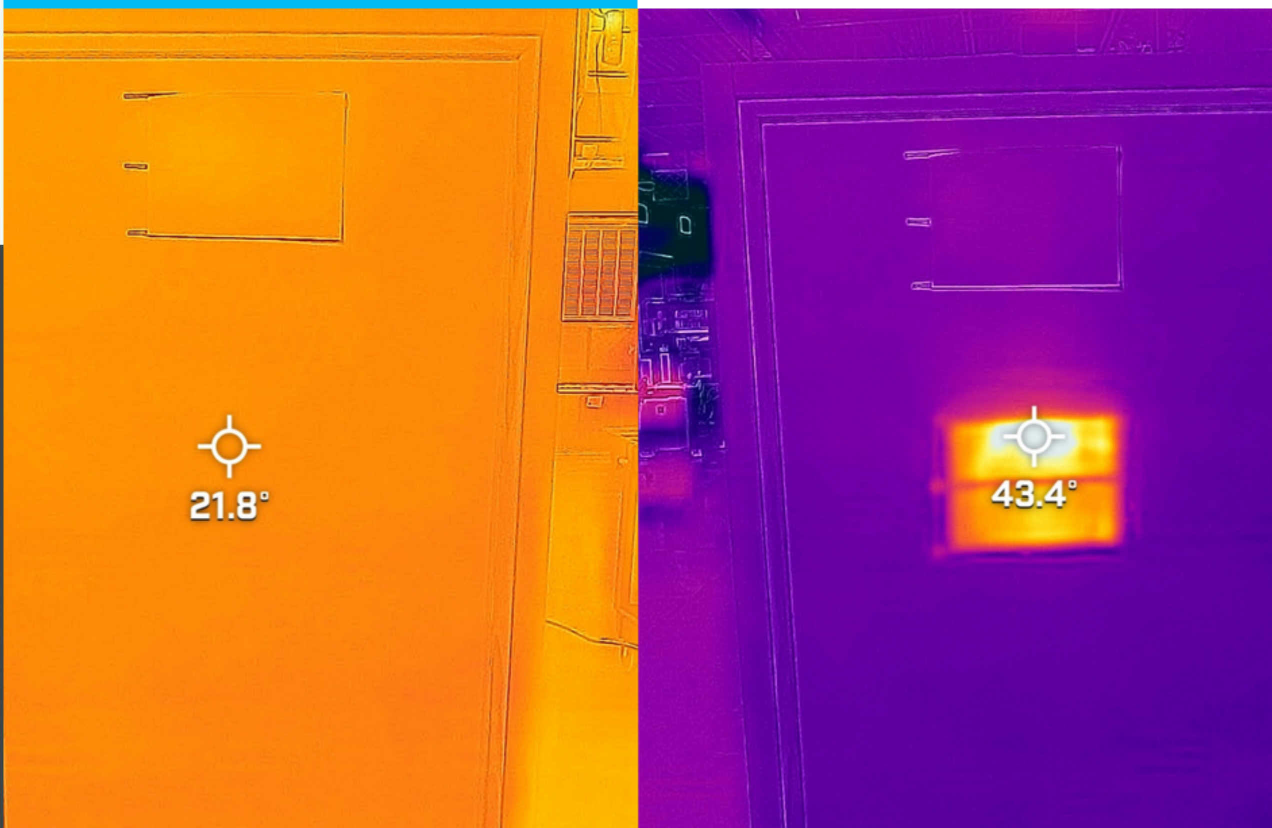
Current thin flexible heating solutions











The top-right image is a front-on visual representation to show how the graphene is placed on the back of our prototype dry wall heater. The thermal scans - taken about five minutes apart - show a temperature rise > 20°C.

Innovating at the Nanoscale

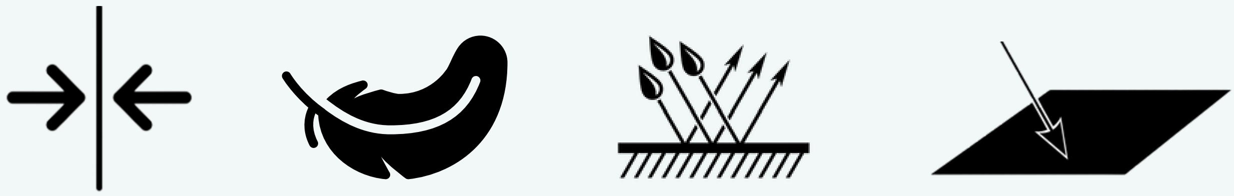
Tackling electromagnetic interference

Ever wonder why you are asked to switch off electronics or keep them on airplane mode on a flight? The answer is that when in airplane mode, the features of your device that require a transmission signal are disabled.

The perceived need to do this reflects the airline industry's concerns regarding the effectiveness of the plane's electromagnetic interference (EMI) shielding.

Electronics can interfere with the communications and navigation equipment of the airplane. EMI shielding protection allows planes to maintain the integrity and performance of their onboard electronics.

Most EMI shielding solutions are metal, and while they generally work well, they are relatively heavy and are sometimes difficult to conform to the shape of smaller, odd shaped electronics, making them vulnerable to EMI pollution.



Ultra-thin | **Ultra-light** | **Corrosion barrier** | **High EMI absorbtion**

We fabricated an ultra-thin (~100 nm) lightweight (~6 mg) graphene EMI shield with a shielding effectiveness (SE) of 90 dB over the K-Band frequency range. This SE meets or exceeds the EMI shielding performance of alternative materials.

Graphene is also a great fit for EMI shielding in smaller electronics and components as it takes up less space due to its thinness and low weight.

Graphene may also help lower the overall cost of EMI shielding by lowering compliance and performance testing expenses.

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Diagnostics of the Future

Graphene field effect transistors can change the landscape of sensing and diagnostics globally.

Because of graphene's high conductivity, ultra-sensitive rapid detection is viable and highly accurate instantaneous measurements are possible, even in the presence of small amounts of analytes.

Currently, the primary sensing products that we are working on are graphene biosensors.
The technology behind graphene biosensors allows for the simultaneous detection of multiple analytes. This could pave the way for multi-parameter diagnostic test kits that can securely provide results on your mobile device using NFC technology.

Such technology is critical in a world where new chronic diseases keep emerging and there is a need to maintain public health measures in order to return to pre-pandemic normalcy.

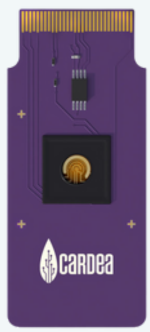
With several partners in this field, General Graphene aims to deliver a multitude of targeted biosensing graphene products that offer significant benefits over traditional technology at a cost of only a few dollars.

Flexible

Bio-compatible

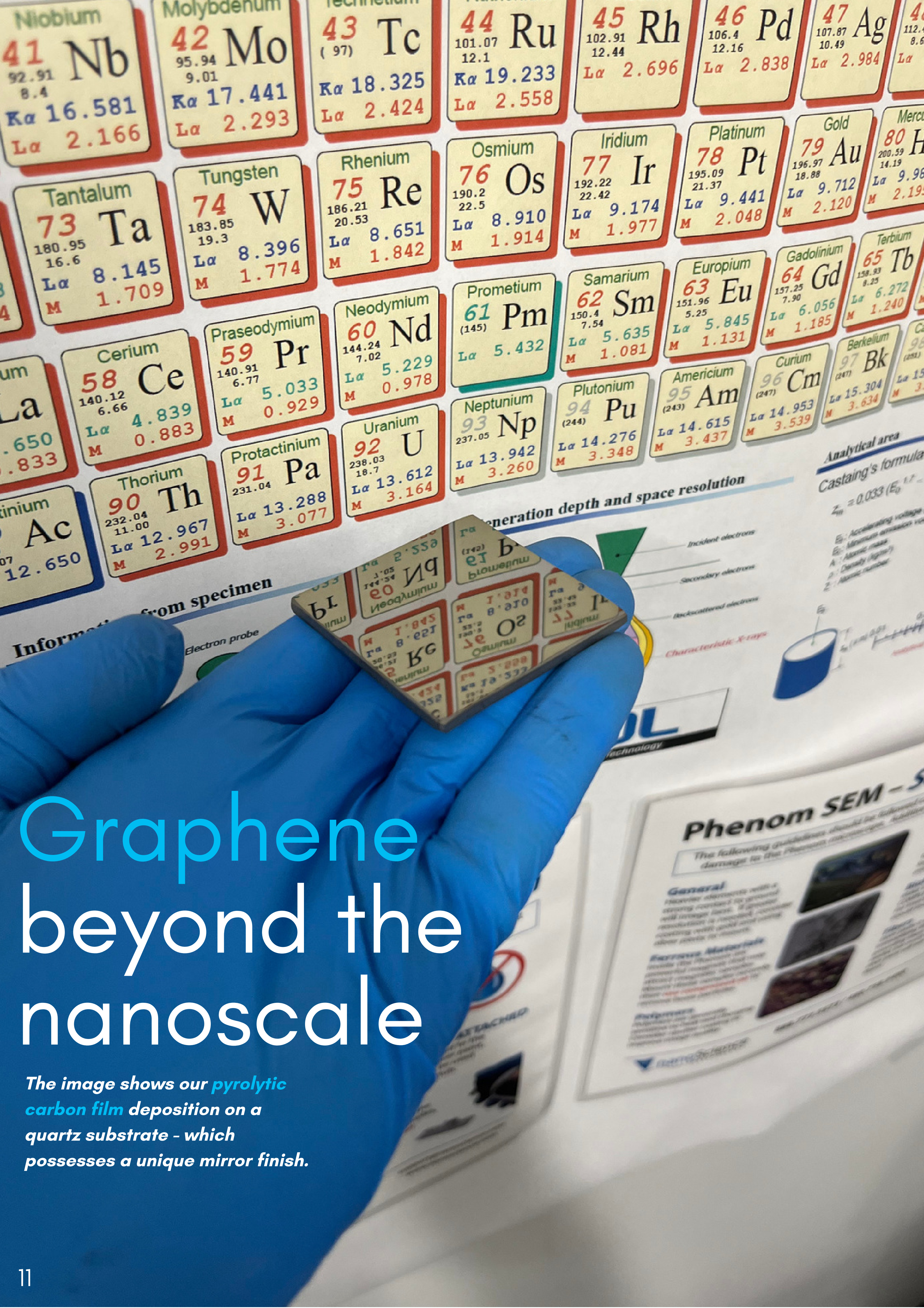
Multi-parameter detection

Non-invasive



Wearable electronics

- **Real-time high measurement sensitivity**
- **Accurate remote health monitoring**
- **Lower healthcare cost**
- **Comfort for user**



Graphene beyond the nanoscale

The image shows our pyrolytic carbon film deposition on a quartz substrate - which possesses a unique mirror finish.

Bio-compatible

Uniform isotropic heat distribution

High temperature stability

Autoclave compatible

Opaque

50 nm to 5 µm thick

Resistance as low as 5 Ω/sq

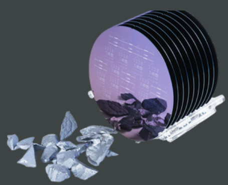
Pyrolytic carbon films

At the nanoscale, carbon exists in the form of graphene and nanotubes. At the microscale, carbon can also be composed of structures that do not have a clear crystal structure – these are known as amorphous carbon materials.

Our proprietary atmospheric pressure chemical vapor deposition (APCVD) process enables the growth of graphene as well as graphene-related carbon materials on a variety of substrates at both the nano and microscale.

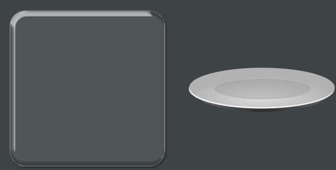
We discovered that, at the microscale, the resulting carbon growth is closer to a pyrolytic carbon film deposition with thickness ranging from approximately 50 nm to 5µm.

Compatible Direct Growth Substrates



Silicon

Quartz

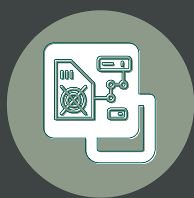


Ceramics

Applications

X-Ray Detection Window

Heating Element



Heat Spreader

Capabilities

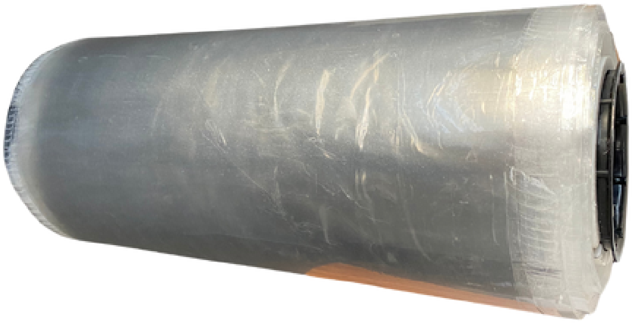
Monolayer graphene grown on copper using General Graphene's specialized roll-to-roll equipment.

Popular for large-scale applications in energy storage.

Roll-to-Roll CVD Graphene on Copper

Monolayer graphene grown on copper and transferred to polymer using General Graphene's specialized roll-to-roll equipment.

Popular for large-scale applications like biosensors and conductive coatings.



Roll-to-Roll CVD Graphene on Polymer

Graphene allows heating capabilities with virtually no added weight.

Its low resistance enables appropriate power consumption requirements to be met at lower voltages.

Popular for window and wall heater applications.

Graphene Wall Heater Panel

Provides resistance against corrosion while retaining strong conductivity.

Graphene-coated Pins

Capabilities

Monolayer Graphene on Silicon

Grown on copper and transferred to silicon wafer.

Popular for characterization, sensor, and microelectronic applications.

Monolayer Single Crystal Graphene on PET

Grown on single-crystal copper and transferred to PET.

Popular for sensor applications.

Monolayer Graphene on Polyimide

Monolayer graphene grown on copper and transferred to polyimide.

Popular for sensor applications needing high chemical and thermal stability.

Graphene on Cardboard

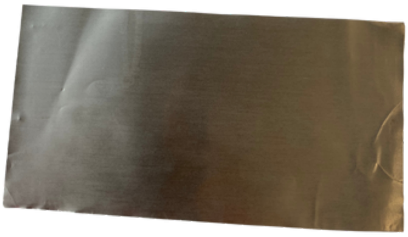
Acts as a moisture barrier for food protection due to its biocompatibility, weightlessness, and flexibility.

Used as a sustainable food packaging solution.

Capabilities

Carbon's solubility enables the growth of multilayer graphene on nickel.

Popular for EMI shielding applications.



Multilayer Graphene on Nickel

Presents a mirror like finish and a low resistance.

Popular as a heating element.

Pyrolytic carbon on Quartz

The low solubility of carbon in copper enables the growth of monolayer graphene.

Popular for biosensor applications.

Monolayer Polycrystal Graphene on Copper

Monolayer graphene grown on single-crystal induced copper. Creates graphene with lower defects and reduced grain boundaries.

Popular for corrosion resistance and biosensor applications.

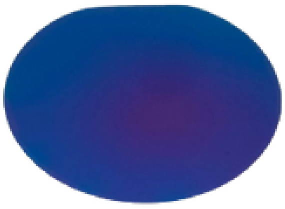
Monolayer Single Crystal Graphene on Copper

Capabilities

Multilayer Graphene on Glass

Grown on nickel and transferred to glass.

Popular for EMI shielding and heater applications.



Multilayer Graphene on Silicon

Grown on nickel and transferred to silicon wafer.

Popular for characterization and thermal management applications.

Multilayer Graphene on PET

Grown on nickel and transferred to PET.

Popular for EMI shielding and heating applications.

Multilayer Graphene on PE

Grown on nickel and transferred to PE.

Popular for food packaging moisture barrier films and EMI shielding applications.

Multilayer Graphene on Nickel Foam

Grown conformally on nickel foam.

Popular for EMI shielding applications.

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