CVD Materials Corporation

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Material Platform for the Manufacturing of Multifunctional Graphene Sheets

a subsidiary of CVD Equipment Corporation

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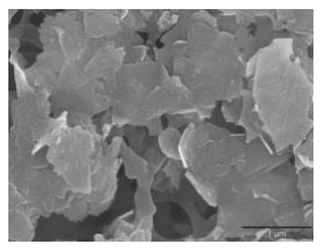
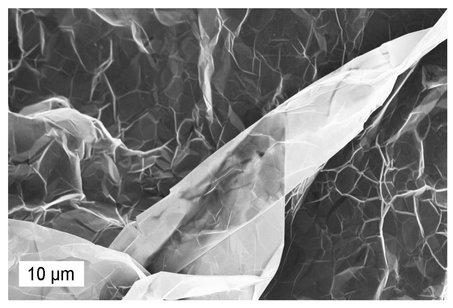
Background / Motivation

The unique PROPERTIES of GRAPHENE ENABLE PRODUCT INNOVATIONS in many fields which can benefit from NANOTECHNOLOGY: capacitors, batteries, flexible electronics, composites, filtrations, sensors, etc.





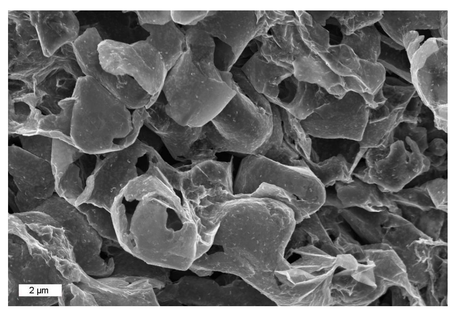
Graphene is a high aspect ratio nanocarbon material *(> 5000:1 possible)*

Cost-efficient, volume scalable graphene production processes lead to *graphene powders* with a high surface area of *> 300 m^2/g* with average graphene sheet diameters of *< 2 µm.*

Many lower cost, higher surface area graphene and/or *graphene nano platelets* production processes create individual graphene sheet sizes in the *50-100 nm* range with multiple layers of graphene: therefore they have *somewhat degraded properties.*

Some graphene production processes produce substantially flat *2D forms* while others produce graphene sheets with a high degree of 3 dimensionality to it (crinkles, eggshell, and other kinds of *3D structures*)

Each unique graphene manufacturing processes that is being explored today for low-cost, volume scale-up produces typically *a unique "flavor" and form of partially functionalized graphene sheets*: this makes each process unique in its output.



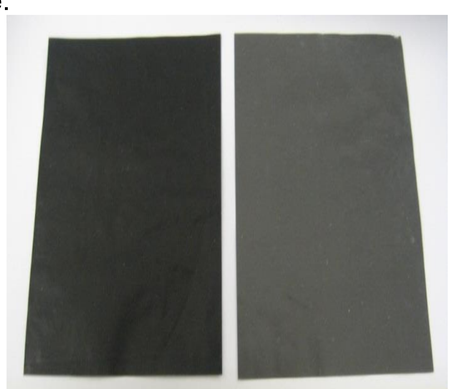
Each innovative end-product that is enabled by the incorporation of a graphene material requires optimization of the graphene manufacturing process to be able to provide the most cost-efficient value proposition for a given application.

Therefore, the value proposition for a given graphene manufacturing process can be significantly improved, if its resulting graphene powder can be transformed with one or more subsequent manufacturing process into different structural and/or chemical formats, each customized for a given target application.

Nano*to*Macro™ *transformation process of graphene powders*

Our patent pending, **Nano*to*Macro™** process is able to transform any size and shape of 2D or 3D graphene powder into self-supported, mechanically strong, flexible, porous sheets without the use of polymer additives. We also provide **Nano*to*Macro™** process compatible, gas phase and/or liquid based functionalization process steps for both the graphene powders and/or the **Nano*to*Macro™** produced sheets. Most material properties are thus tunable.

+ Pre-functionalization + Nano*to*Macro™ + Post-functionalization =

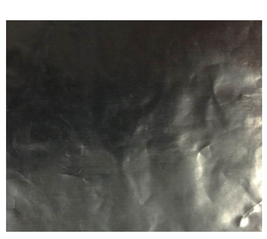


one or more graphene powders	optional gas/liquid *pre-functionalization*	Nano to Macro transformation	optional gas/liquid *post-functionalization*	various types of self-supported, mechanically strong, flexible, porous graphene sheets

common equipment/processes usable for different graphene materials

Multifunctional Graphene Sheets

Our patent pending, **Nano*to*Macro™** process can be used to create/tune from different raw graphene materials novel, **self-supported, graphene sheet materials,** with multifunctional, nano-enabled properties that are optimized for different end-use applications.



flexible **EMI shielding**
@ ½ Al weight
> 400 °C
>70dB @ 8-12GHz

ultrablack, flexible, self-supported **graphene sheets for optics/spectroscopy application**

TIM, thermal heat spreader, better than Al
ρ > 1.6 g/cm^3

porous graphene electrode for **ultracapacitor**
> 60 F/g

porous graphene electrode for **capacitative desalination**

graphene sheet for **carbon-carbon composite applications**

OPTIMIZABLE

- **Thickness**
- **Surface density**
- **Volume density**
- **Electrical conductivity**
- **Thermal conductivity**
- **Chemical functional.**
- **Surface area**
- **Capacitance**
- **High temperature**
- **UV-FIR absorption**
- **Shock absorption**
- **Mechanical strength**
- **Hydrophobic/hydrophilic behavior**
- **Fire retardant**
- **Etc.**

Future Work

- Scaling up process for large size sheets and lower production costs
- Increasing the breath of property ranges achievable with this generic processing solution
- Developing stand alone equipment/processing solutions that can be sold to graphene producers

References:

[1] W. Wei, X.Qu, *Small* **8** (2012), 2138-2151.
[2] Z.Sun , D. K. James , J. M. Tour, *J. Phys. Chem. Lett.* **2** (2011), 2425-2432.
[3] K. Strobl, M. Monville, S. Banerjee, S. Chang, Graphene 2012, Brussels.