3D Continuous CVD Graphene: a New Class of Materials

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GRAPHENE is an IDEAL 2D MATERIAL

Record material properties:
- Electrical Conductivity
- Mobility
- Mechanical Strength

Potential applications in:
- RF Electronics, Energy Conversion and Storage, Biotechnology, NEMS, Filtration, Membranes, Chemical Sensors, Polymer Nanocomposites, etc.

How to take advantage of the exceptional 2D material properties in a 3D World?

The challenge is to create 3D macroscopic materials that preserve some of these record material properties

GRAPHENE: 2D ⇒ 3D

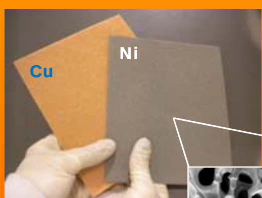
Traditional Solution: the chemical coupling agent route
- *Already studied in the scientific community with nanocomposite structures based on nanocarbons*
- Used to create 3D hybrid architectures based on chemically derived graphene materials[2]

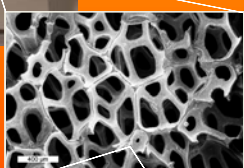
Fundamental problem:
Composite networks based on graphene flakes or nanocarbon materials have limited electrical, thermal and mechanical properties because of:
- Transition problems between the basic building blocks
- Structural defects within the basic building blocks

New Solution: Direct production of 3D continuous graphene-based structures by catalyst template CVD growth method

Creation of so-called "graphene-foam" with high surface area (850 m^2/g), high porosity, mechanical interconnectivity and good electrical conductivity (10 S/cm) has been previously reported[1,3].

STARTING MATERIAL:
Ni or Cu CATALYST TEMPLATE in ANY 3D FORMAT

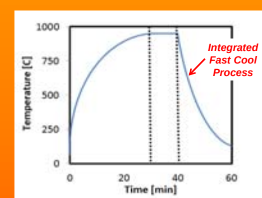




3D CVD GRAPHENE FILM GROWTH:
Standard CVDGraphene™ film growth process

EasyTube™ 3000

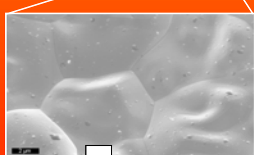
Three-Zone Furnace



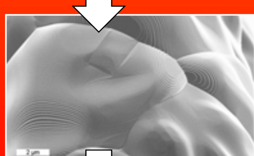
Temperature conditions during run: fast growth, fast cooling mode

Adding a 1000 °C CVD graphene growth step to the standard sintering/annealing step in the Ni foam manufacturing process is relatively straightforward and economical using classic carbon precursors (*methane[1], ethanol[3], etc.*)

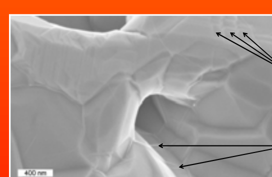
BEFORE CVD graphene film growth



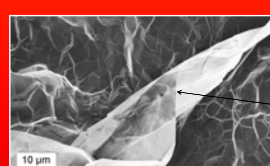
AFTER CVD graphene film growth



AFTER Ni Foam template removal

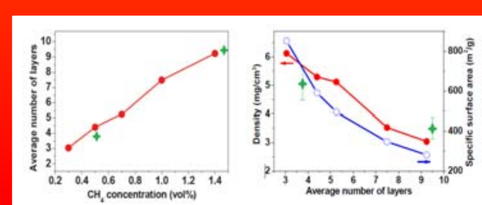


conformal and uniform coating of CVD graphene on Ni template



few (n~9) graphene layer stacking

Graphene coating revealed by color change



Two types of graphene foams were produced from CH_4 (green crosses on graphs), with properties in agreement with previous work by Chen et al.[1]

CONCLUSIONS

Previous pioneering work[1] inspired us to apply CVD to a range of 3D catalyst structures in order to test the manufacturability of a variety of 3D continuous graphene-based material structures and to investigate their commercial scale-up and product integration challenges.

Nickel metallic foam is an ideal catalyst material for 3D CVD graphene because it is commercially available in large volume (NiMH battery electrodes production) in different thickness, densities and pore sizes and tuning of the CVD process allows the manufacturing of graphene-like materials having 3-10 atomic carbon layers.

- ***Control of the porous structure of 3D graphene is primarily achieved by selecting the appropriate catalyst template among the wide range of commercially available Ni and Cu 3D material formats***
- ***Control of the wall thickness of the 3D graphene network is achieved by selecting the CVD process conditions.***

Derivative 3D CVD graphene materials can then be made through additional processing:

- Integration in polymer matrix for making conductive polymers,
- Nanometer thick addition of polymer skins for mechanical stiffness tuning
- Additional graphene surface functionalization with ALD, LPCVD, electrodeposition, chemical grafting, etc.
- Free standing, ultra-light, 3D CVD graphene-like structures with polymer skin - once the supporting catalyst material is removed, etc.

New, ultra-light, high surface area, electrically and mechanically continuously connected 3D material platform that could lead to new sensors[4], ultra-light materials, novel composite materials[1], ultra capacitor electrodes[3], etc.

REFERENCES

1. Chen Z., Ren W., Gao L., Liu B., Pei S., Cheng H-M., *Nature Materials* **10** (2011), 424-428.
2. Potts J., Dreyer D.R., Bielawski C.W., Ruoff R.S., *Polymer* **52** (2011), 5-25.
3. Cao X., Shi Y., Lu G., Huang X., Yan Q., Zhang Q., Zhang H., *Small* **7** (2011), 3163-3168.
4. Yavari F., Chen Z., Abhay V.T., Ren W., Cheng H-M., Koratkar N., *Scientific Reports* **1** (2011), Art.166.