Metrology Solutions for 2-D Nanomaterials

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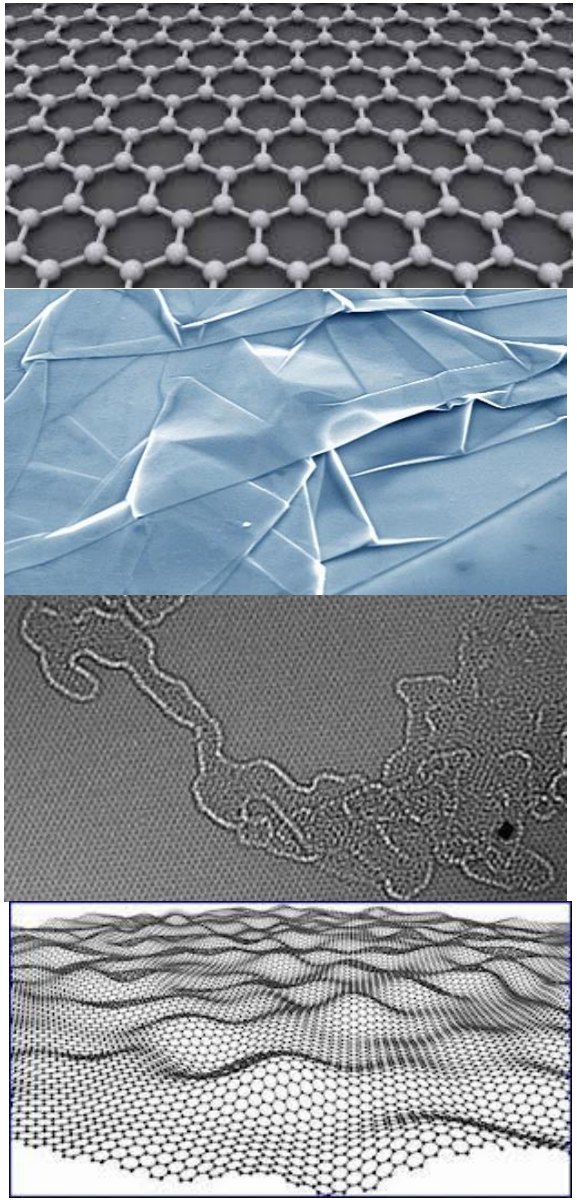
17 October 2013

National Physical Laboratory

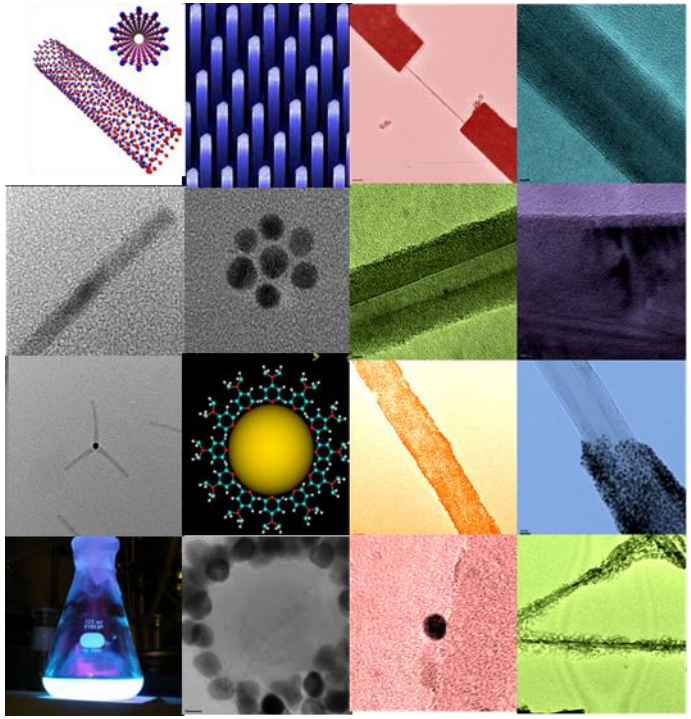
OUTLINE

- NANOTECHNOLOGY
- 2D NANOMATERIALS
  - GRAPHENE
  - HEXAGONAL BORON NITRIDE
  - ALTERNATIVE 2D NANOSHEETS
- POTENTIAL CHALLENGES
- CHEMICAL FUNCTIONALIZED GRAPHENE
- GRAPHENE PROGRAM AT NPL
- SUMMARY



Nanotechnology

- **Nanotechnology:** Technology involving benefits or attributes specifically assigned to the use or inclusion of materials which have one or more of their dimensions less than 100 nm.
  - Synthesis of nanomaterials
  - Application by assembly, processing, and integration of materials and structures
  - Result: Stronger, more conductive, lighter, brighter, thermally conductive, smaller, faster, cheaper
  - Bottom line. Financial, environmental, medical, societal, and scientific benefits resulting from nanotechnology
  - **NANOMATERIALS**



1D NANOMATERIALS
- NANOTUBES:
- NANOWIRES:

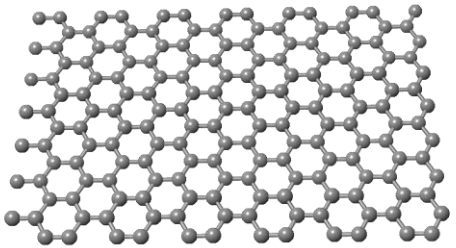
- High aspect ratio
- Highly conductive
- Highly insulating
- Semi-conductive
- Super conductive
- UV-lasing
- Thermally conductive
- High strength

3D NANOMATERIALS
- NANOPARTICLES
- NANORODS
- QUANTUM DOTS
- DNA ASSEMBLIES
- TETRAPODS
- PEPTIDE FIBRES
- MX2 ONIONS
- C_{60}

- Size tuneable plasmonic λ
- Conductive
- Semi-conductive
- Insulating
- Fluorescent
- Catalytic
- Biocompatible
- Anti-oxidative

2D NANOMATERIALS
- GRAPHENE……

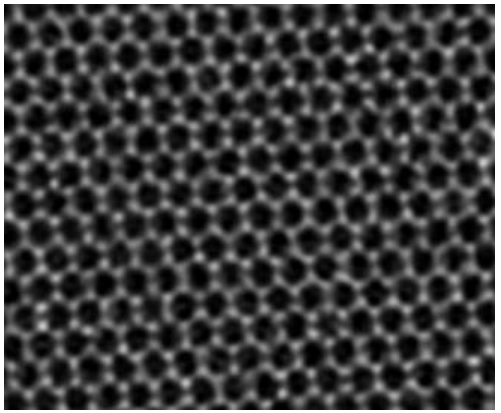
Graphene



- **PROPERTIES**

- Conductive (mobility:200,000 $cm^2v^{-1}s^{-1}$)
- Young's modulus: ~1 TPa
- Low density (2.3 gcm^{-3})
- Thermal conductivity (~5000 $Wm^{-1}K^{-1}$)
- Optical transmittance : 97.7%
- Chemical substrate

Chemically stability (<400 ^oC)
Surface area: 2630 m^2g^{-1}
Non-polar bonds (χ= 0)
Planar structure (sp^2)
Crystalline

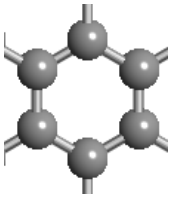


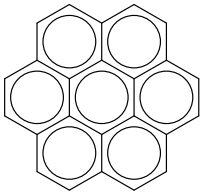
- **ENVISAGED APPLICATIONS**

- Thermal management
- Composite materials
- Batteries/supercapacitors
- Filtration/absorbents
- Optoelectronics
- Lightning strike

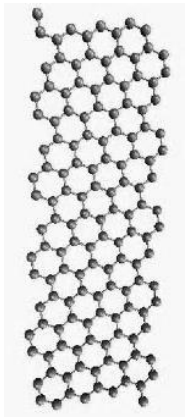
Metrology standards (Ω)
Electronic (sub/super)
Sensing and Diagnostics
Conductive Inks
microwave coatings
Catalysis

GRAPHENE BASIC UNIT





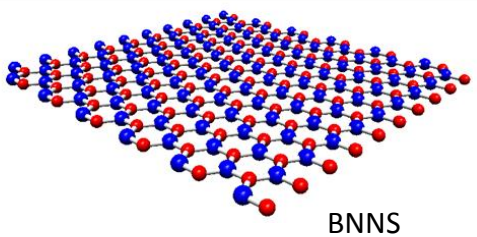
CHEMICAL REPRESENTATION



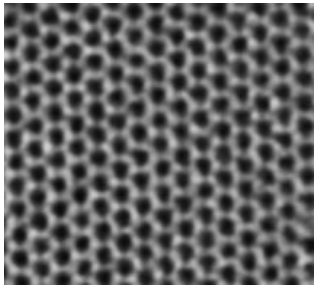
GRAPHENE NANORIBBON (GNR)

Hexagonal-Boron Nitride (h-BN)

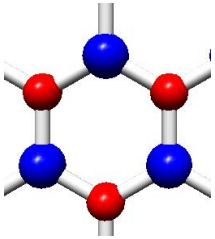
- **PROPERTIES**
  - Insulator (Eg ~5.5 eV)
  - Mechanically robust (E^{2d} = 270 Nm^{-1})
  - Low density (2.3 gcm^{-3})
  - Thermal conductivity (0.3 $W.cm^{-2}.{}^{o}C^{-1}$)
  - Macroscopic colour
  - Chemically stability (0-850 ^{o}C)
  - Large surface area
  - Heteropolar bonds (χ= 1)
  - Planar structure (sp^2)
  - Crystalline



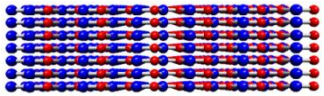
BNNS



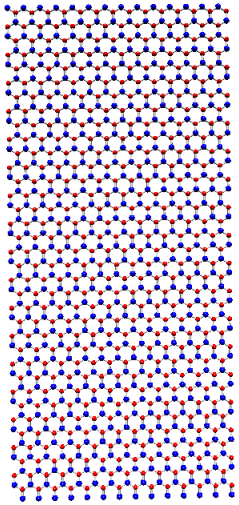
- **ENVISAGED APPLICATIONS**
  - Thermal management
  - Composite materials
  - Storage/ Fuel Cell
  - Optoelectronics
  - Radiation Shielding
  - Electronic (sub/super)
  - Sensing and Diagnostics
  - Catalysis



B-N BASIC UNIT



h-BN BULK PHASE



BN NANORIBBON (BNNR)

- **CHALLENGES TO UTILIZATION:**

  exfoliation, compatibilization, large-area synthesis

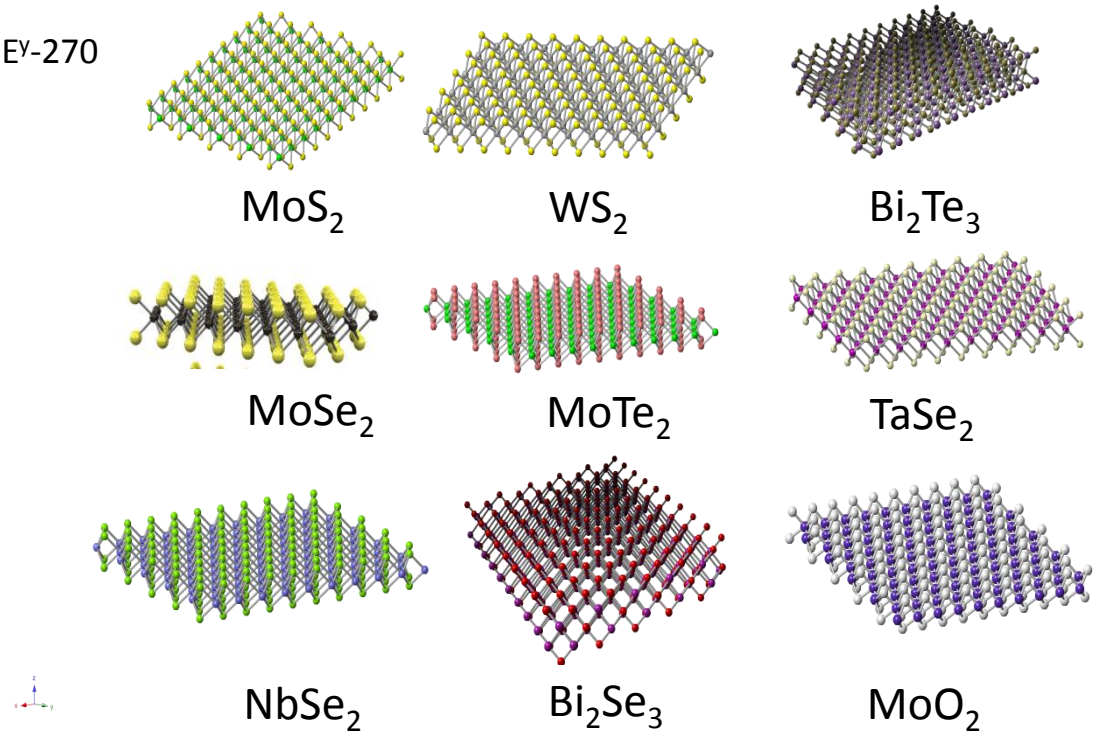
2-D NANOMATERIALS :ALTERNATIVE 2D NANOSHEETS

RANGE OF MATERIAL PROPERTIES

Electrical band gap 0-6 eV
Optical absorption
Thermoelectric (Bi_2Te_3)
Topological insulator (Bi_2Te_3)
Range of mechanical properties (MoS_2 E^y-270 GPa)
Range of thermal properties

APPLICATION OF 2-D NANOMATERIALS

Catalysis
Lubricant additives
Nanoelectronics
Sensors
Nanocomposites
Batteries
Supercapacitors,
Hydrogen storage
Environmental science
Metrology standards
Thermal management
Barriers/membranes
Dielectrics

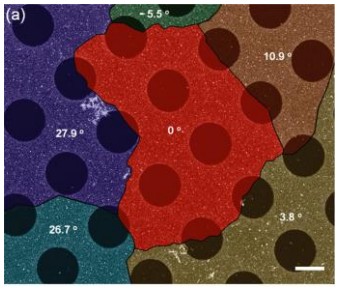


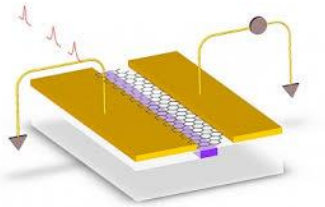
GRAPHENE

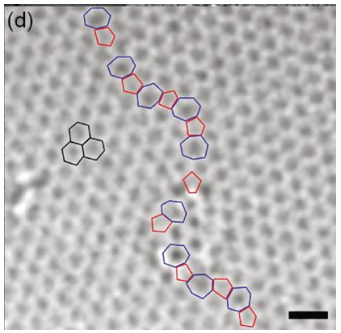
POTENTIAL CHALLENGES TO SUCCESSFUL UTILIZATION

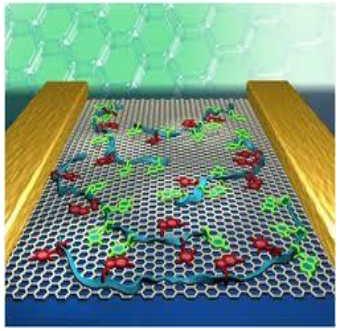
CHALLENGES FOR COMMERCIAL VENTURES

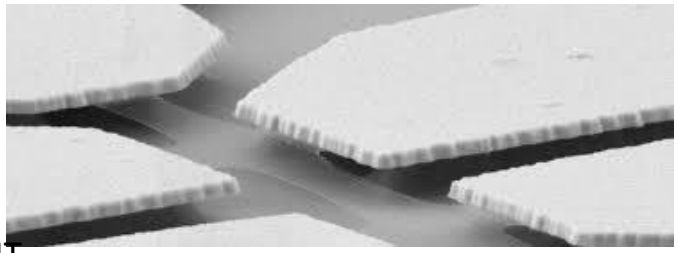
- WIDE-AREA HIGH QUALITY SYNTHESIS
- EFFICIENT EXFOLIATED MATERIAL
- GRAIN BOUNDARIES/DEFECTS
- AGGREGATION
- CHEMICAL INTEGRATION
- ELECTRONIC INTEGRATION
- BAND GAP
- SENSITIVITY TO SUBSTRATES, DOPANTS AND ENVIRONMENT
- SCALE UP OF GRAPHENE-ANALOGUE CHEMICAL PLATFORMS











http://graphene.icfo.eu/

Appl. Phys. Lett. **97**, 083107 (2010);

ACS Nano **5** (3), 2142-46 (2011)

GRAPHENE

POTENTIAL CHALLENGES TO SUCCESSFUL UTILIZATION

ATTRACTIVE INTRINSIC PROPERTIES THEORETICAL AND DEMONSTRATED NANOSCALE/QUANTUM PHENOMENA

COMMERCIAL APPLICATION ACTUAL REAL-WORLD MACROSCOPIC PRODUCTS BENEFITS FINANCIAL SOCIETAL SCIENTIFIC

Is it graphene?

Is it safe?

Is it monolayer?

Will it stay graphene?

Is it dispersed?

Is it chemically pure?

What size is it?

How conductive?

How robust is it?

Concentration?

Contact resistance?

Mobility?

Sheet resistance?

XPS?

HRTEM?

SEM?

Raman spectrum?

Chemistry?

EM Diffraction?

Sheet stats?

Cost to synthesize?

Can it be scaled?

Supply chain?

Who are the suppliers?

FDA approval?

Processing costs?

Who knows the answers?

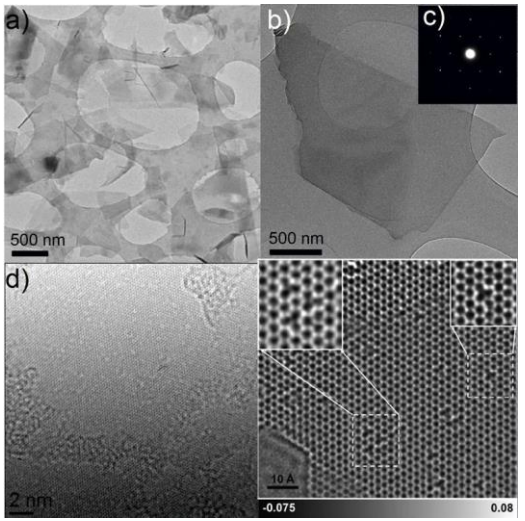
GRAPHENE

POTENTIAL CHALLENGES TO SUCCESSFUL UTILIZATION

NEED

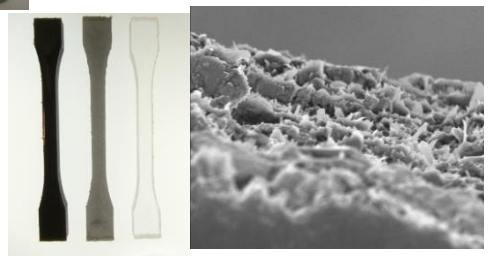
- STANDARDS AND DEFINITIONS
- CHEMICAL INTEGRATION STRATEGIES
- ELECTRONIC INTEGRATION STRATEGIES
- METROLOGY FOR 2-D NANOSHEETS
  - CHEMICAL FUNCTIONALIZATION
  - DISPERSION AND INTEGRATION
  - COMPOSITE CHARACTERIZATION
    - MATRIX INTERFACE
    - MECHANICAL
    - ELECTRONIC
    - THERMAL
    - CHEMICAL

FUNDAMENTAL CHARACTERIZATION

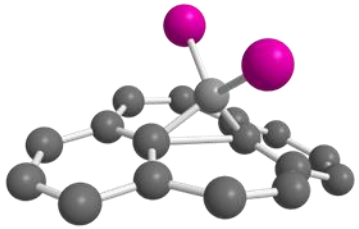


PROCESSING AND INTEGRATION

APPLICATION ANALYSIS

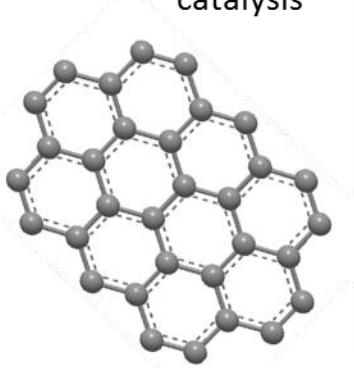


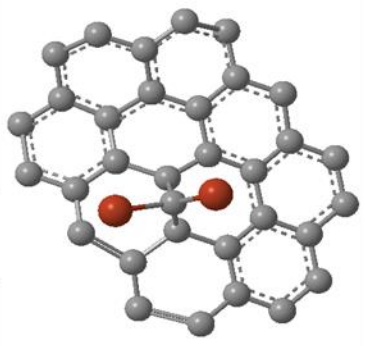
2D NANOMATERIALS

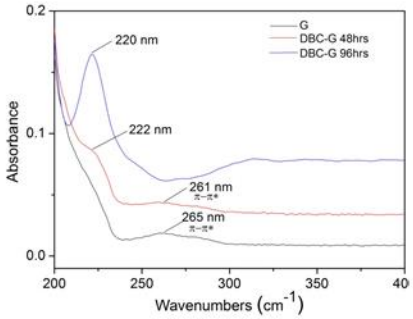


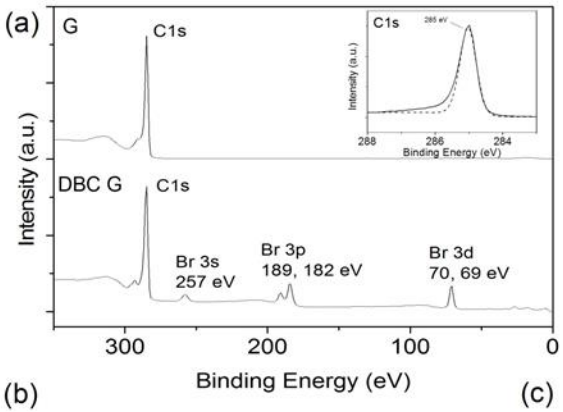
CHEMICALLY FUNCTIONALIZED GRAPHENE

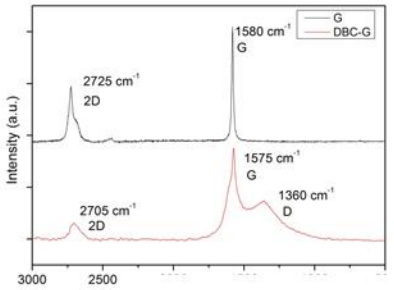
- Distortion of delocalized electron system
- Chemical doping
- Chemical functionality
- Band gap manipulation
- Application:
  - Sensing
  - Electronics
  - Composites catalysis

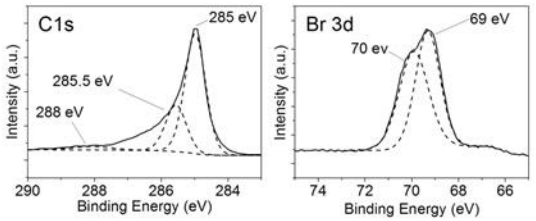


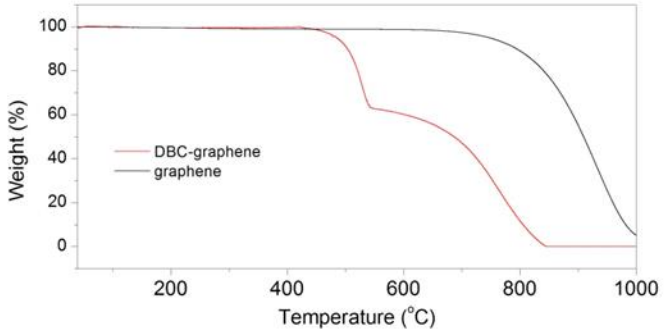












GRAPHENE

POTENTIAL CHALLENGES TO SUCCESSFUL UTILIZATION

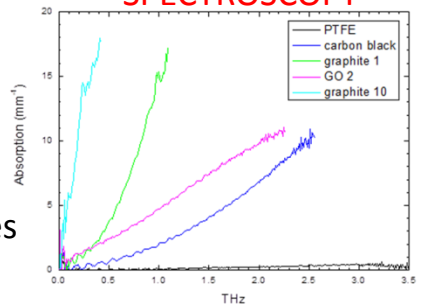
MEASUEREMENT AT NPL:

- Graphene
- Graphene oxide
- Graphene: chemical derivatives
- Graphene aerogel
- Graphene polymer nanocomposites
- Graphene inks
- Graphene -metal composites
- Graphene catalytic platforms
- Graphene sensor platforms

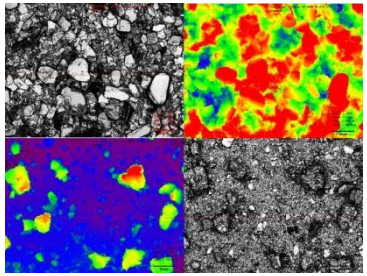
TECHNIQUES

- FTIR
- UV-Vis
- AFM
- TEM
- SEM
- ToF SIMS
- XRD
- XPS
- TGA
- DMA
- DSC
- Gas analysis
- XPS
- Ellipsometry
- Nanoindentation
- Electrical
- SKPM
- Raman/TERS
- Mechanical
- Terahertz spectroscopy

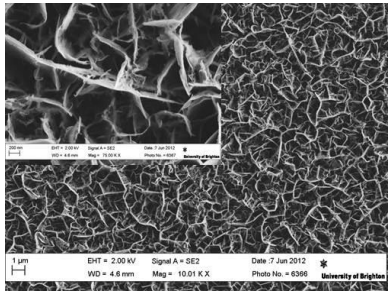
SPECTROSCOPY



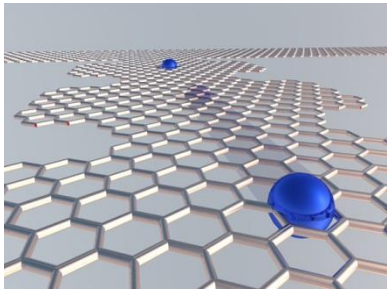
PROCESSING STABILITY



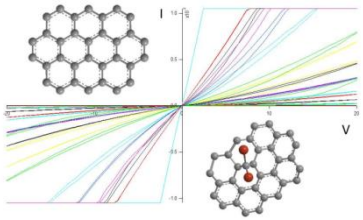
CATALYSIS



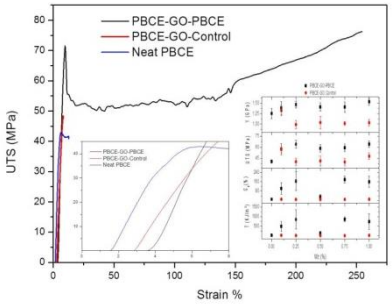
QUANTUM



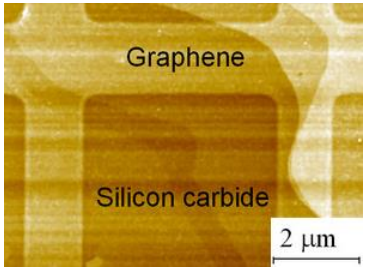
ELECTRICAL COMPOSITES



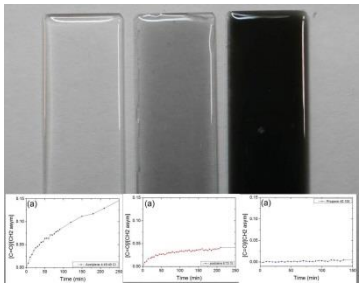
MECHANICAL COMPOSITES



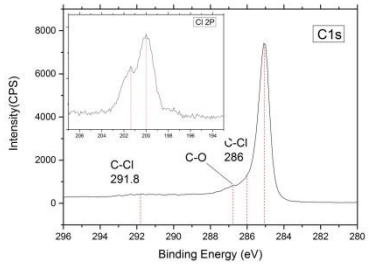
QUANTUM METROLOGY



CHEMICAL STABILITY



SURFACE CHEMISTRY



NPL
National Physical Laboratory

SUMMARY

- GRAPHENE
- CHALLENGES TO SUCCESSFUL UTILIZATION
- OPPORTUNITIES FOR METROLOGY ENABLED SOLUTIONS
- NPL FRAMEWORK AND COLLABORATIVE ASSOCIATIONS

NPL GRAPHENE PROGRAM

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