



# Welsh Centre for Printing and Coating



SWANSEA UNIVERSITY  
PRIFYSGOL ABERTAWE

College of Engineering



## Potential applications for plasma functionalised GNP's for active packaging

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## Centre of excellence for Printing and Coating



Winner of the 2009 Regiostar's award  
for technology

- Open access centre
- Comprehensive laboratories
  - Product Development
  - Fundamental research
  - Underpinning science
- Education and training
  - Technology transfer

# Swansea University Bay Campus – Opened August 2015

- Printing R2R and sheet fed - bench scale to customer acceptance trials
- Ink formulation to pilot scale production
- Analysis of materials and prints



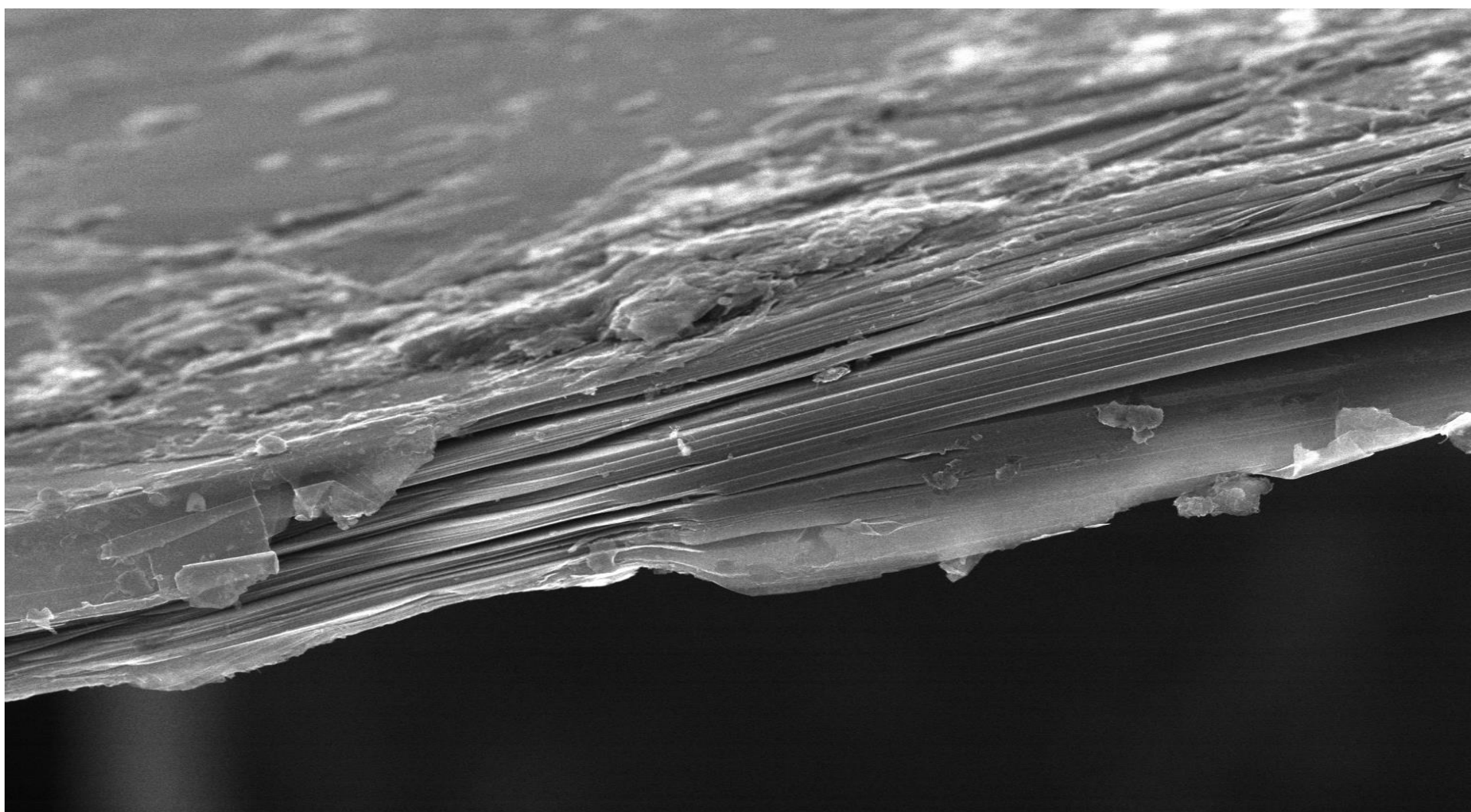
- Listed on London Stock Exchange 14<sup>th</sup> April 2014
- Raised \$10m for expansion in 2014 and on 2<sup>nd</sup> November a further \$9m for commercialisation. Post money valuation is \$40m
- Now have centres of excellence in USA and Far East
- Acquired a composites business in November 2014
- Focussed on plasma treatment of Graphenes and other nano materials that adds compatible chemical groups to ensure homogeneous dispersion

An enabling technology focussed on

- Composites
- Inks/Paints and technical coatings
- Energy storage



# Graphite



S4800 10.0kV 10.1mm x5.00k SE(U) 10.0um



# Nano Carbons



Type	Carbon Layers	Properties/Applications	Typical cost (\$/KG)	Commercially available
Epitaxial CVD	1-2	Conductive/almost Transparent/ITO? High end electronics	High- +10,000	CVD systems- Scale up? Cost!
FLG	3-10	Conductor/flexible/very high surface area/Sensors	200-2,000	Yes- consistency?
GNPs	11-100	Composites/Inks and coatings/Lubricants/Printing	50-200	Yes- variable product
GO	various	Insulator- semiconductor? Hydrophillic-dispersions Defects and voids	200-2,000	In Part
Graphite	100+	Lubricants/Refractories/brakes/Engineering materials	3-20	Established >70,000mt pa



# The Graphene Challenge



- Graphene as a carbon is relatively inert
- Properties not realised unless dispersed and bonded
- Tailored functionalisation is crucial for dispersion
- Structural integrity must be maintained
- Production must be repeatable and cost effective
- Production route must be scalable
- Environmental impact must be minimal





# Functionalisation

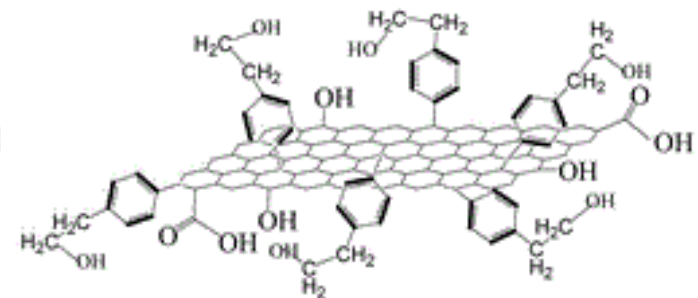
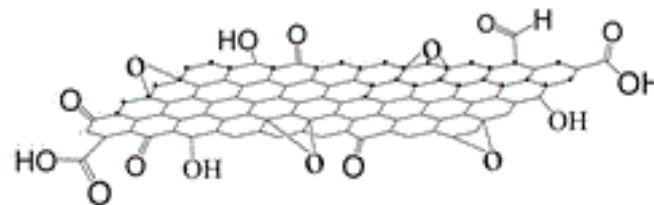
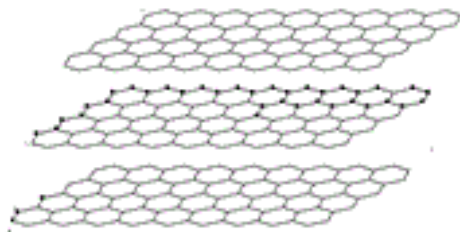


Carbon is its various forms including CNT and GNP is inert.

Thus carbon is difficult to bond to and to disperse.

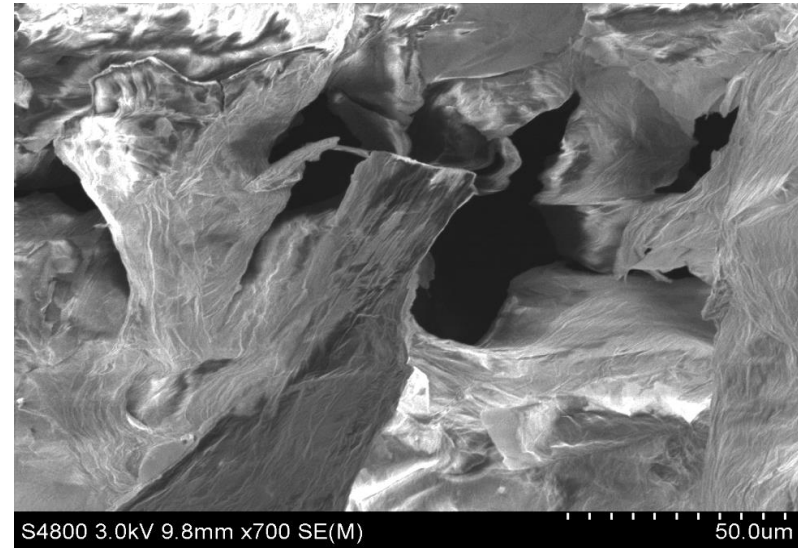
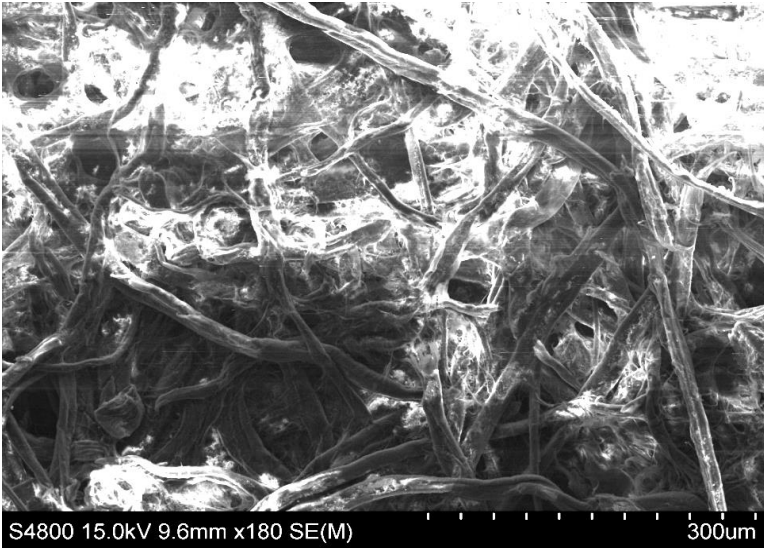
Adding free radicals to the surface of the carbons can :

- exfoliate sheets
- enhance particle segregation
- improve dispersion
- enabled tailored interactions





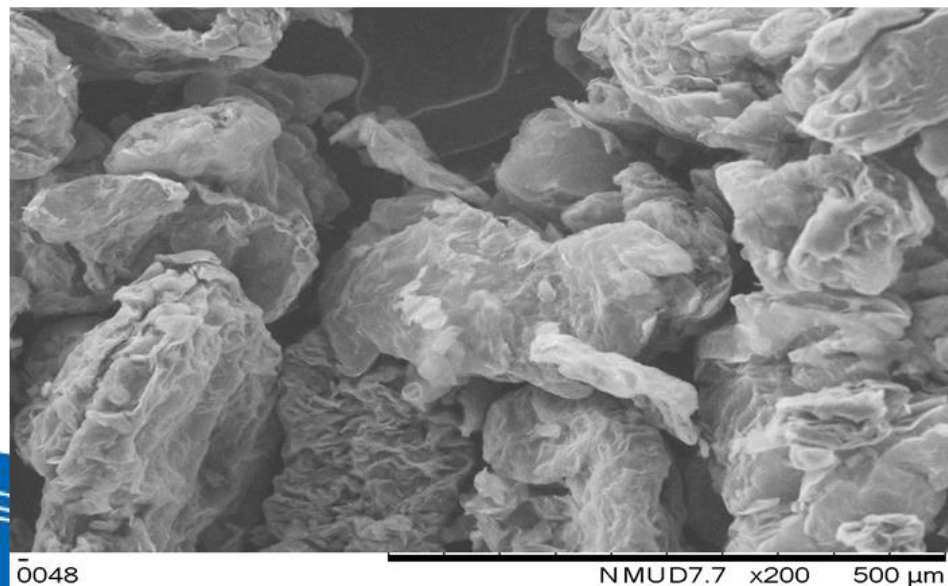
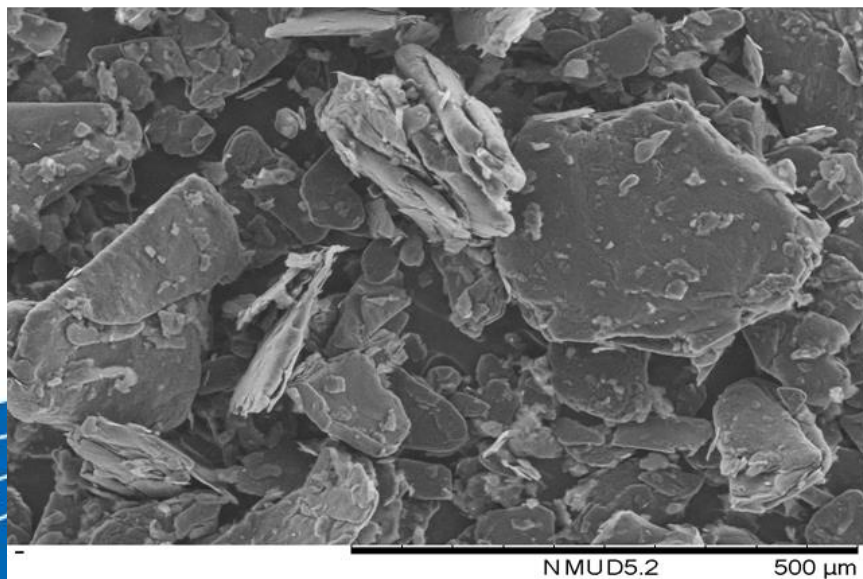
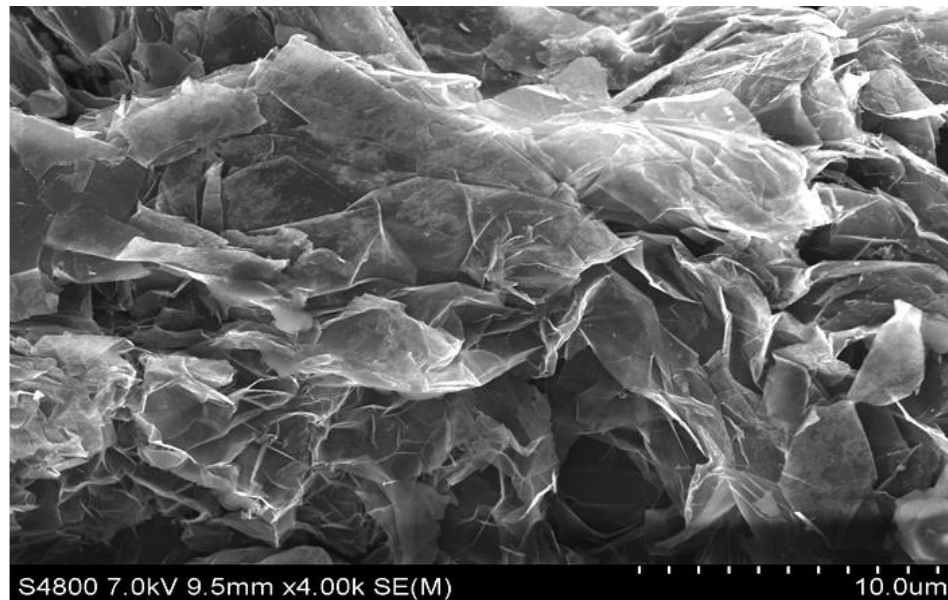
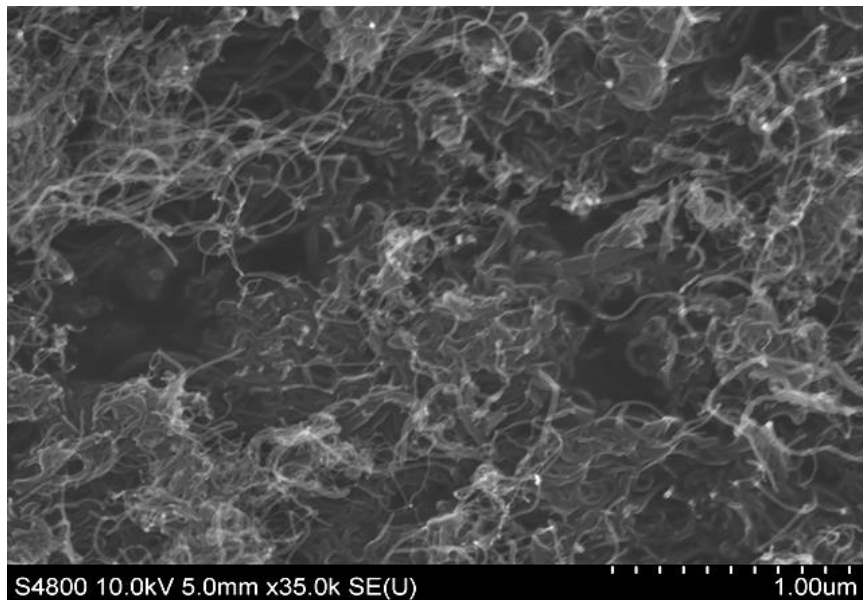
# Typical acid treated CNTs and GNPs



- Choice of functionalisation is limited to the acid groups used
- Harsh acid treatments are costly and environmentally unfavourable
- Acid Reflux breaks up nano carbon agglomerates but leaves acid residues
- Boiling fullerenes in acid with ultrasound can significantly damage aspect ratios

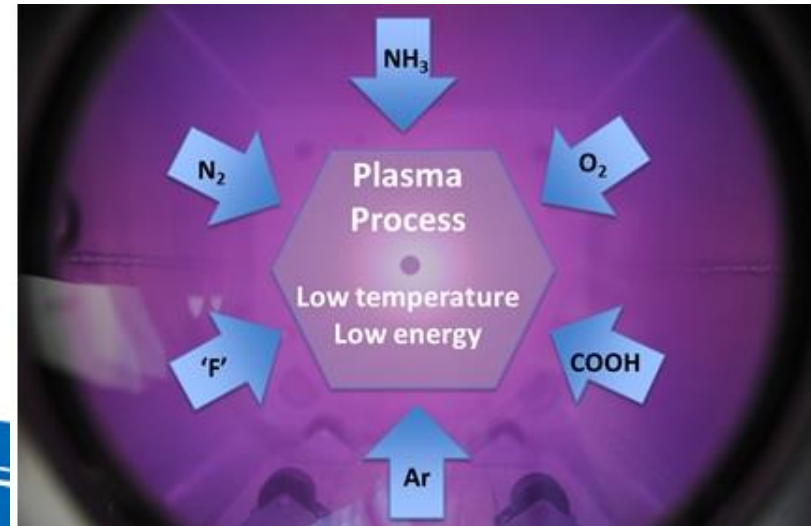
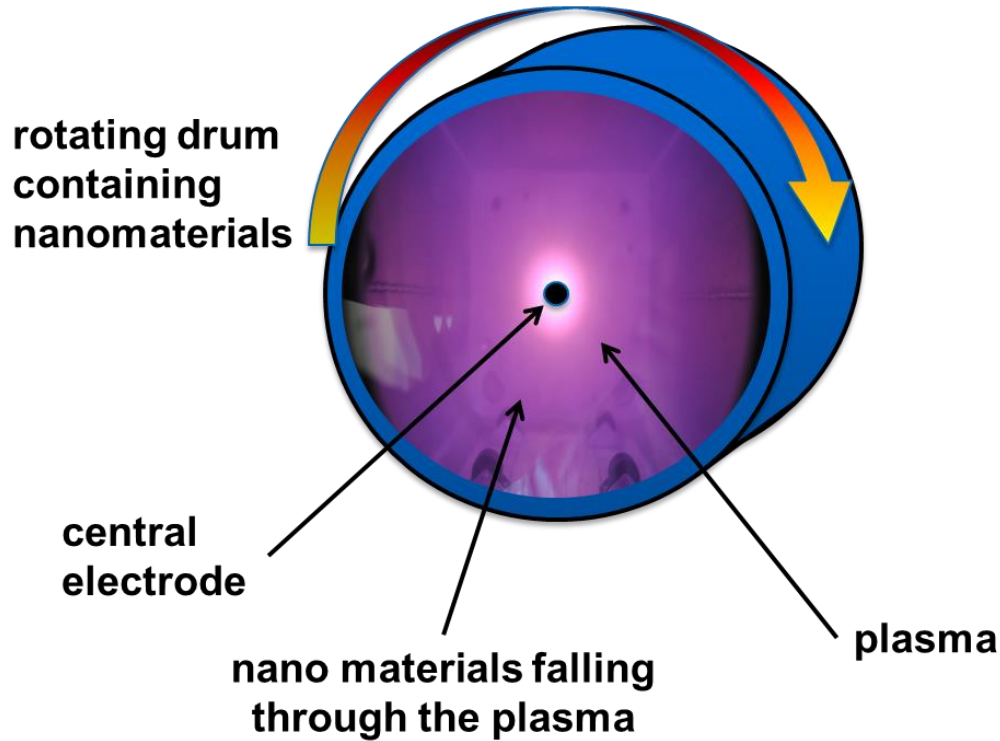


# Plasma treated CNTs and GNPs





# HAYDALE PLASMA TECHNOLOGY

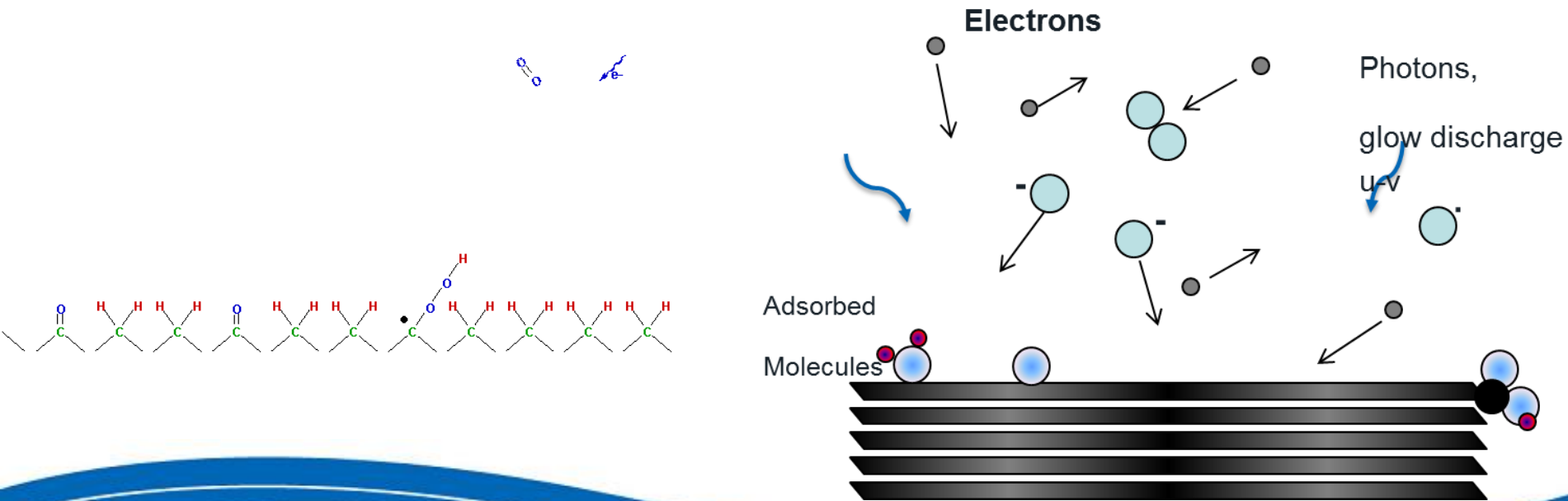




# HAYDALE PLASMA PROCESSING



- Low pressure gas plasma generated from controlled gas and vapour mixtures
- Functionalisation: Ionised gases (plasma) interact with the CNT / GNP surface , disassociated molecules readily bond with a surface
- 'Cleaning' : Reactive electrons and ions bombard the material surface removing contamination



## Functionalisation and Dispersion

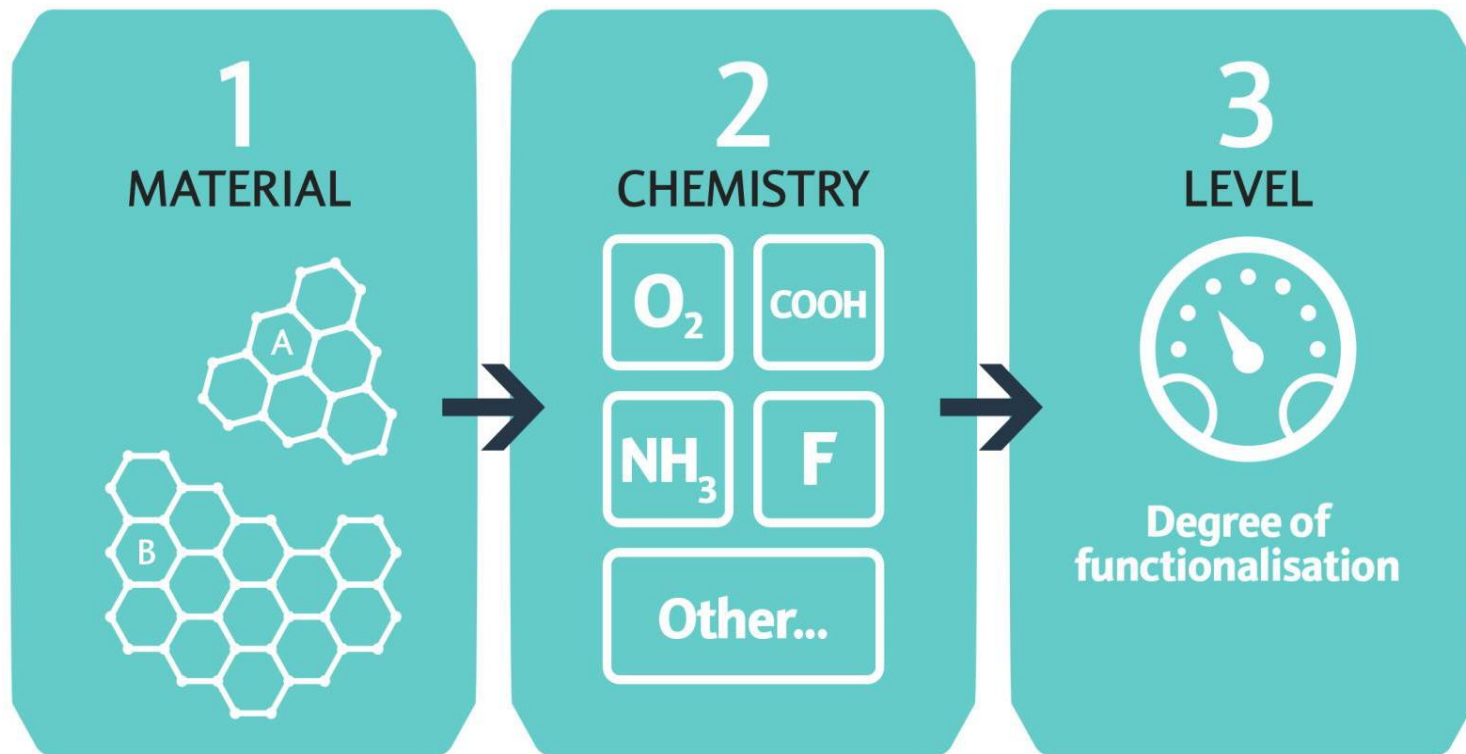
**HDPlas™  
MWCNT  
in Oil**



**As supplied  
MWCNT  
in Oil**



# 3 levels of customisation



**3 Levels of Customisation™**

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**One material and limited functionalisation will not fit all applications!**



# Projects with Haydale



- Applications for functionalised Carbon nano materials

- High precision manufacture
- PV
- Printable electronics
- Batteries
- Sensors
- Membrane

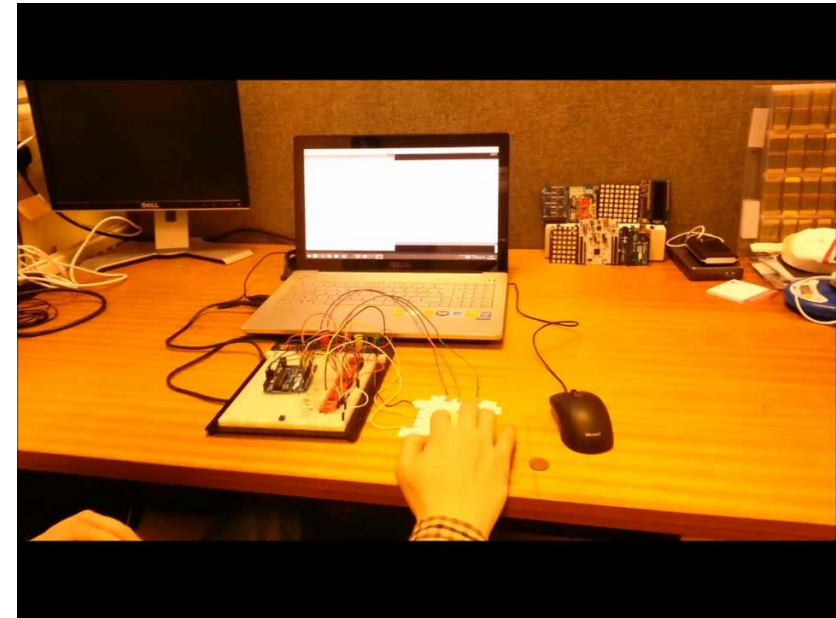


- Graphene based inks & coatings

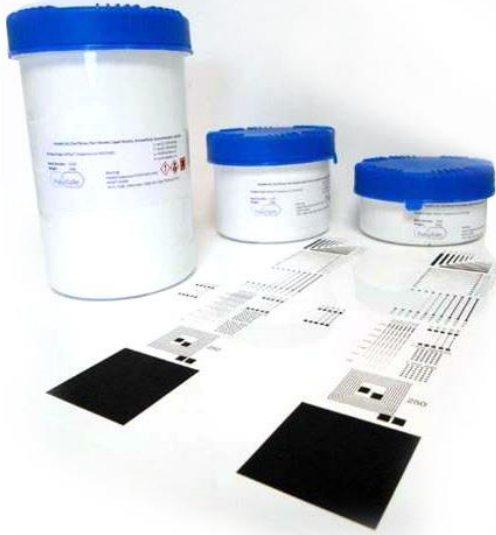
- Optimisation
- Consistency
- Manufacturing SOP
- QA requirements

- Functionalised Nano Carbon composites

- Control of complex rheology during production
- Microscale modelling of electrical, thermal and mechanical properties of composites





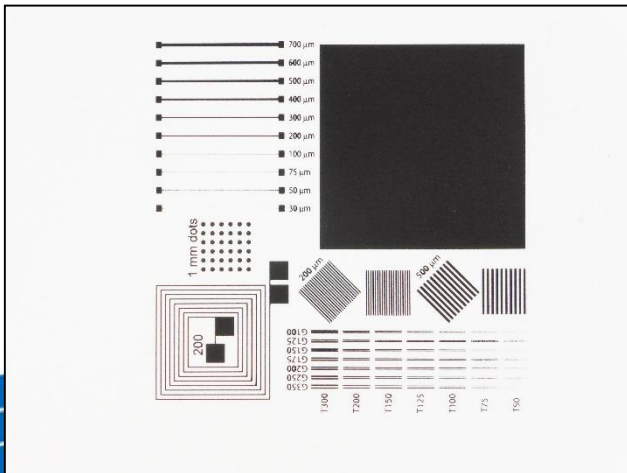


## Advantages:

- More environmentally friendly than silver
- Higher resistance per unit area
- Lower cost per ohm

## Applications

- Conductive tracks
- Strain gauges
- Piezo resistive
- Heaters
- Batteries, supercaps
- PV

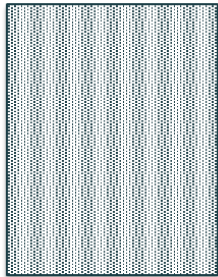




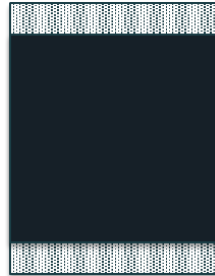
# Pressure sensor



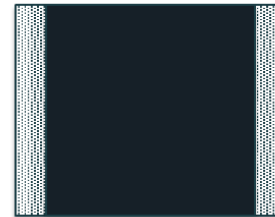
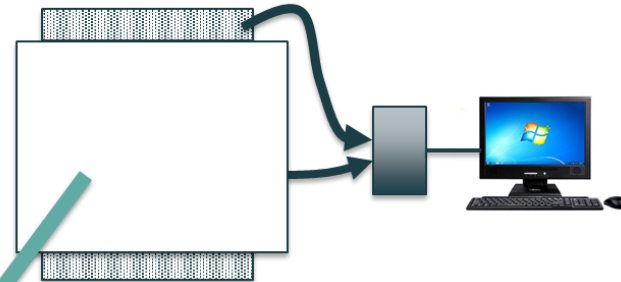
**STEP 1.**  
Print a conductor  
pattern onto  
plastic sheet



**STEP 2.**  
Coat with graphene  
Piezo-Resistive ink



**STEP 3.**  
Assemble two sheets together  
& connect conductors to  
computer interface



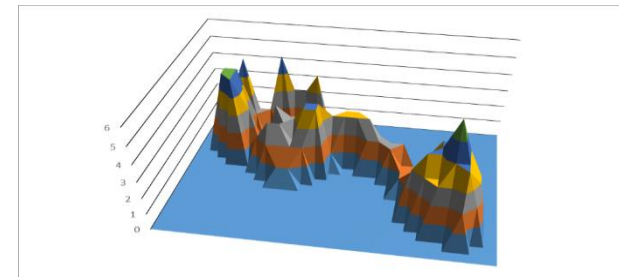
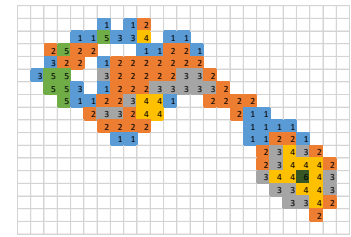
**Sheet now acts  
as a matrix of  
pressure  
sensitive cells**



# Advantages



- Low cost
- Thinner than a credit card
- Flexible
- Any size/shape
- Wide pressure range
- Real-time
- Applications:
  - Security, Health care, Sports training, Industrial Measurement, Retail footfall, Smart packaging

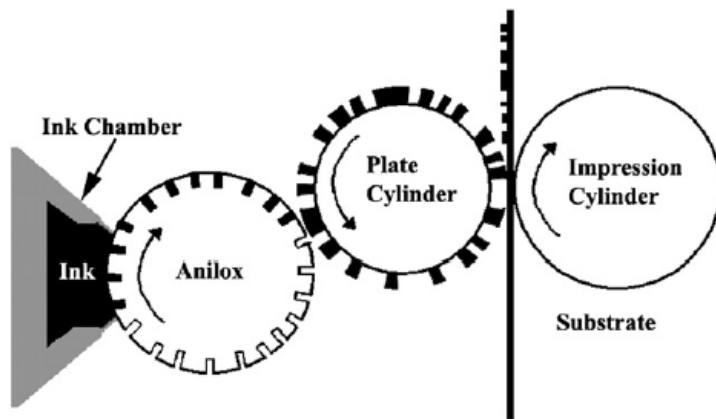




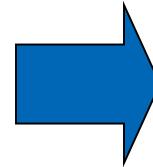
# CNT TFT



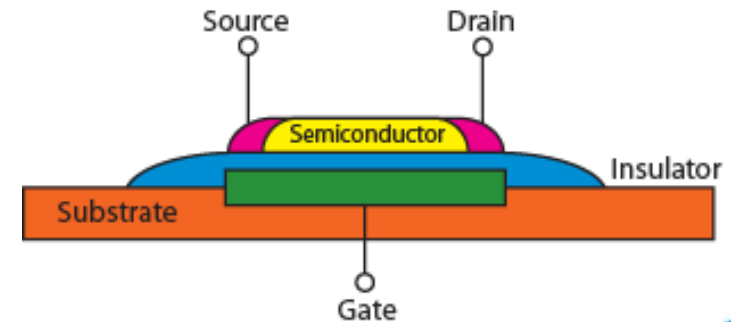
- Carbon Nanotube based Thin Film Transistors printed by flexography
  - Field effect devices
  - CNT as semiconductive layer



*Flexographic printing process*



*Flexo printed CNT TFT*





# Summary



- Graphene
  - Epitaxial – single layer, high price, no route yet to volume scale up
  - FLG – has future potential
  - GNP – High volume, scalable
- Compatible with recycling
- Graphene is relatively inert
- Functionalisation
  - Enables dispersion
  - Adds functionality
  - Could be applied to other nano and micro materials
- Applications
  - Printed electronics – conductive inks, sensors, integrate with Si
  - Active coatings

# Welsh Centre for Printing and Coating WCPC Bay @WCPCSwansea

