Low Cost Graphene And 2D Layered Material Inks for Printed Electronics

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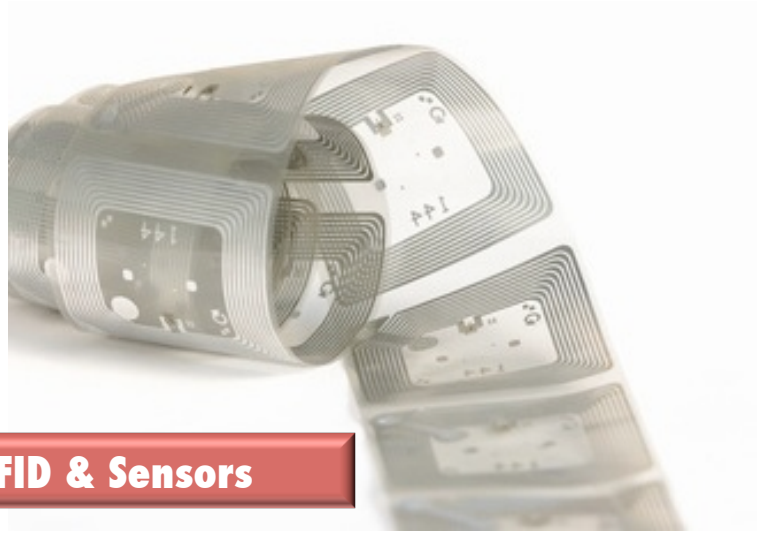
HVM Graphene 2013 Conference
5 November 2013 Cambridge
www.hvm-uk.com/graphene

Cambridge Graphene Platform

Potential Applications for Graphene & 2D Inks

Touch Screen & Display



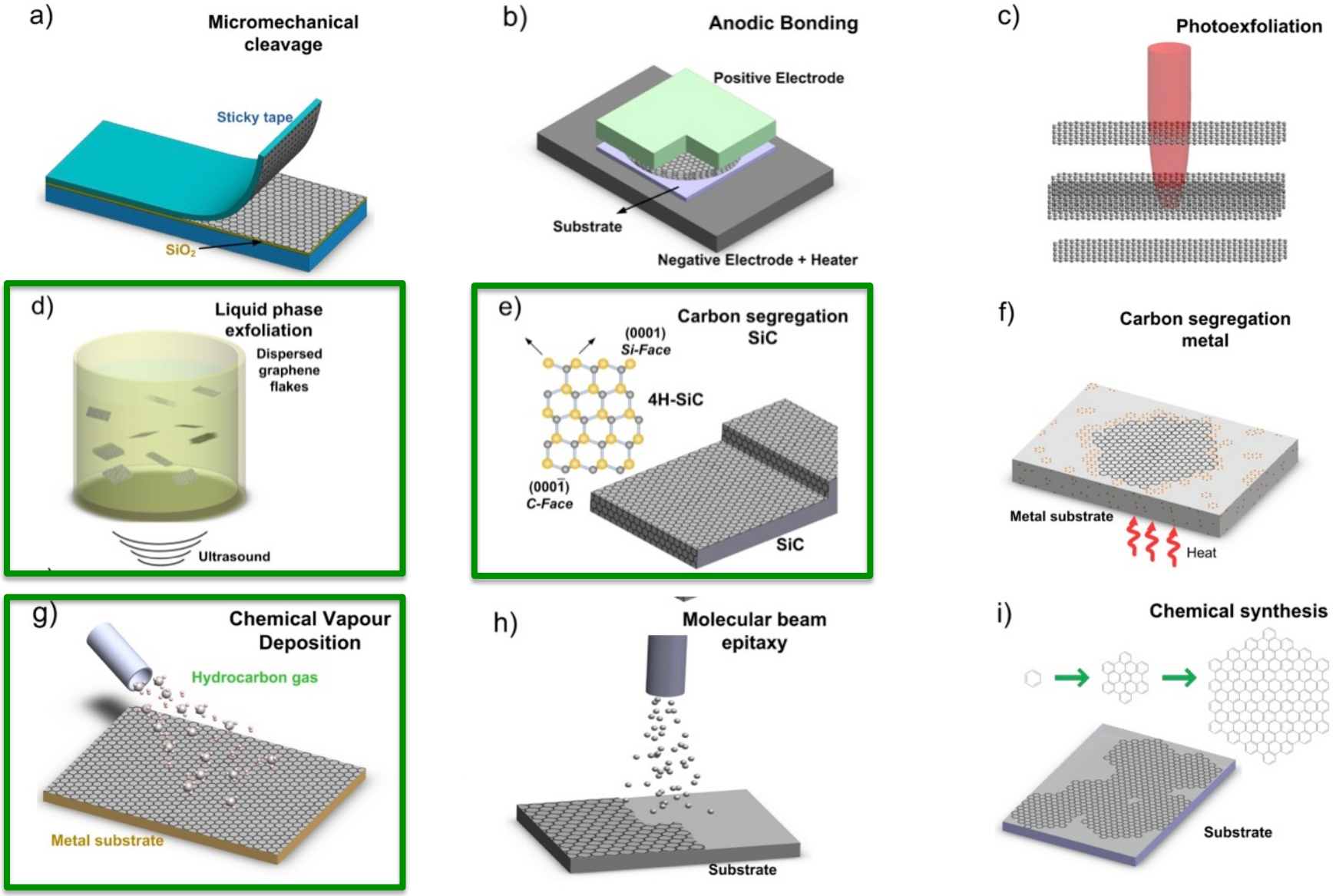
RFID & Sensors

E-Paper

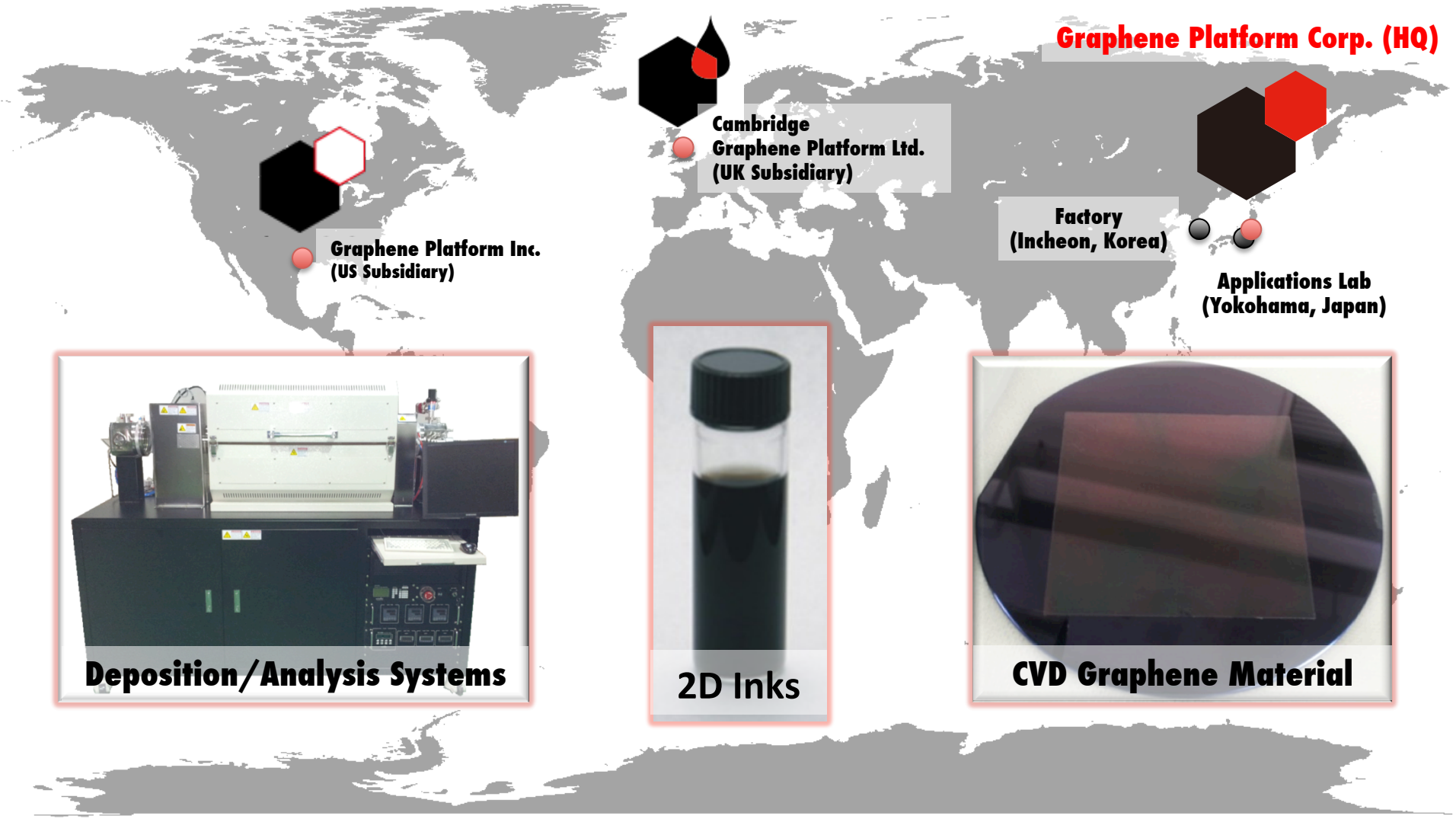
Photovoltaics

Samsung Flexible AMOLED Display

The Many Ways to Make Graphene



Business Organization
Group Company Overview



Deposition/Analysis Systems

2D Inks

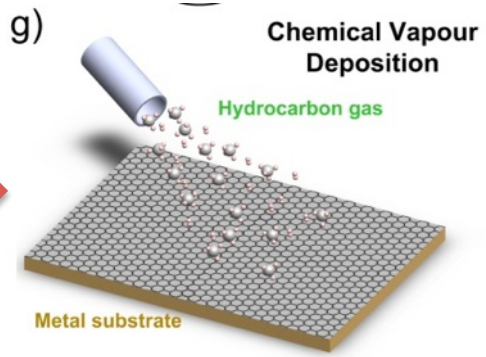
CVD Graphene Material

Process Differences

Chemical Vapor Deposition

Copper Foil

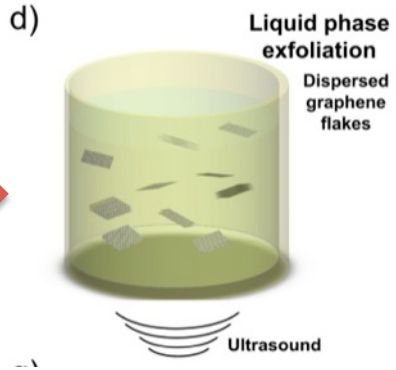
Methane Gas



- **Excellent Quality**
- **Suitable for R&D**
- **Low Throughput**
- **Relatively Expensive**

Liquid Phase Exfoliation

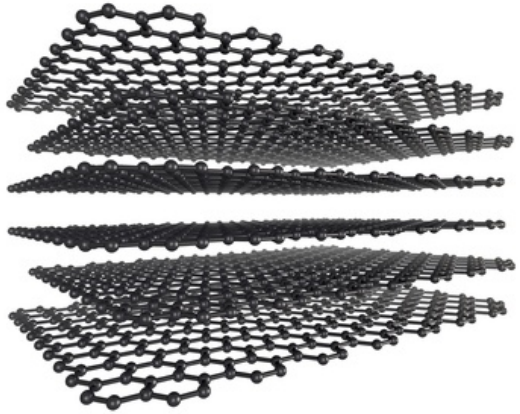
Graphite



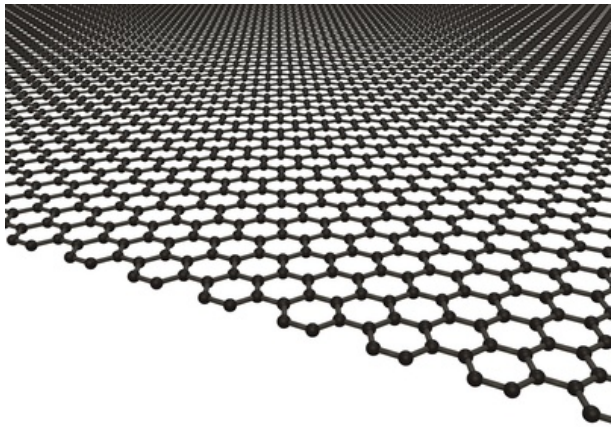
- **Chemically Pristine**
- **Low-cost Preparation**
- **Scalable Production**
- **No Post-processing**

Desirable Properties of 2D Crystal Inks
Graphene Case

Graphite



Nano Platelets

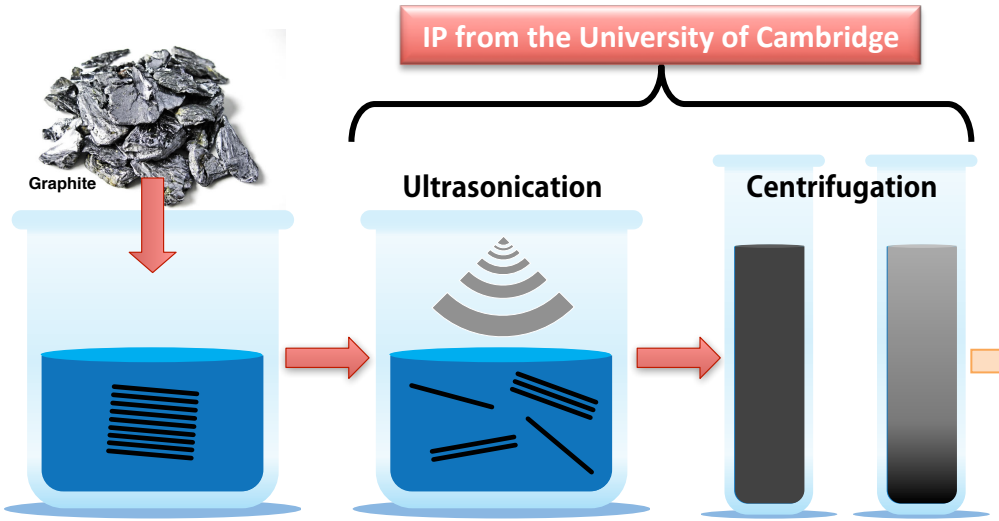


Monolayer Graphene

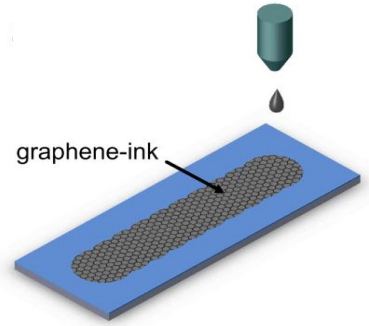
- **High Monolayer Yield**
- **Large Flake Size (>1µm)**
- **High Concentration of Dispersed Graphite**

2D Crystal Ink Production (Liquid Phase Exfoliaton)

Graphene Case



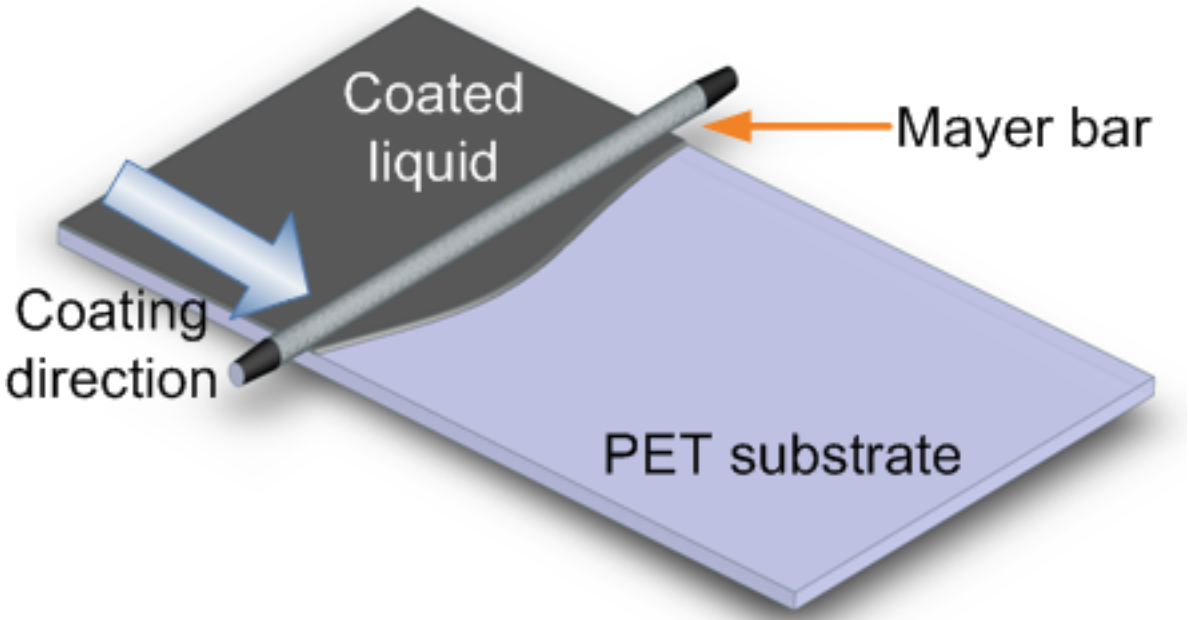
- No Chemical Contamination (Water-based)
- High Monolayer Flake Yield (up to 70%)
- Large Flake Size (>300nm)

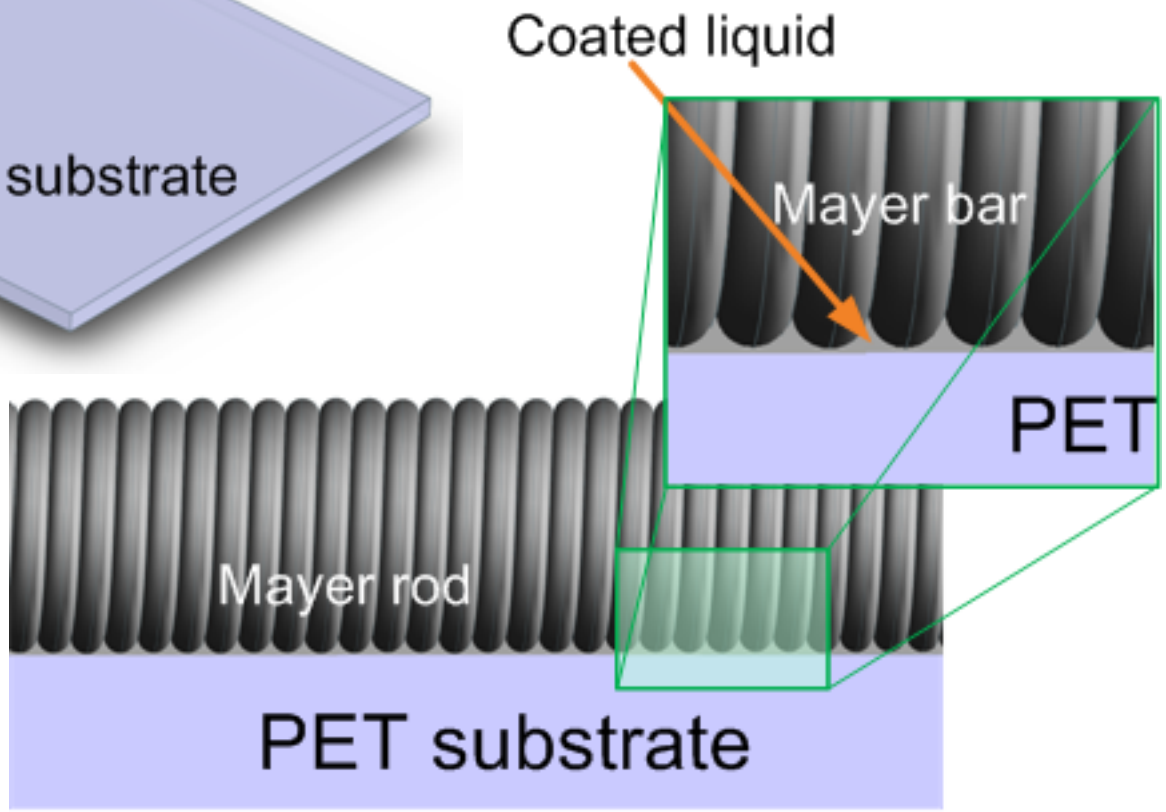


Equipment for LPE: Ultrasonicator & Centrifuge

Roll Coating 2D Crystal Inks

Graphene Case, PET Substrate





- **Electrical & Optical Homogeneity**
- **Max Process Temp ~80°C**
- **Roll-to-Roll Processing**
- **Width Limited Only by Bar Size**

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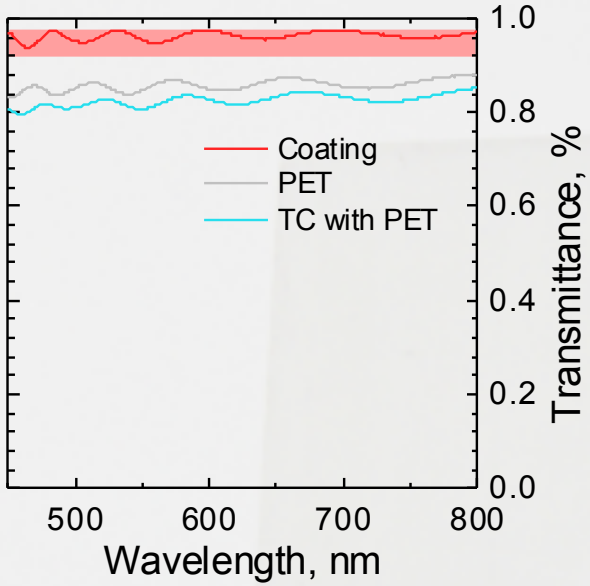
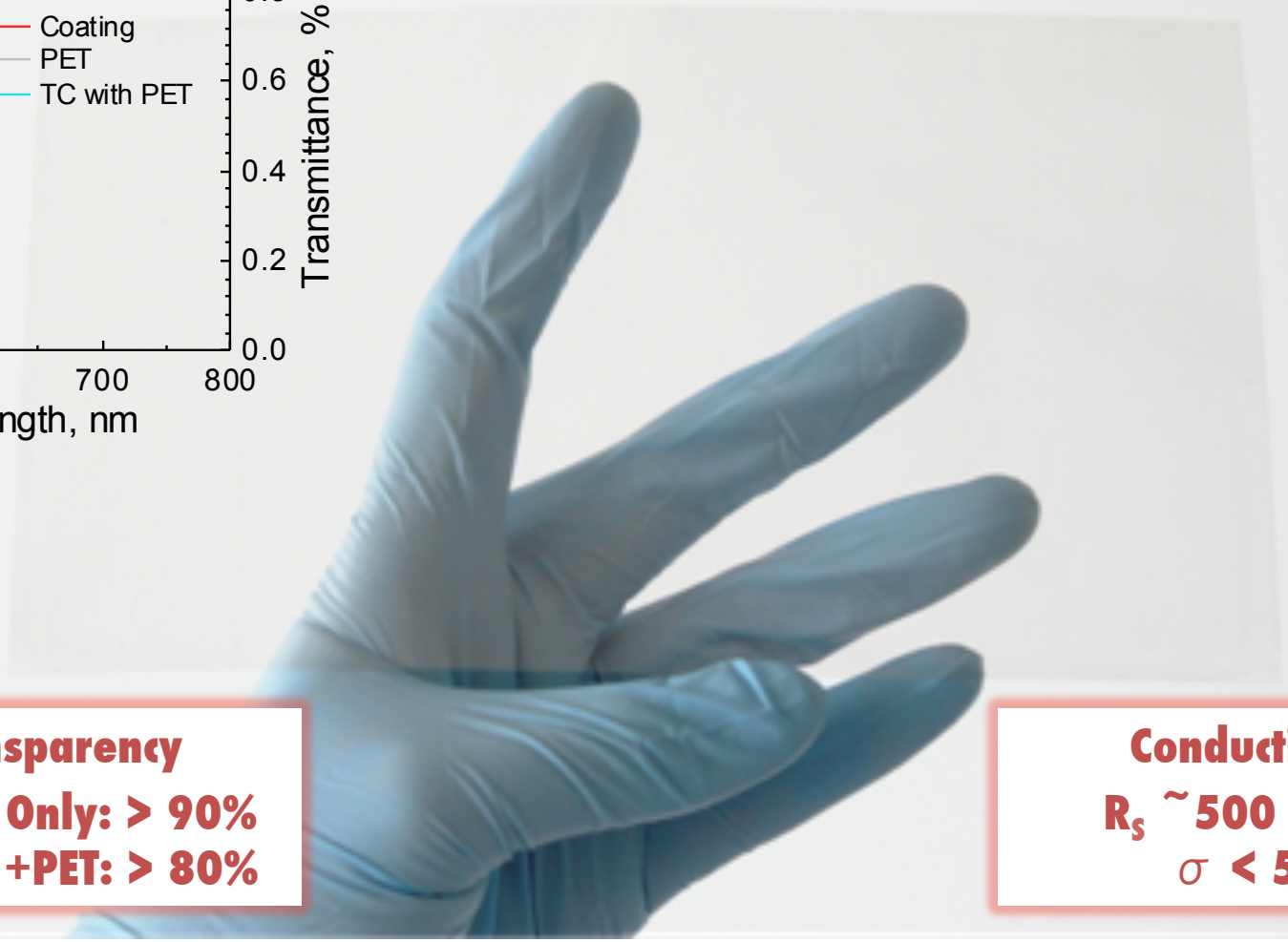
Roll Coating Graphene Ink on PET Substrates





Transparency

Coating Only: > 90%

Coating +PET: > 80%

Conductivity

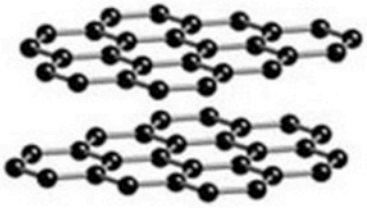
R_S ~500 Ω/□

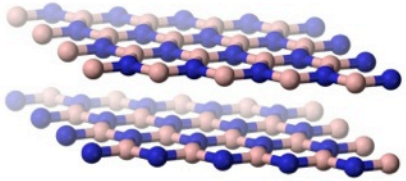
σ < 5%

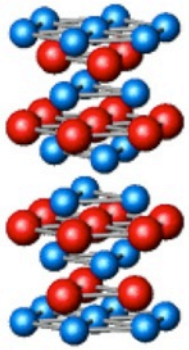
Other 2D Crystal Materials

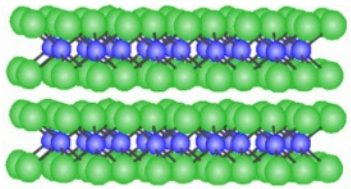
Graphene
- Mechanically strong yet highly flexible;
- Atomically thin and highly transparent;
- High electrical conductivity;
- High thermal conductivity;
- Excellent impermeability;

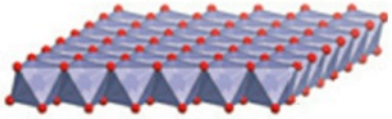
BN: Ideal substrate for graphene
- No dangling bond, increases graphene electron mobility;
- Small lattice mismatch of just 1.7%
- Fewer charged impurities;
- Flexible & transparent;
- Can realize new devices, such as tunneling transistors;


Graphite


Boron Nitride

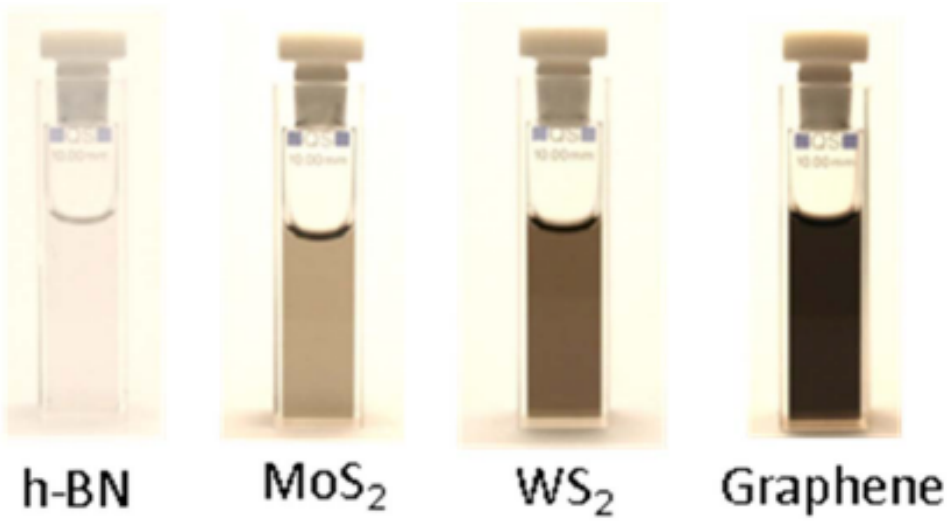

Bi_2Te_3
Sb_2Te_3
Bi_2Se_3


Metal chalcogenides

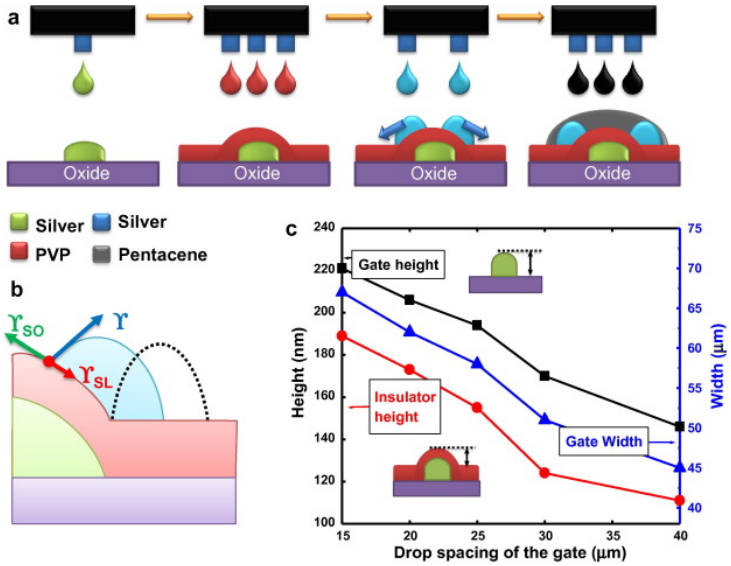

Metal Oxides

MoS2: Semiconducting; alternative for transistors
- Large on/off ratio;
- High mobility;
- Flexible & transparent;
- Low power consumption;
- High selectivity;

Other 2D Crystal Inks via LPE

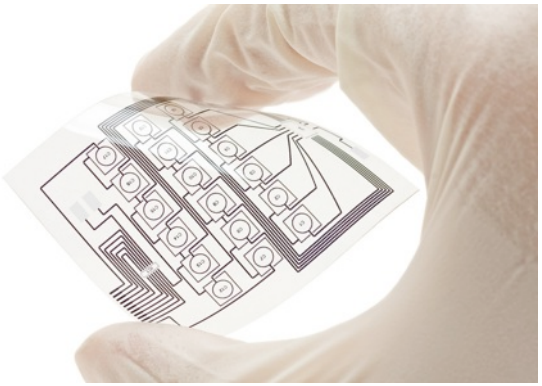


(Insulator) (Semiconductor) (Semiconductor) (Conductor)



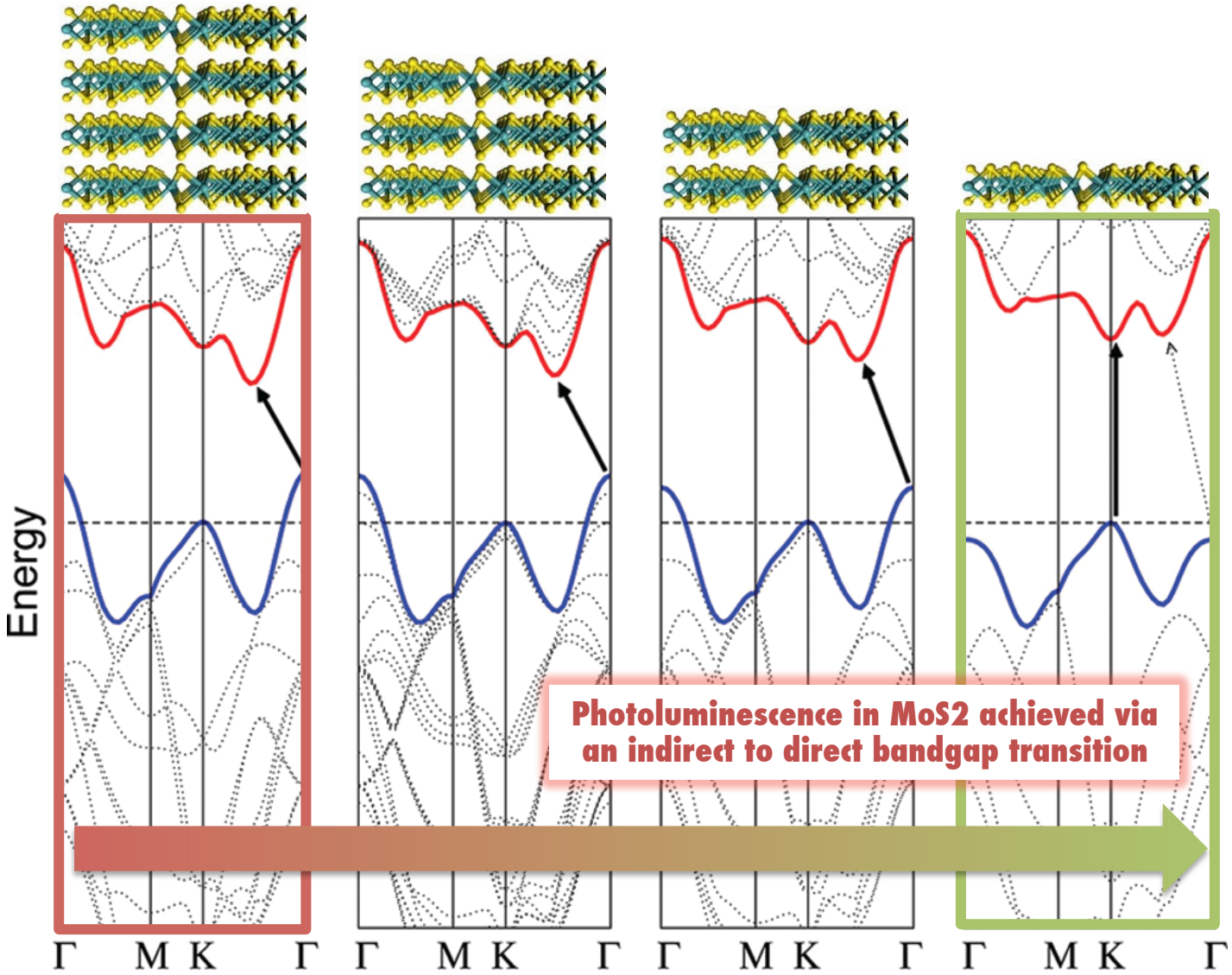
The Possibilities

- **A Variety of 2D Inks**
- **Layering of 2D Inks**
- **Fully Flexible Printed Electronics**



Other 2D Crystal Inks via LPE

MoS_2 Case



Commercialization Model

University of Cambridge

CAMBRIDGE GRAPHENE CENTRE

IP

Graphene Platform

Cambridge Graphene Platform Ltd.

- **Dedicated Ink Development**
- **Consulting Services**
- **Ink Production, Sales & Licensing**

Design-in

Device Makers

Apple Inc. NOKIA SONY SAMSUNG

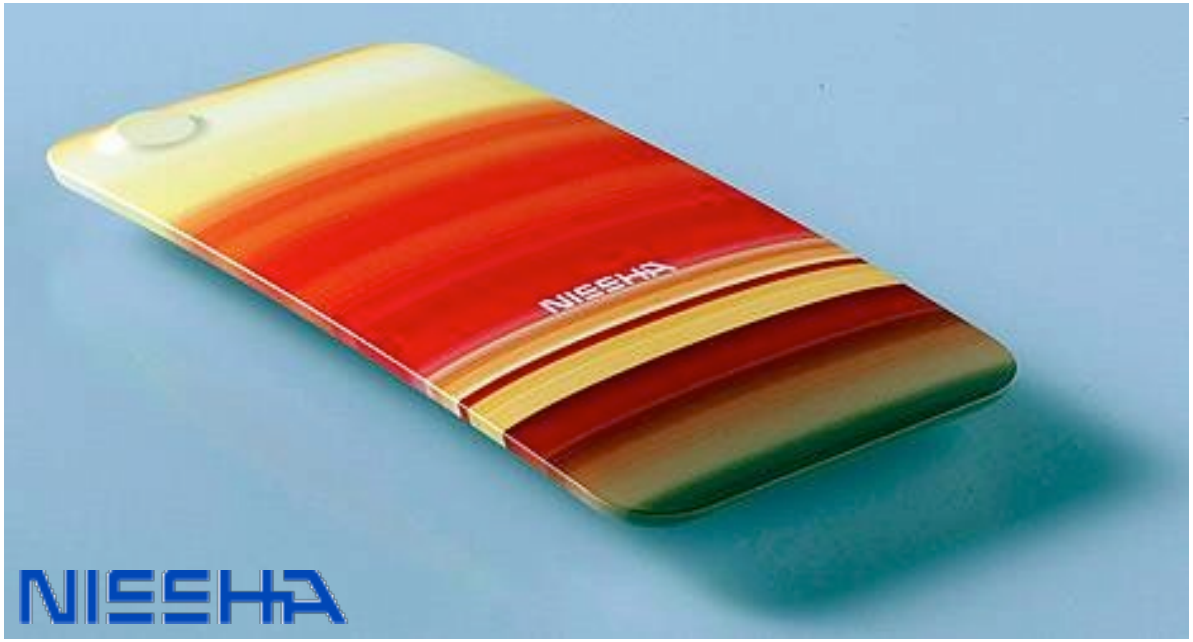
DNP NISSHA NITTO DENKO TOPPAN TEIJIN AsahiKASEI 'TORAY' Innovation by Chemistry

Cambridge Graphene Centre

http://www.graphene.cam.ac.uk/

Partnership with Nissha Printing Co., Ltd.
(Front Page of *Nikkei Business Daily*, September 5, 2013)

- **Graphene Ink Supply**
- **Joint Product Development (e.g. Curved Touch Panels)**
- **Commercialization Within 2 Years**



日本写真印刷とグラフェンプラットフォーム

曲面タッチパネルで提携

日本写真印刷とナノテクベンチャーのグラフェンプラットフォーム（東京・渋谷）は先端素材、グラフェン（シート状炭素分子）を使ったタッチパネルの共同開発で提携した。グラフェンの粉体を溶液中に分散させたインクを使い、印刷技術で電子回路を形成する。腕に巻くブレスレット型端末の曲面パネルなどを2年後に実用化する。

2年後実用化

グラフェンプラットフォームはグラフェン成膜装置の開発などを手掛けている。英ケンブリッジ