Graphene materials: Role in Energy Storage, Mobility and Coating & Inks

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5th HVM New Materials 2019, 6-7 November
Cambridge, UK

www.cir-strategy.com/events

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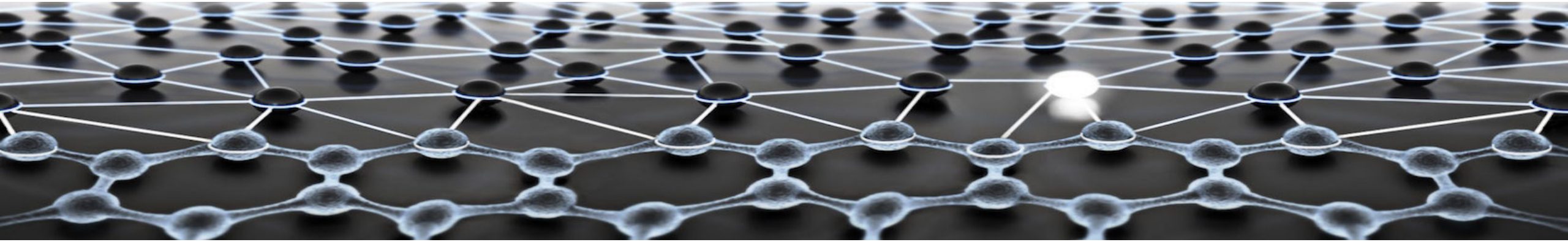
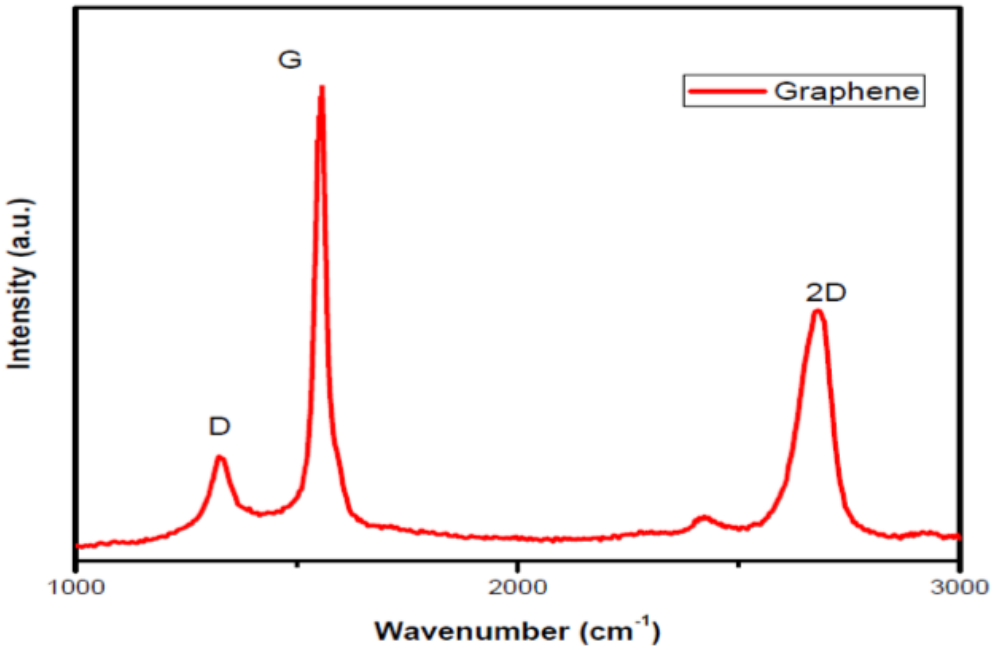
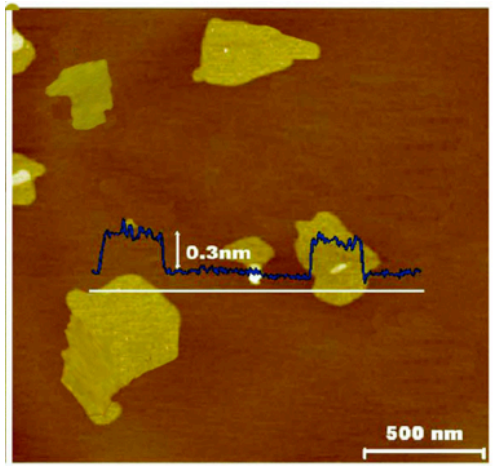
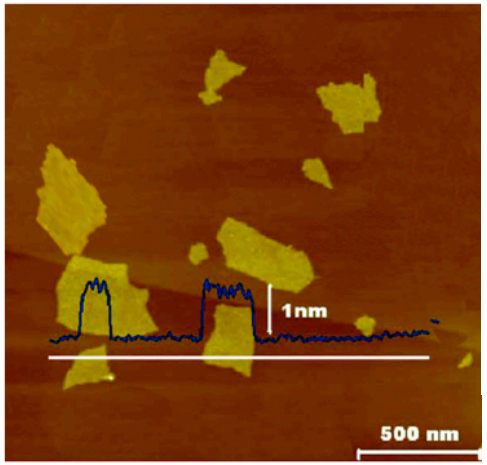


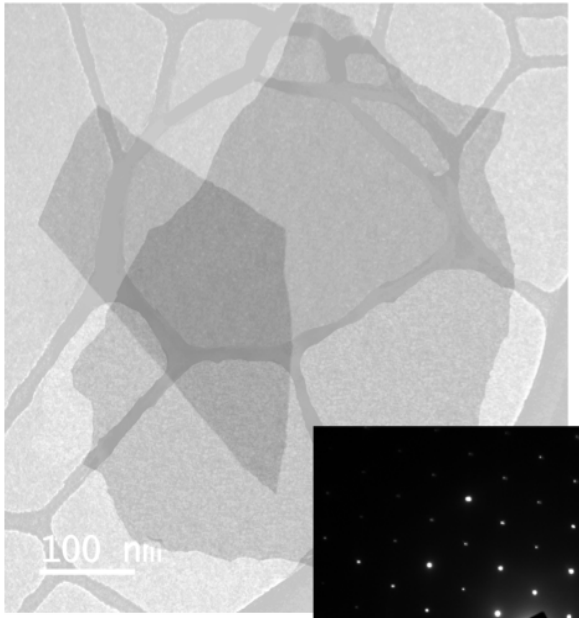
Dr. Siva Bohm FRSC, The Royals Society Industry Fellow & CAMI Ltd (CTO)

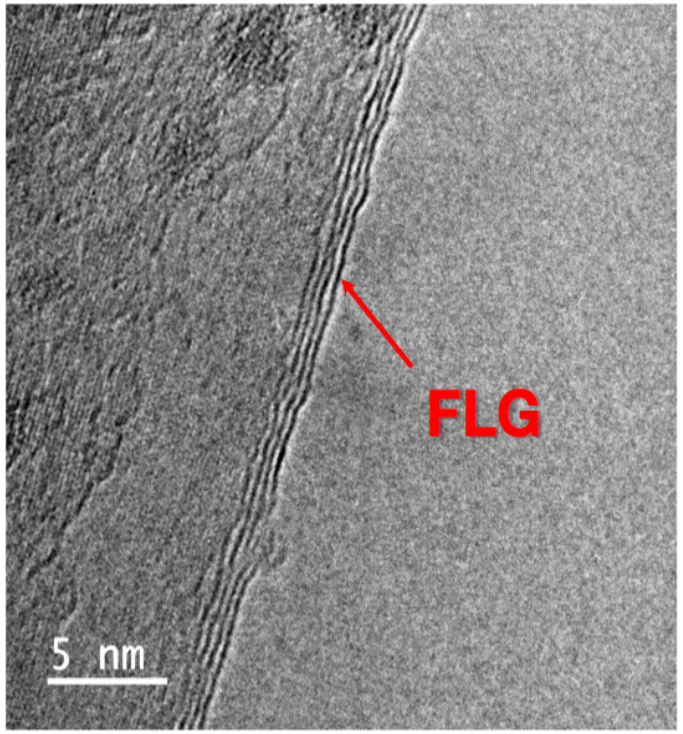
Quality OF Graphene play Key - Performance

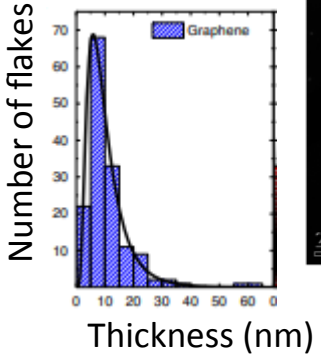




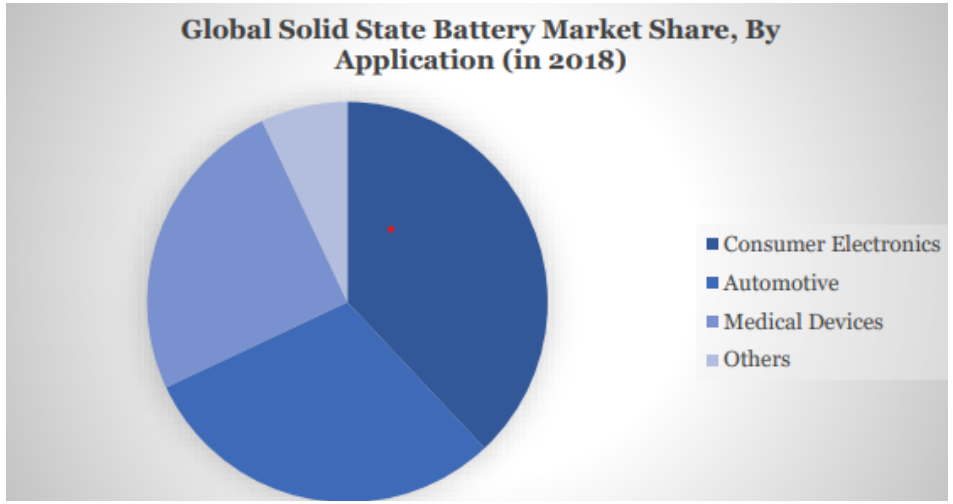




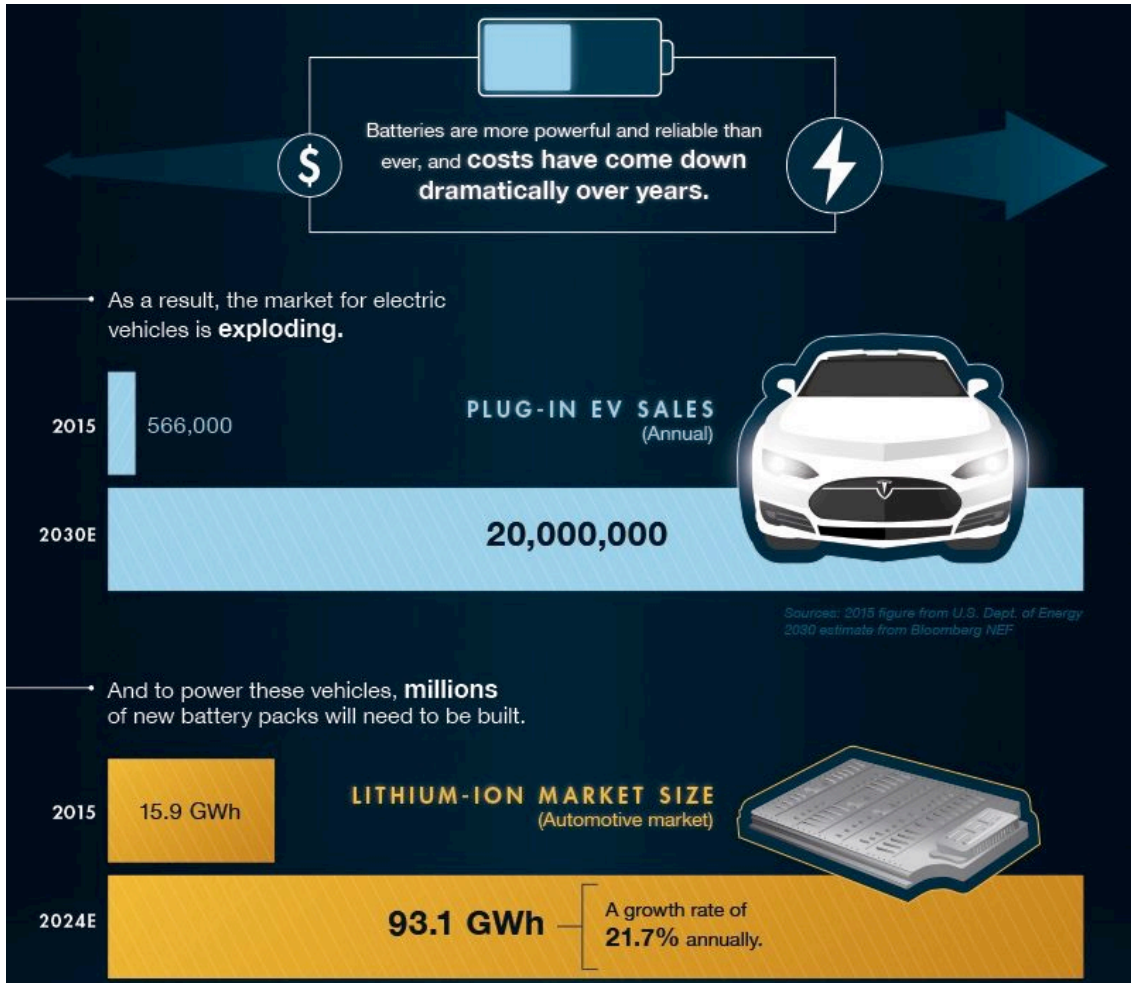




Solid-State Li-Ion Batteries & Silicon Anodes



- **Global Solid-State Battery Market – Competitive Landscape**
  - **Solid Power Inc.**
  - **Maxwell Technologies**
  - **Cymbet Corporation**
  - **Toyota Motor Corporation**
  - **Infinite Power Solutions, Inc.**
  - **Robert Bosch GmbH**
  - **Planar Energy Devices, Inc.**
  - **Front Edge Technology, Inc**
  - **Panasonic Corporation**

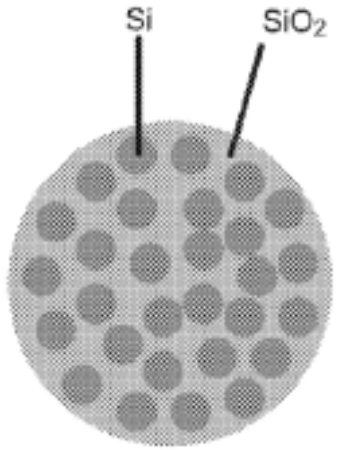


Source: b-science.net

SILICON ANODES: NANOTECHNOLOGY COMPENSATE VOLUME CHANGE

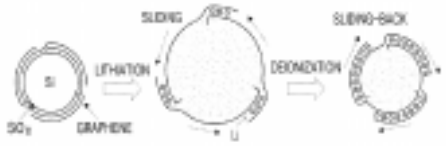
SiO_x ($X \approx 1$)

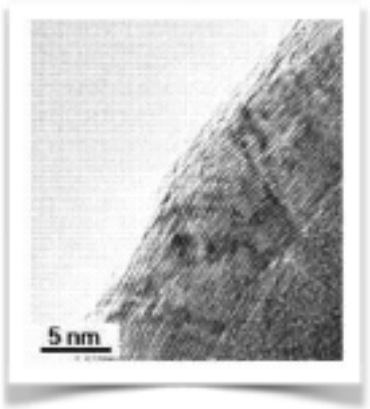
Si nanodomains (ca. 4 nm diameter) in SiO_2 matrix



Si Nanoparticles

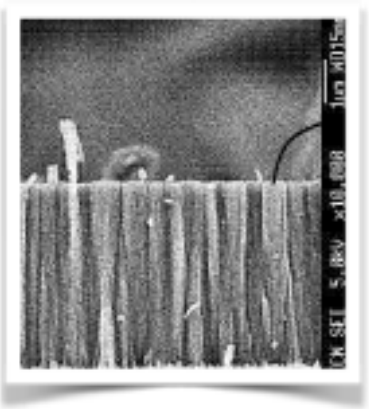
Small diameter (<150 nm) prevents crack formation





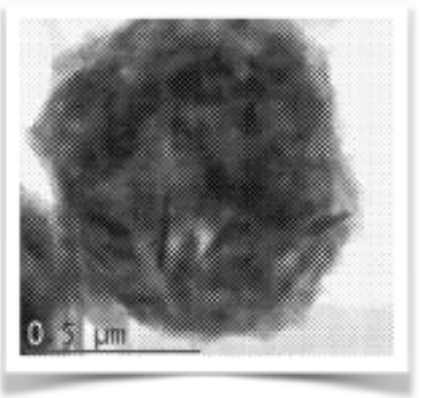
Si Nanowires

Small diameter (<150 nm) prevents crack formation, anisotropic structure



Si-C Core-Shell Composites

Void volume inside core is protected from electrolyte access by shell



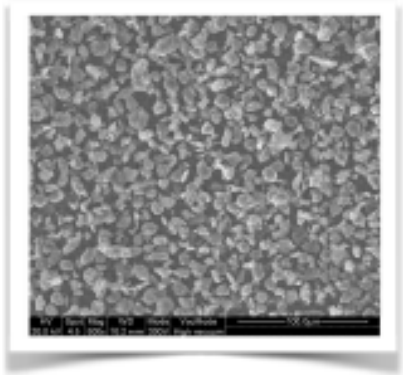
SILICON ANODES PARTICLE SIZE: ADVANTAGES & DISADVANTAGES

SiO_X ($X \approx 1$)	Si Nanoparticles	Si Nanowires	Si-C Core-Shell Composites
Advantages	**Advantages**	**Advantages**	**Advantages**
Low surface area, high technology readiness level	High capacity, tailored surface	High capacity, favorable Li-ion diffusion	Low surface area, high capacity
Potential Disadvantage	**Potential Disadvantage**	**Potential Disadvantage**	**Potential Disadvantage**
Parasitic reactions caused by SiO_2	Elevated surface area may cause parasitic reactions	Elevated surface area may cause parasitic reactions	Large number of process steps

SILICON CARBON CORE-SHELL COMPOSITES PLAYERS

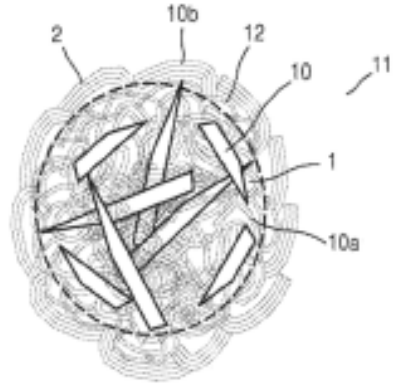
Shanshan

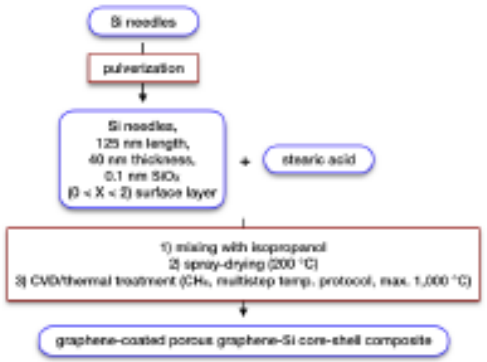
- Multi-step procedure to generate Si-graphite-carbon black core with void space, protected by pitch-based shell.

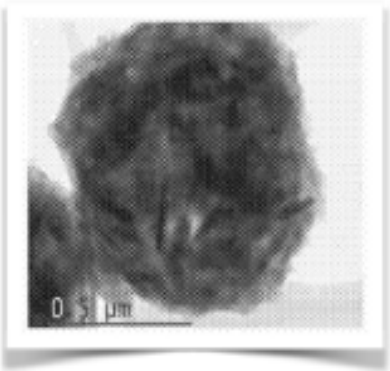


Samsung

- CVD-based formation of graphene-Si core and graphene shell in one process.







LOW COST FUEL CELL DEVELOPMENT

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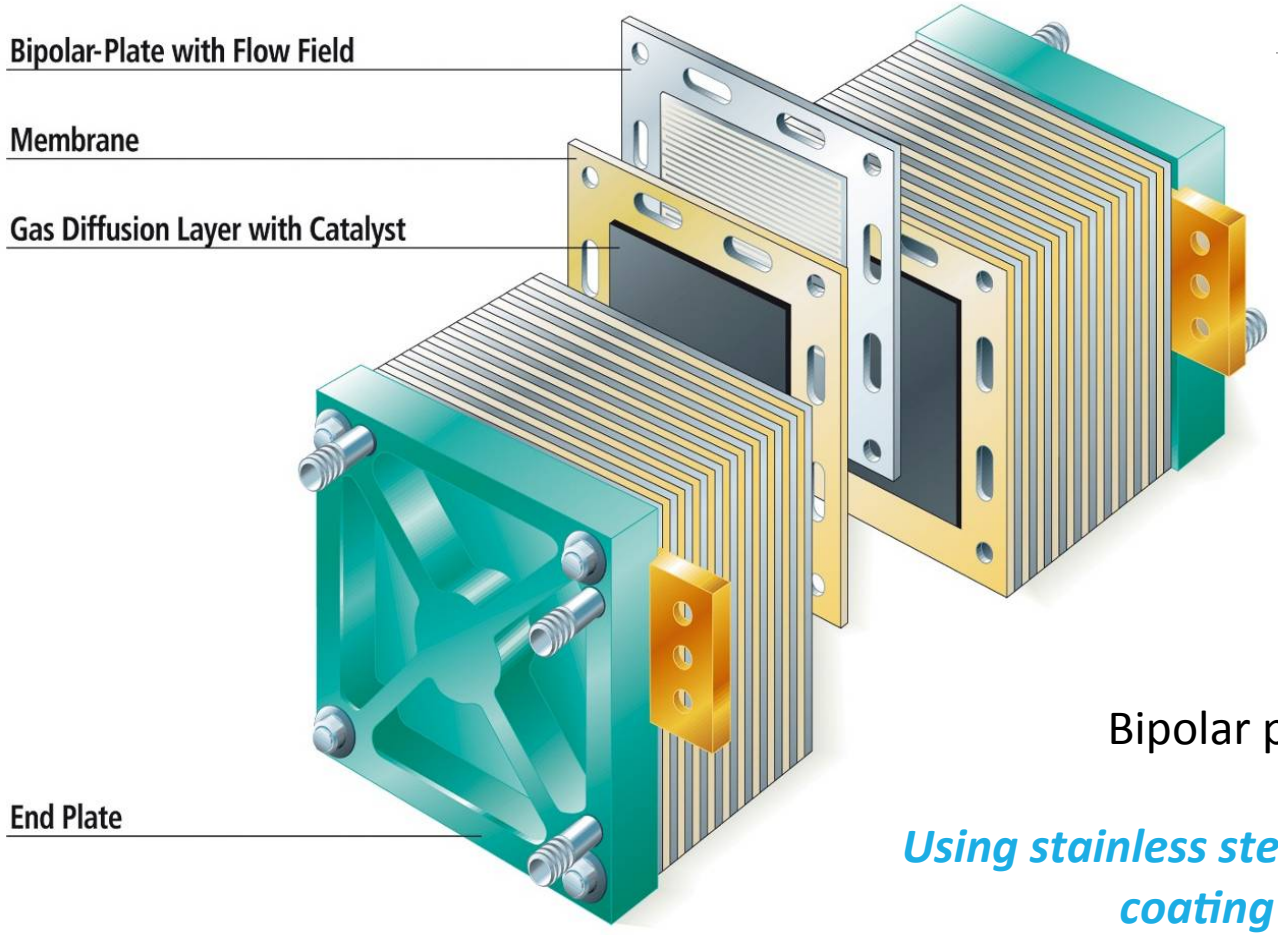

Bipolar plate represents **~50% of total cost** of a fuel cell stack.

Using stainless steel ("SS") offers lower cost bipolar plates, but requires coating solutions for oxidation, conductivity and other issues

IMPROVED CORROSION RESISTANCE BIPOLAR PLATE

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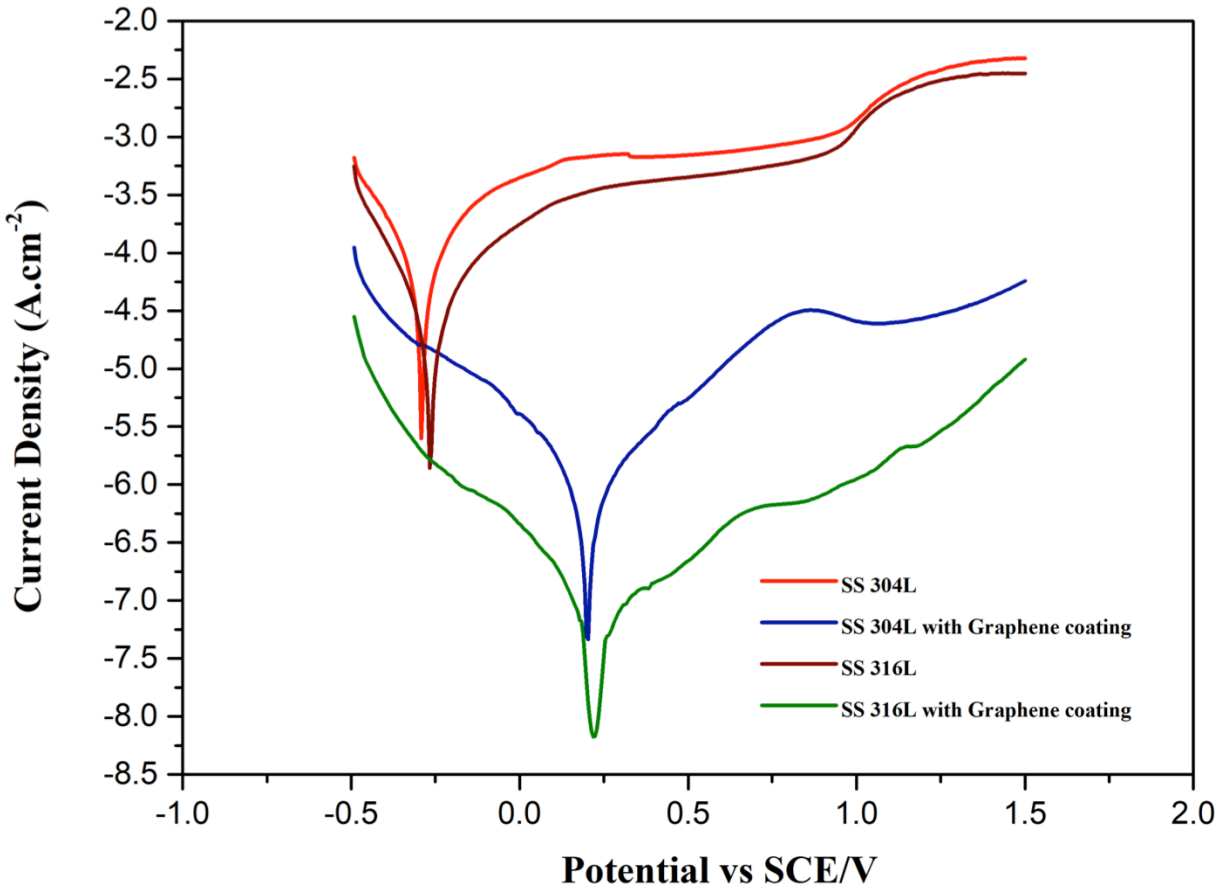
Corrosion resistance of SS316 plate improved x 500
Corrosion resistance of SS304 plate improved x 20

No.	Sample	Potential (V vs SCE)	Current ($A.cm^2$)	Corrosion rate (mmpy)
1	SS 304L	-0.265	7.94E-5	0.92
2	SS 304L + Graphene coating	0.231	1.58E-6	0.018
3	SS 316L	-0.258	3.16E-5	0.37
4	SS 316L + Graphene coating	0.248	6.31E-8	0.0007



Corrosion resistance improved x 500 in 1M H2SO4 acid

CONDUCTIVITY AND ADHESION OF HYBRID GRAPHENE INK

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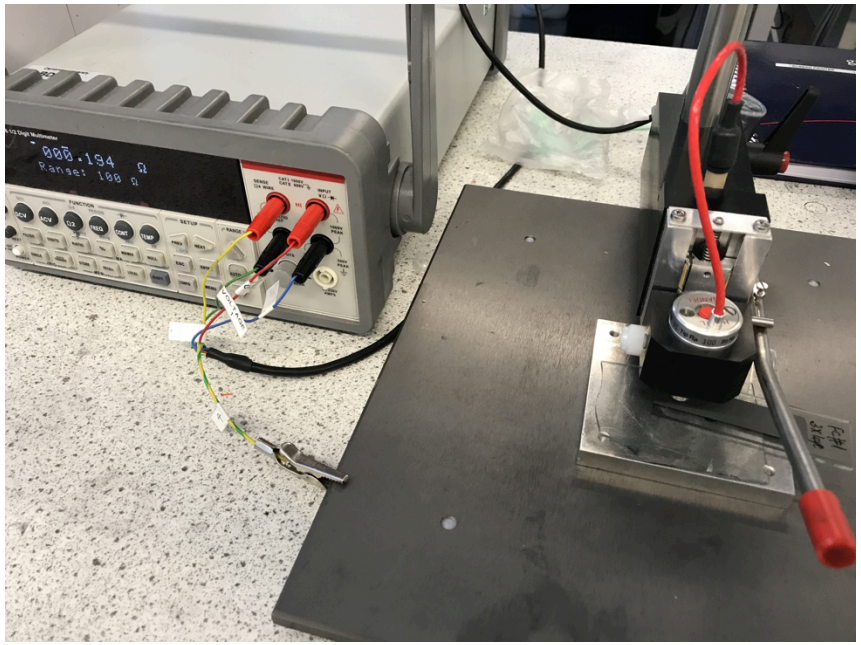

Four point probe measurement on glass
Sheet resistance 1 Ohm/sq

Crosshatch test ASTM D[9]3359 – 97
Good adhesion on various substrates, incl. SS & PET

Batteries vs Fuel Cells

	Batteries	Fuel cells
Advantages	Smaller and lighter High energy density Low self discharge Longer life scan	Consistent output High level of Energy efficiency Significantly reduced/zero CO2 emission Better fuel economy Effective Energy Storage
Disadvantages	Sensitive to temperature Aging effect Safety concern Deep discharge	Costly to manufacture, storage and transport, Hydrogen station availability in UK Not suitable for every situation Temperature regulation is required

Cost of Corrosion on Economic Scale is Significant!

United Kingdom

GDP (2007): $2,279 billion

Annual cost of corrosion: $70.6 billion

Australia

GDP (2008): $920 billion

Annual cost of corrosion: $70.6 billion

USA

GDP (2007) $13,840 billion

Annual cost of corrosion: $429 billion

All figures US Dollars

Reference: NACE figures:
http://events.nace.org/publicaffairs/cocorrindex.asp
GDP figures: http://www.economywatch.com/

Safety is the Key, Can Graphene contribute?

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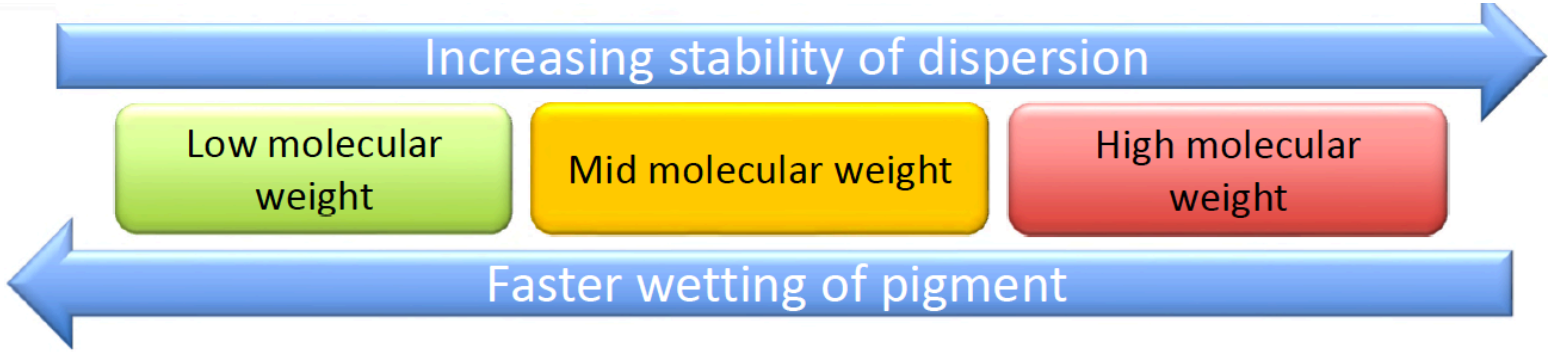
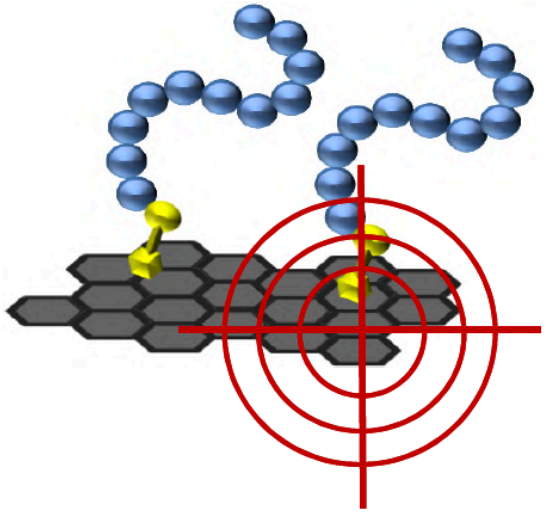
CHOICE OF W&D IS IMPORTANT-GRAPHENE W&D TECHNOLOGY

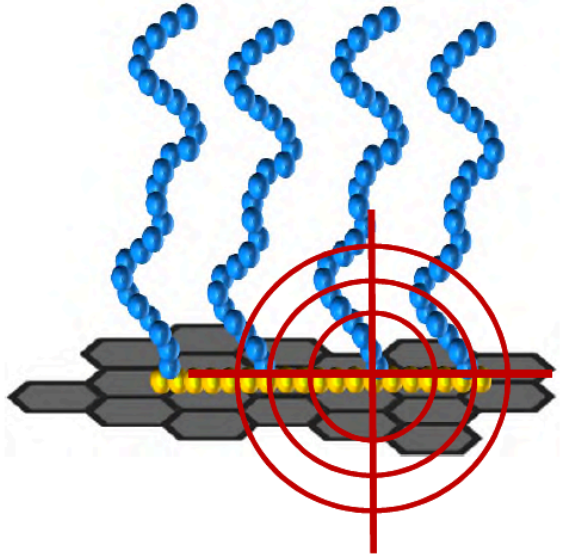
W&D Additive – Concentration play key role



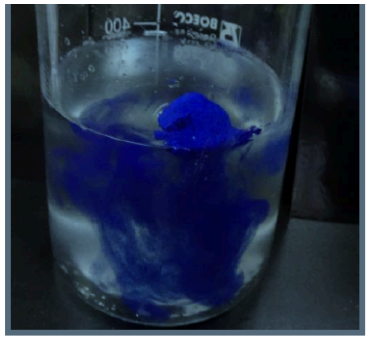
Single anchor (SA)



Multi Anchor (MA)



Poor wetting

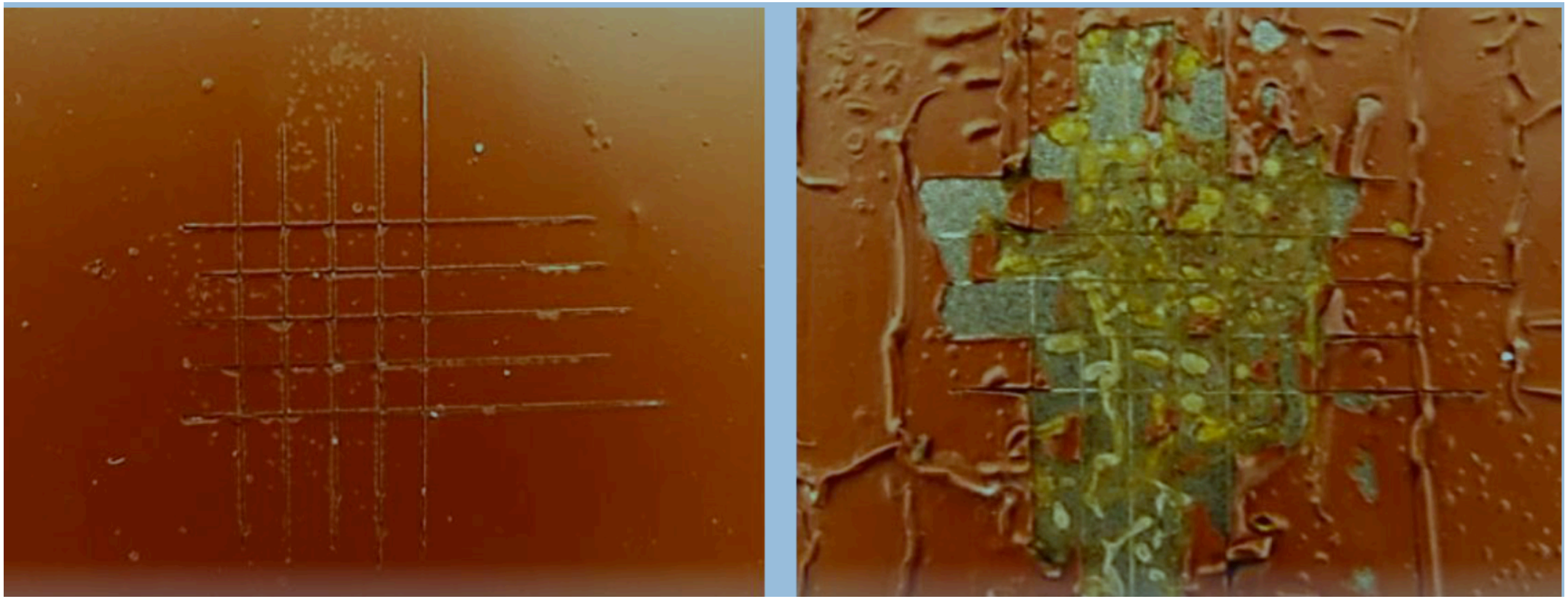


Good wetting

Source: Lubrizol

FUNCTIONALISATION-GRAPHENE DISPERSION TECHNOLOGY

IMPACT of incorrect W&D additives in Water bone Primers



Correct W&D for WB Coating

Wrong W&D for WB Coating
(everything else constant)

Source: Atlanta - BYK

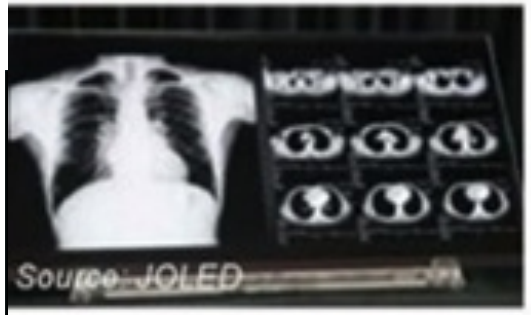
2018 Market Snapshot

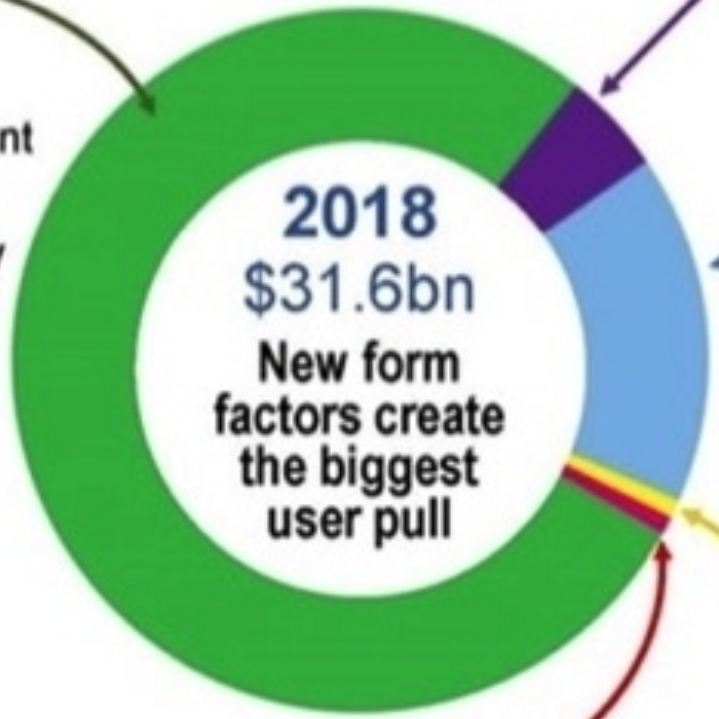
IDTechEx Research

Flexible & Plastic Displays are the majority in 2020

Displays $26.0Bn

- >$10Bn investment in 24 months
- Many new display technologies





Conductive Ink $1.9Bn

- Booming PV market in 2017
- New markets: In Mold Electronics, Stretchable inks, die attach, shielding

Printed & Flexible Sensors $3.6Bn

- Mature: Glucose test strips, force sensors, capacitive sensors
- Establishing: Organic photodetectors, printed temperature sensors, gas sensors

Logic, Batteries, OPV $21M

Companies become more vertical, creating new markets

OLED Lighting $50M

Aesthetic & capability differentiation

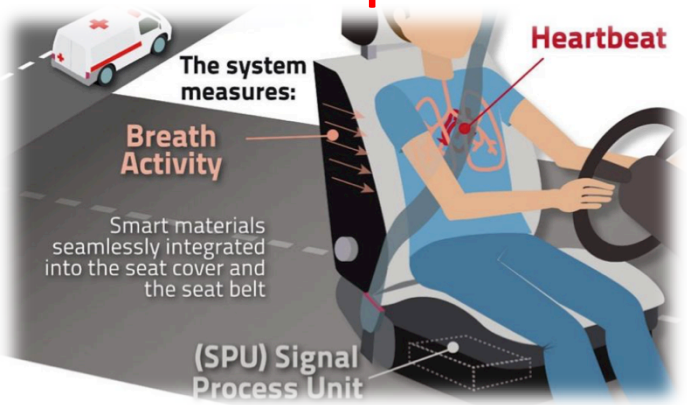
Next generation Automotive/Defence and organic electronics – G-Inks

Automotive

Communication

Flexible electronics

Transport



Fatigue Monitoring

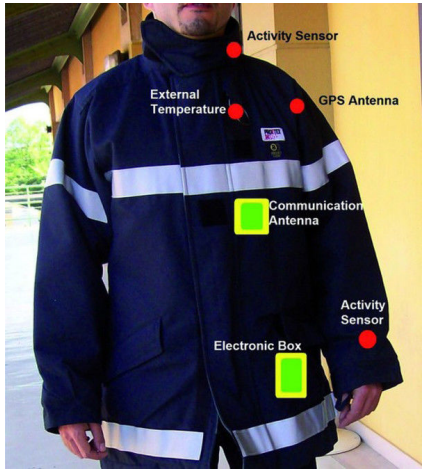
Automotive

Radiator – heat transfer

Sport and Fitness

Motion Analysis

Safety : Defence/Protection



Smart Garments

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