
Usage of Graphene in display technology: “Where Graphene can really over perform, and where not”

Ivica Kolaric

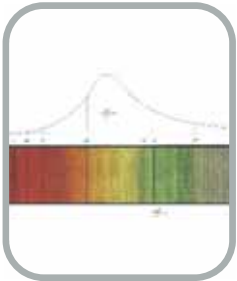
Ivica Kolaric





Joseph von
Fraunhofer

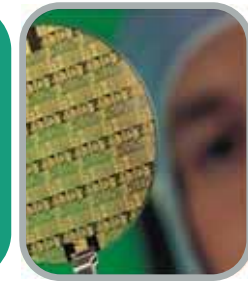
The Fraunhofer-
Gesellschaft



discovery of
„Fraunhofer
Lines“ in the sun
spectrum

Re-
searcher

R&D for the
industry, service
sector and public
administration



new methods of
lens processing

Inventor

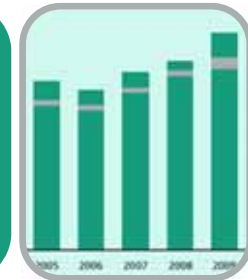
MP3, white LED,
...



head of royal
glass factory

Entre-
preneur

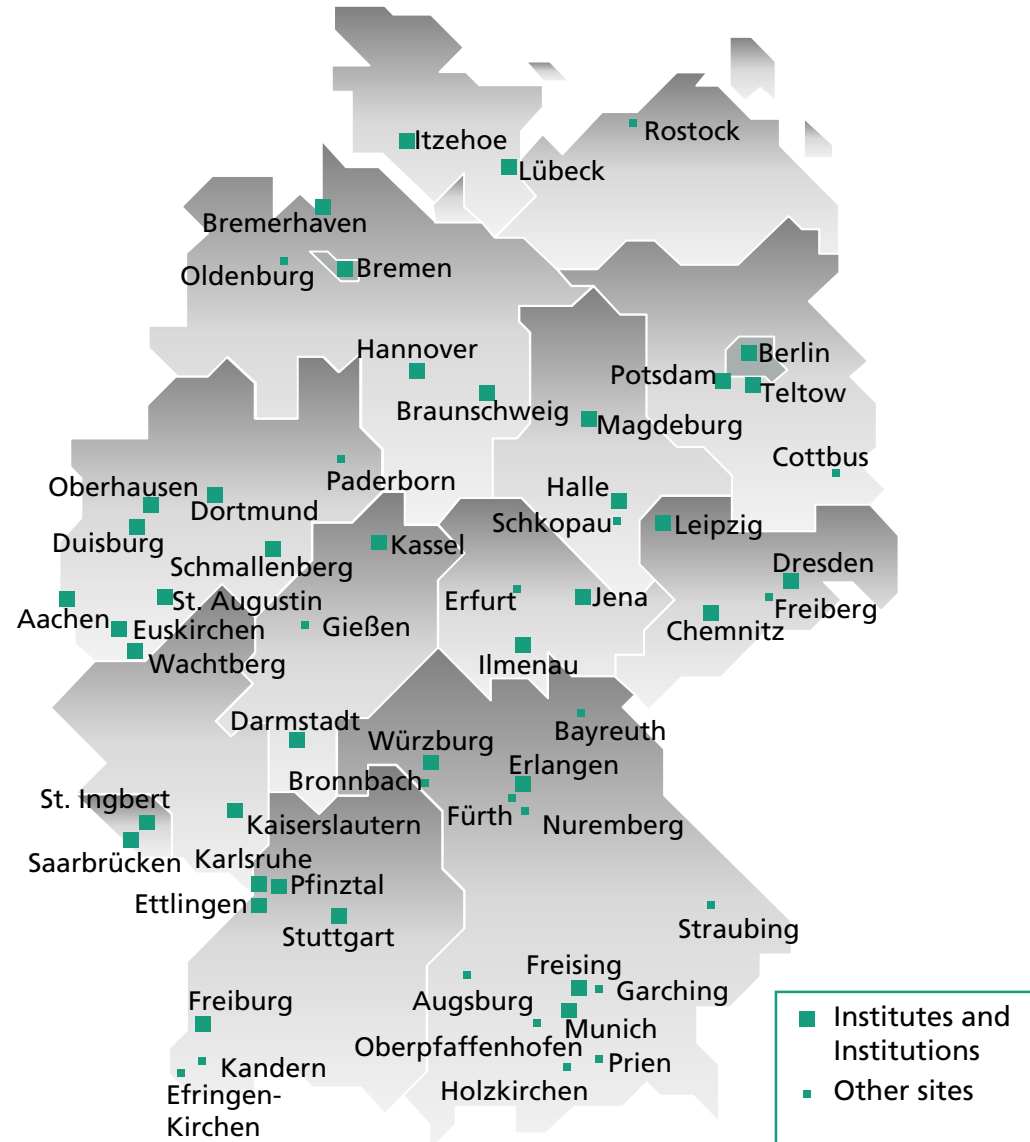
1.8 billion euros
budget per year



Facts and Figures

- More than 22 000 employees
- € 2 billion budget
- 60 institutes

Largest Application
Research Organization in
Europe!



Highlights of Research Projects

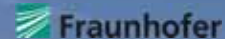
Active Research Environment for the Next Generation of Automobiles

ARENA2036: Flexible production of the future for function-integrated lightweight construction

- PPP
- Duration: 15 years
- Research factory as integration platform
- Sponsored by:



DAIMLER



Research highlights

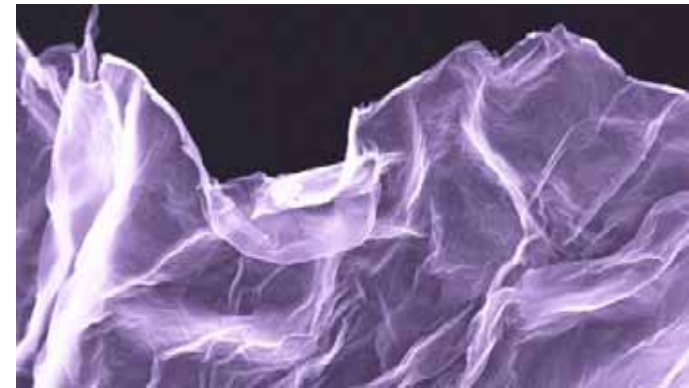
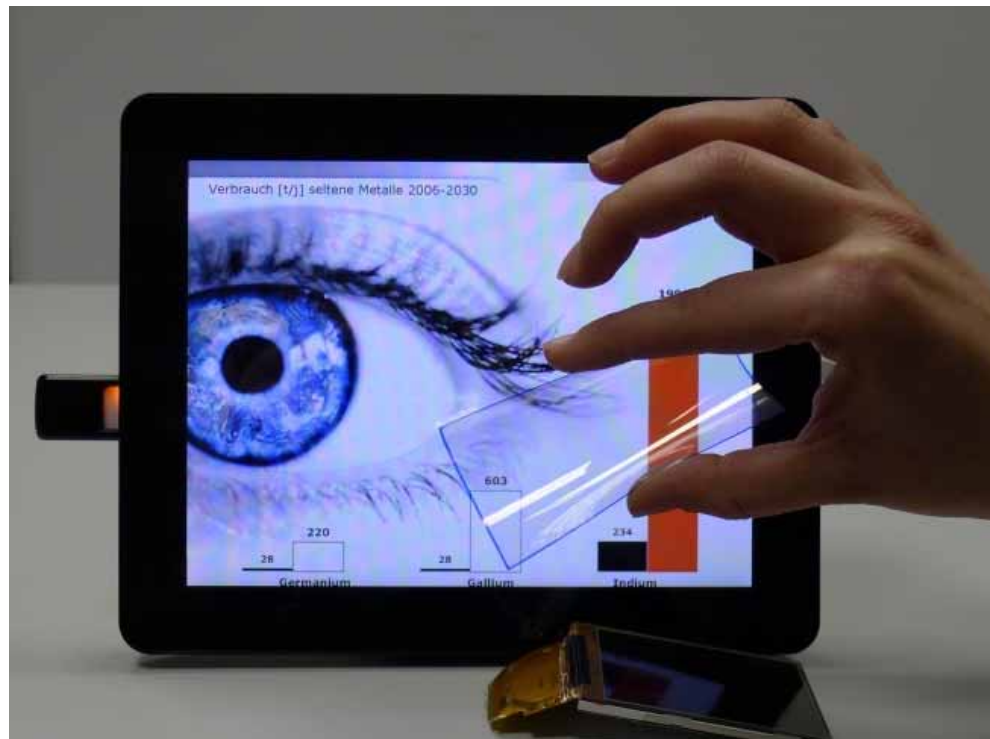
Household robot Care-O-bot[®] 3

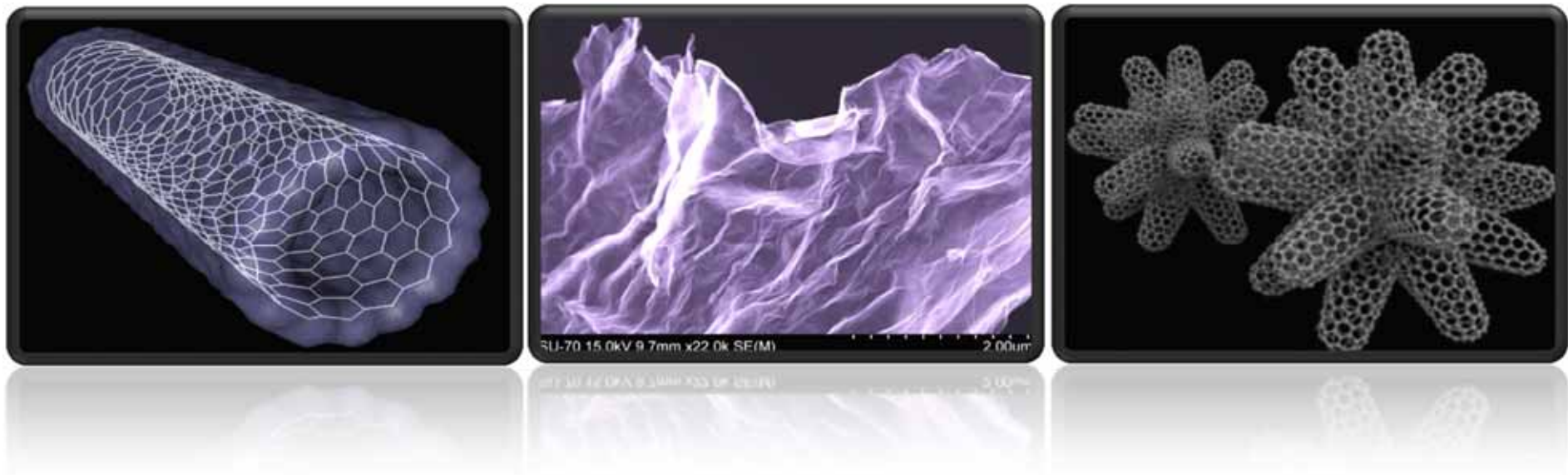


Highlights of Research Projects

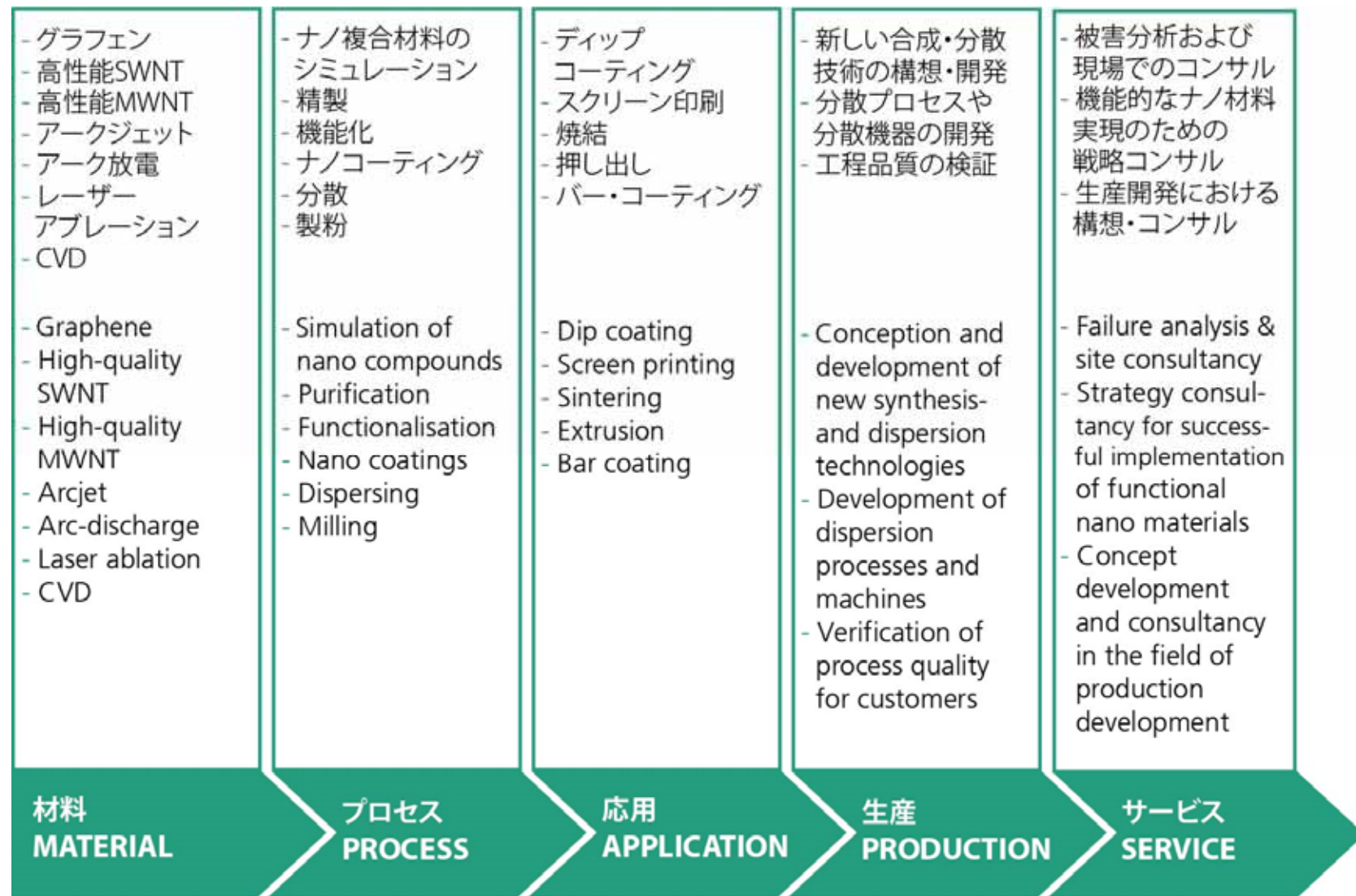
EcoTouch as an Example of Functional Surfaces

Transparent electrodes based on carbon nanotubes





Service Range at Fraunhofer IPA



History of Fraunhofer IPA's Research on Functional Materials

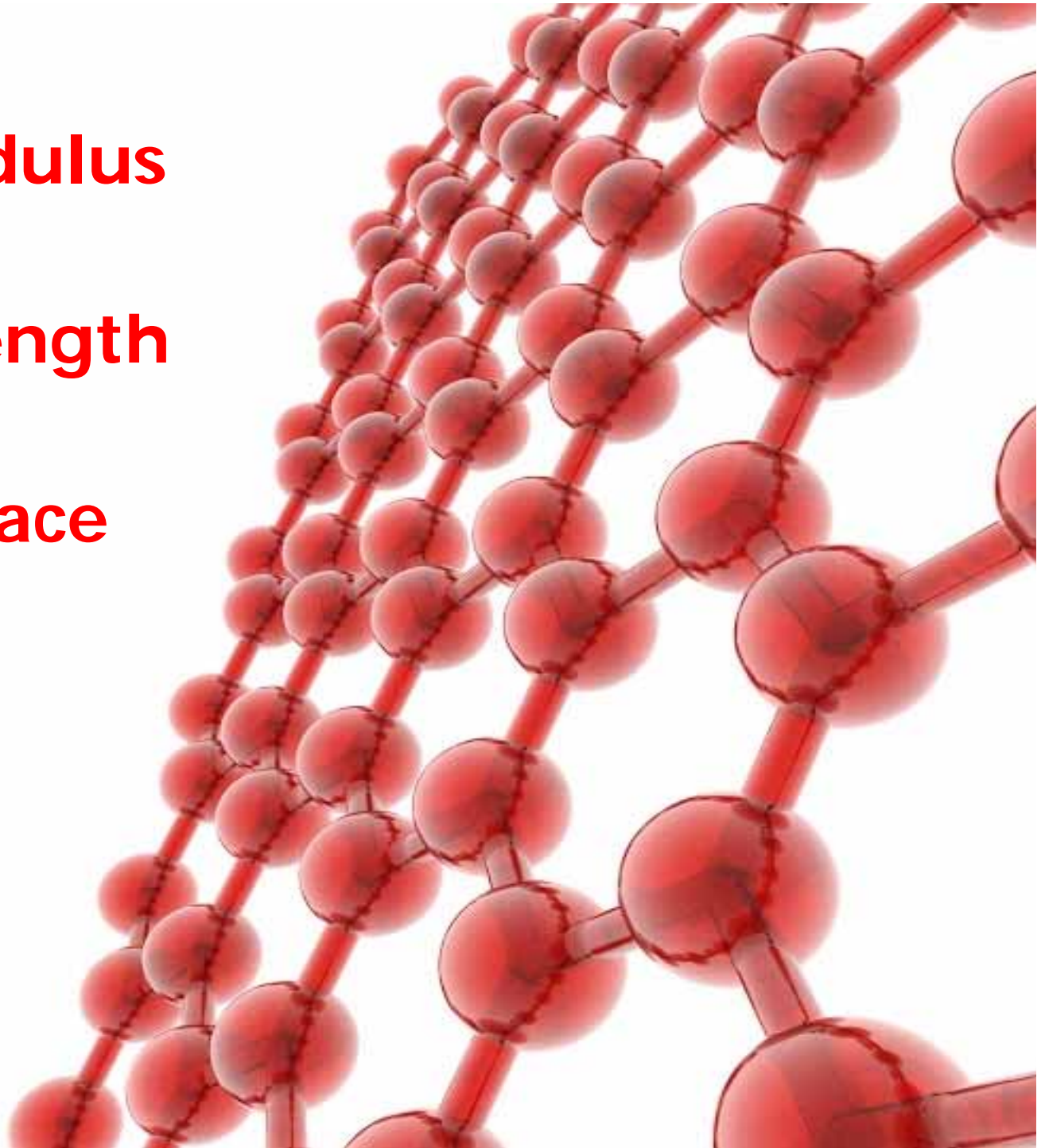


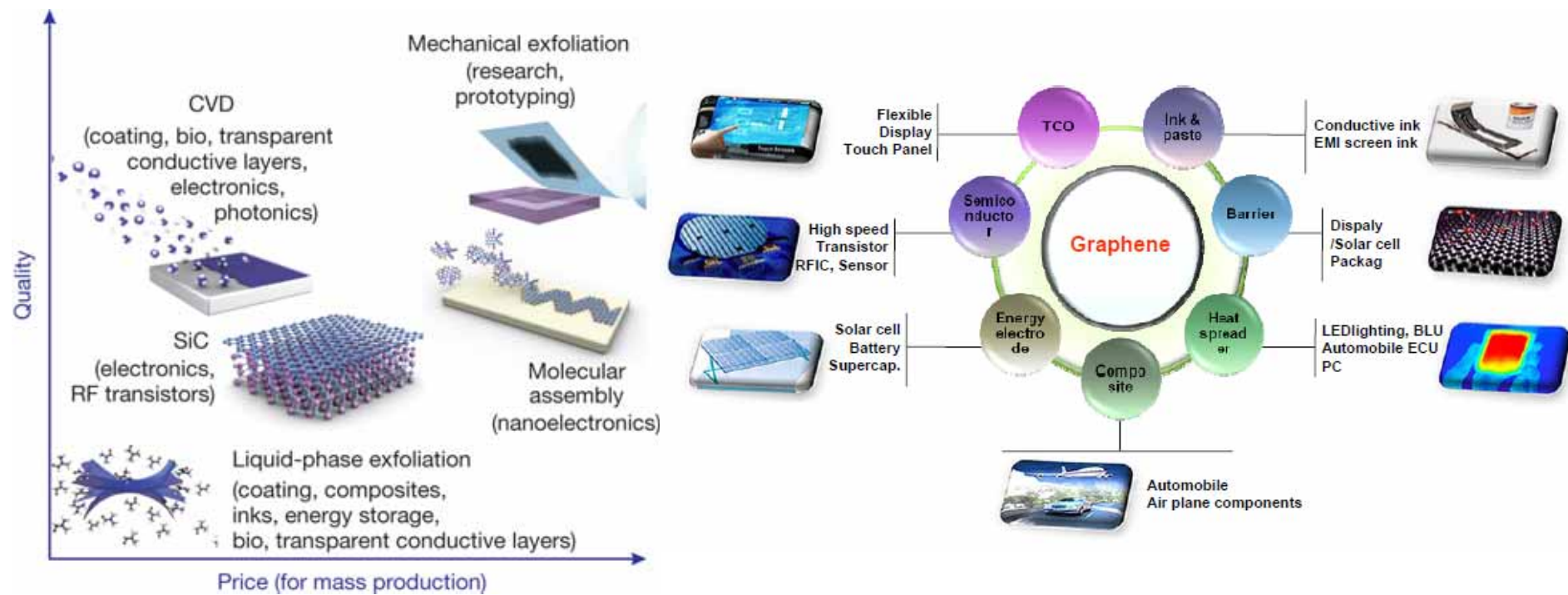
Young's modulus
~ 1 100 GPa

Fracture strength
125 GPa

Specific surface
area

2 630 m²/g





Quelle: K.S. Novoselov *et al. Nature* **490**, 192-200 (2012)
doi:10.1038/nature11458

Quelle: Andrea Ferrari, Graphen Roadmap to Applications 2013



NATURE | BREAKING NEWS

Billion-euro brain simulation and graphene projects win European funds

Efforts to model the whole brain and to push graphene into the marketplace triumph in flagship contest.

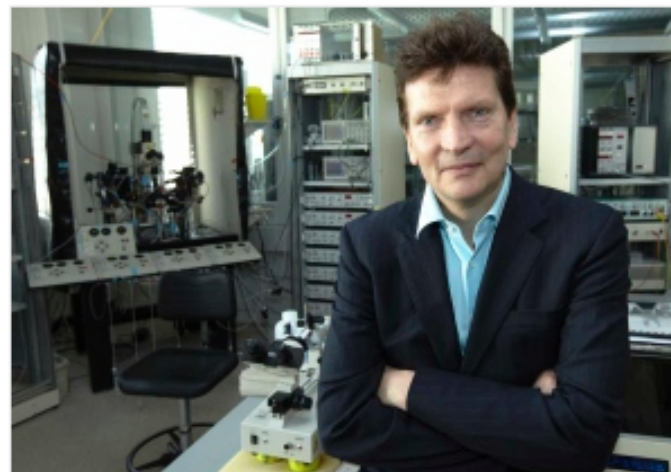
Alison Abbott

23 January 2013

The European Commission has selected the two research proposals it will fund to the tune of half-a-billion euros each after a two-year, high-profile contest.

The Human Brain Project, led by neuroscientist Henry Markram at the Swiss Federal Institute of Technology (EPFL) in Lausanne, plans to simulate everything known about the human brain in a supercomputer — a breathtaking ambition that has

For graphene research 1000 million € for 10 Years



Henry Markram is co-director of the Human Brain

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Nature | 24 January 2013

December 29, 2013 6:52 pm

UK regulator warns on graphene ‘investment’ schemes

By Jonathan Eley

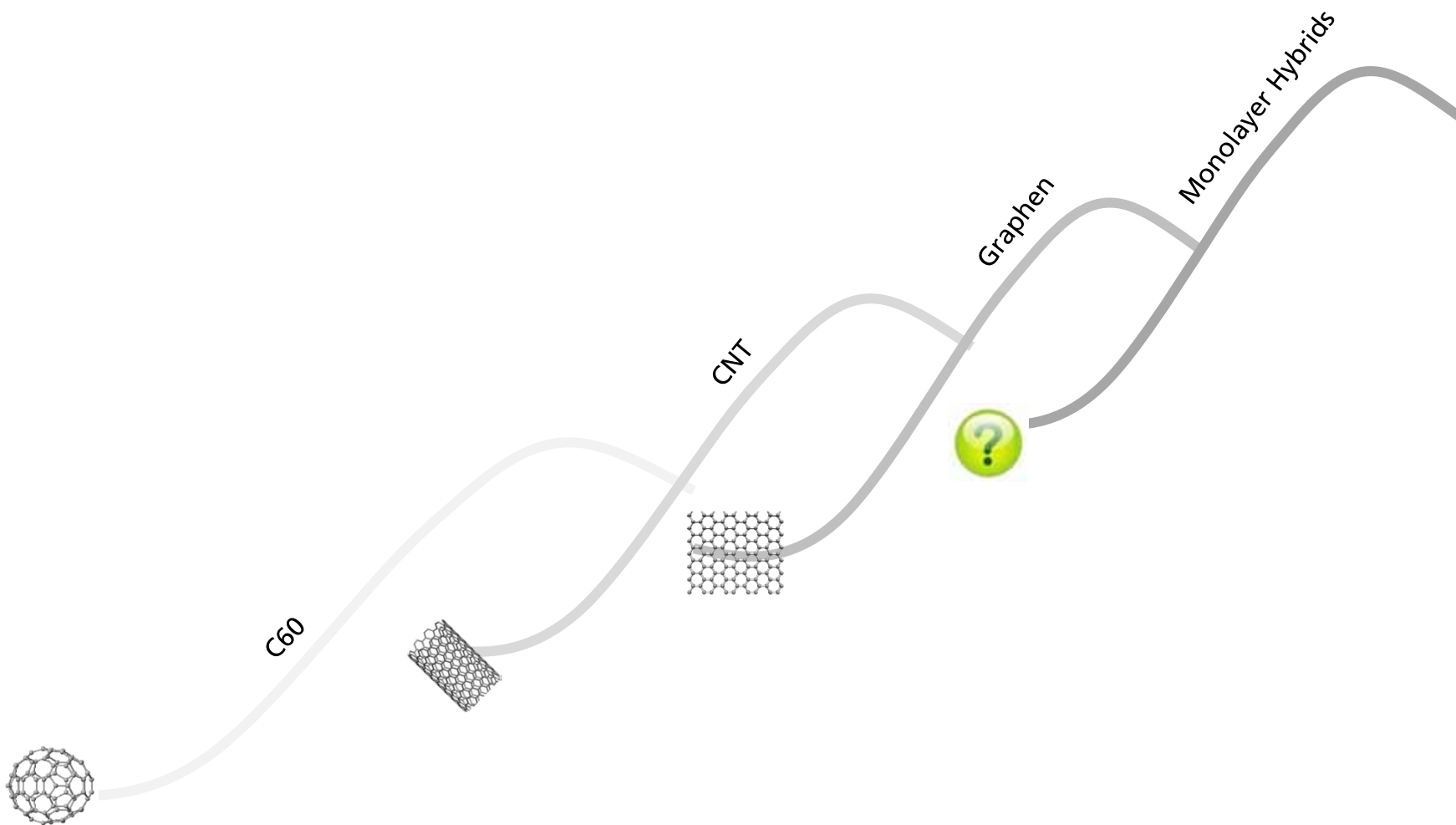
Financial regulators in the UK have warned that consumers are increasingly being targeted by “dubious” companies offering investment opportunities in graphene, the carbon-based wonder material with a vast range of potential applications.

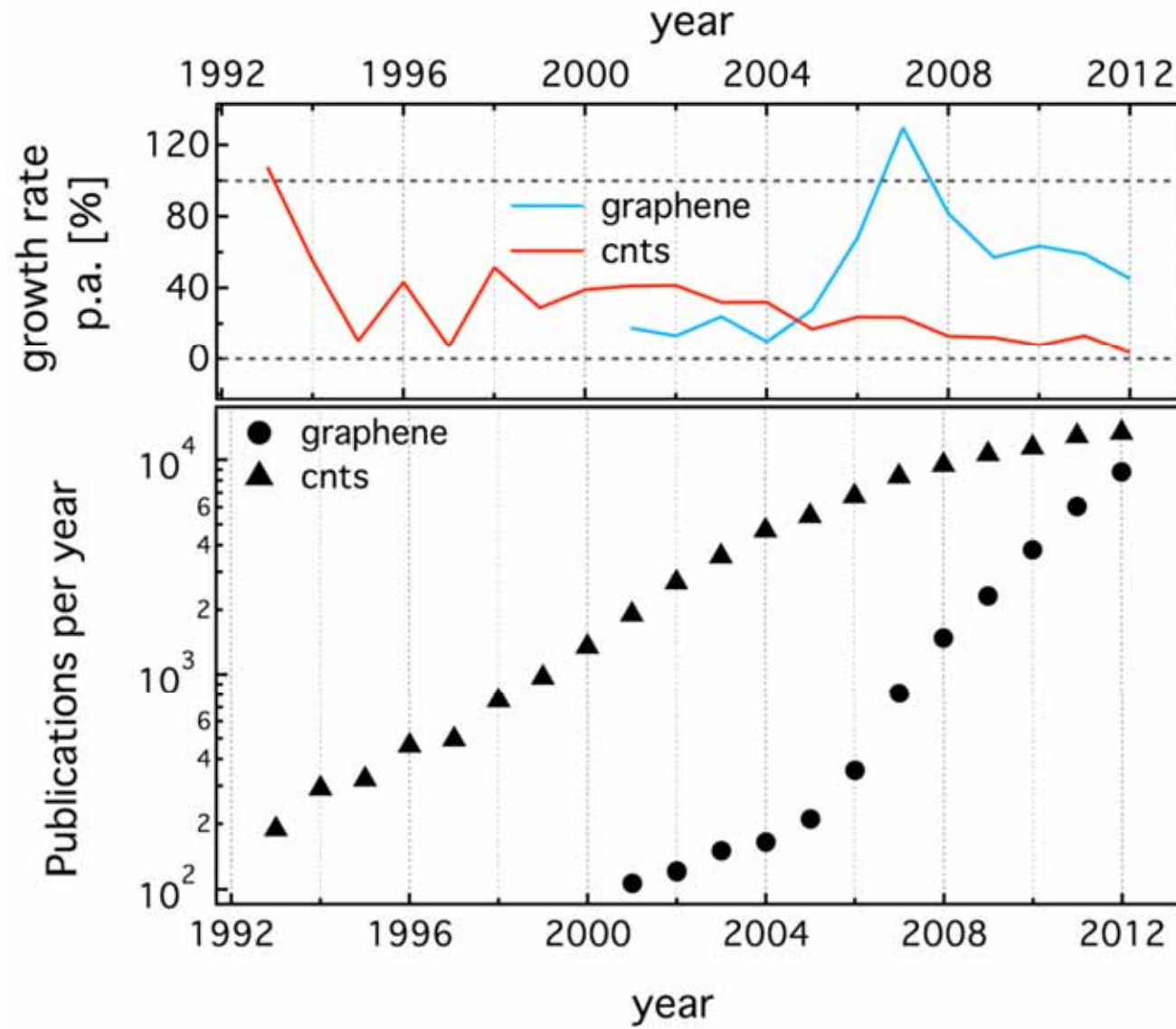
The Financial Conduct Authority will on Monday post new warnings on its website relating to “unscrupulous brokers” who “appear to be taking advantage of the hype surrounding graphene and are using uncertainty about its future as a way to entice consumers to invest”.

It decided to take action after finding details relating to a graphene investment company on the computer servers of a suspected UK ‘boiler room’ operation that it investigated.

Graphene, discovered in 2004 by Andre Geim and Konstantin Novoselov at the University of Manchester, consists of endless two-dimensional sheets of carbon atoms. This structure gives graphene remarkable mechanical and electronic properties that are being developed for use in products such as display screens, electrical circuits, solar cells and batteries.

Although governments and companies are pouring billions of dollars into graphene research and development it is unlikely to be used commercially on a significant scale until around 2020.





Overview

Graphene family	Graphene	BN „white Graphen“	Silicene	BCN BC ₃	Fluorographene	Graphene oxide
2D chalcogenides	MoS ₂ , WS ₂ , MoSe ₂ , WSe ₂		Semiconducting dichalkogenides: MoTe ₂ , WTe ₂ , ZrS ₂ , ZrSe ₂ etc.		Metallic dichalkogenides: NbSe ₂ , NbS ₂ , TaS ₂ , TiS ₂ , NiSe ₂ etc.	
					Layered semiconductors: GaSe, GaTe, InSe, Bi ₂ Se ₃ etc.	
2D oxides	Micas, BSCCO	MoO ₃ , WO ₃	Perovskite-type: LaNb ₂ O ₇ , (Ca,Sr) ₂ Nb ₃ O ₁₀ , Bi ₄ Ti ₃ O ₁₂ , Ca ₂ Ta ₂ TiO ₁₀ etc.			Hydroxides: Ni(OH) ₂ , Eu(OH) ₂ etc
	Layered Cu oxides	TiO ₂ , MnO ₂ , V ₂ O ₅ , TaO ₃ , RuO ₂ etc.				Others

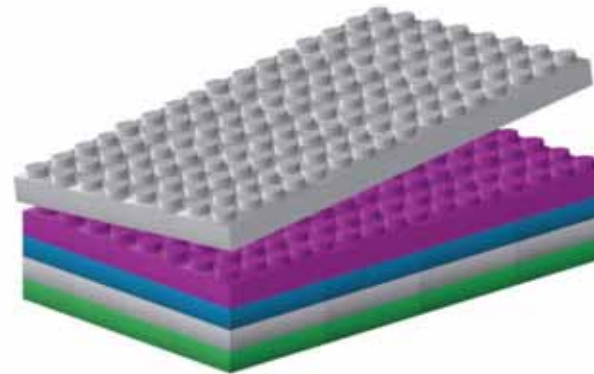
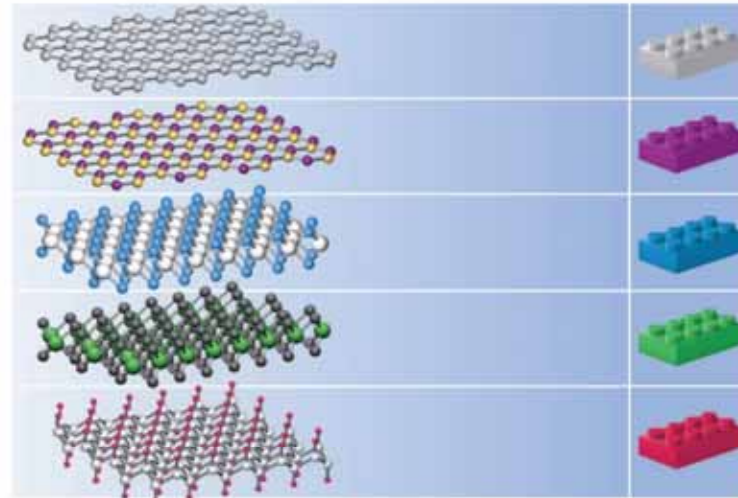
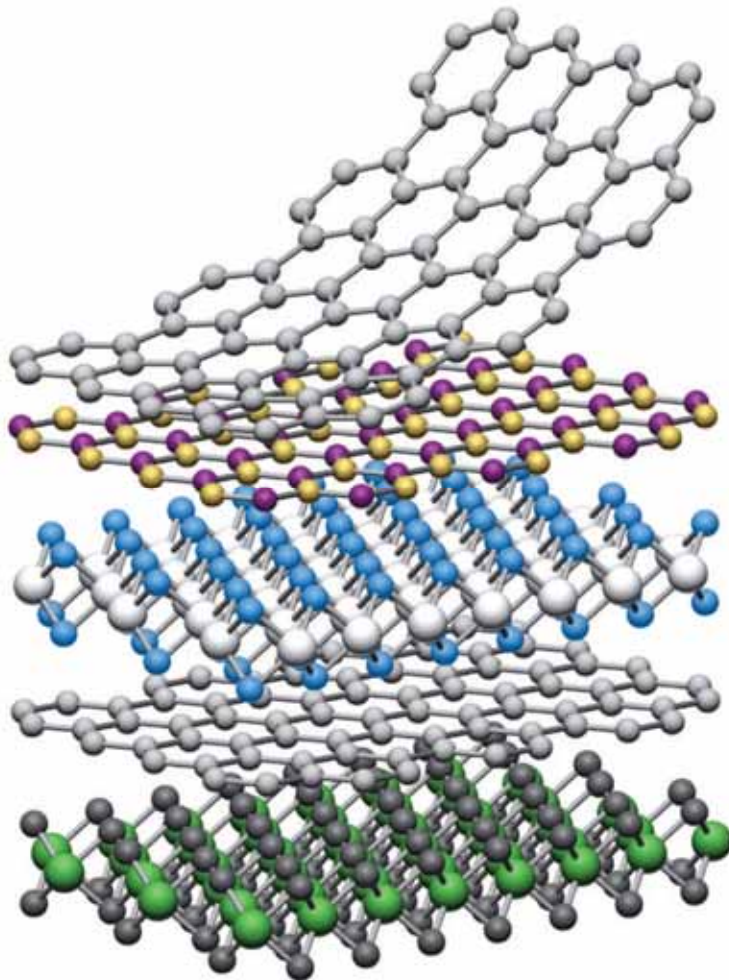
stable under ambient conditions (room temperature in air)

probably stable in air

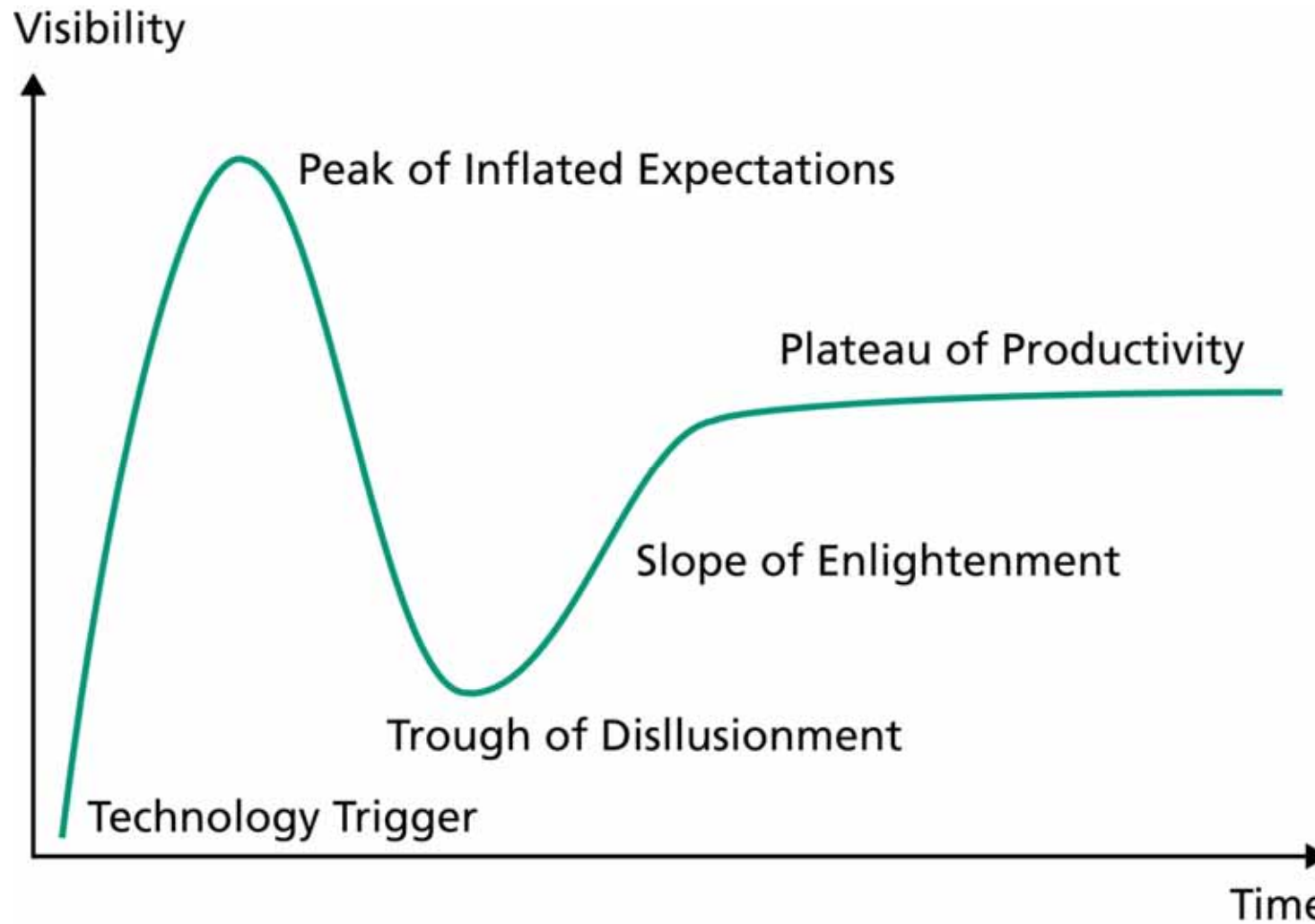
unstable in air but that may be stable in inert atmosphere

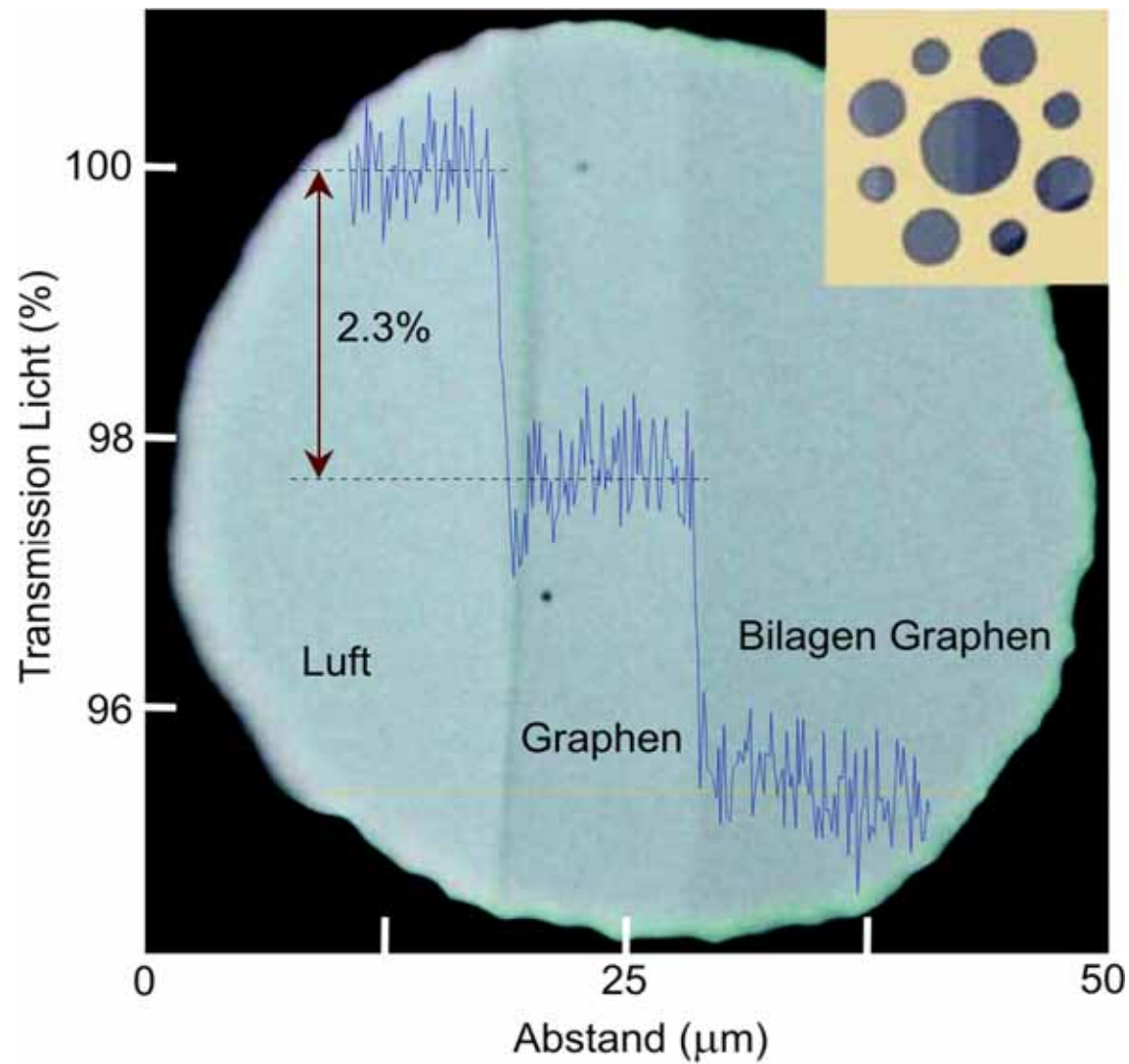
A K Geim and I V Grigorieva, *Nature*, 2013, **499**, 419 (DOI:10.1038/nature12385)

Motivation



Gartner's Hype-Cycle





Source: R. Nair *et al.*, Science **320**, 1308 (2008)

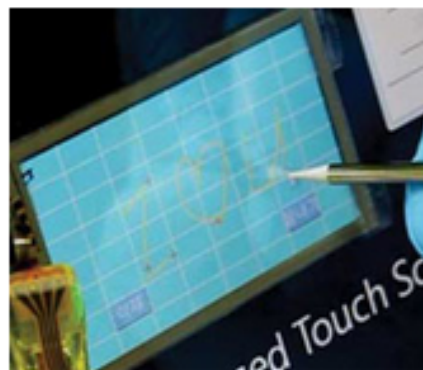




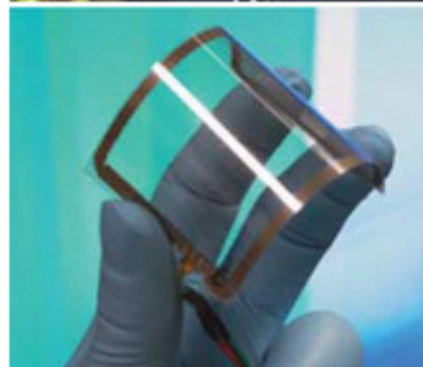
Flexible Touch Screen Made with Printed Graphene

Sheets of atom-thick carbon could make displays that are super fast.

By Nidhi Subbaraman on June 21, 2010



Graphene, a sheet of carbon just one atom thick, has spectacular strength, flexibility, transparency, and electrical conductivity. Spurred on by its potential for application in new devices like touch screens and solar cells, researchers have been toying with ways to make large sheets of pure graphene, for example by shaving off atom-thin flakes and chemically dissolving chunks of graphite oxide. Yet in the thirty-some years since graphene's discovery, laboratory experiments have mainly yielded mere flecks of the stuff, and mass manufacture has seemed a long way away.



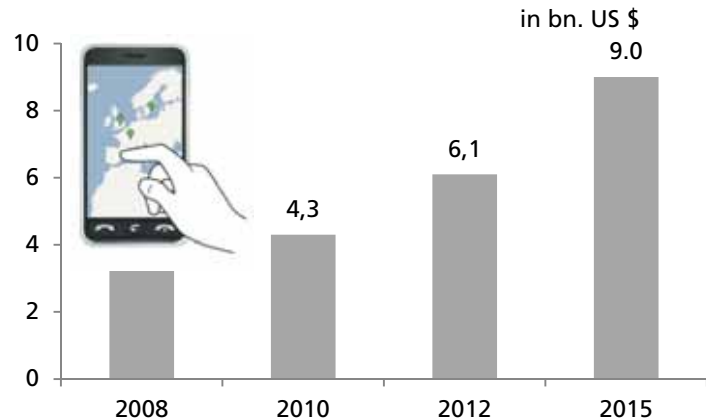
"The future of the field certainly isn't flaking off pencil shavings," says [Michael Strano](#), a professor of chemical engineering at MIT. "The large-area production of monolayer graphene was a serious technological hurdle to advancing graphene technology."

Now, besting all previous records for synthesis of graphene in the laboratory, researchers at Samsung and [Sungkyunkwan University](#), in Korea, have produced a continuous layer of pure graphene the size of a large television, spooling it out through rollers on top of a flexible, see-through, 63-centimeter-wide polyester sheet.

See through:
Researchers have
created a flexible
graphene sheet with
silver electrodes.

ECO TOUCH – conductive ink with CNT

Sales Volume Touch Module



Source: Display Search 2009 Touch Panel Market Analysis

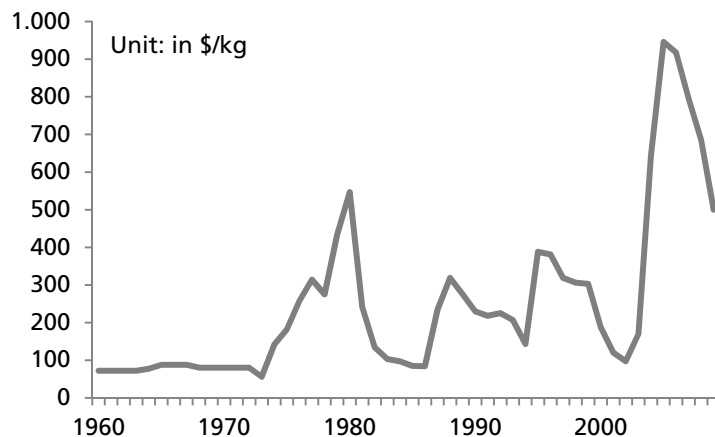
ECO TOUCH concept

- *ECO TOUCH I*: conductive polymer + CNT
300Ω/□ at 84% transparency, improved in environmental stability
- *ECO TOUCH II*: pure single-walled CNT
300Ω/□ at 85% transparency, improved in UV-light resistance

Merits:

- Flexible
- Sustainable (no rare metal, recyclable material)
- Easy and energy-saving process

Indium Price Fluctuation



Source: U.S. Geological Survey, Indium Statistics, 2010

Energy-saving process

Conventional process:



sputter = 890 Wh/qm

ECO TOUCH Process:



coating = 50 Wh/qm

Source: Fraunhofer FEP

Source: Fraunhofer IPA

NEWS

Breakthrough in CNT display design

Antony Savvas

Monday 09 May 2005 16:54



Motorola Labs has unveiled a colour video display prototype based on proprietary Carbon Nanotube (CNT) technology, a breakthrough technique that could create large, flat panel displays with superior quality, longer lifetimes and lower costs than current offerings.

Optimised for a 42in High Definition Television (HDTV) that is less than 1in thick, the prototype NED (Nano Emissive Display) 5-inch section uses CNTs to show how the design and fabrication of flat panel displays can be substantially changed.

NED technology is a scalable method of growing CNTs directly onto glass to enable an energy efficient design which excels at emitting electrons. The cost-effective process and design demonstrates the potential to create longer-lasting NED flat panel displays with high brightness and colour purity, said Motorola.

"With over 15 years experience and 160 patents in CNT and flat panel displays, we have developed a technology that could enable the next generation of large size flat panel displays to deliver an extraordinary visual experience at a fraction of current prices," said

Latest I

[Indian I](#)

[E-comm](#)

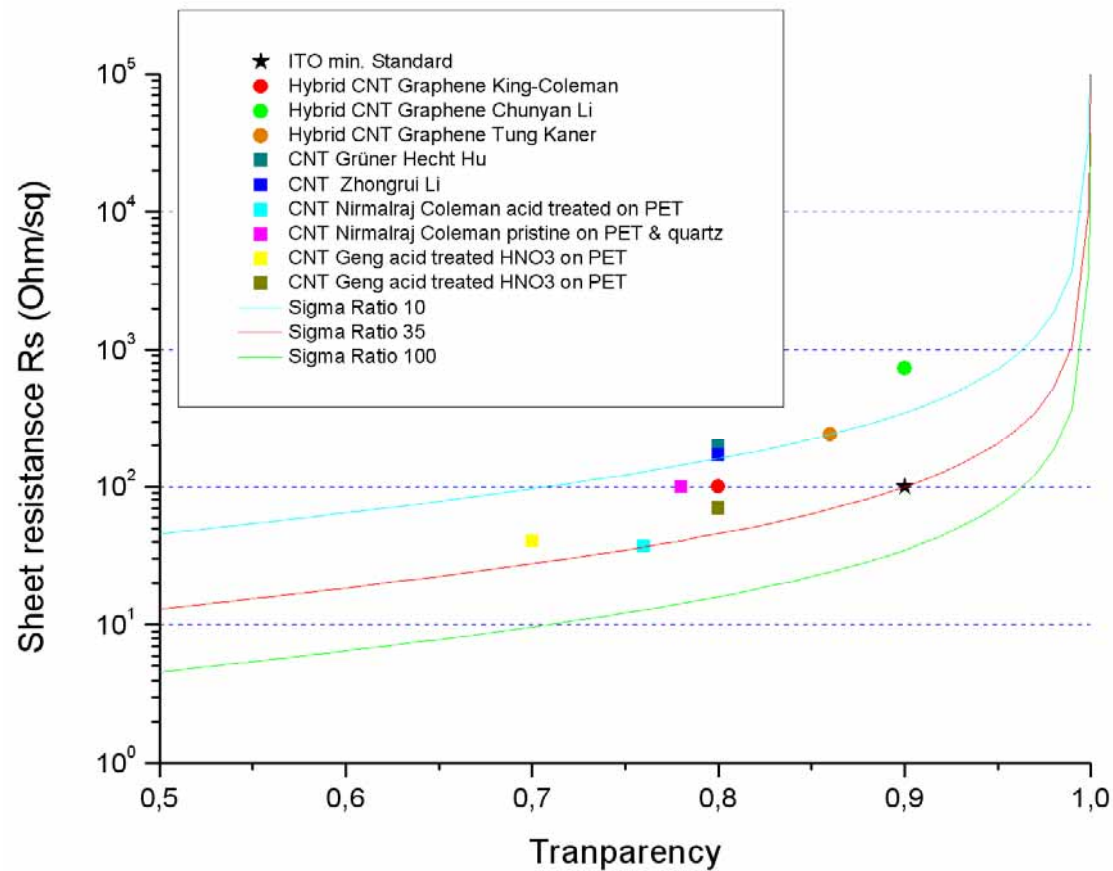
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[Red Oc
flaws, e](#)

[G-Clou
growth](#)

Hot Top

Figure of Merit



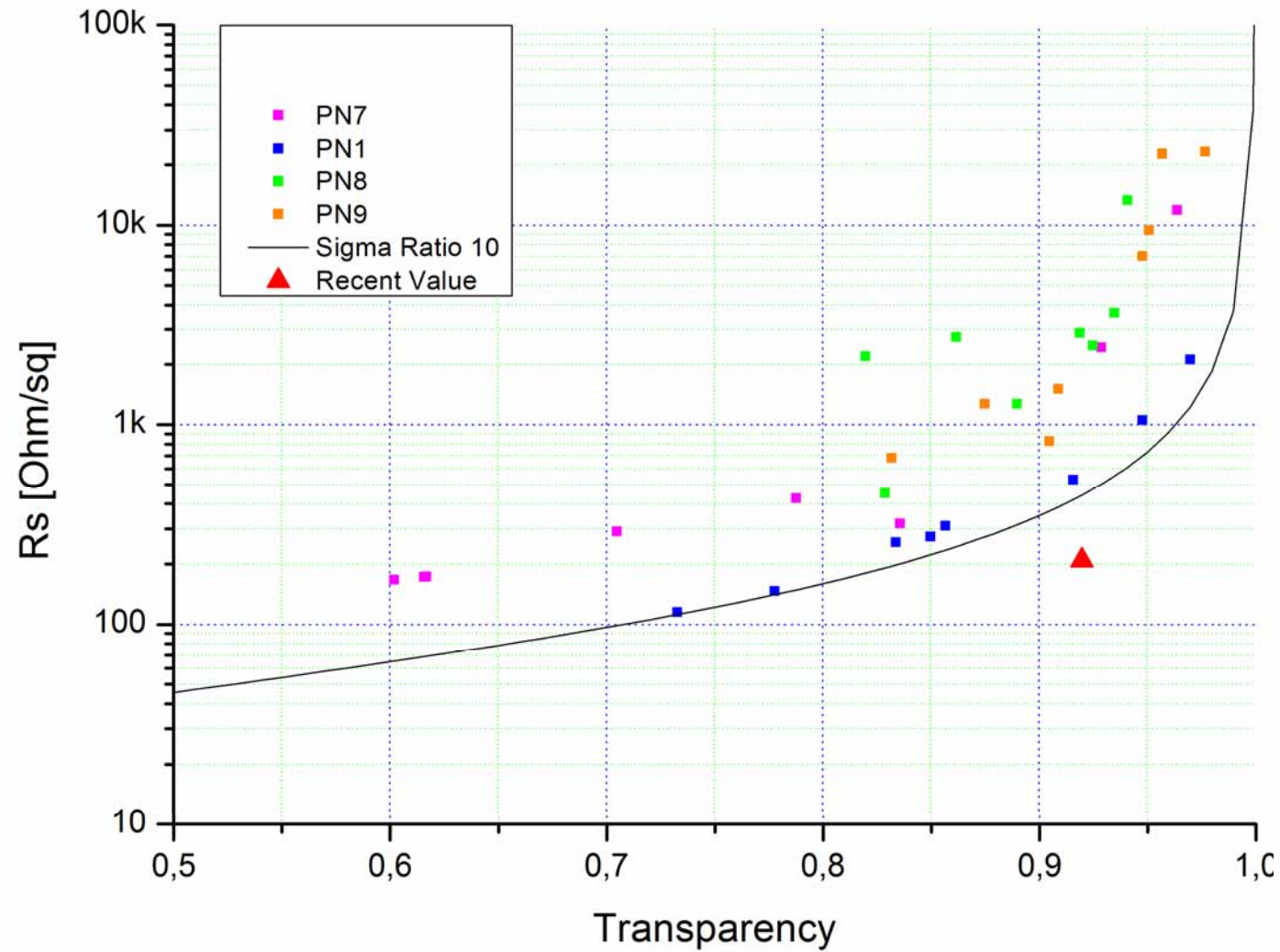
Ratio of optical conductivity to electrical conductivity

$$T(\lambda) = \left[1 + \frac{188,5}{R_s} \frac{\sigma_{Op}(\lambda)}{\sigma_{DC}} \right]^{-2}$$

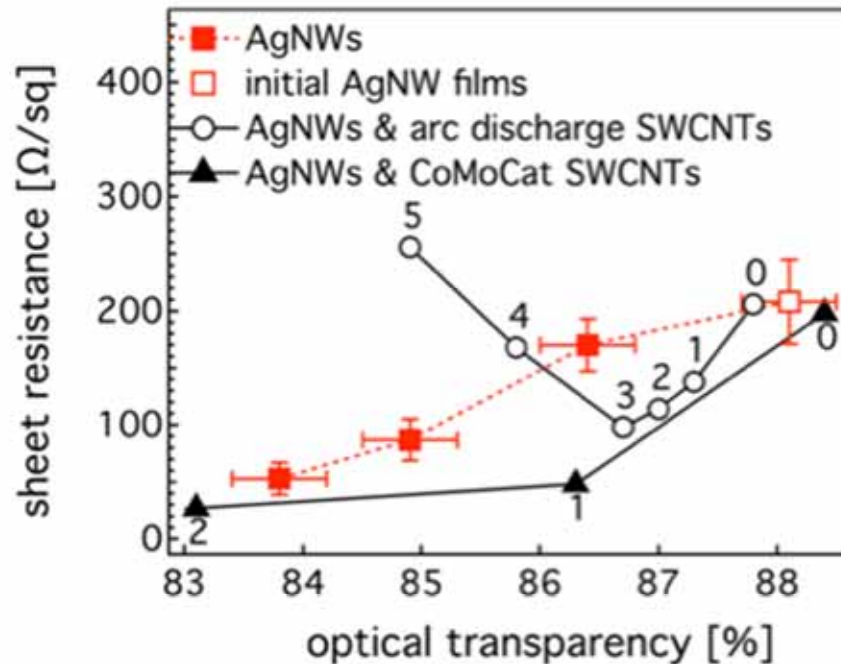
For a layer with 100 Ohm/sq and a transparency of 90%

$$\frac{\sigma_{Op}}{\sigma_{DC}} = 35$$

CNT TCF Values



MATERIALS FOR TRANSPARENT ELECTRODES – AgNW/SWCNT hybrid films



AgNWs

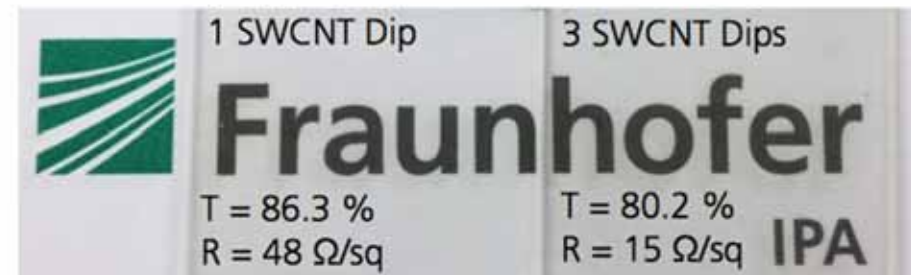
- ✓ High conductivity
- ✓ Low temperatures
- ✓ Moderately bendable

- Haze
- Electromigration
- Percolation Threshold

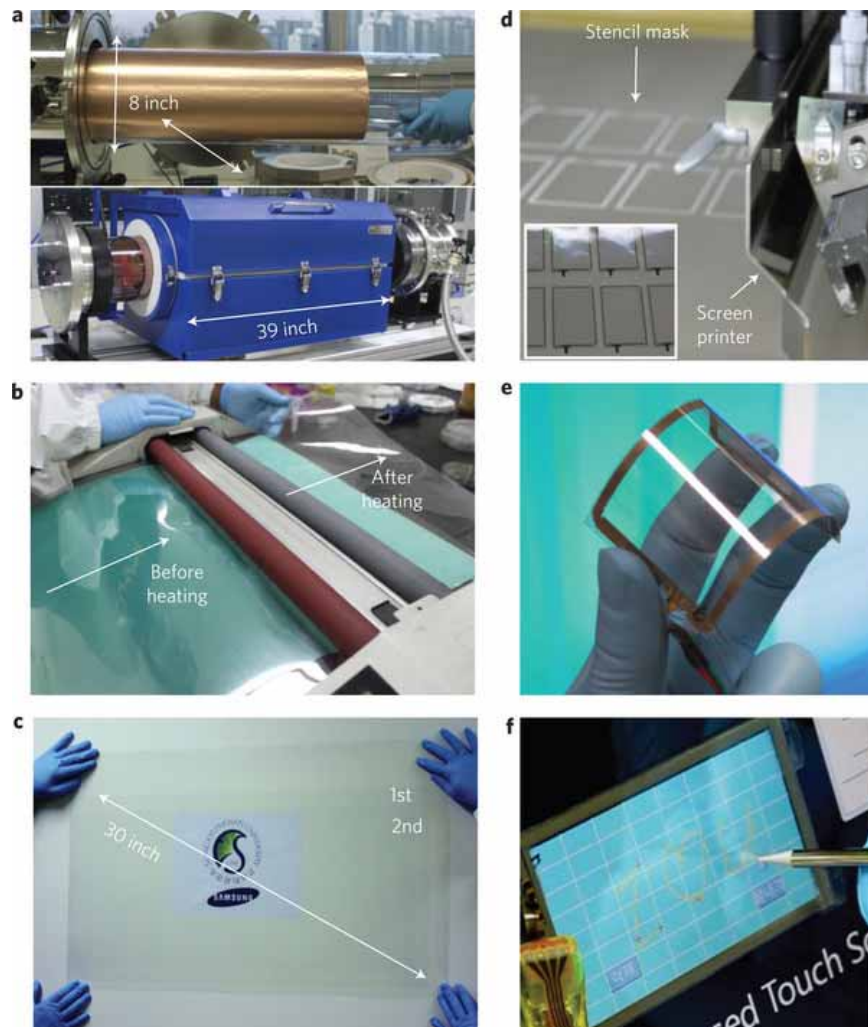
SWCNTs

- ✓ Low temperatures
- ✓ Bendable
- ✓ Stretchable

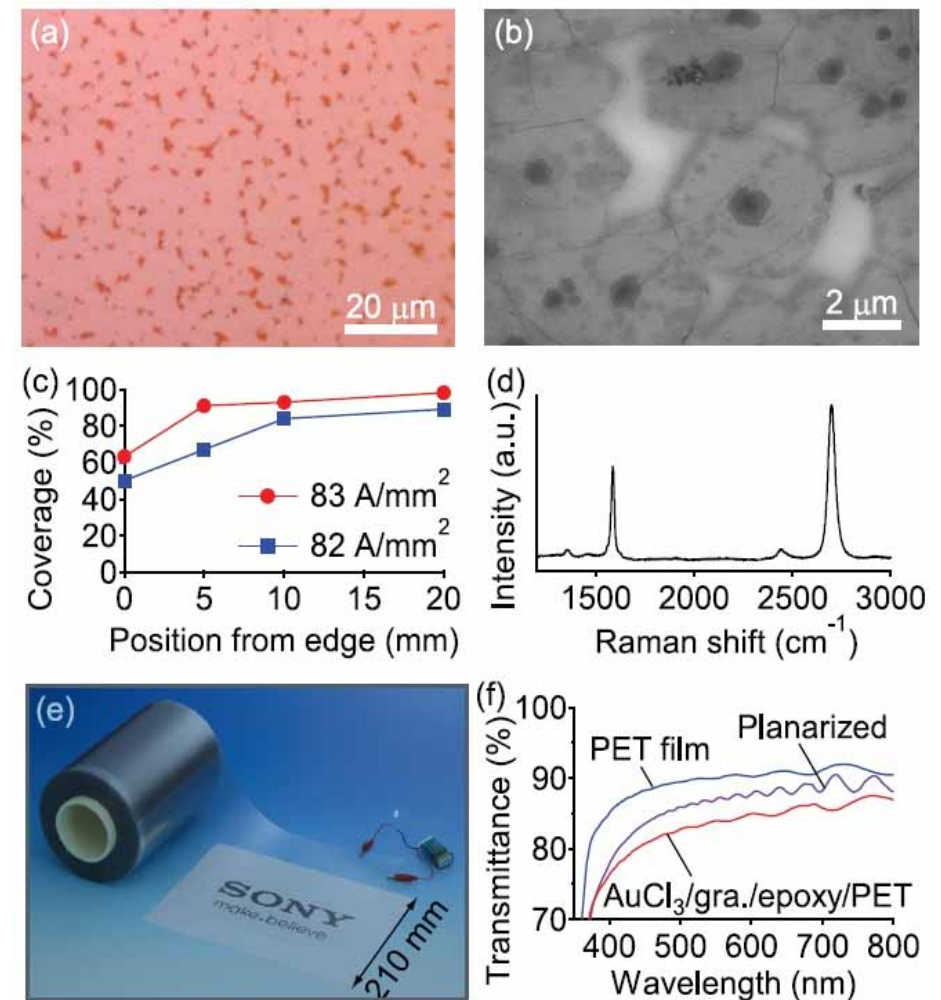
- Low conductivity
- Ink purification
- Percolation threshold



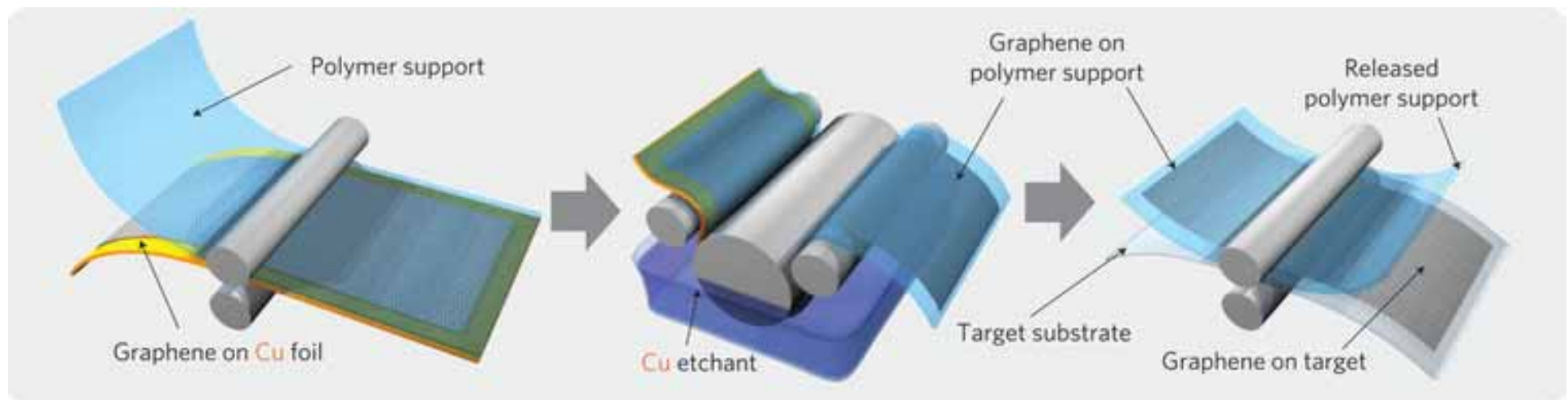
AgNW films (before: 197 Ohm/sq @ 88% T) after dip coating with SWCNTs



Quelle: S. Bae et al., *Nature Nanotechnol.*, 2010, **5**, 574.



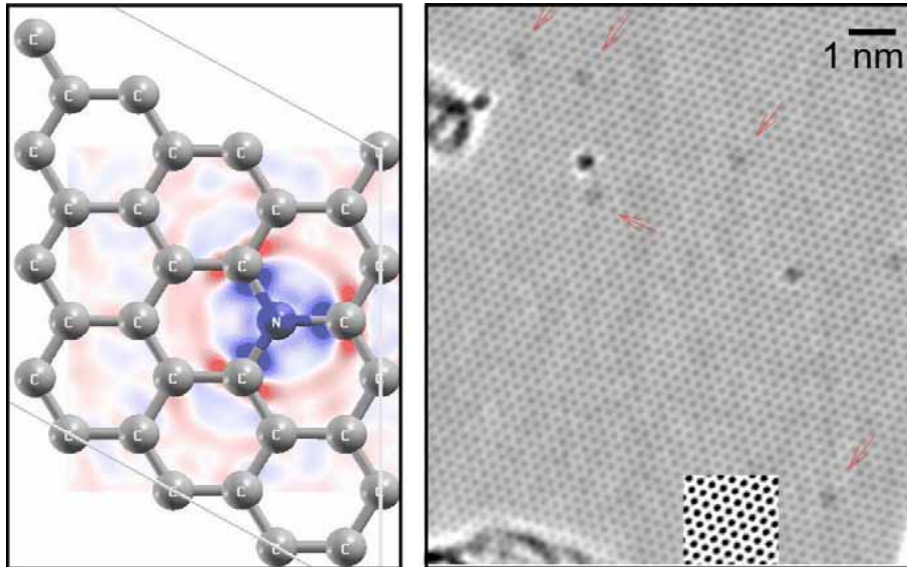
Quelle: T. Kobayashi et al., *Appl. Phys. Lett.*, 2013, 102, 023112.



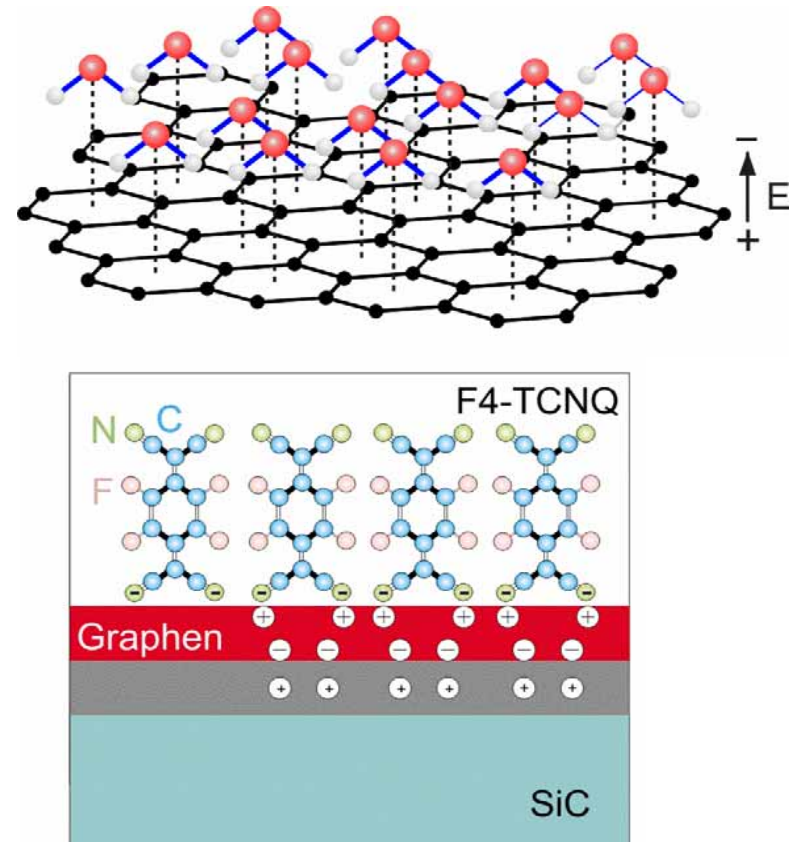
Source: Sungkyunkwan University (Korea), Bae Sukang

Doping of Graphene

Substitution



Adsorption of Molecules

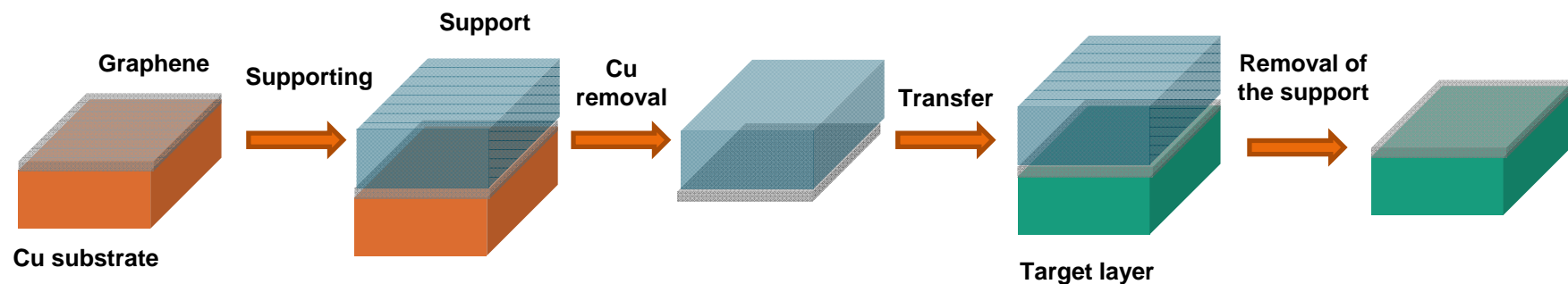


Source: J.Smet MPI

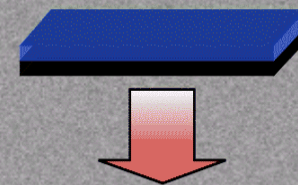
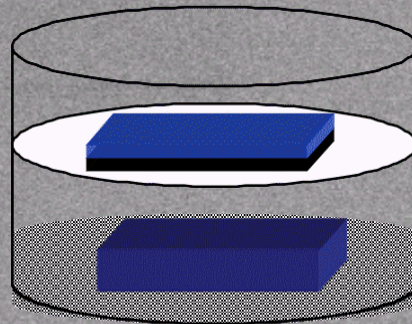
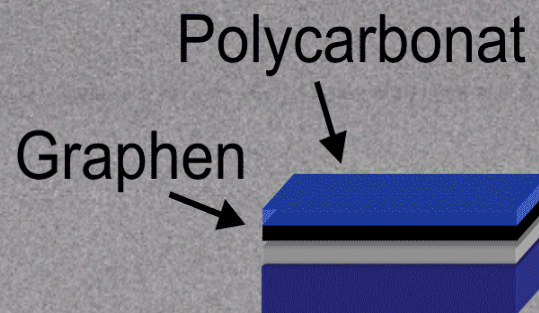
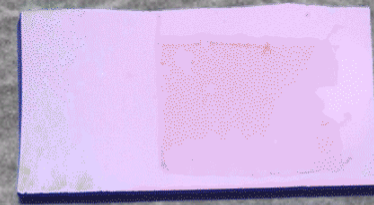
Graphene Transfer

Demands on industrial transfer techniques

- Up-scalable
- Reproducibility
- Economical
- Environmentally friendly
- Simple with standard machinery
- Automated



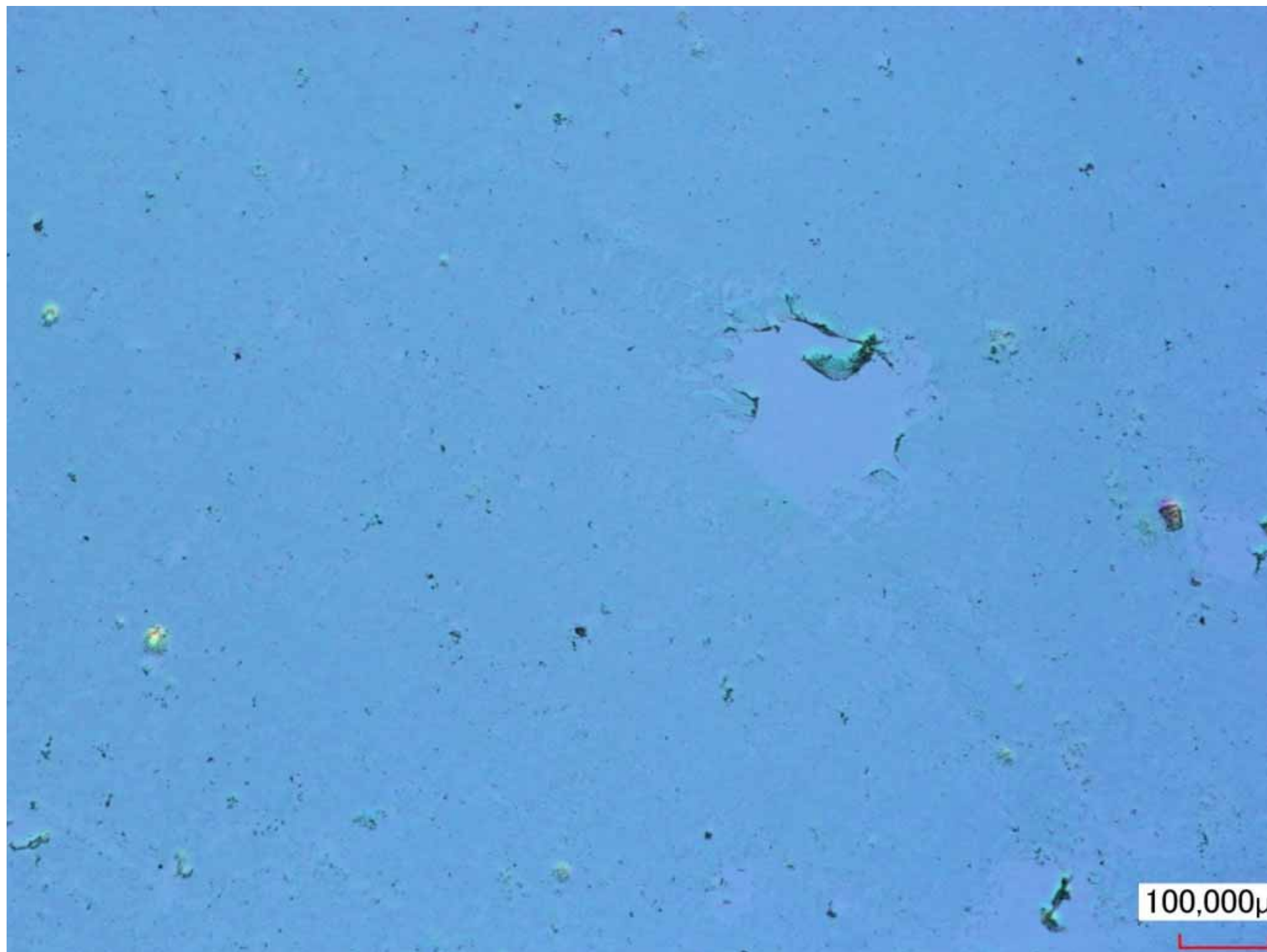
2 μm



transparent

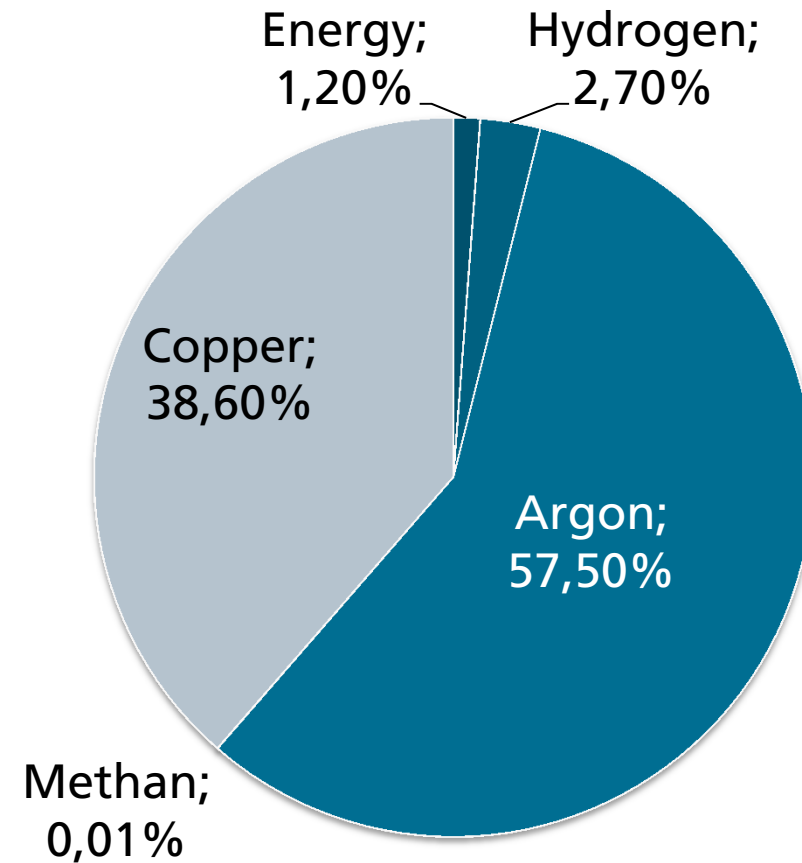


Quelle: Manchester Universität



Production Cost of 1m² Graphene

Cost (€/1m²): ~**197 €**
Time: ~**3 h**
Temperature: ~**1,000 °C**
Pressure: ~**1 atm**

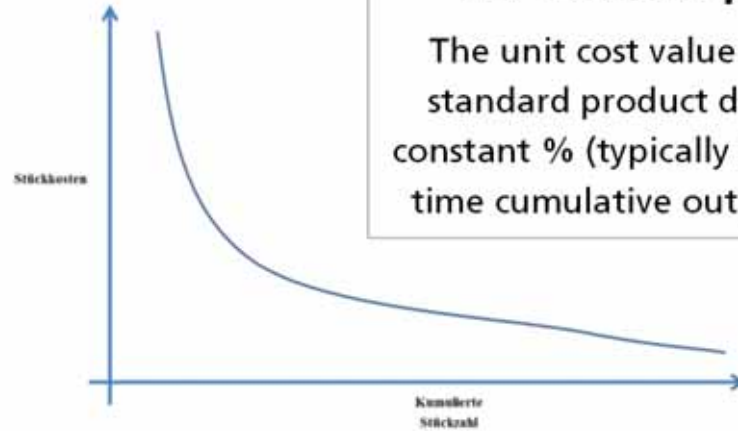




>90% cost saving potential
with recycling



~8 € m² Graphene
(* @lab-scale)



The “Law of Experience”

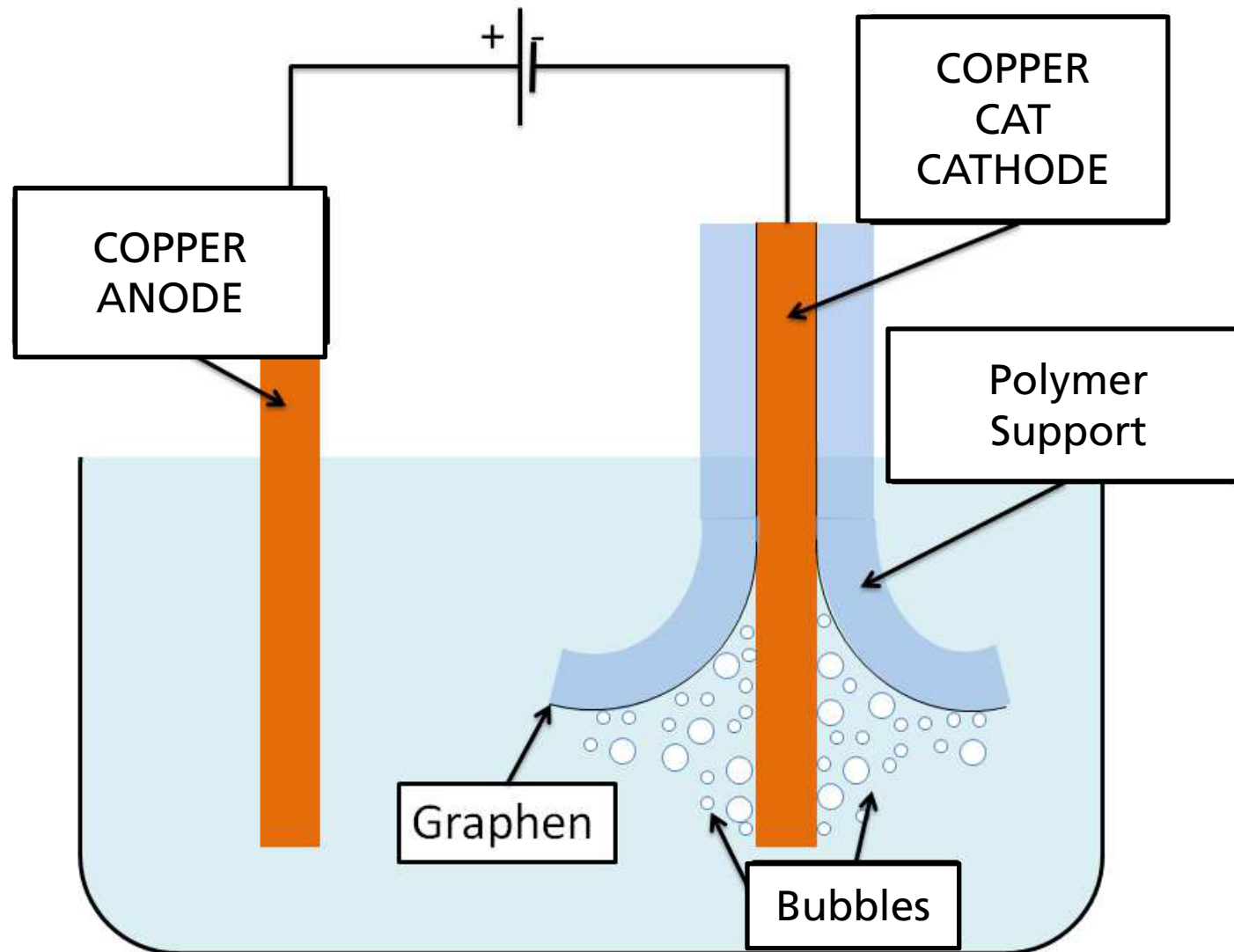
The unit cost value added to a standard product declines by a constant % (typically 20-30%) each time cumulative output doubles.

Lowering production cost by learning curve

$$K_L(p) = K_0 \cdot L^{\lg\left(\frac{p}{p_0}\right)}$$

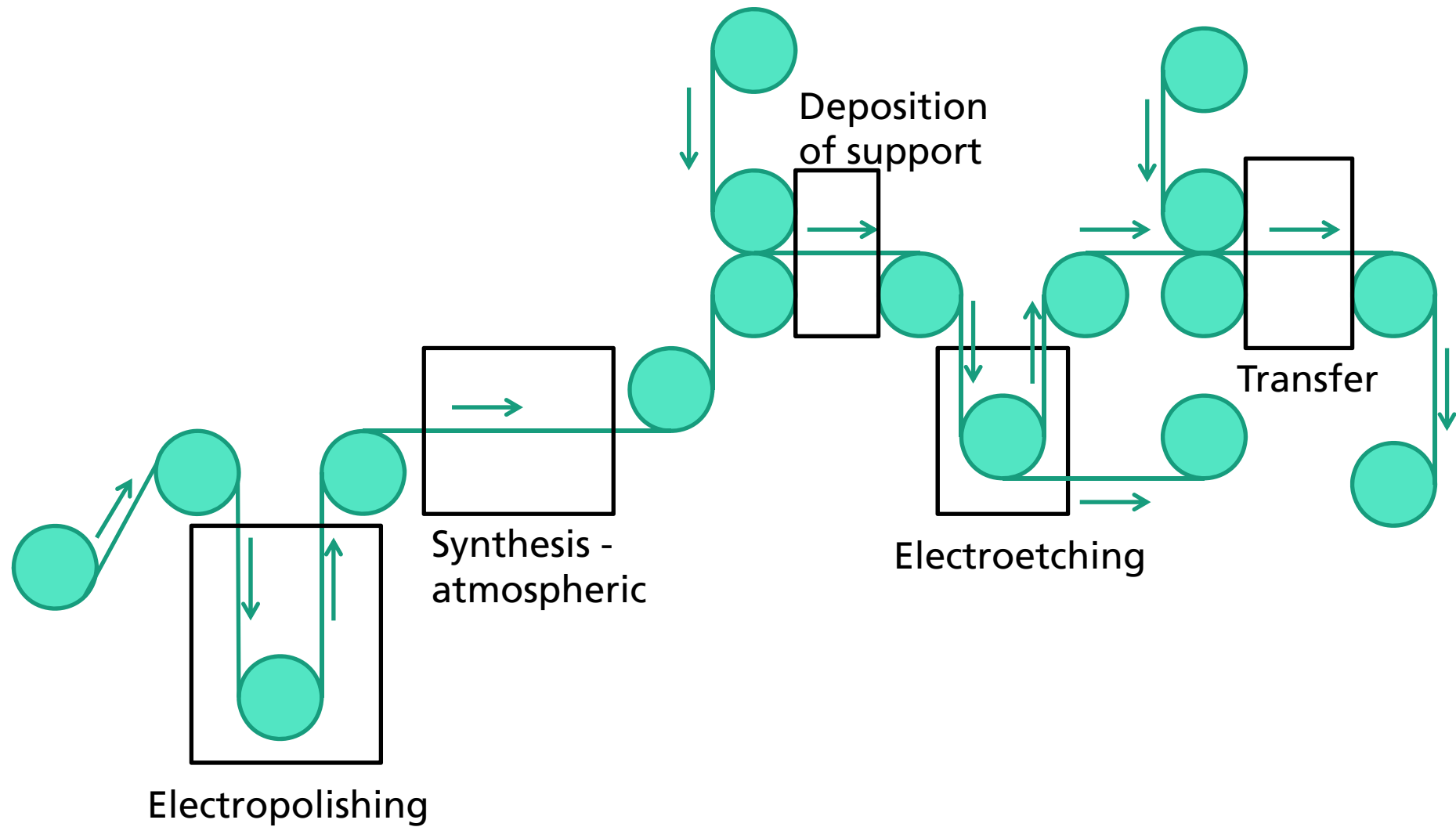


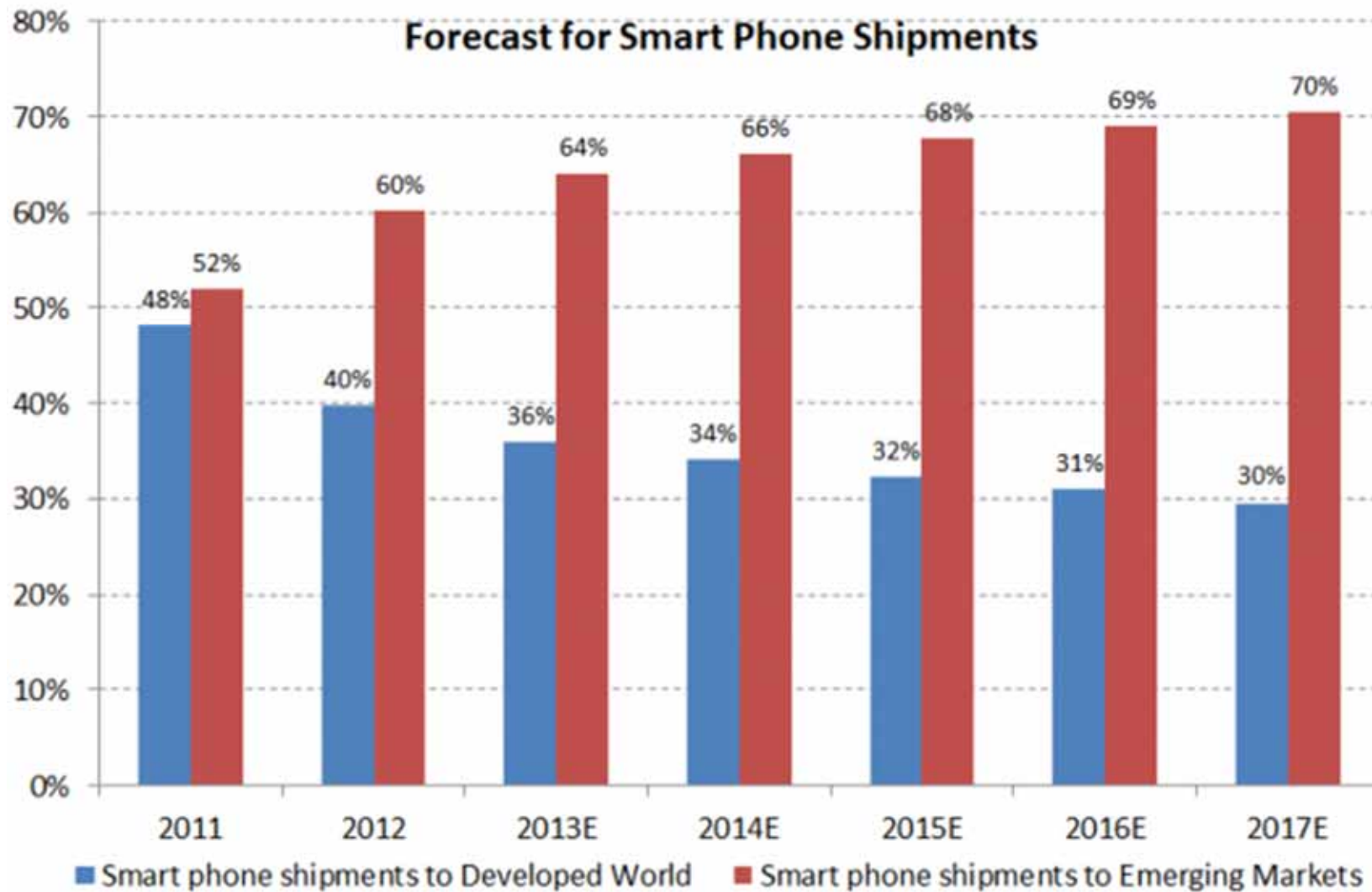
Need for an inline production method





R2R SYNTHESIS AND TRANSFER OF CVD GRAPHENE

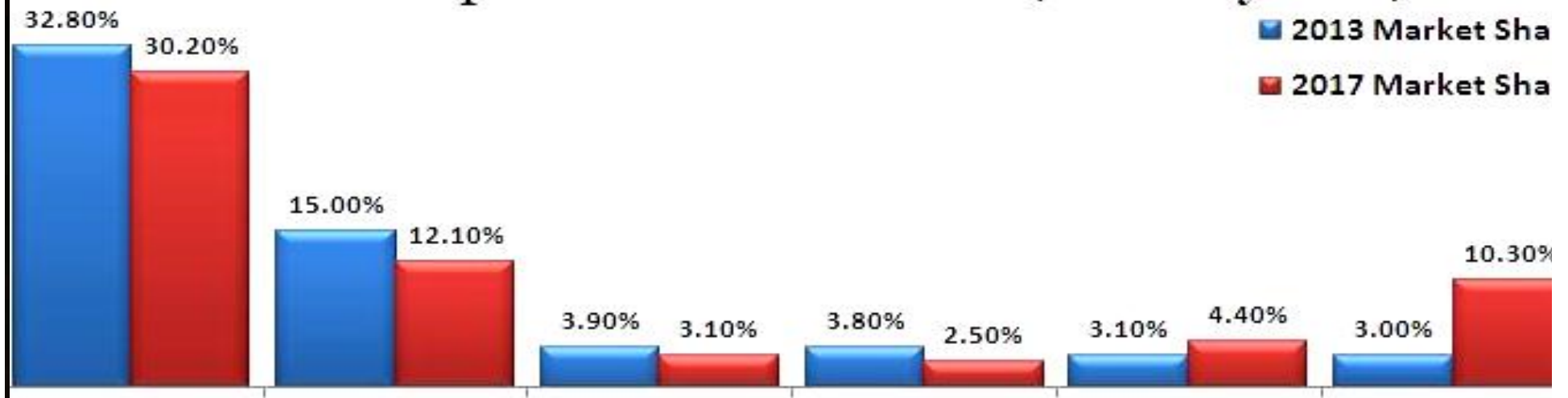




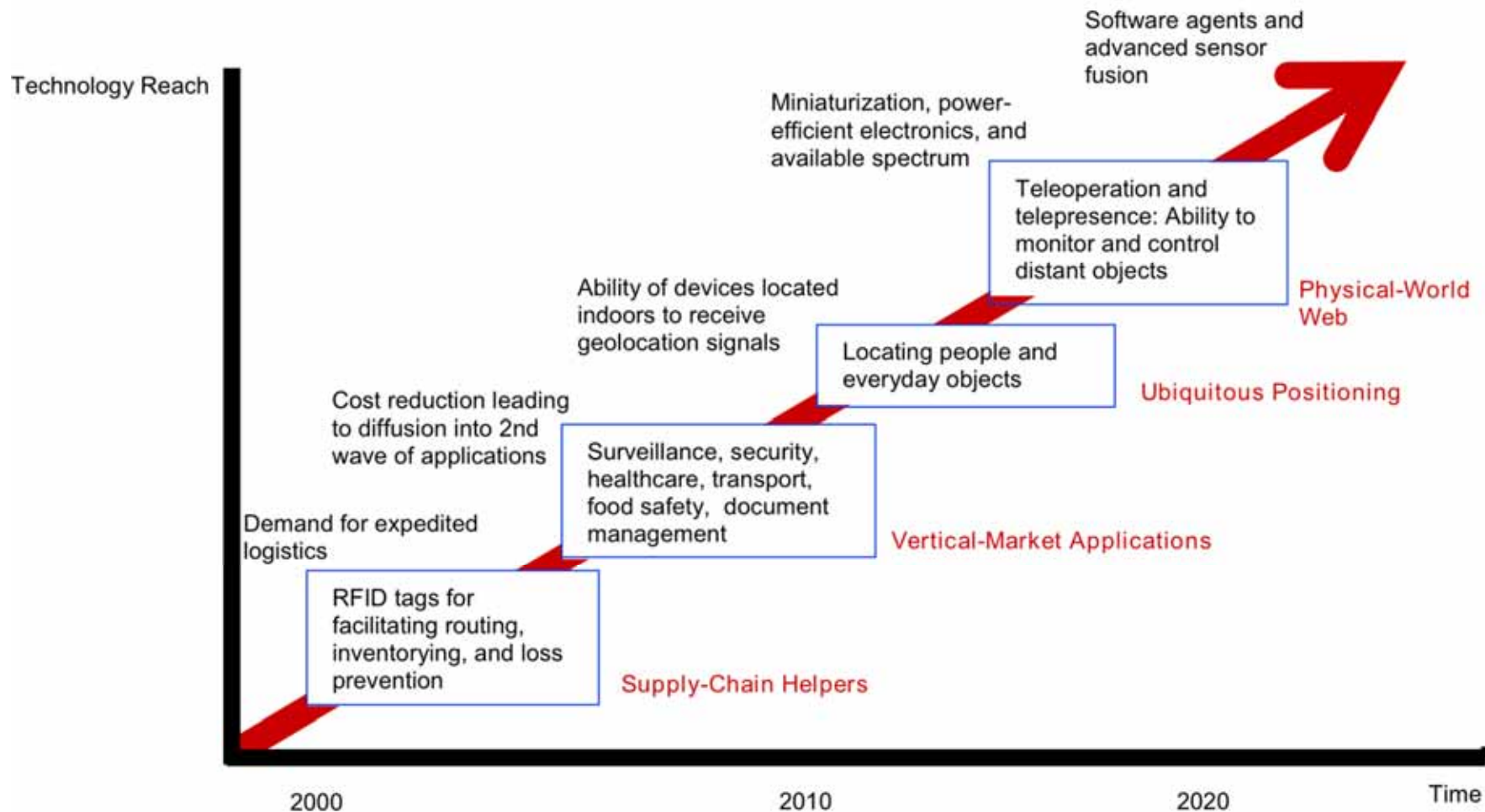
Source: International Data Corporation



Smartphone Market Share (Countrywise)

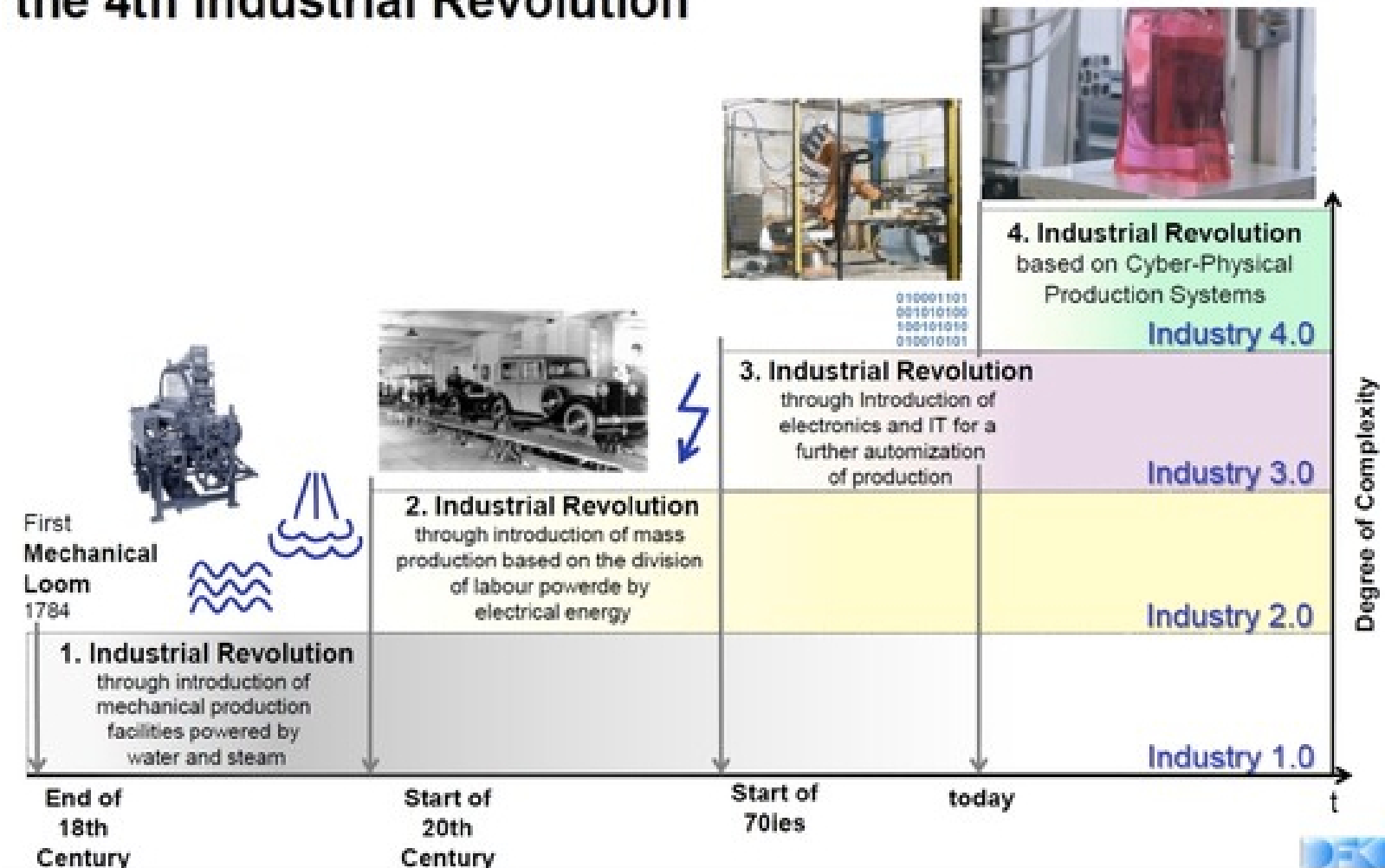


TECHNOLOGY ROADMAP: THE INTERNET OF THINGS

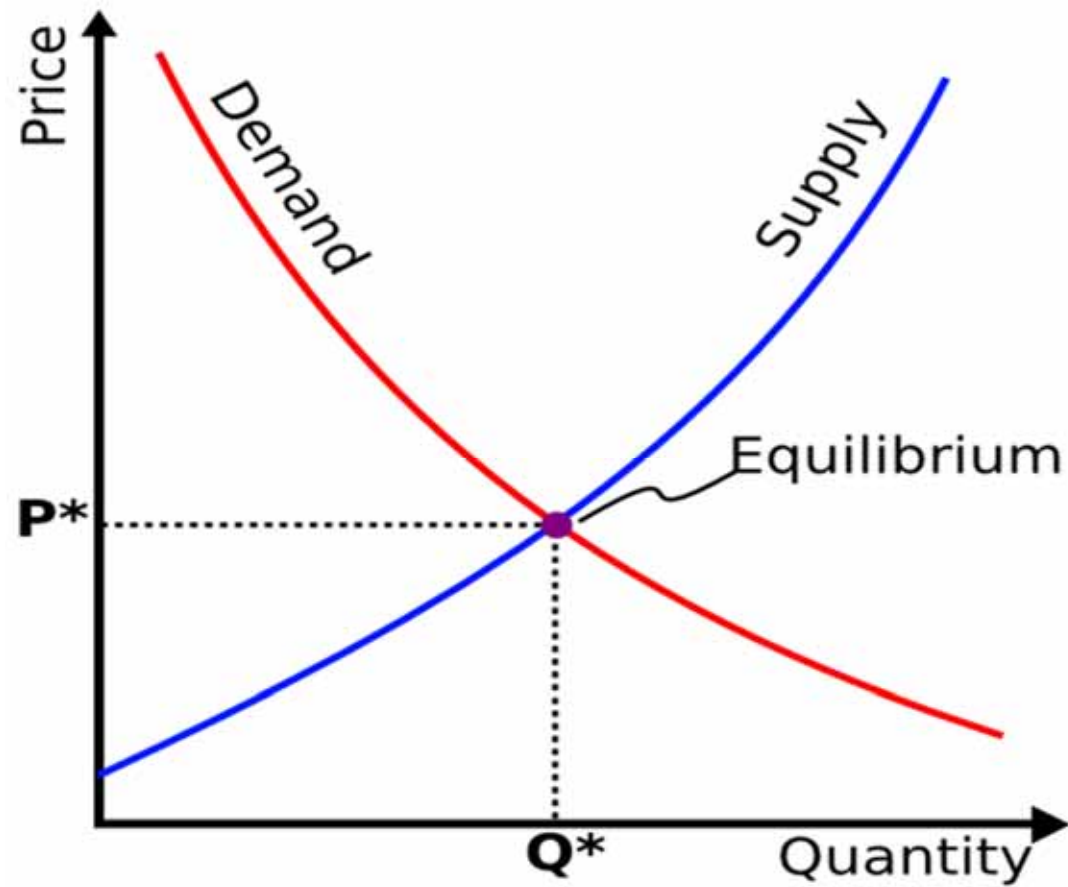


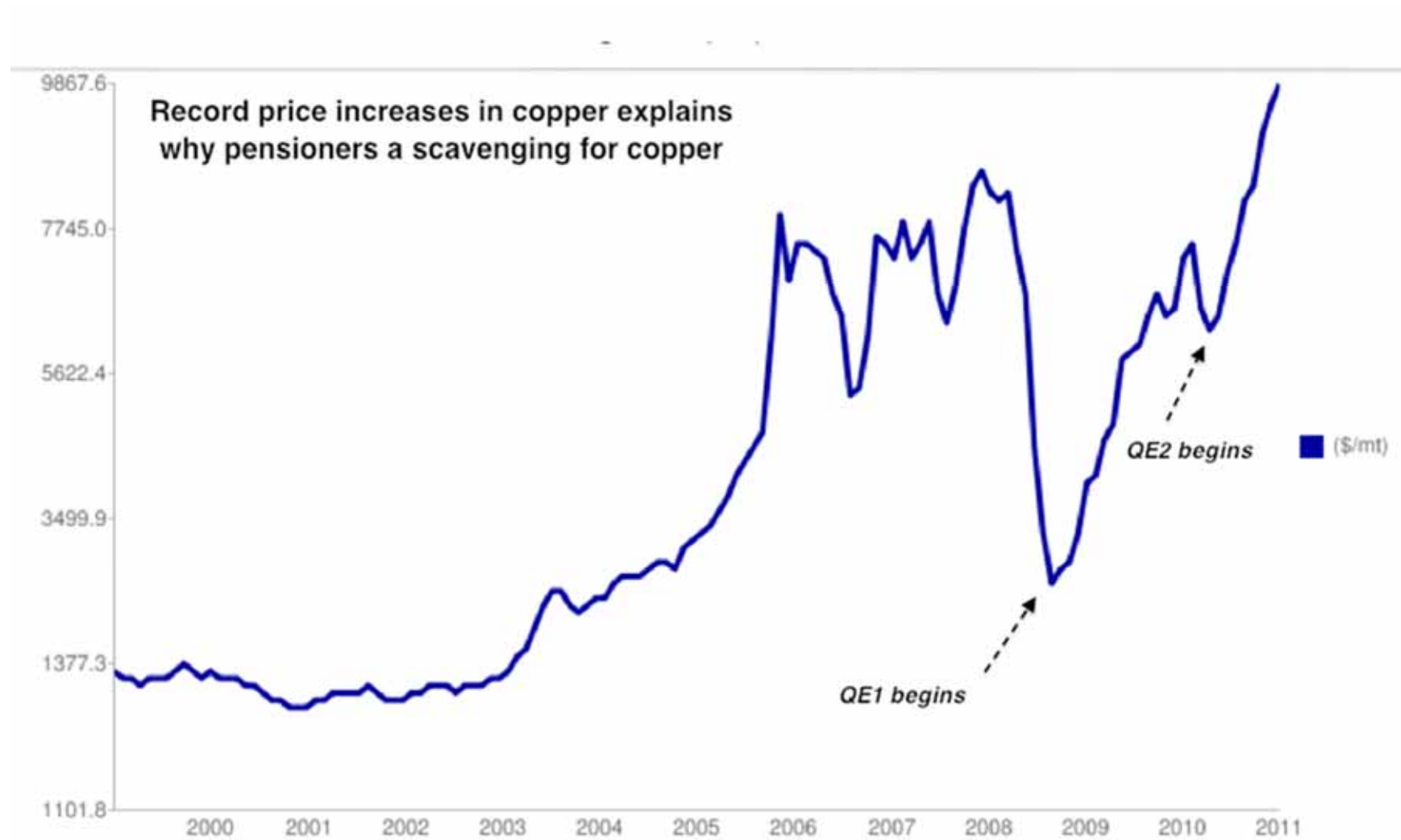
Source: SRI Consulting Business Intelligence

From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution

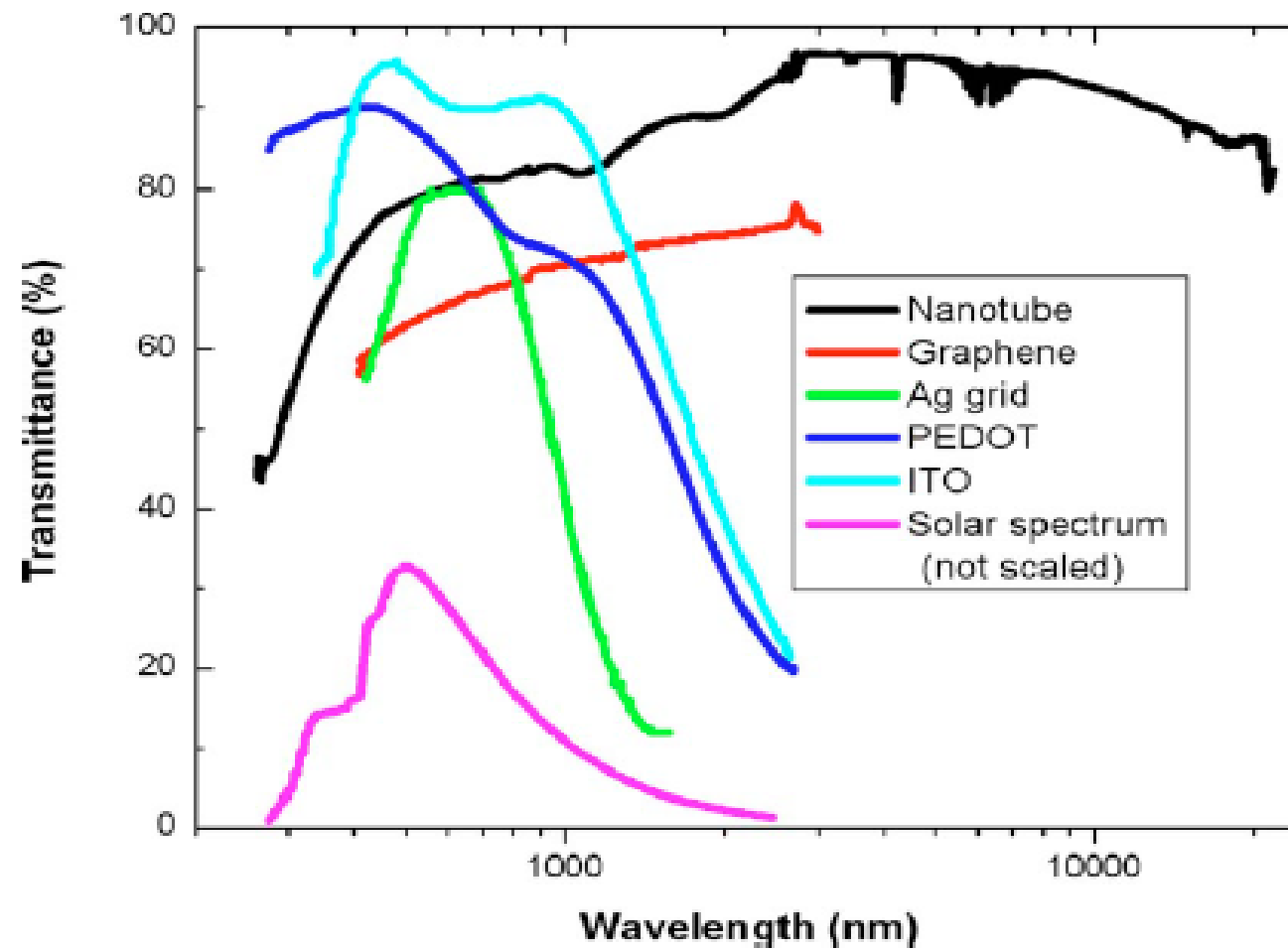


Source: uberb2b.com









Source: Hu, Applied Physics Letters 94, (2009)

Thank you very much for your attention

Stuttgart NanoDays 2014 :

17/ 18 September



@Fraunhofer_oper @Ivica_Nano