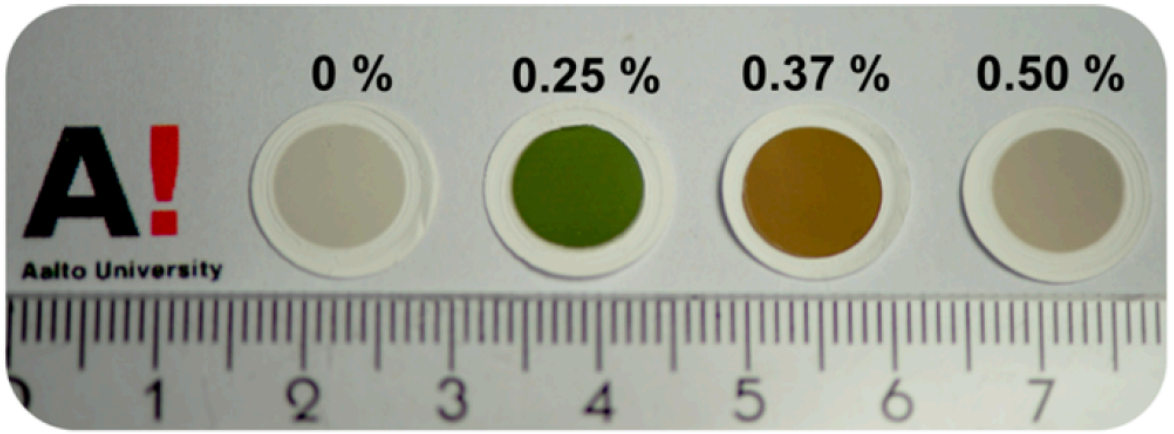
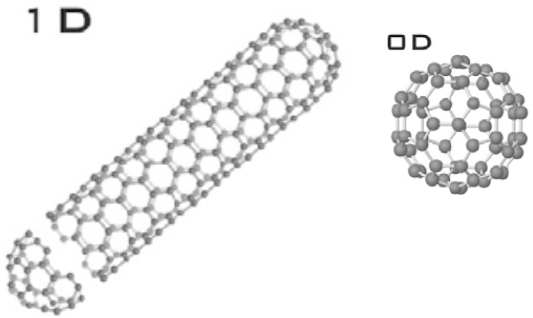
Aalto University



Carbon nanotubes towards industrial applications - results of my MIDE project and how MIDE helped us forward

Prof. Dr. Esko I. Kauppinen
Department of Applied Physics,
Aalto University School of Science
Espoo, FINLAND

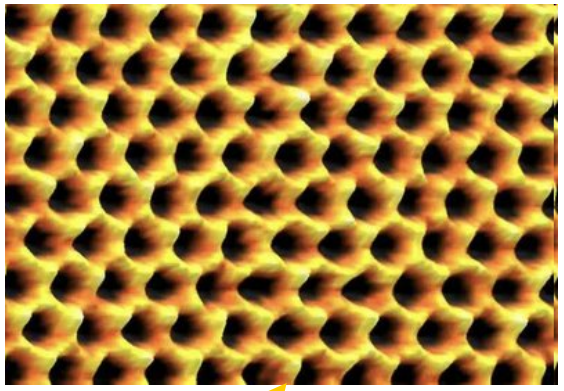
esko.kauppinen@aalto.fi



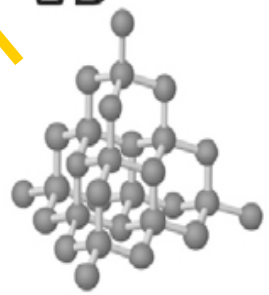
Yrjö Neuvo Jubilee Seminar

November 3rd, 2020

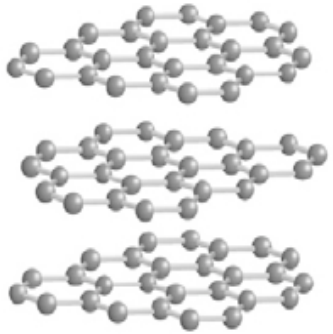
Allotropes of carbon – CNT and graphene - NANOCARBONs for future electronics ?



3D

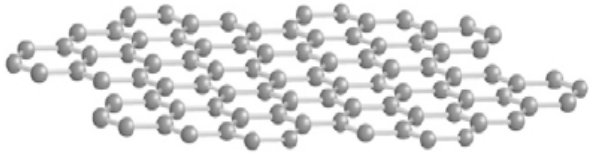


diamond



graphite

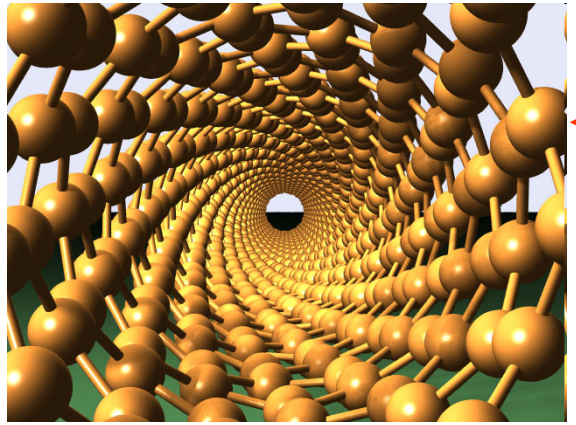
2D



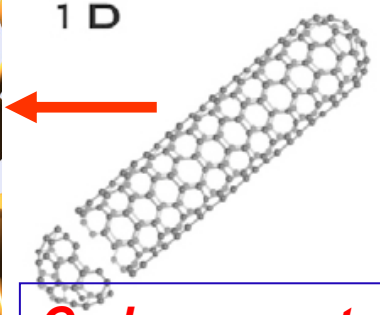
Graphene – NO band gap

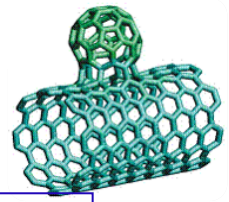
C – C

Nanobud (CNB)



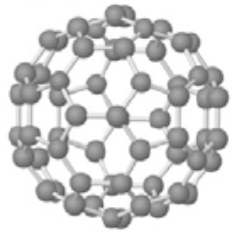
1 D





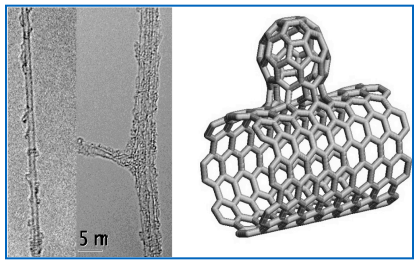
Carbon nanotube –
YES has band gap

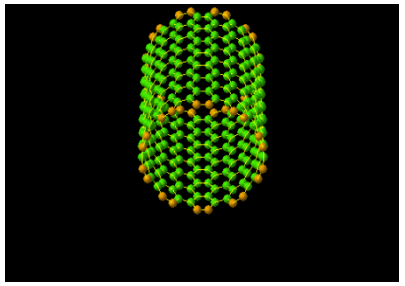
0D

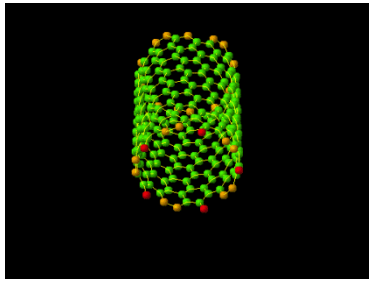


fullerene

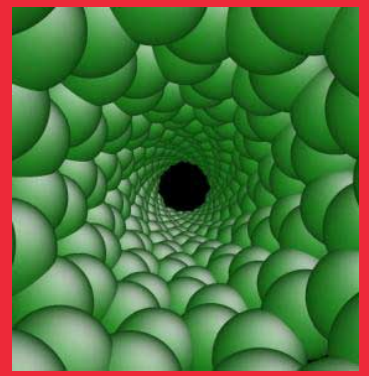
Aalto University
School of Science
and Technology



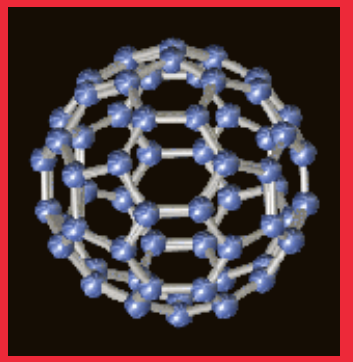




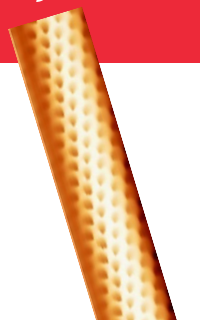
Carbon NanoBud based Energy Systems for Mobile Devices (CNB-E) 2008-2012



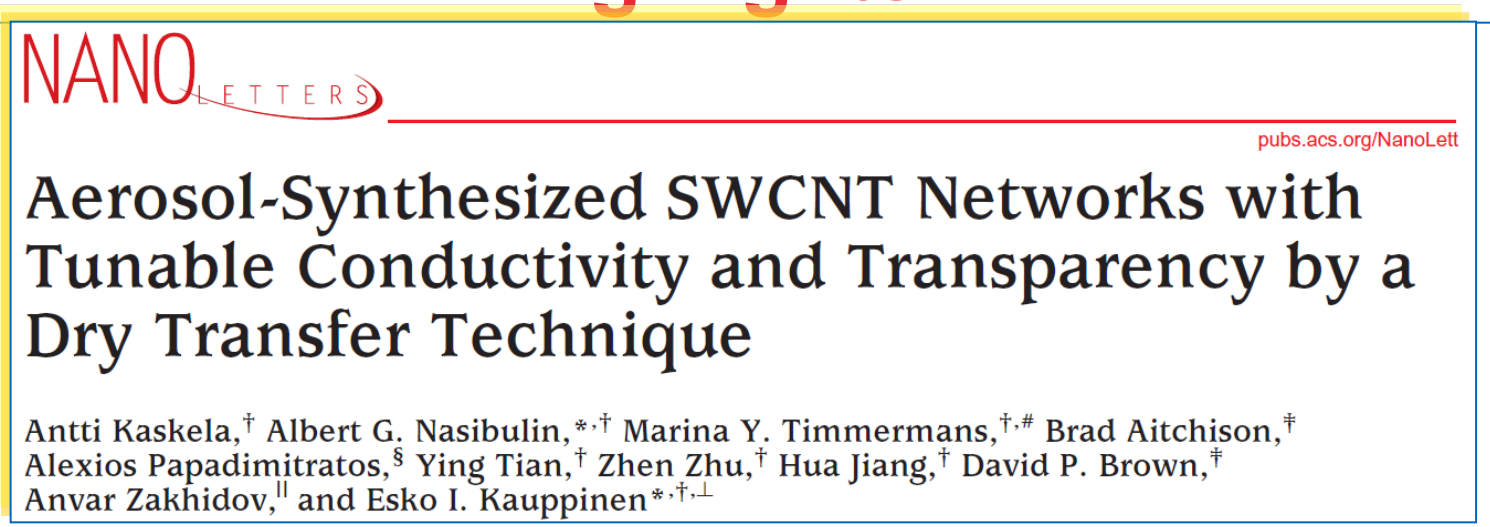
Prof. Esko I. Kauppinen



MIDE Review Meeting
November 2, 2010
Kalastajatorppa, Helsinki, FINLAND



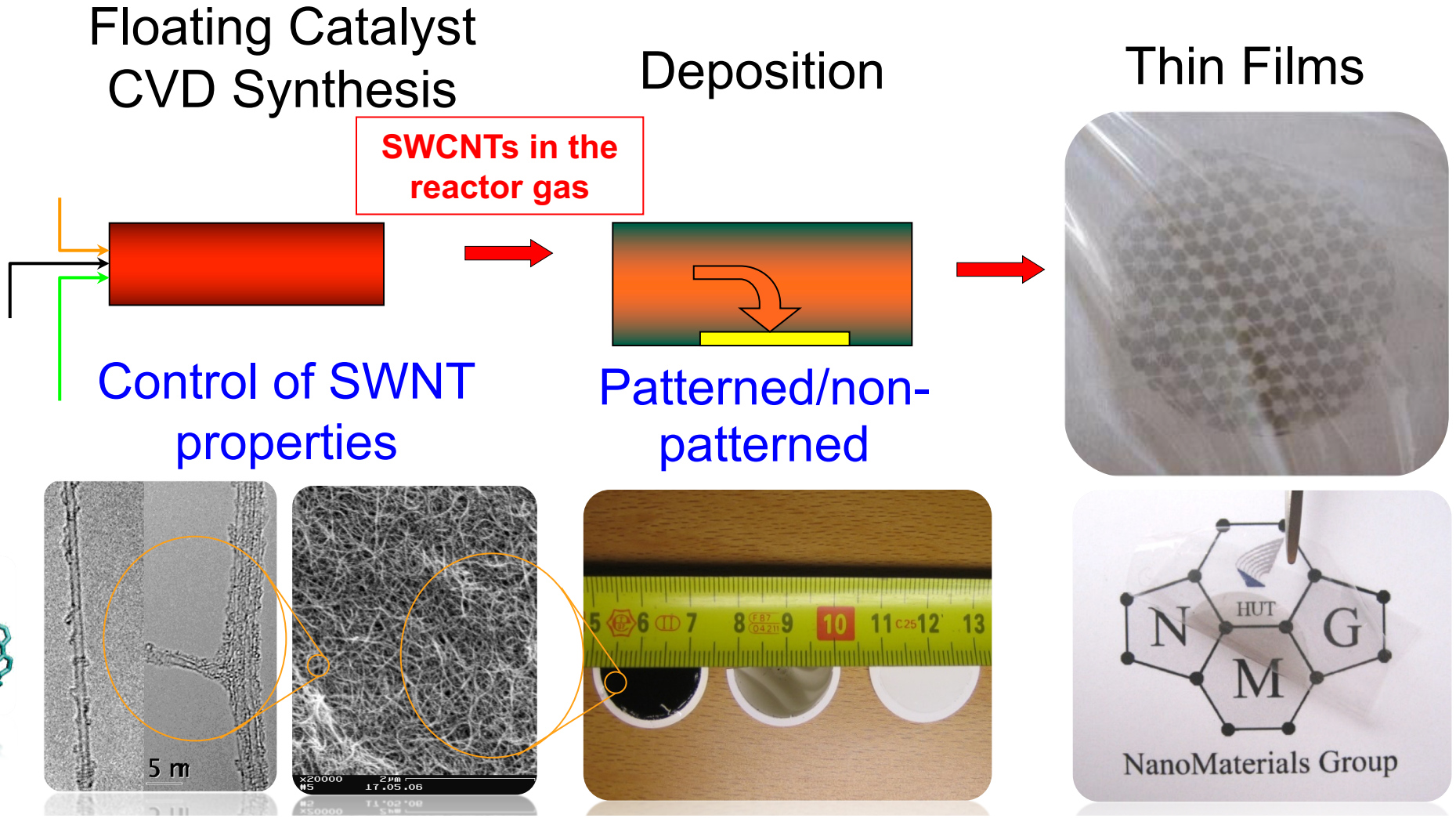
Highlights



- He, M. S.; Chernol, A. I.; Fedotov, P. V.; Obraztsova, E. D.; Sainio, J.; Rikkinen, E.; Jiang, H.; Zhu, Z.;Tian, Y.;Kauppinen, E. I.; Niemelä, M.; Krause, A. O. I. "Predominant (6,5) single-walled carbon nanotube growth on a copper promoted iron catalyst". *J. Am. Chem. Soc.* 132, 13994-13996 (2010).
- Halme, J., Vahermaa, P., Miettunen, K., and Lund, P., Device physics of dye solar cells, Advanced Materials 22, pp. E210-E234, (2010).
- 2 Ph.D. Dissertations: A. Anisimov & M. Toivola
- 16 reviewed publications and 13 invited international scientific meeting talks since 1.1.2009
- World record carrier mobility and on-off *ratio* ***SWCNT thin film field effect transistors (TFT-FET) and integrated circuits (IC) on polymeric substrates*** (collaboration with Nagoya Univ.
  with joint NEDO-funded project)
- Started ***Japan-Finland*** collaborative LiB project (Fortum, Toyota, Tokyo A&T U. and Aalto U.)

Aalto University direct & continous nanotube synthesis and thin film deposition: *DPP – Direct Dry Printing*

Industrial manufacturing – Canatu Oy



Chemical Physics Letters (2005) **402**, 227 – 232; *Chemical Engineering Science (2005)* **61**, 4393-4402; *Chemical Engineering Journal (2008)* **136**, 409-413; *NanoLetters (2010)* **10**, 4349-4355; *Nature Nanotechnology* (2011) **6**, 156–161; *ACS Nano* (2011) **5**, 3214-3221; *Nature Communications (2013)* **4**, 2302

History: The Canatu Team in 2009

Ari Ahola (Finland)
Investor, Chairman of the Board

David P. Brown (USA)
Founder, CEO, Ph.D.
Board Member

Yrjö Neuvo (Finland)
Board Member, Professor

Bill Paulin (USA)
Advisor and Sales, Ph.D.

Esko I. Kauppinen, (Finland)
Founder, CTO, Professor,
Board Member

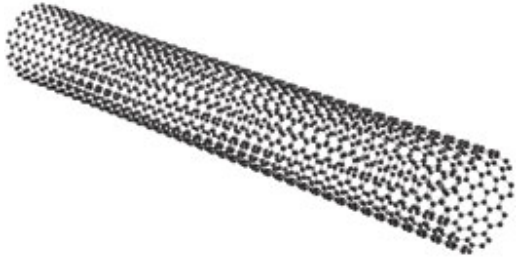
Albert G. Nasibulin (Russia)
Founder, Chief Scientist, Ph.D

Mikko Kärkkäinen (Finland)
COO, CFO

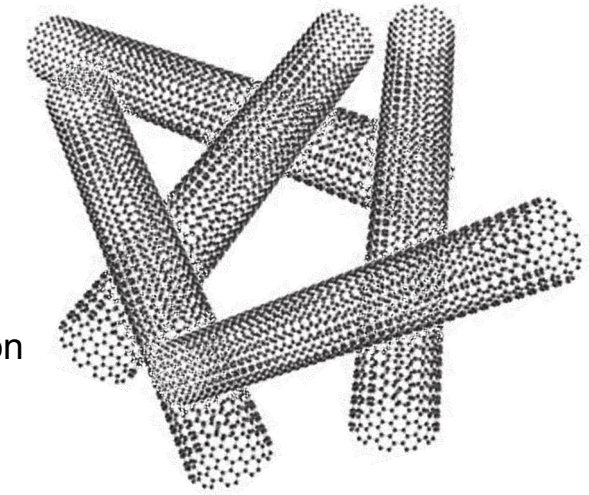
Brad Aitchison (USA)
Production Manager, M.S.

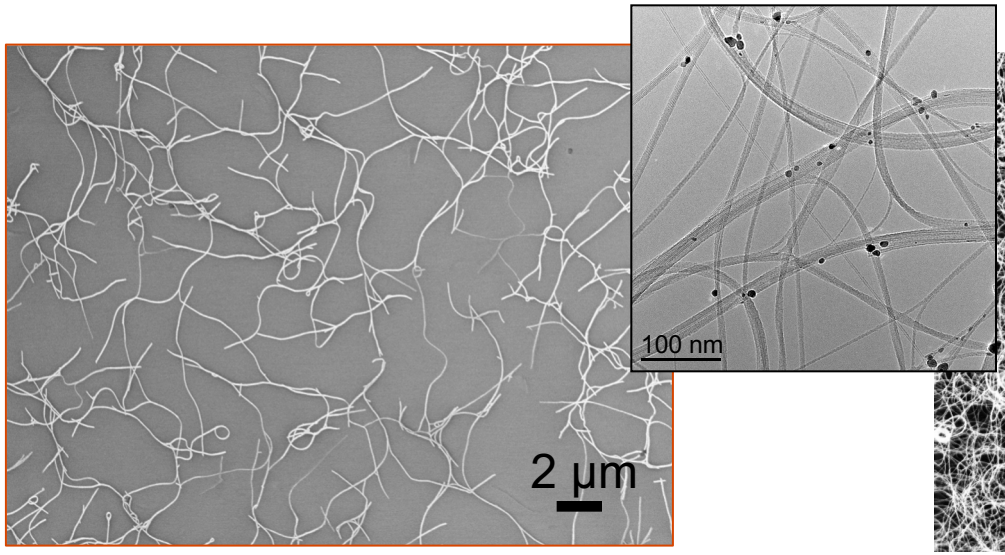
How to use SWNT without full (n,m) control – as a network

Carbon Nanotube

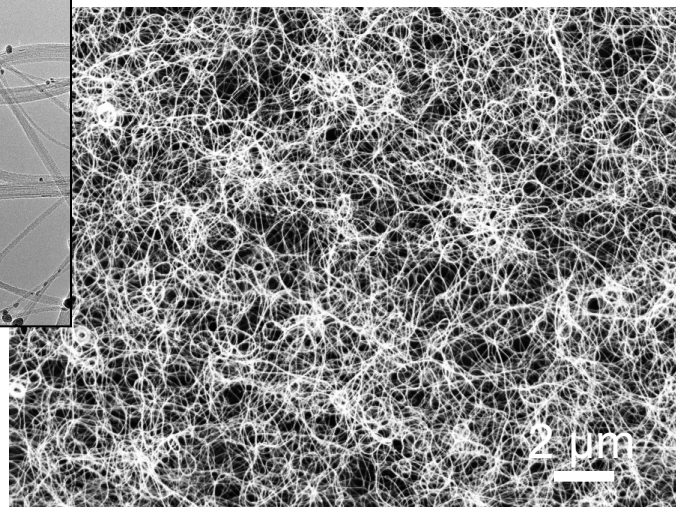


- Highly conductive
- Flexible, tough
- Transparent
- Simple and fast formation (depend on method)





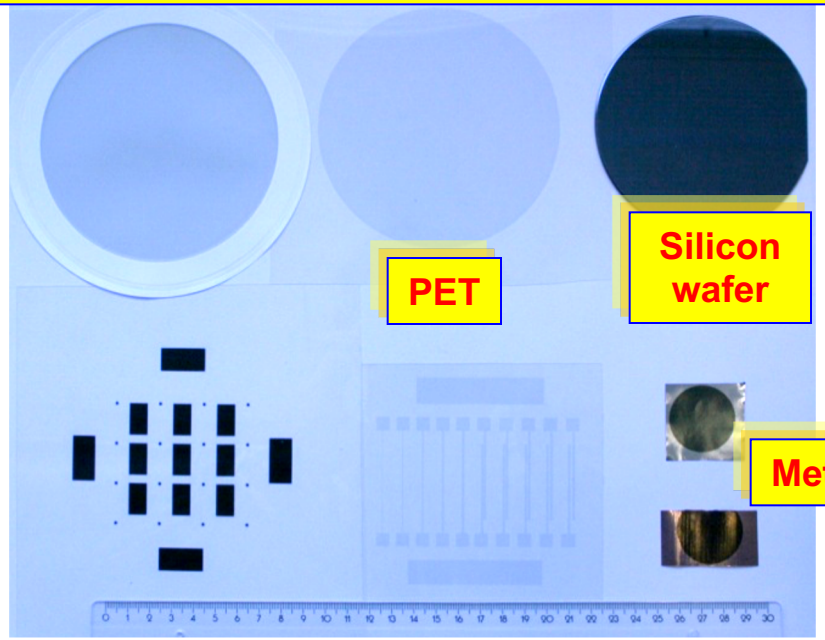
Carbon Nanotube Network – TFT-FET

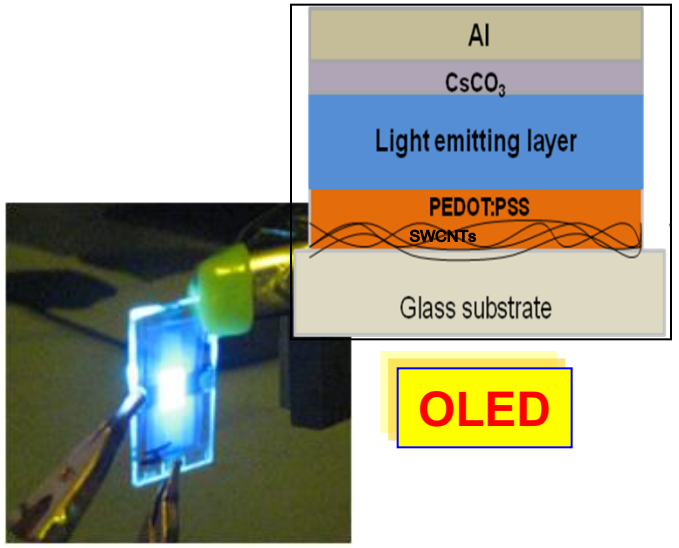


Carbon Nanotube Film – transparent conductor TCF

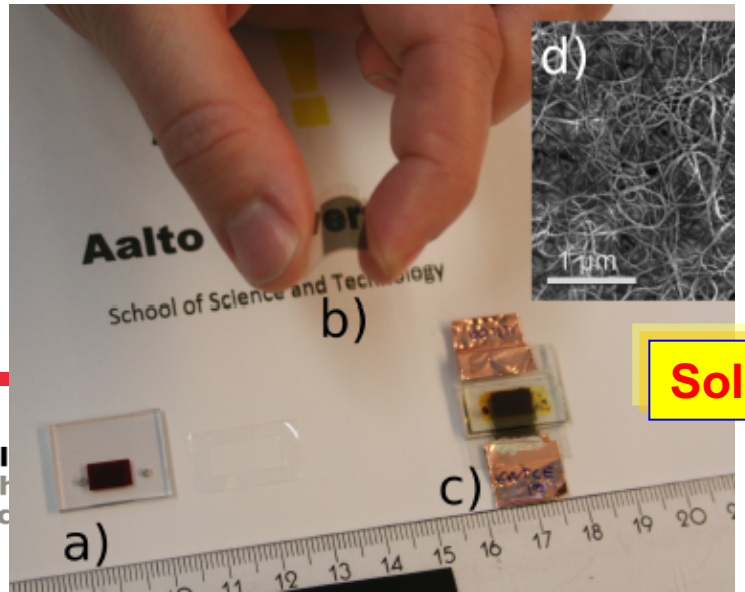
Applications of SWCNT-electrodes

Patterned deposition on various substrates



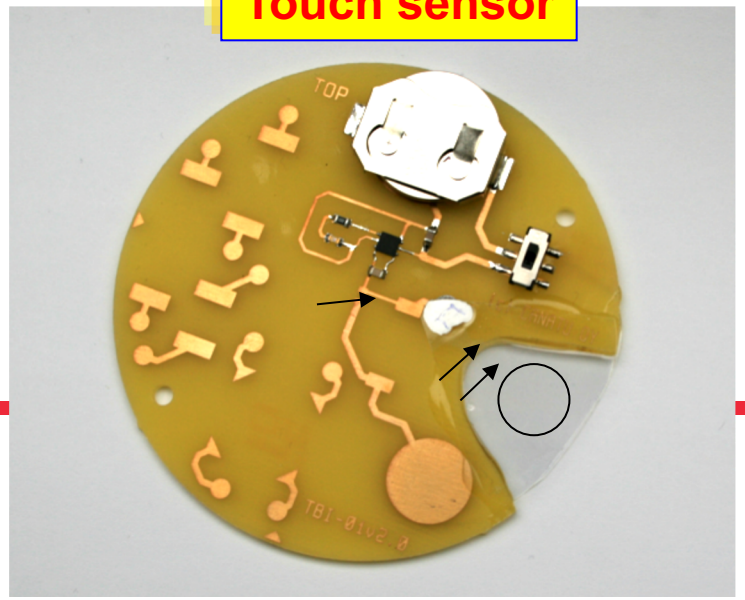


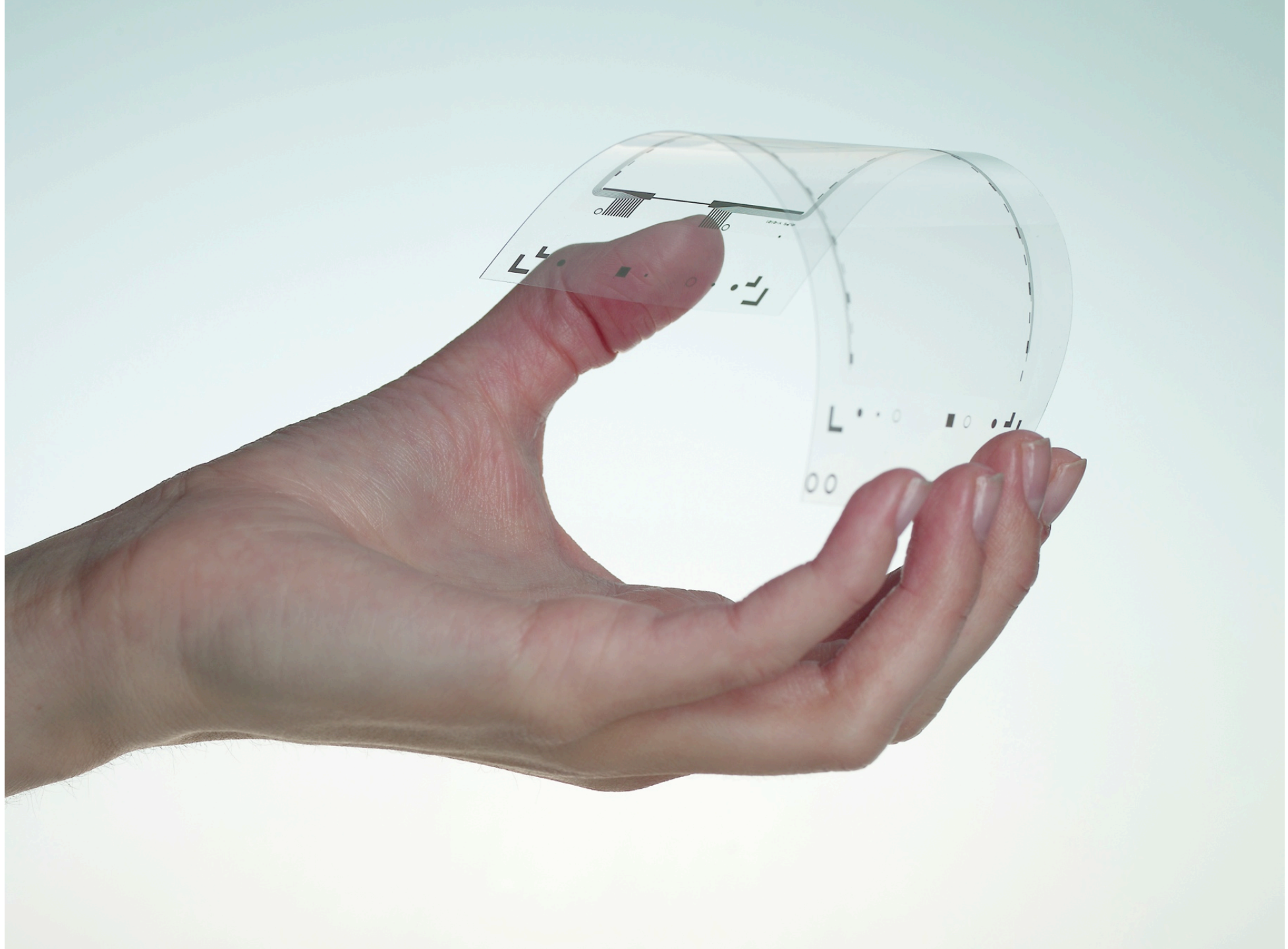
OLED

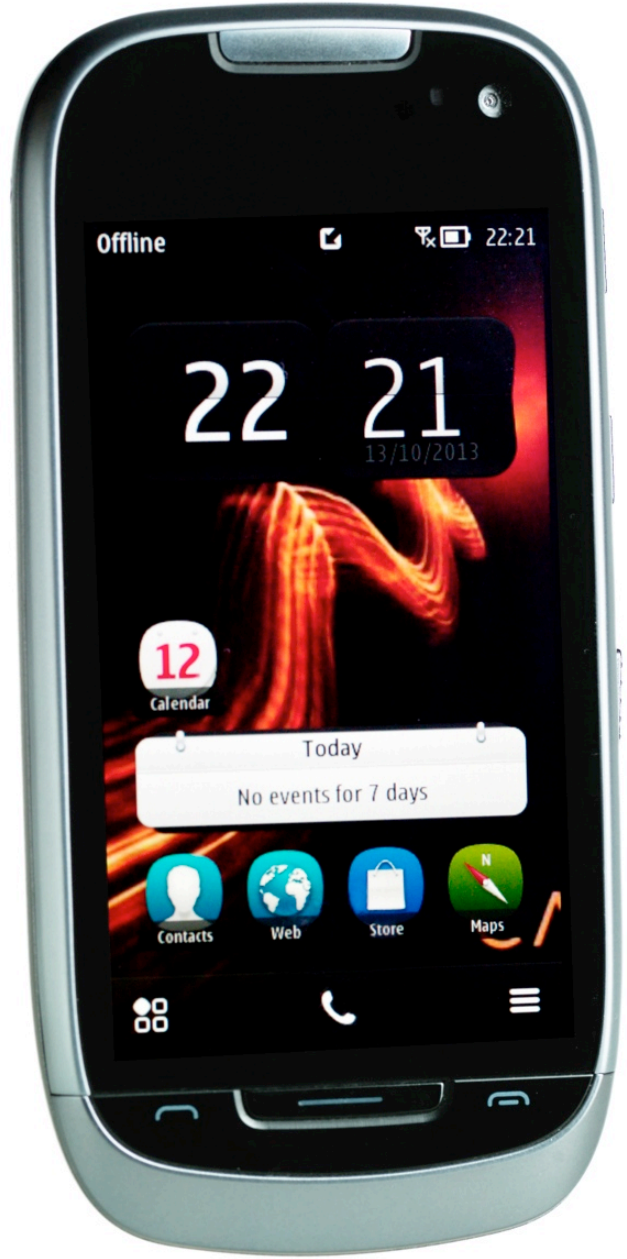


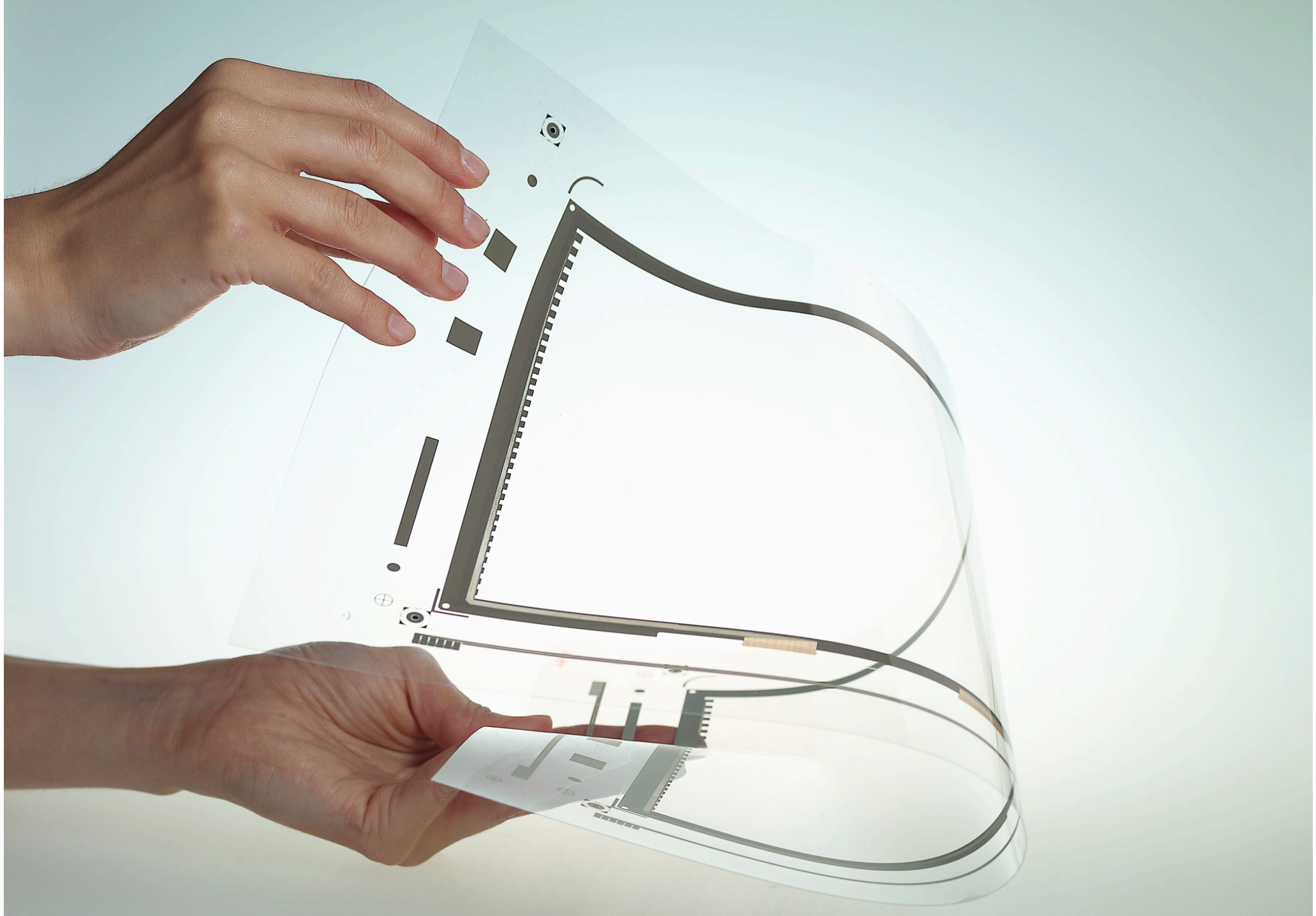
Solar cell

Touch sensor






Offline
22:21
22 21
13/10/2013
12
Calendar
Today
No events for 7 days
Contacts
Web
Store
Maps



intel

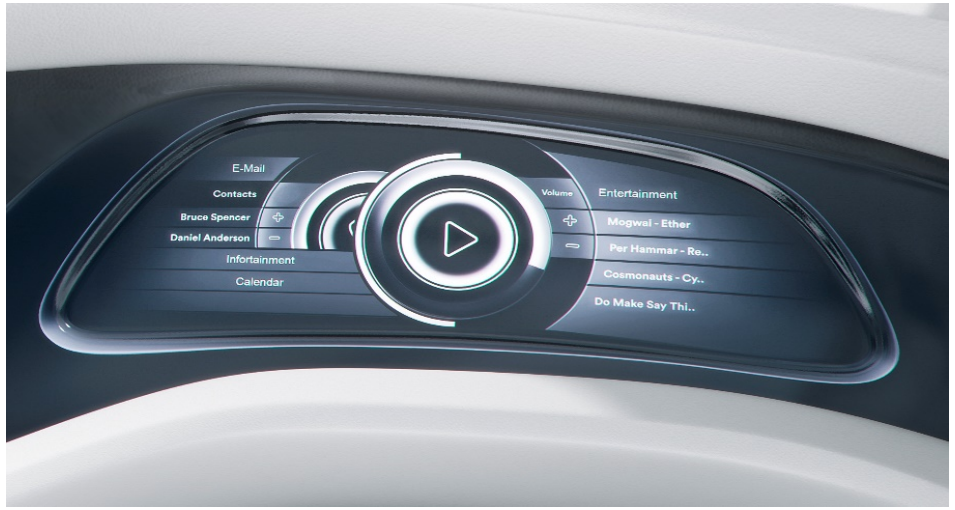
ATMEL

CANATU

CID- 3D Touch Surface with intuitive finger guides, no driver distraction


Navi
Media

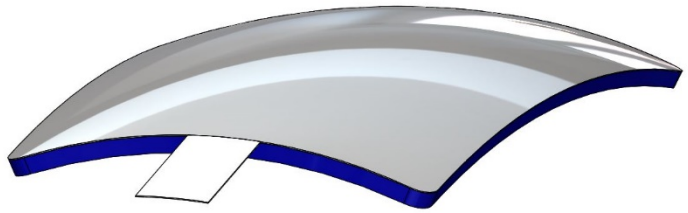
Smart Canatu 3D Touch and Heater surface solutions

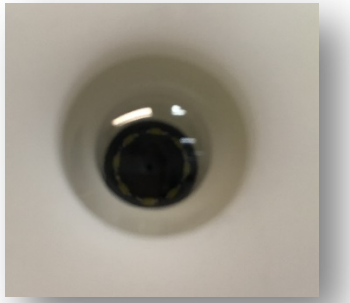


3D touch surface with Passenger Entertainment Display

Smart Steering wheel with touch and heating integration

Light and thin center or overhead console with intuitive 3D touch functionality –hidden til-lit



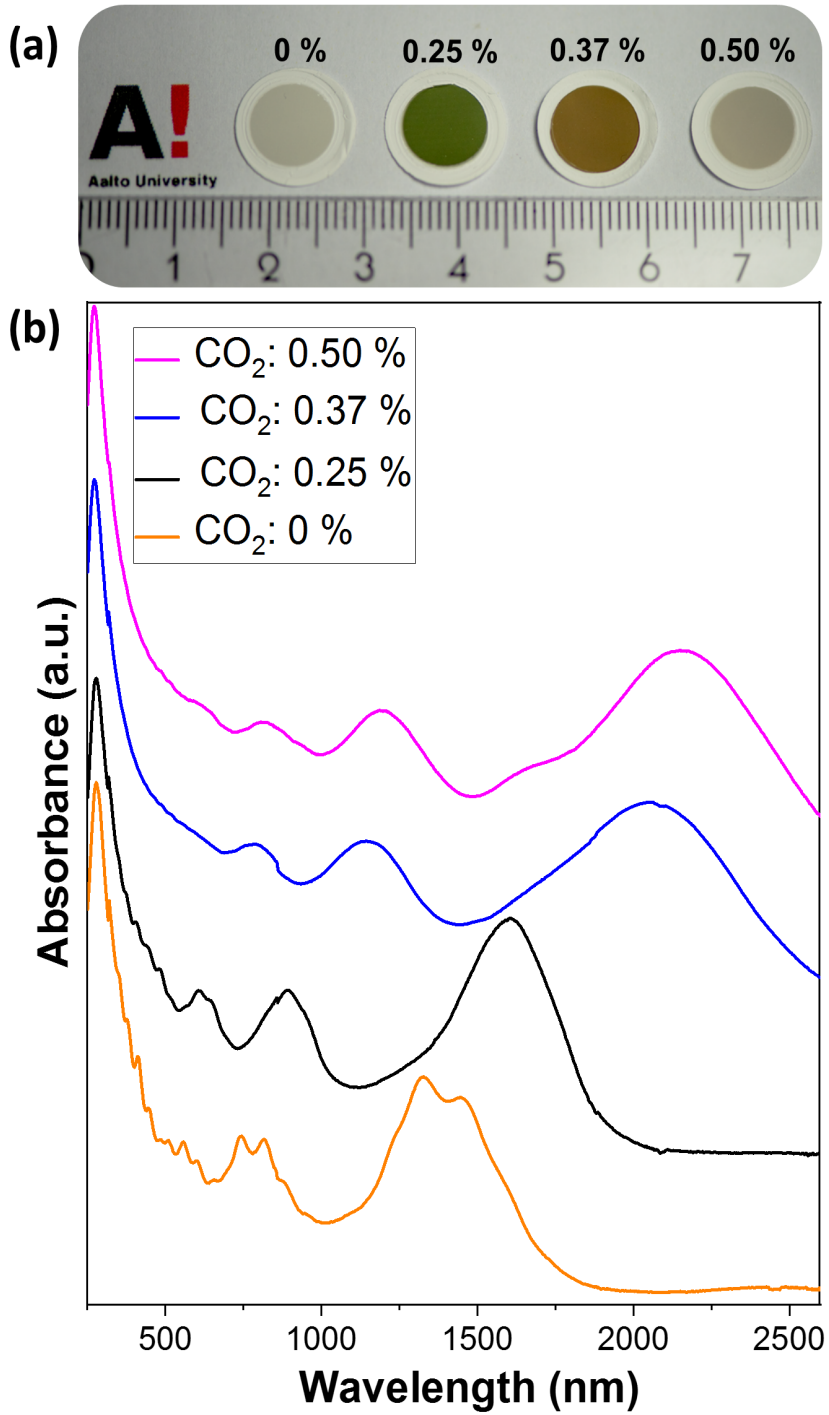


3D surface heater - Lidar and camera sensor heating solution. High transparence and heating distribution

New Factory Opening

20th November 2019 | Vantaa, Finland

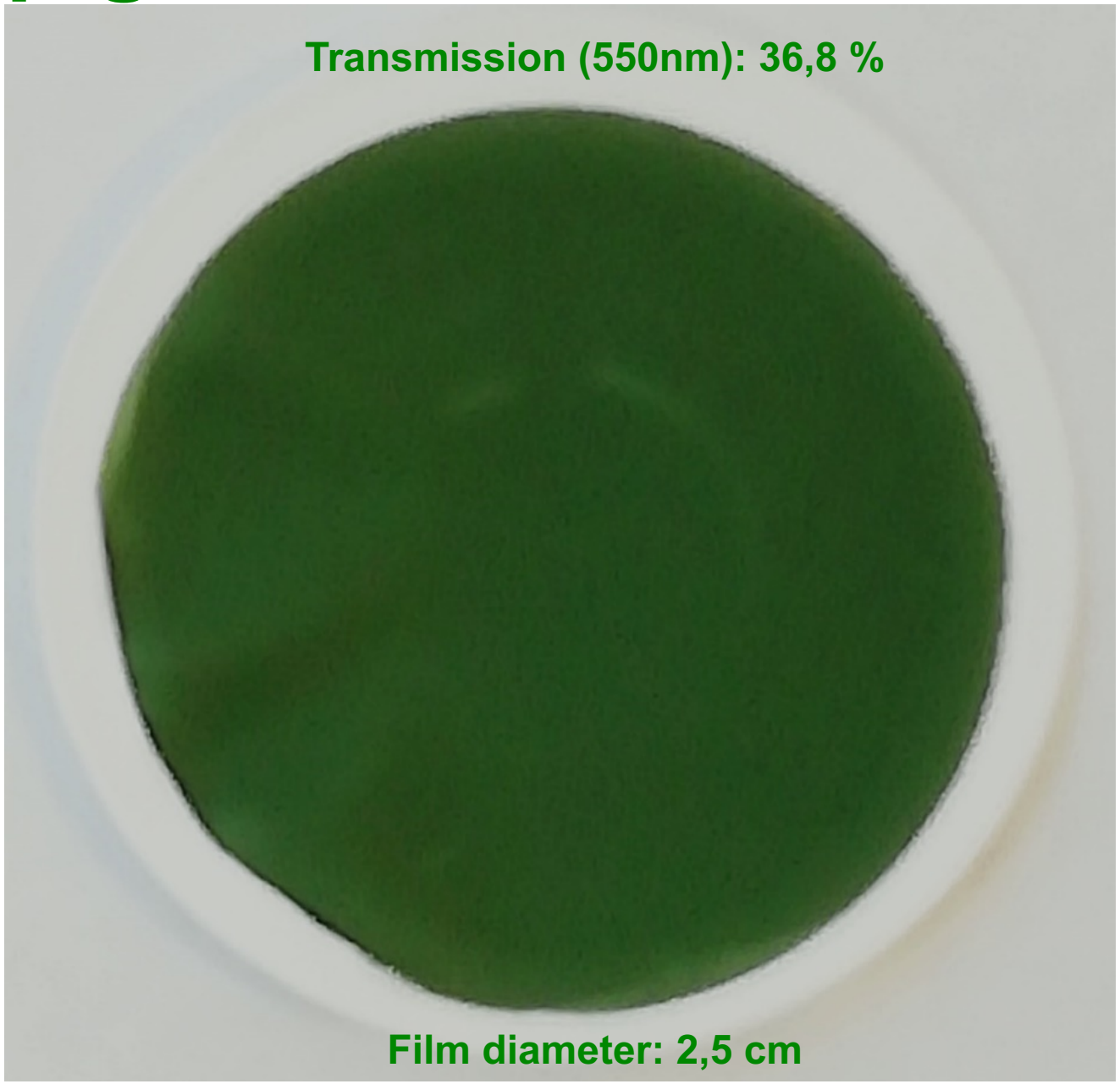
Canatu's new factory was opened on the 20th November 2019 in Vantaa, Finland. The new factory has room to increase the manufacturing capacity 150 times compared to old Konala factory. In the new factory, Canatu introduced the new automated CNB film production line and one of the Finland's largest clean rooms. Canatu has several design wins which will lead to mass production according to our customers' product plans. The first mass production case started in 2015.



Direct synthesis of coloured SWNT thin films in CO/CO_2 @ 850 °C

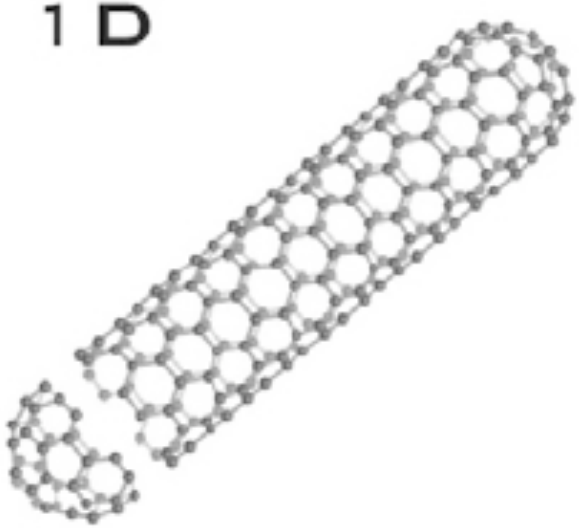
Liao et al. (2018) JACS 140, 9797-9800.

Deep green colour with thicker film



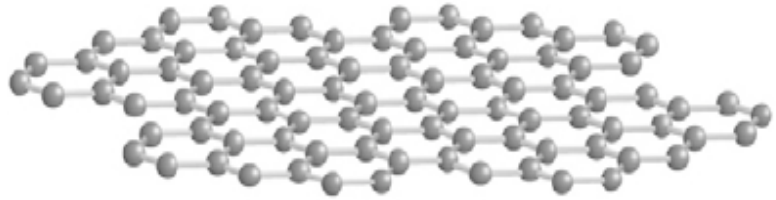
Compete ? Or collaborate ?

1 D



Nanotube

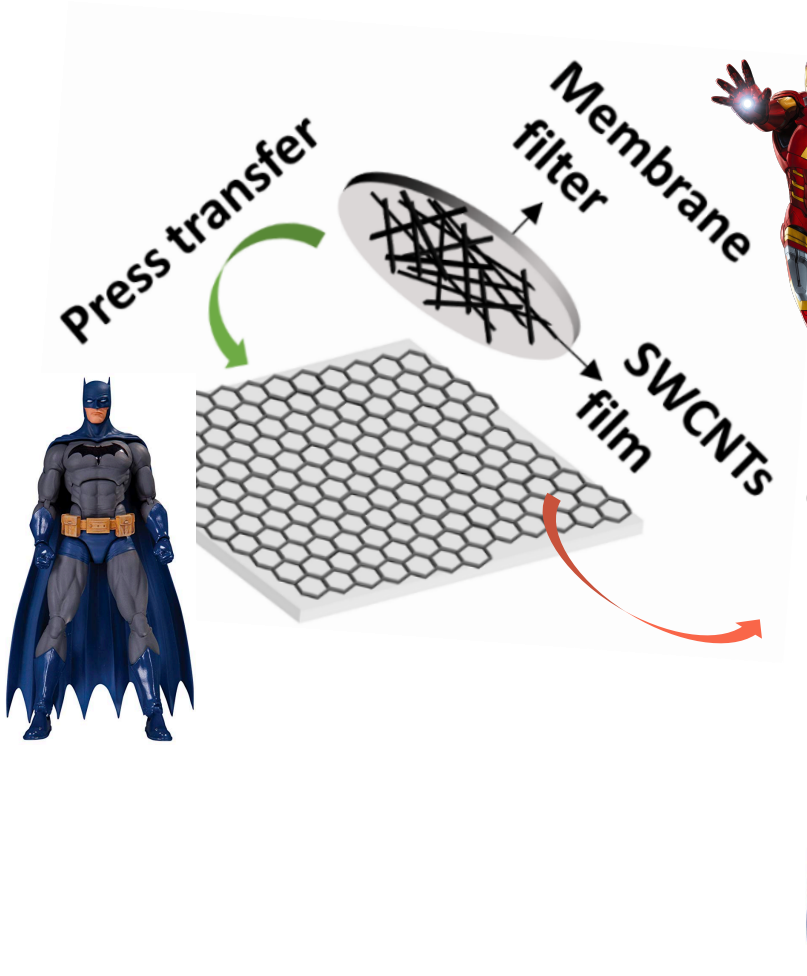
2D

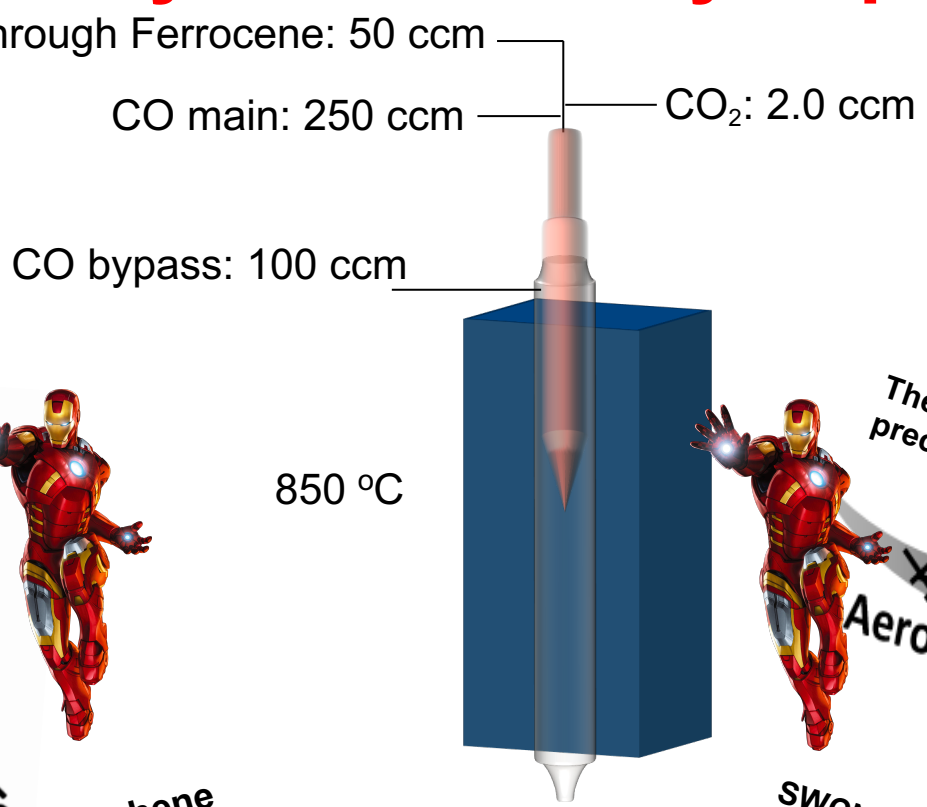


Graphene

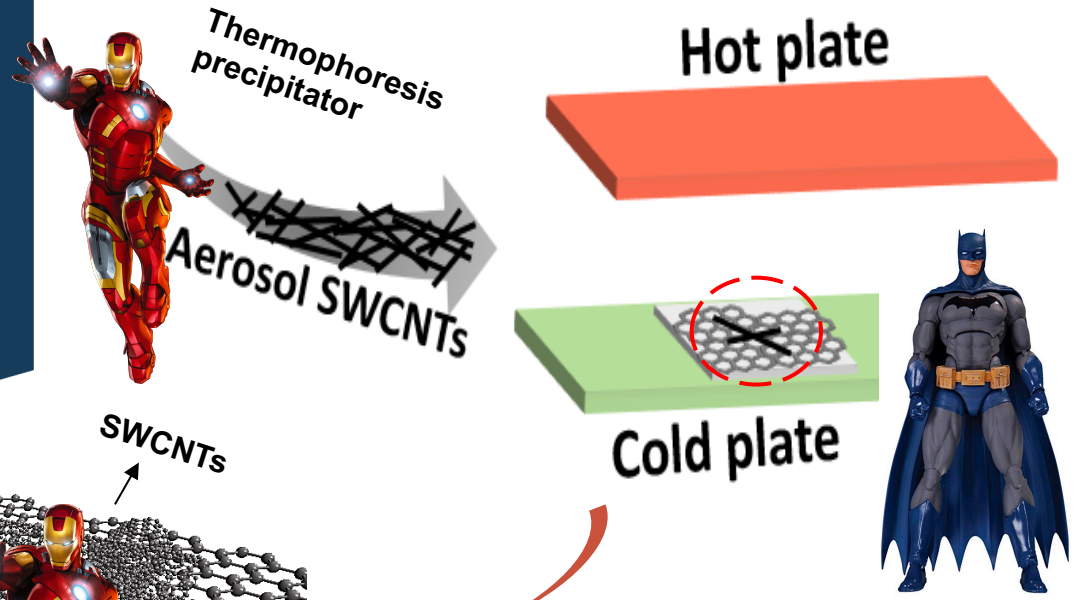
How: FC-CVD SWNT synthesis & dry deposition onto graphene

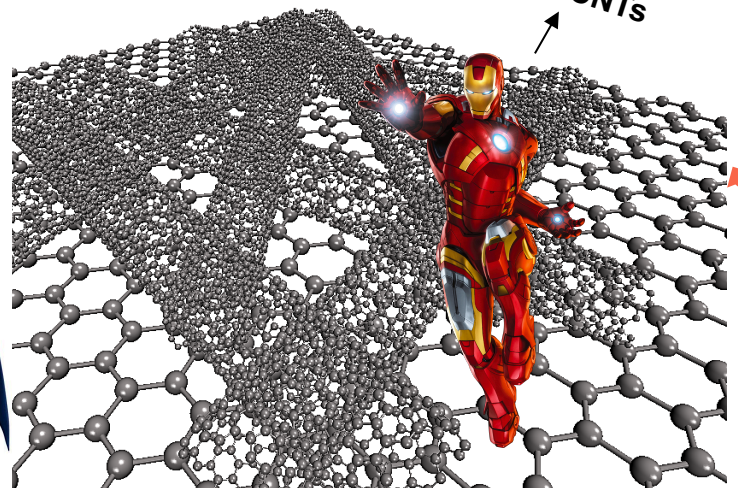
Filer collection & press transfer deposition





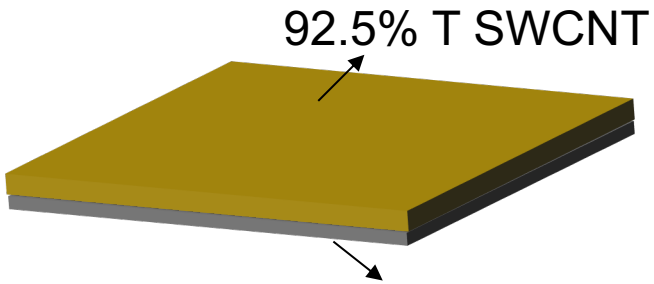
Thermophoretic (TP) deposition

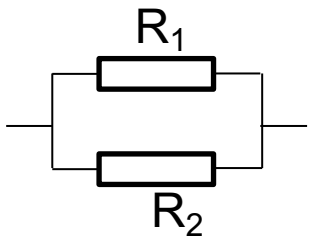




Note: Graphene from *Graphenea In*

A parallel resistor model *cannot* interpret our results !

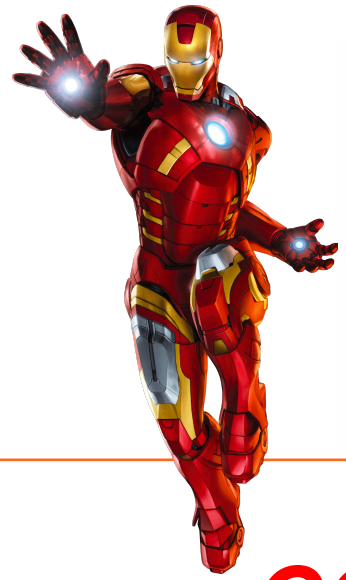




$1/R = 1/R_1 + 1/R_2$

90% T (SWCNT/graphene) = 97.5% T (graphene) + 92.5% T (SWCNT)

Films	Pristine SR (Ω/□)	Doped SR (Ω/□)
Graphene (97.5% T)	650	250
SWCNTs (92.5% T)	750	145
SWCNTs/graphene (90% T)	350 (Predicted)	91 (Predicted)
	180 (Measured)	36 (Measured)



COLLABORATION !


Thank You Very Much
for Your Attention