האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

2D,3D and 4D printing in AM of Electronics

Manufacturing Through Printing

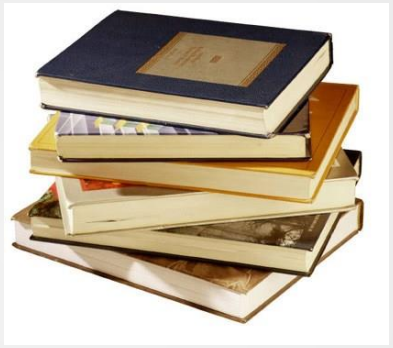
Shlomo Magdassi

IEEE Israel, 20-4-21

Additive Manufacturing of Electronics

2D Printing

Controlled deposition of materials in predesigned patterns
Additive Manufacturing (AM)



Screen Printing

Inkjet Printing

Many printing technologies

Conductive Inks For Printed Electronics

Providing the materials and the technology needed to form the “electric wiring “ in printed electronics

Nanomaterials synthesis, ink formulations, printing and sintering technologies

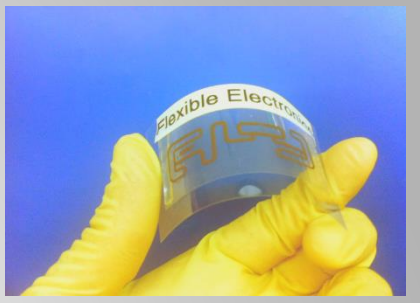
Silver, copper, CNTs

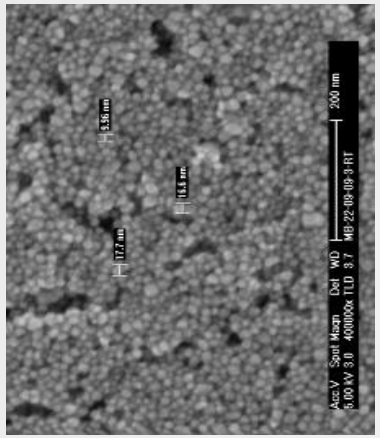
Review on conductive materials:

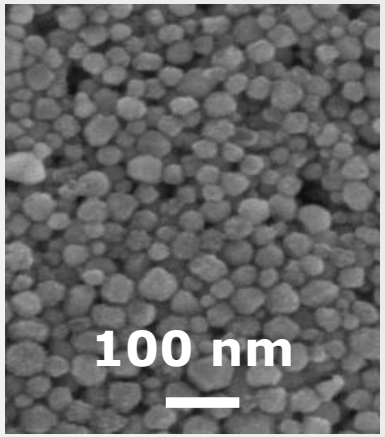
Chemical Society Reviews 2018

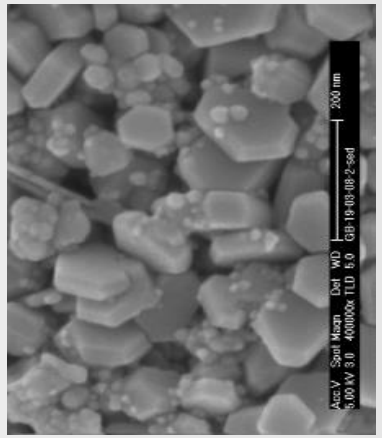
Conductive inks

One pot synthesis of silver nanoparticles

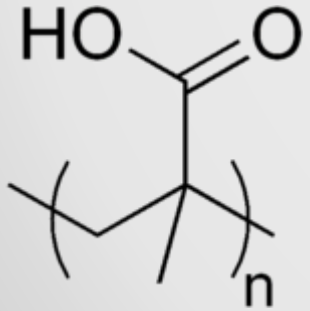




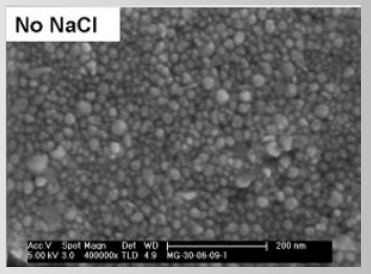


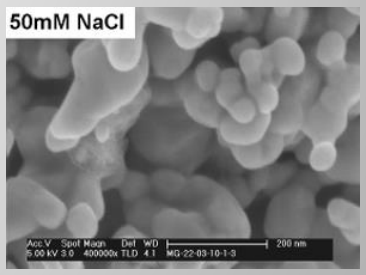


Size and morphology control



Particles can be chemically sintered even at room temperature

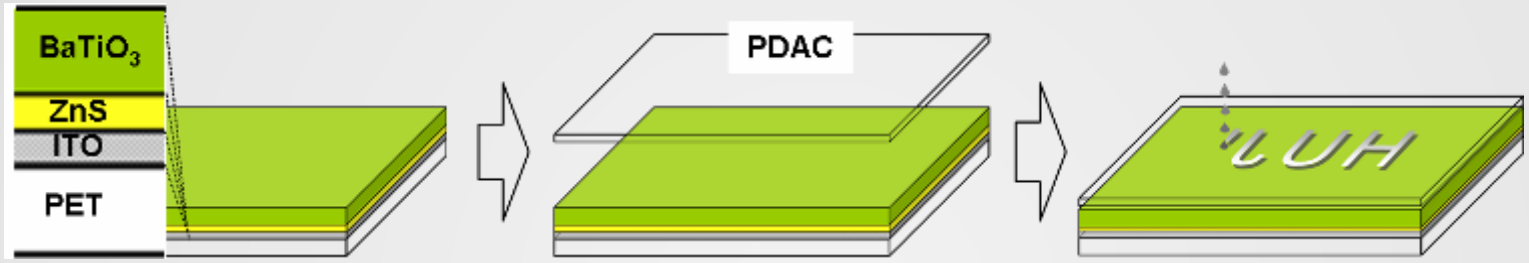


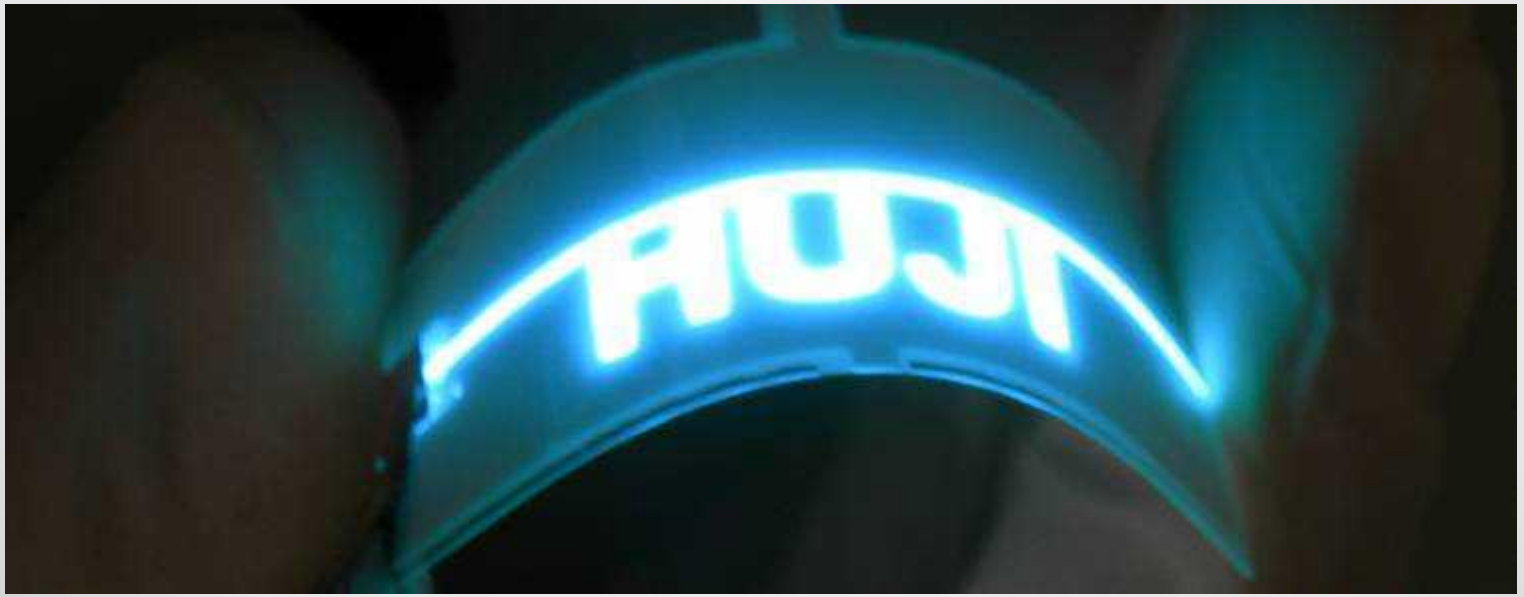


1000's liters produced by Xjet, Nanodimensions

Flexible electroluminescent paper

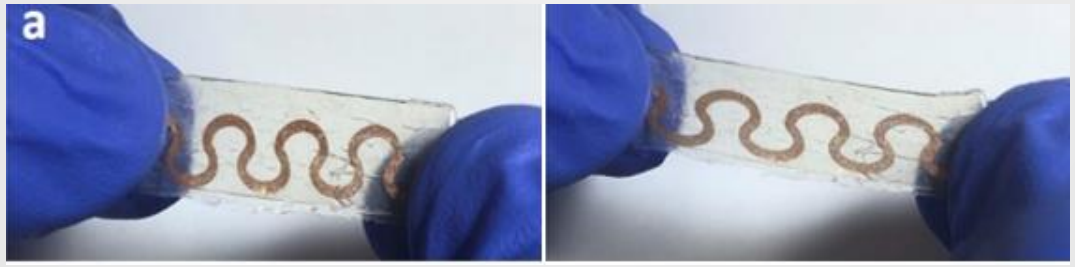
Immediate sintering at room temp





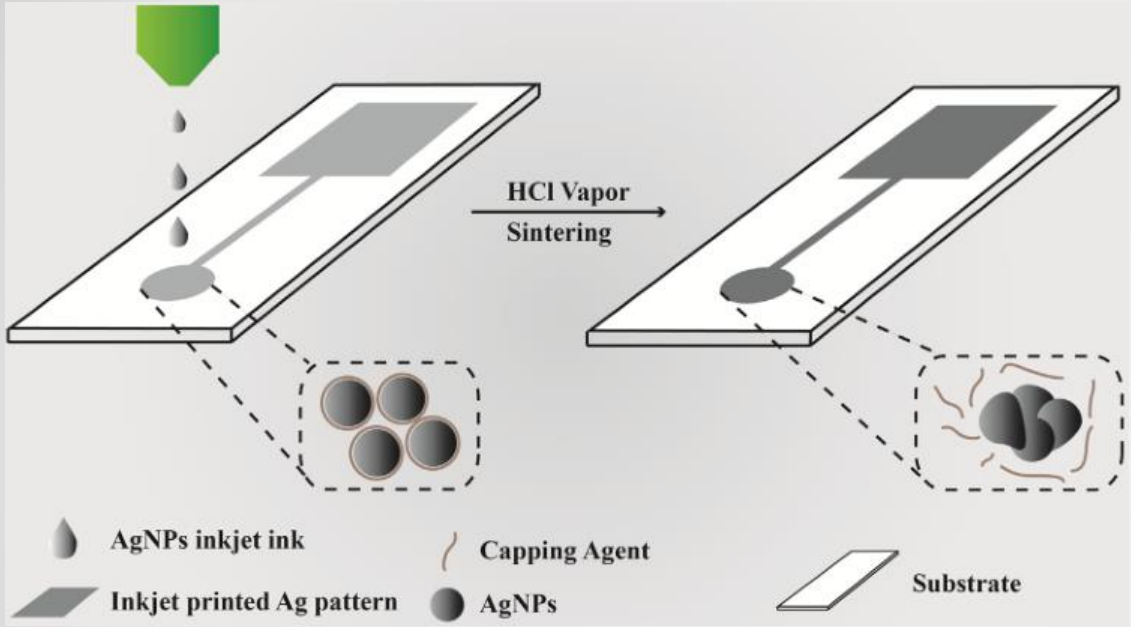
Sensing and communication
Paper substrate

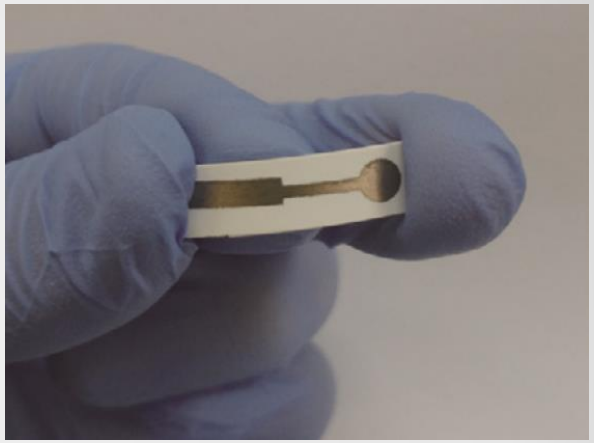
NFC Antenna/conductors on
stretchable substrate

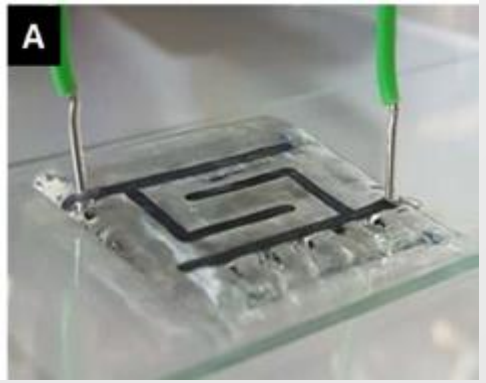


Biosensors

- Inkjet printed silver **paper** electrode for Electrochemical Detection of H2O2
- Electrodes embedded within **hydrogels**







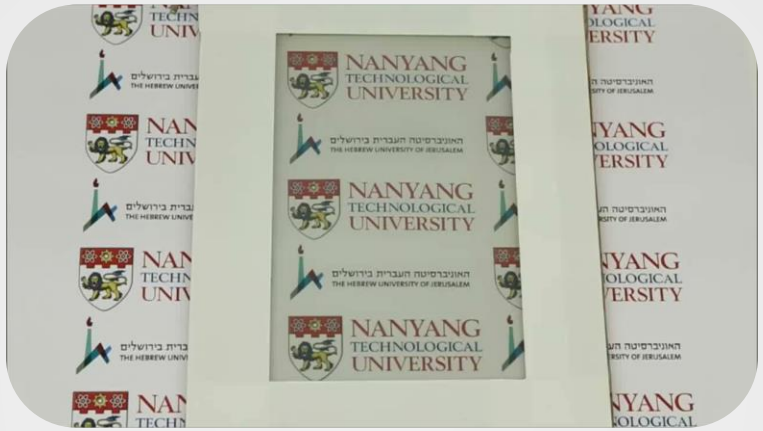
Sensors and Actuators B 2018
With Minbo Lan, ECUST

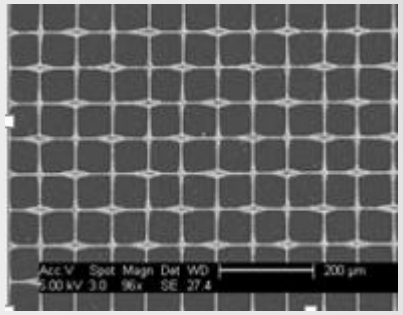
Biosensors and Bioelectronics 2018 With S. Agarwala

Transparent electrodes made of Ag NP

Electrochromic and Electro-thermocromic windows

Boeing's 787 Dreamliner



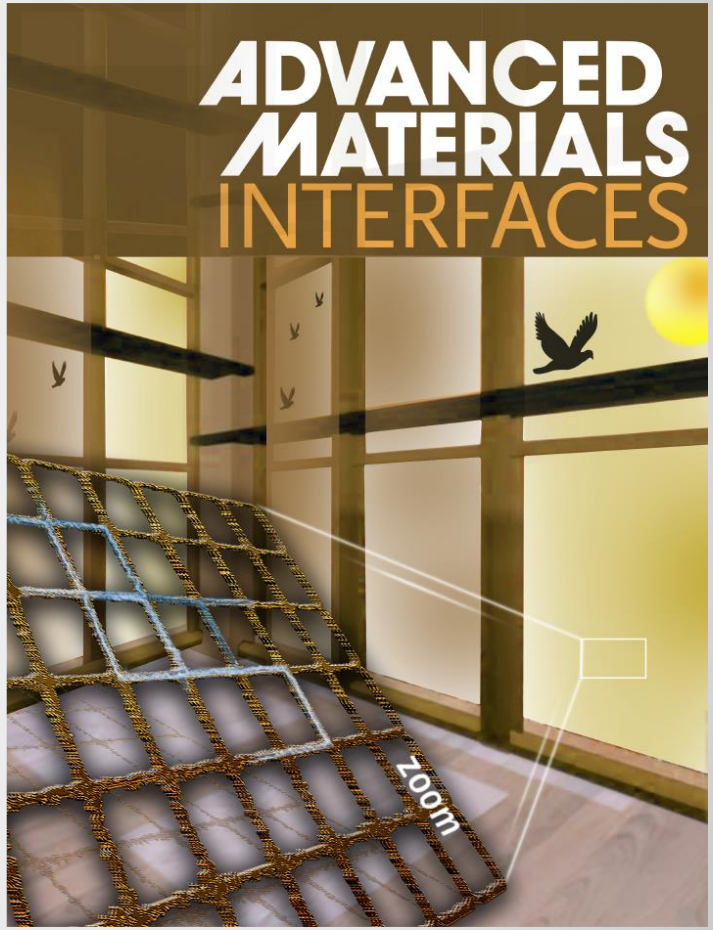


Advanced Functional Materials, 2017
Advanced Energy Materials 2016
Nanoscale 2014
J. Mater Chem. 2011

With PS Lee, NTU
With L. Yi, NTU

Towards all-printed semi transparent solar cells

Sustainable Energy & Fuels 2017



Advanced Materials Interfaces 2015
J. Mater Chem. A, 2016

With Prof. Lioz Etgar

Printing conductors with other metals ?

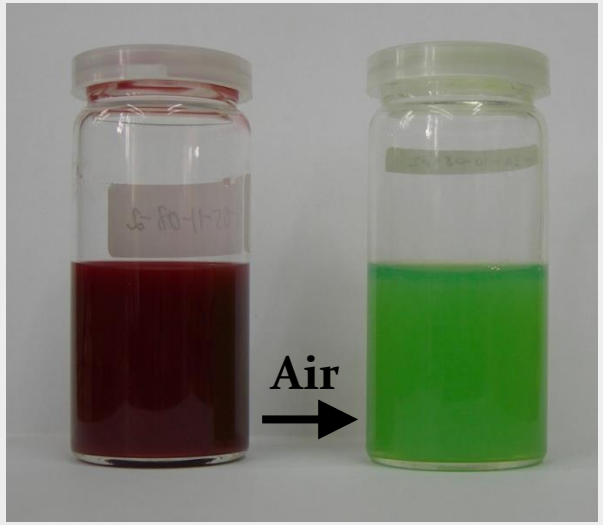
	Conductivity relative to silver	Cost relative to silver	
Silver	**1.00**	**1.00**	**Ag 820 $/Kg**
Copper	**0.94**	**~0.01**	**Cu 9.3 $/Kg**
Aluminum	0.56	0.002	Al 2.3 $/Kg

Copprint
PV Nano cell
PrintCB
CIC3D

Prices 19-4-21

Cu inks main challenge:

Copper NPs are unstable in air

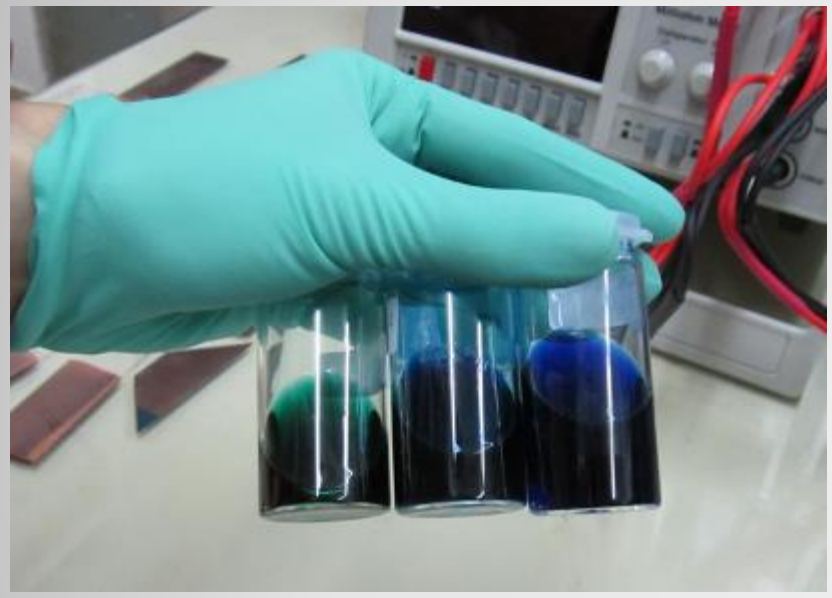


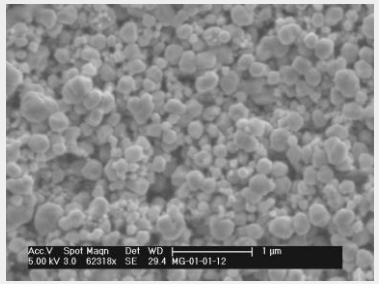
$Cu \rightarrow Cu_2O$ & CuO

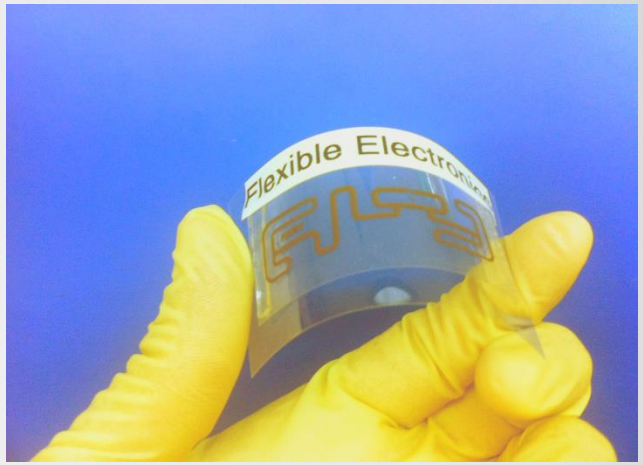
How can we overcome the oxidation ?

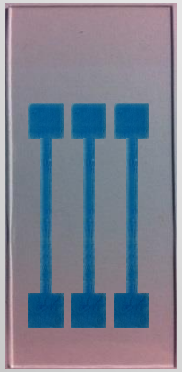
Core/shell particles, soluble complex

Copper formate NP nano particles become copper after heating

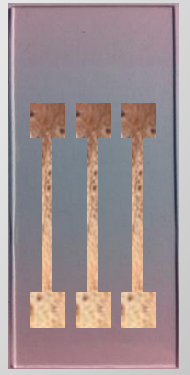








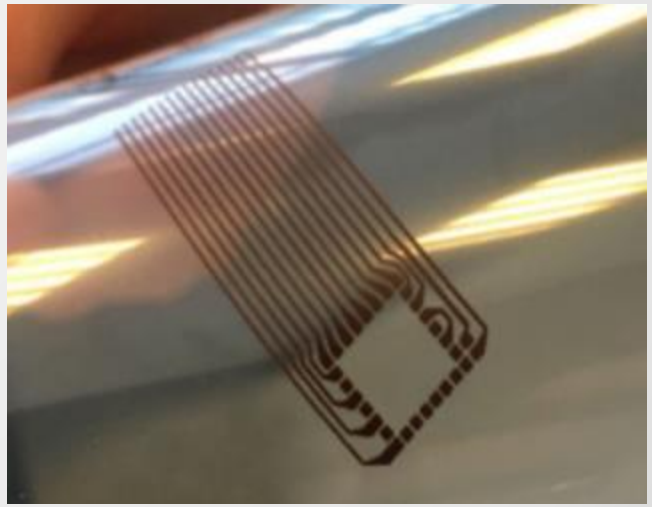
Casali Institute for Applied Chemistry
The Hebrew University of Jerusalem



Adv. Mater. Interfaces 2015

A new company in Singapore:
AMat
for production of low-cost copper inks

AMaT
ADVANCED MATERIALS



Non-metals ? CNTs
Flexible/Stretchable electronics

Unique properties:

- **High chemical stability**
- **Mechanical properties**
- **Optical properties**
- **Electrical conductivity**
- **Thermal conductivity**
- **Flexibility**

Applications:

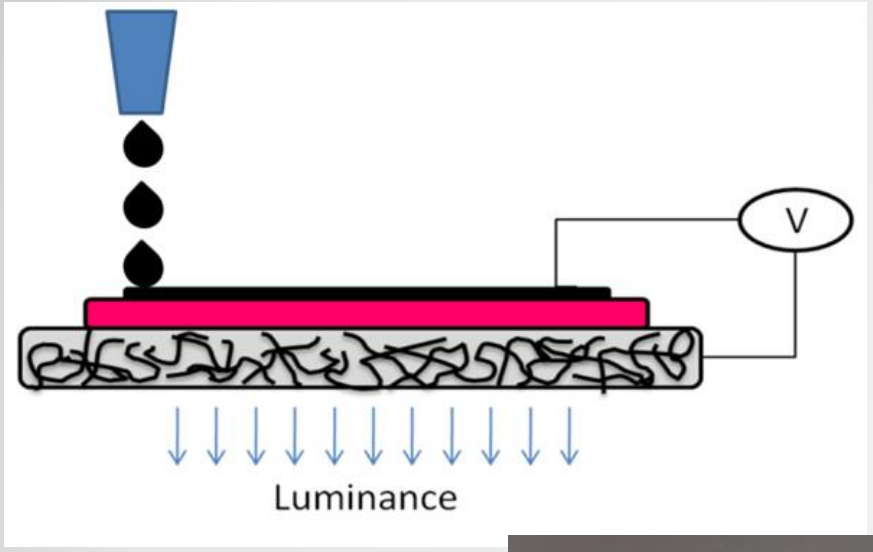
- **Nanoelectronics**
- **Solar cells**
- **Super capacitors**
- **Transistors**
- **Optoelectronic**

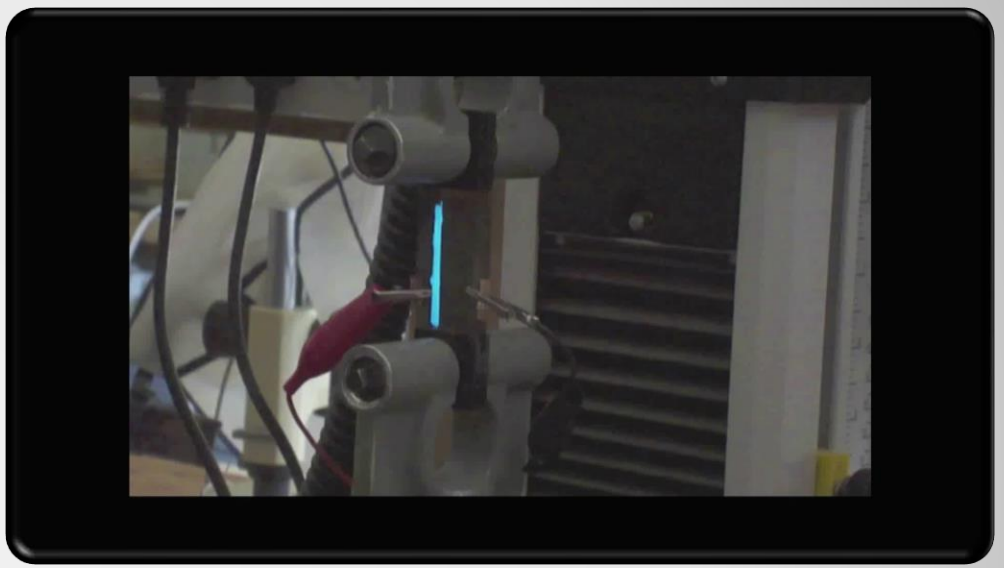
Main challenges in making CNT inks:

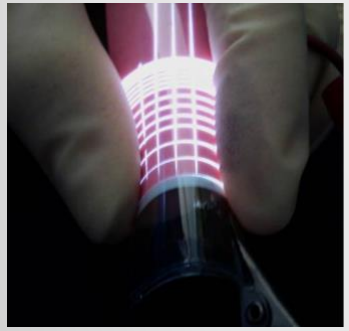
De-agglomeration, CNT-CNT contact, adhesion, micron length wires- jetting ?

Collaboration with D. Porath and Y. Paltiel

CNTs as all electrodes for flexible devices



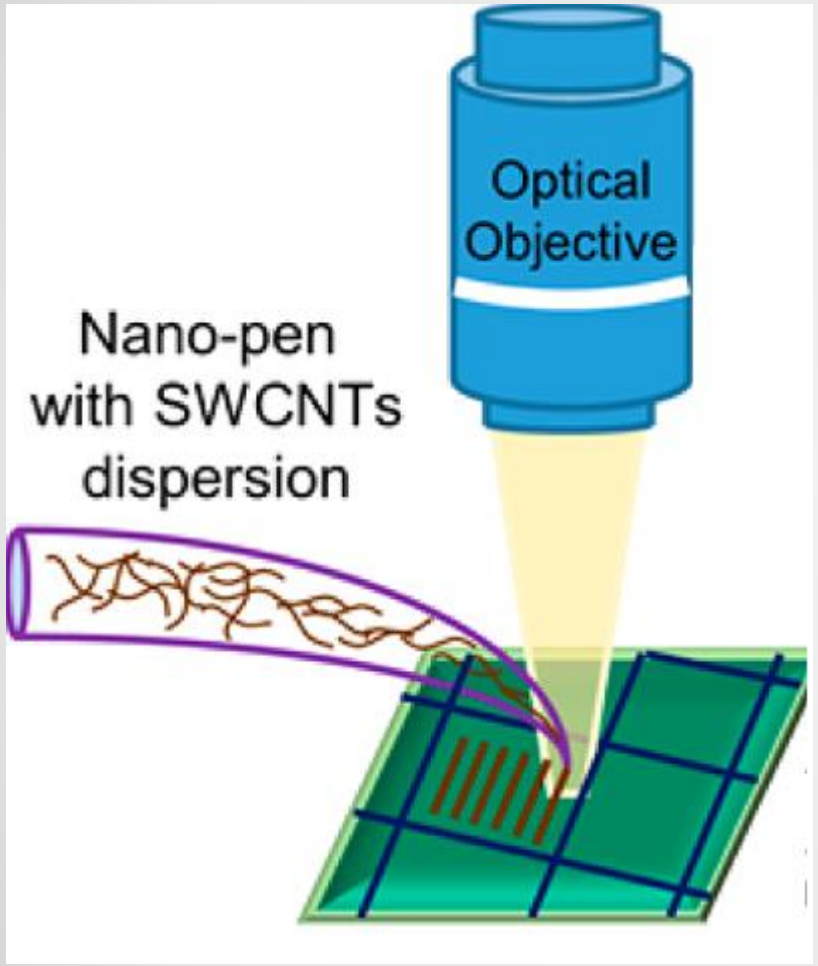


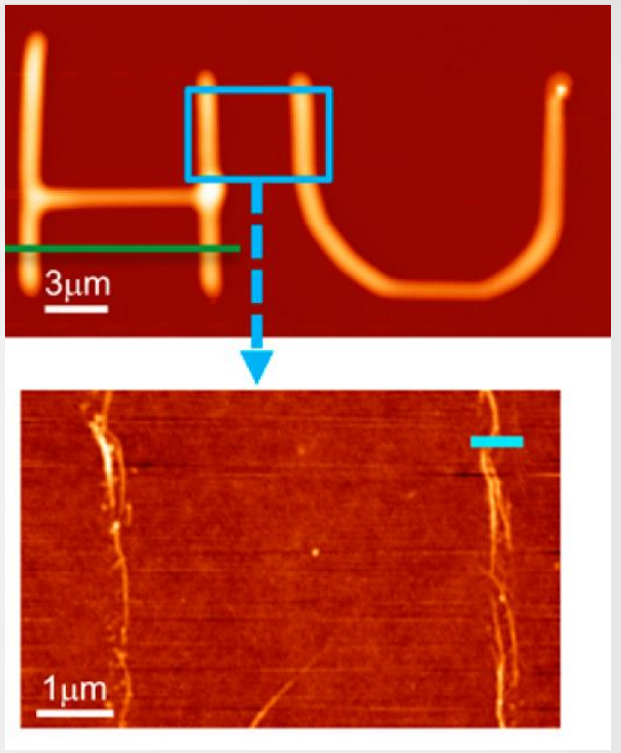


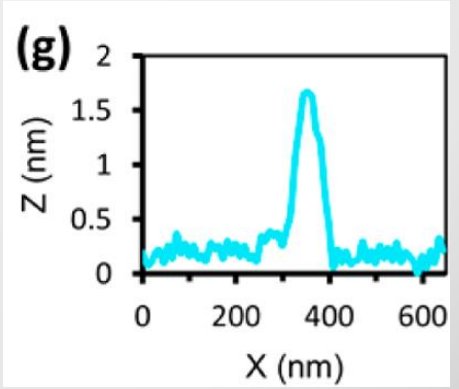
Nano Letters 2016, J. Mater. Sci. 2015, The Journal of Physical Chemistry C 2018, ACS Appl. Mater. Interfaces 2014, Nanoscale 2014, J. Coll. Interface Sci. 2013, Nanotechnology 2012, Sensors and Actuators 2014

Printing micron size lines ?

Nanodrawing of Aligned Single Carbon Nanotubes with a Nanopen



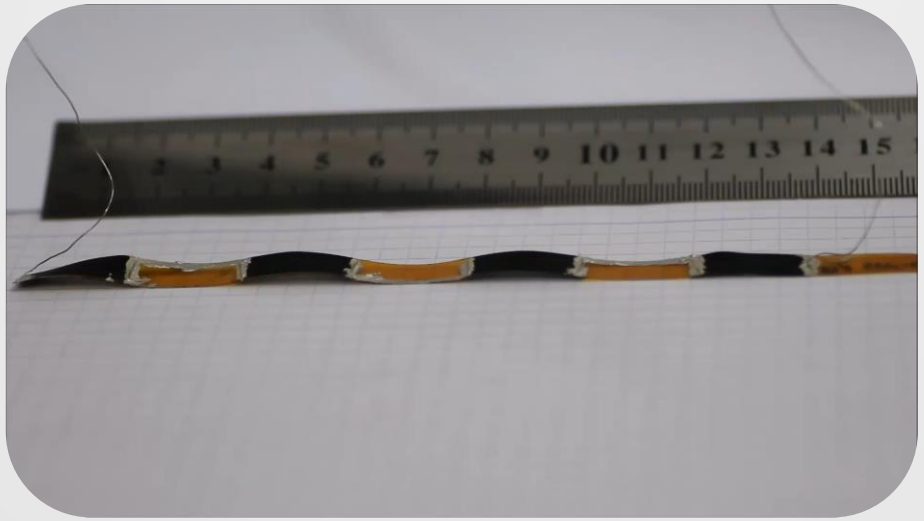




Nano letters 2016

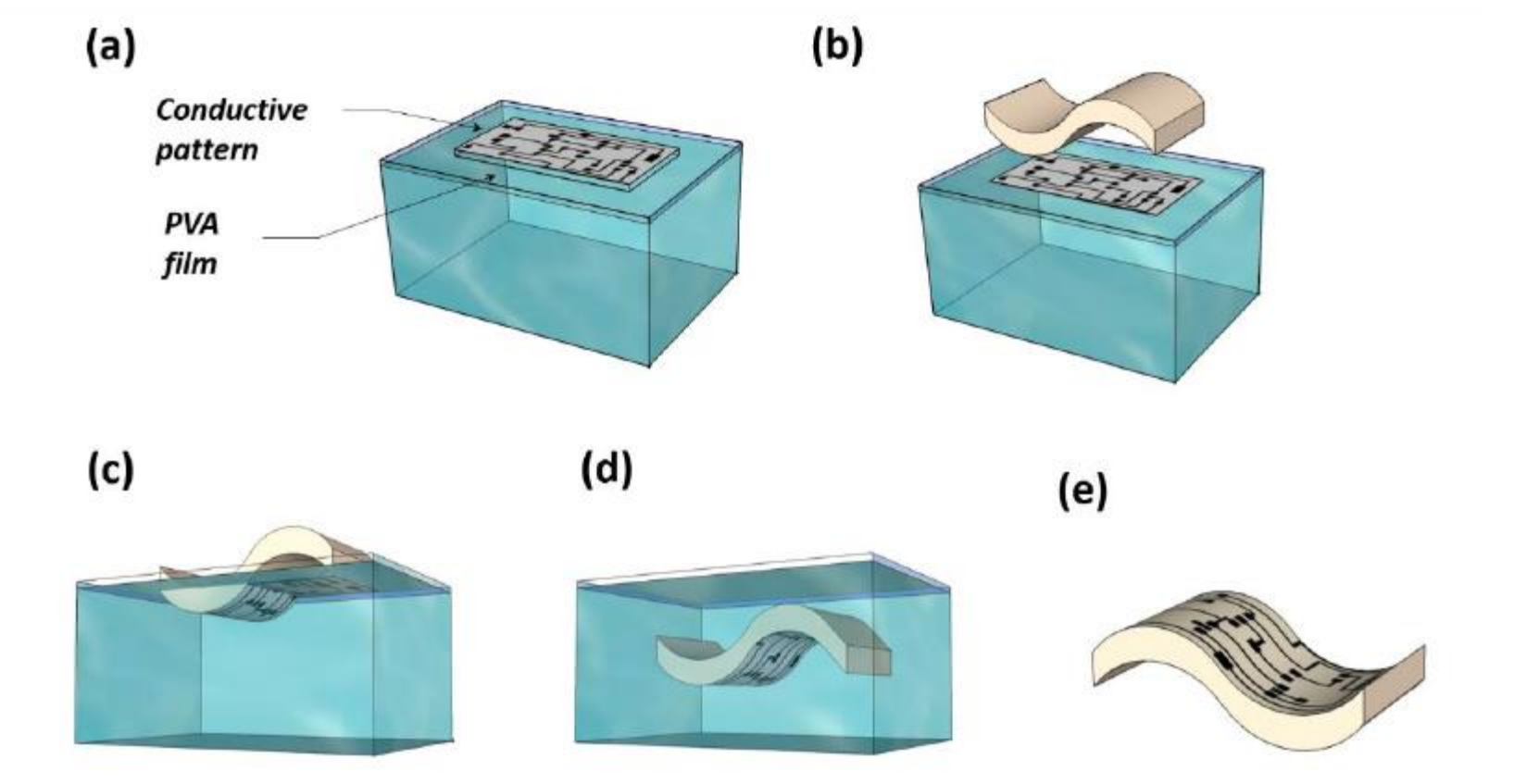
With Lewis

Soft robotics
Moving objects by different thermal expansion

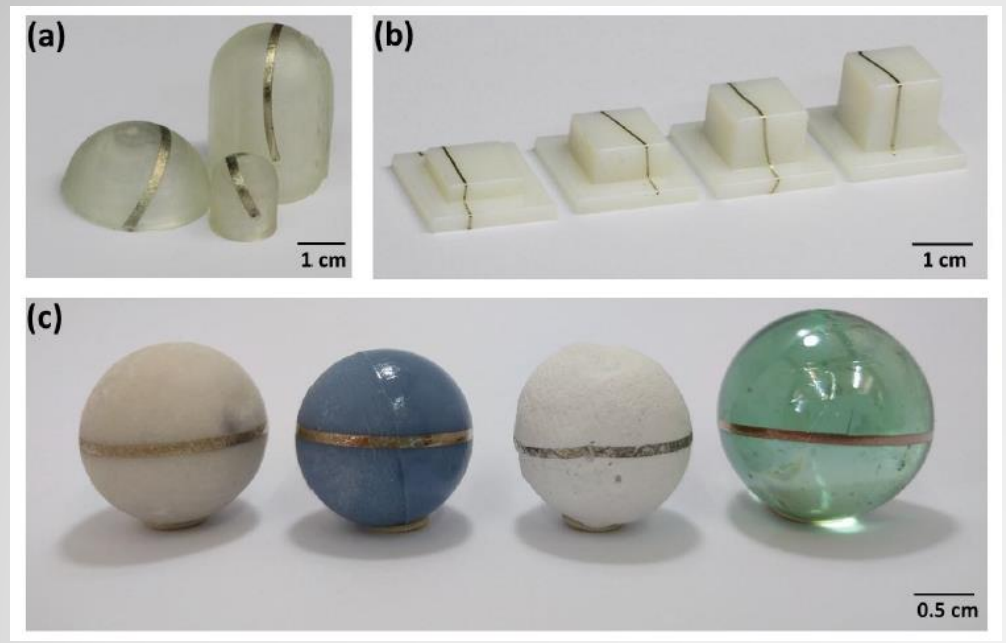


Sensors and actuators 2017

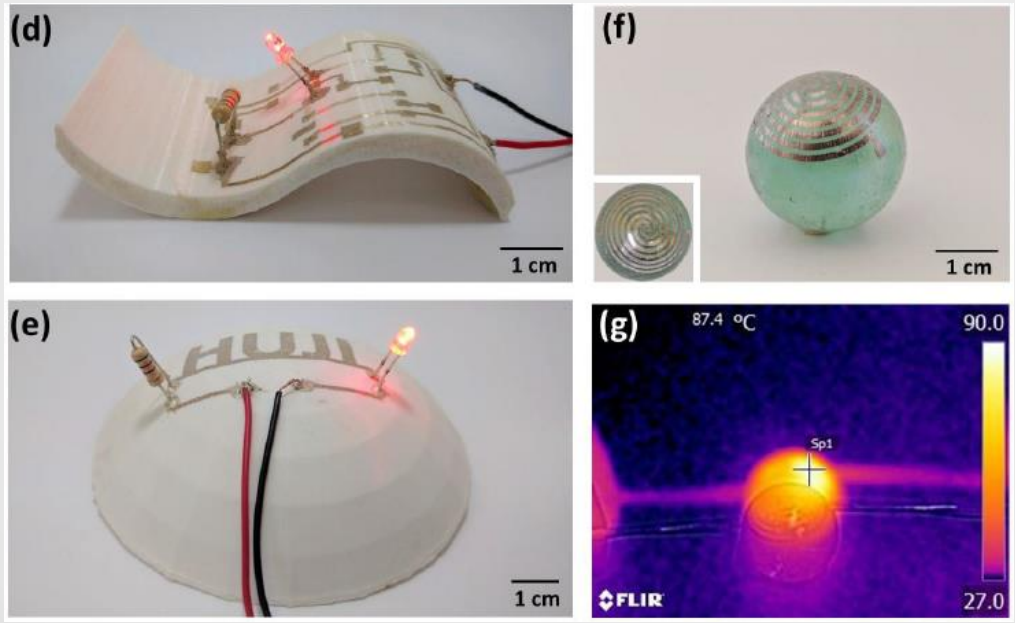
Printing onto 3D objects (2.5D)
Functional Hydro-printing



Advanced Materials Technology 2017

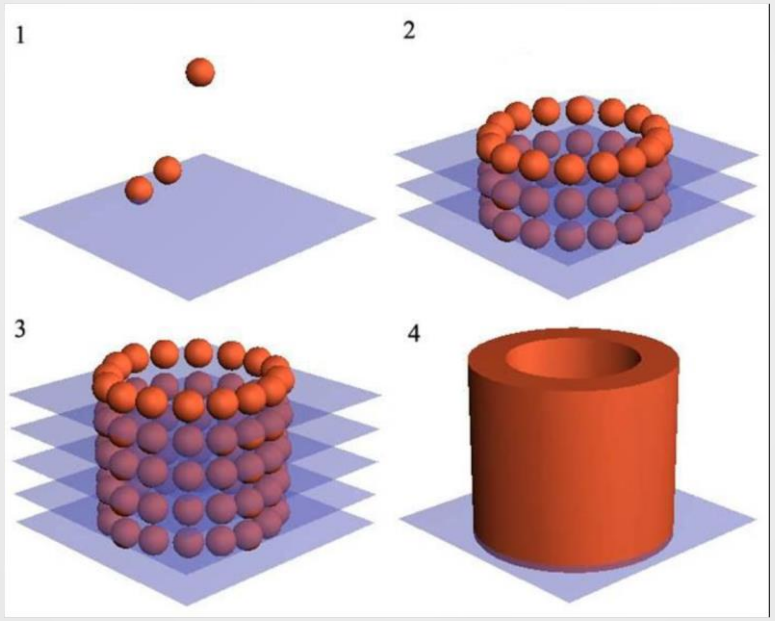


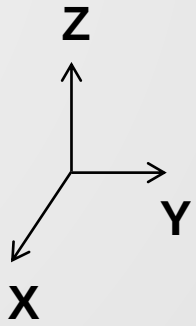
Antennas for IoT



Making multi-layer structures by repeated 2D printing:

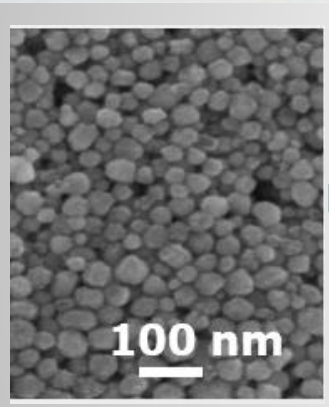
Additive Manufacturing

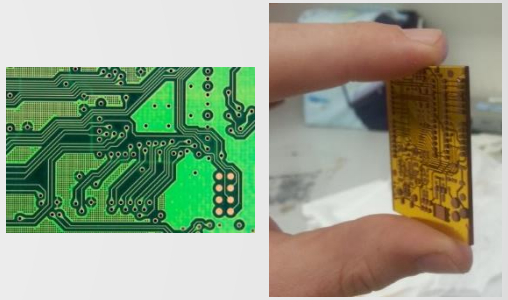




Multi-material 3D Printing of electronic circuit boards

Conductor/insulator layers





NANO DIMENSION
3D PRINTED ELECTRONICS

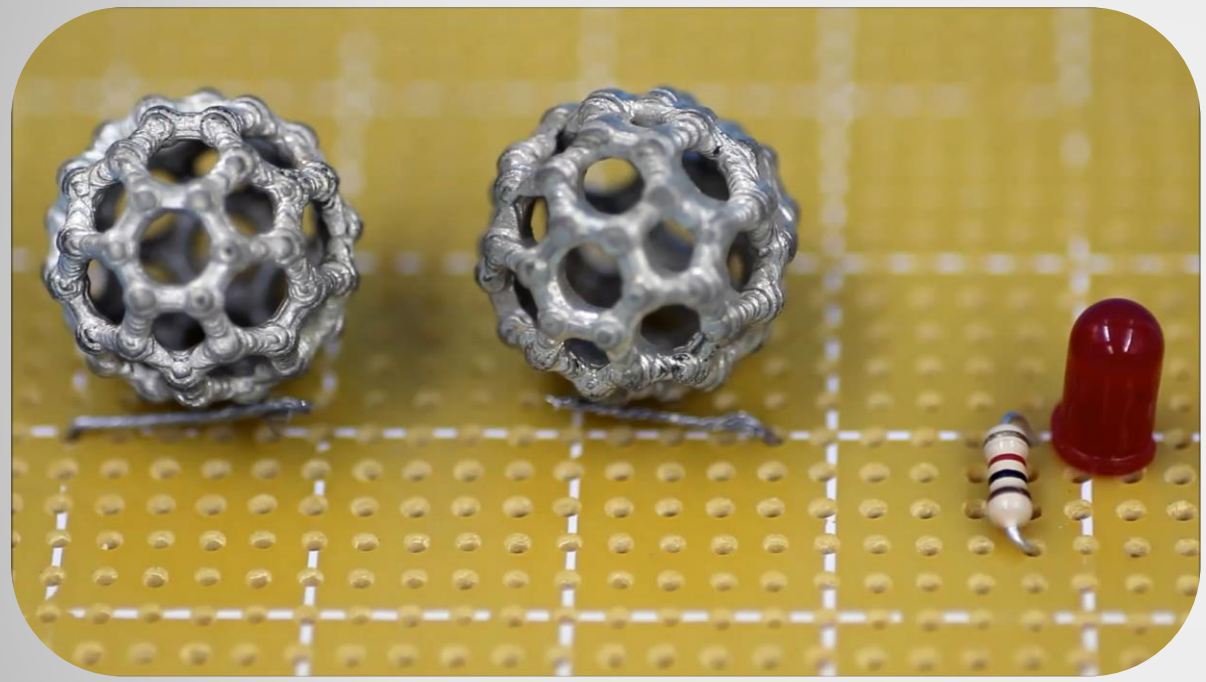
NANO DIMENSION

3D printed electronics

Silver inks licensed to Nanodimension Israel

Combining RT sintering with 3D printing

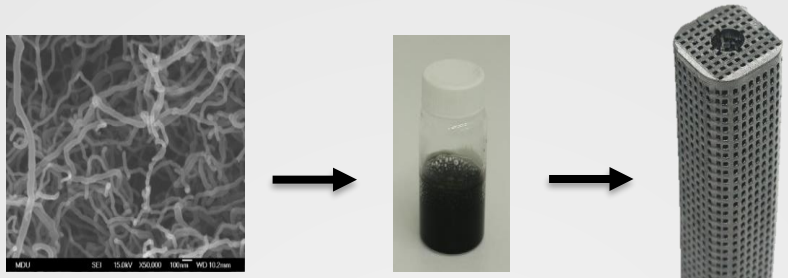
3D stretchable connectors



Resistivity during stretching

Advanced Materials 2017

CNT embedded in 3D printed stretchable objects



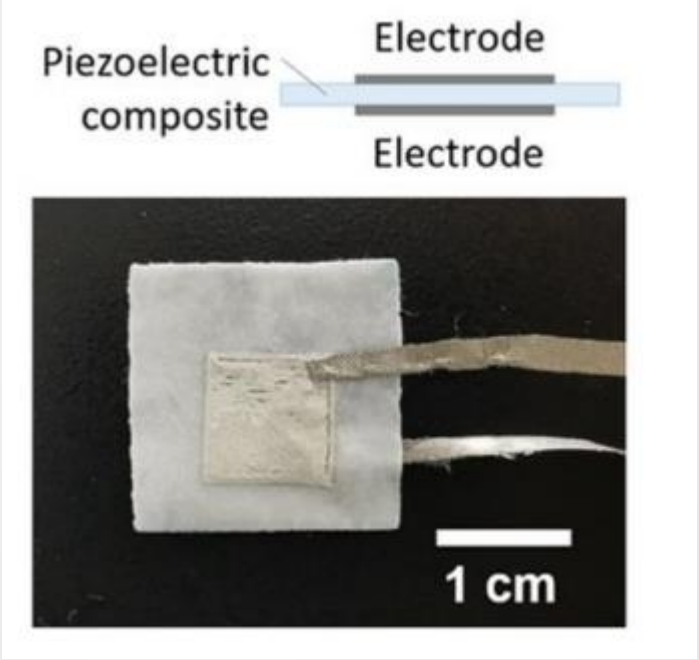
3D ink

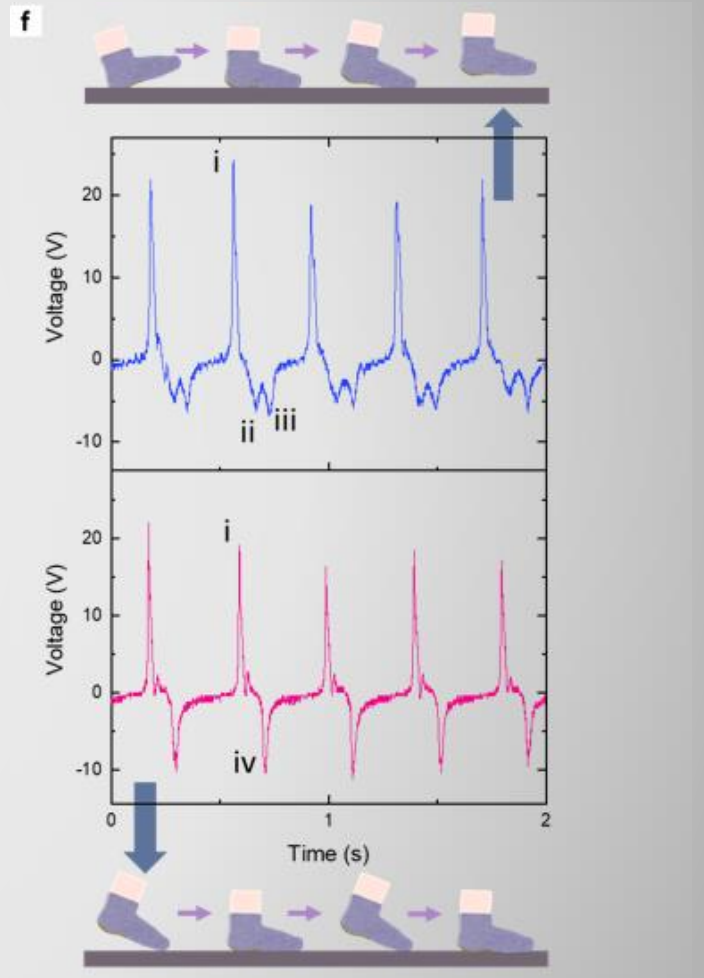
3D electrode

3D pressure sensors

Wearable electronics ?

3D stretchable piezoelectric energy harvester





Nano Energy 2020
PS Lee

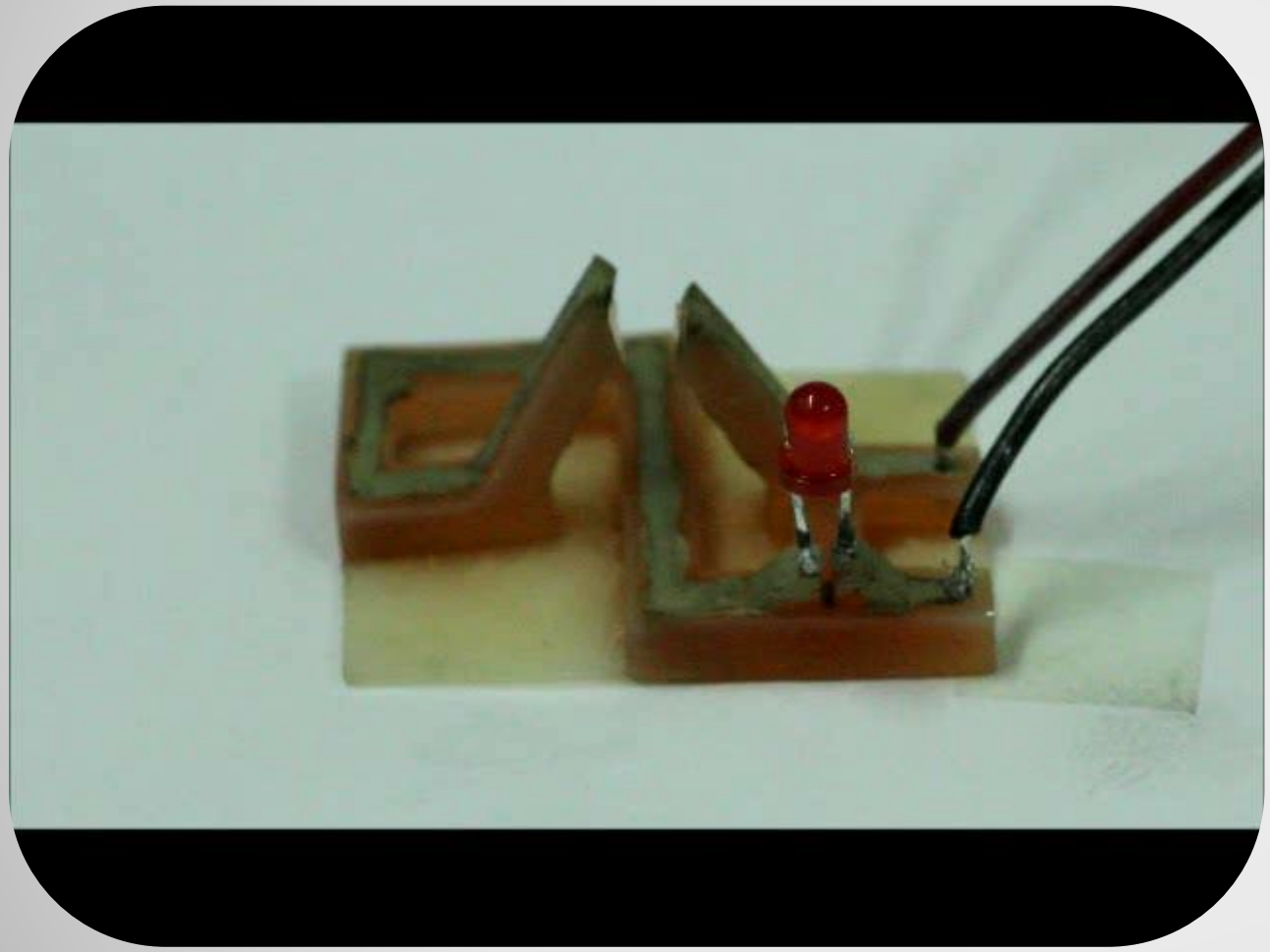
PENG : Piezoelectric Nanogenerator

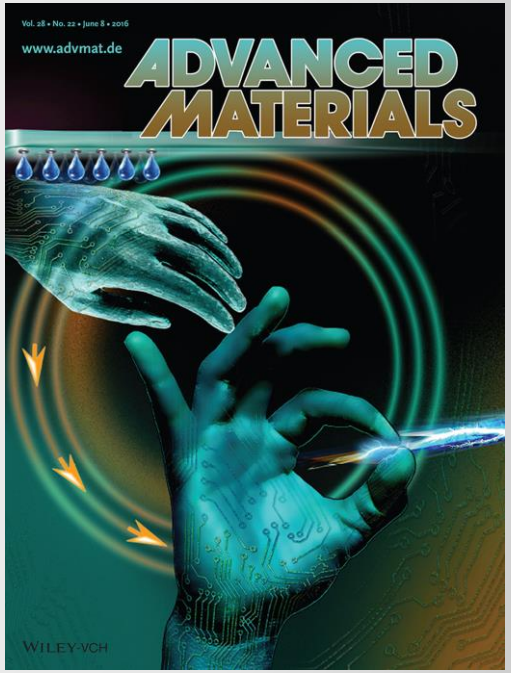
4D printing: The new frontier

Objects changing shapes

- Temperature
- pH
- Ionic strength
- Electrical field
- Magnetic field
- Light
- Humidity
- Time

Electrical circuits with shape memory: heat responsive sensor





Advanced Materials 2105

Main Challenges

- Industrial production scale
- Meeting electronics industry standards
- Cost
- Stretchable/plastic devices
- Environmental issues
- Multilaterials: dielectrics, conductives, isolators, magnetic
- Resolution/miniaturization
- Advanced packaging/thermal management
- Resistance-Space, humidity, solderability etc.

While maintaining the function of the device!

köszönöm תודה! děkuji
mahalo 고맙습니다
thank you
merci 谢谢 danke
Ευχαριστώ شكرا
どうもありがとう gracias

EU: FP6 - SelectNano, FP7 - Lotus, CoWet
Horizon 2020-Proboscis,NanoPaInt
Singapore NRF - CREATE
Israel Ministry of Science
Israel Ministry of Economy
Israel Ministry of Defense

PROBOSCIS