Printed and Flexible Electronics Devices

Jin-Woo Han
jin-woo.han@nasa.gov

Universities Space Research Association
NASA Ames Research Center

All images courtesy of NASA

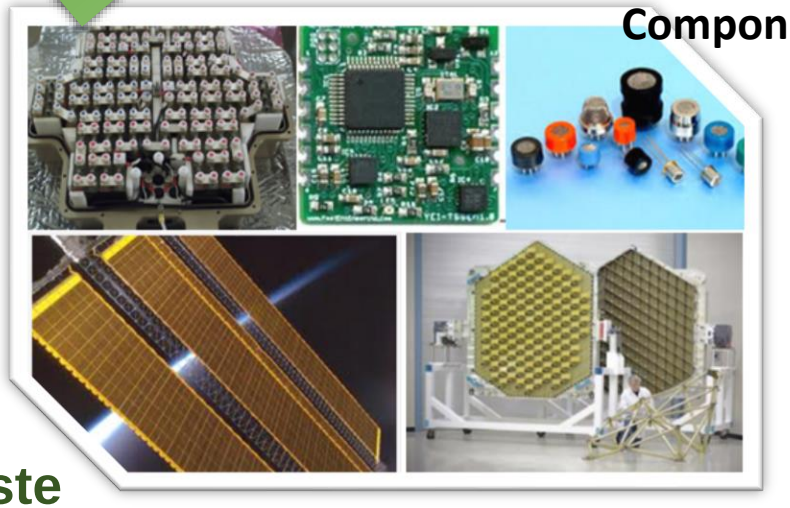
Motivation for Our Work

In-Space Manufacturing (ISM) Program

In space

☹ Space flight 2~3 / year
☹ Significant cost as payload

Electronic Components

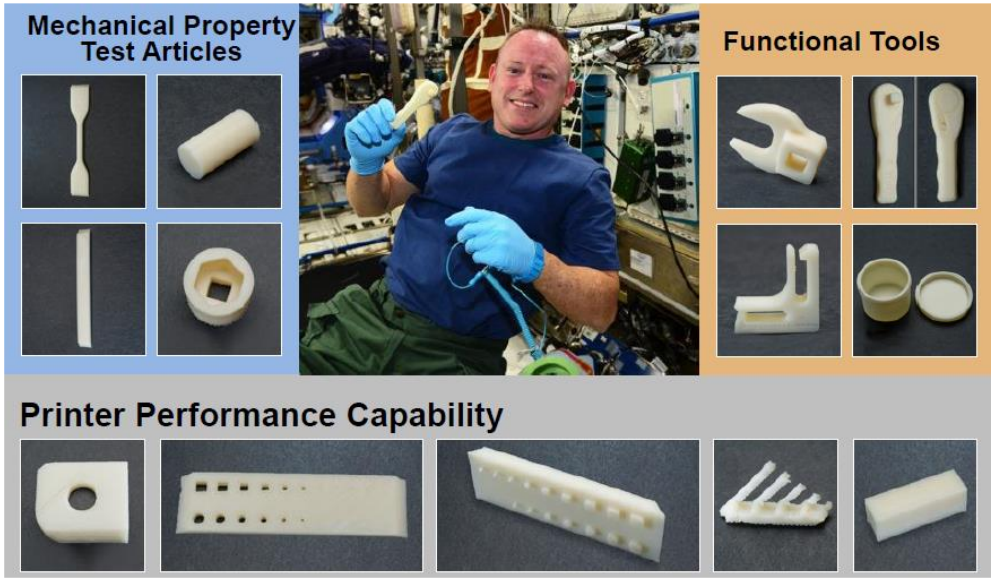


On Ground

☹ Not green
☹ Energy waste

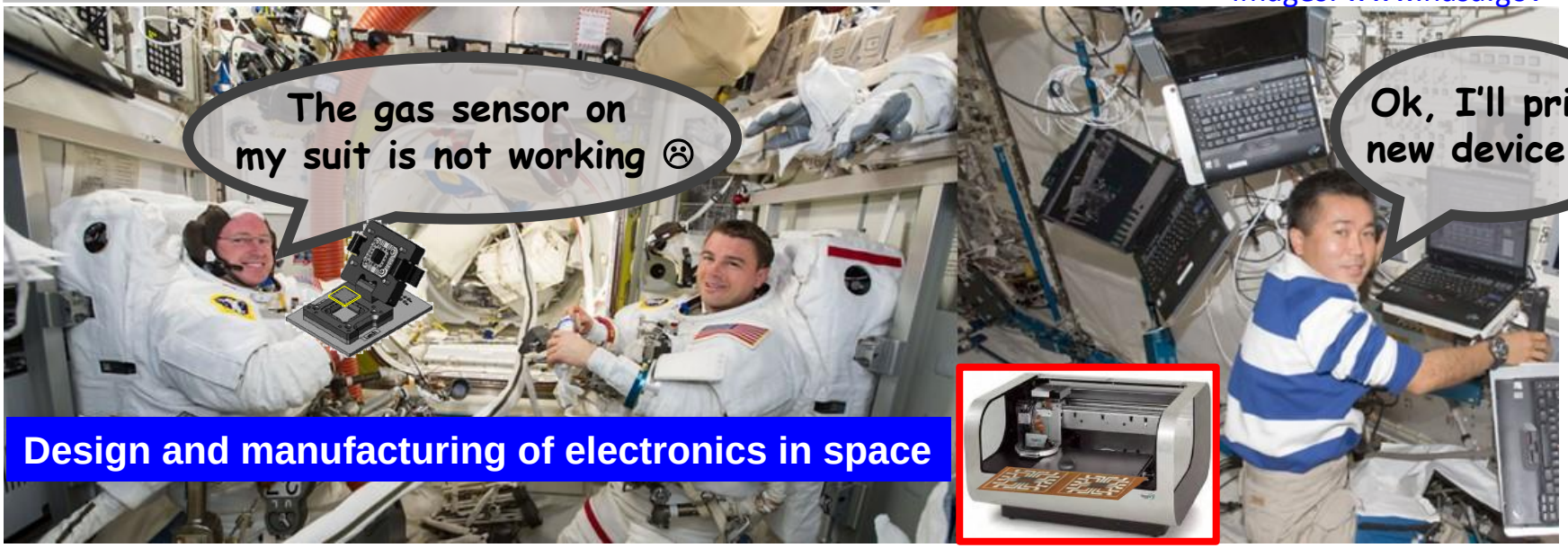
All images courtesy of NASA

ISM in International Space Station (ISS)



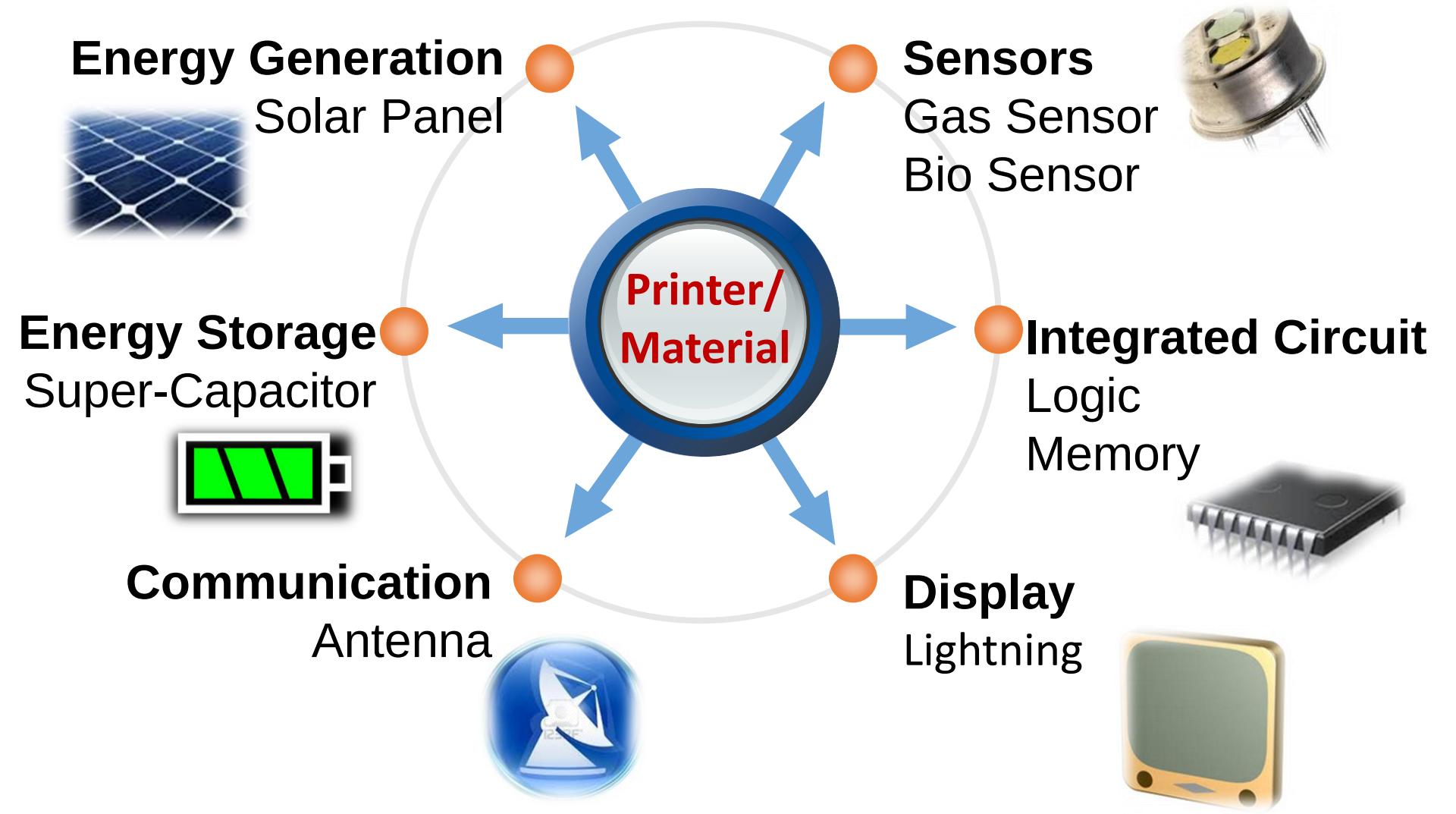
3D printer in ISS

Images: www.nasa.gov

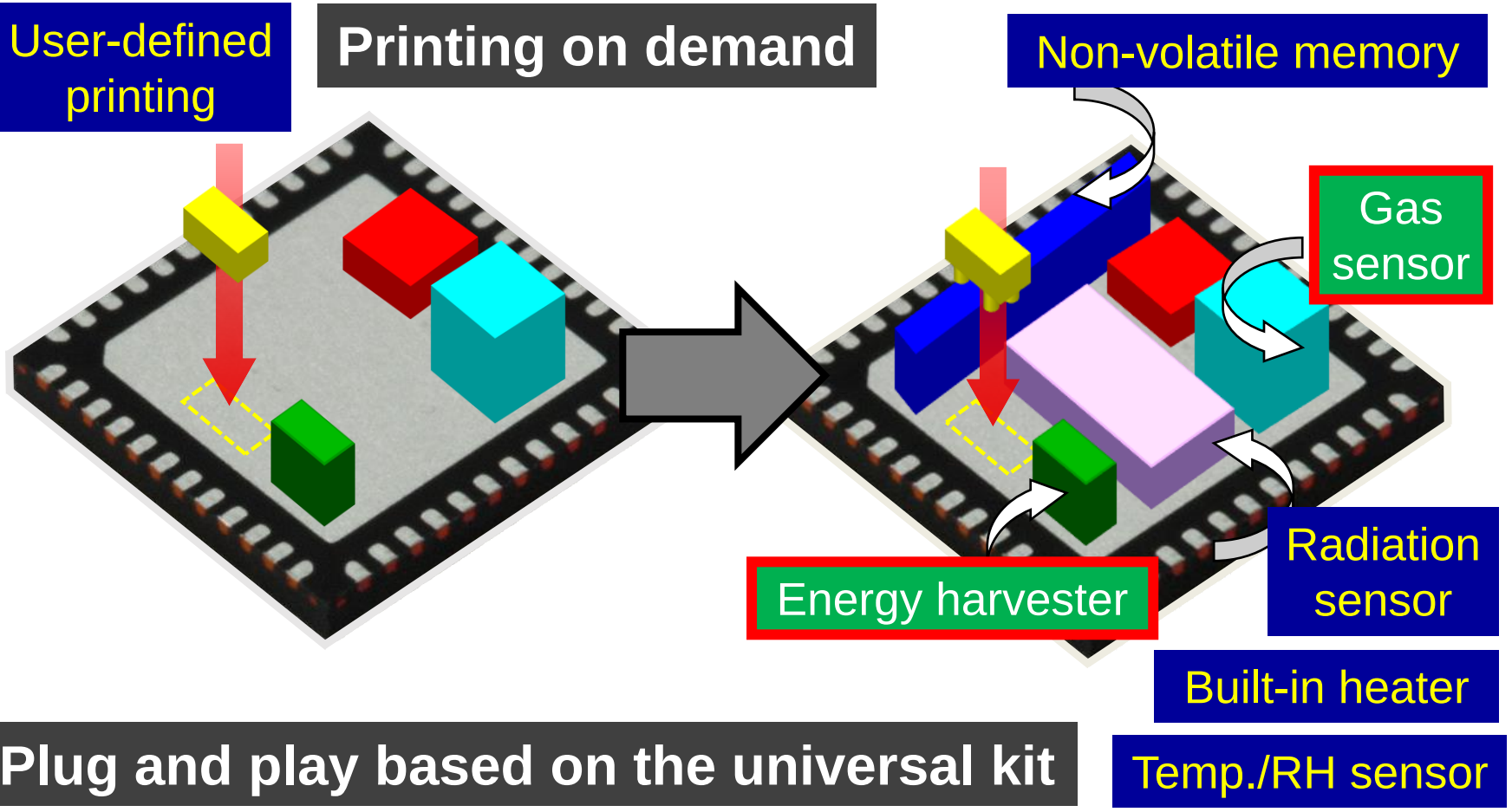


All images courtesy of NASA

Printable ‘Electronic’ Components



Printed Device Platform: A Universal Kit



Gas Sensors

ACS Sensors, vol. 3, pp. 1782−1788, 2018.
ACS Applied Nano Materials, vol. 2, pp. 6445-6551, 2019.

Ammonia Gas Leak Accident in ISS

Intl. Space Station
@Space_Station
Follow

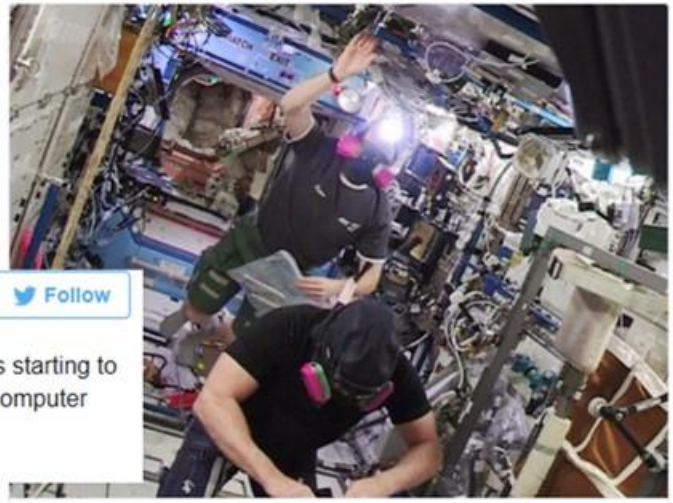
#Exp42 open US segment hatch & return 3:05pm ET. @AstroTerry & @AstroSamantha sample #ISS air, no ammonia indication.

12:16 PM - 14 Jan 2015

NASA
@NASA
Follow

Update: #Exp42 crew informed by controllers that it's starting to look like a false indication, either a faulty sensor or computer relay.

5:17 AM - 14 Jan 2015

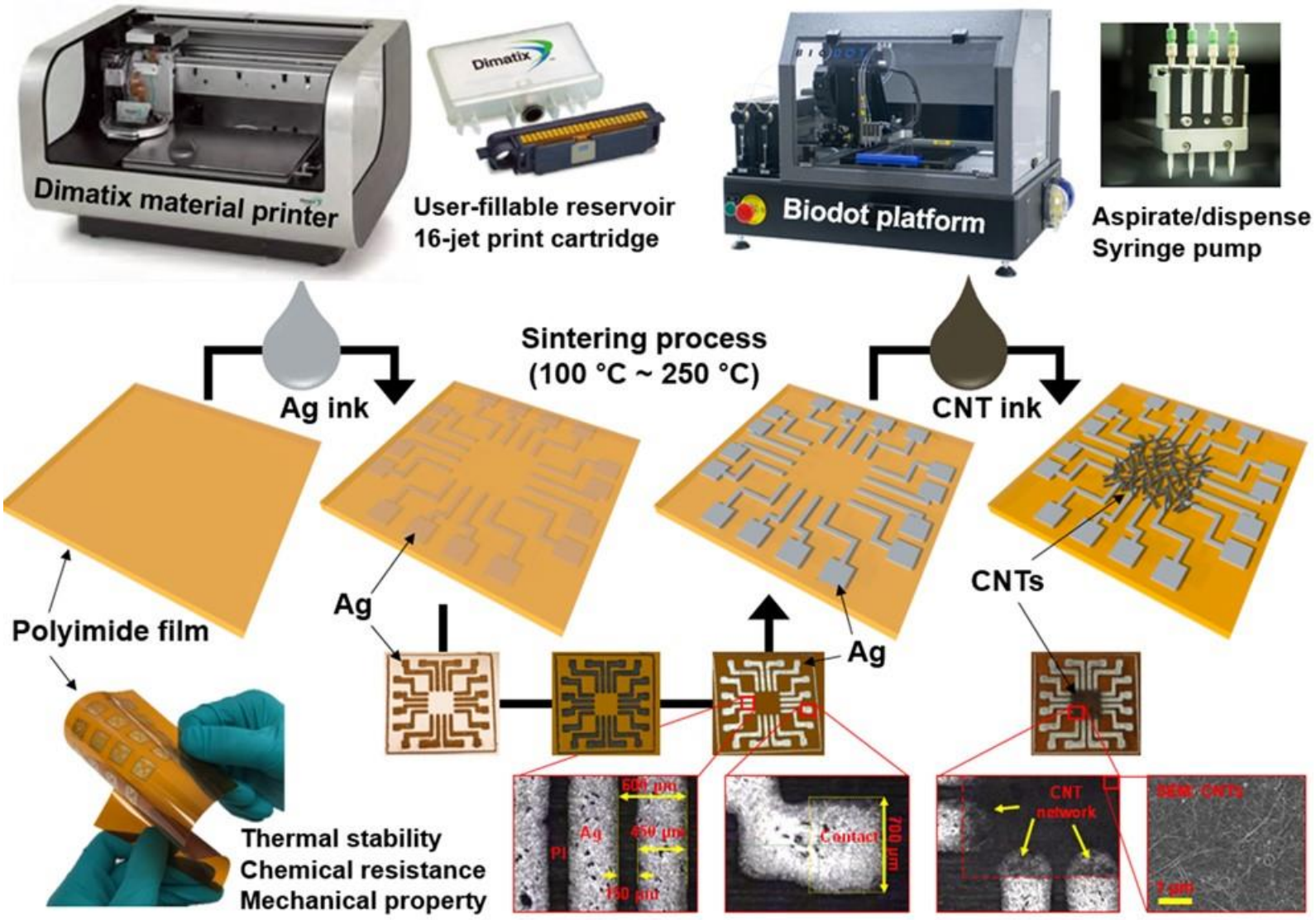


Space Applications: cabin air quality in ISS, leak detection, planetary atmosphere

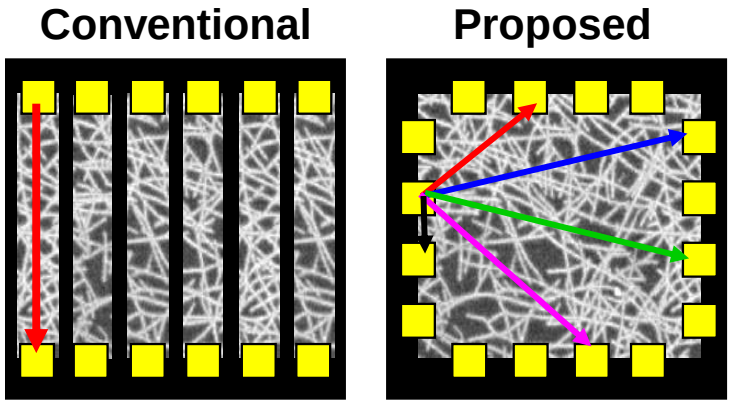
Societal Applications: Indoor/outdoor air quality, industrial leaks, breath analysis

All images courtesy of NASA

Printing Process

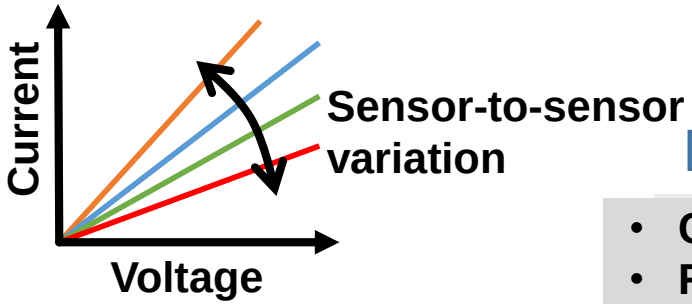


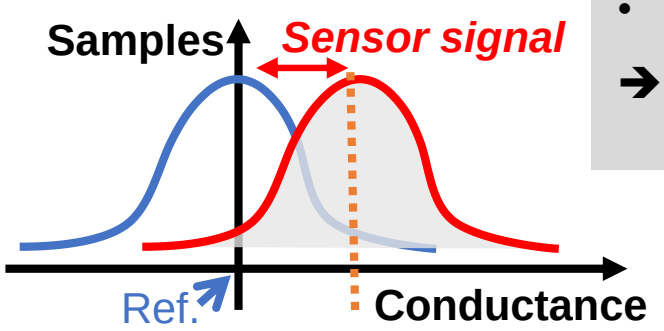
Multiport CNT Gas Sensor



	Conventional	Proposed
Electrode	16	16
Output data	8	120
Area*	8 by 8	12 by 12
Data/Area	0.125	0.833

*Unit area = half pitch of the contact to contact distance





- Cancelation of external noise
- Reduction of internal variation
- Statistical sensing result

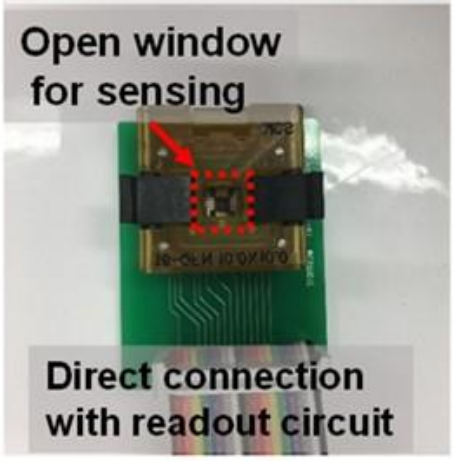
➔ Stable and reliable sensor in same footprint

Sensor Experiments

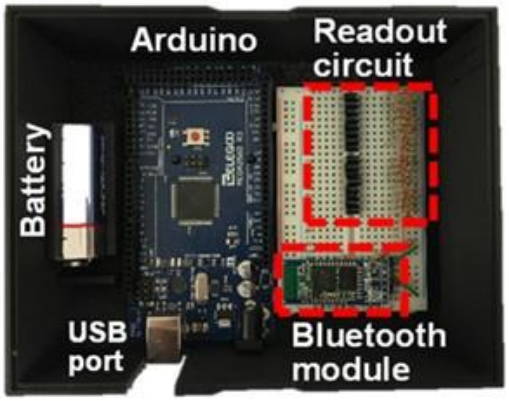
1) Sample preparation

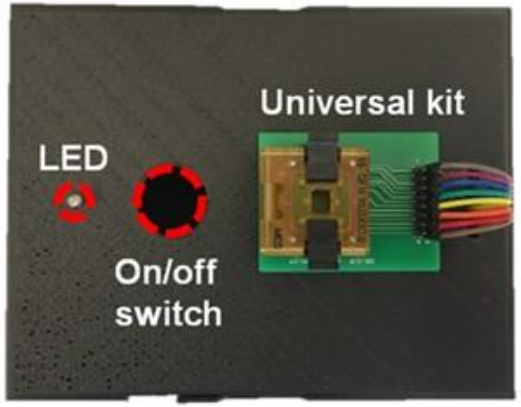
2) Mount of the sensor on the universal kit

3) Electrical connection



4) Gas connection



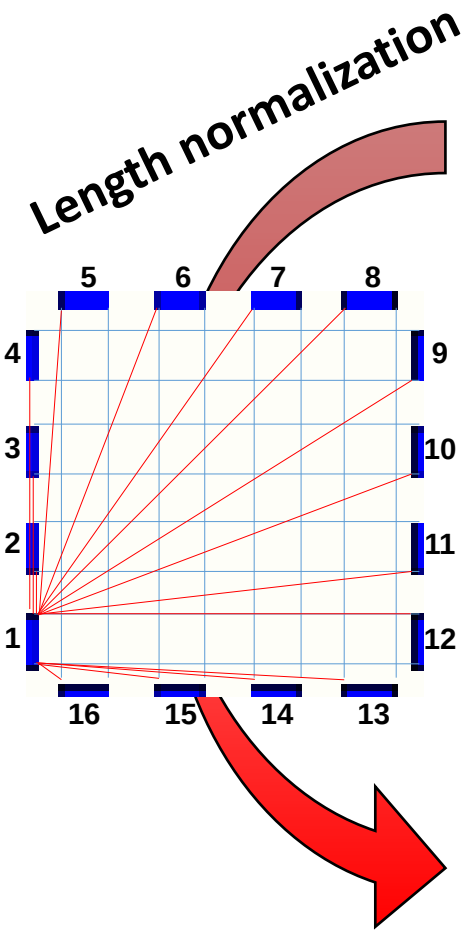


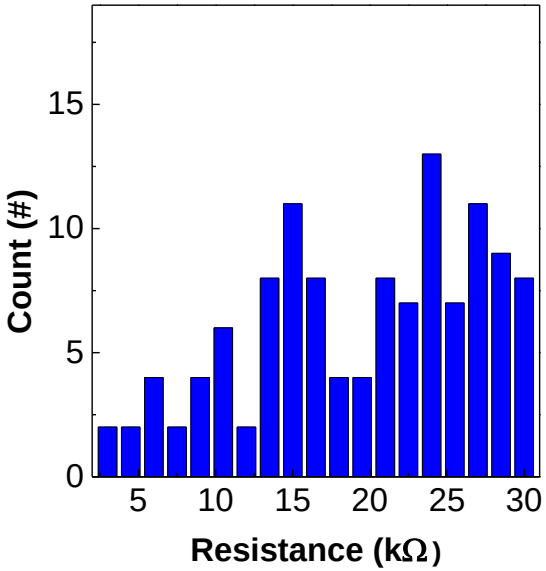
- Automatic system operation
- Battery power and remote control
- Wireless data log from 16-channel I/O

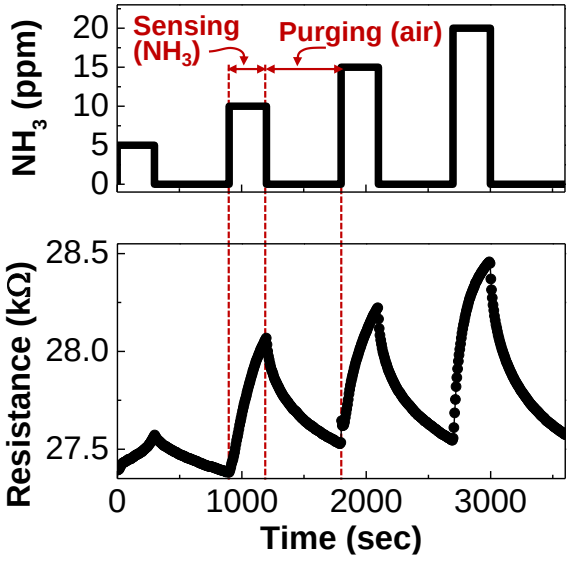
Universal kit for printed electronics

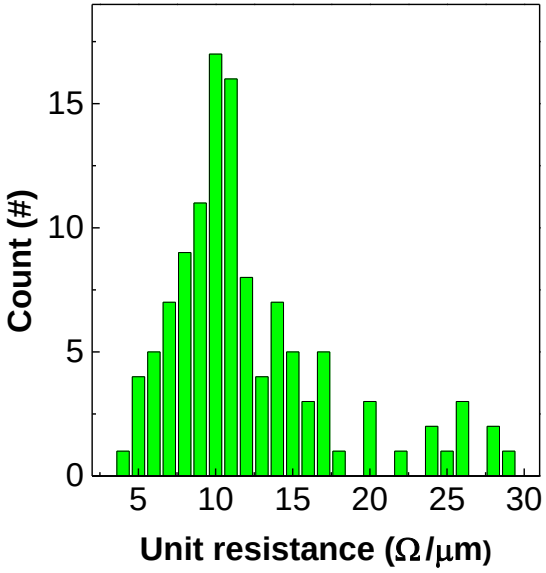
3D printed remote sensing kit

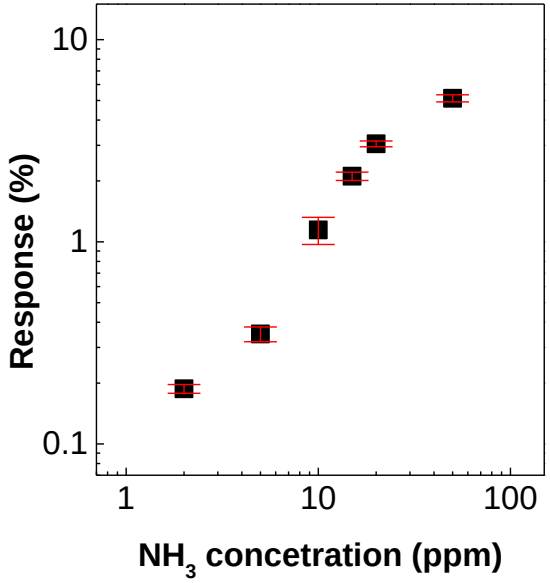
Ammonia Gas (NH_3) Detection



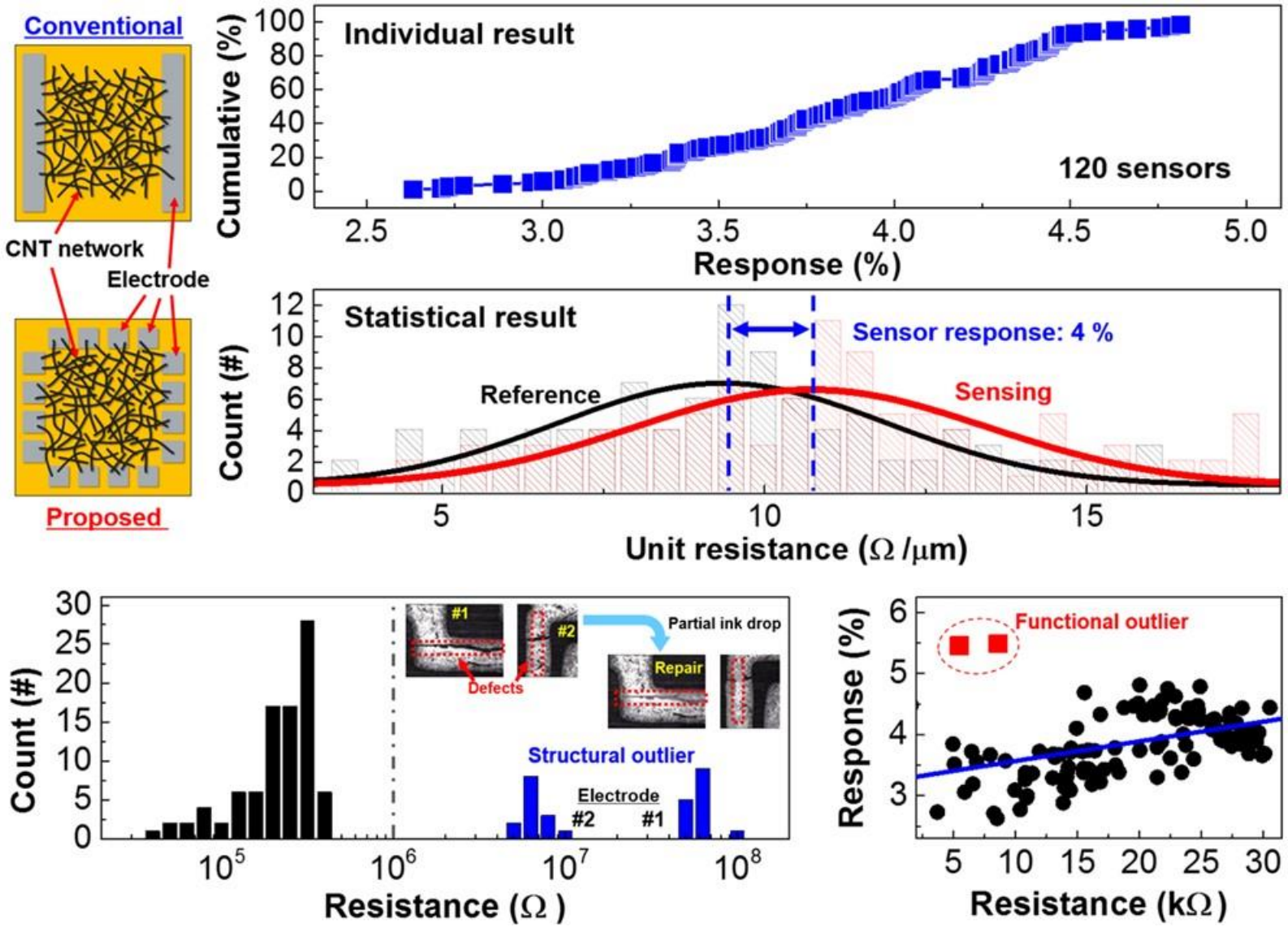




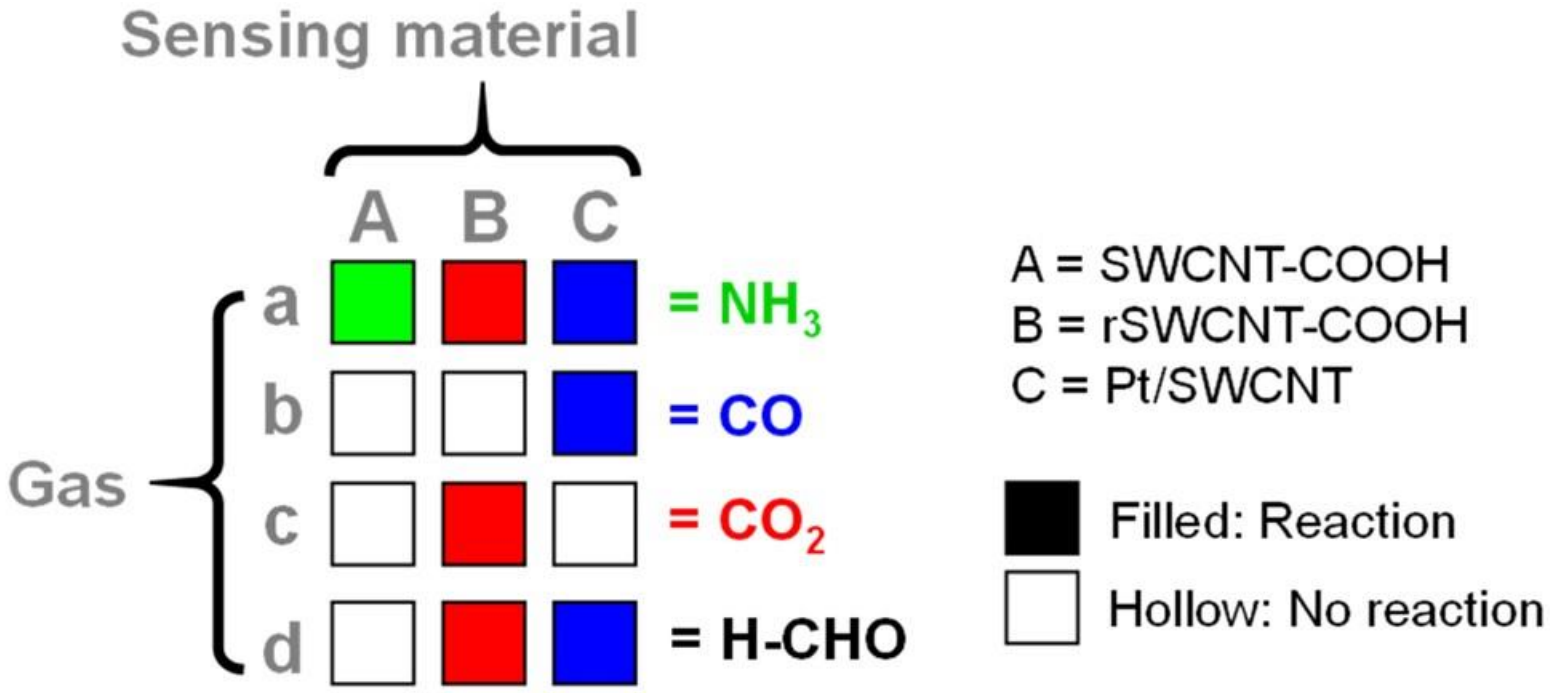




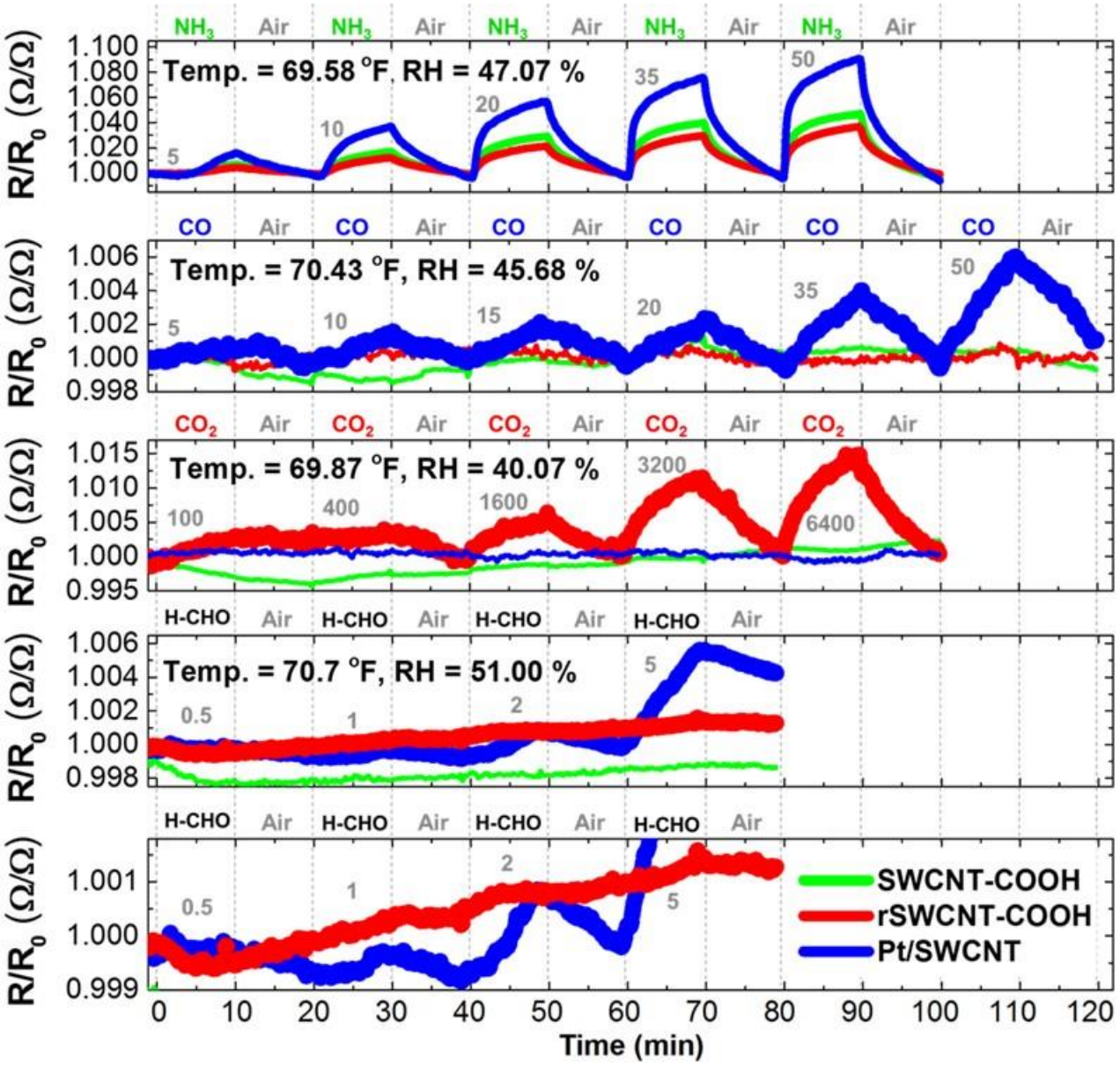
Variation Tolerance



Electronic Nose (E-nose)



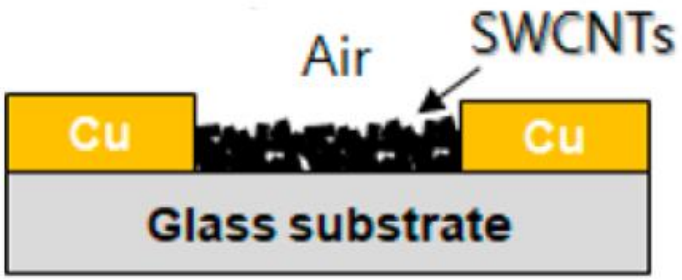
Multiple-Gas Detection



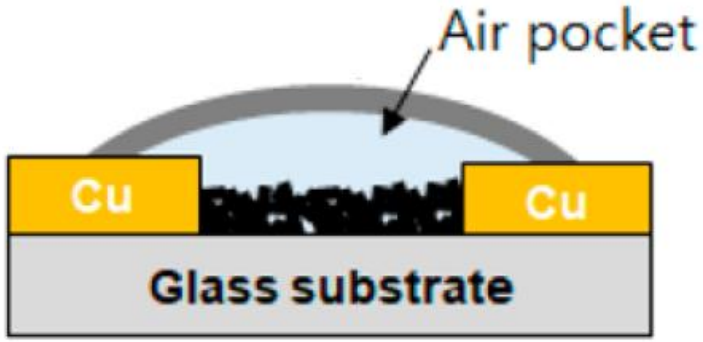
Radiation Sensors

ACS Sensors, vol. 2, pp. 1679-1683, 2018.
ACS Sensors, vol. 4, pp. 1097-1102, 2018.

All-Printed UV Sensor

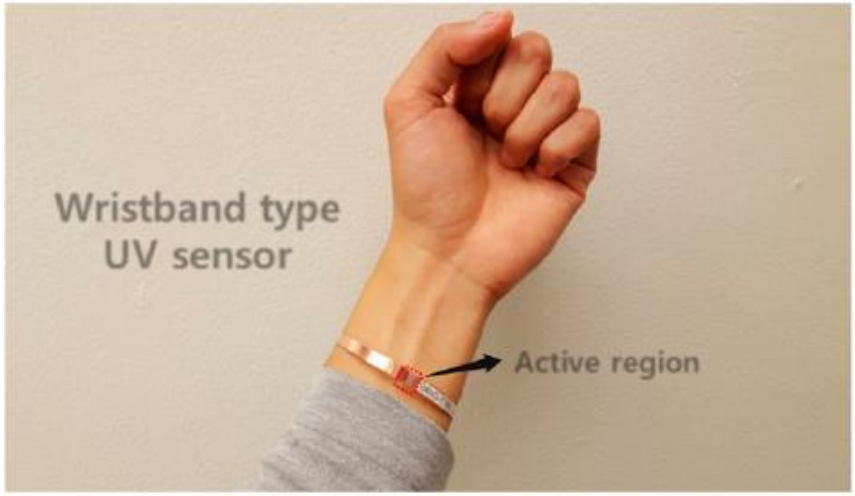


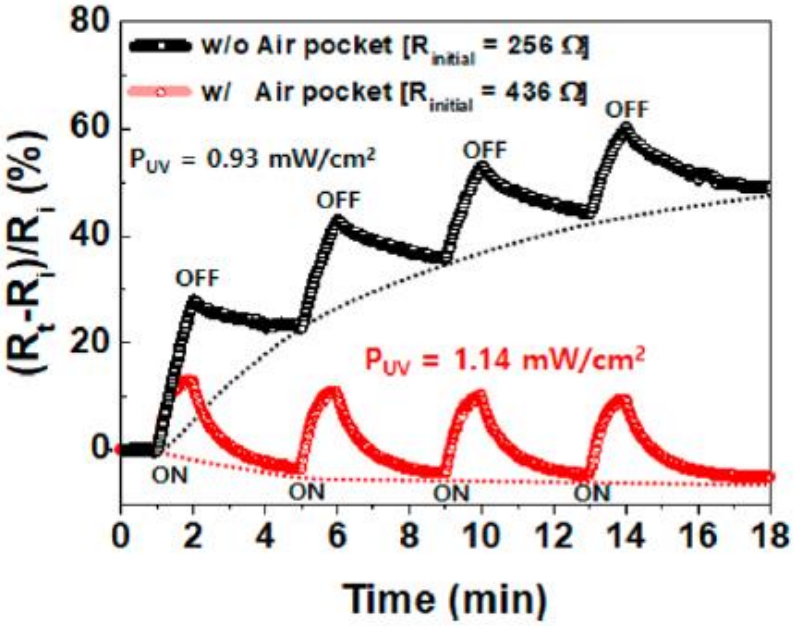
vs.



Exposed to Ambient Gas

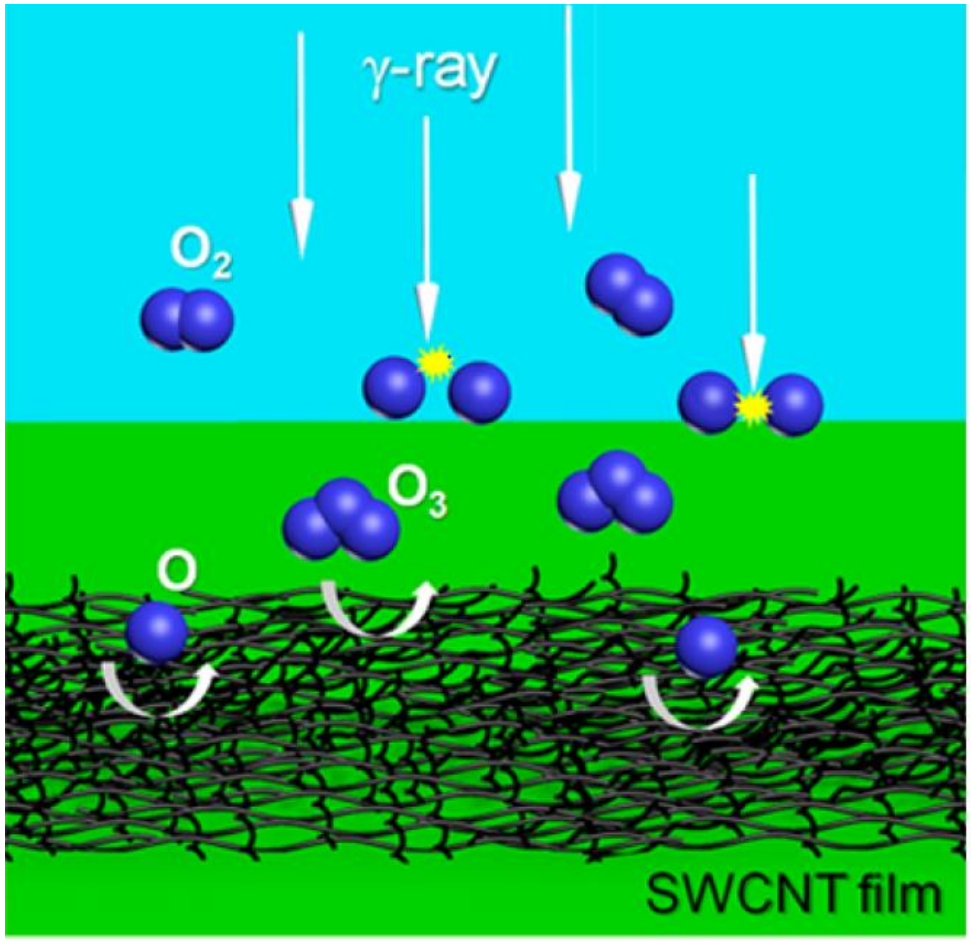
Isolated Air (Oxygen) in Pocket

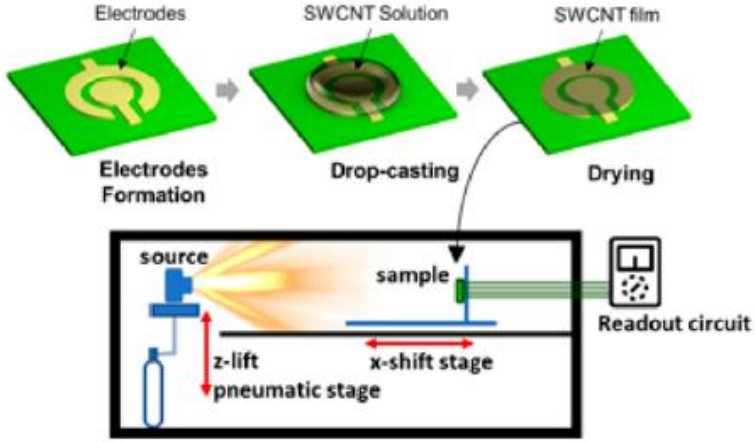


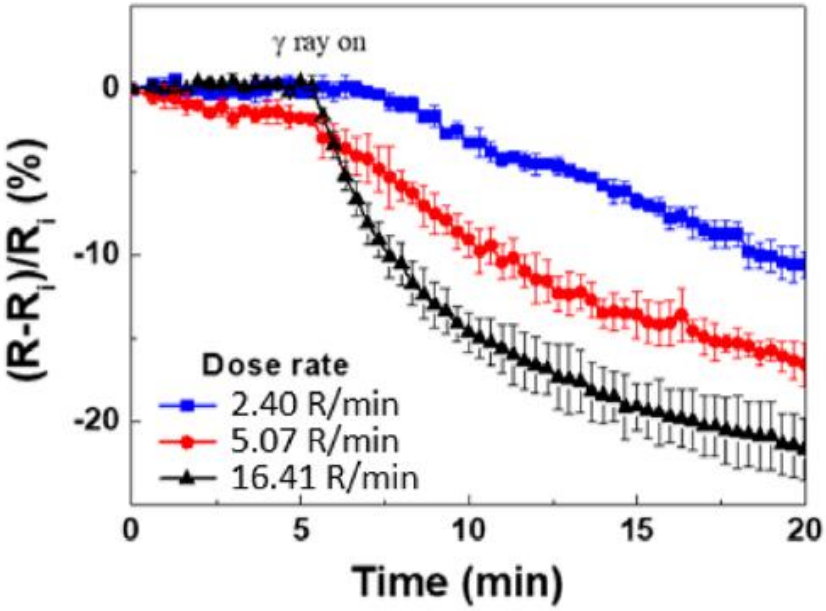


UV makes CNT less conductive.

All-Printed Gamma Ray Sensor

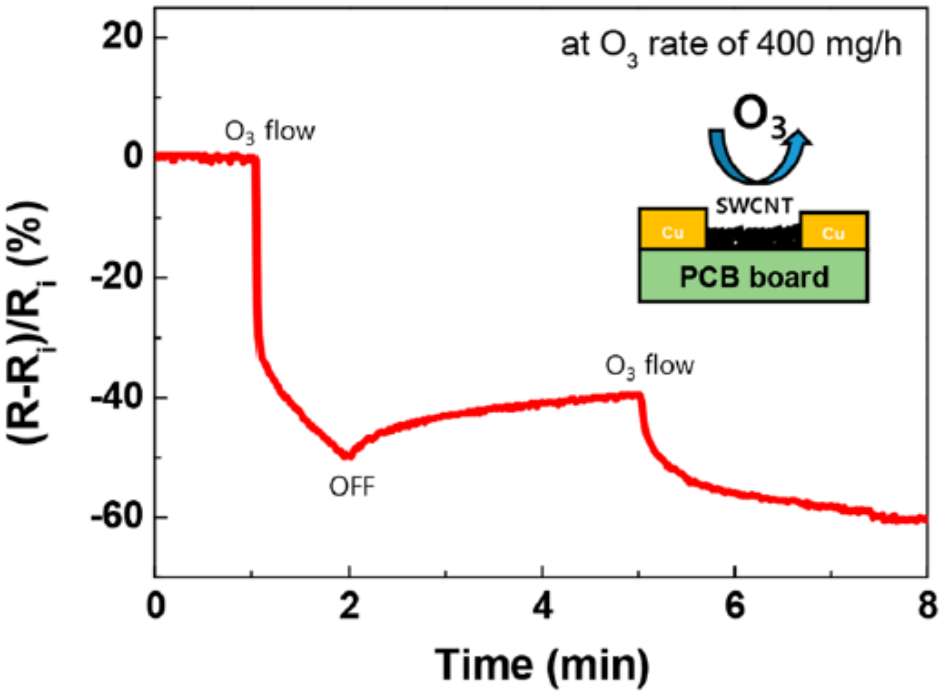




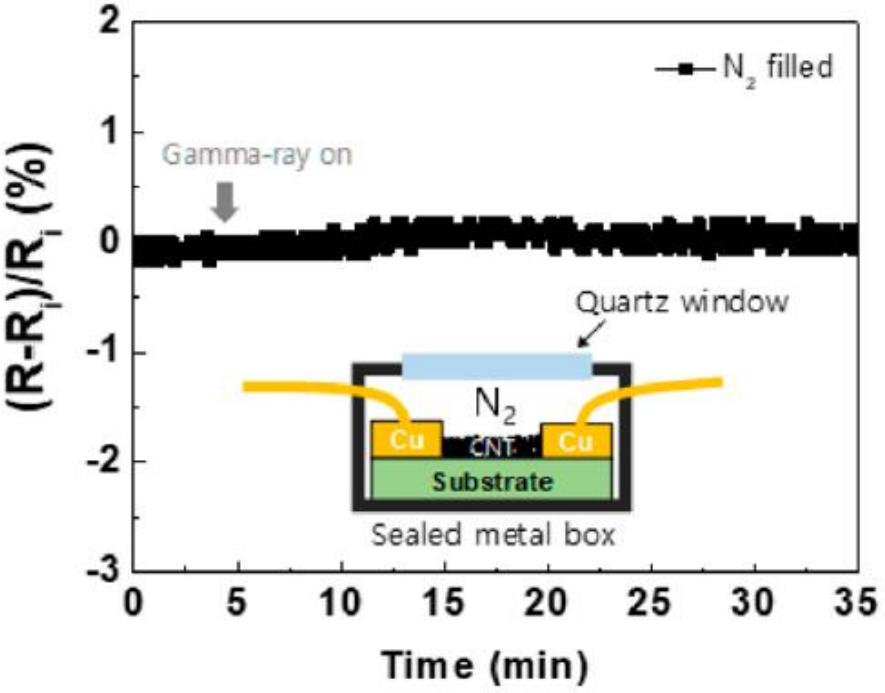


Gamma ray makes CNT more conductive.

Gamma Sensing Mechanism Experiment



Direct Ozon Exposure

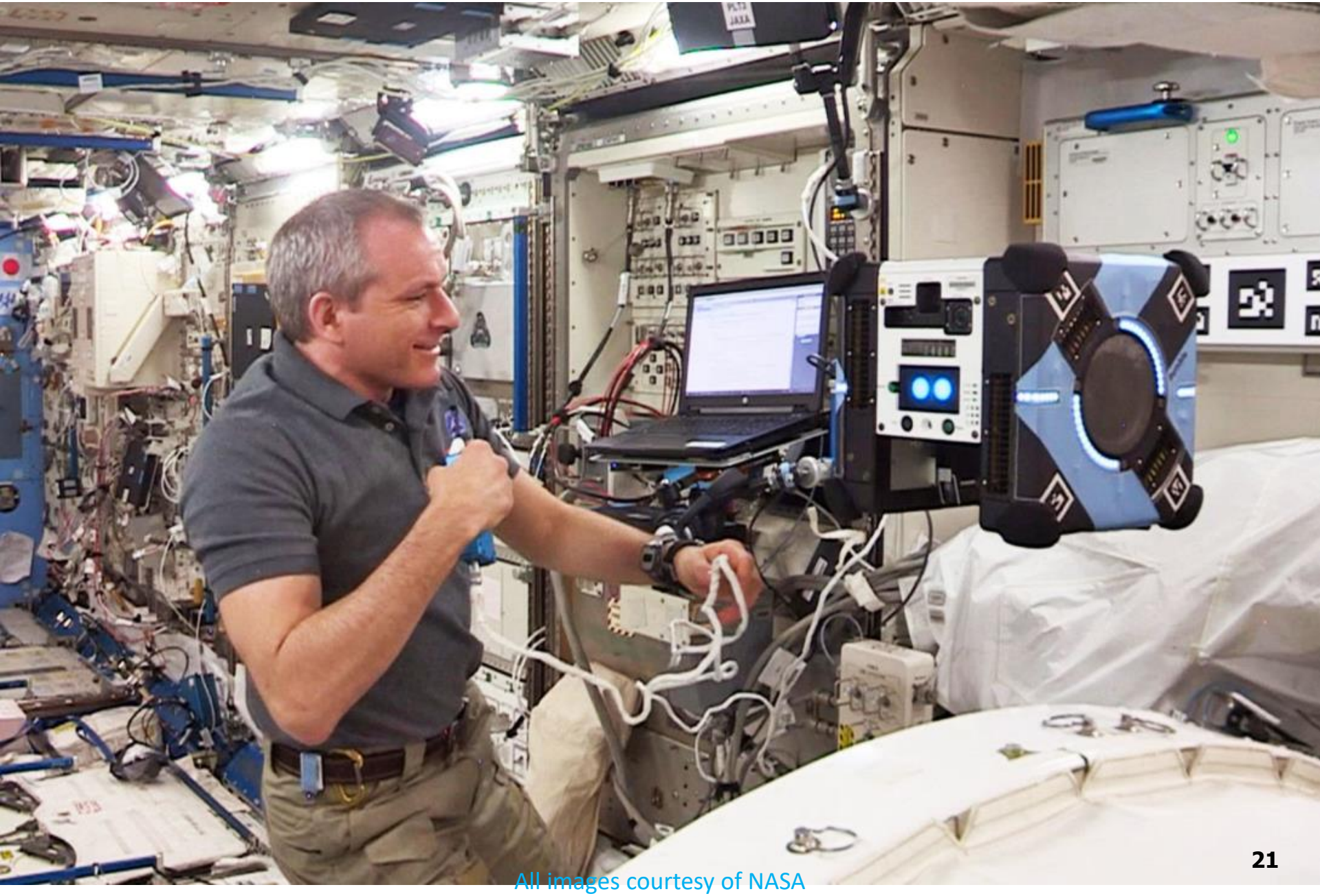


Nitrogen Filled Ambient

Resistive Switching Memory

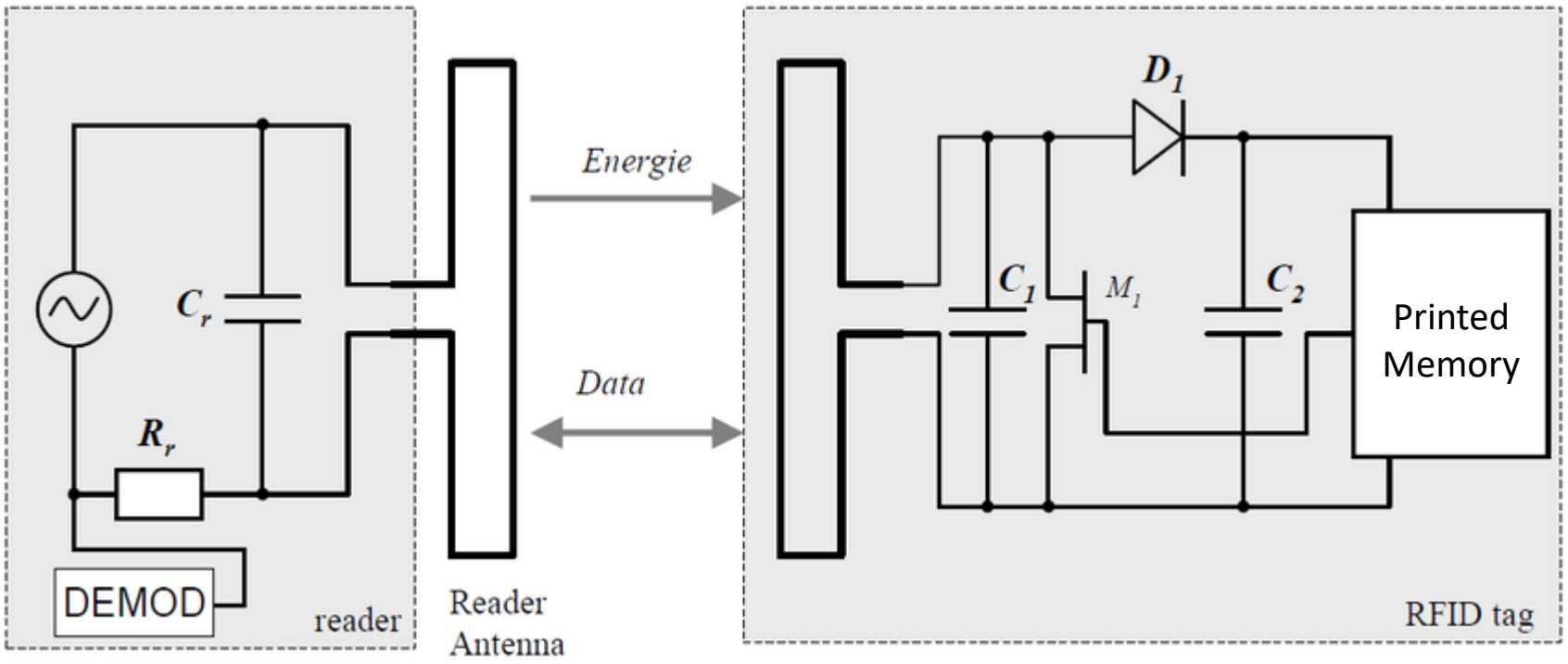
Nanoscale Adv., Vol. 1, 2990-2998 (2019).

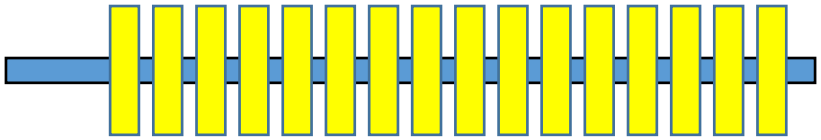
Autonomous Inventory Management Control



All images courtesy of NASA

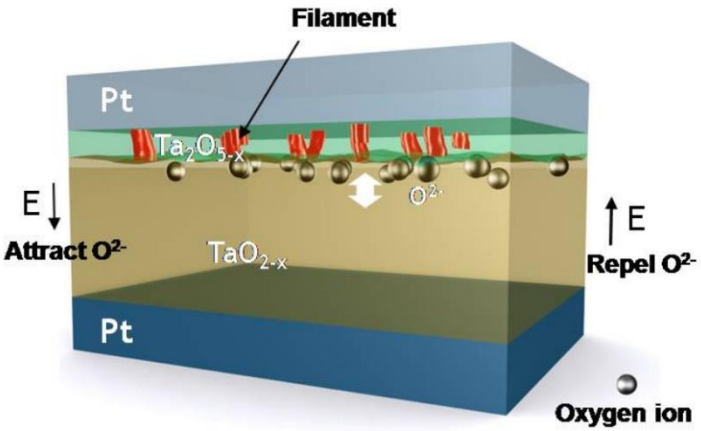
Passive RFID

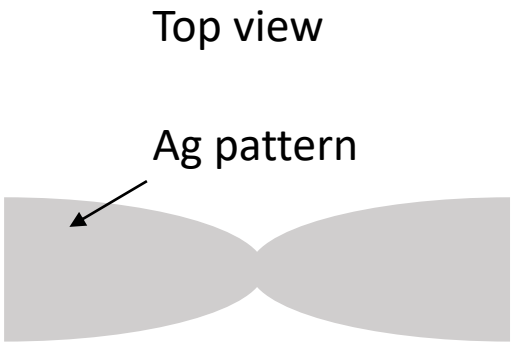




16 bit memory = 65,536 IDs

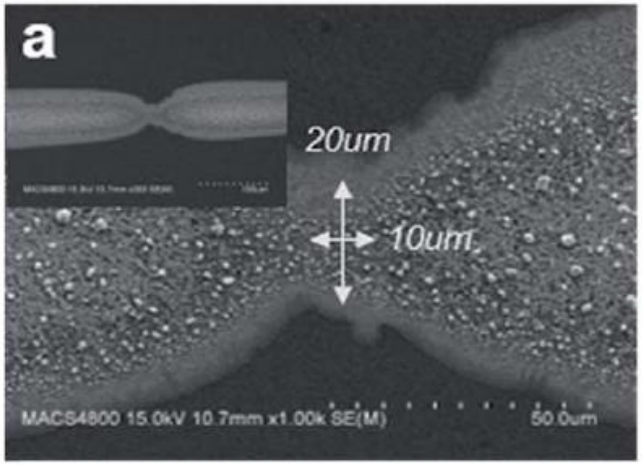
All Printed Resistive Switching Memory

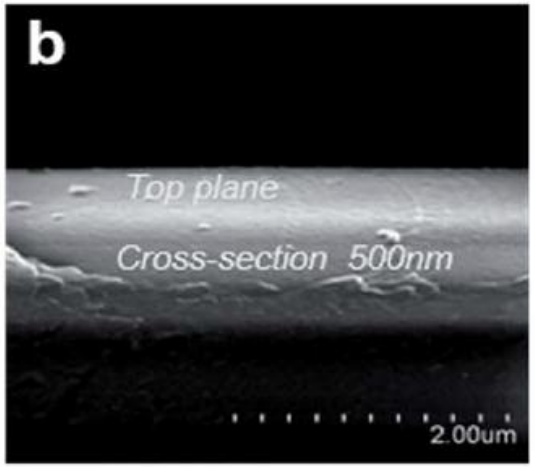




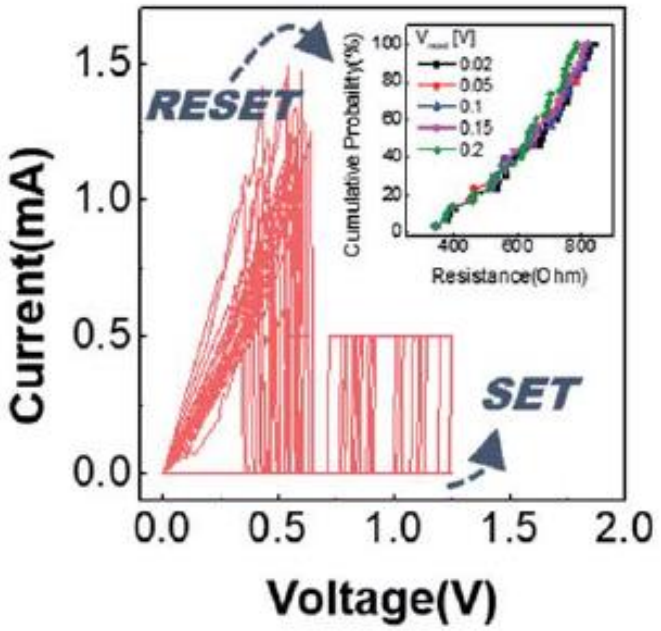
Conventional Sandwich Type

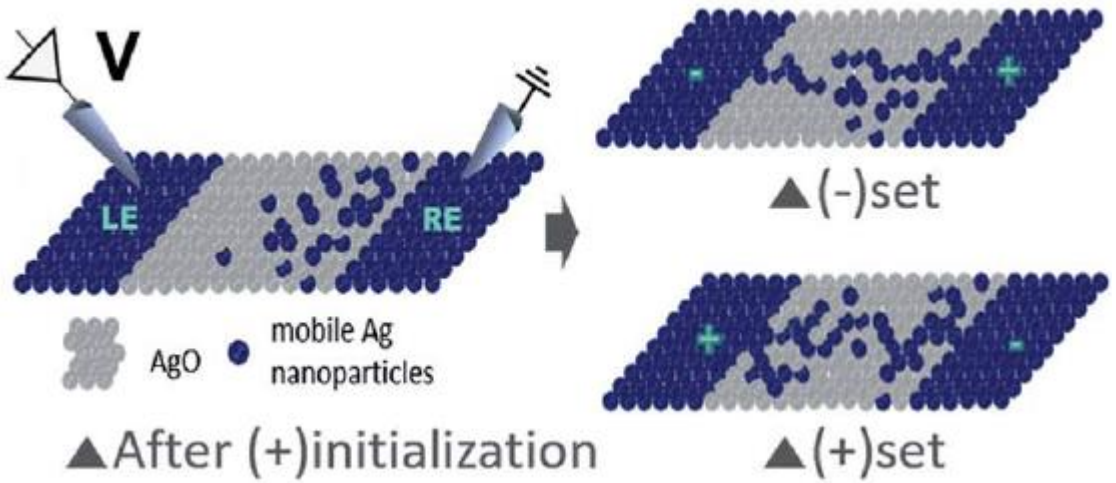
Single Material Structural Type

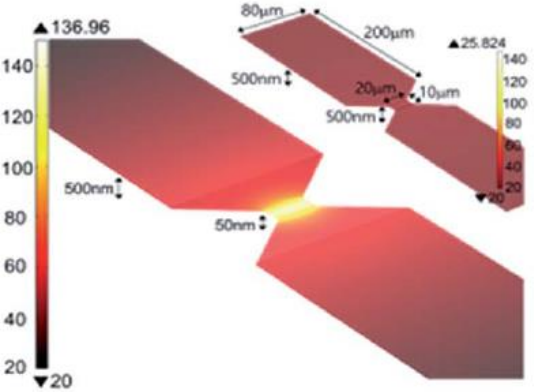


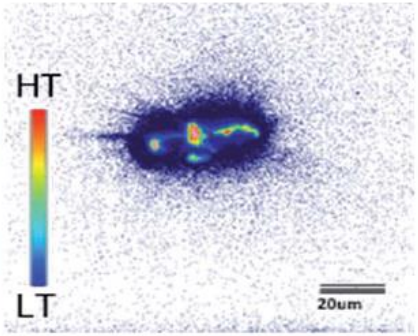


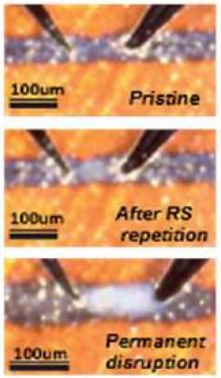
All Printed Resistive Switching Memory

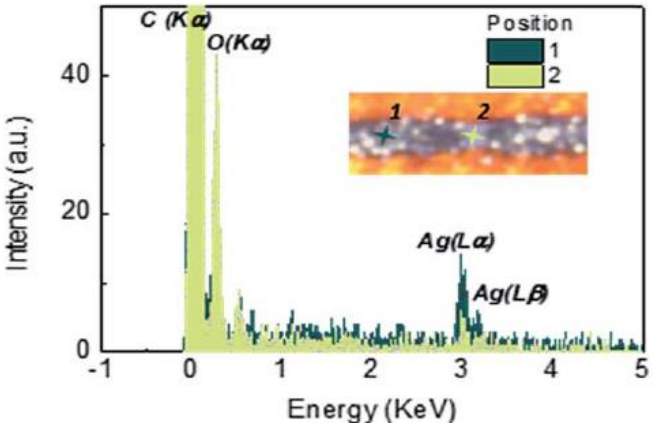




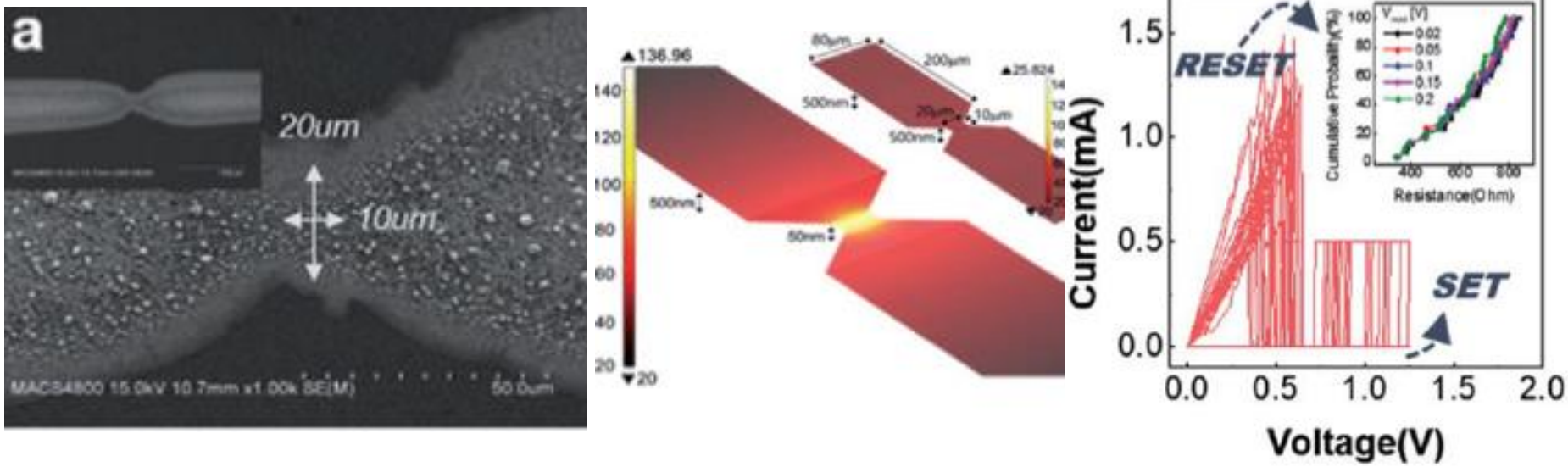








All-Printed Resistive Switching Memory



Clever single Ag ink system to create Ag-AgO-Ag system using an hourglass-shaped pattern and Joule heating.

Unipolar resistive switching with an on/off ratio of 10^8 at a reading voltage of 0.02 V.

Bipolar resistive switching is also available, which is beneficial in reducing switching current and power.

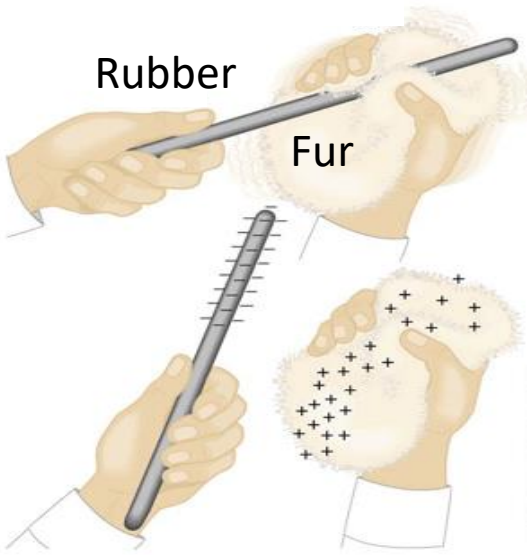
***Nanoscale Advances* 1, 2990 (2019)**

Mechanical Energy Harvester

For both small scale energy scavenging and large scale wind power generation where the heavy conventional electromagnetic motors are not favored for launch

Nano Energy, vol. 52, pp. 271-278, 2018.
Nano Energy, vol. 44, pp. 82-88, 2018.
Nano Energy, vol. 39, pp. 238-244, 2017.

Triboelectricity (Static Electricity)



- Triboelectricity is created at any contact interfaces.
- Triboelectricity is an unwanted phenomenon because too strong voltage causes breakdown of electronics and fire in environments.

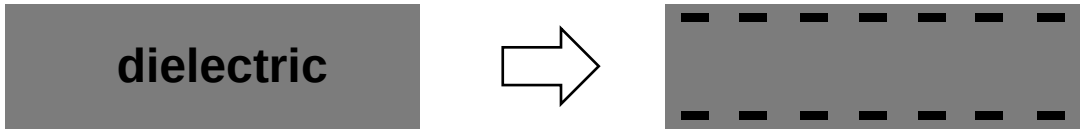
→ Attractive energy source when properly managed

Printable Mechanical Energy Harvester

	Electromagnetic	Piezoelectric	Triboelectric
Material	Magnet and coil	PZT, BTO, PVDF	Polymers (PTFE, PDMS)
Mass	Heavy	Light	Ultralight
Power density	0.29 – 1.85 mW/g	0.35 – 0.43 mW/g	0.48 – 8.8 mW/g
Cost	Low	High	Ultralow
Mechanical Durability	Good	Poor	Good
In-Space Manufacturability	No	No	Yes

Operation Principle: Step 1

Step 1. Triboelectric charging (Contact electrification)



Dielectric surface gains static charges by repeated contacts
→ **Triboelectric layer**

Order of electrification (OE)

Positive

Silk
Aluminum
Paper
Cotton, woven
Steel, Nickel, Copper
Brass, Silver
Polyvinyl alcohol
Polyester
Natural rubber
Polyvinylidine chloride
Polyimide (Kapton)
Polyvinvi chloride (PVC)
Polydimethylsiloxane (PDMS)
Polytetrafluoroethylnene (PTFE)

Negative

Positive OE material

+

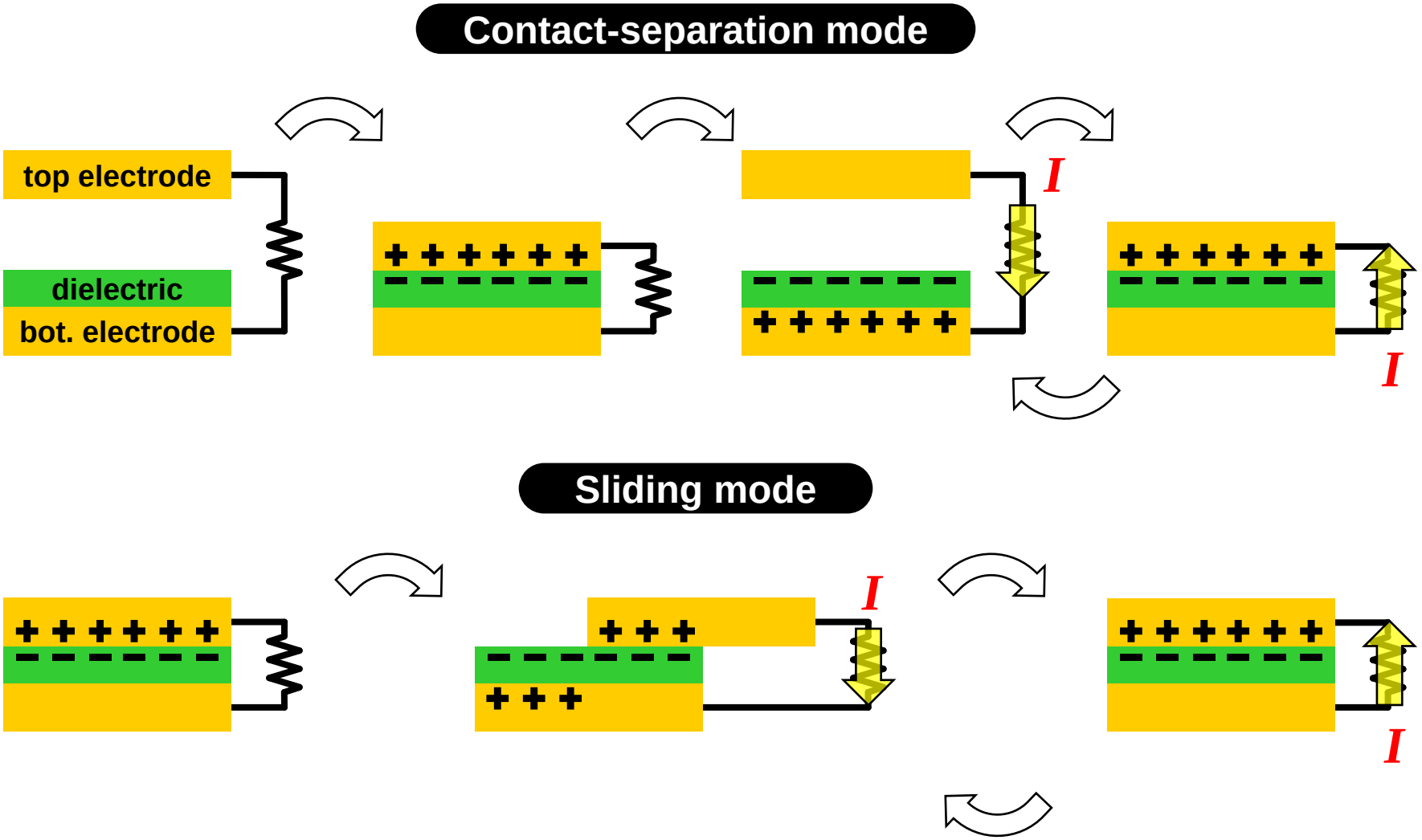
Negative OE material

=

Strong triboelectricity!

Operation Principle: Step 2

Step 2. Electrostatic induction

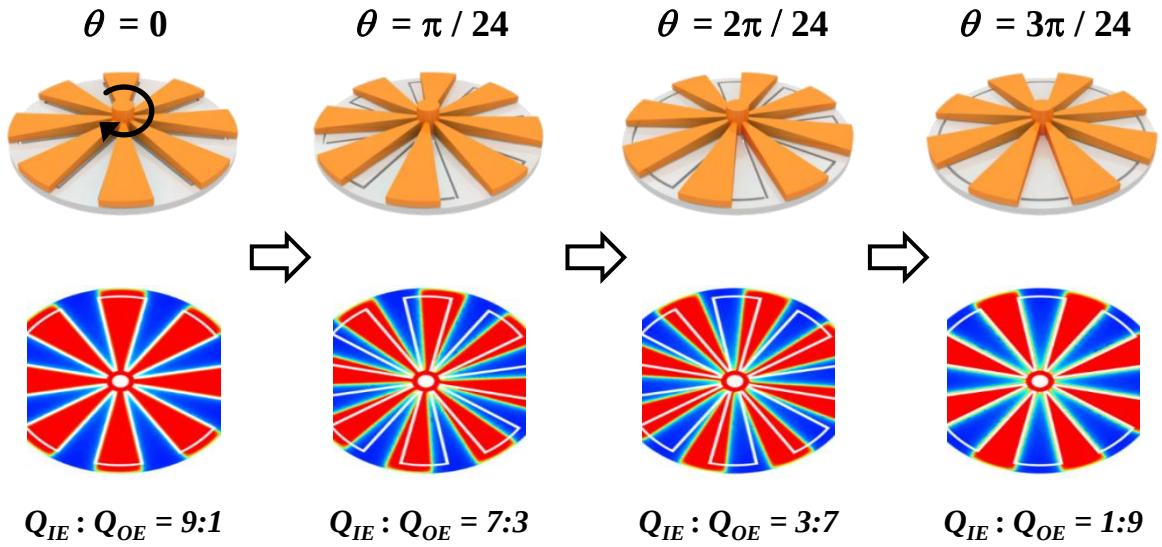


All 3D Printed TENG - Structure

Structure

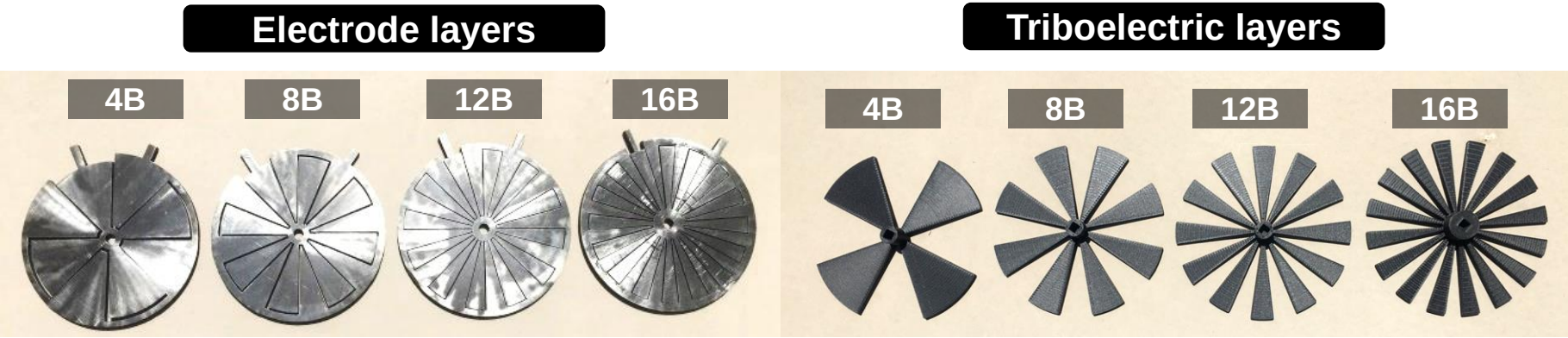
3D printed TL
3D printed EL
3D printed case
(bottom to top)

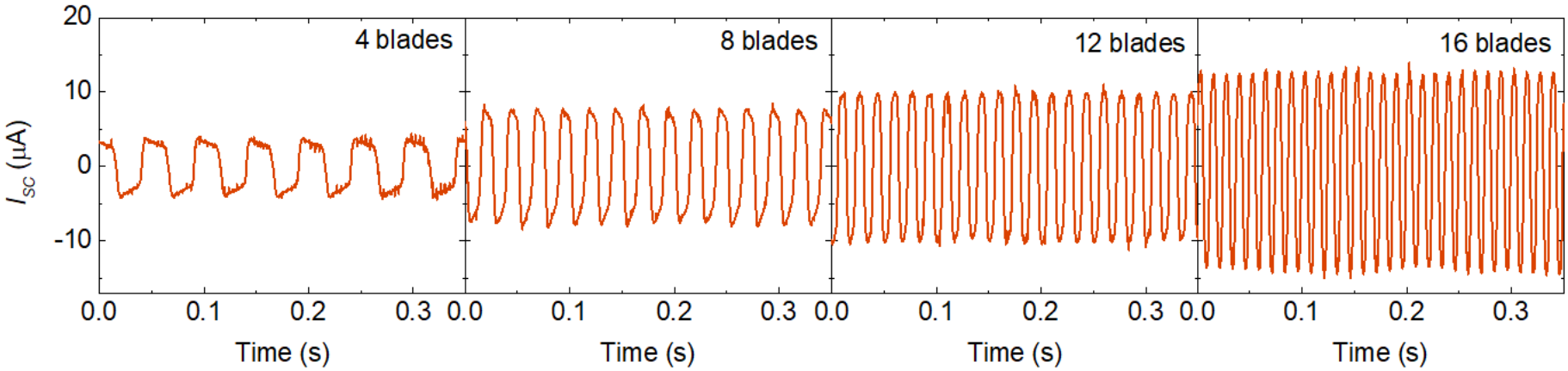
Operation principle



	Previous device	This device
Source type	Linear motion	Rotation
Manufacturing	2D + 3D printing	3D printing

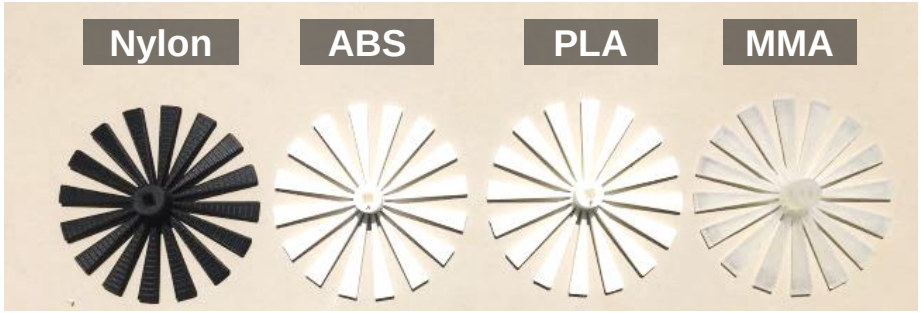
Grating Configuration Effect

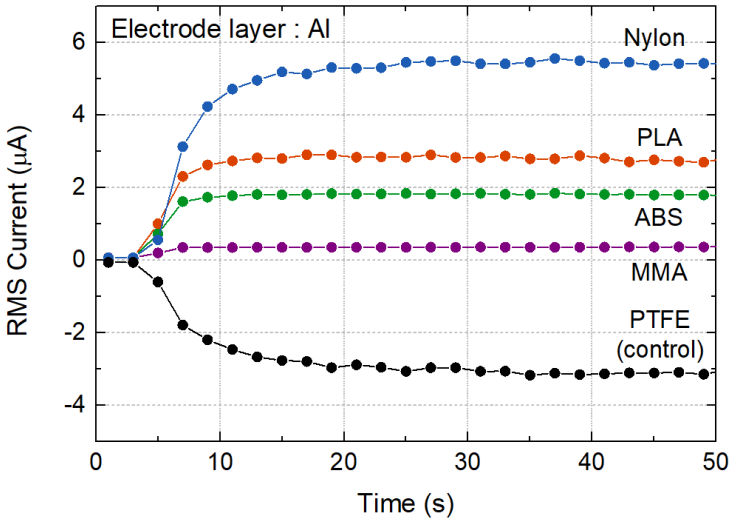


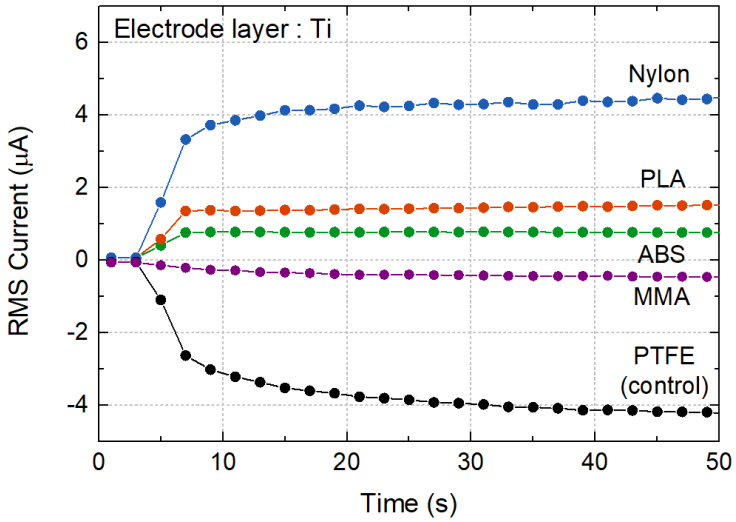


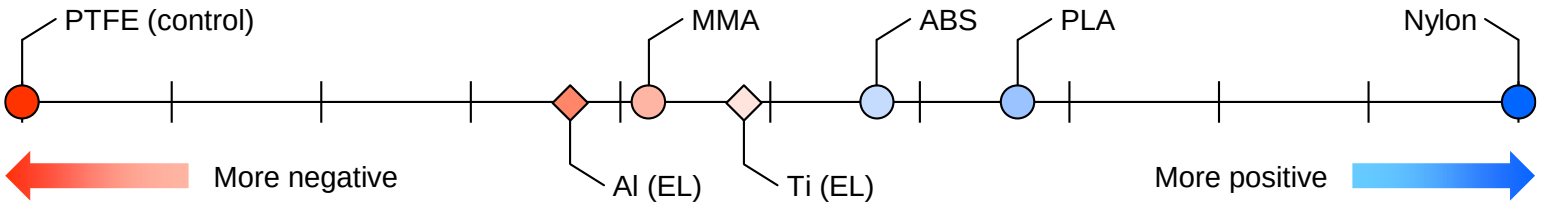
- More blades make more frequent charge movement → Higher energy generation
- Accurate patterning by 3D printing is beneficial.

Printable Material Effect

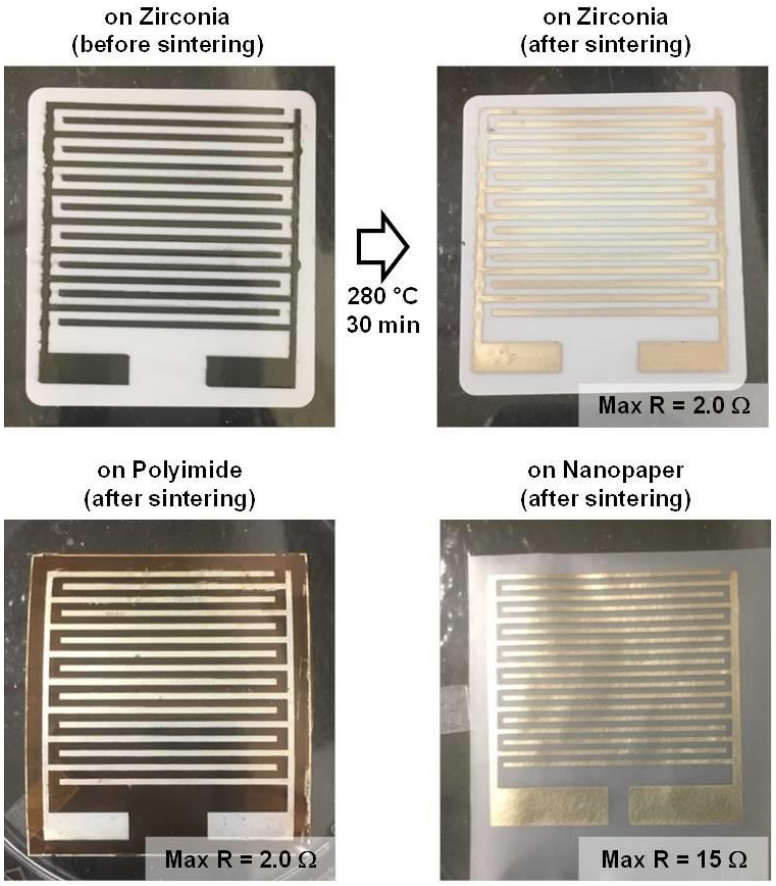


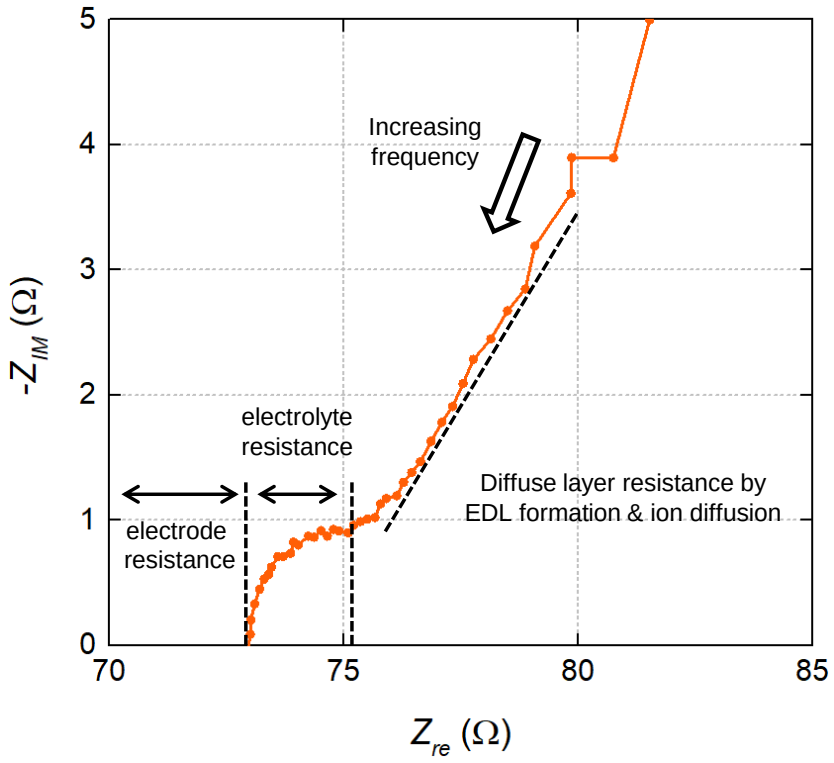






Printed Supercapacitors





- CNT and other carbon inks, Ag ink for electrode
- Specific capacitance ~ 170 F/g. Energy density ~ 15 Wh/Kg
- Power density ~ 2 KW/Kg, 100,000 cycles without loss of performance

Thank you