

# Nano-engineered environment & human monitoring devices for wearable applications

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**Director, Micro and Nano Transducer (MINT) Laboratory, KAIST**



# Advancement of Computing & Electronics Technology

*Smaller, Lighter, Softer, and More Human-Friendly*

1960's



mainframe

1990's



personal laptop

2000's



smart phone

2010-20's



google glass



b/w crt tv



projection tv



ultrathin led tv



flexible display

# Wearable Electronic Devices : Already Popular in the Market!

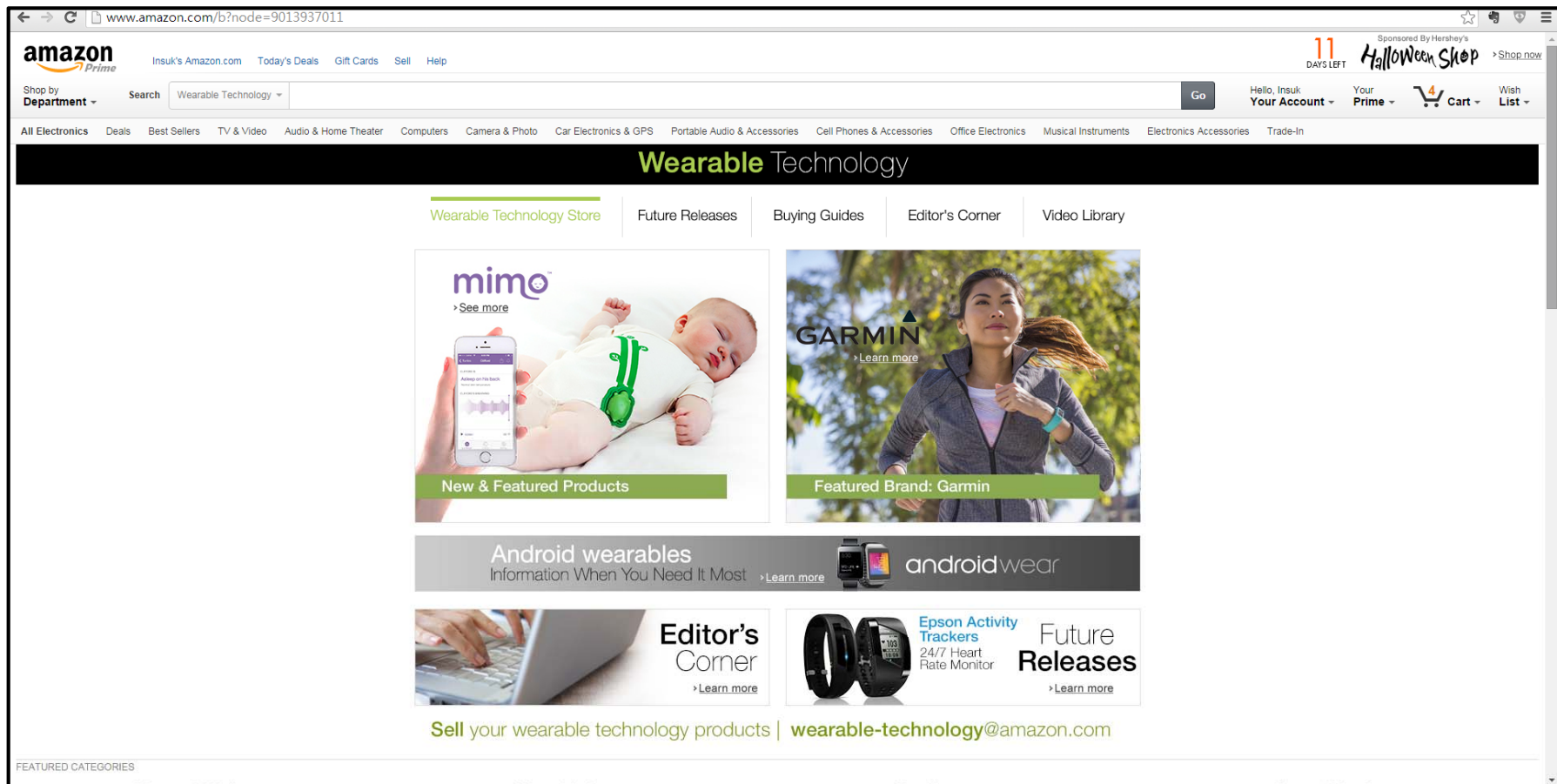
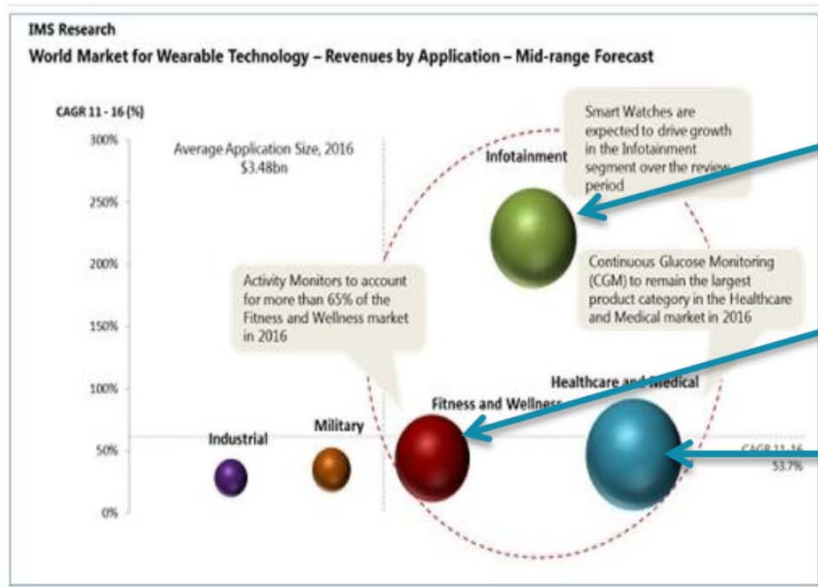


Image from Amazon.com

# Current Status & Outlook of Wearable Electronic Devices

## Wearable Market Opportunity

15 Million wearable devices expected to be sold in 2013  
Rising to 70 million by 2017



Areas of biggest growth by 2016:

### Infotainment

- Smart watches
- Smart glasses

### Activity Monitors

- ~65% of Fitness and Wellness market

### Healthcare

- Continuous Glucose Monitoring (CGM)

Source: IMS Research  
Juniper Research

The Architecture for the Digital World®

Image from ARM Corporation

**Still bulky, hard, heavy and power-hungry...**

**Truly flexible (even epidermal / skin-mountable), stretchable, invisible, light-weight, low-power, but high-performance & reliable**

**→ Will enable huge growth of market & real-life applications**

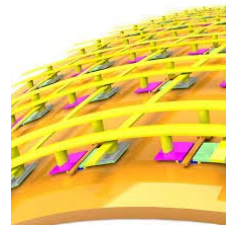
# Next-Gen Truly "Flexible" and Wearable Devices & Essential Components

## Wearable electronics

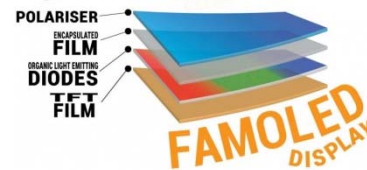
With chips shrinking and sensors becoming cheaper, personal computing is moving from that smartphone in your pocket to your arm, your wrist, right out to your fingertips.



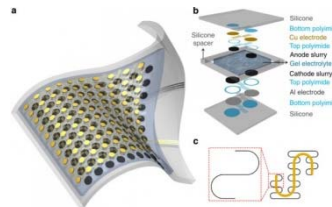
- Logic & memory



- Display & lighting



- Power storage



- Biomedical sensors



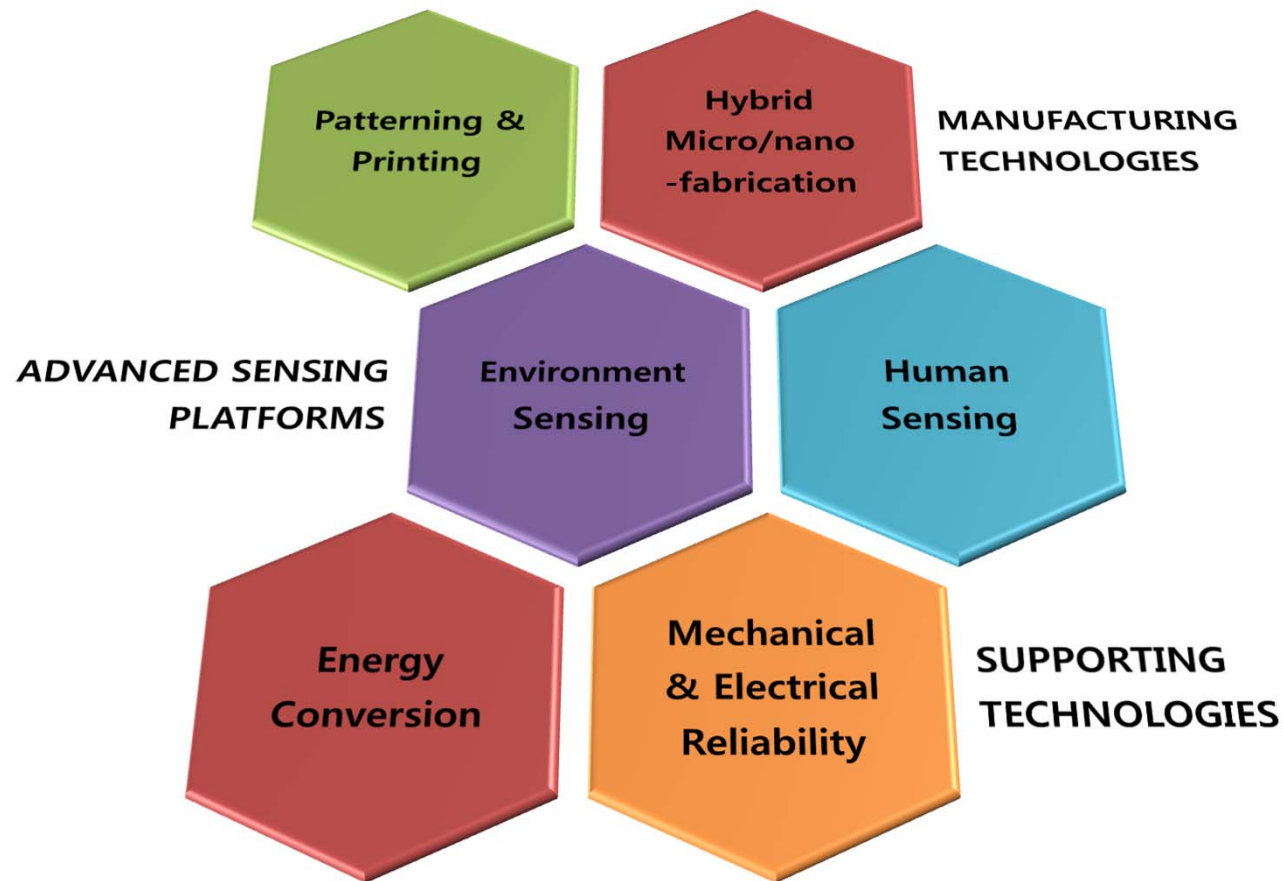
- Environmental sensors



- Power conversion

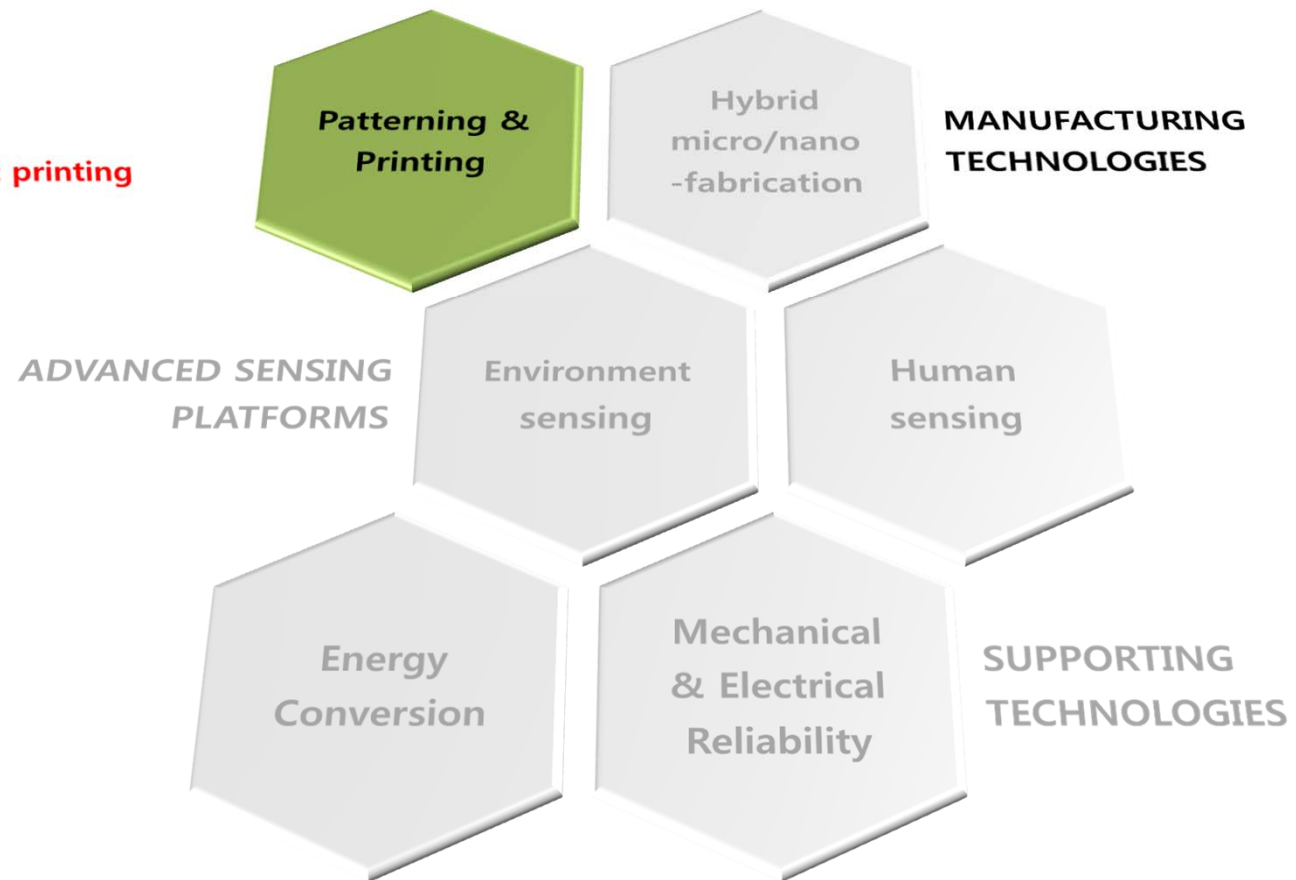


# Micro/nanotechnologies for Flexible Device Applications @ MINT Lab



# Micro/nanotechnologies for Flexible Device Applications @ MINT Lab

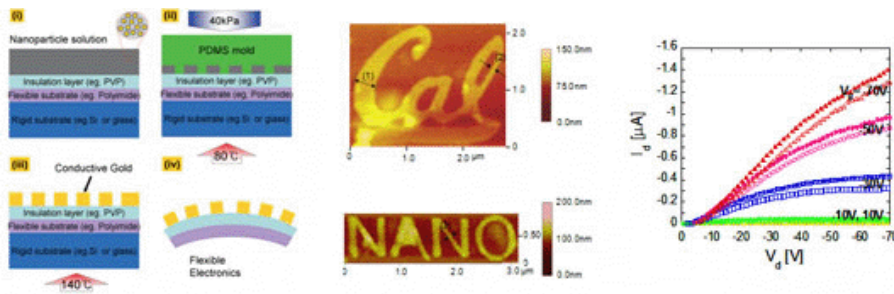
- Nanoimprinting
- Transfer printing
- Electrospinning
- Electrohydrodynamic printing
- Screen printing





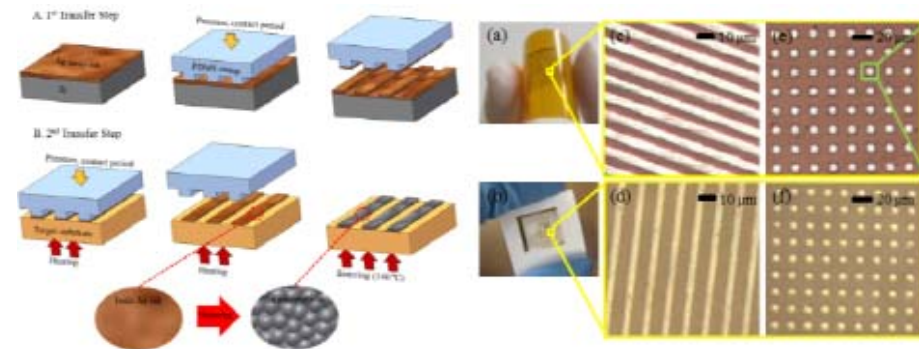
# Patterning & Printing Technologies for f-Device Fab

## • Nanoimprinting of Functional Materials



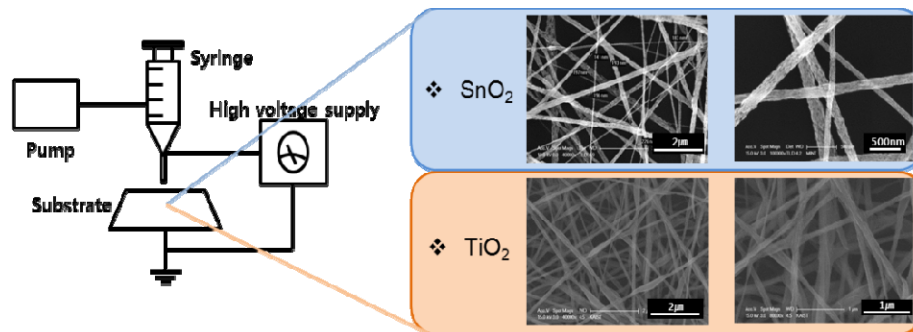
I. Park, et al., *Nano Lett* (2007) & *Adv. Mater.* (2008)

## • Transfer printing



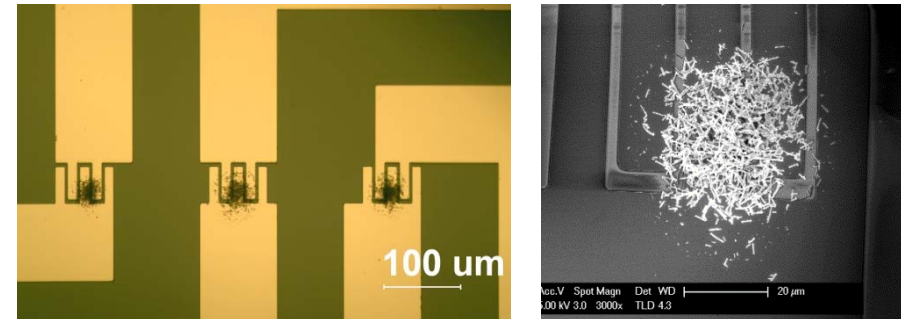
S. Kim, I. Park, et al., *Nanotechnology* 23, 285301 (2012)

## • Electrospinning



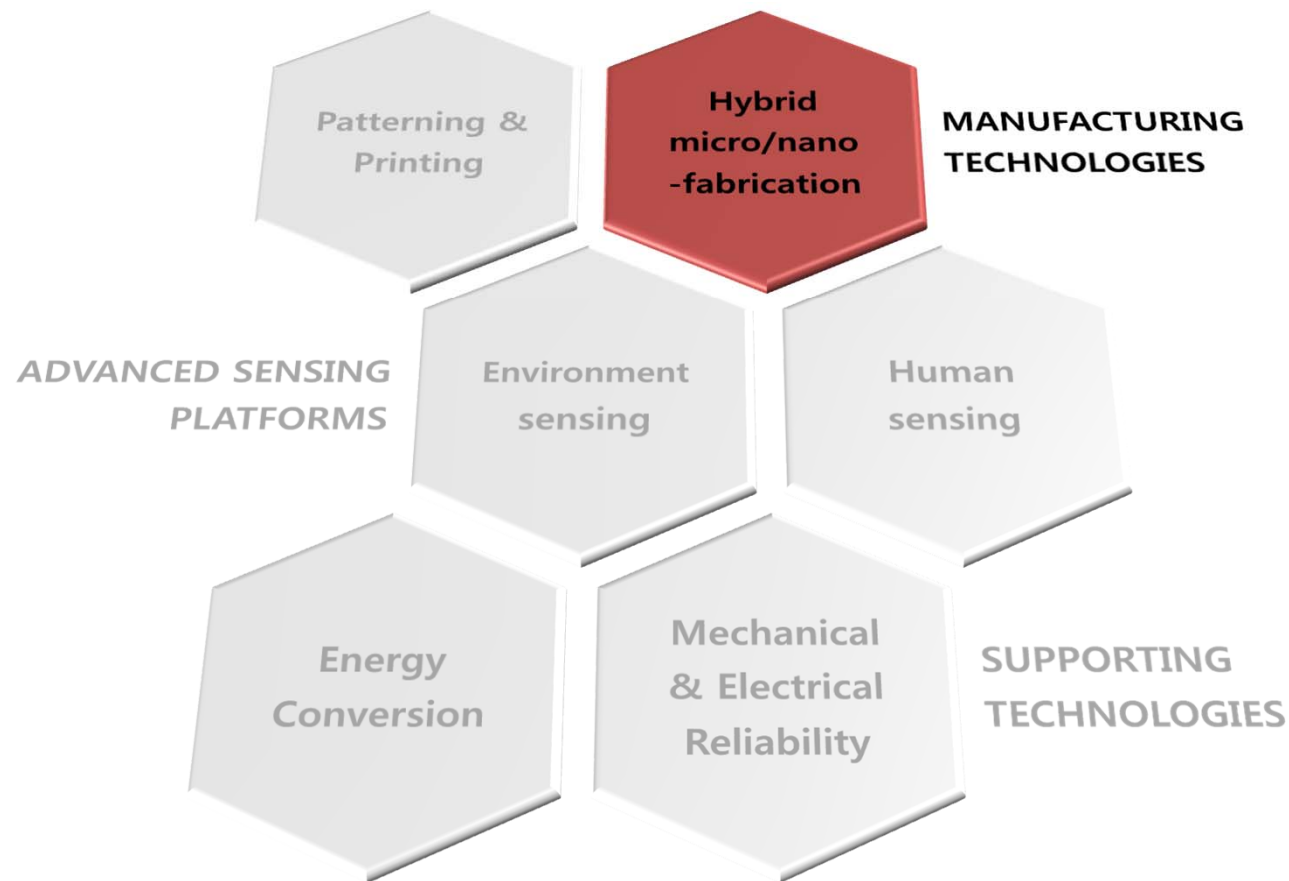
K. Kang, I. Park, et al., *Nanoscale*, in review (2014)

## • Electrohydrodynamic printing



K. Kang, I. Park, et al., *Nanoscale*, in review (2014)

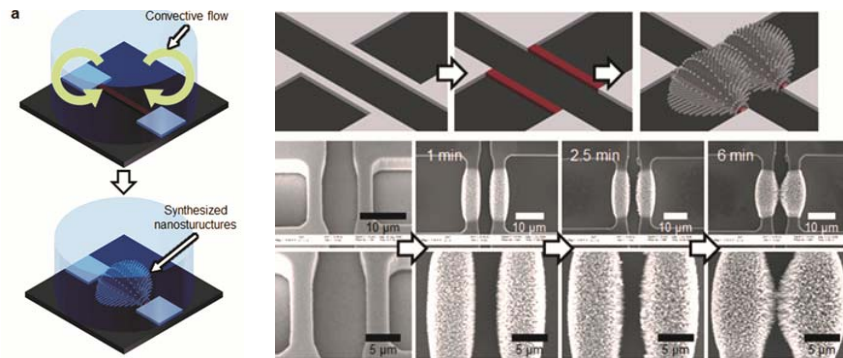
# Micro/nanotechnologies for Flexible Device Applications @ MINT Lab



- **Selective Nanomaterial Synthesis**
- **Templated Synthesis of Metallic Nanotubes**
- **Core-shell Nanowire Synthesis**

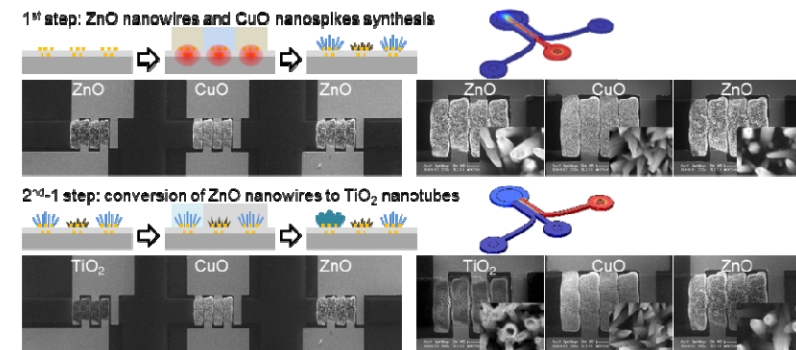
# Hybrid Micro/nano-Fabrication Process for f-Device

## • Localized, low-temp. Nanomaterial Synthesis



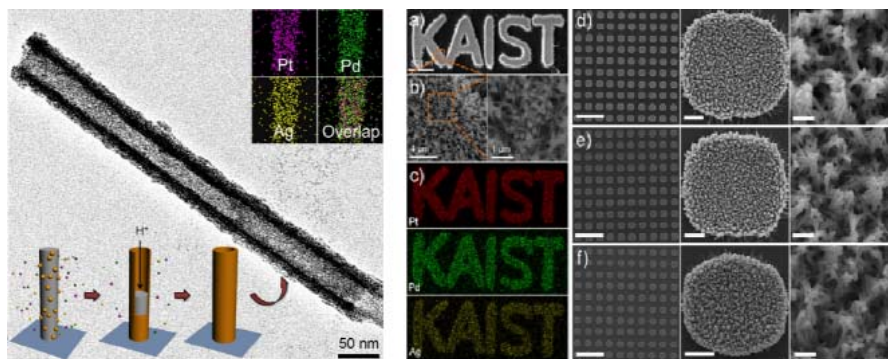
D. Yang, I. Park, et al., *Advanced Materials* (2014)

## • Microchannel-based Multiplexed Nanofabrication



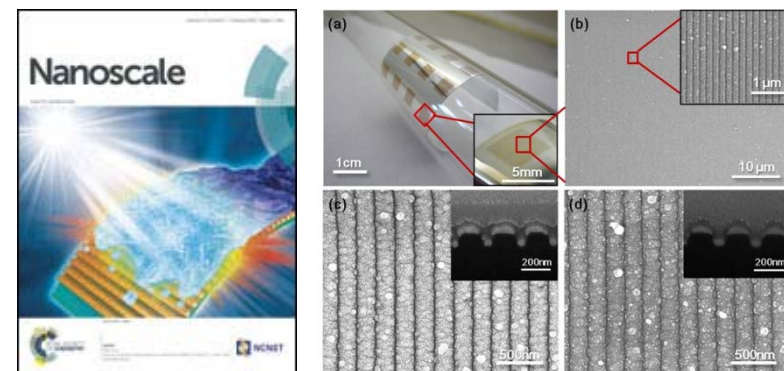
D. Yang, I. Park, et al., *Adv. Mater.*, in review (2014)

## • Template-based Metal Nanotube Synthesis



M. Lim, I. Park, et al., *ACS NANO* (2012 a,b)

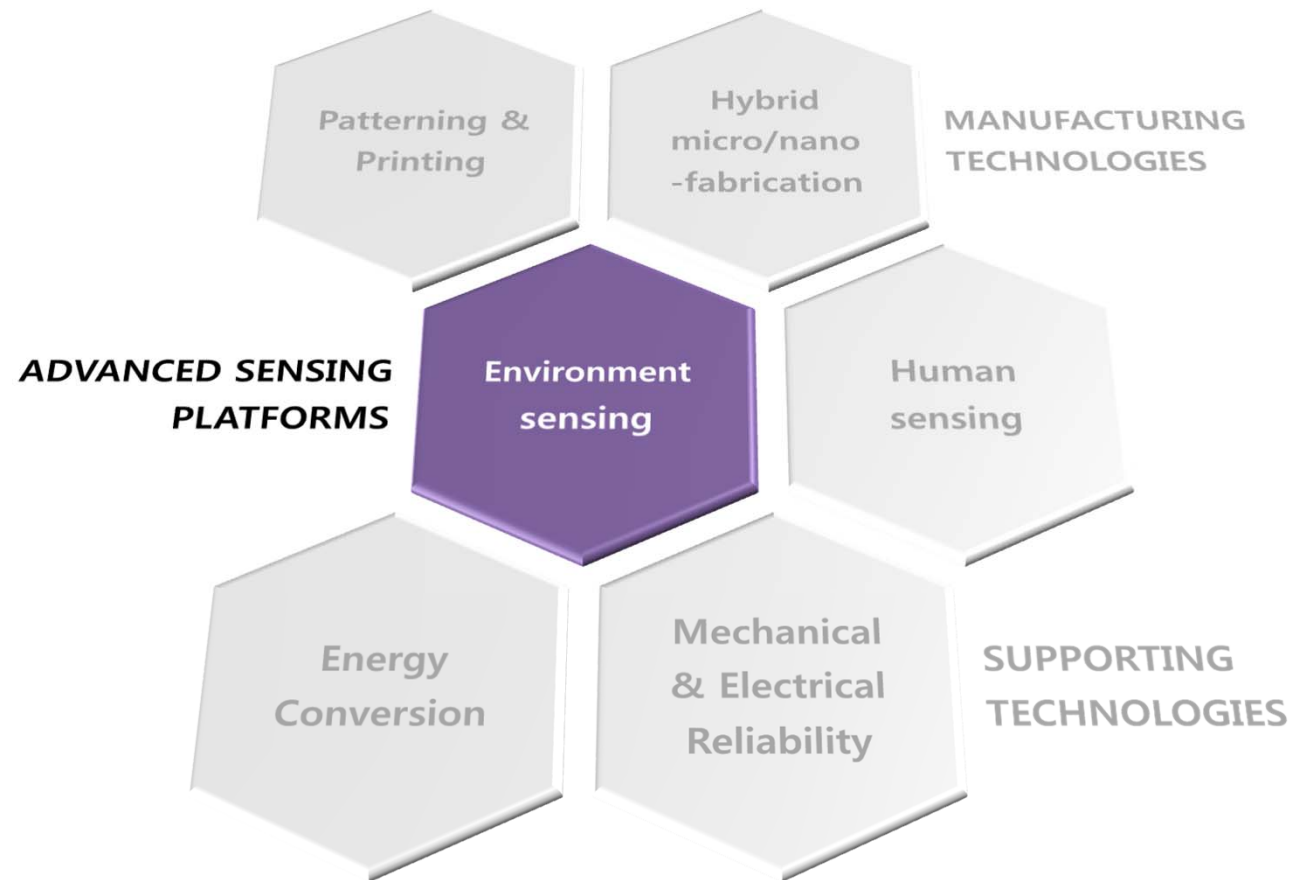
## • Core-shell Nanowire Array by Local Electrodep.



H. Eom, I. Park, et al., *Nanoscale* (2014), [Front Cover](#)

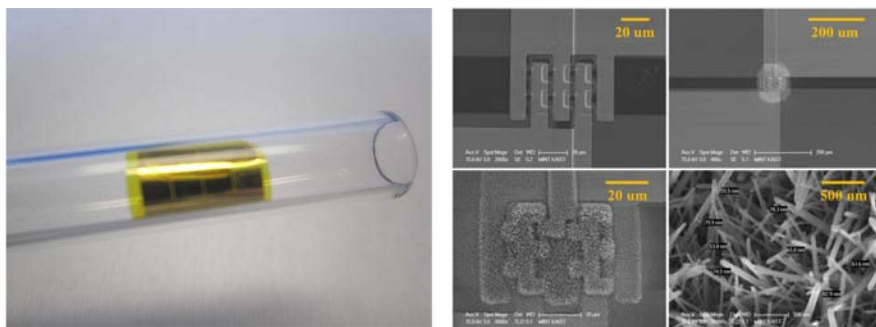
# Micro/nanotechnologies for Flexible Device Applications @ MINT Lab

- Toxic gas sensors
- Hydrogen gas sensors
- Ultraviolet light sensors



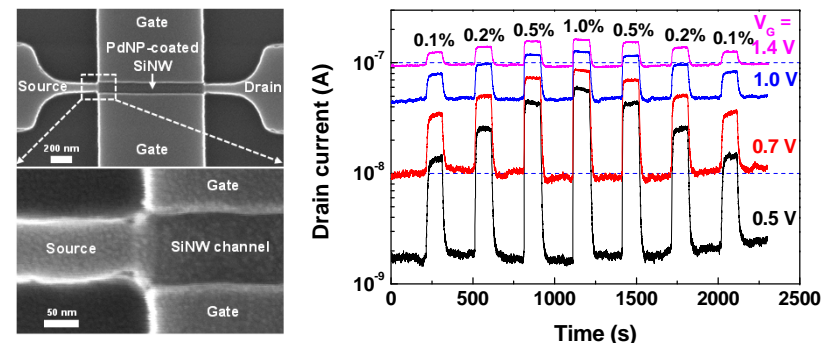
# Flexible Environment Sensor based on Micro/Nanostructures

## • Flexible Sensor for Toxic Gas Detection



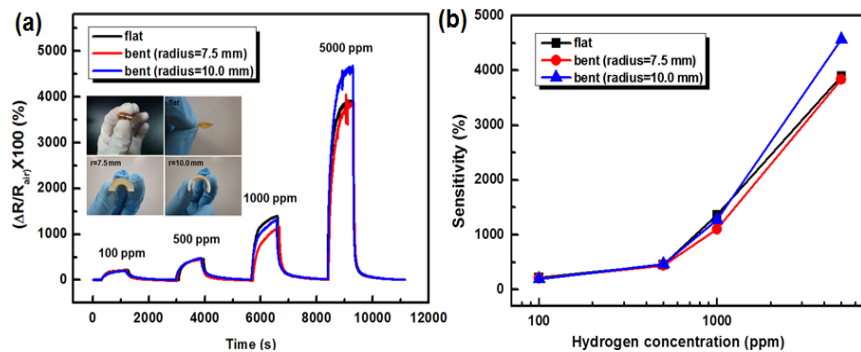
D. Kim, I. Park, et al., *Nano Lett.*, in review (2014)

## • Silicon Nanowire Sensor for Hydrogen Detection



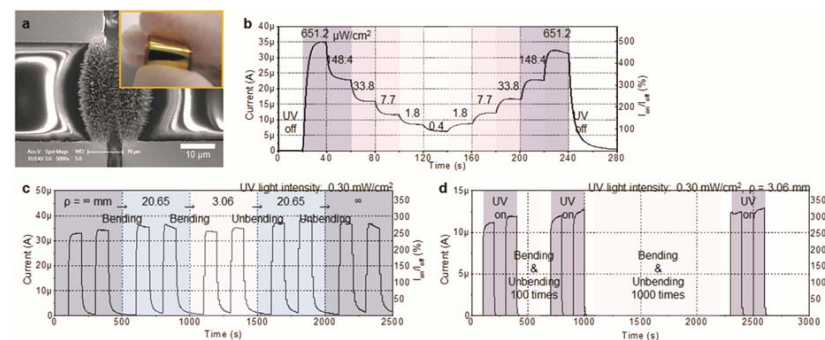
J. Ahn, I. Park, et al., *Appl. Phys. Lett.* (2014)

## • Metal Nanotube-based Flexible Hydrogen Sensor



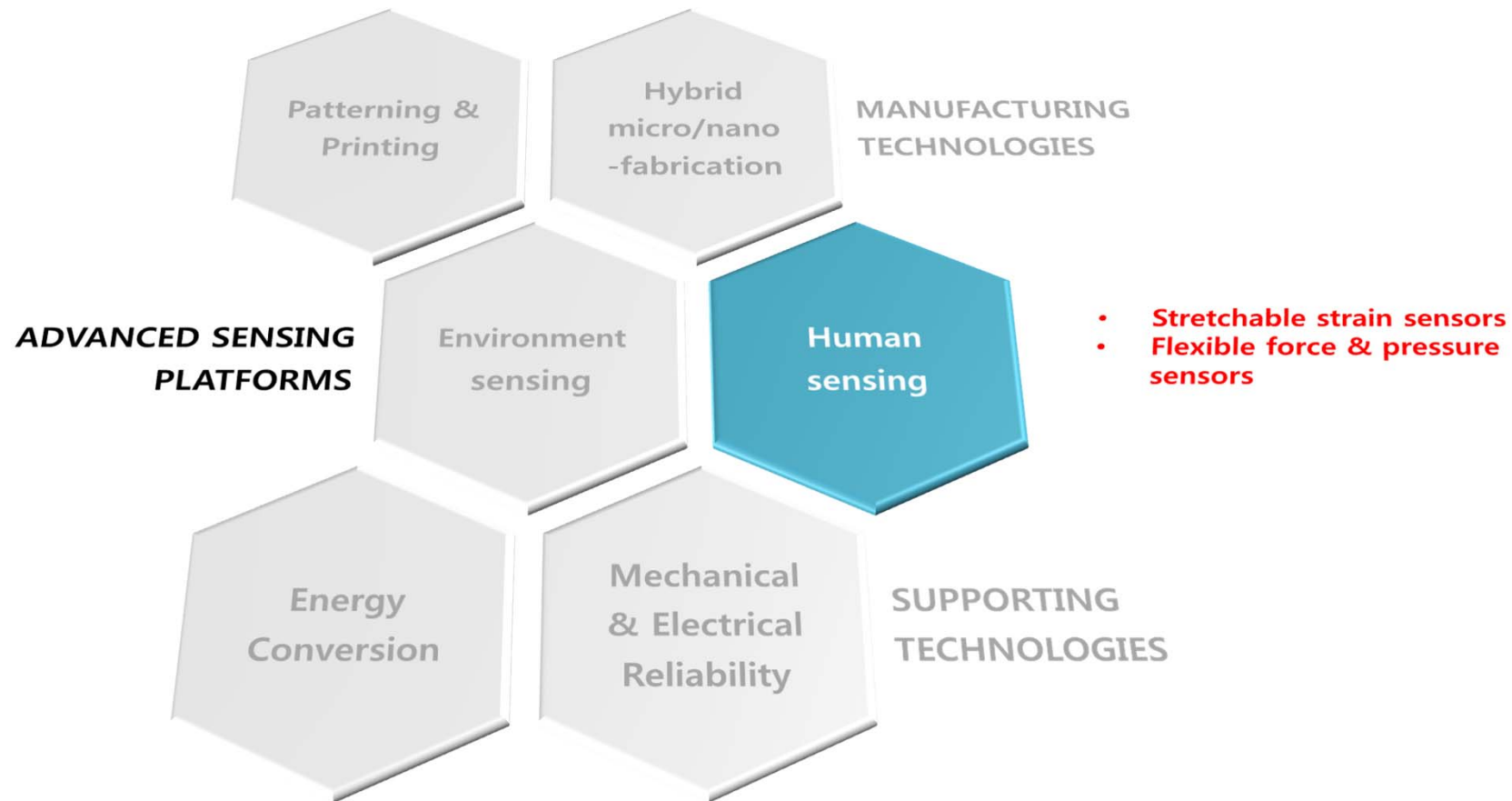
M. Lim, I. Park, et al., *ACS NANO* (2012 a)

## • Flexible Ultraviolet Light Sensor



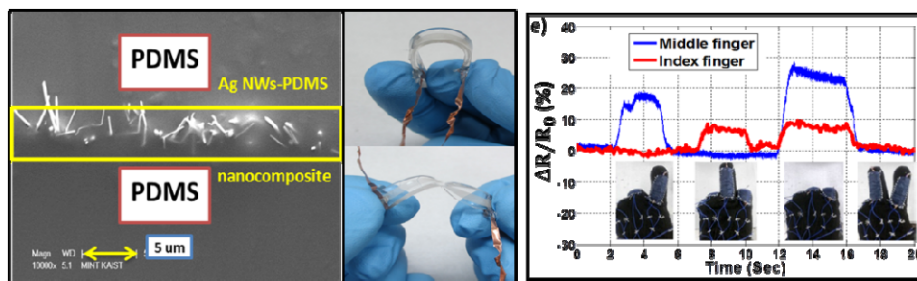
D. Yang, I. Park, et al., *Advanced Materials* (2014)

# Micro/nanotechnologies for Flexible Device Applications @ MINT Lab



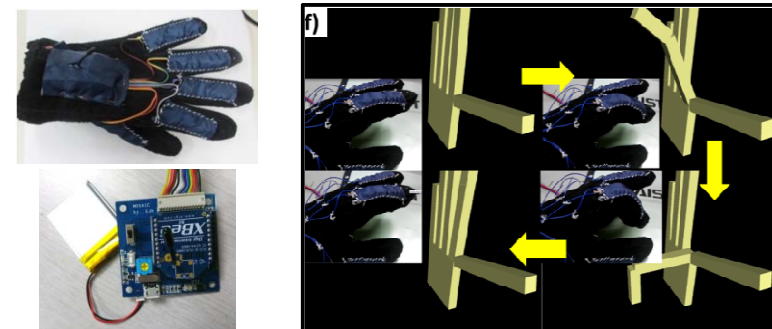
# Flexible Human Motion & Force Sensing Devices

## • Stretchable Strain Sensor based on Nanowires



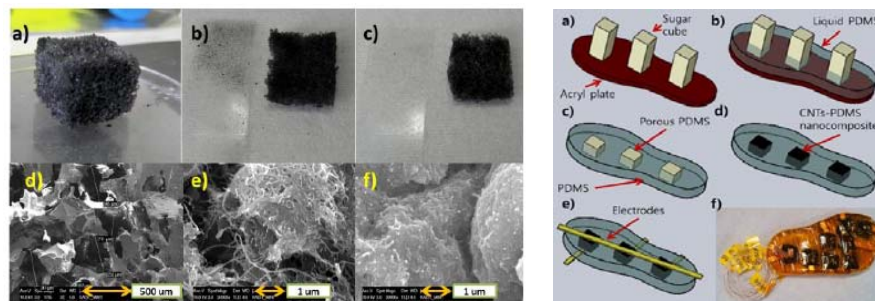
M. Amjadi, I. Park, et al., *ACS NANO* (2014)

## • Wearable Human Motion Detection System



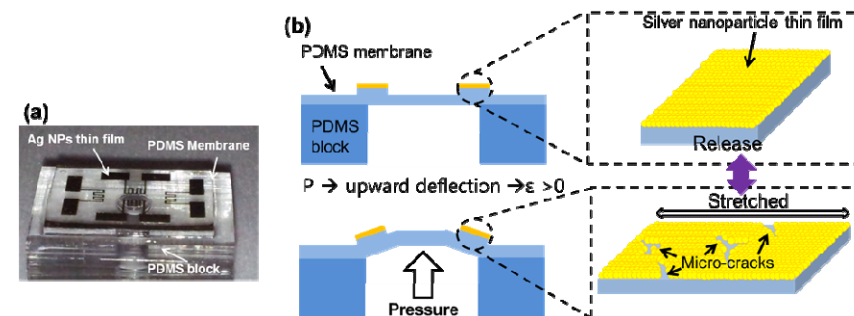
M. Amjadi, I. Park, et al., *ACS NANO* (2014)

## • Flexible Touch and Contact Force Sensor Array



M. Amjadi, I. Park, et al., *Small*, in review (2014)

## • Flexible Pressure / Force Sensor



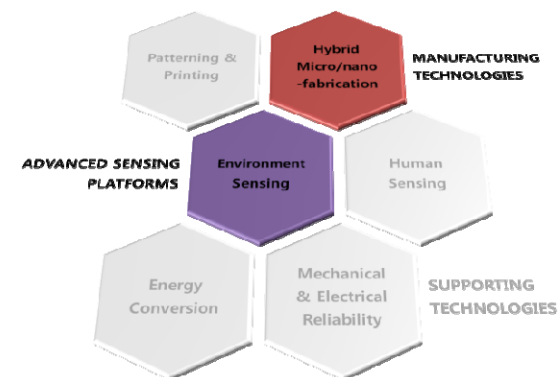
J. Lee, I. Park, et al., *Nanoscale* (2014)

# (1) Flexible UV Photonic Sensors

*Nano Letters (2007)*  
*Nano Letters (2012)*  
*Langmuir (2012)*  
*Nanotechnology (2012)*  
*Adv. Mater. (2014)*

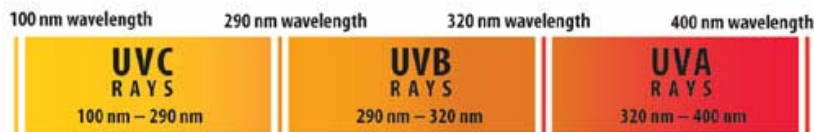
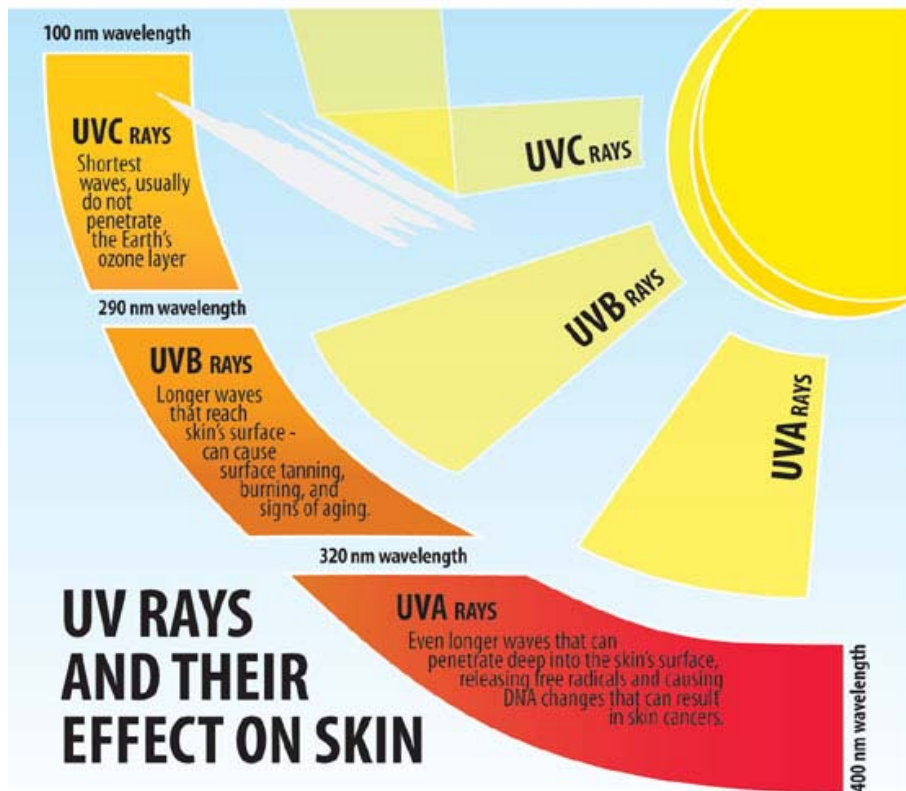


**Daejong Yang**  
 (5th yr, combined  
 MS-Ph.D.)





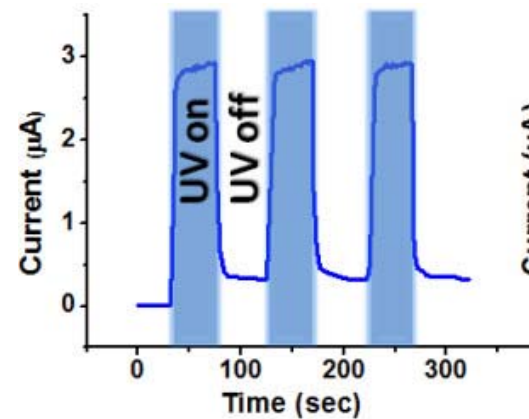
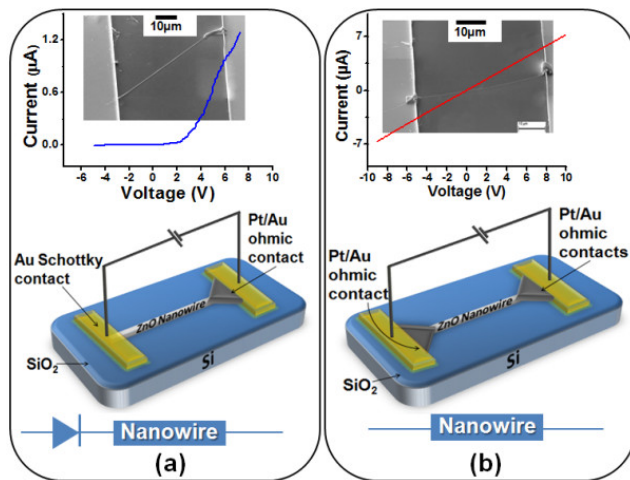
# UV Detection



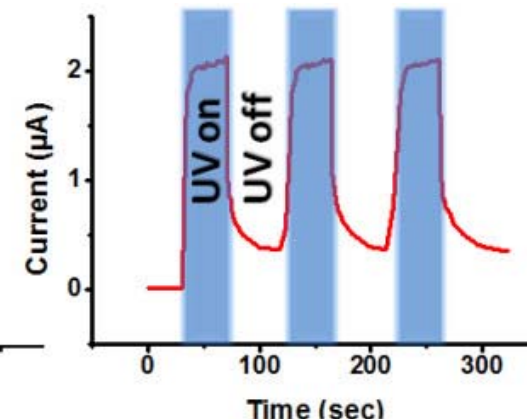
The wavelength of UV (ultraviolet) rays is measured in nanometers (or billionths of a meter), abbreviated as "nm."



# Metal Oxide Nanostructures for UV detection



(a)



(b)

Work by Hasan, et al. (Nanoscale Research Letters 2011)

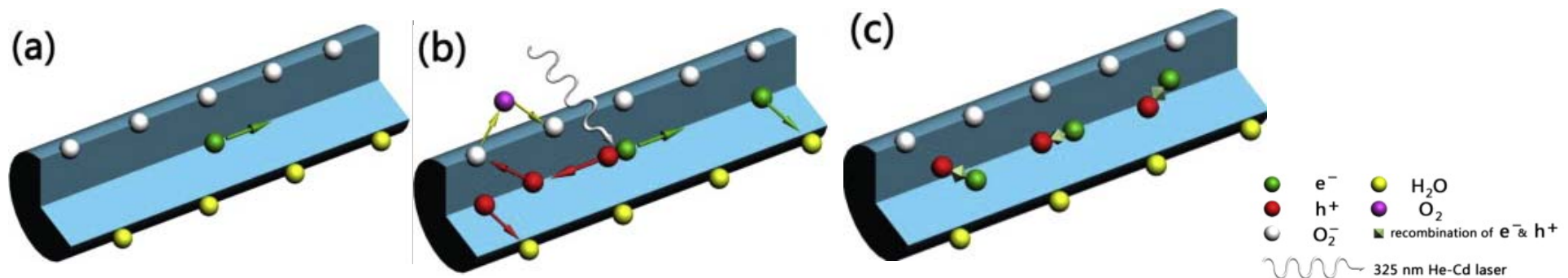
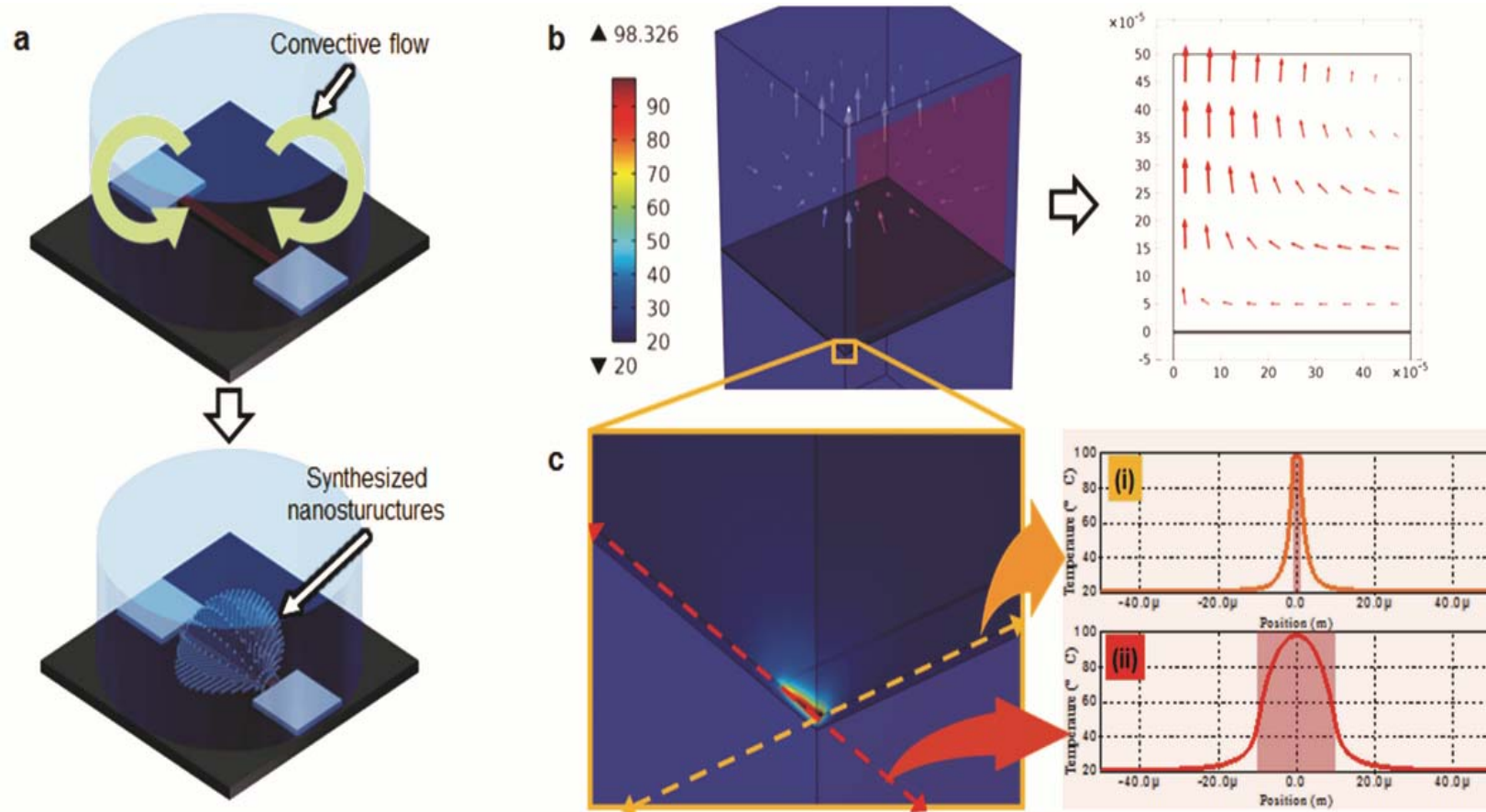


Image by Hou, et al. (Sensors and Actuators A 2012)

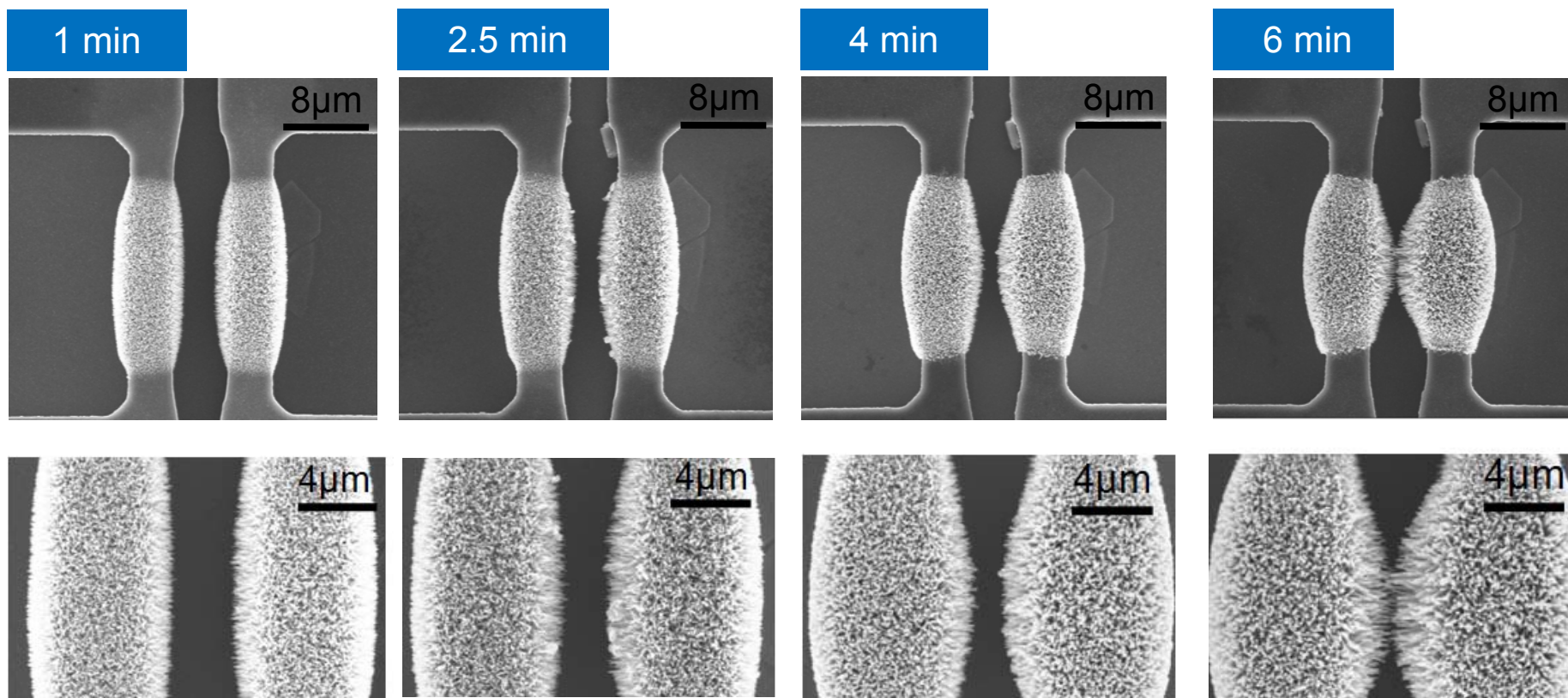
# Direct Nanomaterial Synthesis & Integration



*Adv. Mater. (2014)*

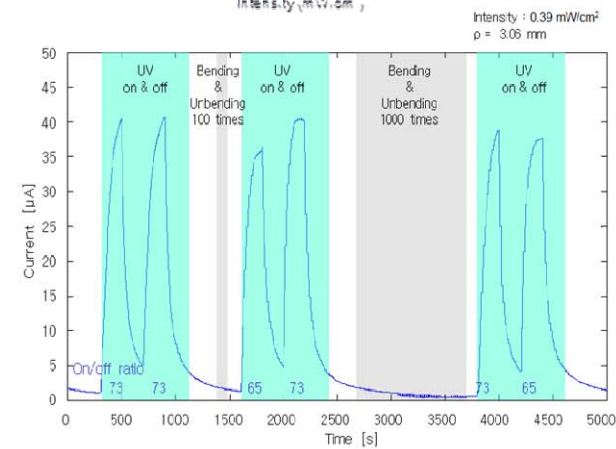
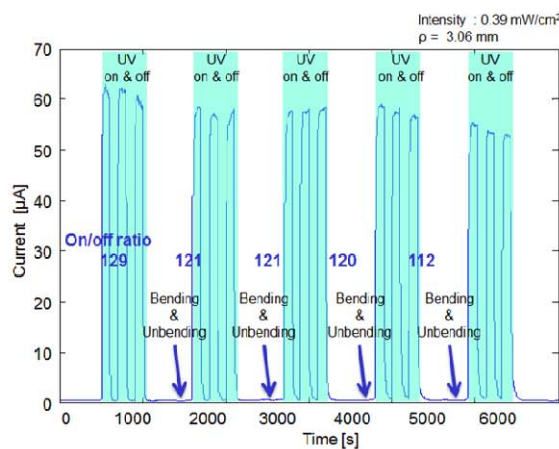
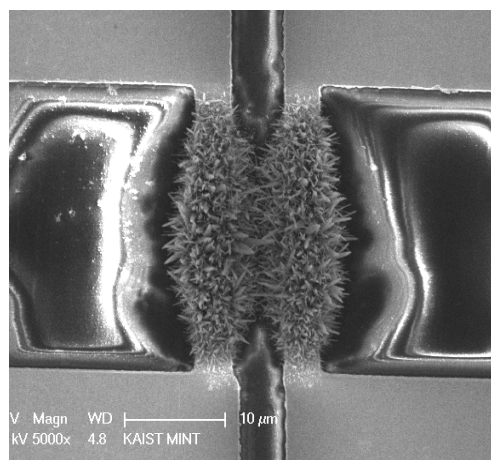
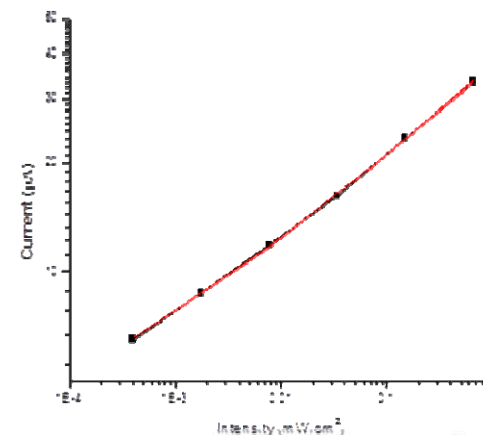
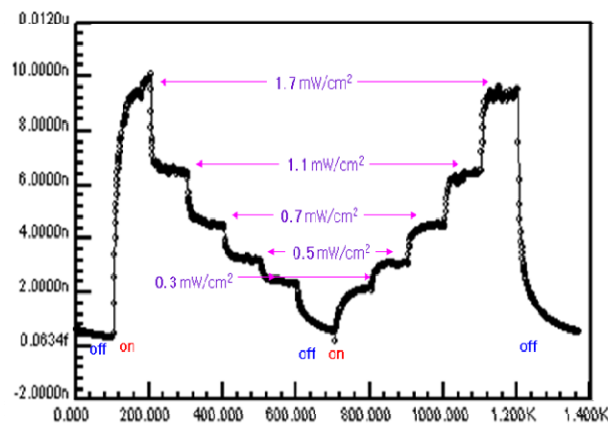
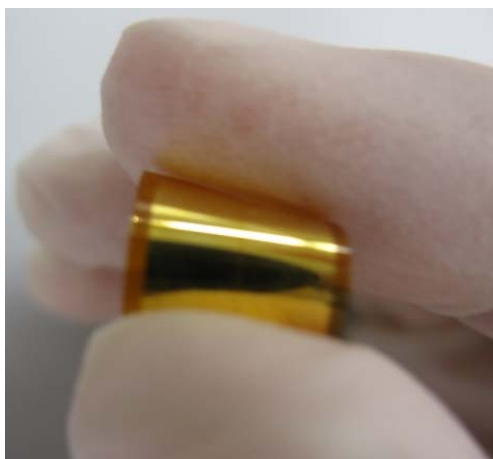
Nov 2014 © Prof. Inkyu Park

# Time Lapse Imaging of Nanomaterial Synthesis



*Adv. Mater. (2014)*

# Flexible UV Sensor based on FEF-synthesized ZnO Nanowires



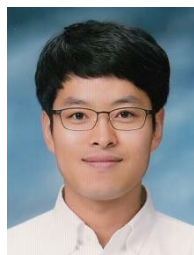
*Adv. Mater. (2014)*

## (2) Flexible & Multiplexed Gas Sensors

*Nano Letters (2012)*  
*ACS Nano (2012)*  
*Advanced Materials (2014)*



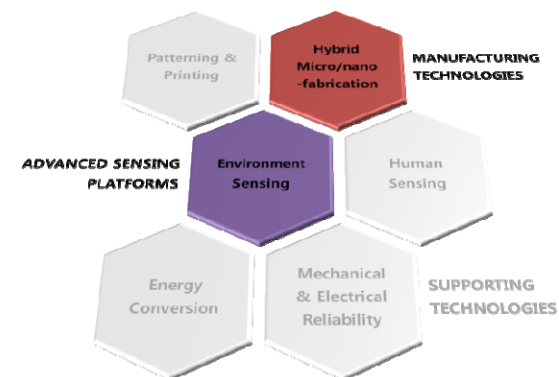
**Daejong Yang**  
 (5th yr, combined  
 MS-Ph.D.)



**Jae-Hyuk Ahn**  
 (Postdoc.)



**Kyungnam Kang**  
 (1st yr, M.S.  
 candidate)



# Needs of Compact & Personalized Gas Sensing Devices

- **Monitoring of air quality in outdoor, industrial facilities, public places, and buildings**
- **Source of pollution:** hydrocarbon fuels, car emission, industrial emission, etc.
- **Existing air quality monitoring system: large, expensive, and immobile**

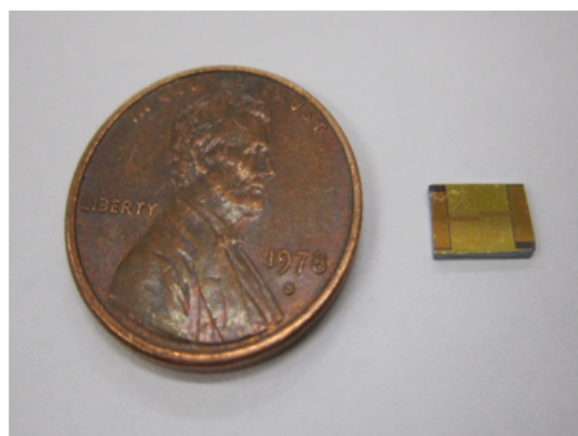
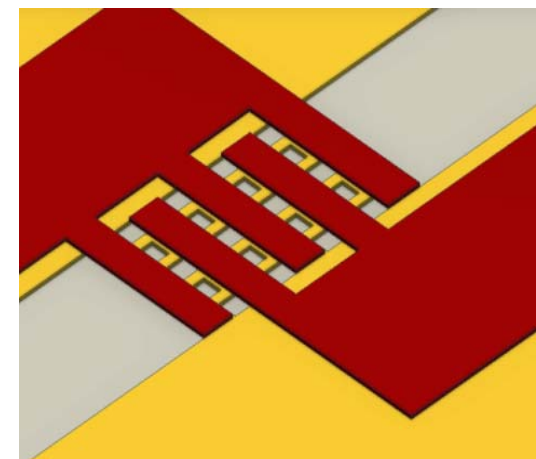
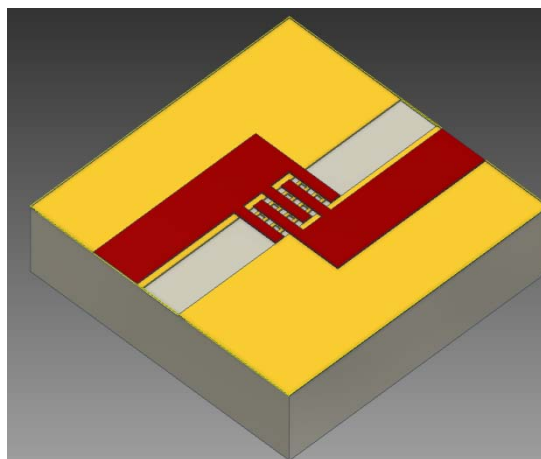
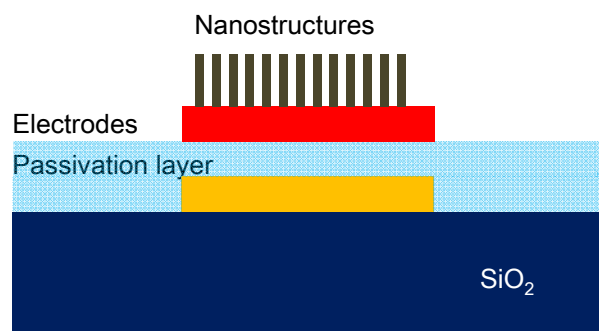


Mobile Air Quality Index (AQI) Unit  
Image by Ministry of Environment, Ontario

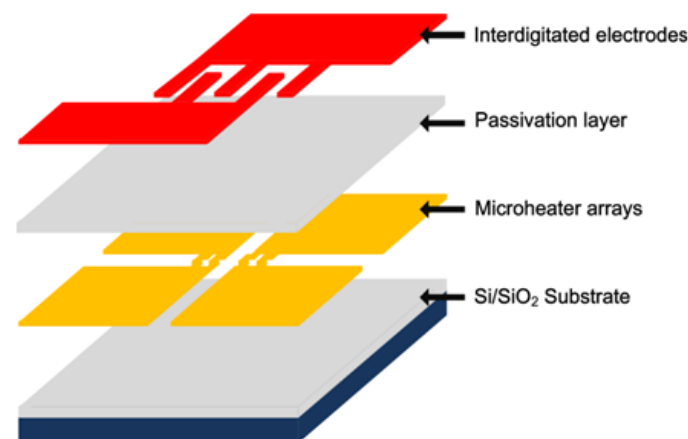


"Compact" Ambient Air Monitoring System  
(800x600x500mm), Air Monitors, Ltd., USA

# Selectively Synthesized Nanomaterials for Gas Sensing



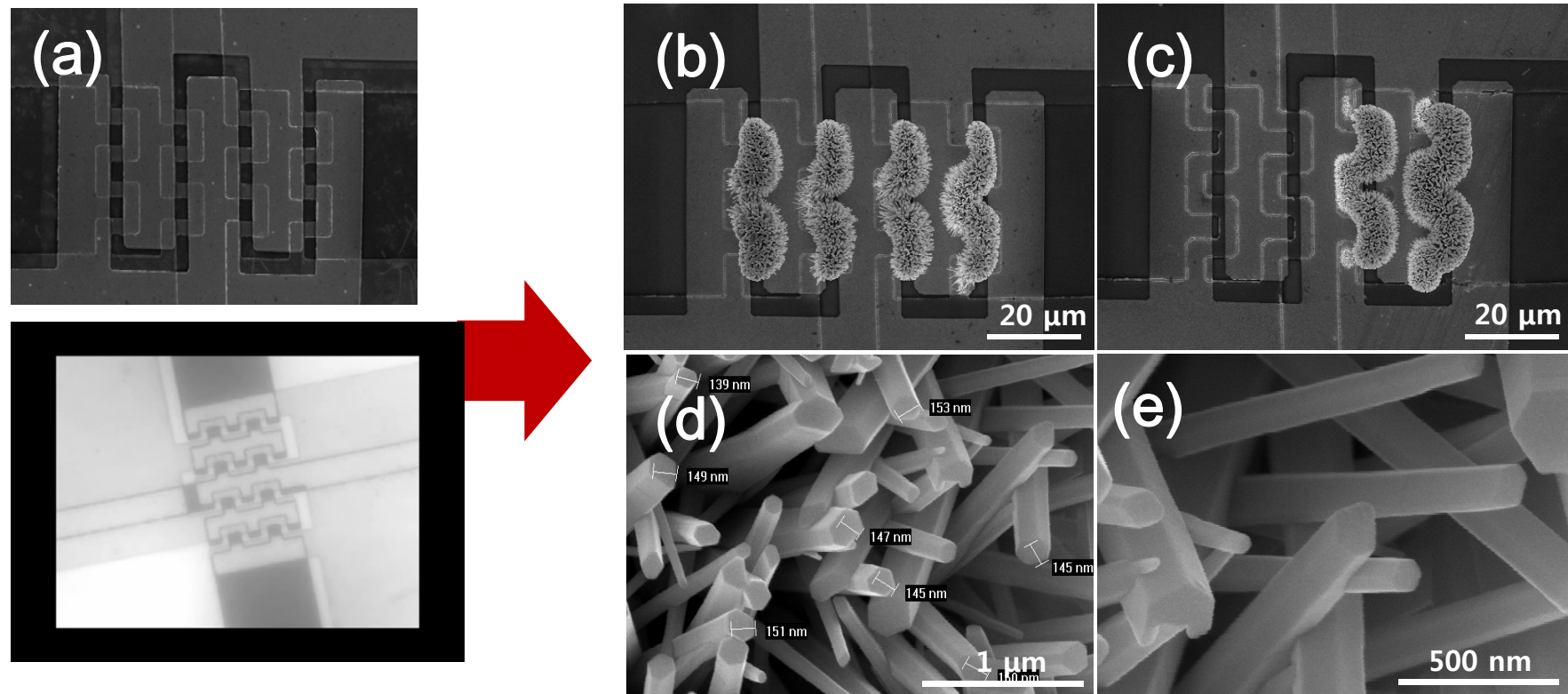
Photograph of fabricated device



Exploded view of the device components

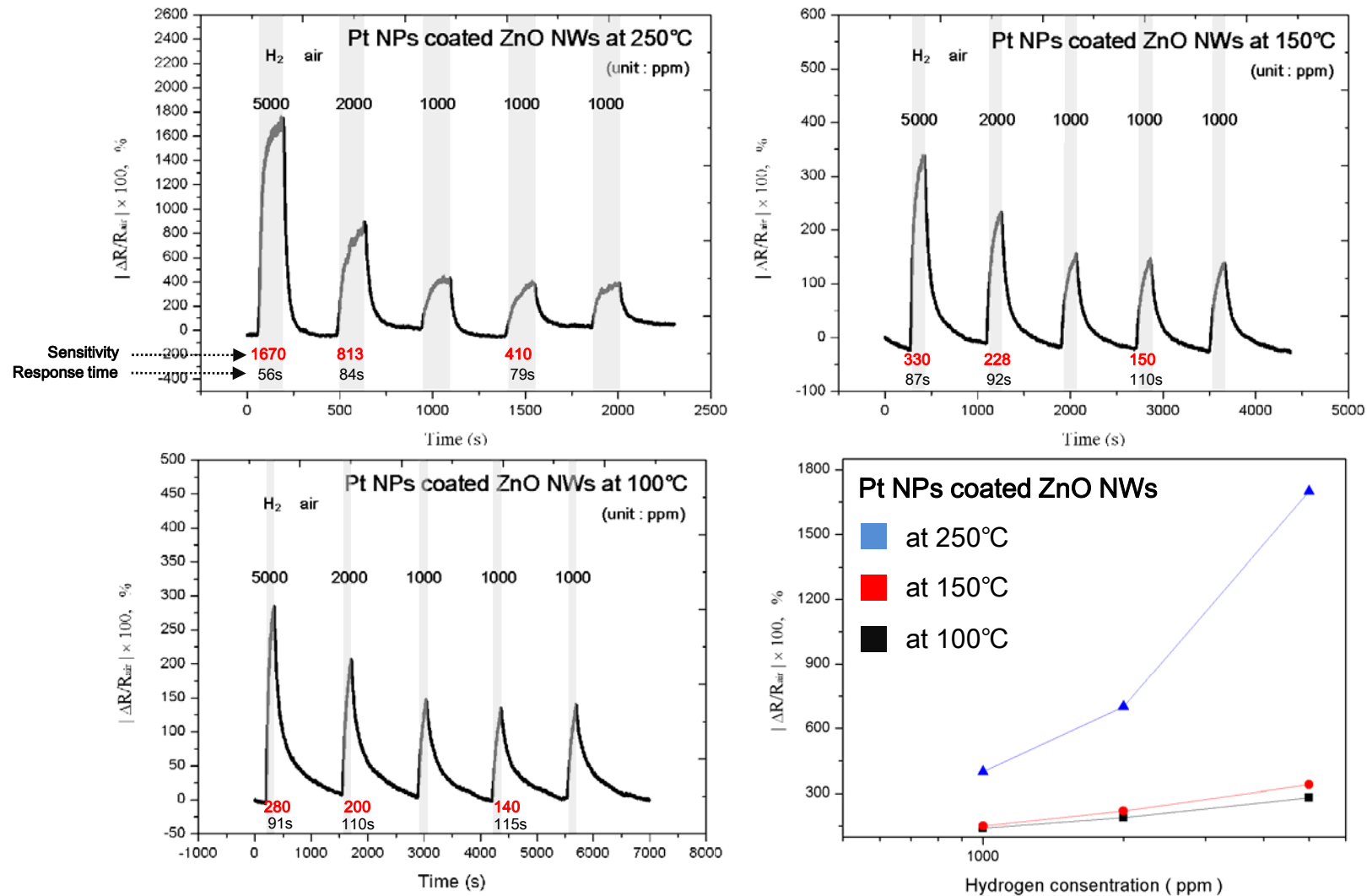


# Focused Energy Field (FEF) Method for Localized Hydrothermal Synthesis

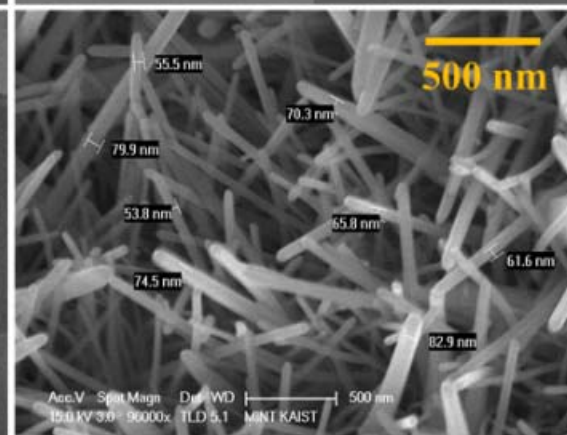
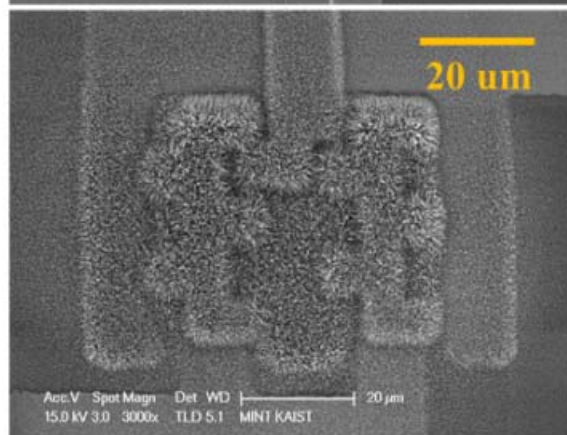
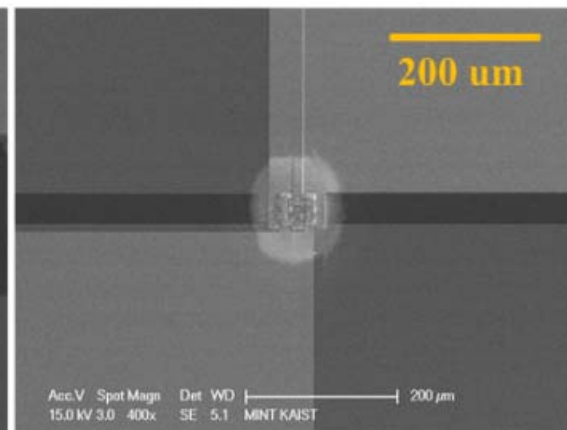
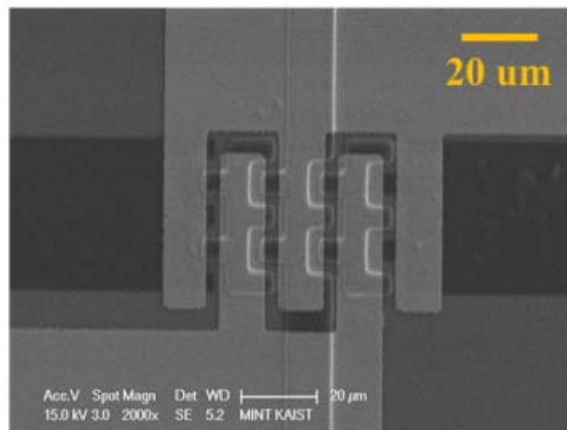
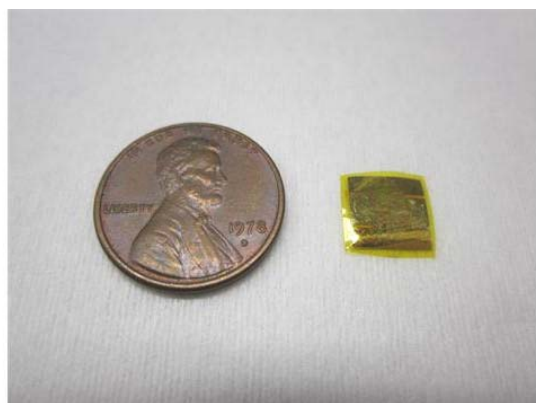
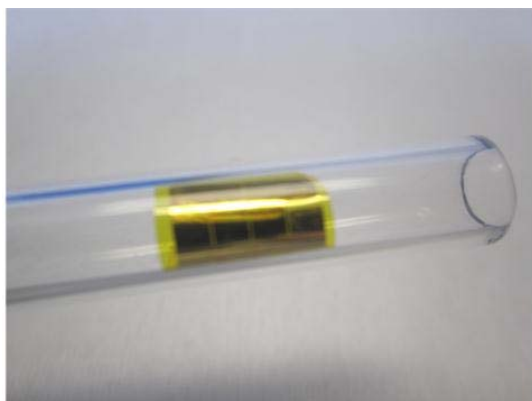


(a) SEM image of the device. (b) Fully grown ZnO NWs, (c) selectively grown ZnO NWs on the right-side heaters, (d) zoomed-in image of locally grown ZnO (the diameters are 50~100nm and lengths are 1-2µm). (e) Nanojunctions between ZnO NWs.

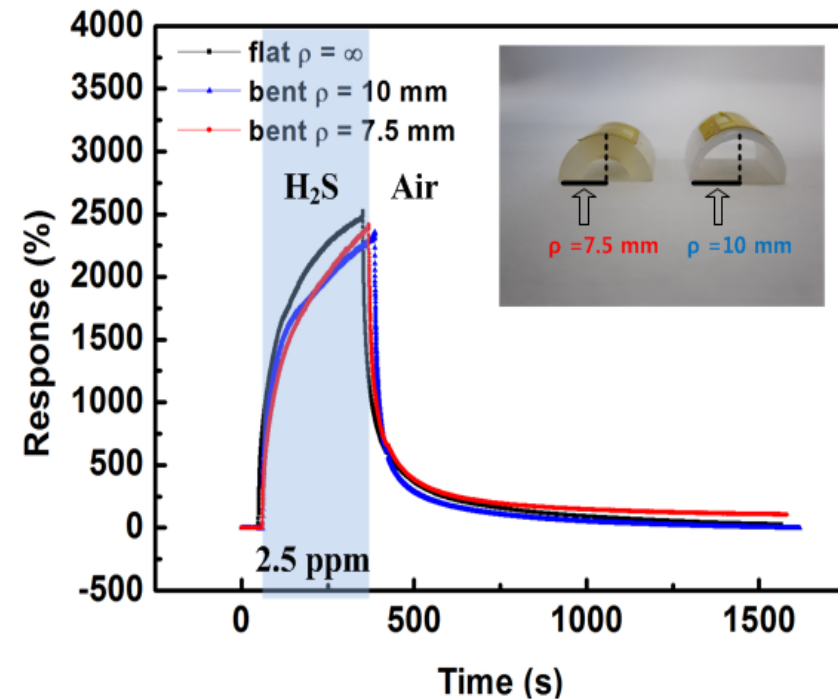
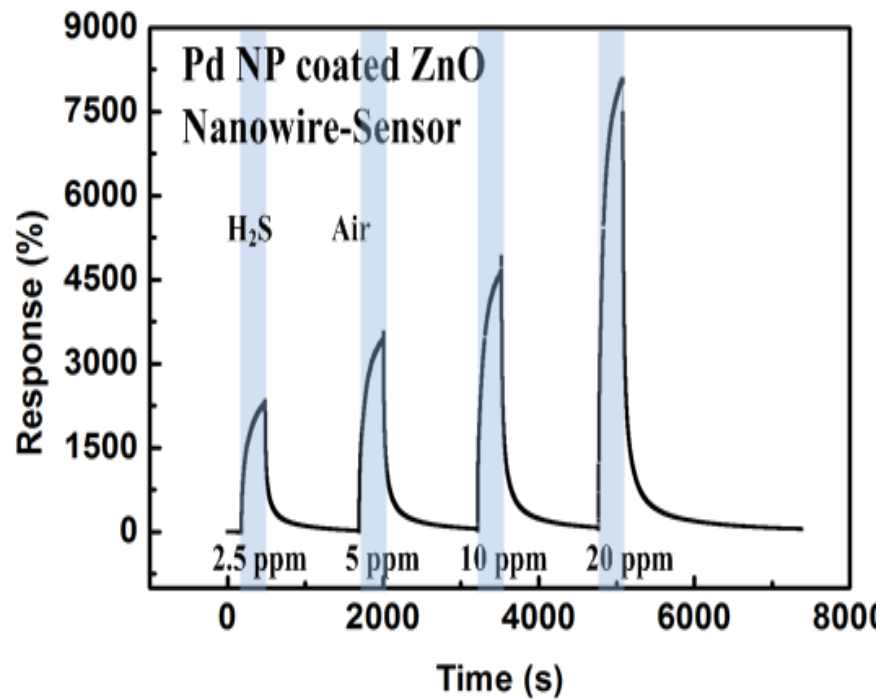
# PtNP-coated ZnO nanowire-based H<sub>2</sub> Sensor



# Flexible & Heater-integrated Chemical Sensor



# Flexible & Heater-integrated Chemical Sensor



# (3) Conductive Nanomaterial – Elastomer Composite Based Sensor for Human Motion Detection

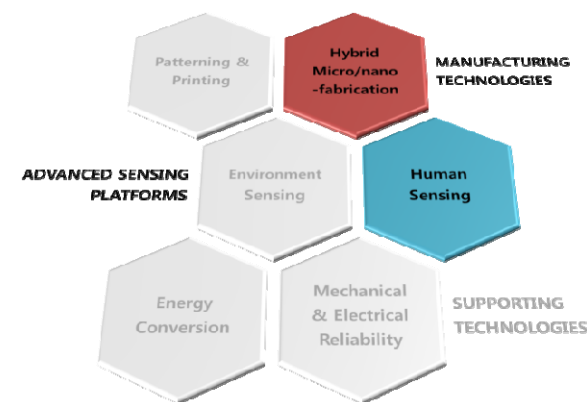
*Adv. Mater. (2008)*  
*Nanotechnology (2012)*  
*Nanotechnology (2013)*  
*ACS Nano (2014)*  
*Nanoscale (2014)*



Mr. Jae Hwan Lee (former graduate student)



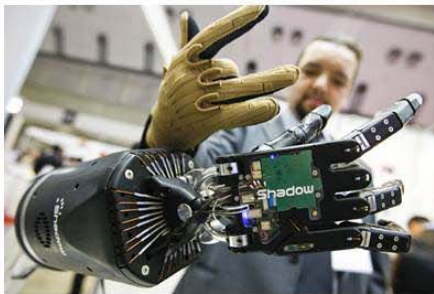
Morteza Amjadi (2nd yr, MS.)



# Wearable Human Motion Detection



Entertainment



Smart glove; surgical robot, entertainment

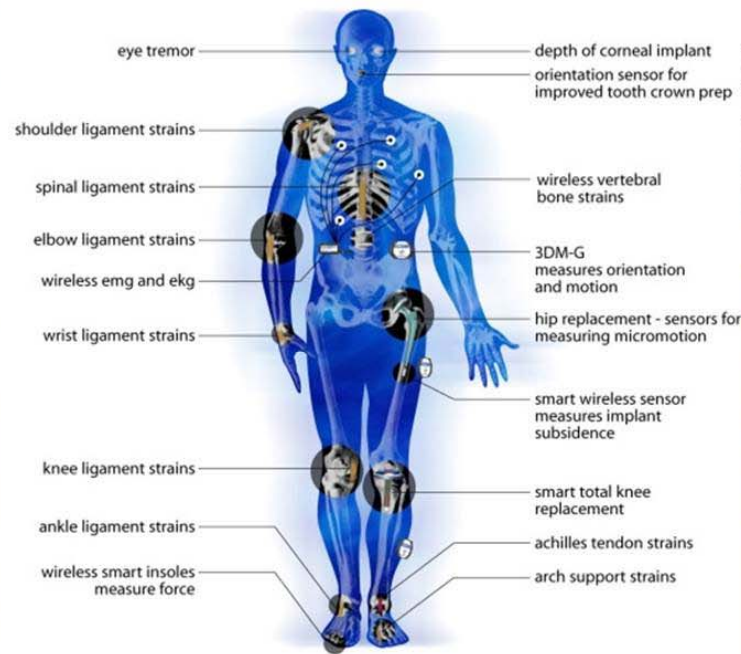
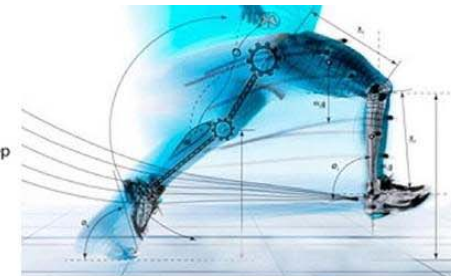


Image courtesy of Microstrain, Inc.

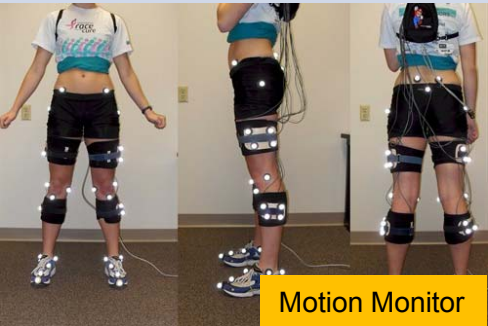

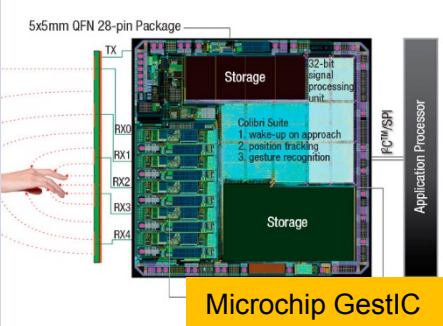
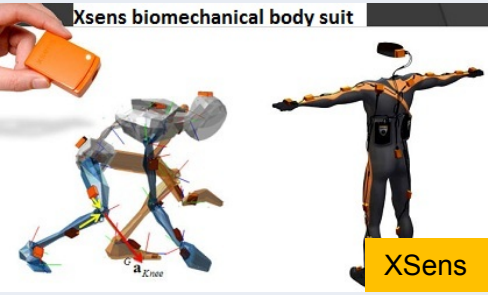



Sports dynamics

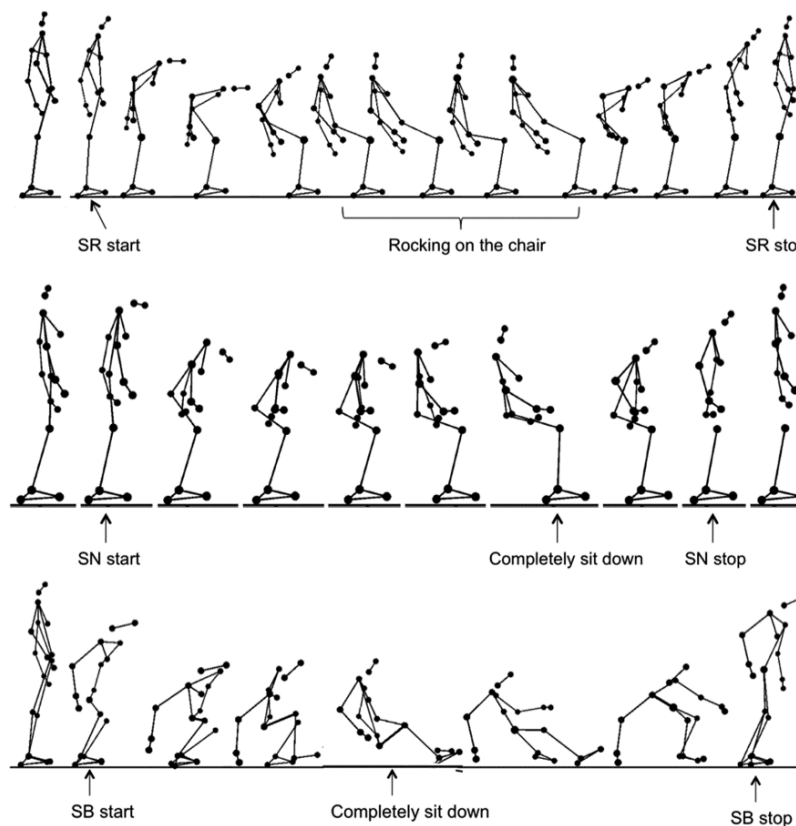


Personal health care; rehabilitation

# Human Motion Monitoring : Commercial Technology Types

<p><b>Fixed system</b></p>	<p><b><u>Optical tracking</u></b></p>  <p>Motion Monitor</p>	<p><b><u>Infrared imaging</u></b></p>  <p>Leap Motion</p>	<p><b><u>Electrical field</u></b></p>  <p>Microchip GestIC</p>
	<p><b>Mobile, Wearable system</b></p>	<p><b><u>MEMS accelerometer</u></b></p>  <p>Xsens</p>	<p><b><u>Mechanical measurement</u></b></p>  <p>Dexta Robotics</p>

# Human Motion Detection by Strain Measurement at Joints

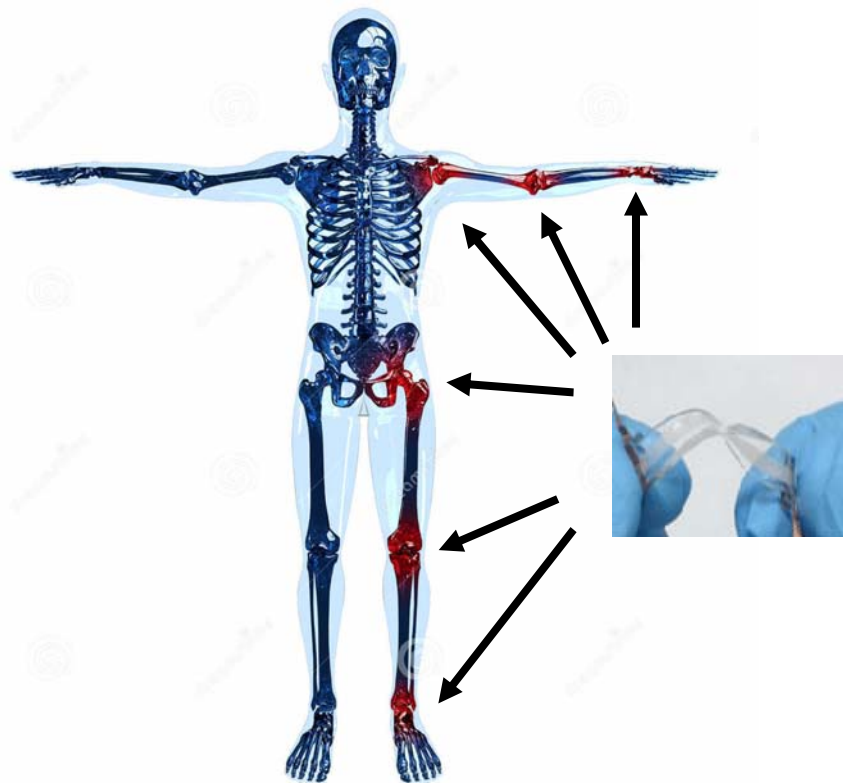


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 31886122 Szabolcs Szekeres | Dreamstime.com

**Simple bandage type strain sensor  
 feasible for passive type with near field wireless communication**



# Human Motion Detection by Strain Measurement at Joints



## Simple bandage type strain sensor

- ✓ Absolute position of human body can be calculated by kinematic transformation of multiple joint angles
- ✓ Light weight; inexpensive; low-power; less calibration needs
- ✓ Highly flexible, stretchable and attachable to human skin with small form factor & inconvenience
- ✓ Feasible for passive sensor type with near field communication

Download from  
Dreamstime.com

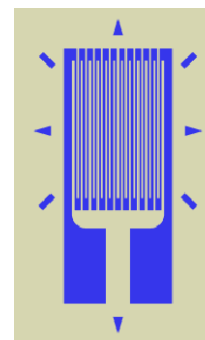
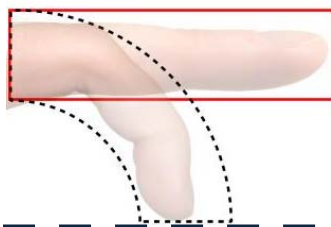
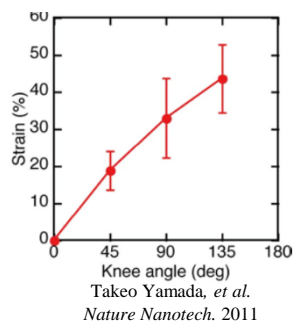
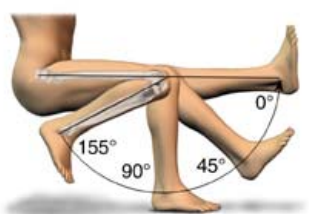
21686122  
Szabolcs Szekeres | Dreamstime.com

# Stretchability Issues in Detecting Human Motion

**High dynamic range of human motion**

**Vs.**

**Conventional strain sensor**

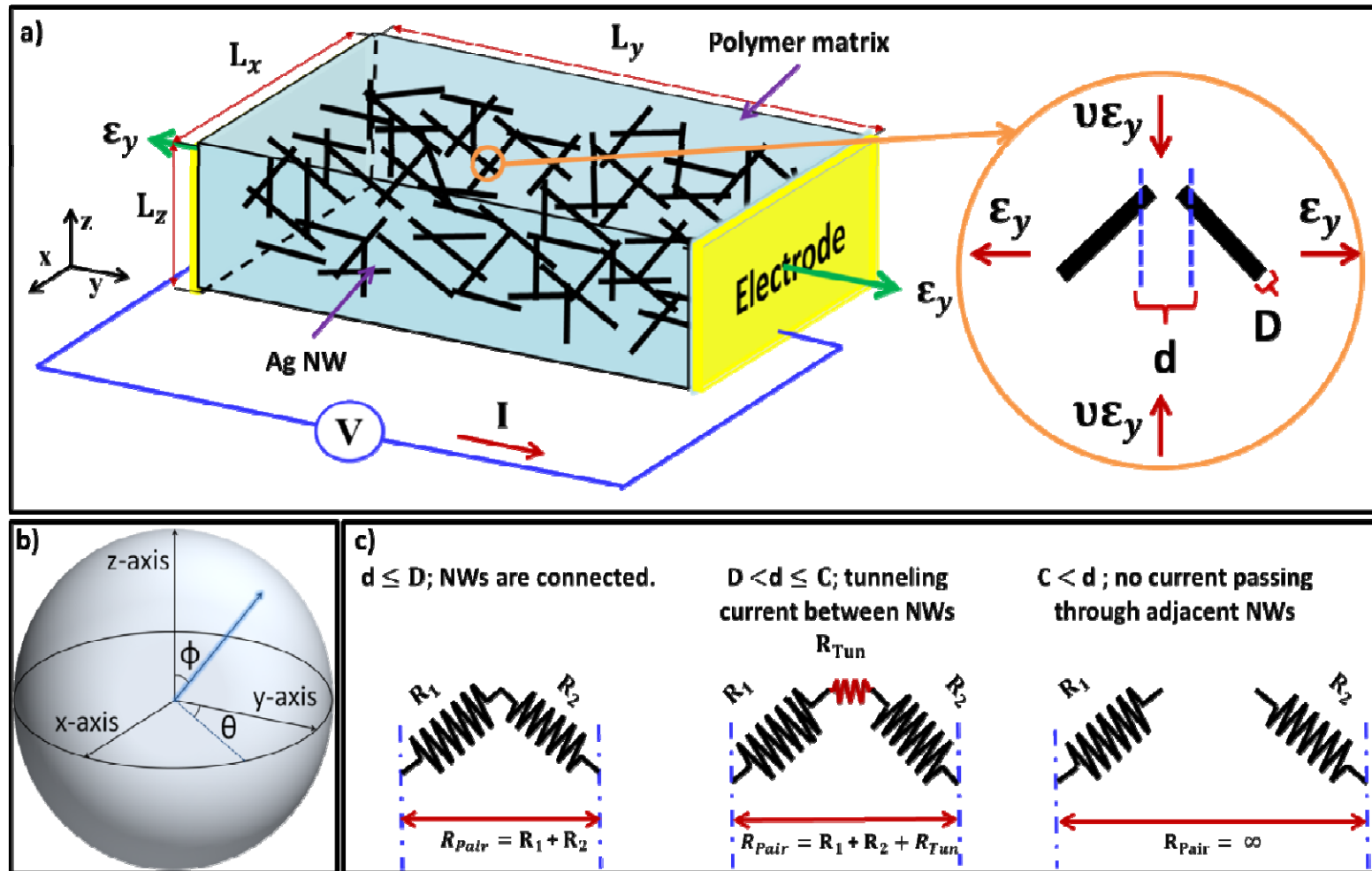


- Metal foil strain gauge**
- Gauge factor : 1-5
  - Maximum strain : 5%



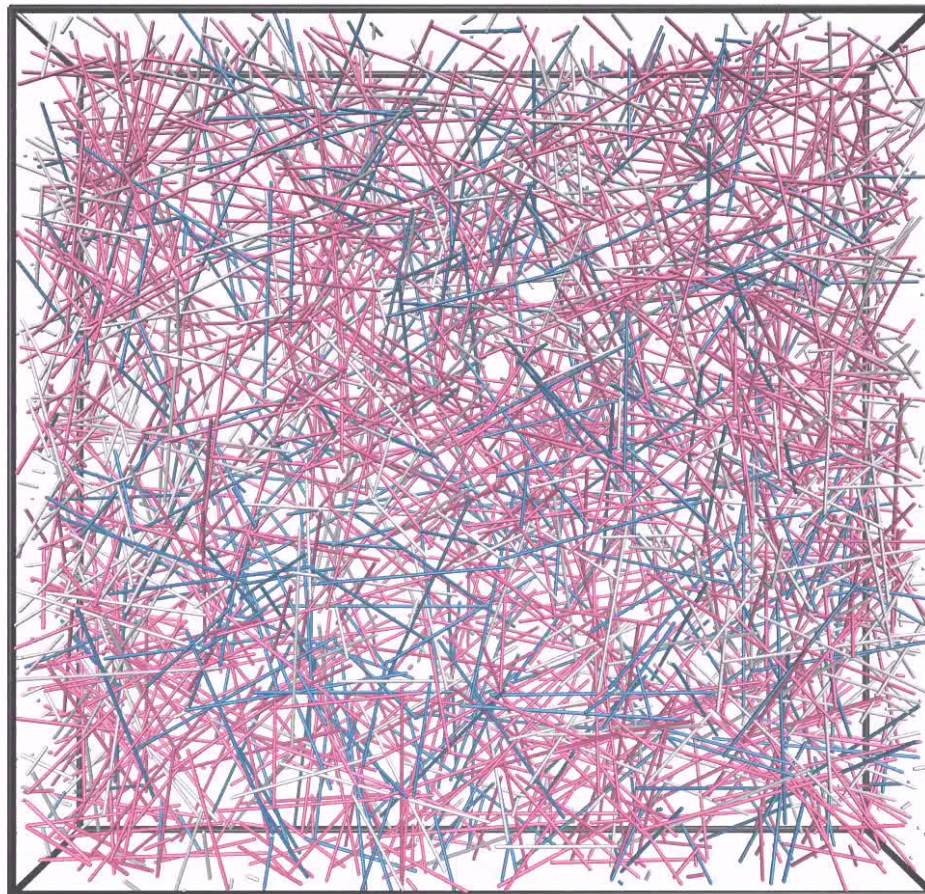
**How to solve?**

# Silver Nanowire – Elastomer Composite : Stretchable Strain Sensor



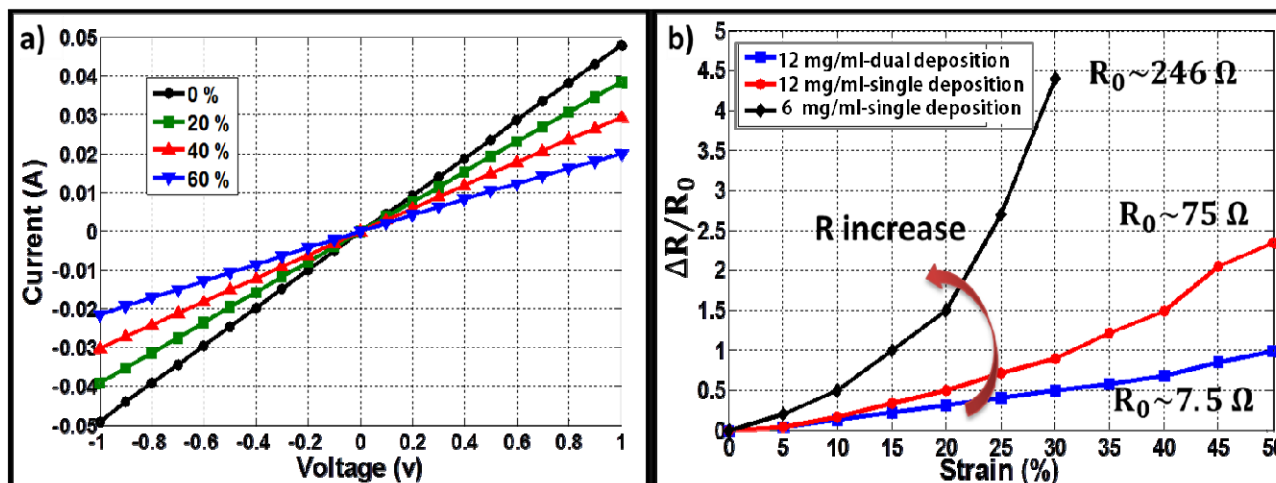
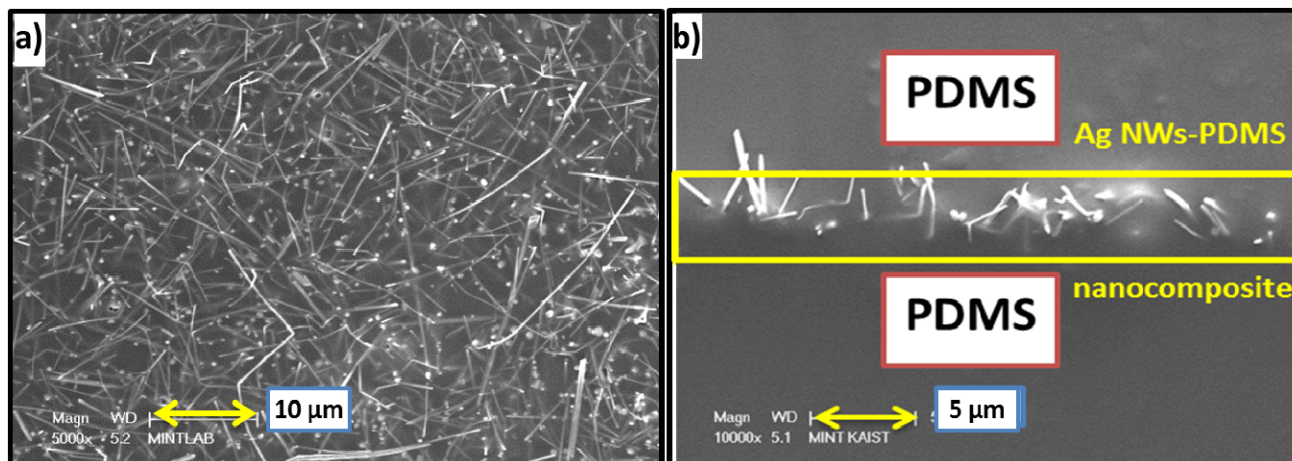
# Rearrangement of AgNW Percolation Network by Tensile Strain

VideoMach unregistered



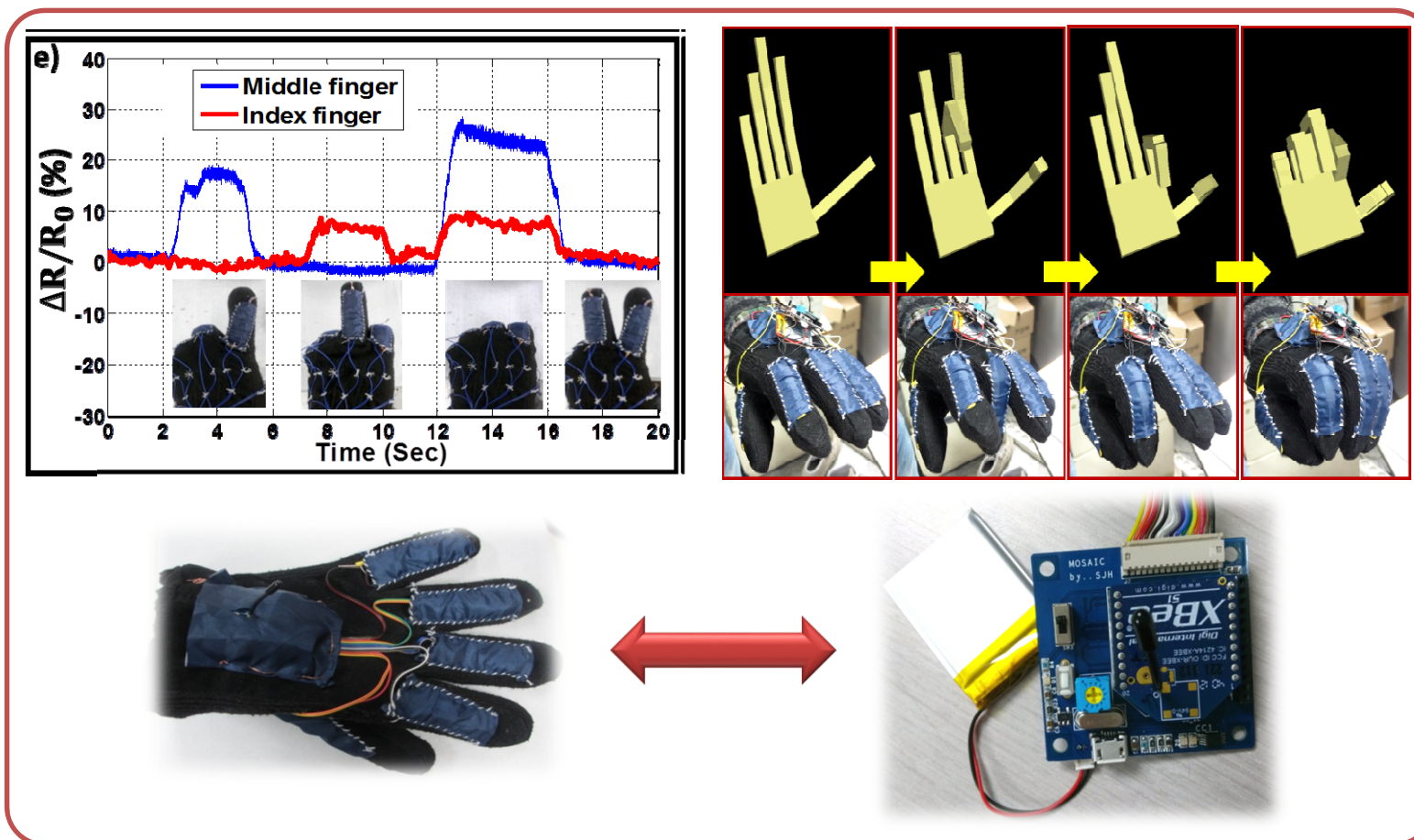
*ACS NANO (2014)*

# Fabricated Strain Sensor : Sensing Performance



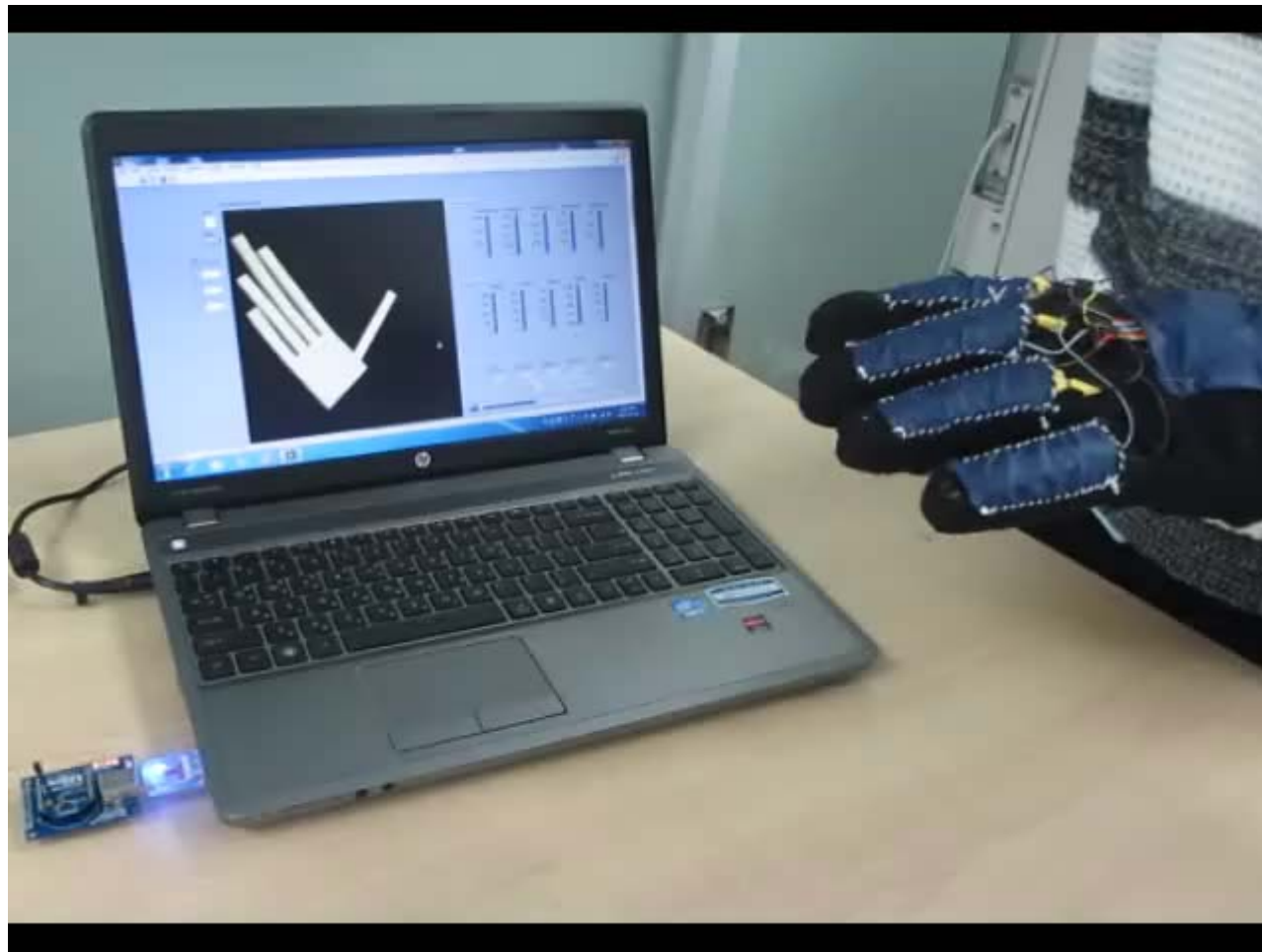
ACS NANO (2014)

# Wireless Smart Glove System for Human Motion Detection



ACS NANO (2014)

# Wireless Smart Glove System for Human Motion Detection



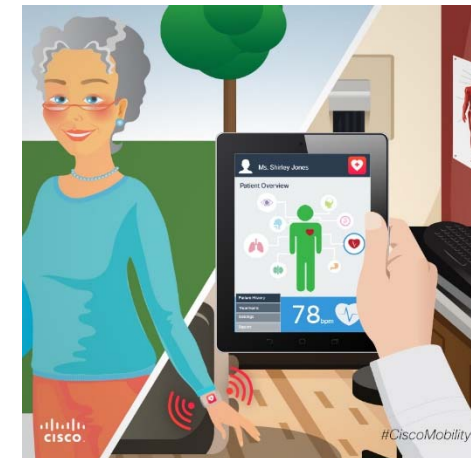
# Outlook for the Trillion Sensor Market

- Personalized environment & health monitoring → wearable devices ; smartphones



My Air  
My Health

U.S. Department of Health and Human Services  
U.S. Environmental Protection Agency



- Essential factors for success in the trillion sensor market :
  - ✓ Low-cost ; Low-power
  - ✓ Small maintenance /re-calibration needs
  - ✓ High reliability & High-performance
  - ✓ Comfort (flexible, skin-mountable, small-form factor, light-weight & invisible)





# Thank You !