



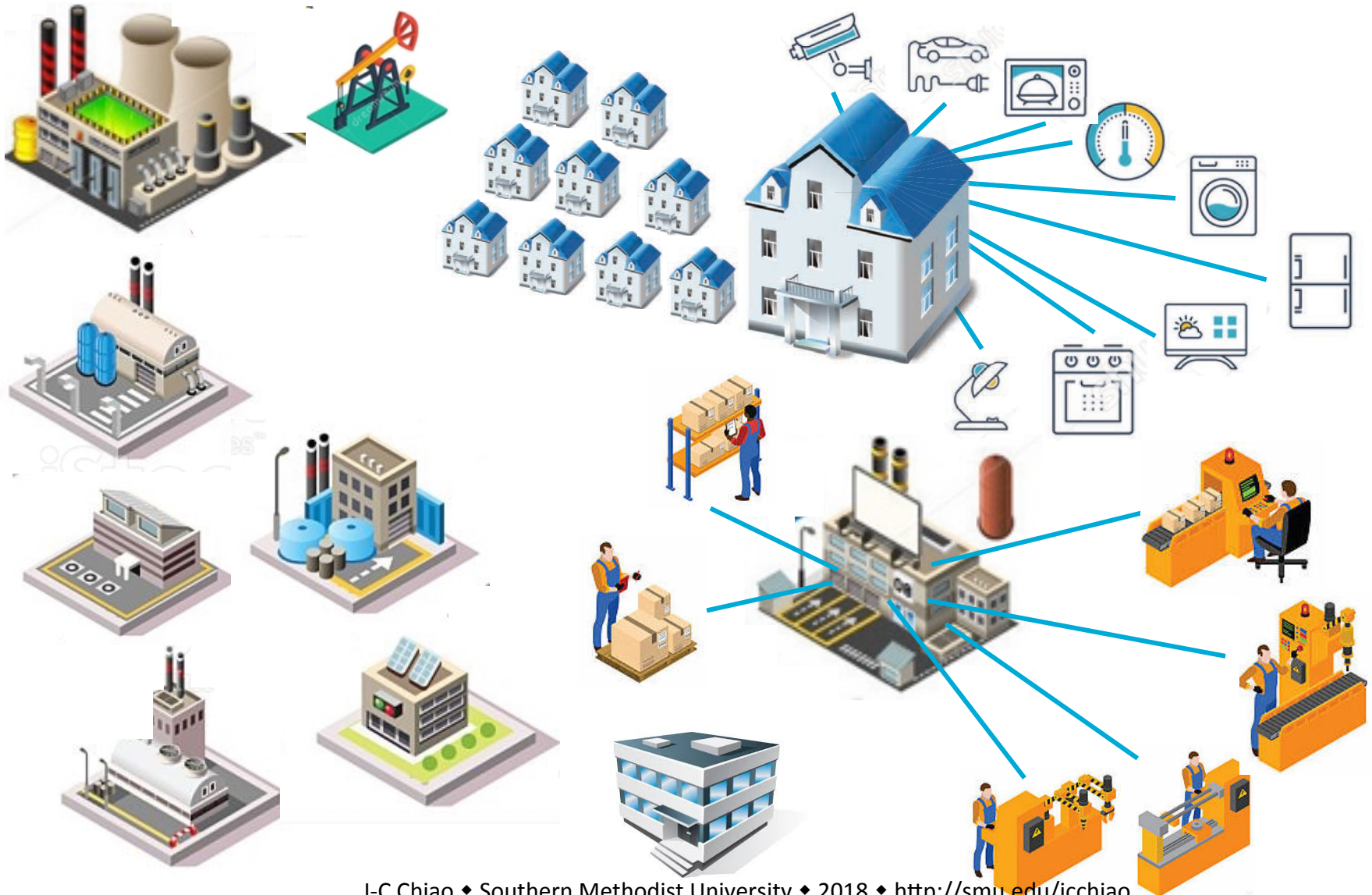
Miniature Batteryless Wireless Sensors

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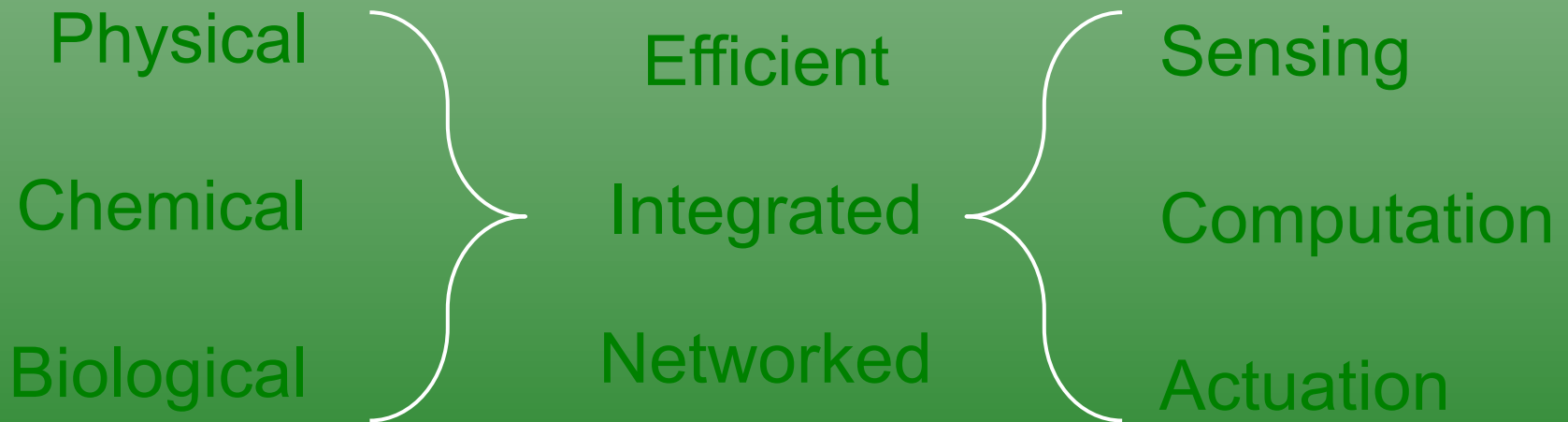
IoT Internet of Things **Sensing** **Connecting**



Mass production

Design for large populations

Small



Smart

Adaptive



IoT Internet of Things **for Your Body**

5 organs

206 bones

360 joints

24 ribs

31 pairs of spinal nerves

650-840 skeletal muscles

100,000 miles blood vessels

100 billion neurons

37.2 trillion cells

Wearable Devices



Pristine Glasses



FitBark



KMS Wristband



Pebble



Fitbit



EKG recorder/Polar belt



Zepp sensor



Garmin
Heart Rate Monitor



Qualcomm Toq



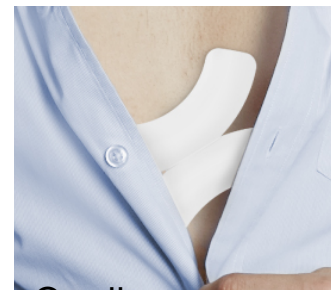
Corventis
ECG recorder



Ring Heart Rate
Pulse Oximeter



Fingertip
Pulse Oximeter



Qardiacore
EKG recorder



Vitalsens Cardiac
Event Monitor

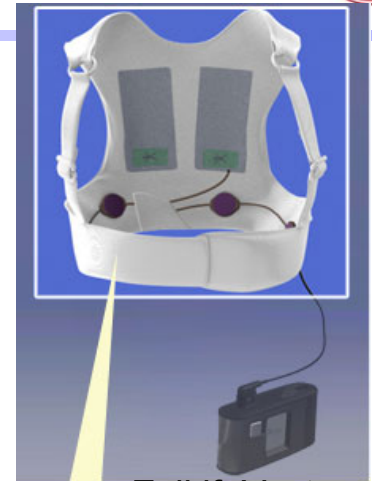
Wearable Devices



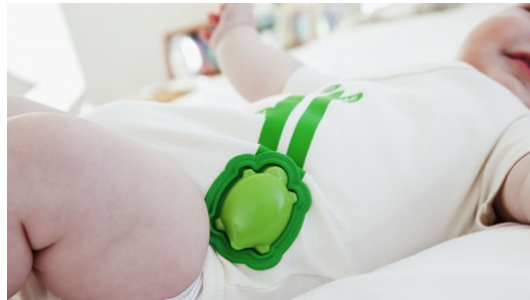
Sensoria Smart Sock



IMEC emotion monitor



Zoll lifeVest
wearable defibrillator



Mimo Baby monitor



IMEC EEG headset



Vivonoetics
LifeShirt for sensors

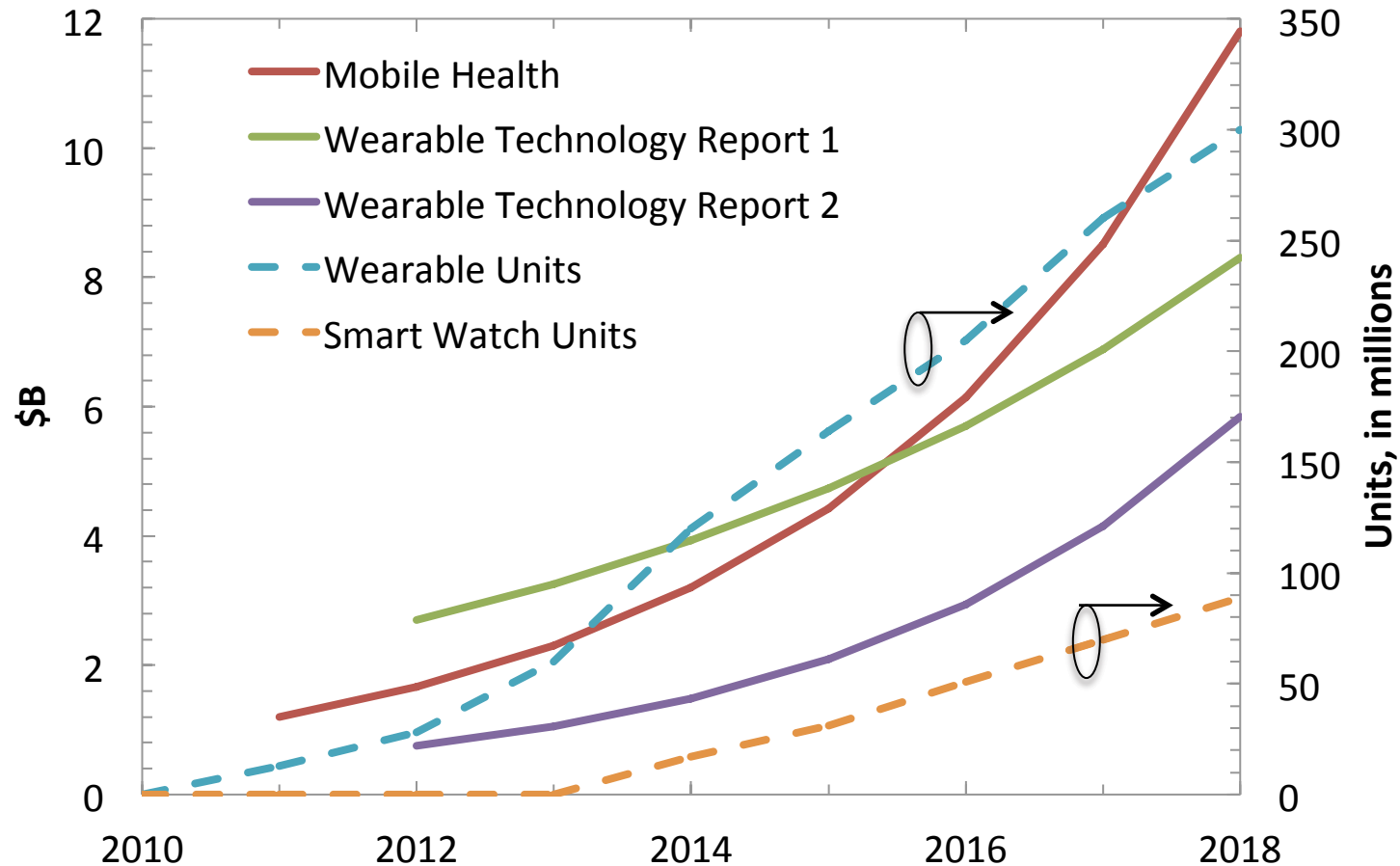


SensibleBaby SmartOne



Medtronic CGM

Markets



Data sources: Mobile Health market (GlobalData),
Wearable Technology (1: Research & Markets; 2: Transparency Market Research),
Wearable Units and Smart Watch Units (BI Intelligence Estimates).

The diagram illustrates the Physiotronics system architecture. A human figure is shown with internal organs and a network of red lines representing the body's internal system. Three yellow circles labeled "Sensor" are positioned on the chest, abdomen, and lower leg. Three blue circles labeled "Therapy device" are positioned on the upper leg, lower leg, and foot. A green dashed line labeled "Power" connects the chest sensor to the upper leg therapy device. A green dashed line labeled "Command" connects the lower leg therapy device to the foot therapy device. A green dashed line labeled "Policy" connects the foot therapy device to the upper leg therapy device. A green dashed line labeled "Data" connects the chest sensor to a smartphone. A green dashed line labeled "Data" connects the abdomen sensor to the smartphone. A green dashed line labeled "Data" connects the lower leg sensor to the smartphone. A green dashed line labeled "Data" connects the upper leg therapy device to the smartphone. A green dashed line labeled "Data" connects the lower leg therapy device to the smartphone. A green dashed line labeled "Data" connects the foot therapy device to the smartphone. A green dashed line labeled "Data" connects the smartphone to a cloud labeled "Cloud data". A green dashed line labeled "Data" connects the cloud to a cloud labeled "Big data Intelligence". A green dashed line labeled "Data" connects the cloud to a cloud labeled "Patient's subjective feeling". A green dashed line labeled "Data" connects the cloud to a cloud labeled "Clinic".

PhysiotronicsTM

Power

Command

Policy

Command

Sensor

Sensor

Sensor

Therapy device

Therapy device

Therapy device

Data

Data

Data

Data

Data

Data

Data

Cloud data

Big data Intelligence

Patient's subjective feeling

Clinic

J-C Chiao ♦ Southern Methodist University ♦ 2018 ♦ <http://smu.edu/jcchiao>

Sensing elements



Features

- Low power consumption
- Electrical interface
- RFID compatible
- Flexible, deformable, bendable
- Low cost fabrication method
- Wearable and implantable

Sensors

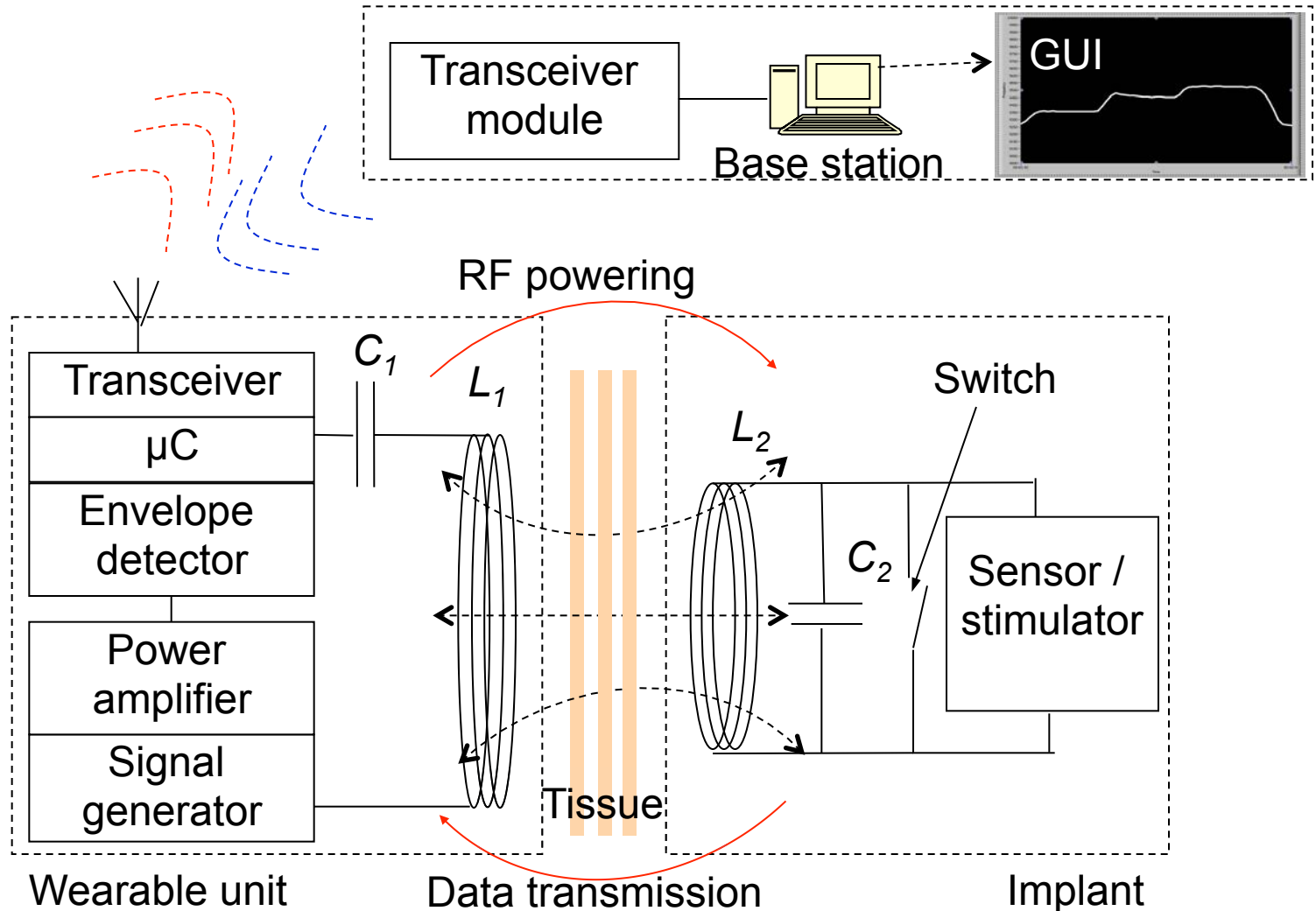
- Bio-electro-chemical sensors
 - pH, Na⁺, lactate, glutamate sensors
- Amorphous carbon strain sensors
- Nanorod surface modification

Wireless power transfer

- Batteryless and wireless



Wireless Implant System Configuration





Impedance and Electrochemical Sensors Driver

Four sensors (impedance, potential)

FSK modulation of sensor signals

2 modulation bands

Time/Frequency multiplexed

AMI 0.5 μ m (C5N)

1.95mm x 1.95mm

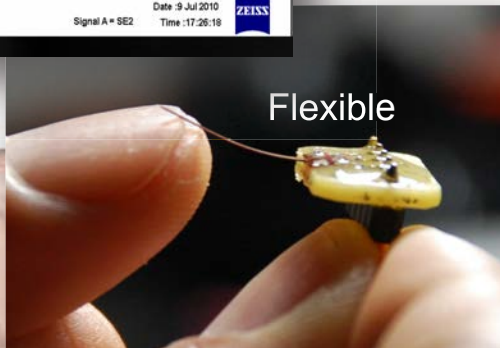
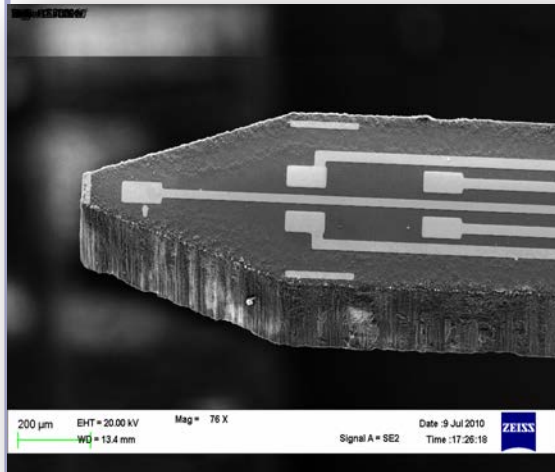
Less than 37 μ A



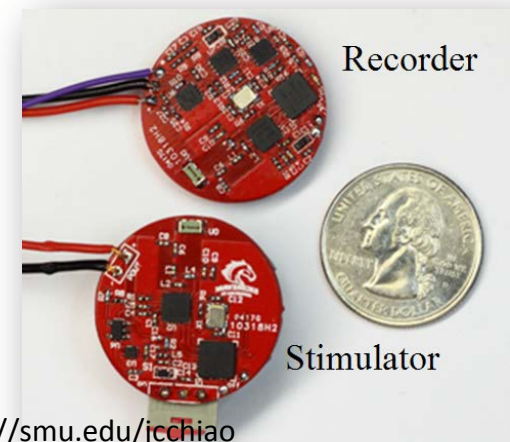
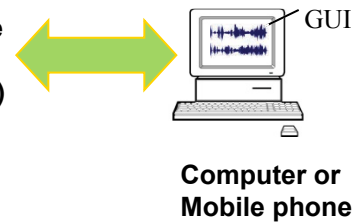
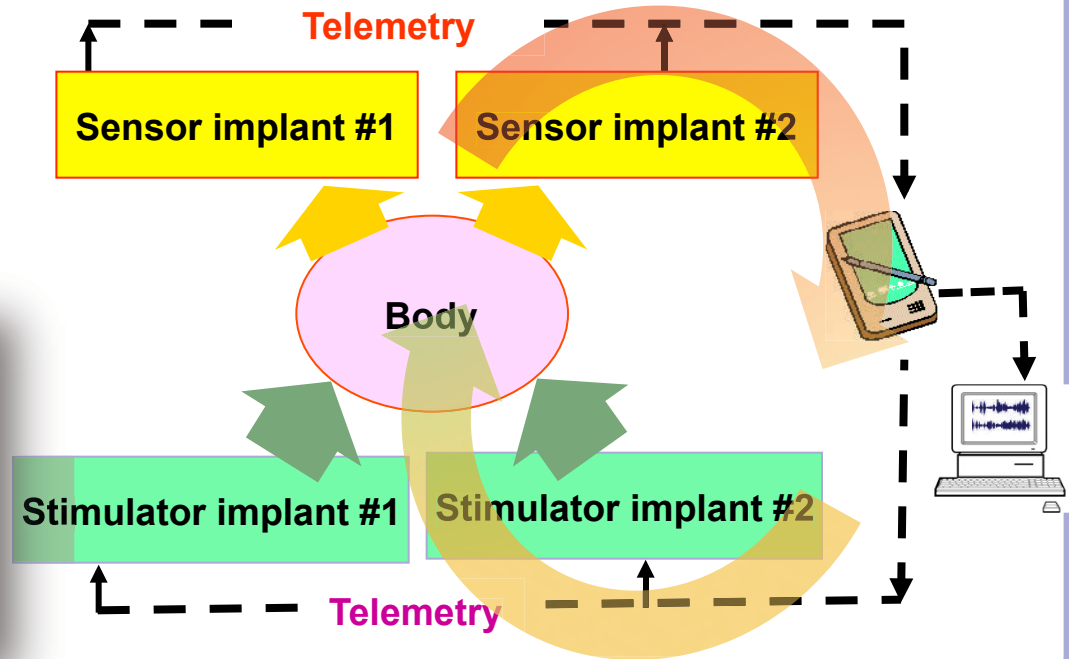
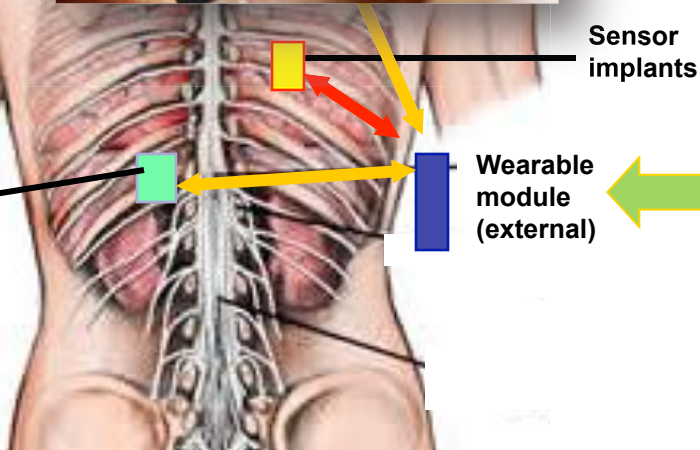
Demonstration in Medical Applications



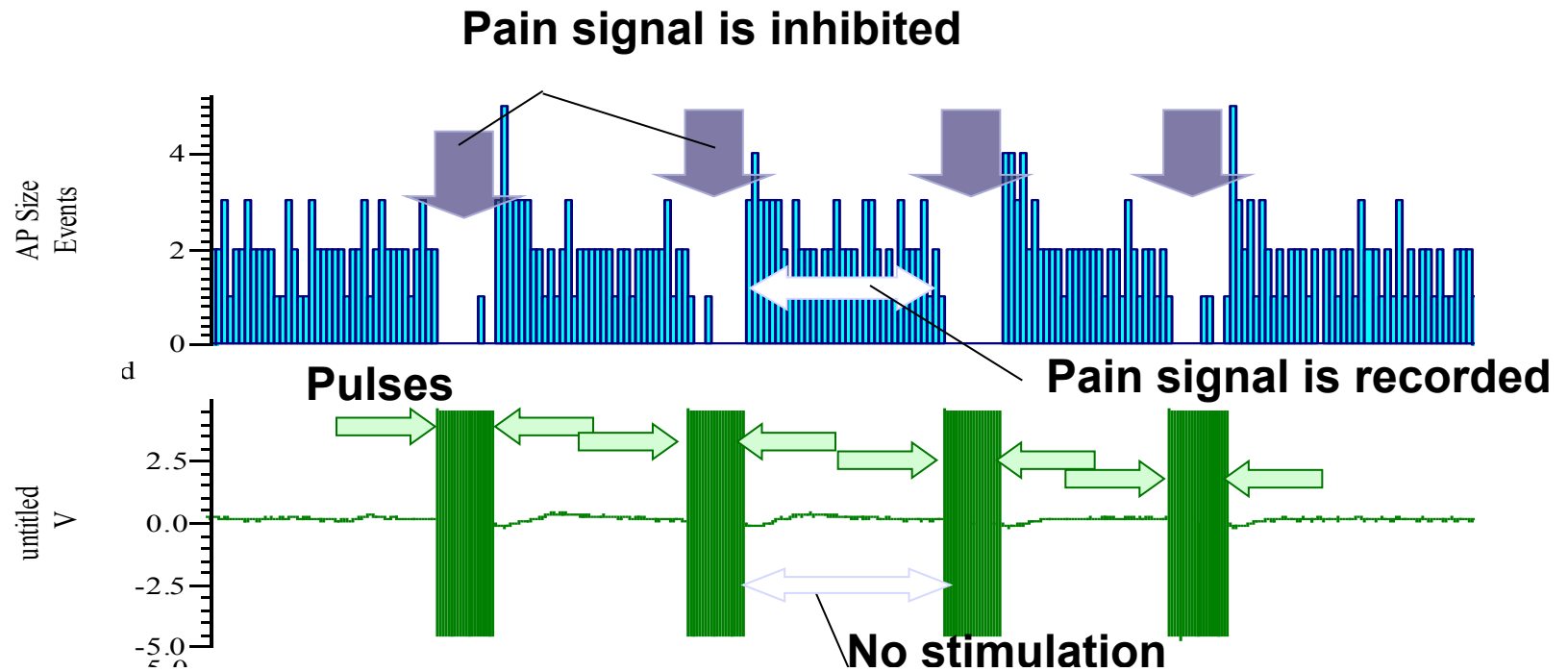
Digitalize Pain Signals



Stimulator implant ID#1



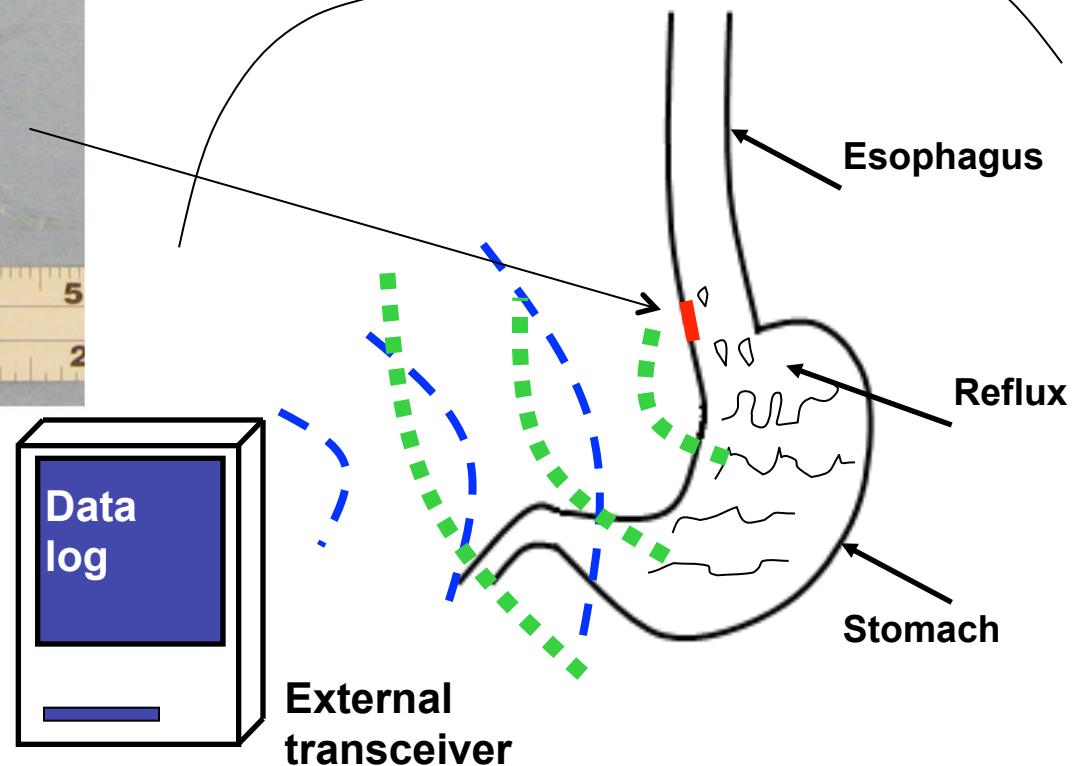
Pain Inhibition



GERD Symptom Monitoring

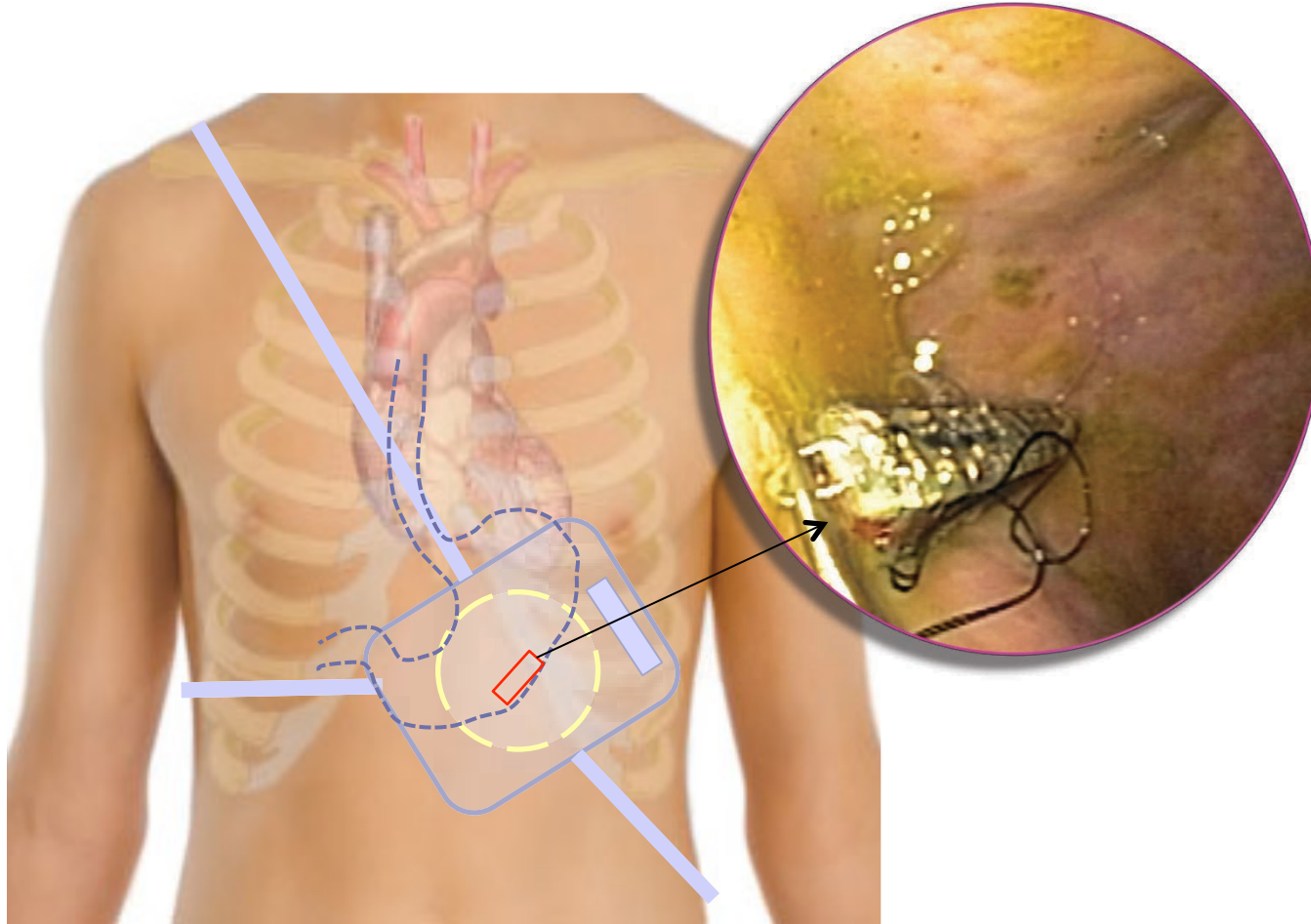


Batteryless wireless dual-sensor implantable capsule to monitor continuously reflux episodes and their pH nature



BatteryLess EndoScopically-implantable Stimulator

Batteryless wirelessly-powered gastrostimulator to manage **gastroparesis**





Sensors

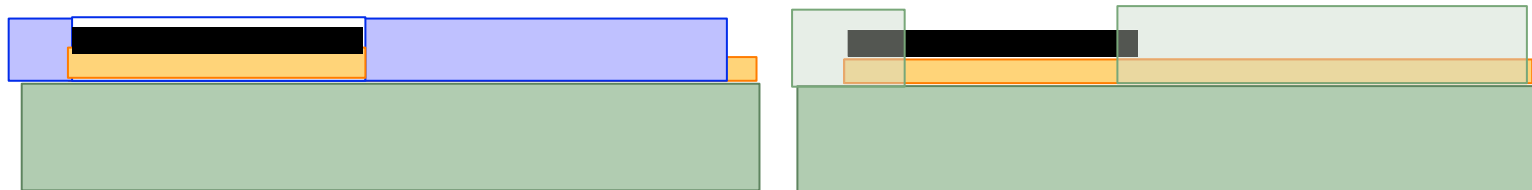
Flexible Electro-chemical Sensor

Flexible Strain Sensor



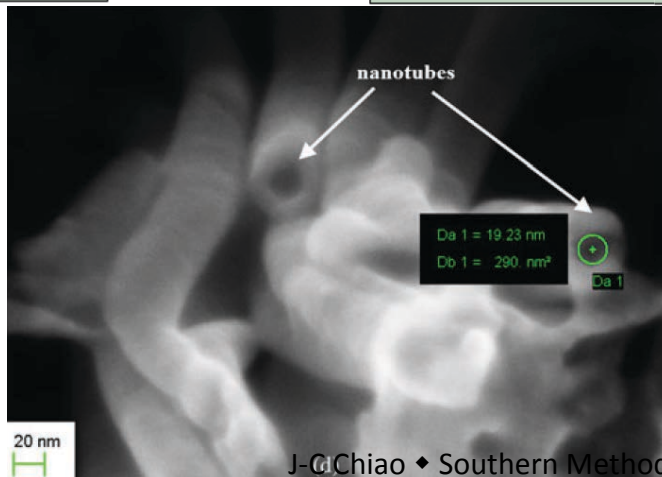
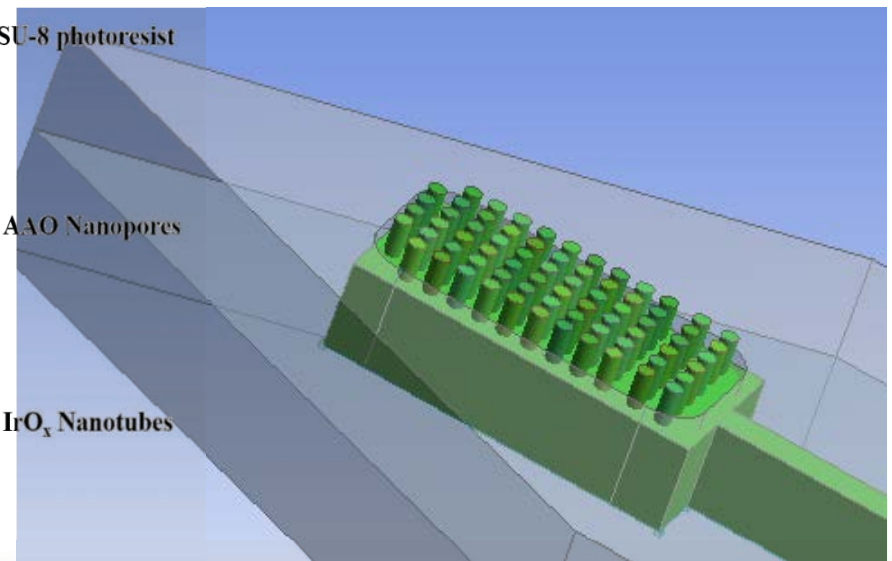
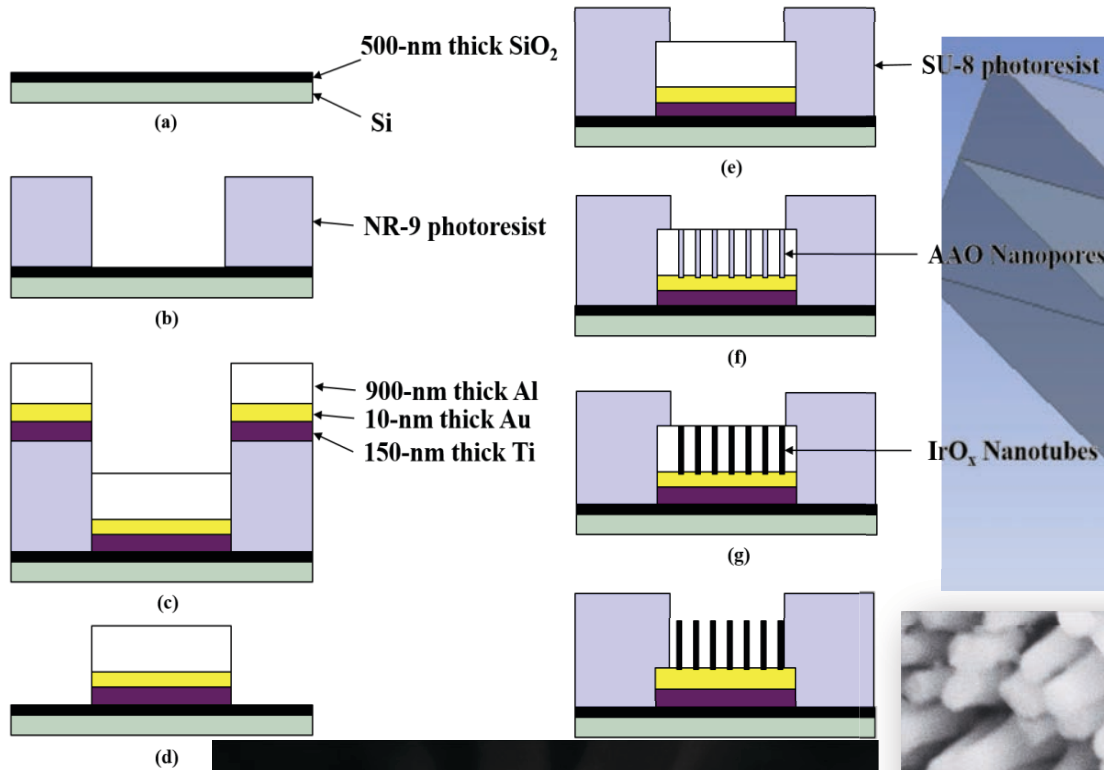
Sol-Gel IrOx Sensing Film

- Sol-gel solution was dip coated onto the sensing area
- Thermal treatment at 325° C oxidizes the IrCl_4 to IrO_x
- Multiple dipping to increase thickness
- Very low material and fabrication costs
- Fabrication areas are scalable
- Biocompatible
- Functionalization





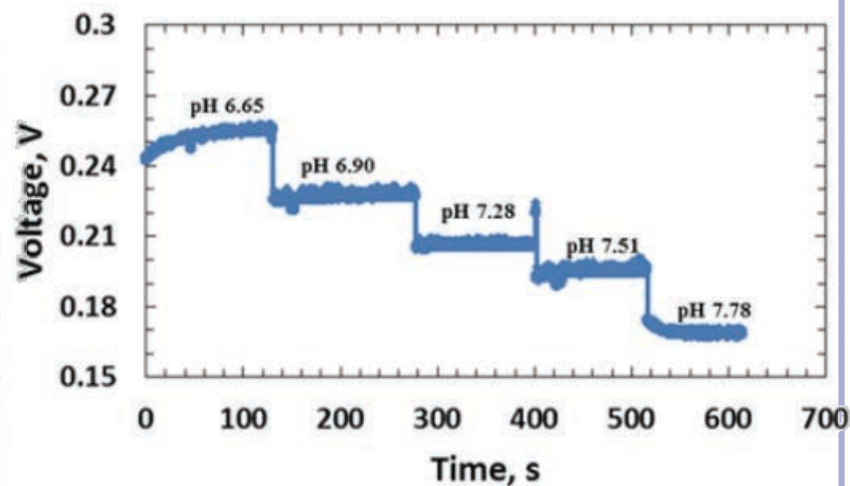
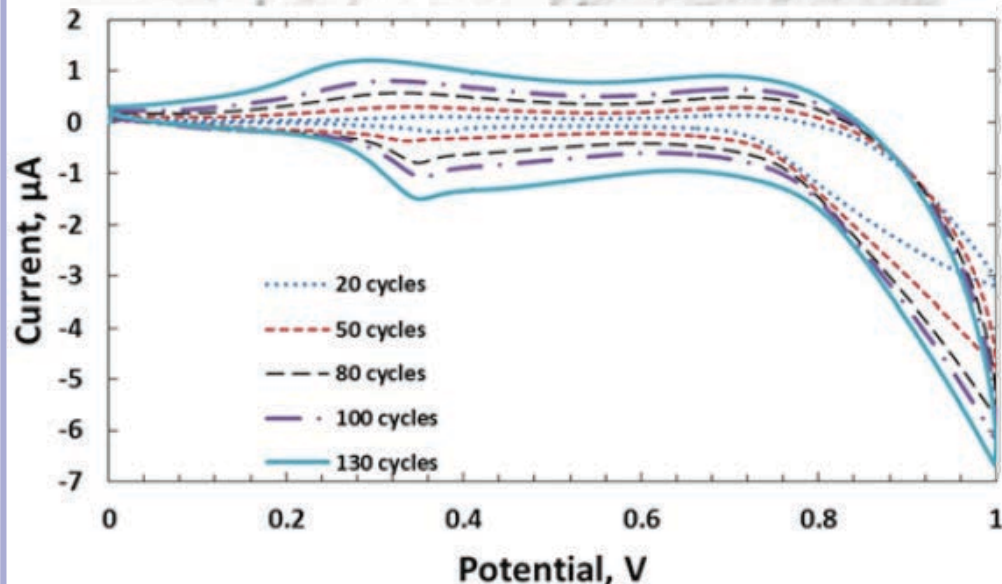
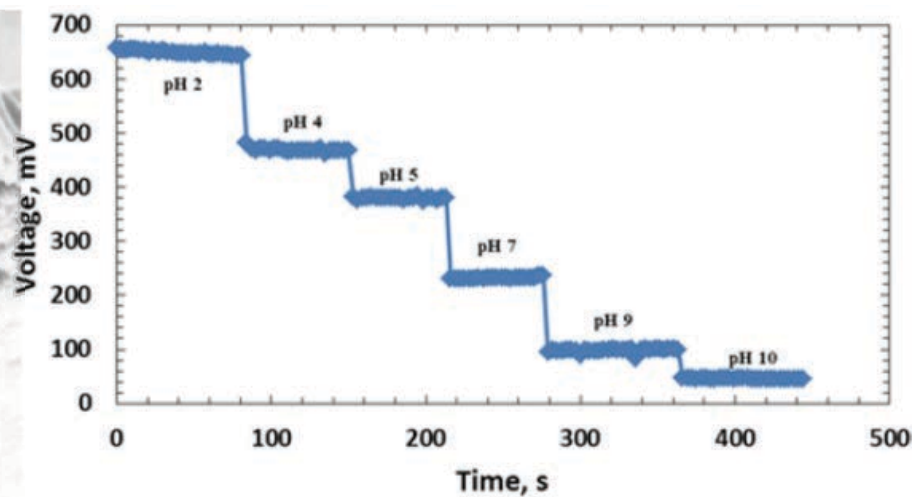
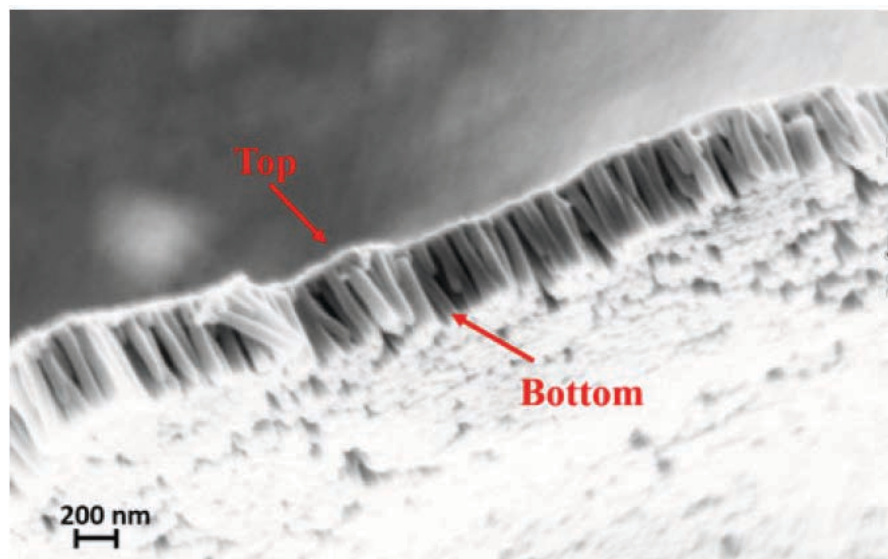
IrOx Nanorod Sensing Film



Nanorod Deposition

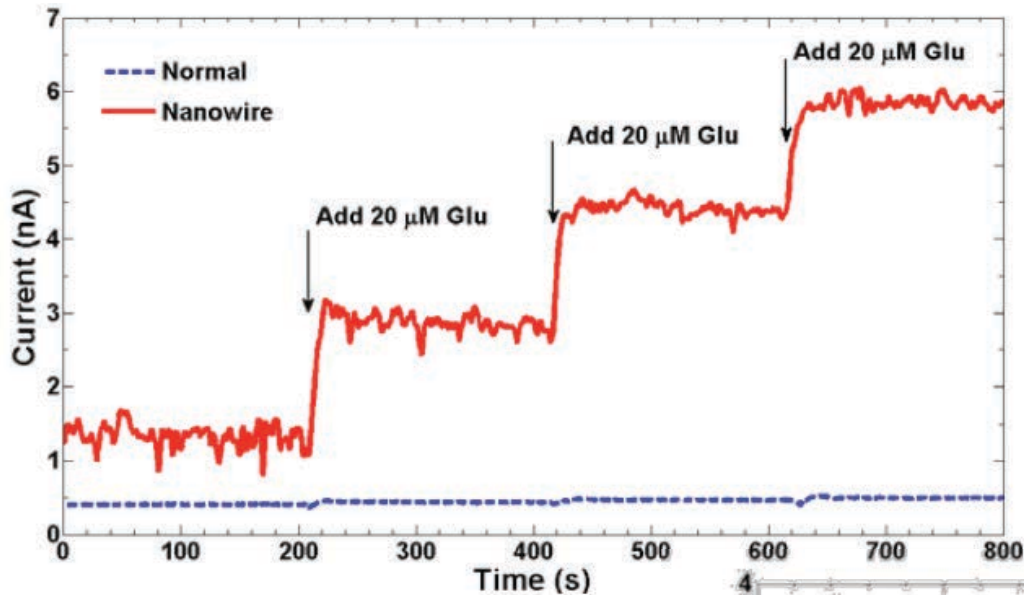


Sensing pH



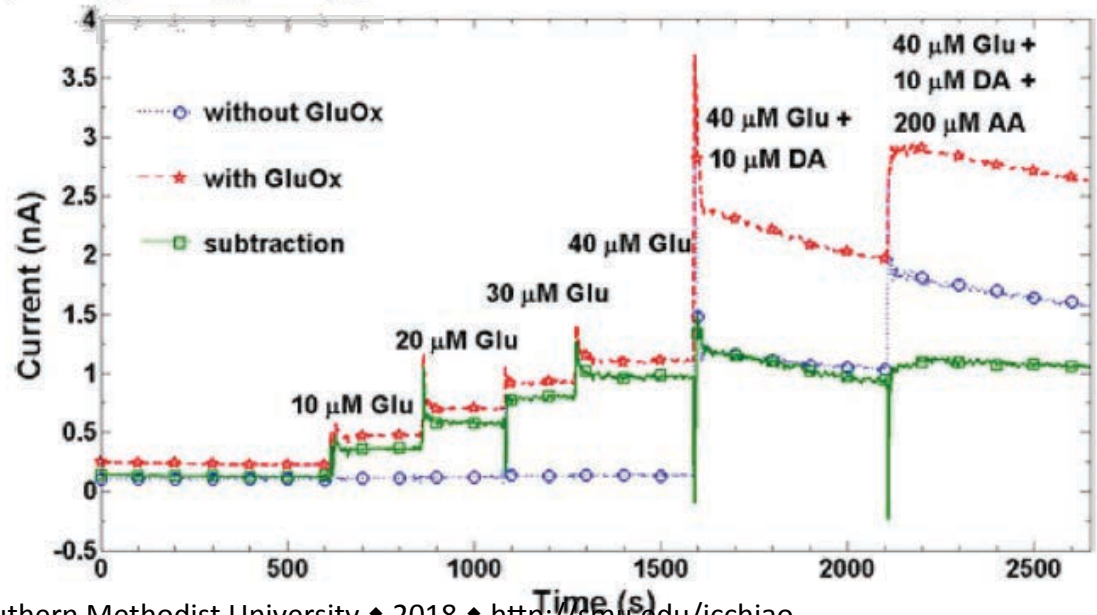
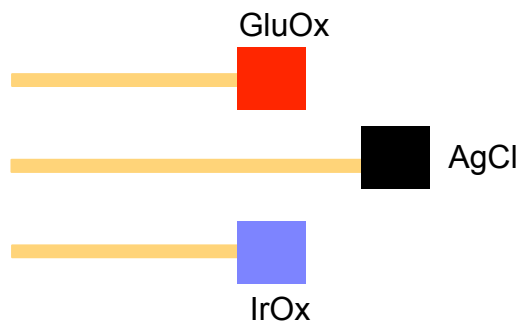


Nanorod Glutamate Sensor



Increase sensitivity

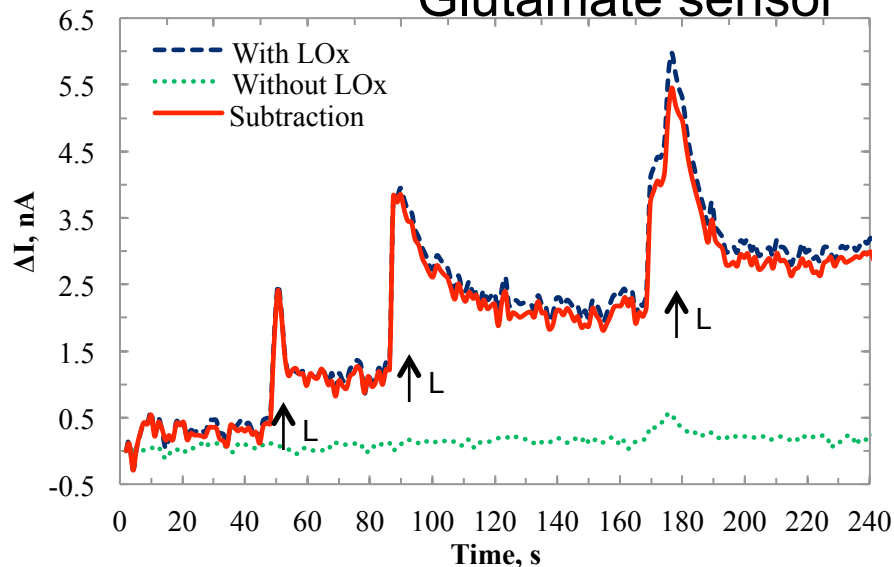
Self reference



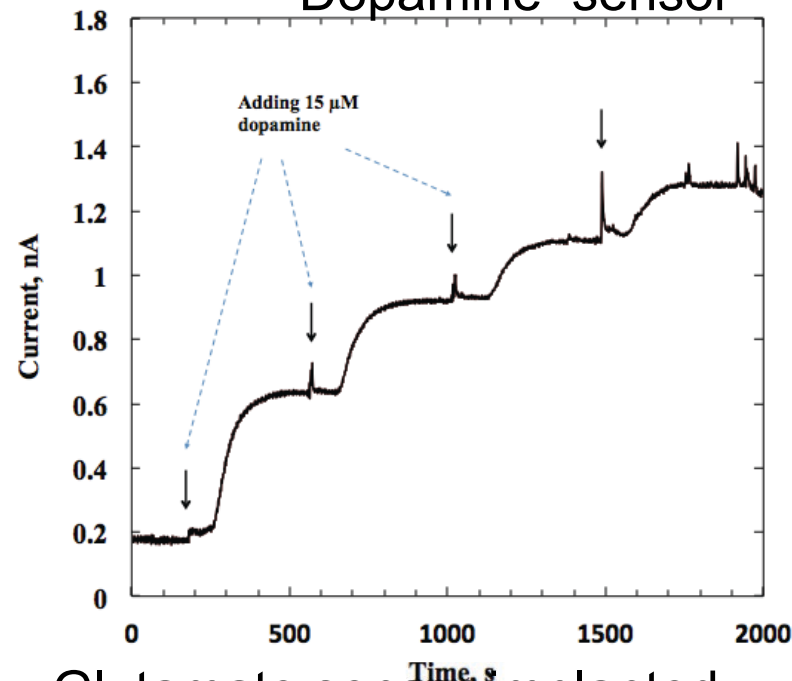
Biochemical Sensors



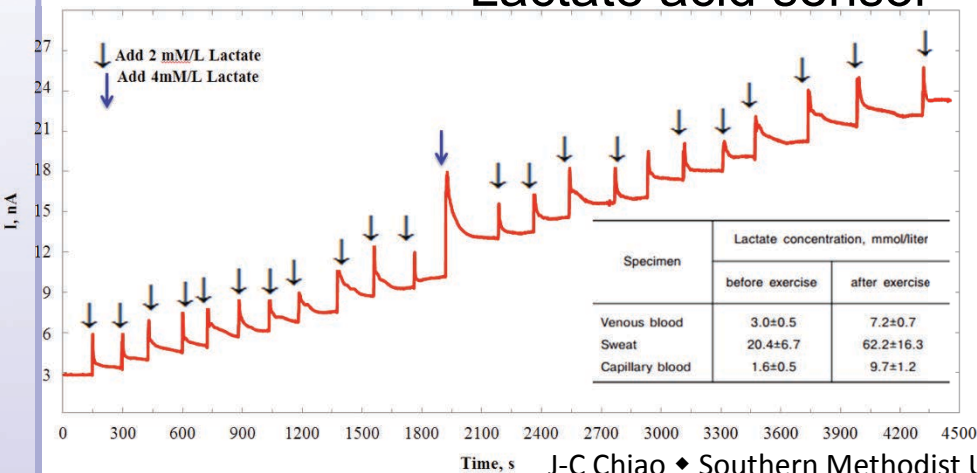
Glutamate sensor



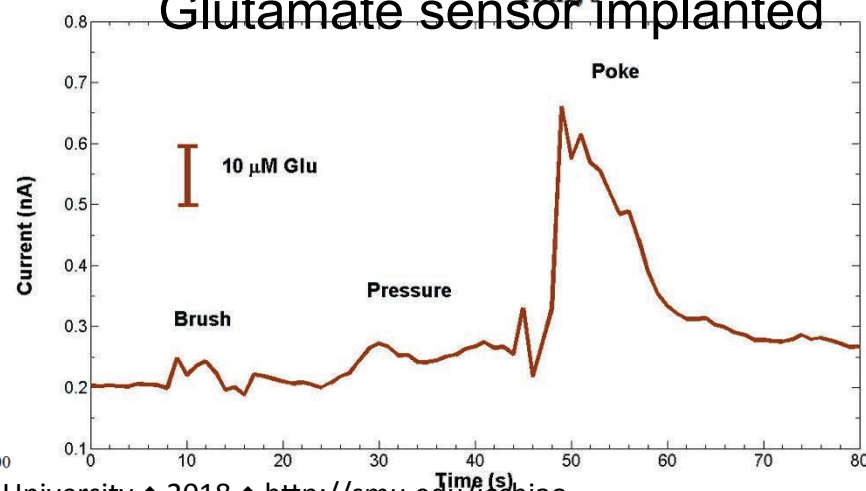
Dopamine sensor



Lactate acid sensor



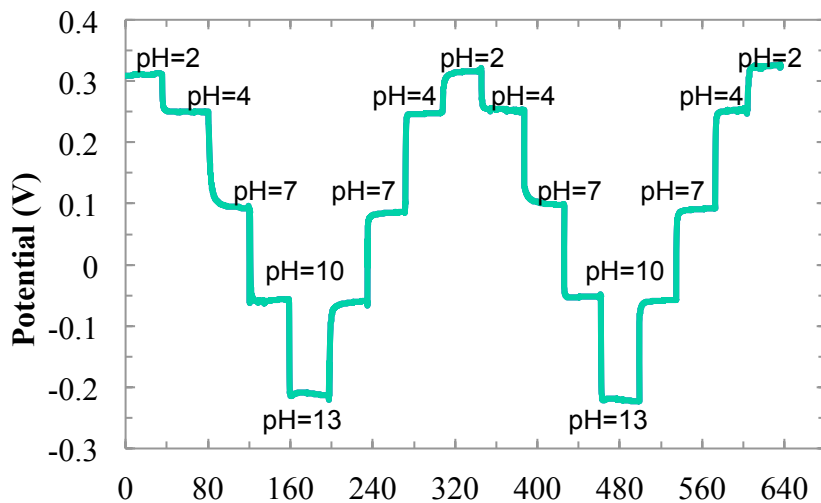
Glutamate sensor implanted



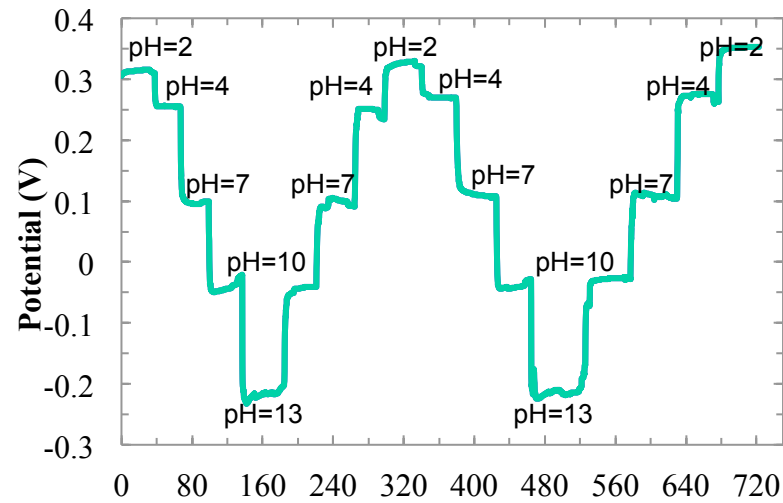
Ultra-Flexible Sensor



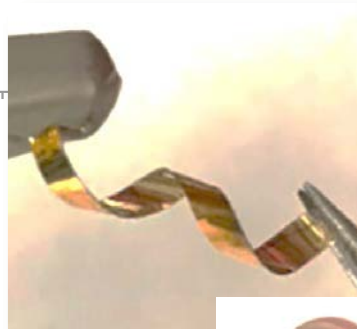
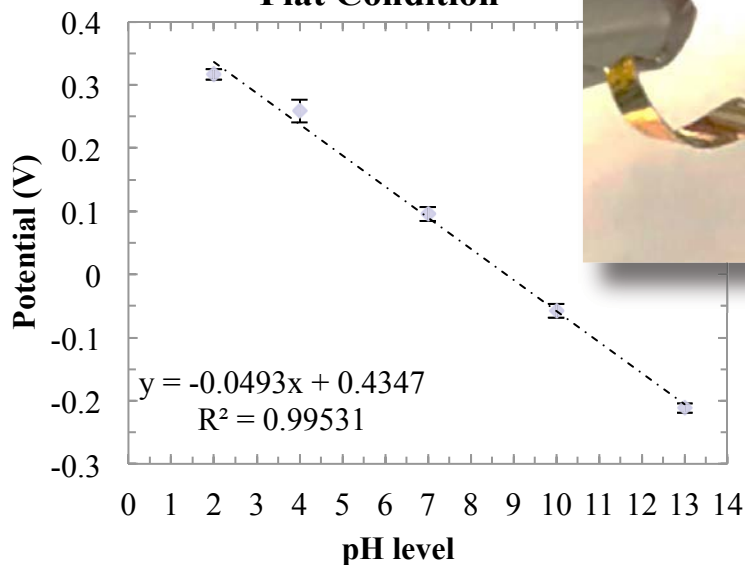
Flat Condition



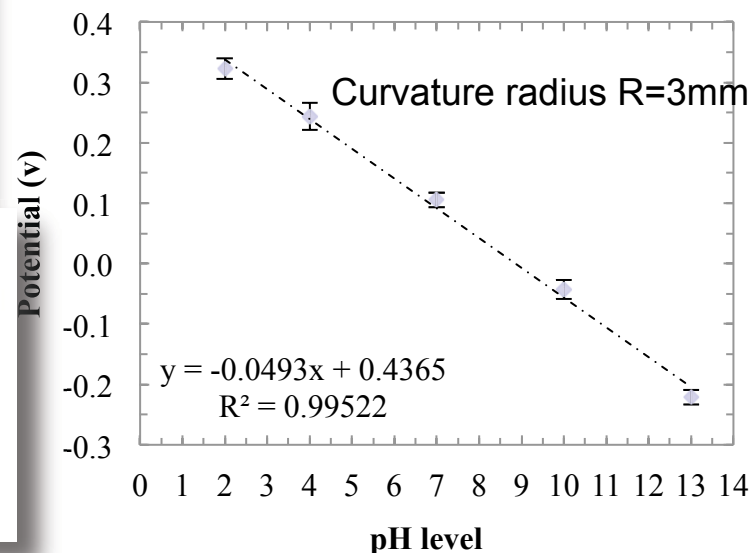
Deformed Condition



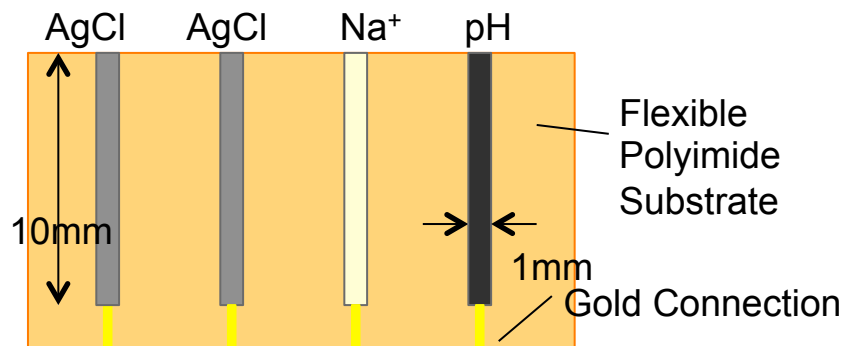
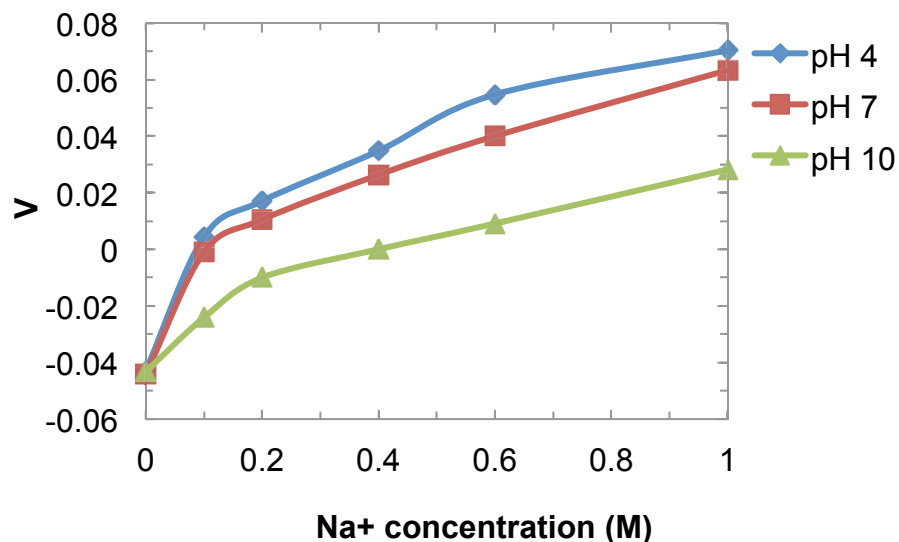
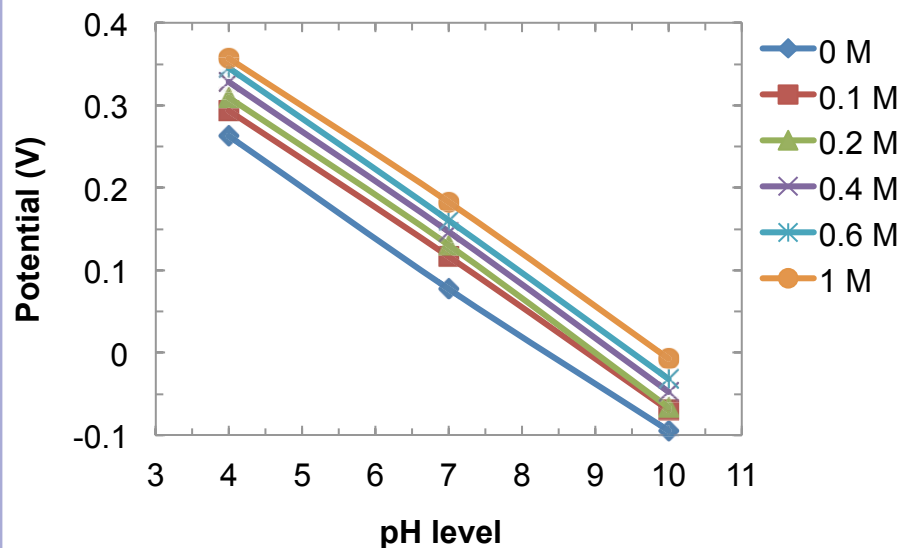
Flat Condition



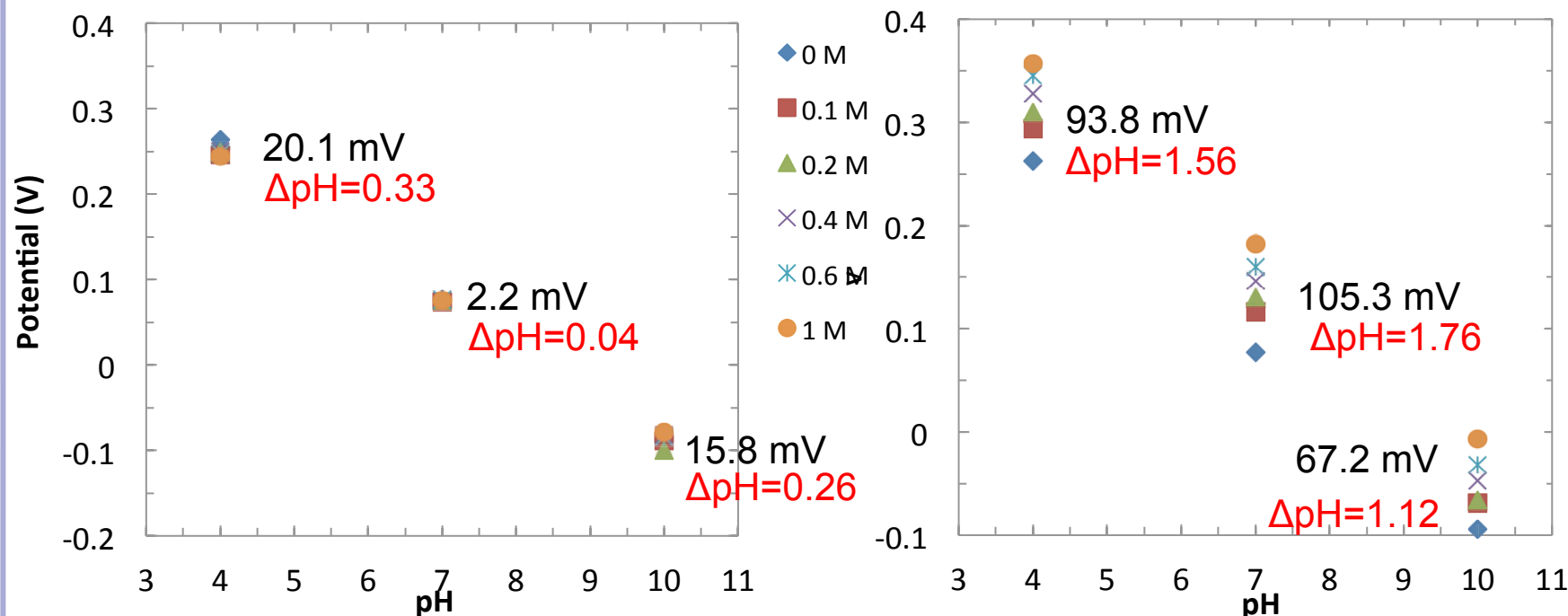
Deformed Condition



Integrated Sensor pH and Na⁺



Calibrated vs pH Sensors

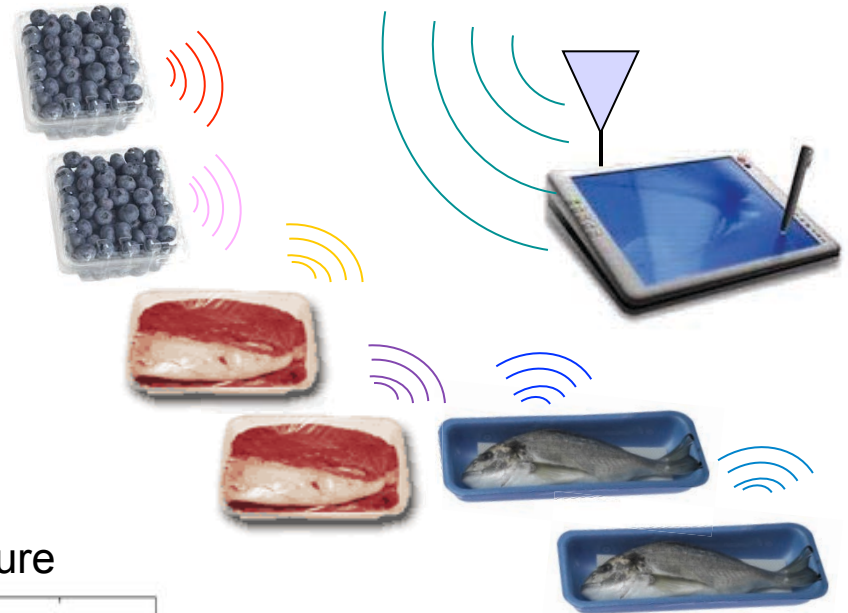


- Planar
- Flexible substrate
- Integrated
- No cleaning between tests

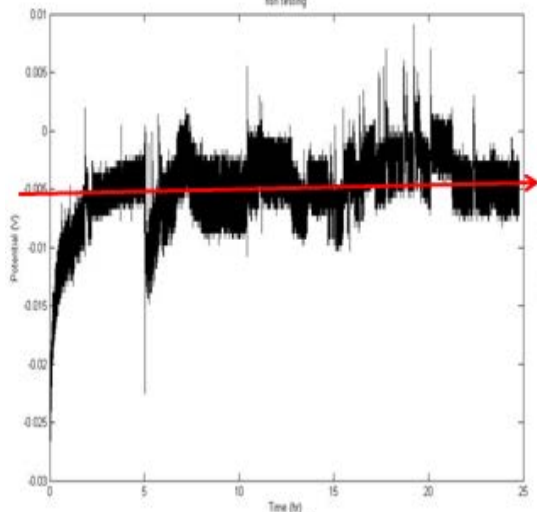
IoT Applications



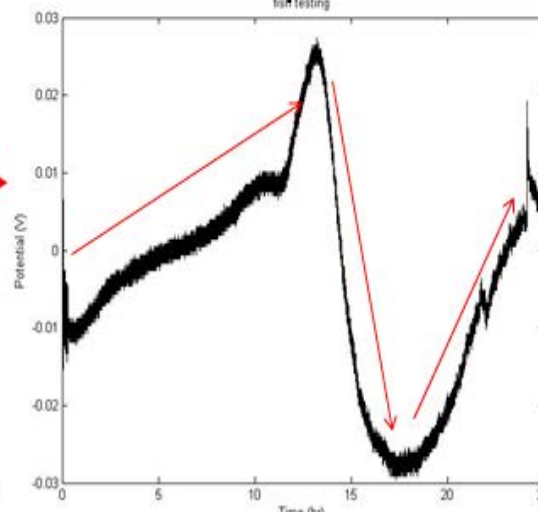
Produce quality remote monitoring and tracking



In freezer



In room temperature



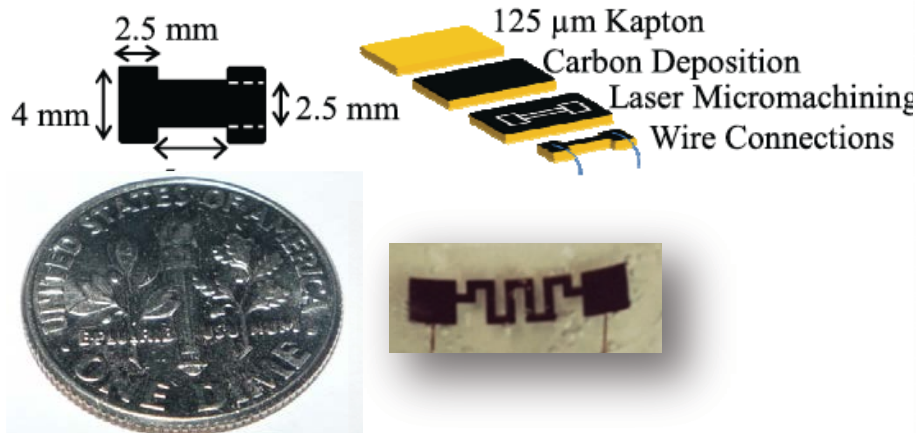


Sensors

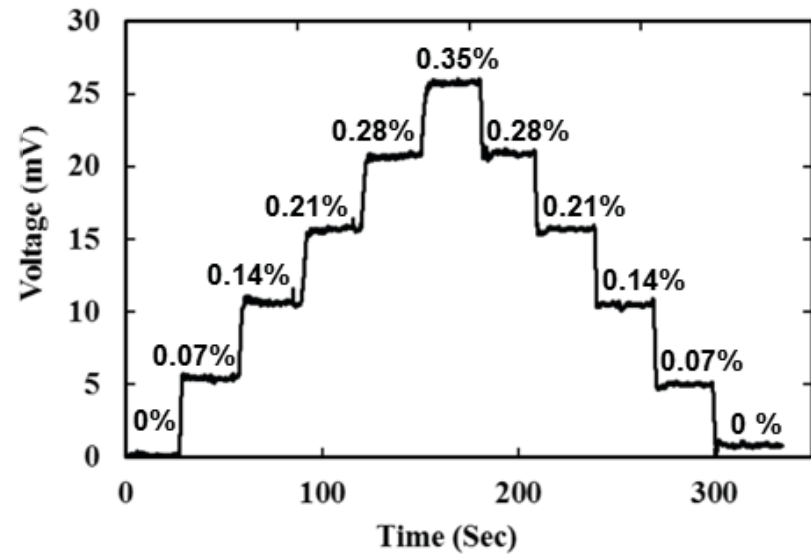
Flexible Electro-chemical Sensor

Flexible Strain Sensor

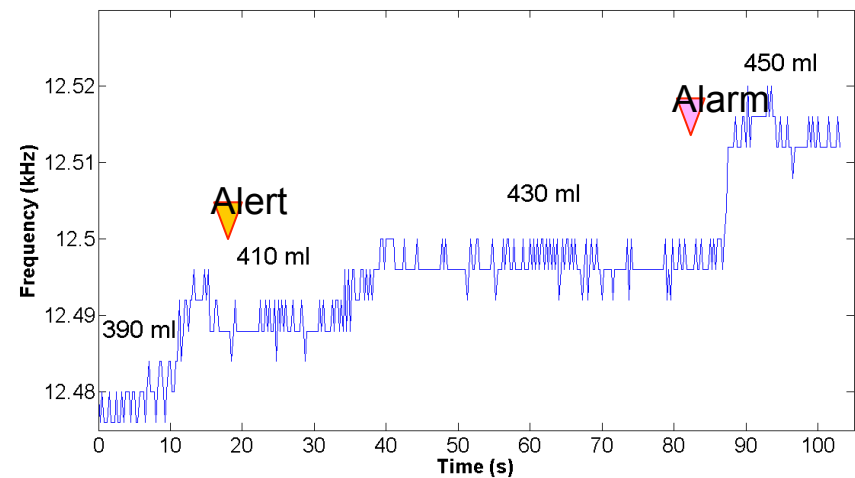
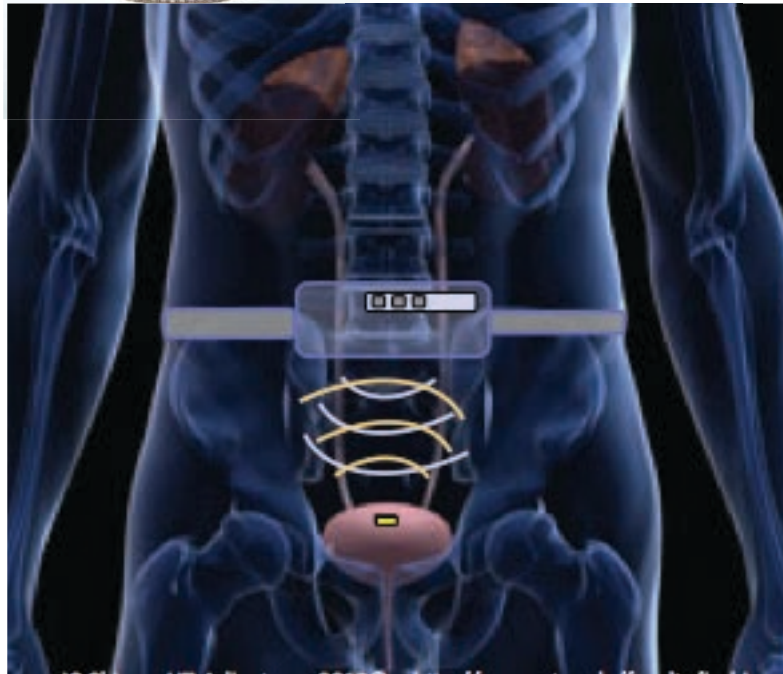
Carbon Strain Sensor



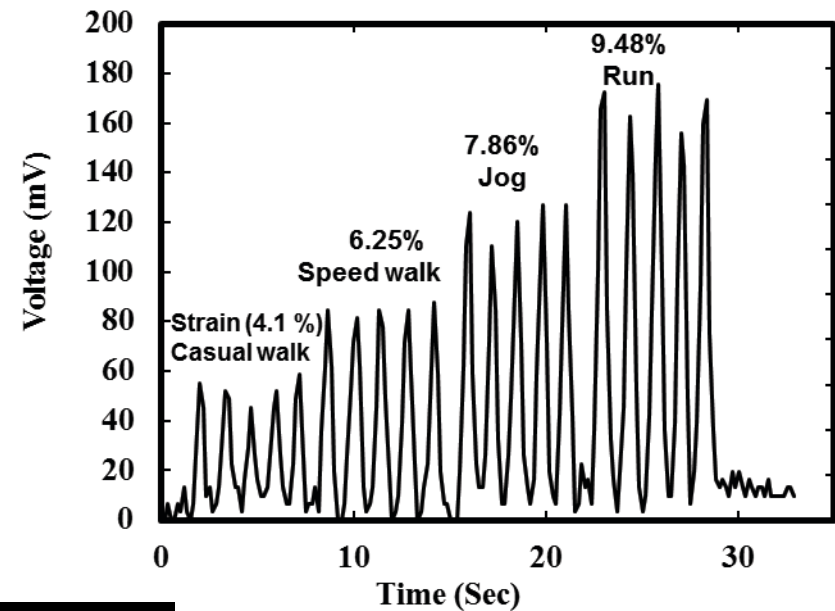
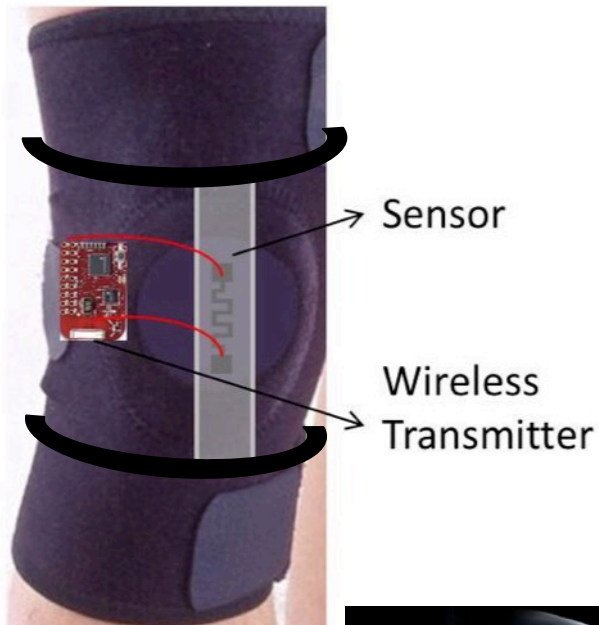
Strain for single strip



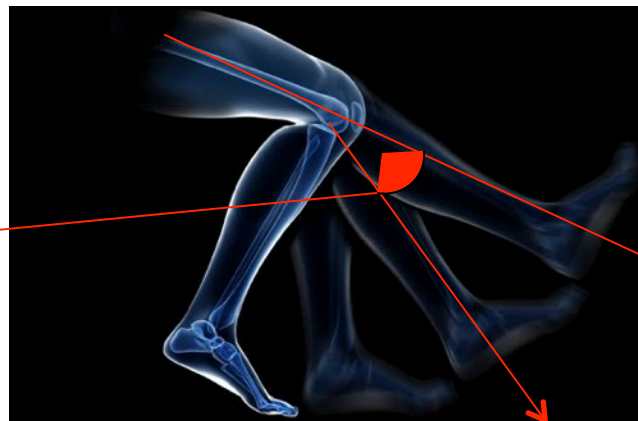
Detect bladder volume



Knee Joint Motion Detection



Flexing angle



Resting position

Flexed position

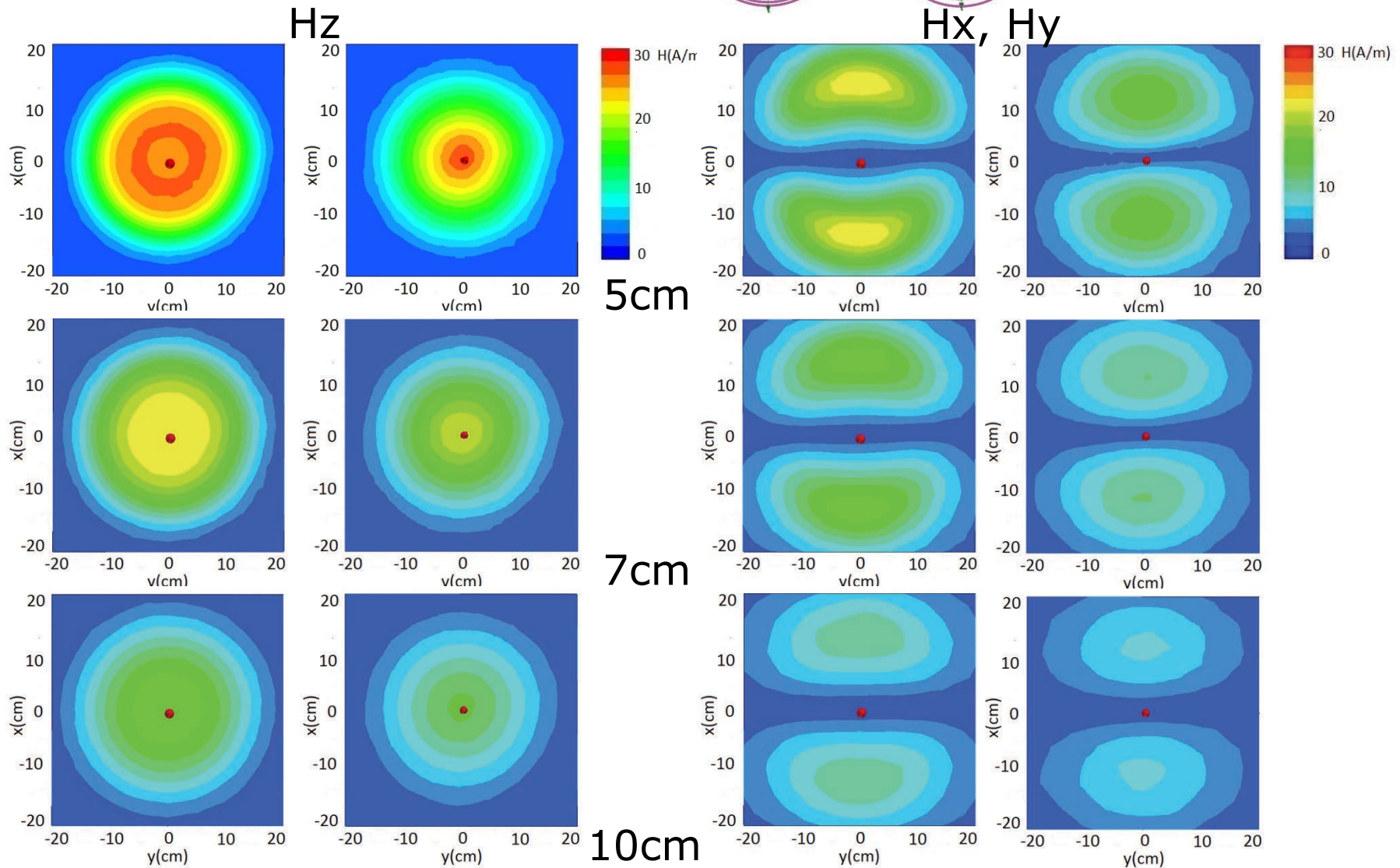
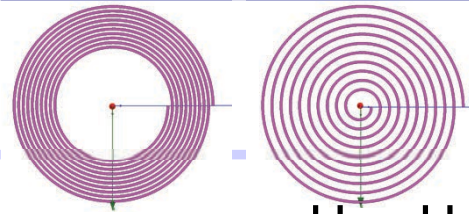


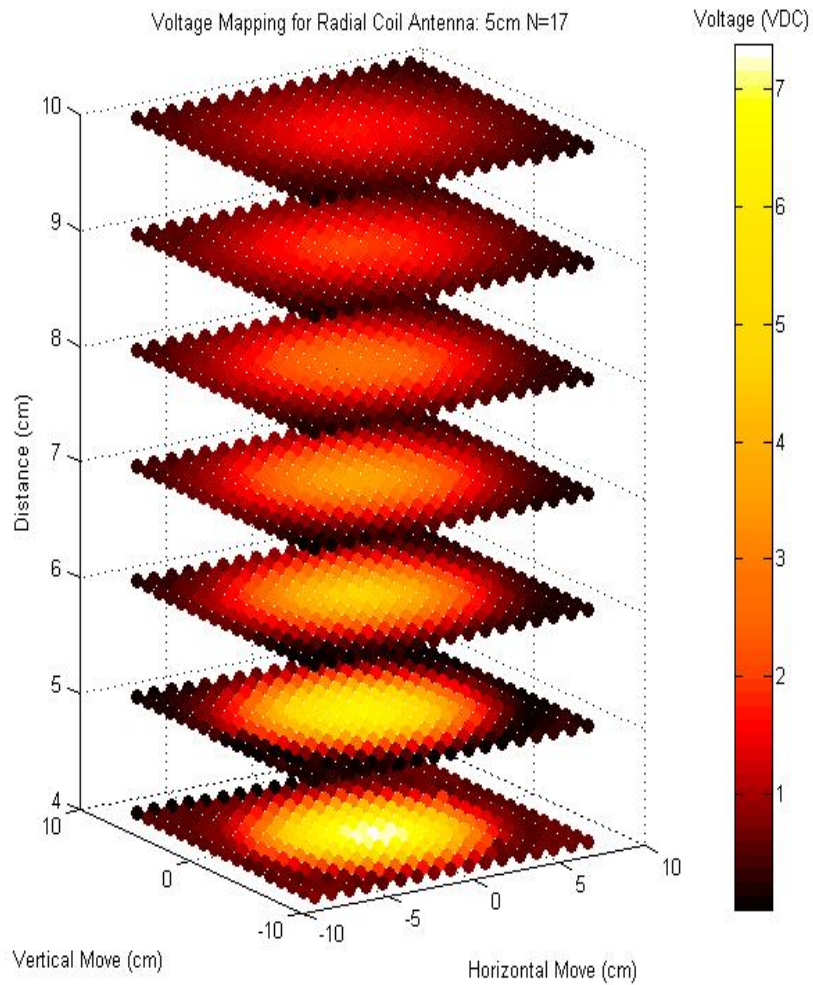
Wireless powering

Antenna designs

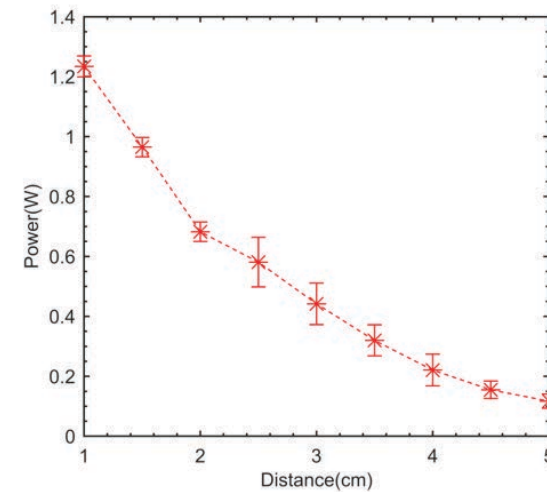
- Portable size
- Trade-off between distance and misalignment
- Tunable

Antenna Designs

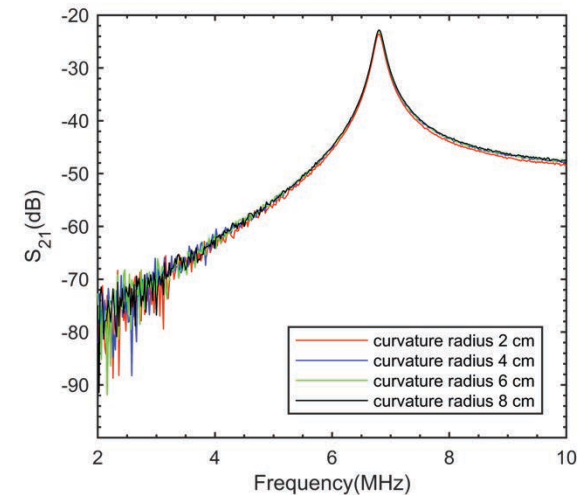




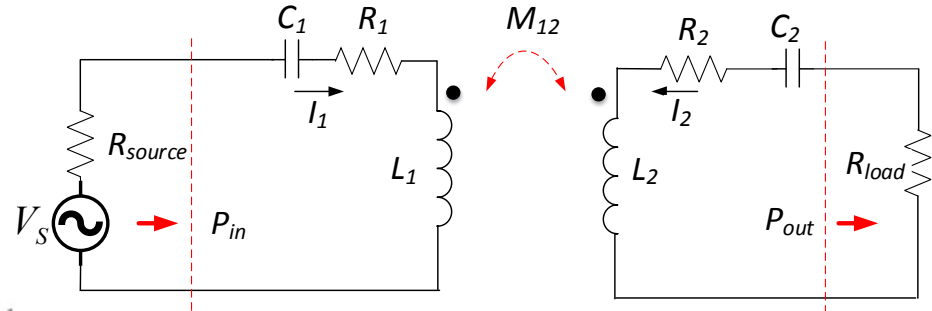
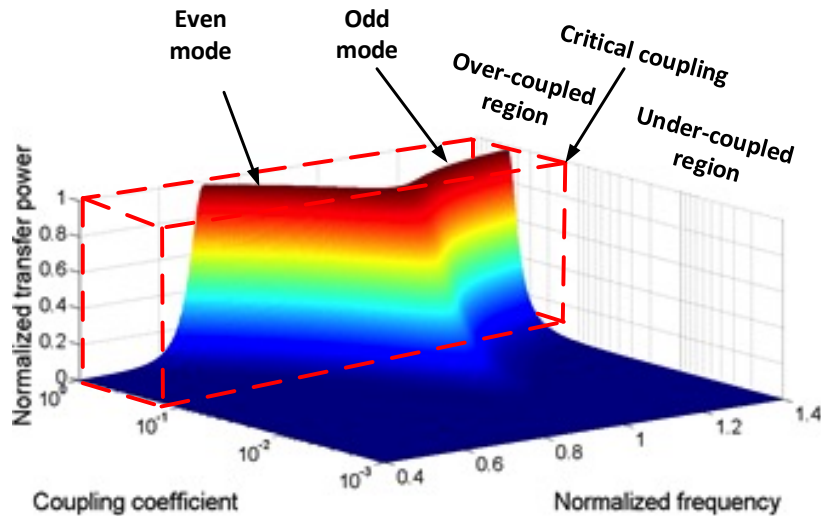
Power transferred with distance



Quality factor variations due to curvatures



Determining the Frequency Modes

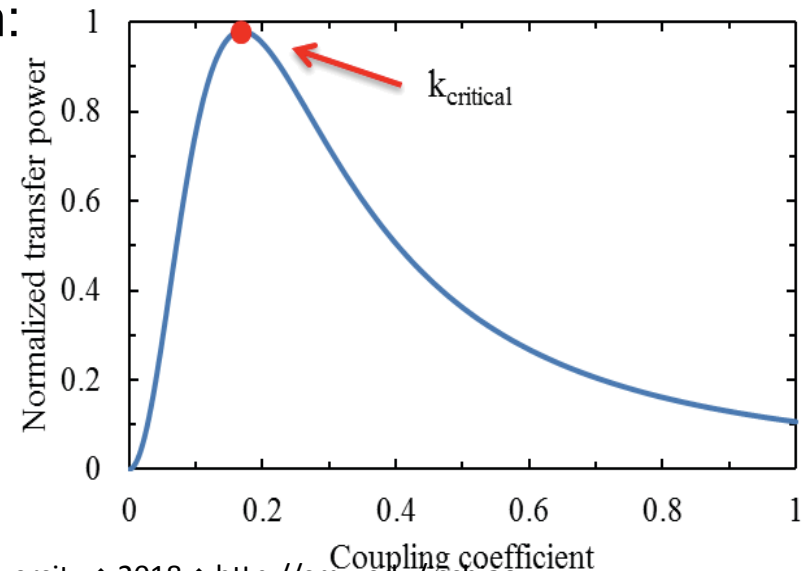


Impedance matrix under no excitation:

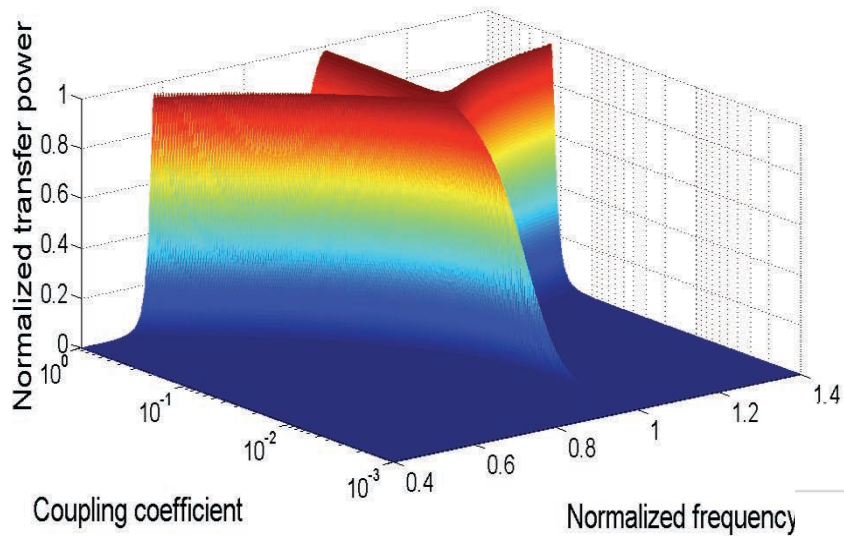
$$\begin{bmatrix} R_1 + j\omega L_1 + \frac{1}{j\omega C_1} & j\omega M_{12} \\ j\omega M_{12} & R_2 + j\omega L_2 + \frac{1}{j\omega C_2} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\omega = \frac{\omega_0}{\sqrt{1 \pm k_{12}}}$$

Even and Odd Modes



Experimental validation for MIMO 2x2

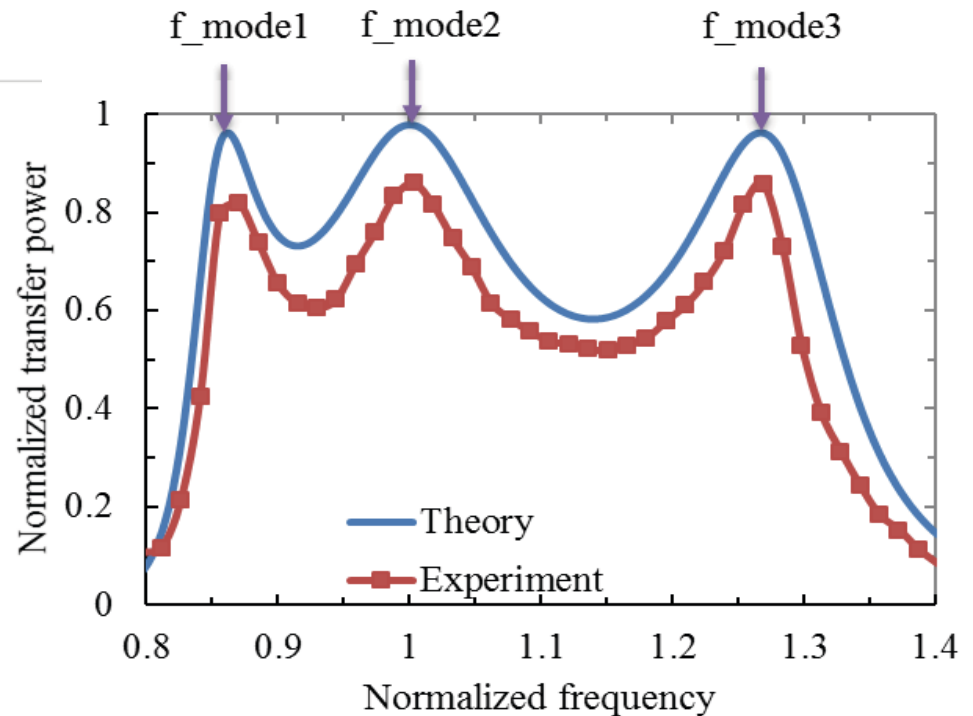


$k = 20\%$

$$F_{\text{mode1}} = 0.86$$

$$F_{\text{mode2}} = 1$$

$$F_{\text{mode3}} = 1.25$$



Batteryless Wireless Sensors



Features

- Low power consumption
- Electrical interface
- RFID compatible
- Flexible, deformable, bendable
- Low cost fabrication method
- Wearable and implantable

Sensors

- Bio-electro-chemical sensors
 - pH, Na⁺, lactate, glutamate sensors
- Amorphous carbon strain sensors
- Nanorod surface modification

Wireless power transfer

- Batteryless and wireless

Batteryless Wireless Sensors



Beside medical applications

- Large-scale soil moisture monitoring
- Produce logistics
- Livestock monitoring
- Precision manufacturing
- Cosmetics
- Fitness performance
- Prosthetic feedback



<http://smu.edu/jcchiao/>