

Bridging the Gap Between Technological Advancement and Manufacturability: Development of Solderable Stretchable Sensing Systems

By

Yun Soung Kim

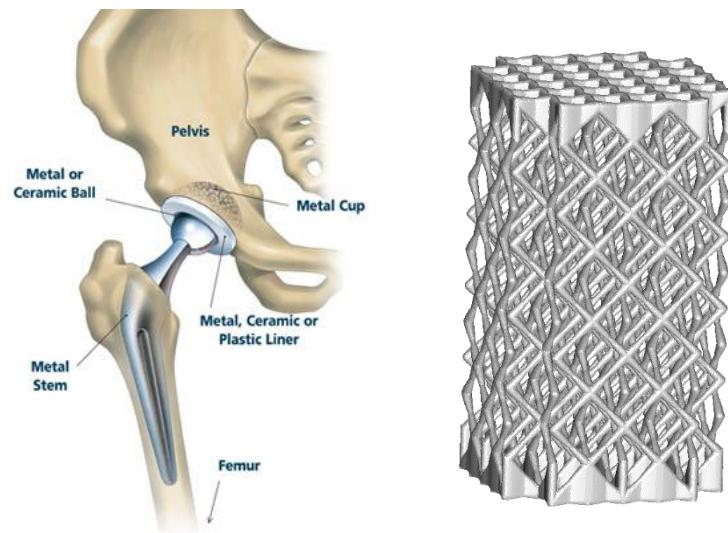
Overview

- About Me
- Motivation
- Development of Solderable Stretchable Systems
- Respiration Sensing Using Solderable Stretchable Sensing System (S4)
- Wireless S4
- Wireless S4 with an Integrated Stretchable Antenna
- Next Steps & Conclusion

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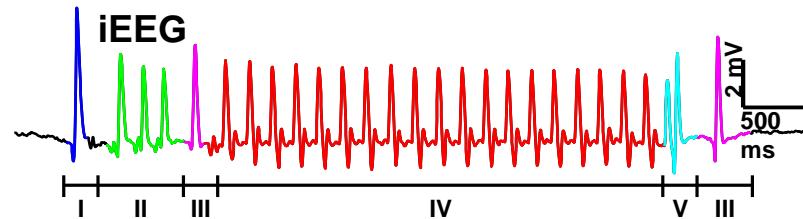
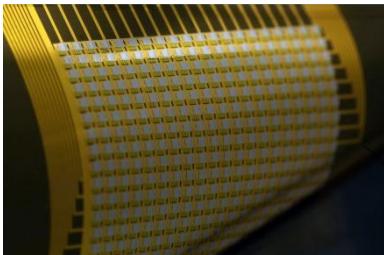
About Me



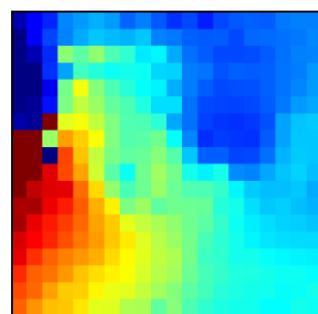
UIUC, B.S.
Materials Science
and Engineering

About Me

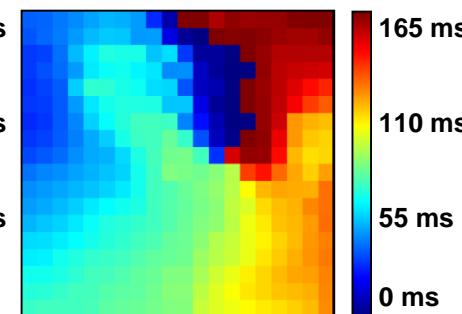
High density neural mapping devices



II Clockwise spiral delay map



IV Counterclockwise spiral delay map

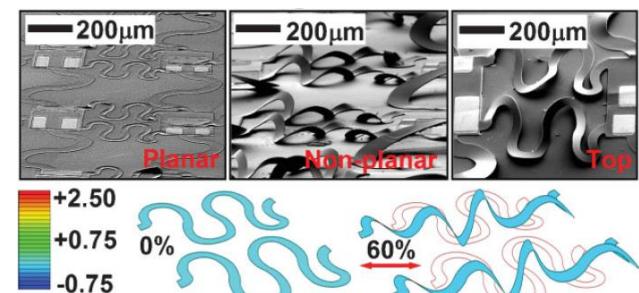
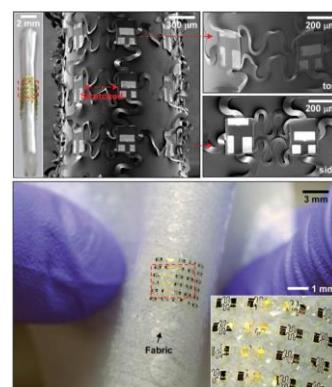
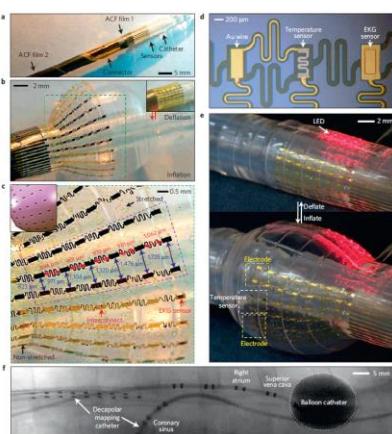
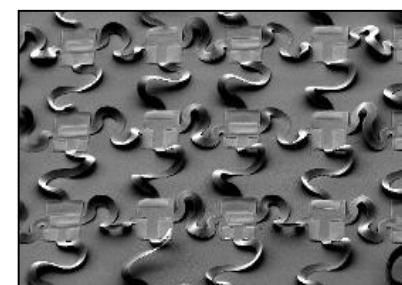
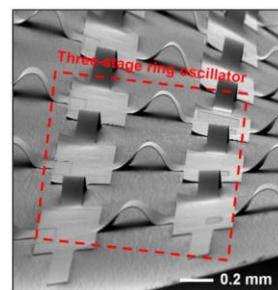
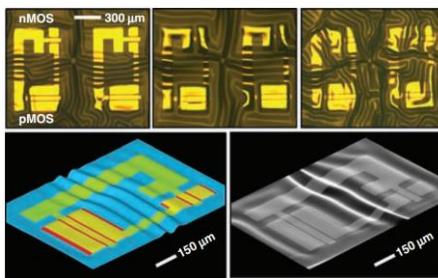


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About Me



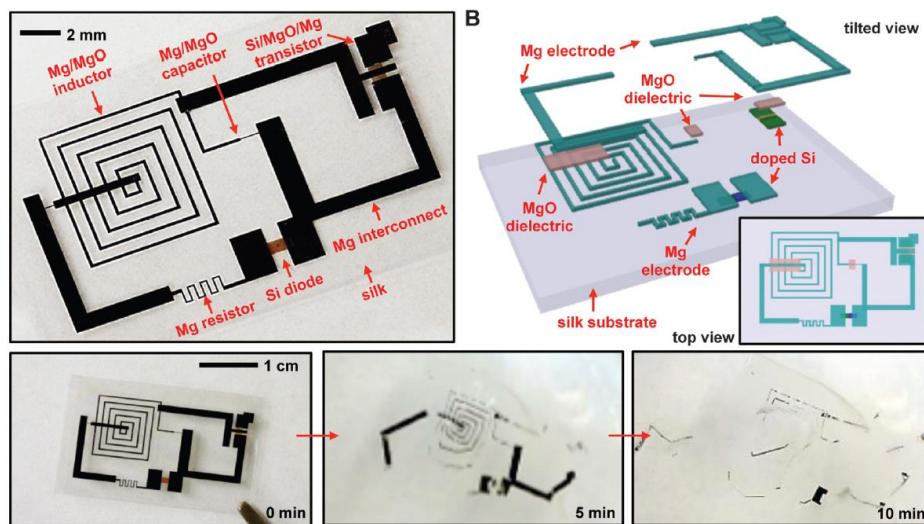
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About Me

Dissolvable (transient) electronics



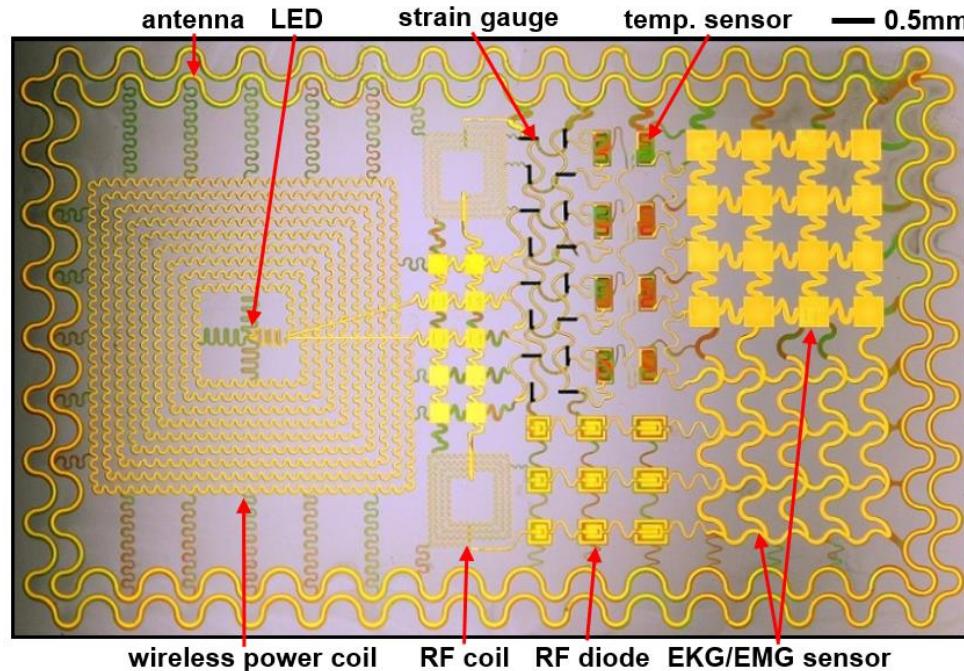
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Epidermal electronics

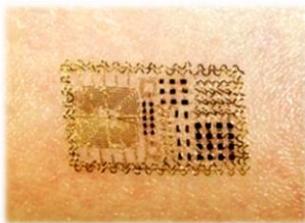


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Todd Coleman John Rogers

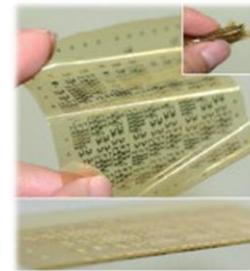
Motivation



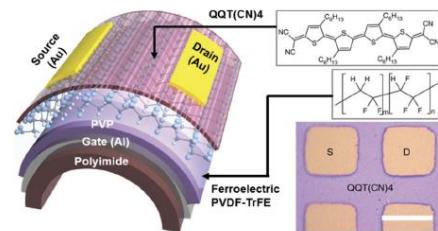
Tattoo electronics
Kim *et al.*



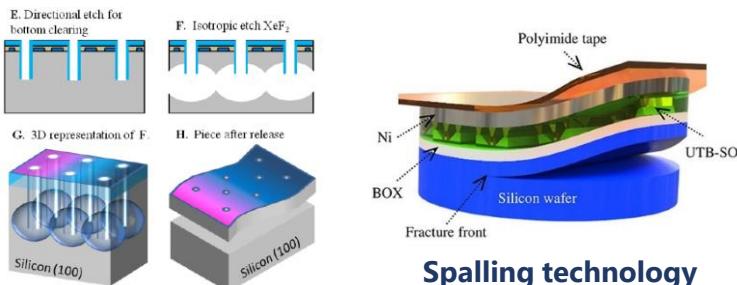
Microneedles
Kim *et al.*



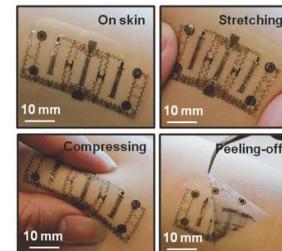
Organic IC
Someya *et al.*



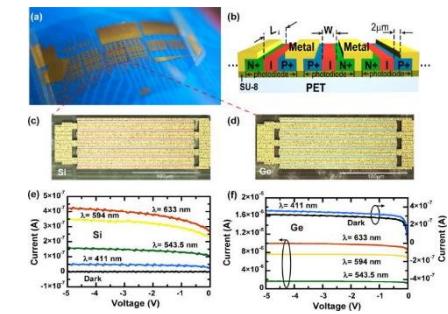
Organic memory
Kim *et al.*



Thin/porous Si electronics
Rojas *et al.*

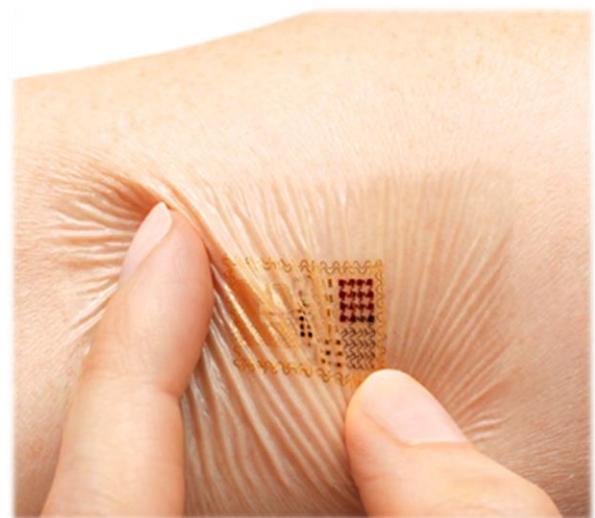
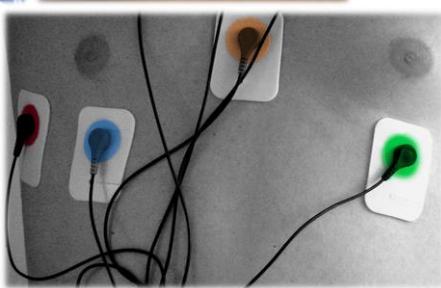


Epidermal stimulation
Xu *et al.*



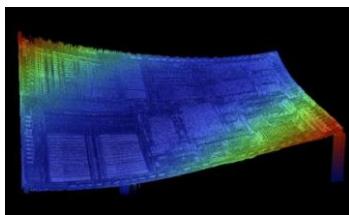
Single-crystalline
Dang *et al.*

Motivation

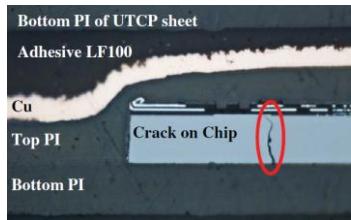


Motivation

Internal stress & fragility

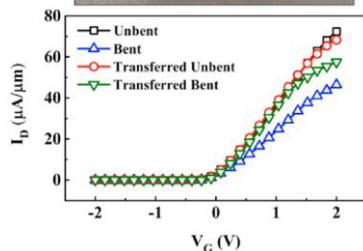
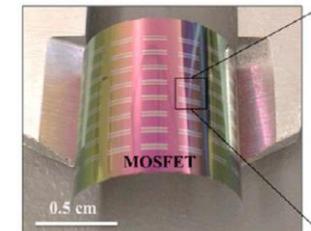


Sterken *et al.*

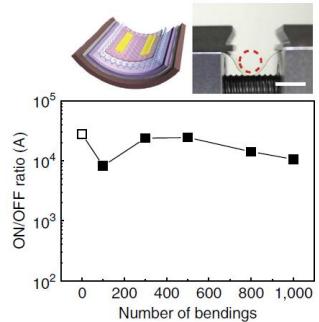


Priyabardini *et al.*

Robustness in bending

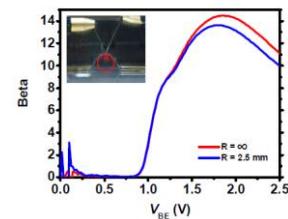
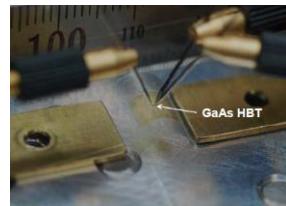


Rojas *et al.*

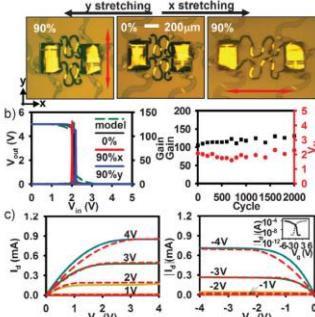


Kim *et al.*

Consistency in aggregate function

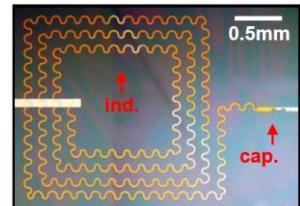


Jung *et al.*

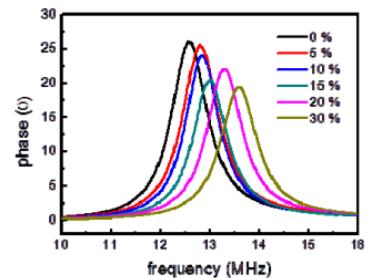


Kim *et al.*

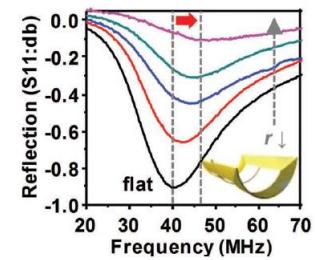
High frequency properties



Kim *et al.*

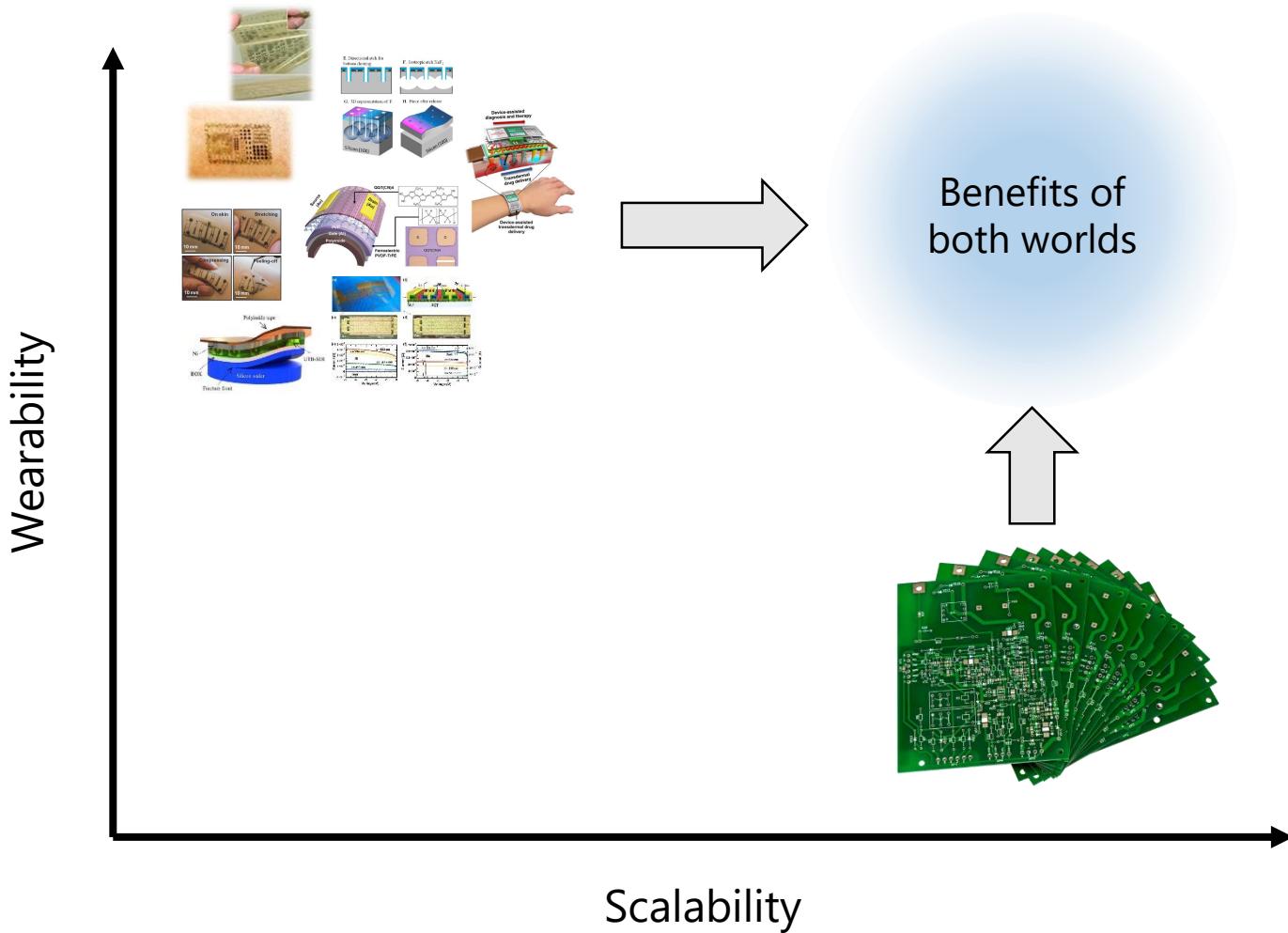


Paik *et al.*

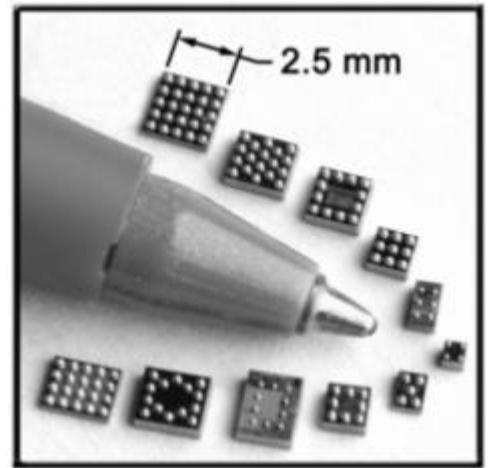
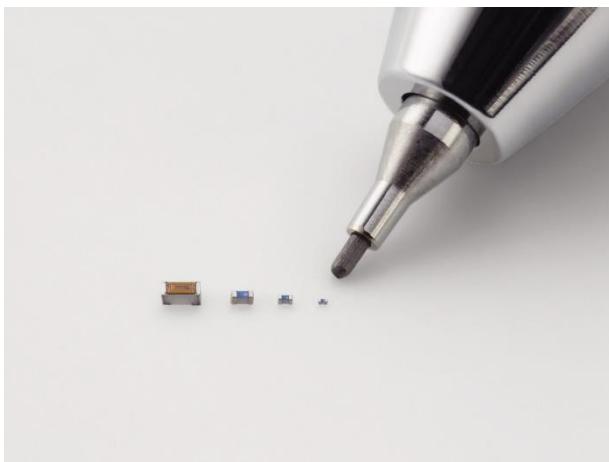


Kim *et al.*

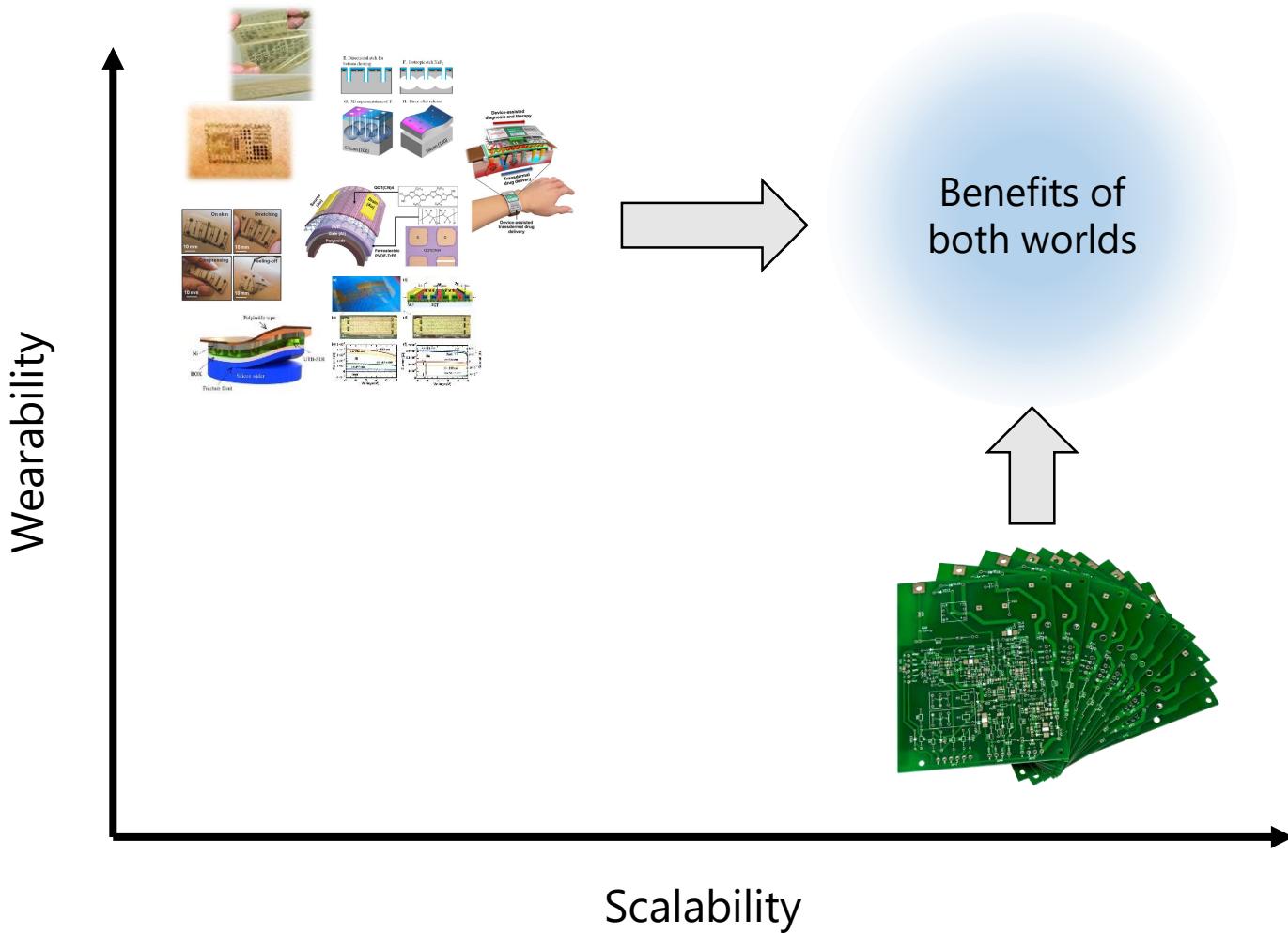
Motivation



Motivation



Motivation



Motivation

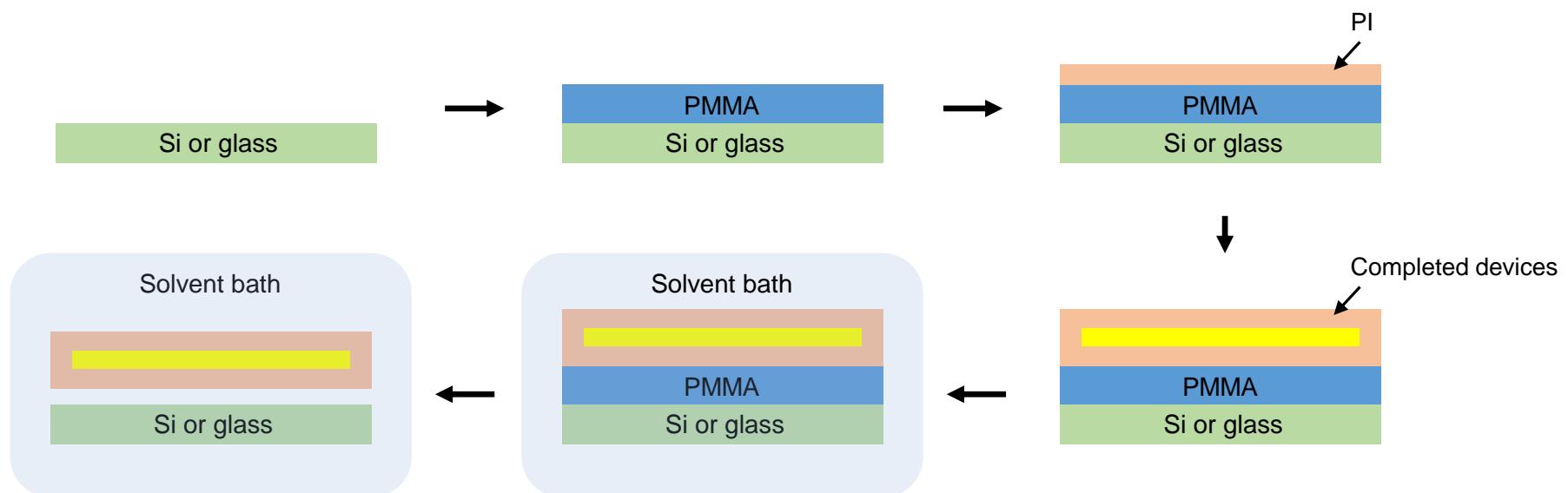
- Develop a platform that:
 1. Is **Stretchable** and **Comfortable** to wear
 2. Provides **intimate contact** with Skin
 3. Compatible with **surface mount technology**
 4. Is feasible to manufacture in **large scale**

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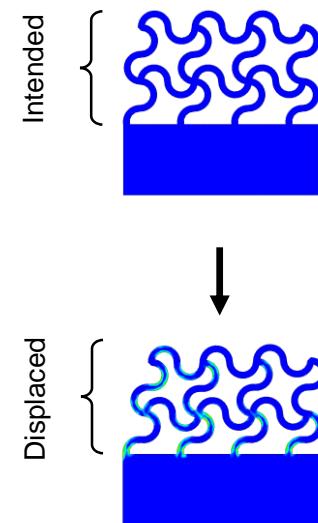
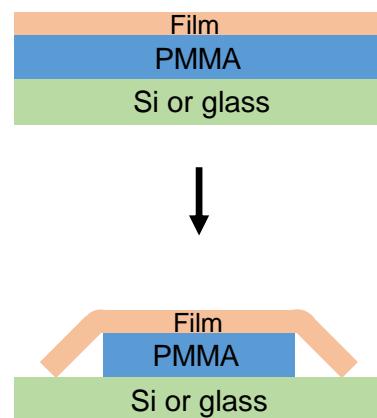
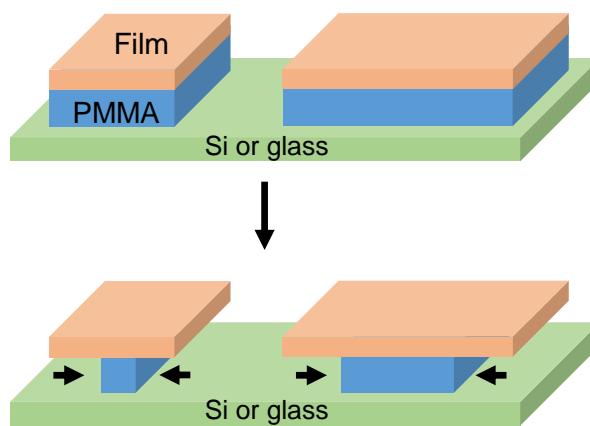
Handling and Transfer of Thin-film Electronics

Use of a sacrificial layer



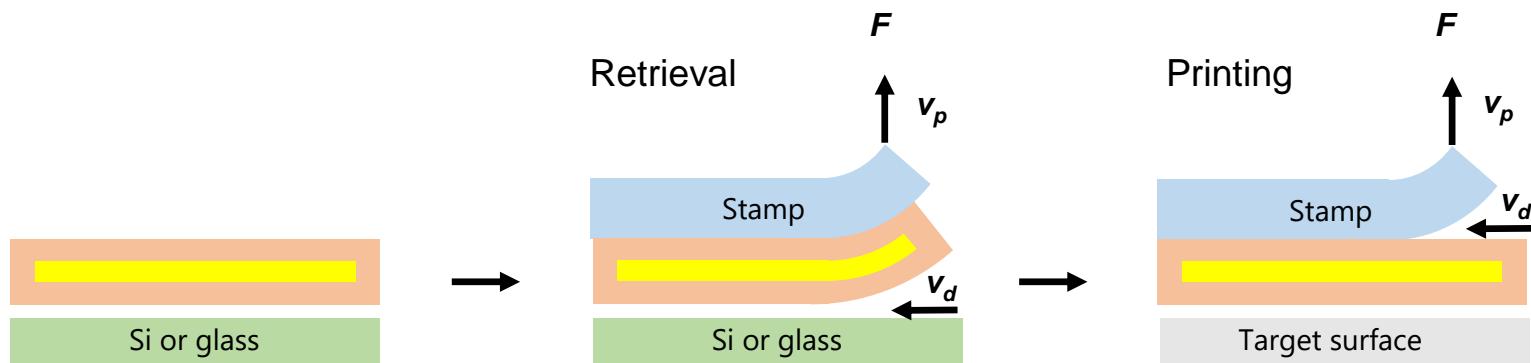
Handling and Transfer of Thin-film Electronics

Drawbacks of sacrificial layer

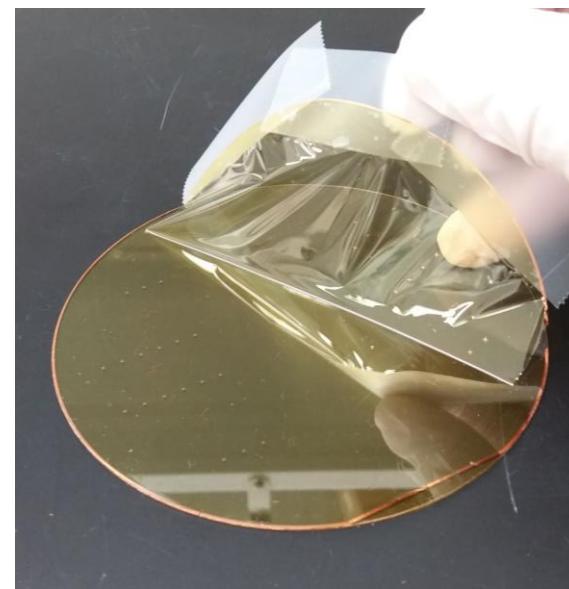
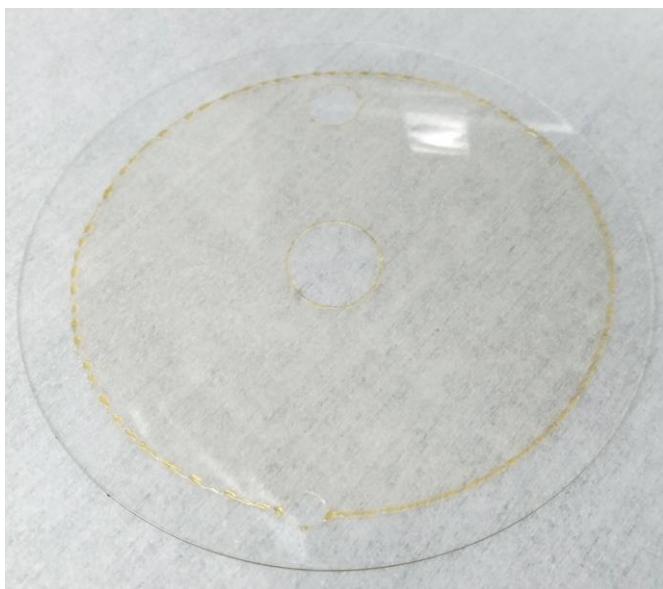


Handling and Transfer of Thin-film Electronics

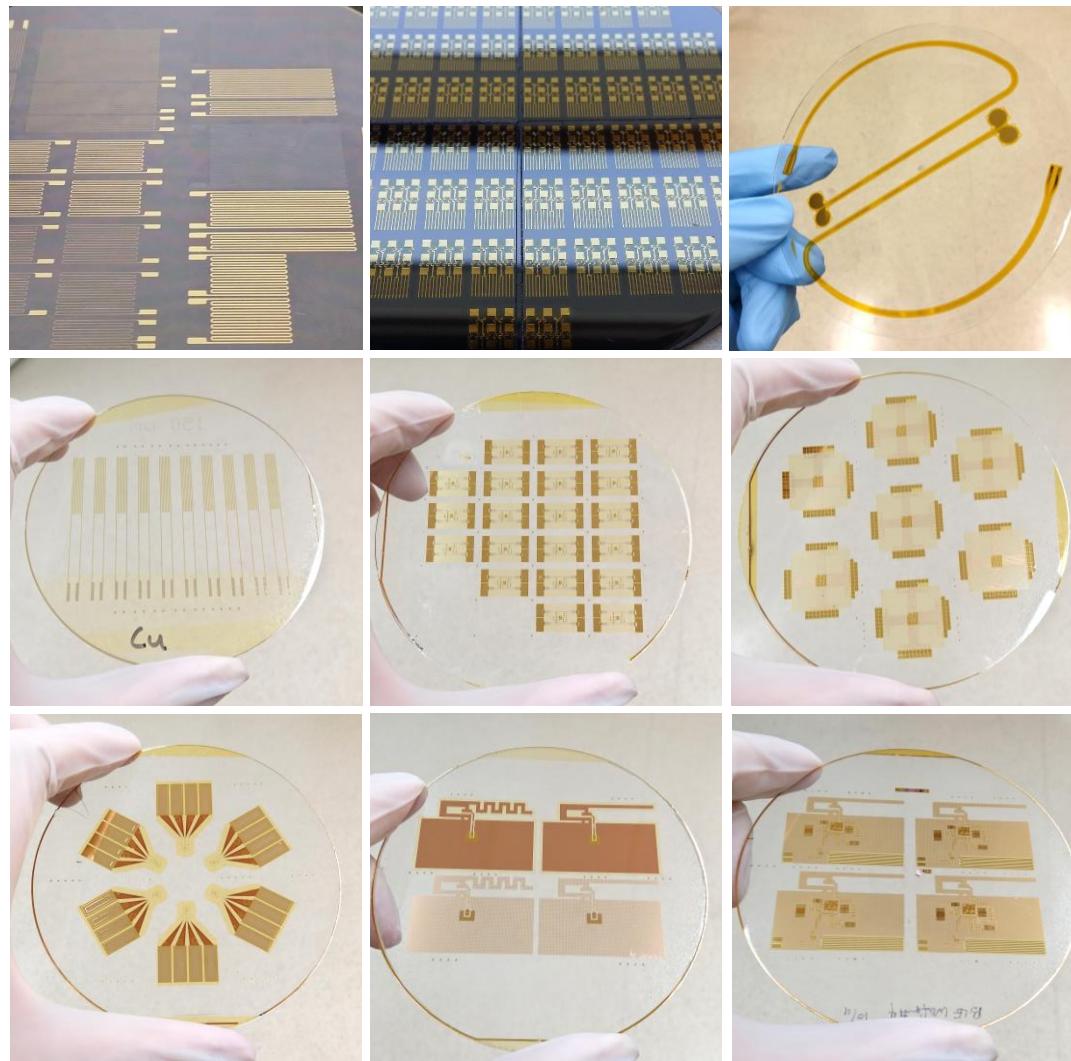
Drawbacks of sacrificial layer



Microfabrication on PDMS-coated Substrates

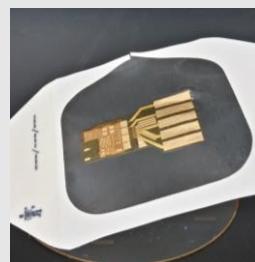
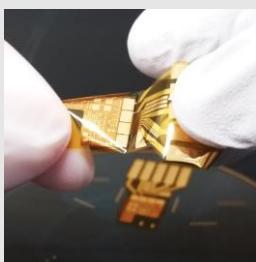
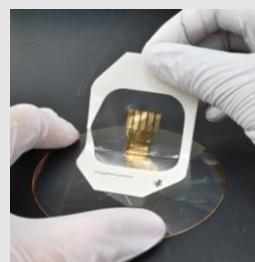
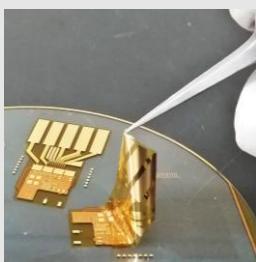


Microfabrication on PDMS-coated Substrates



Release of Devices from PDMS-coated Wafers

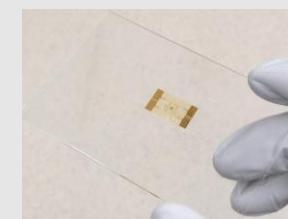
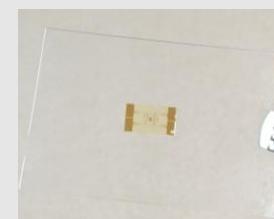
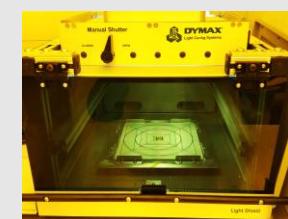
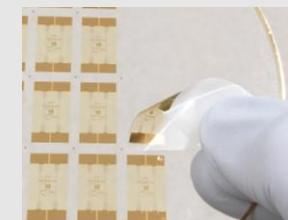
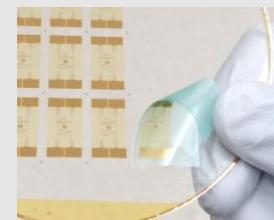
One-step



Free-standing

Adhesive-integrated

Two-step



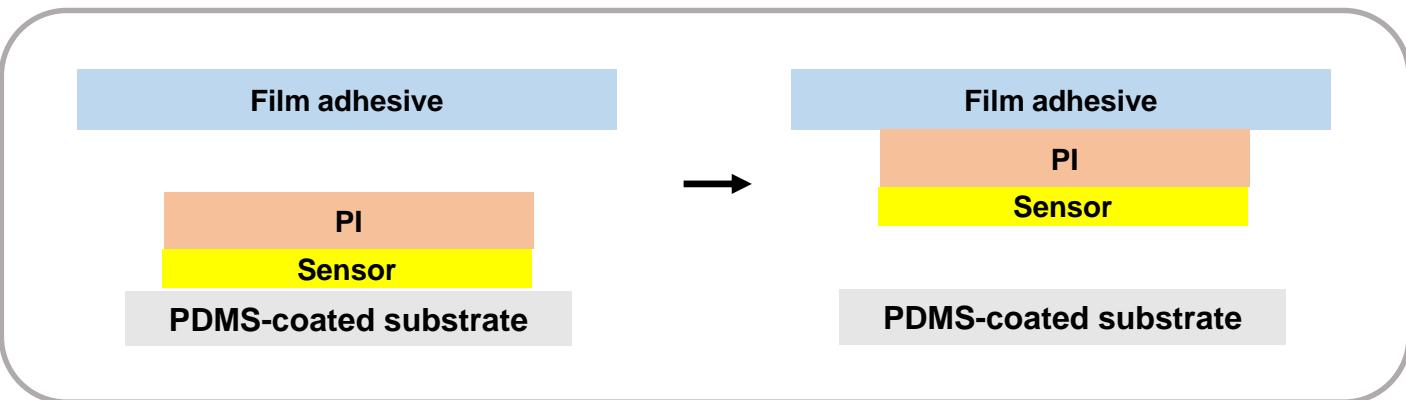
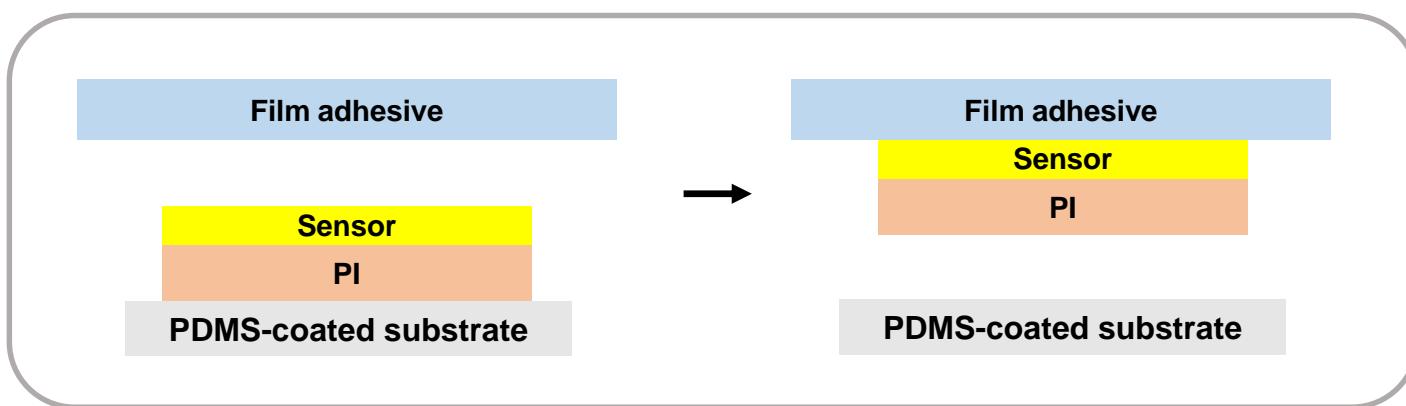
Water-soluble
tape

Thermal tape

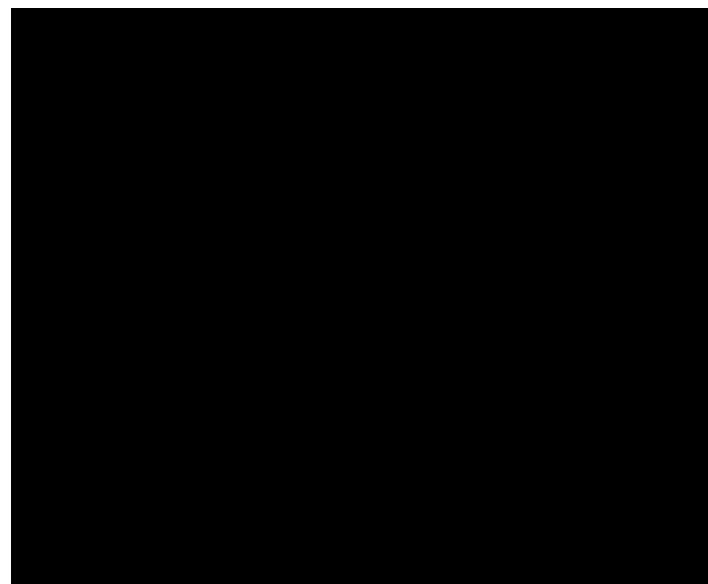
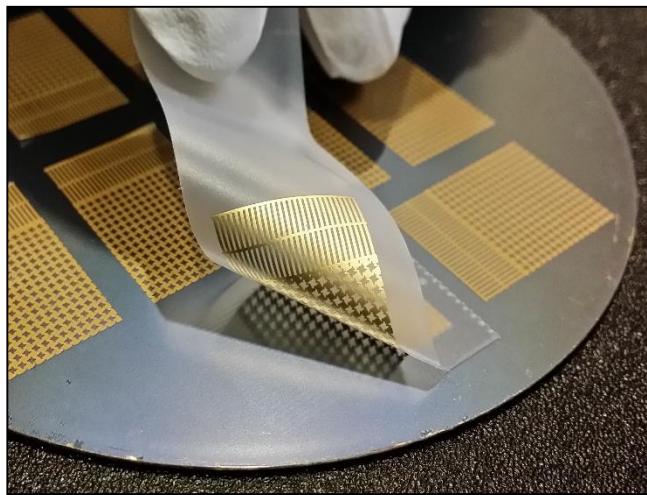
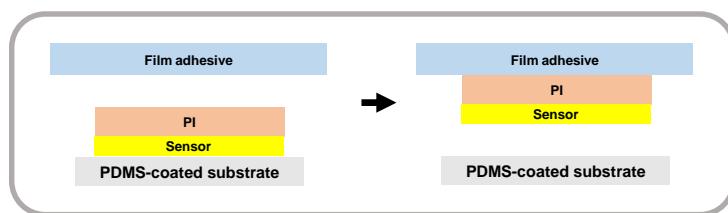
UV tape

Handling and Transfer of Thin-film Electronics

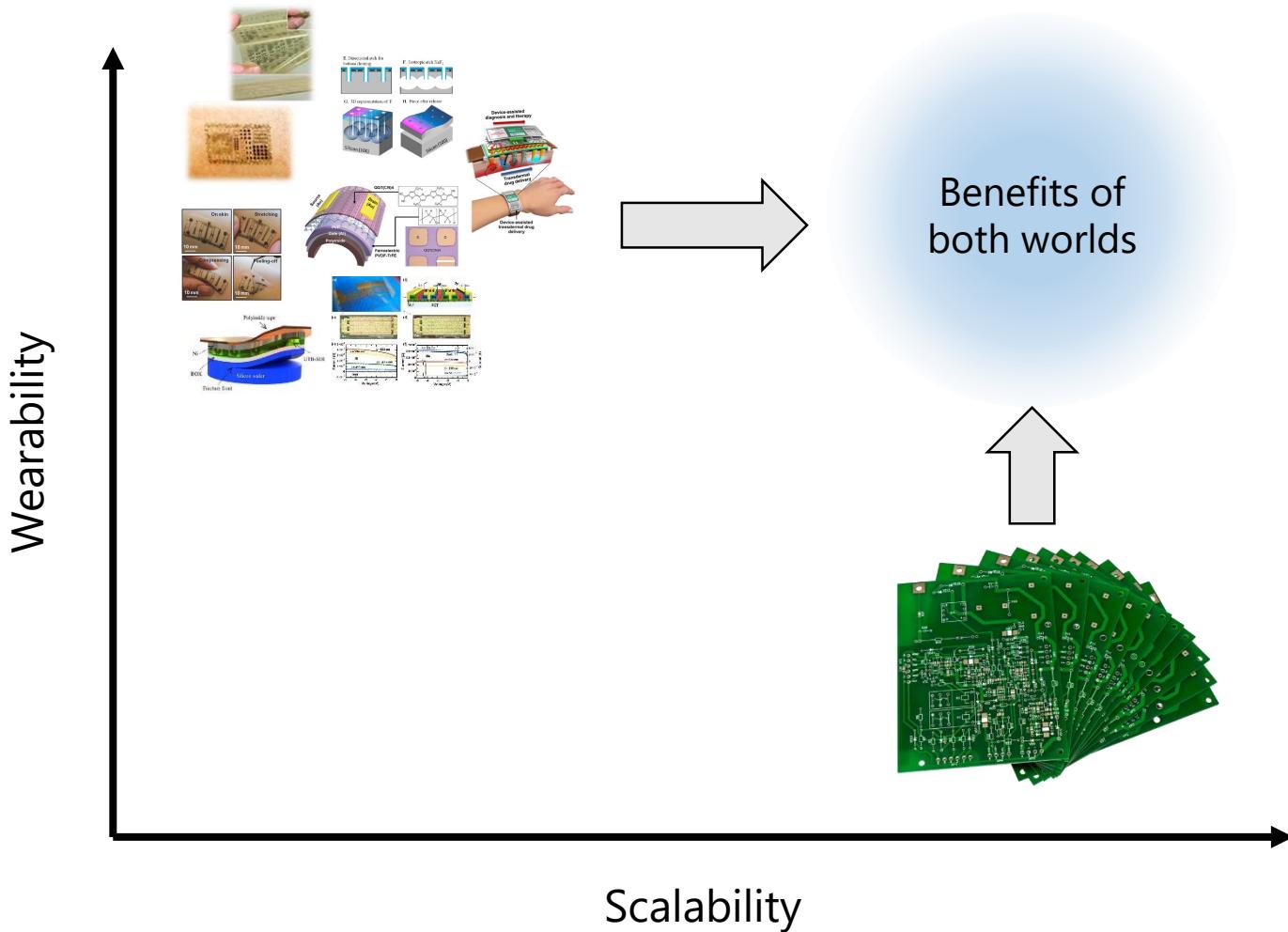
With a single step...



Reverse Microfabrication

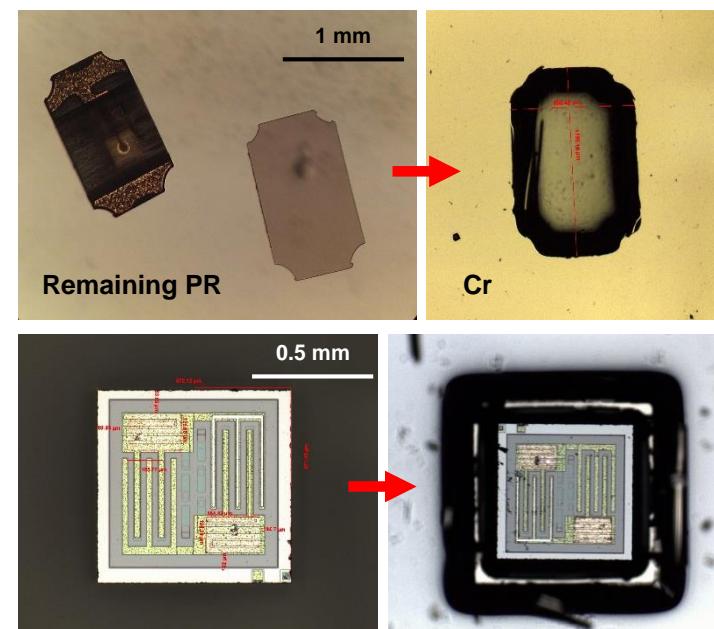
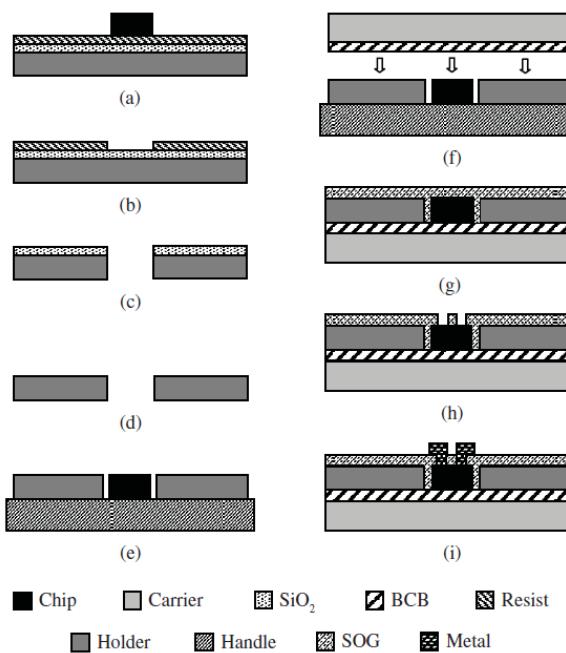


Integration of Commercial Off-the-Shelf Components



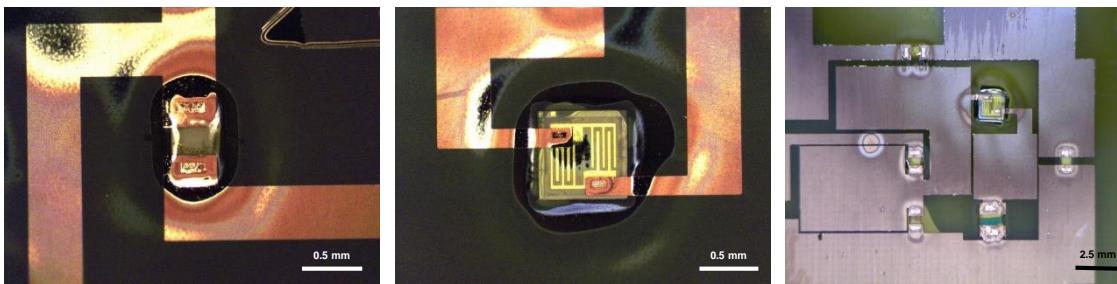
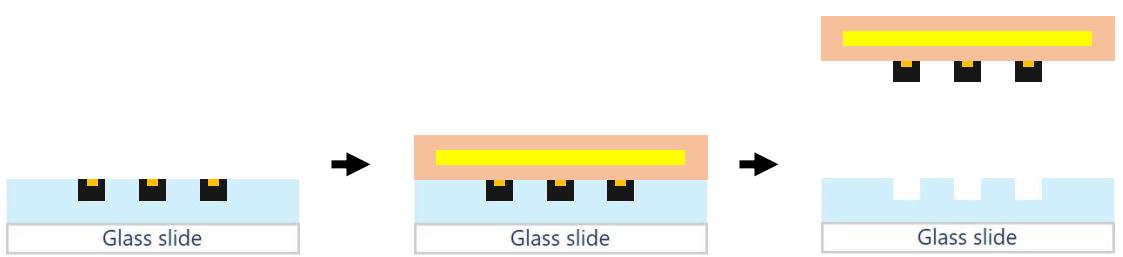
Integration of Commercial Off-the-Shelf Components

(1) Si Trench Using Self-Aligning



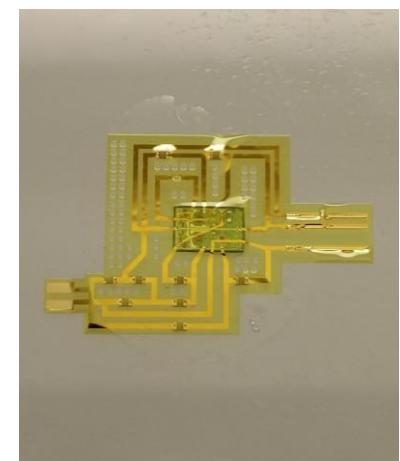
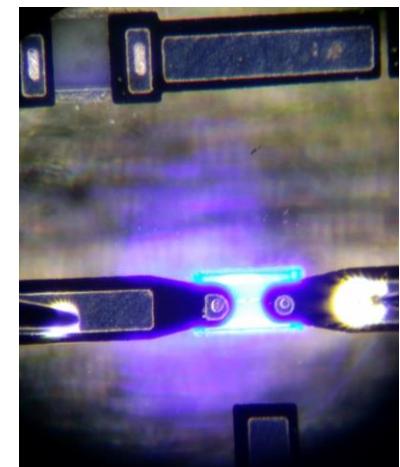
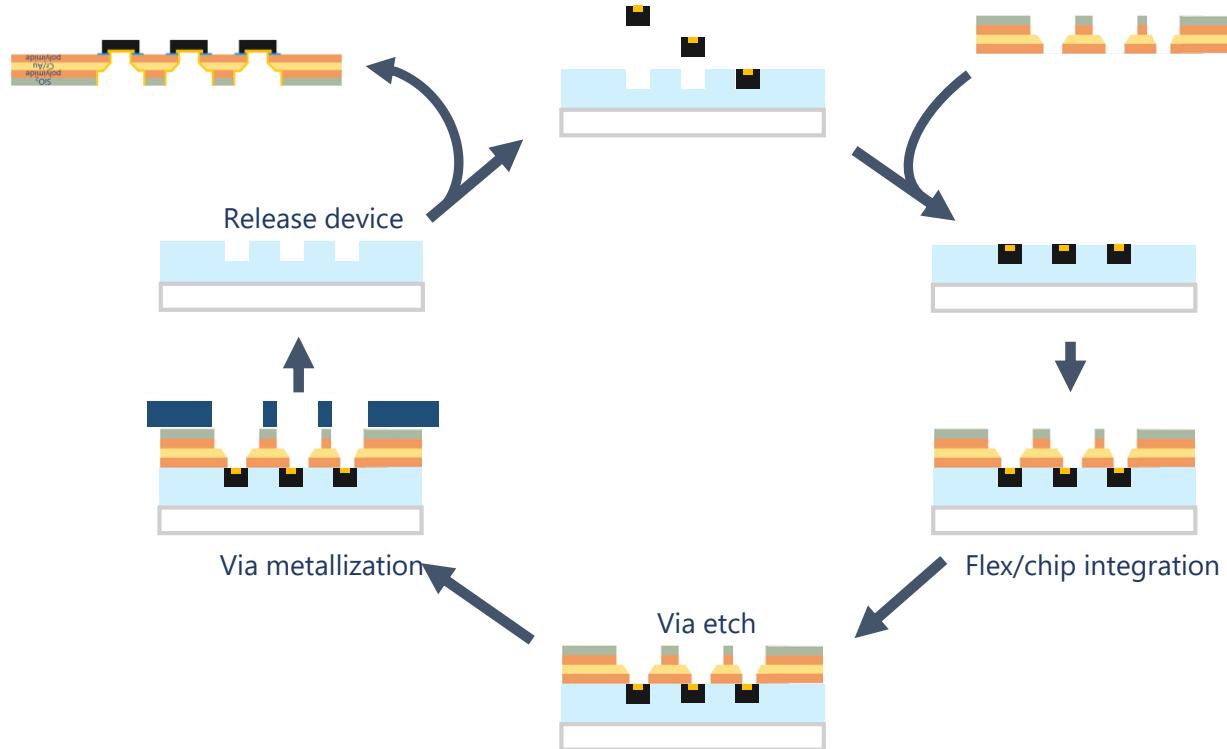
Integration of Commercial Off-the-Shelf Components

(2) PDMS Trench with Sequential Layer Formation



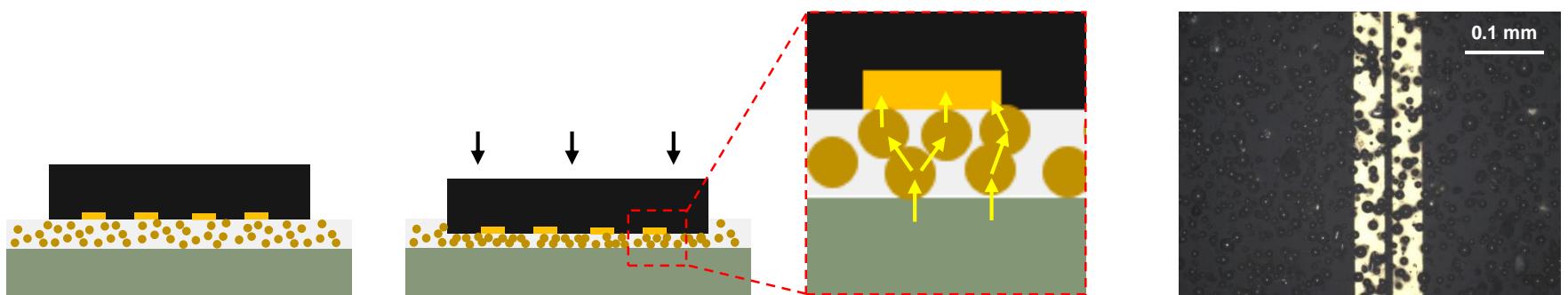
Integration of Commercial Off-the-Shelf Components

(3) PDMS Trench with Preformed Layer Integration



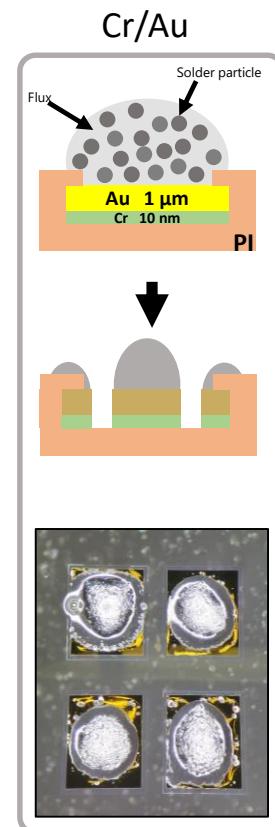
Integration of Commercial Off-the-Shelf Components

(4) Chip Bonding Using Anisotropic Conductive Adhesive (ACA)



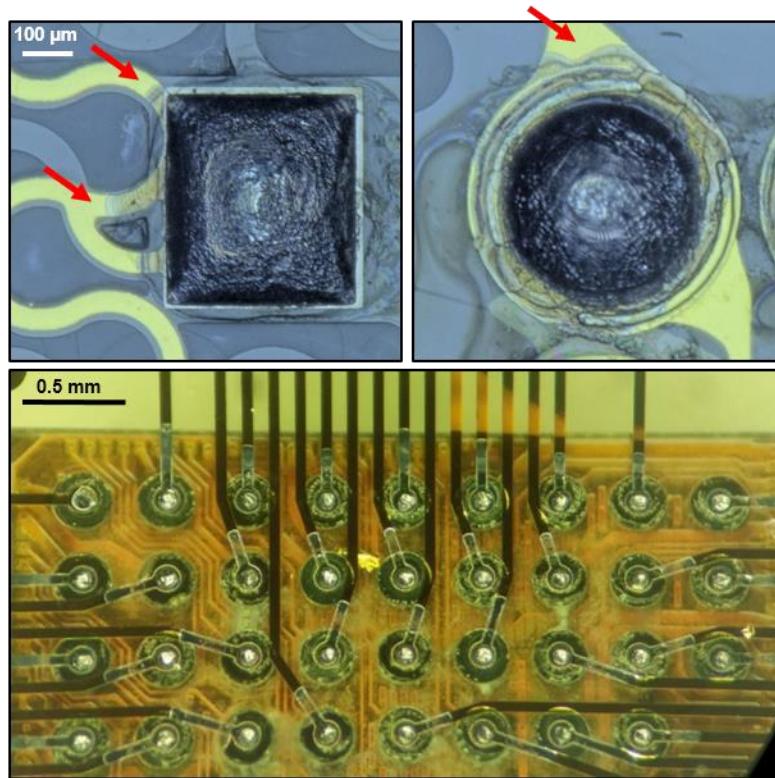
Integration of Commercial Off-the-Shelf Components

(5) Reflow soldering Using Solder Paste



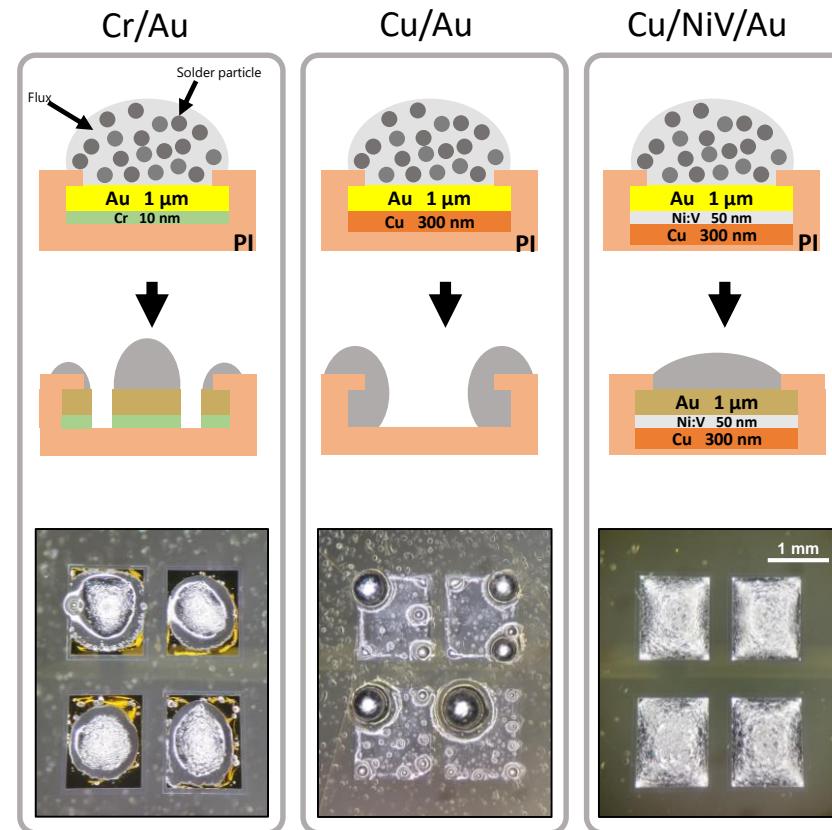
Integration of Commercial Off-the-Shelf Components

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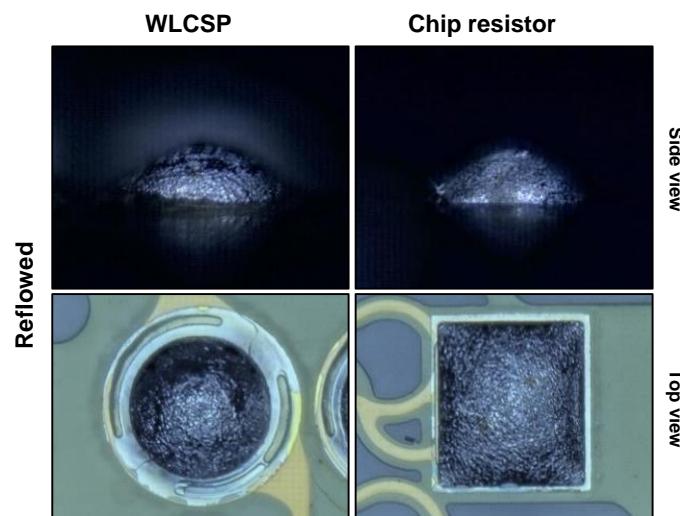
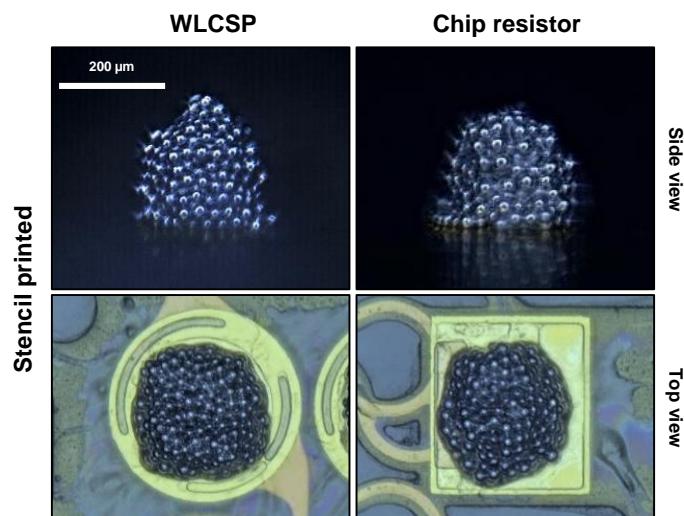
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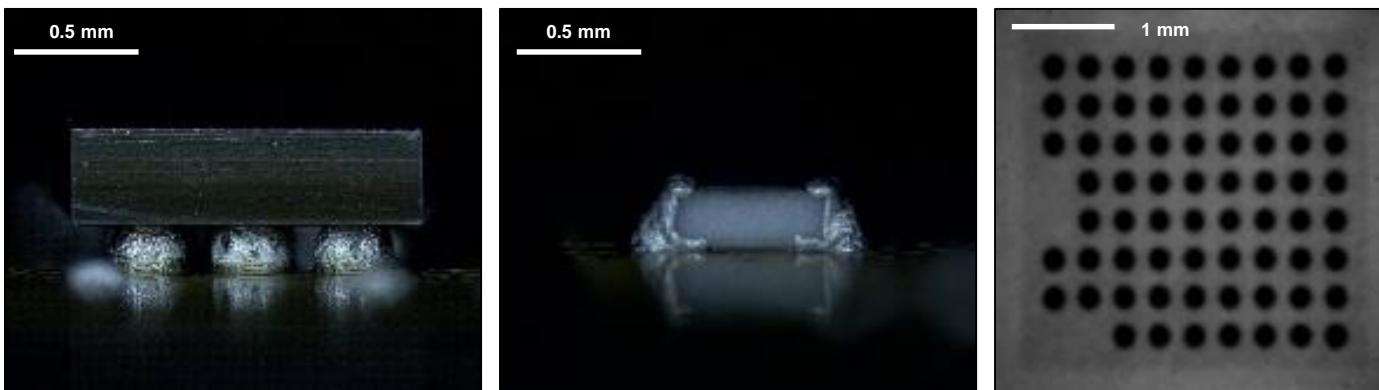
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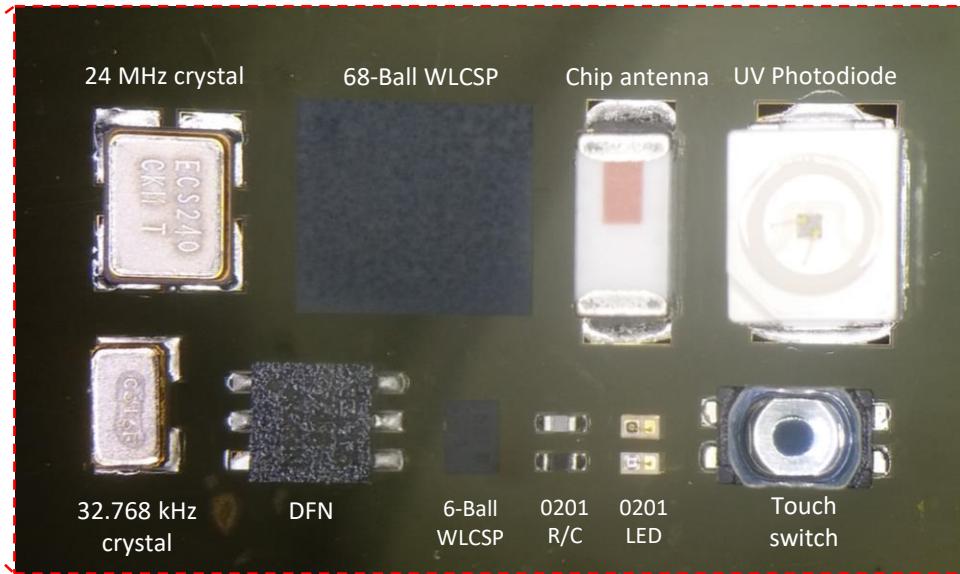
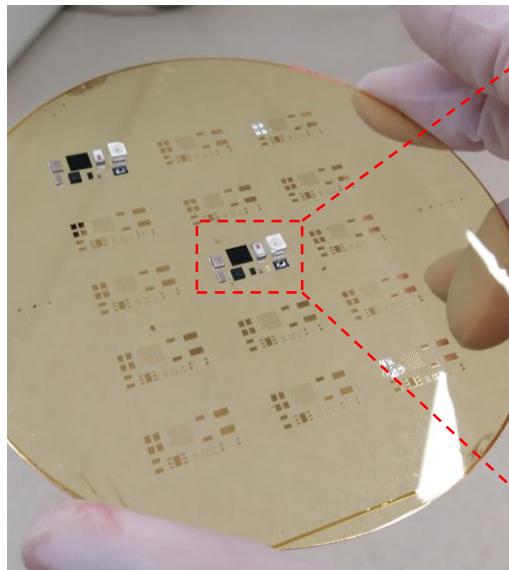
Integration of Commercial Off-the-Shelf Components

(5) Reflow soldering Using Solder Paste



Integration of Commercial Off-the-Shelf Components

(5) Reflow soldering Using Solder Paste



Overview

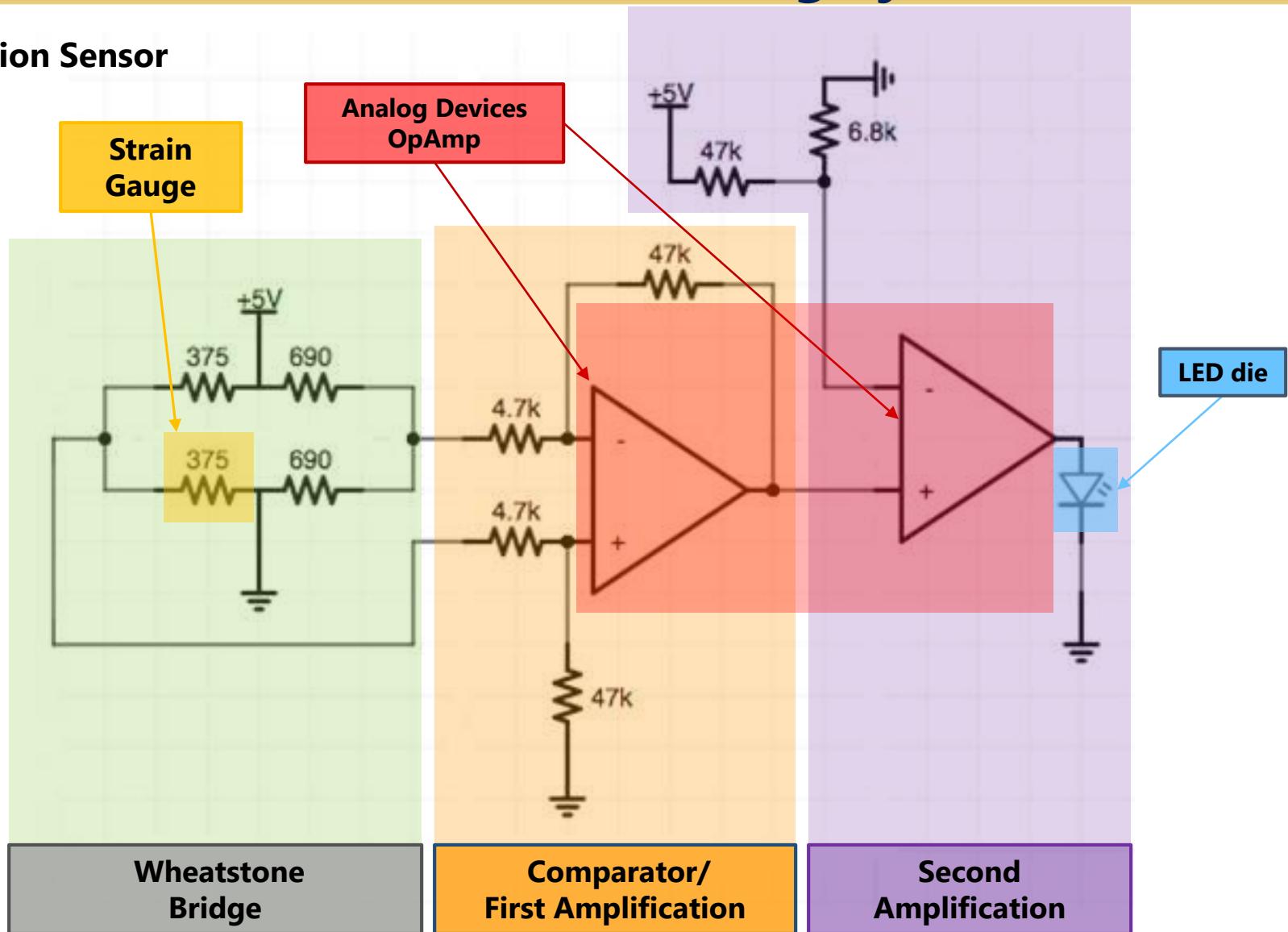
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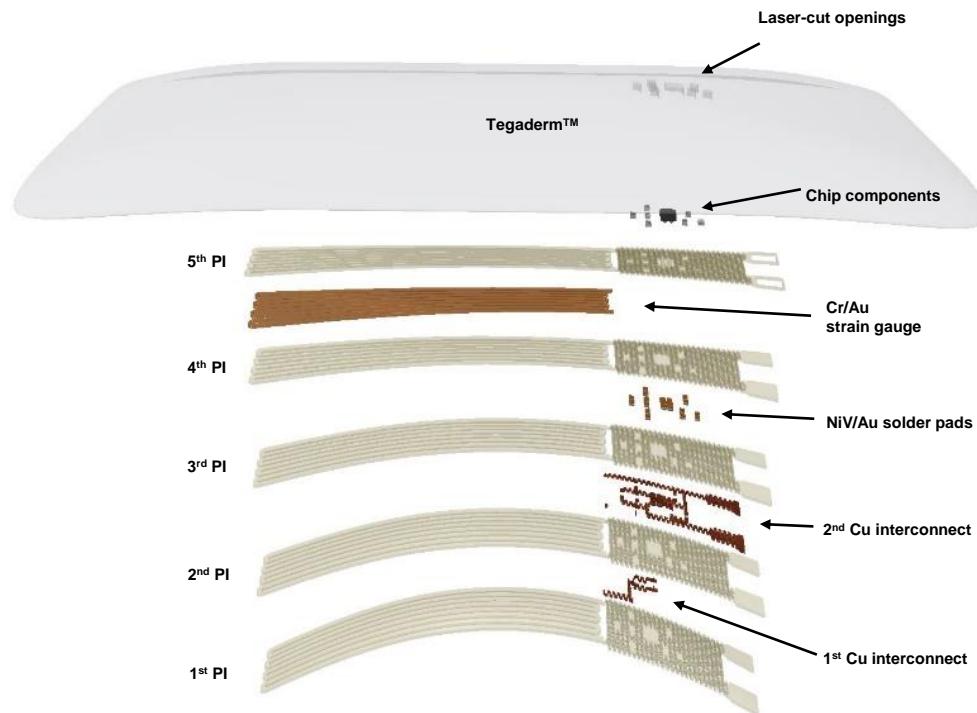
Solderable Stretchable Sensing System (S4)

Respiration Sensor



Solderable Stretchable Sensing System (S4)

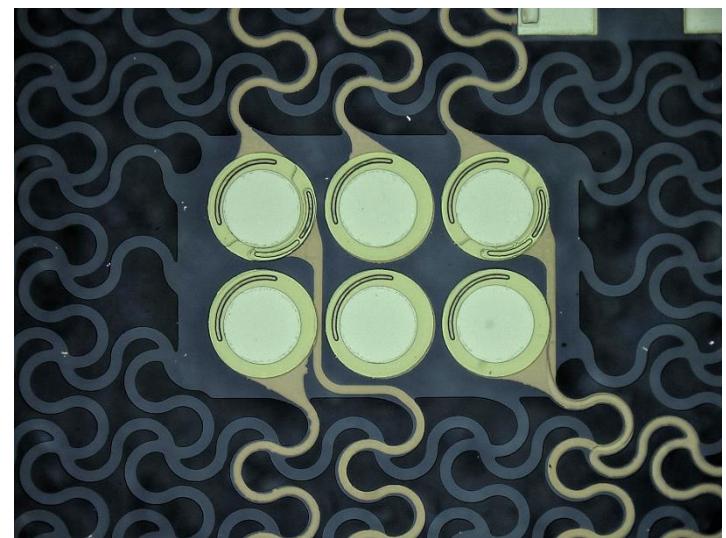
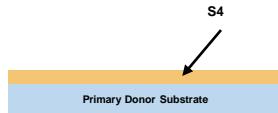
Respiration Sensor



Solderable Stretchable Sensing System (S4)

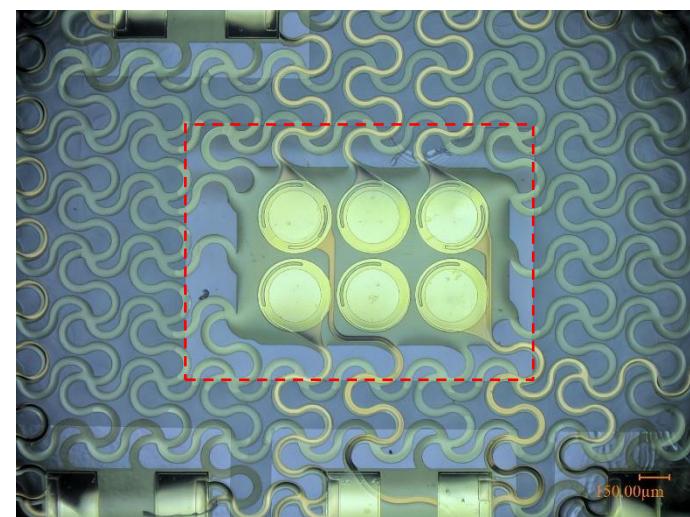
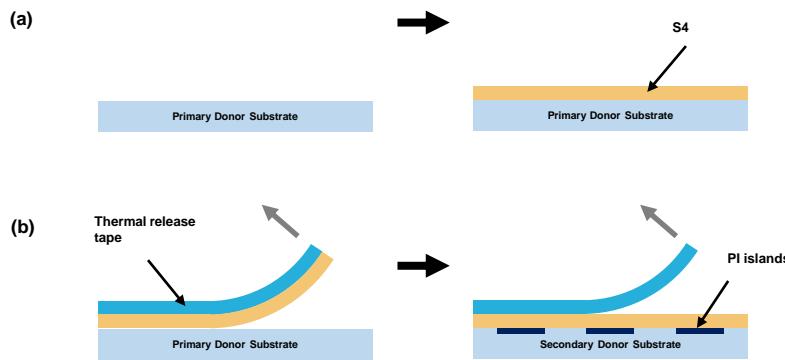
Respiration Sensor

(a)



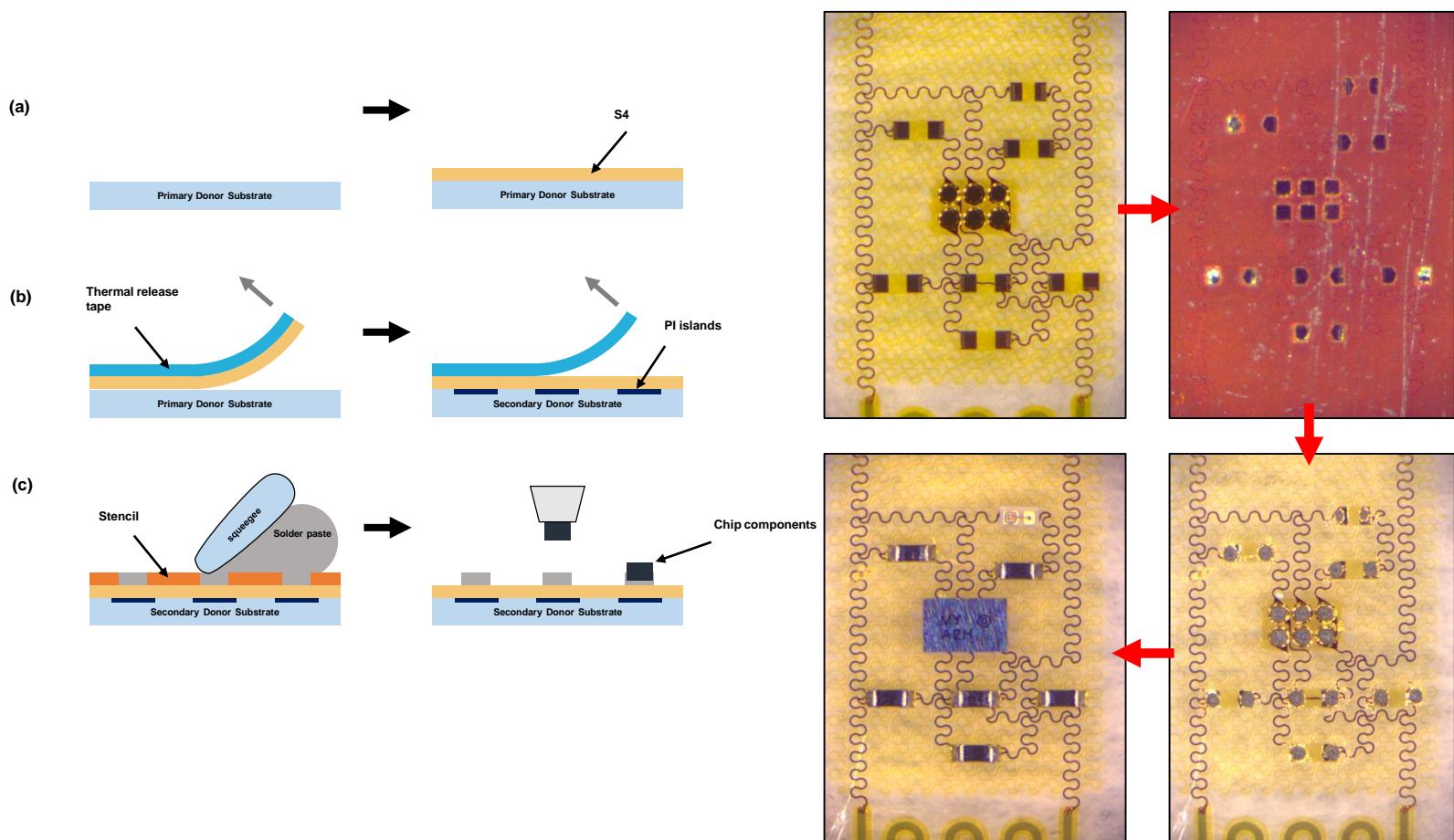
Solderable Stretchable Sensing System (S4)

Respiration Sensor



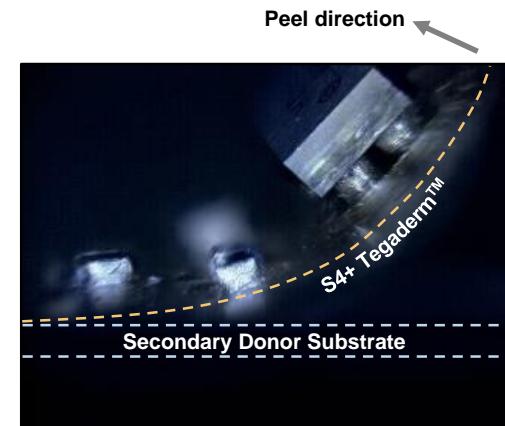
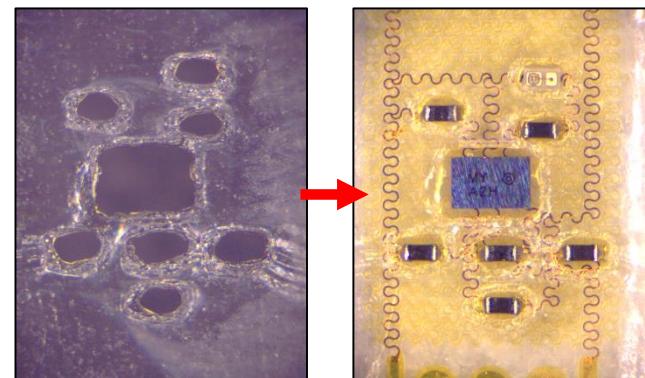
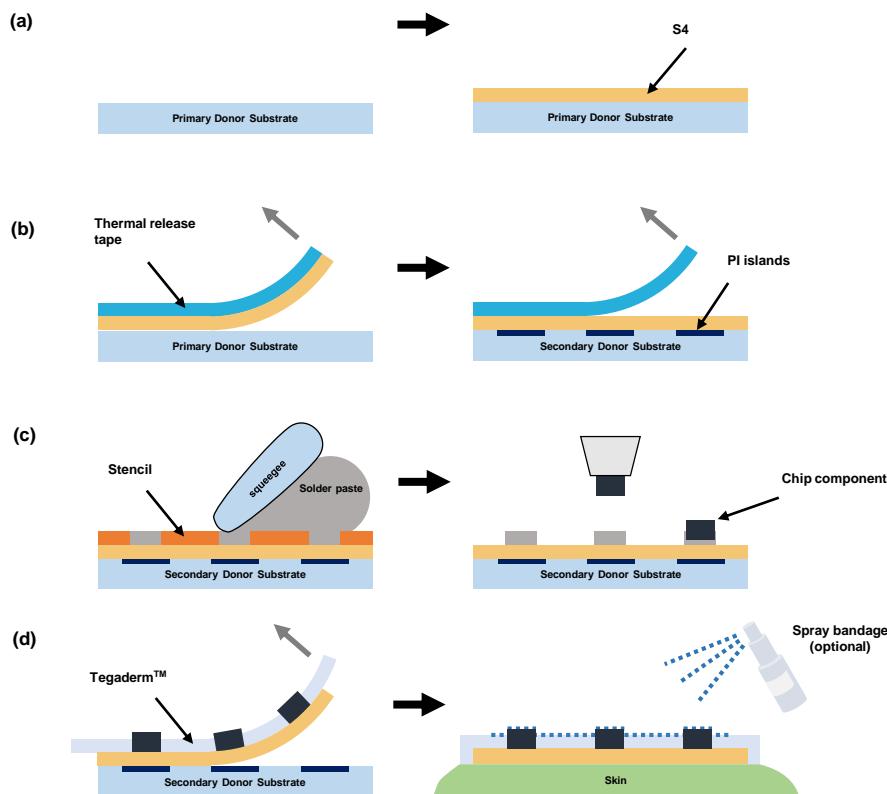
Solderable Stretchable Sensing System (S4)

Respiration Sensor



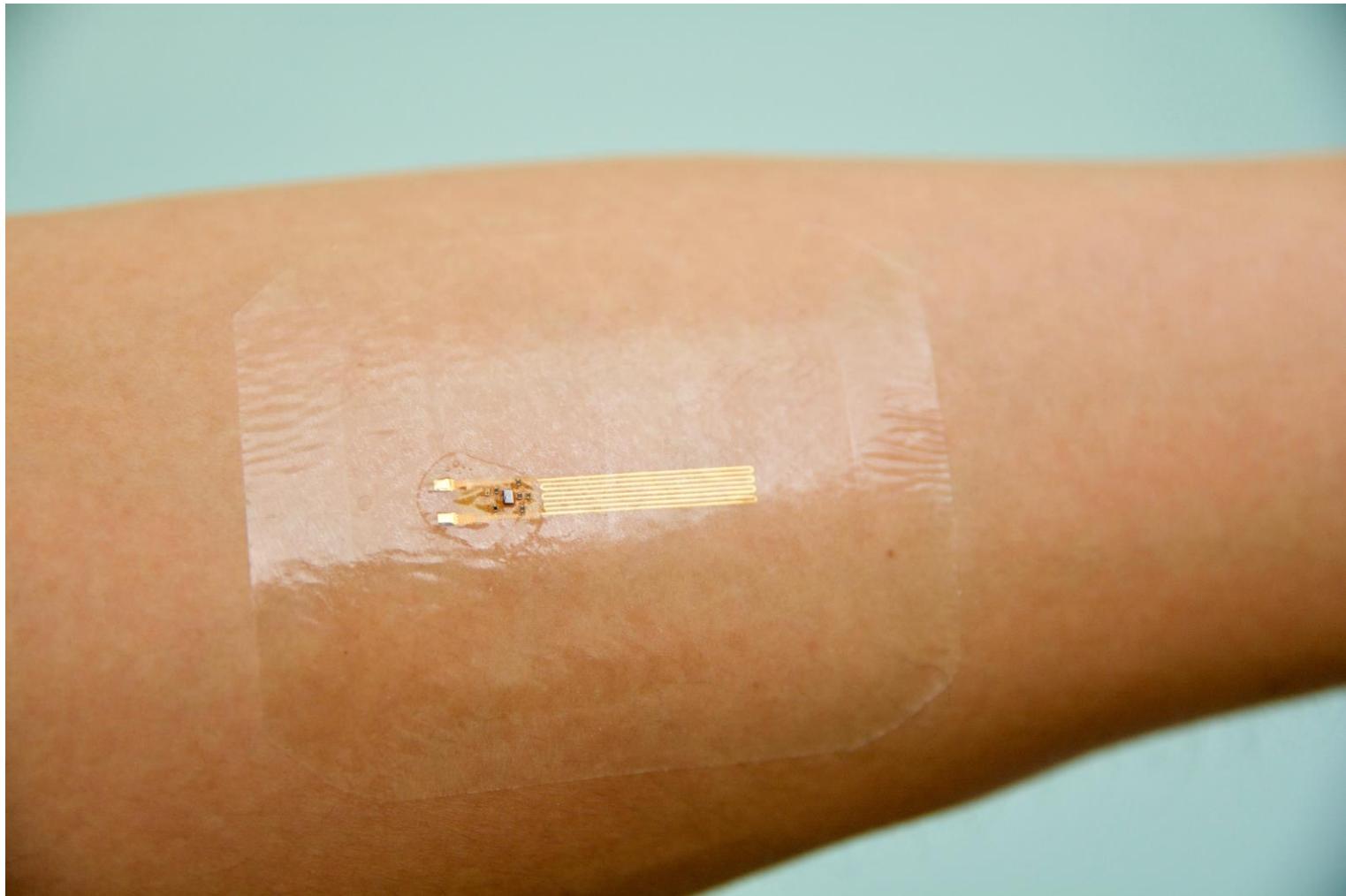
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Respiration Sensor



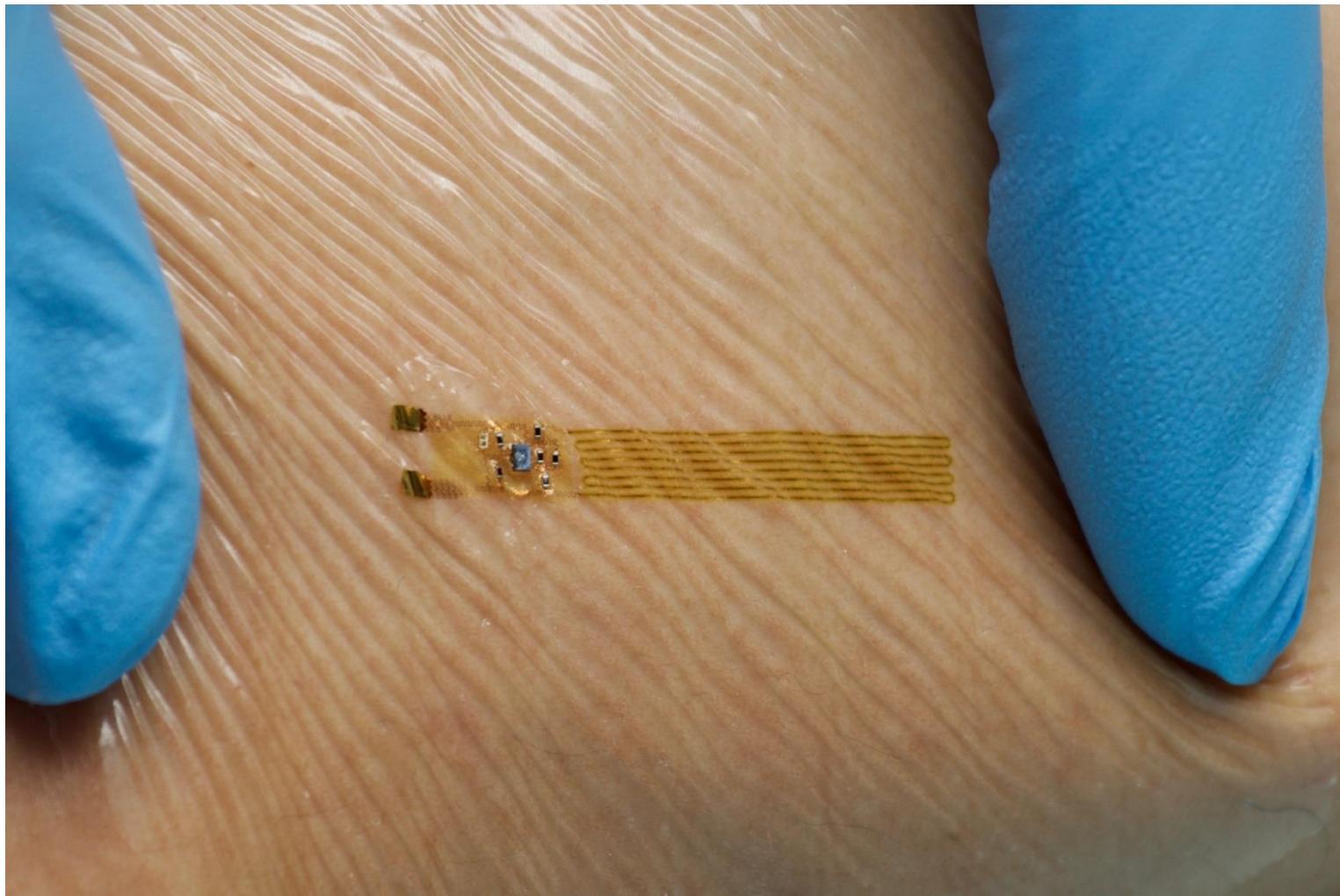
Solderable Stretchable Sensing System (S4)

Respiration Sensor



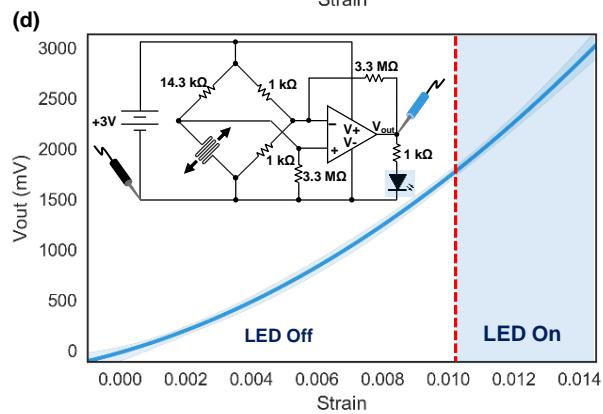
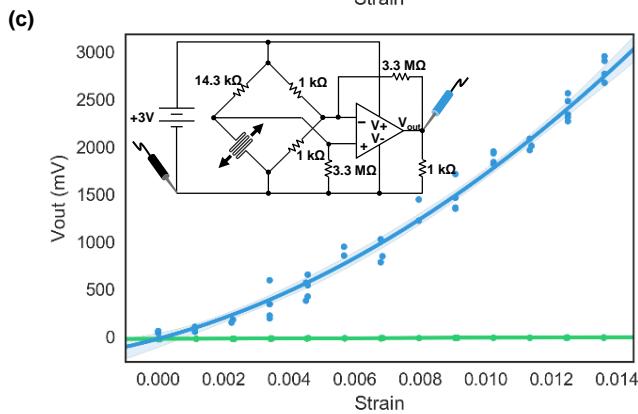
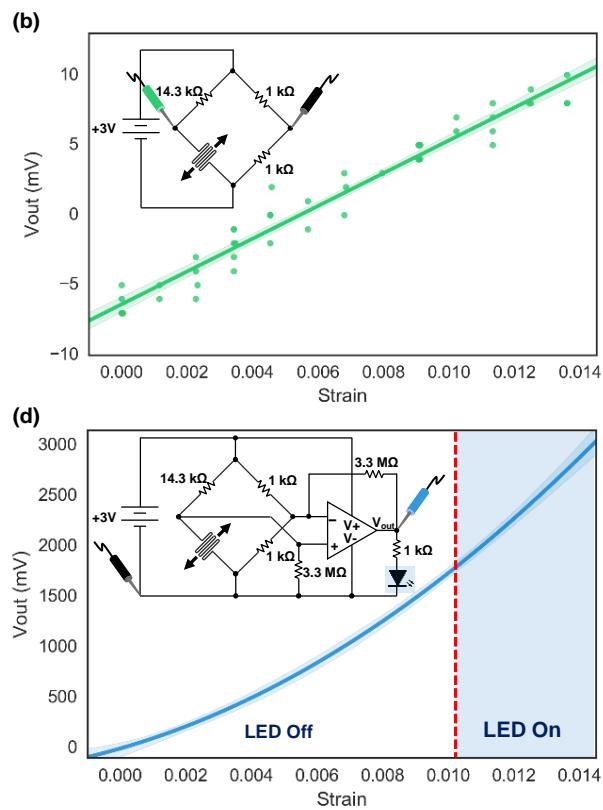
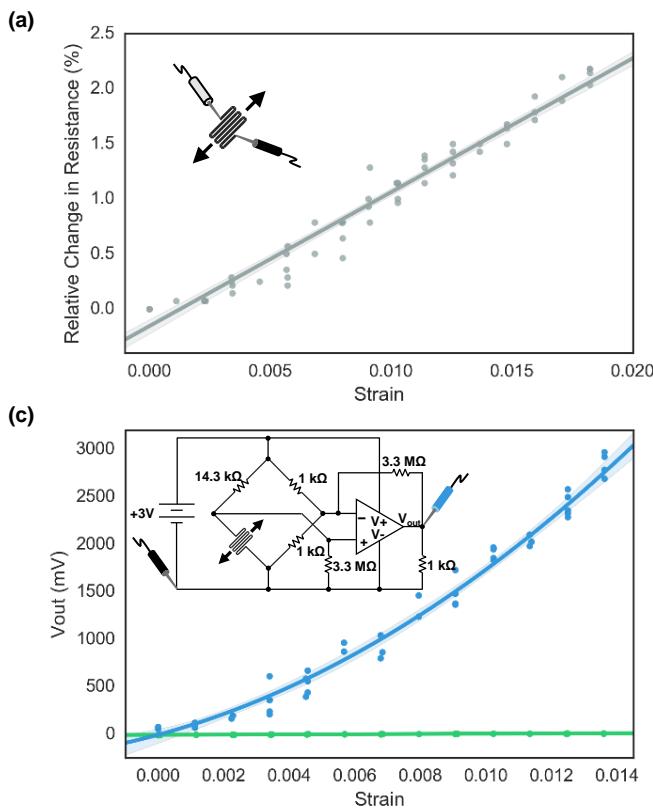
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Respiration Sensor



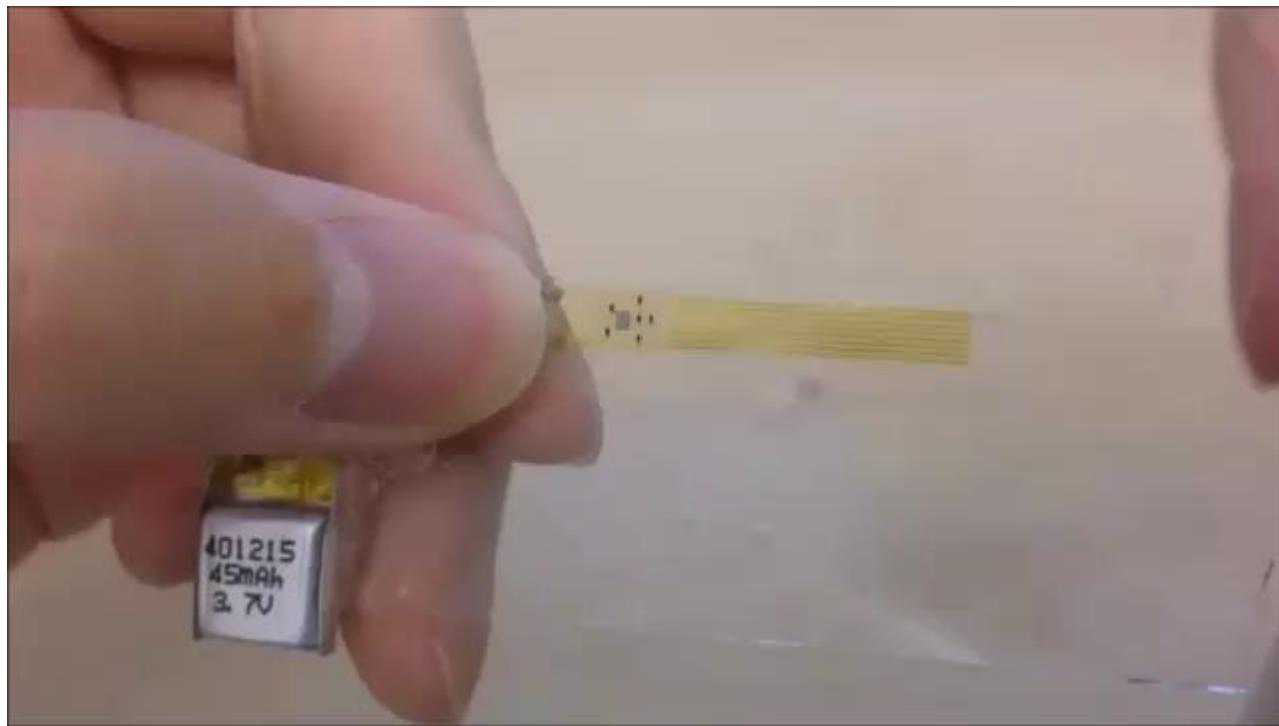
Solderable Stretchable Sensing System (S4)

Respiration Sensor



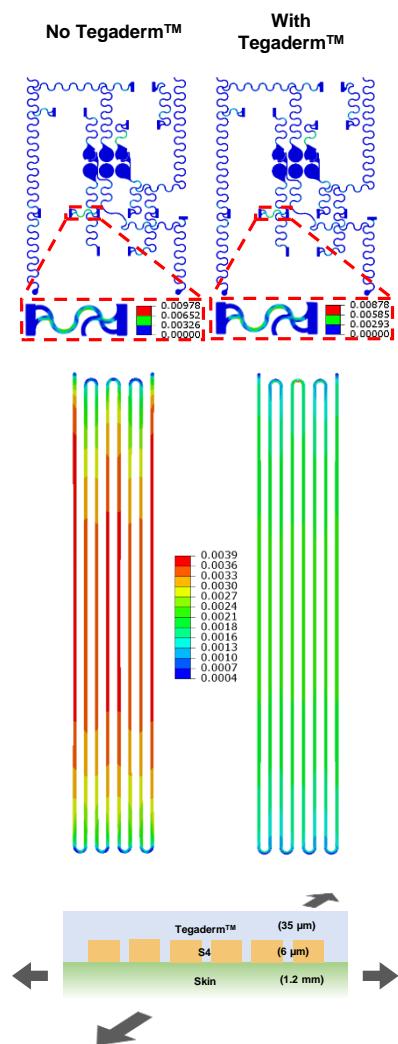
Solderable Stretchable Sensing System (S4)

Respiration Sensor



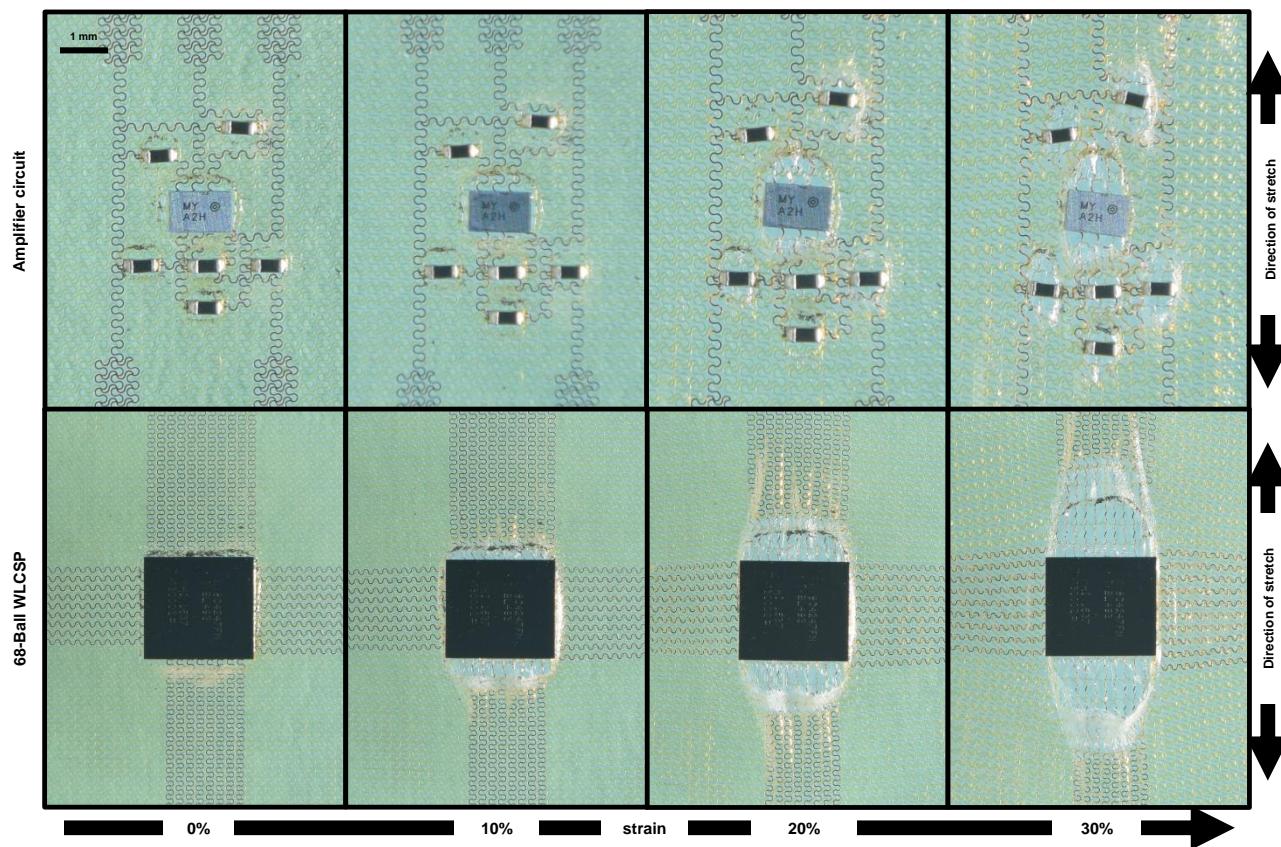
Solderable Stretchable Sensing System (S4)

Respiration Sensor



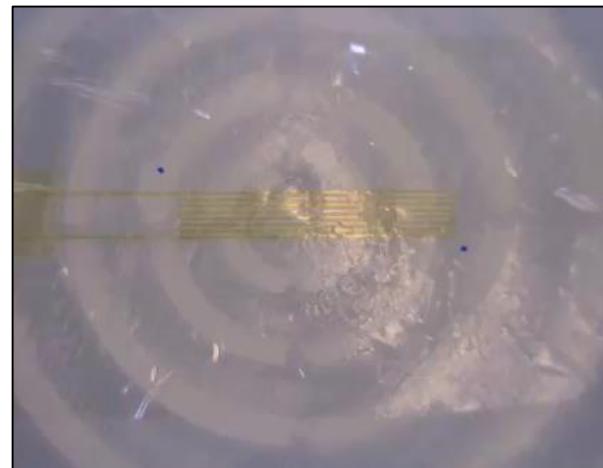
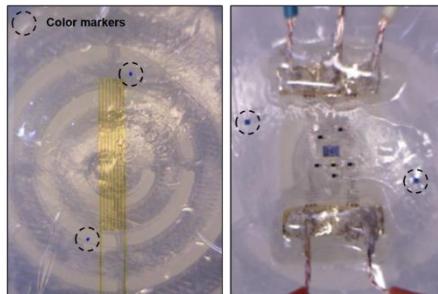
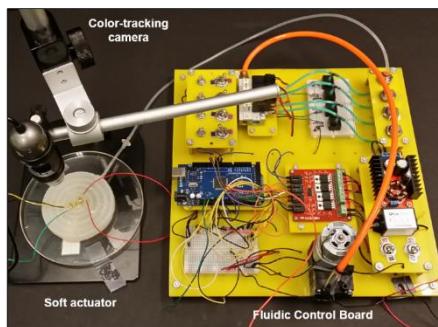
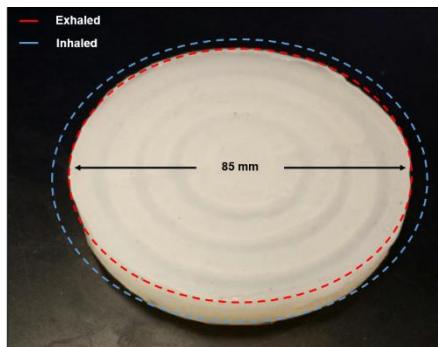
Solderable Stretchable Sensing System (S4)

Respiration Sensor



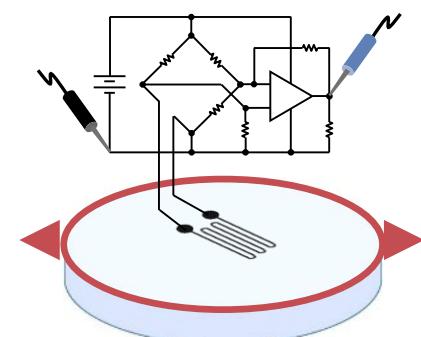
Solderable Stretchable Sensing System (S4)

Respiration Sensor

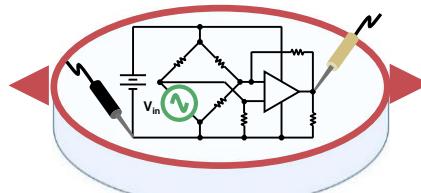


Solderable Stretchable Sensing System (S4)

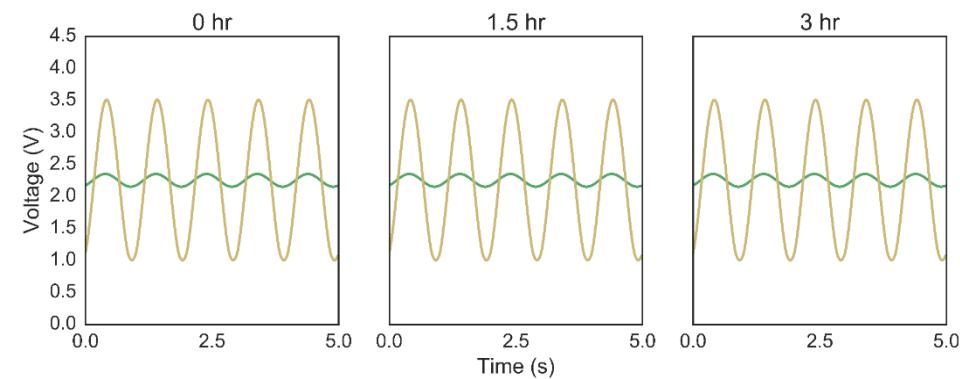
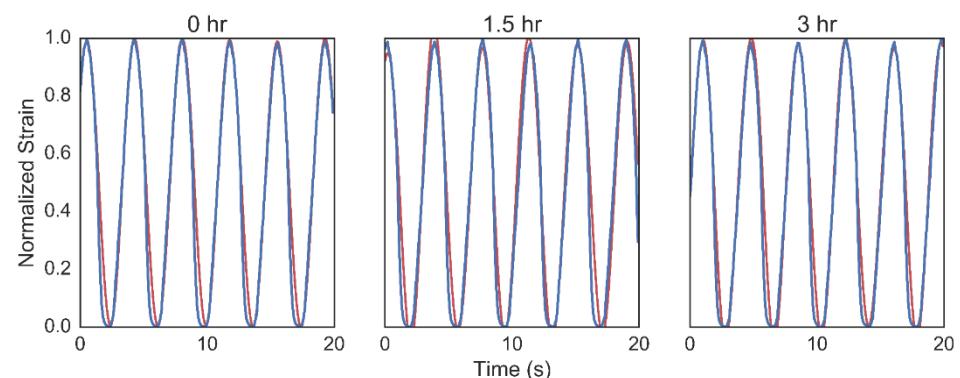
Respiration Sensor



Mechanical input
Strain gauge

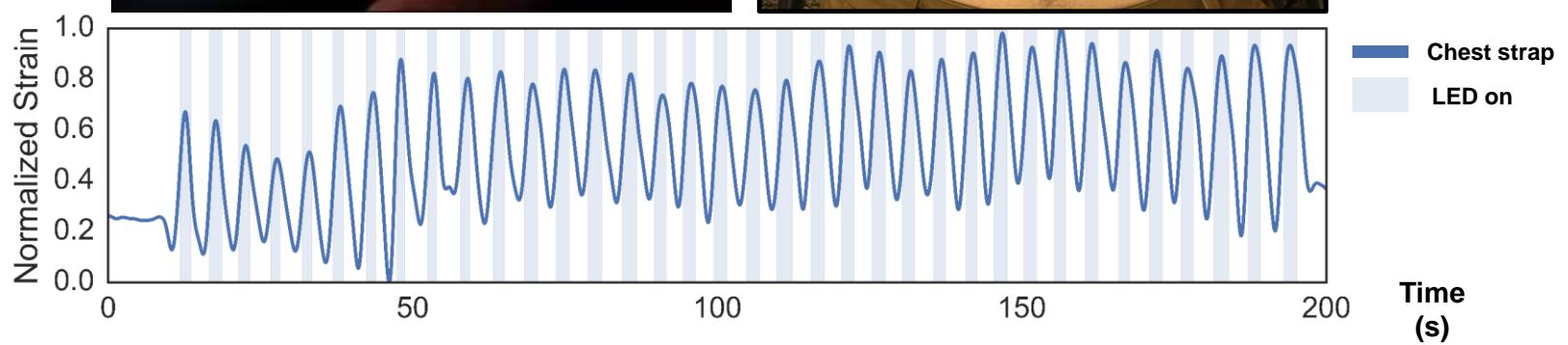
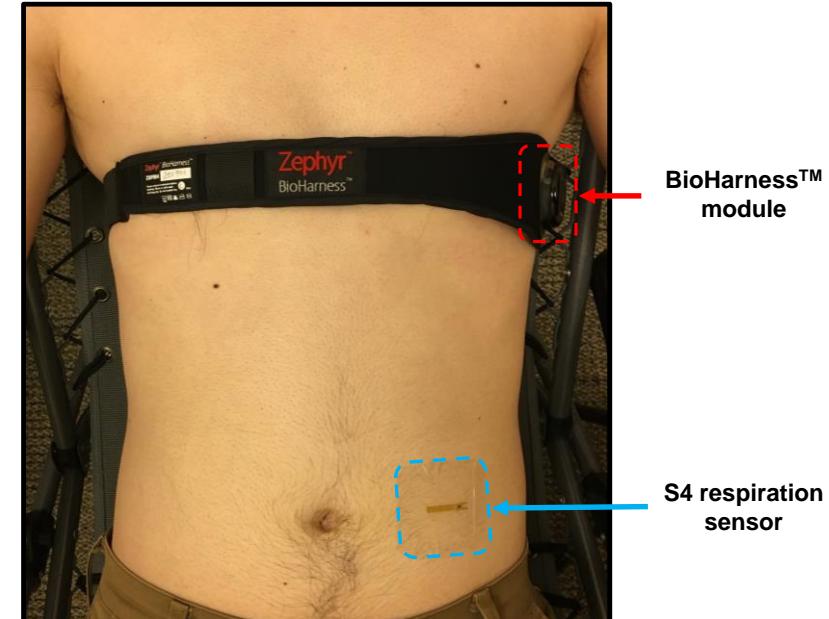


Electrical input
Measured output



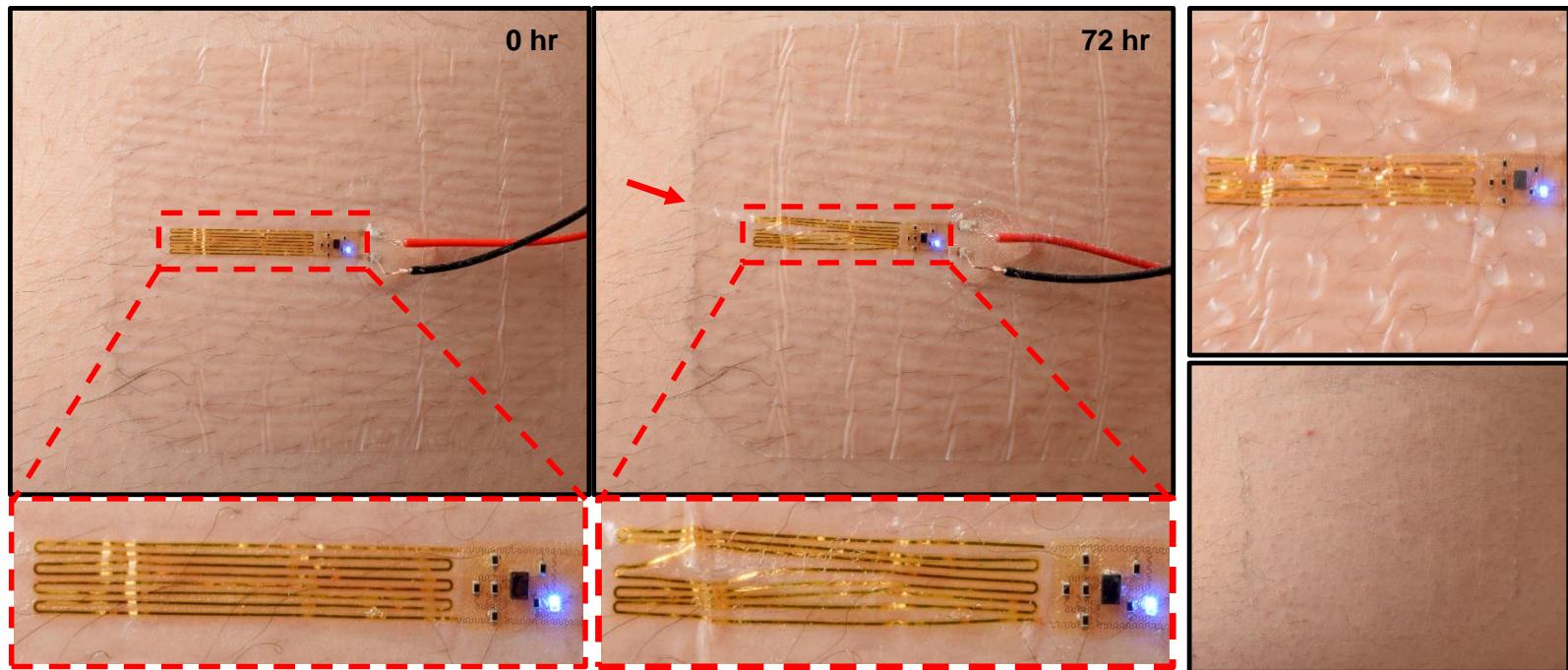
Solderable Stretchable Sensing System (S4)

Respiration Sensor



Solderable Stretchable Sensing System (S4)

Respiration Sensor

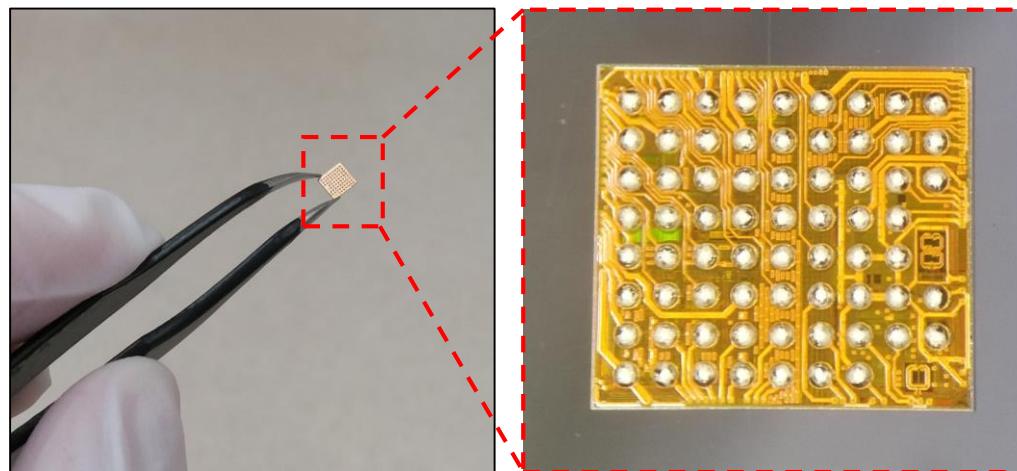


Overview

- About Me
- Motivation
- Development of Solderable Stretchable Systems
- Respiration Sensing Using Solderable Stretchable Sensing System (S4)
- Wireless S4
- Wireless S4 with an Integrated Stretchable Antenna
- Next Steps & Conclusion

Wireless S4

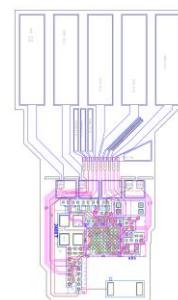
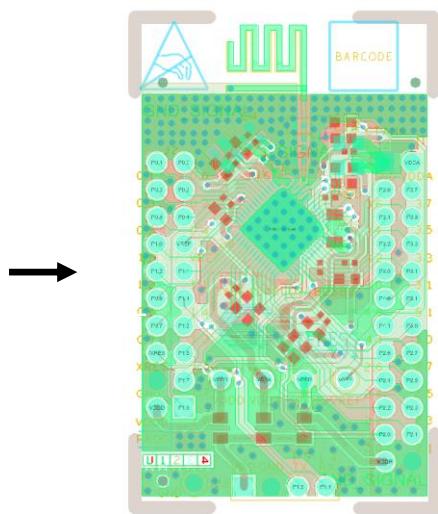
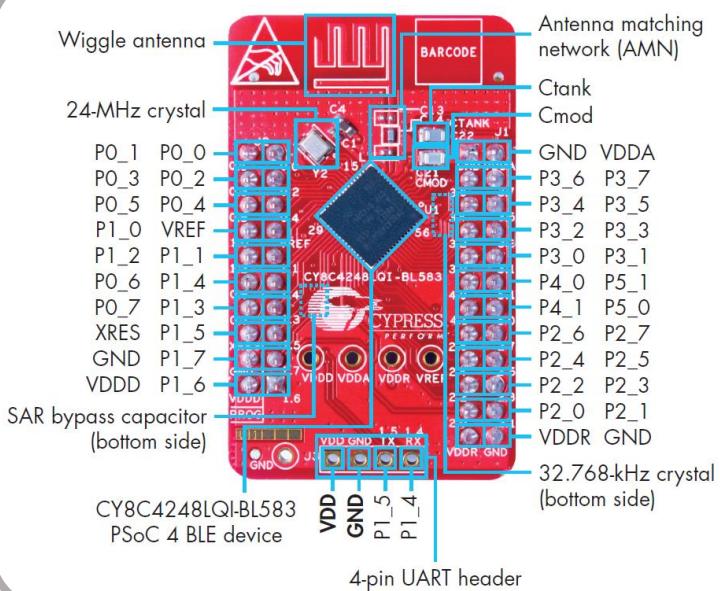
Programmable System-on-Chip (PSoC)



- Commercial Programmable System-on-Chip (PSoC) by Cypress
- CPU (ARM Cortex-M0)
- 2.4 GHz RF transceiver or Bluetooth Low Energy (BLE)
- Programmable analog and digital blocks
- Analog-to-digital conversion (ADC)
- 4 opamps
- 36 Programmable GPIOs
- 3.5 mm x 3.9 mm 68-Ball CSP package with SAC305 solder system

Wireless S4

Miniaturization Process



1 cm

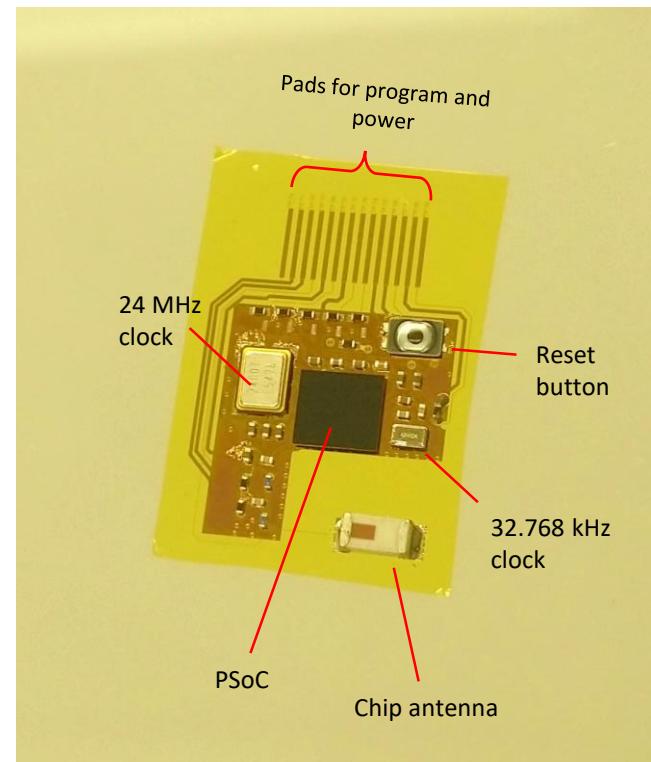
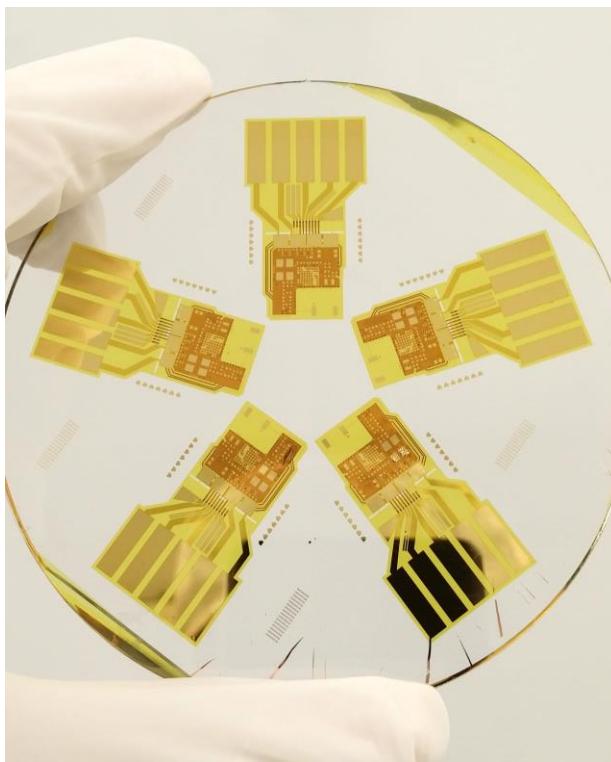
Cypress PSoC BLE Module

Module layout

CAD Translation
for S4
Microfabrication

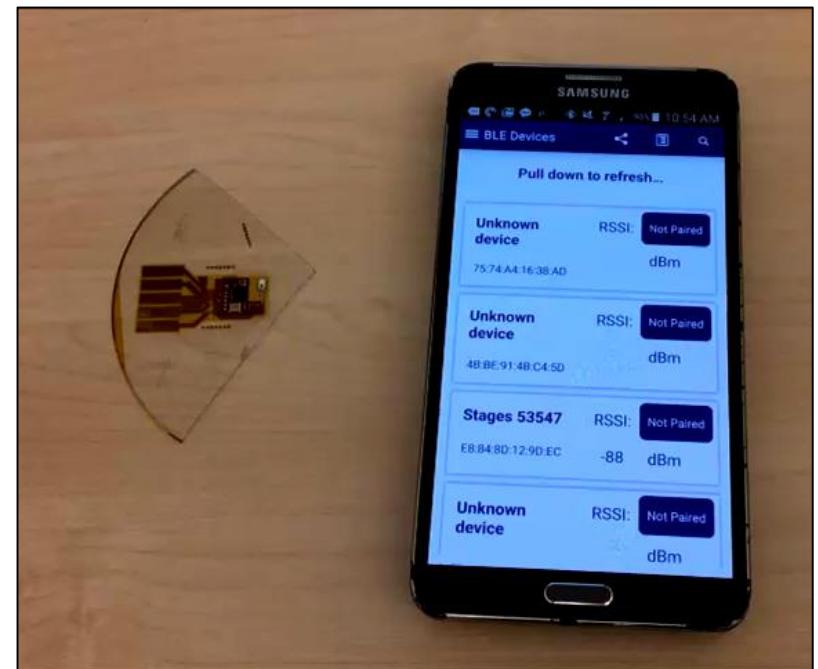
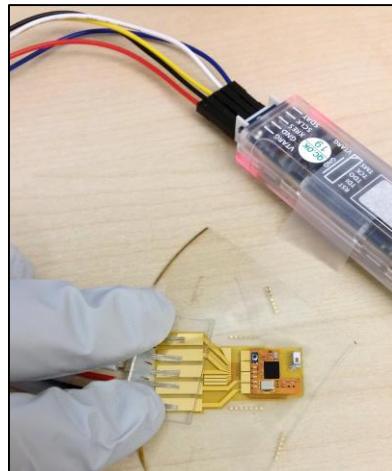
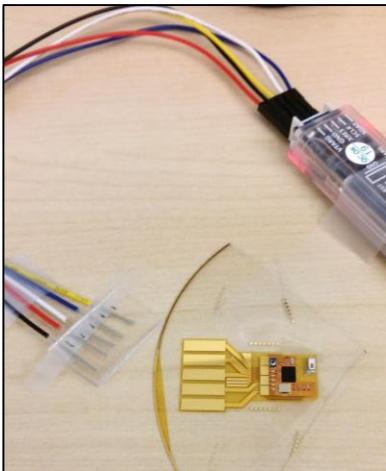
Wireless S4

Fabrication and Assembly



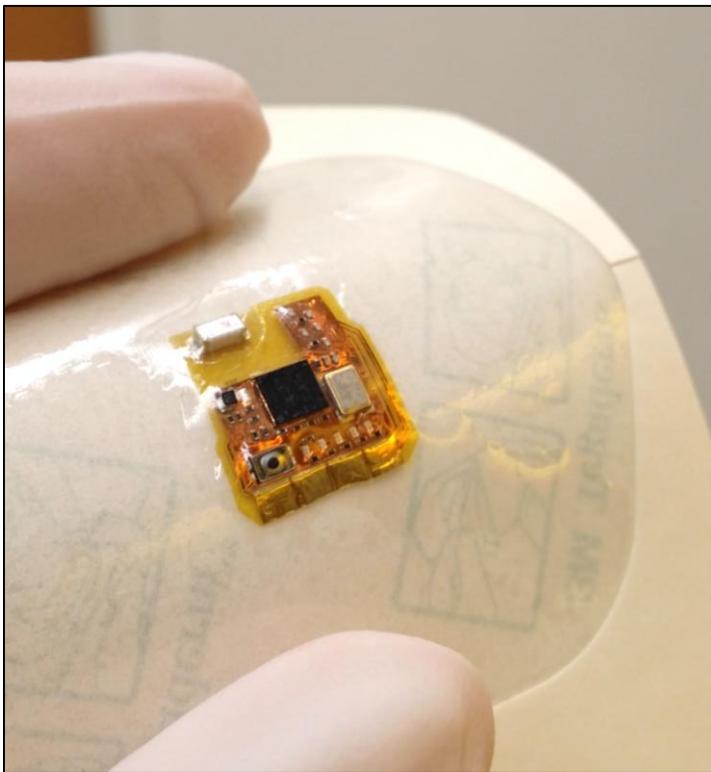
Wireless S4

Program and Verification



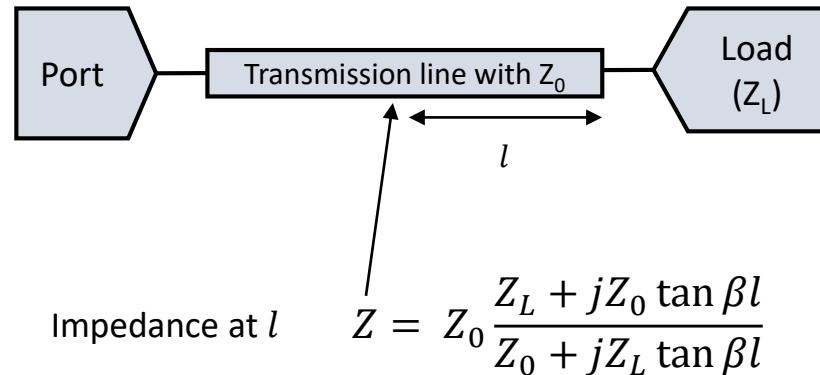
Wireless S4

Two issues...



Wireless S4

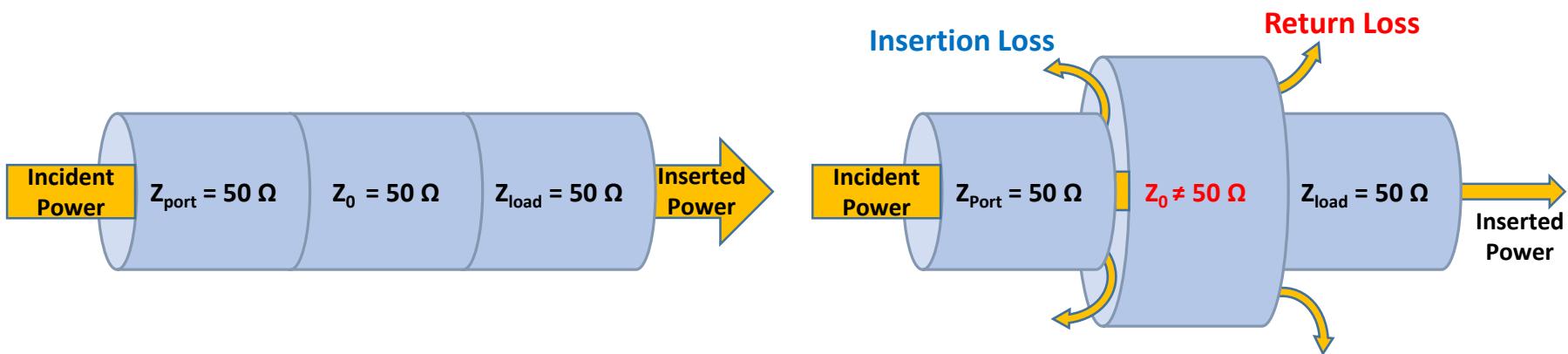
RF Impedance



Reflection coefficient $\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$

Wireless S4

Pipe Analogy



$$\text{Return Loss (dB)} = 10 * \log \frac{\text{Incident Power}}{\text{Reflected Power}}$$

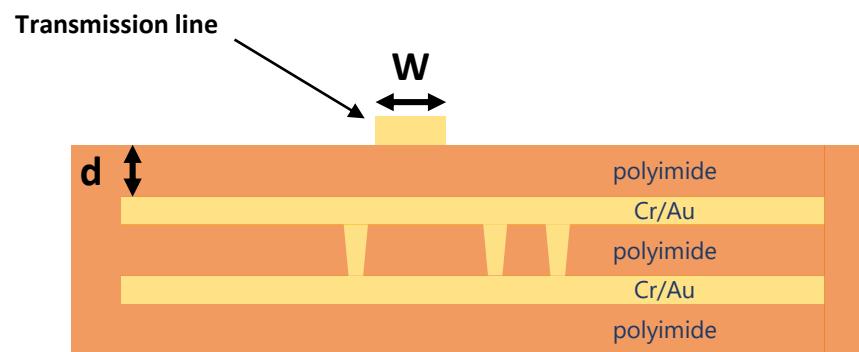
$$\text{Insertion Loss (dB)} = 10 * \log \frac{\text{Inserted Power}}{\text{Incident Power}}$$

Ex1) In return loss of 15 dB, ~3% of power is reflected.

Ex2) In return loss of 5 dB, ~30% of power is reflected.

Wireless S4

Transmission Line Theory

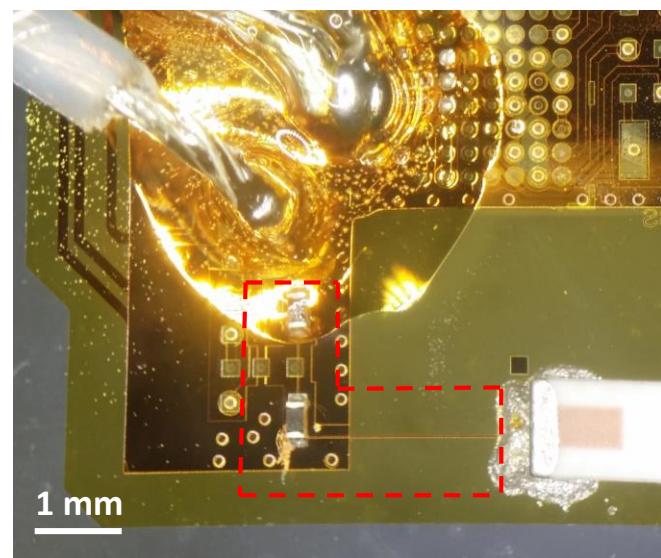
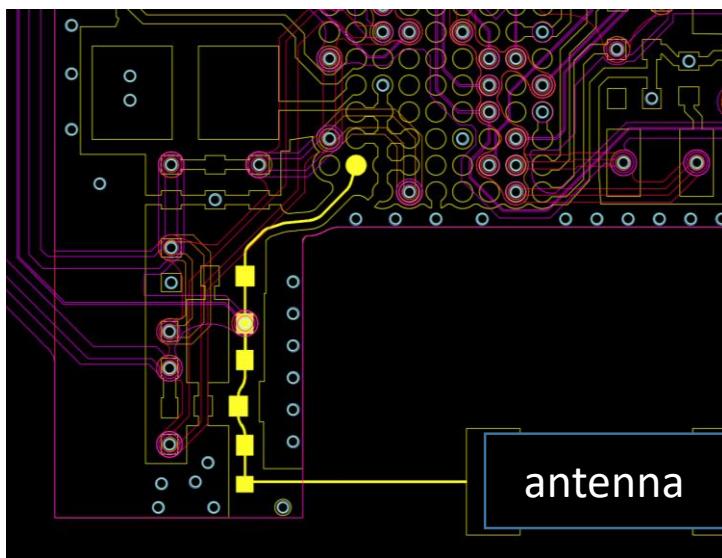


$$\frac{W}{d} = \frac{2}{\pi} \left[A - 1 - \ln(2A - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left\{ \ln(A - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right\} \right]$$

$$A = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad \varepsilon_r = 3.2 \quad d = 1 \text{ } \mu\text{m} \quad \rightarrow \quad W = 5.7 \text{ } \mu\text{m}$$

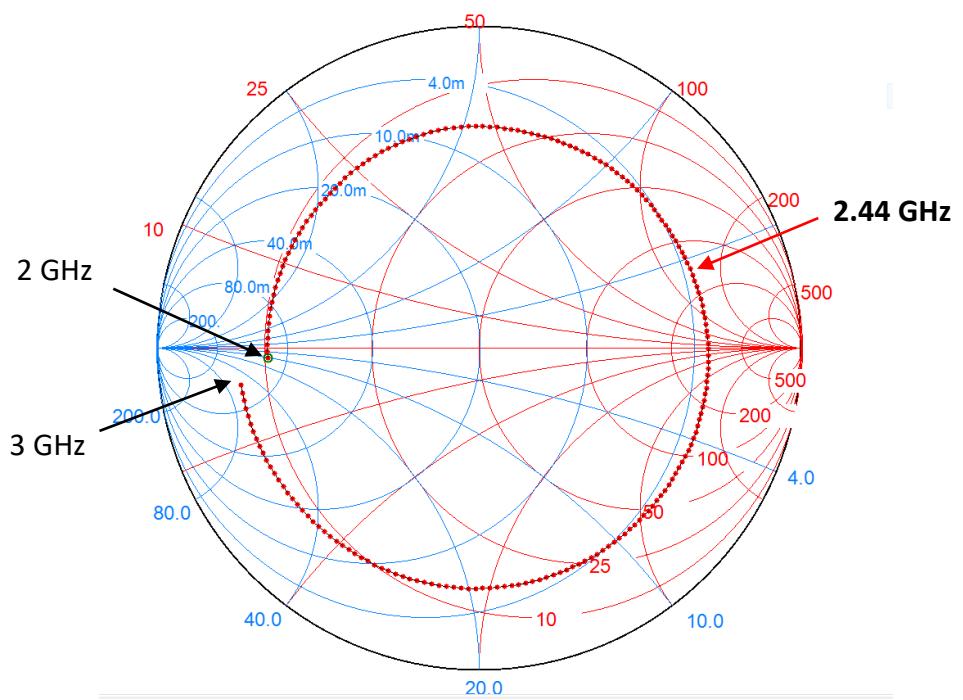
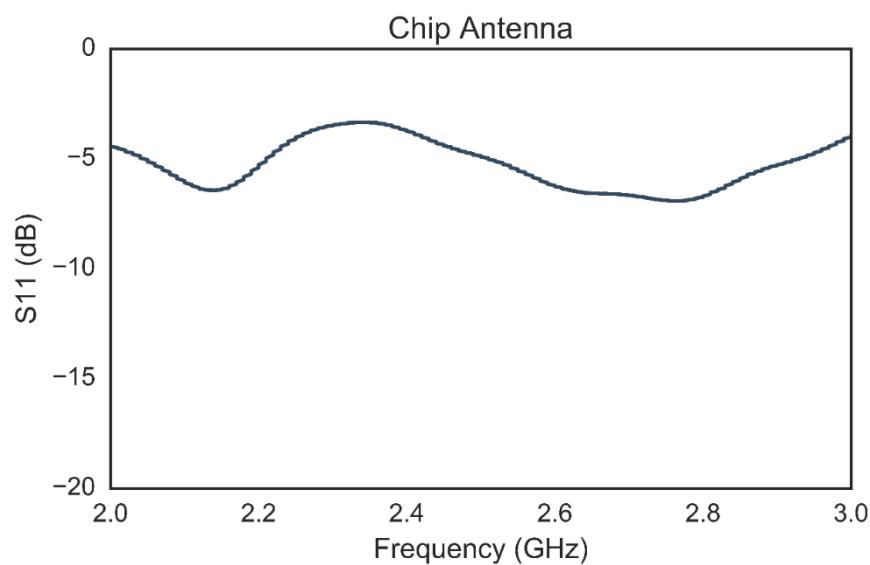
Wireless S4

Transmission Line Theory



Wireless S4

S11 Measurements with VNA

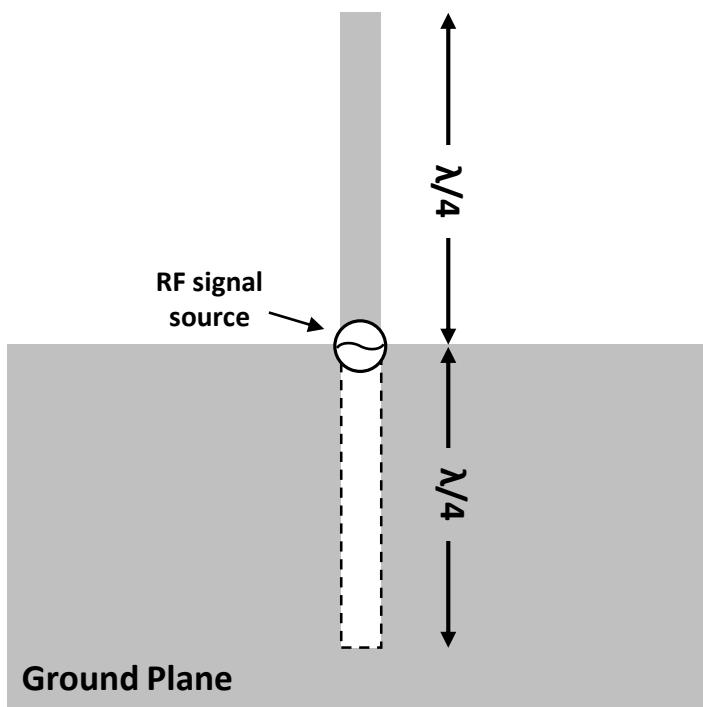


Smith chart:

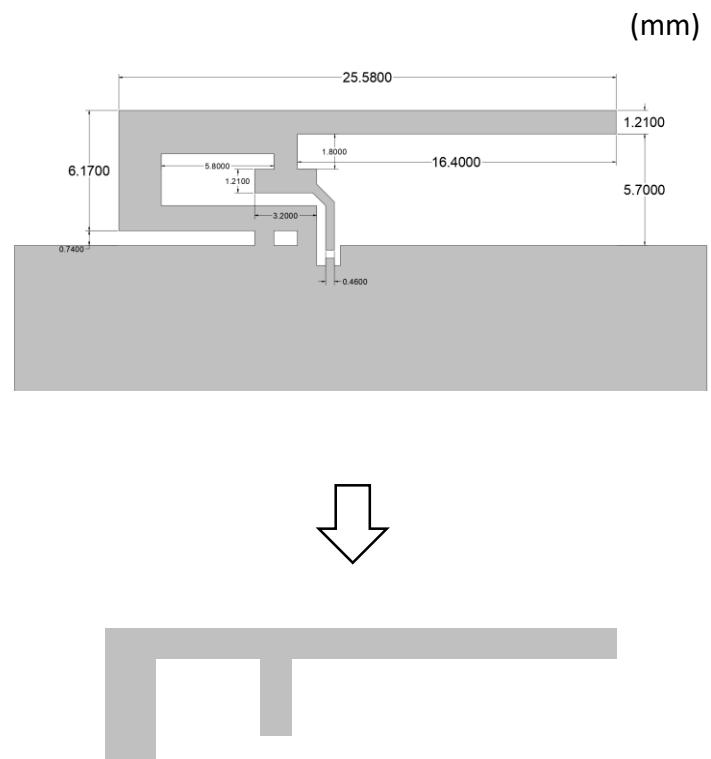
Graphical tool to plot the complex impedance $Z = R + jX$
R is the resistance and X is the reactance

Wireless S4

Inverted-F Antenna (IFA)

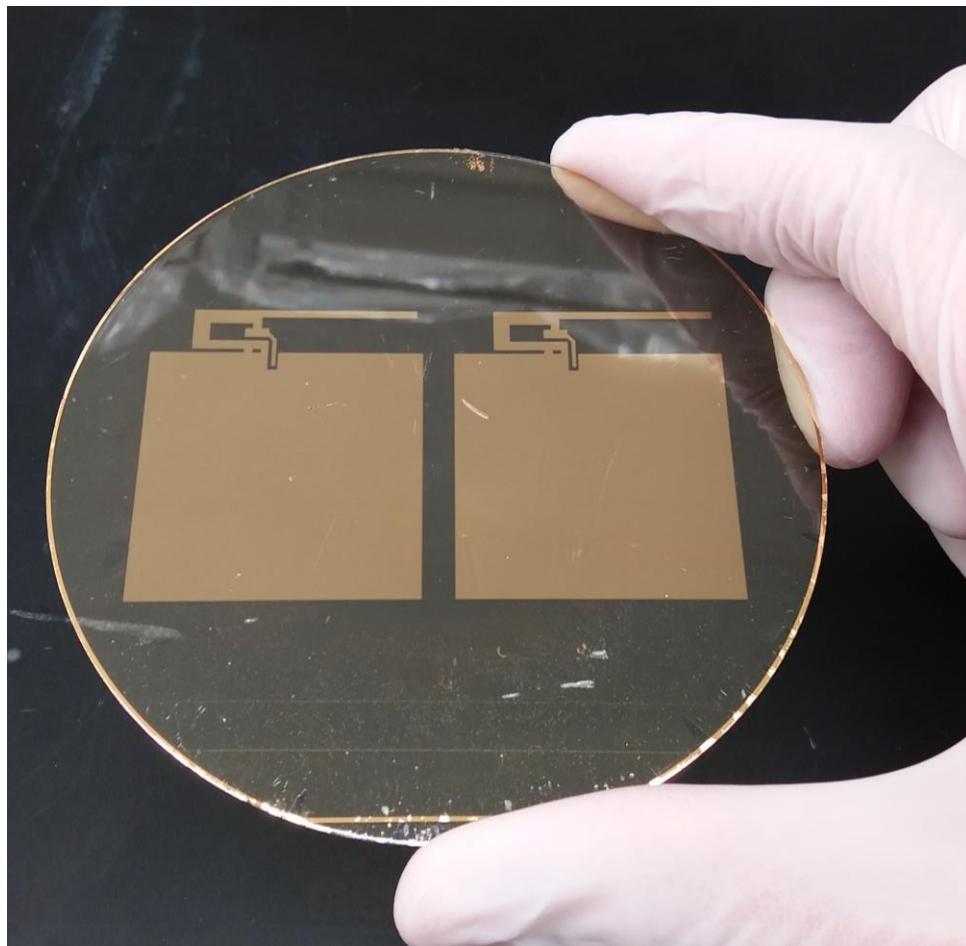


Texas Instruments' IFA



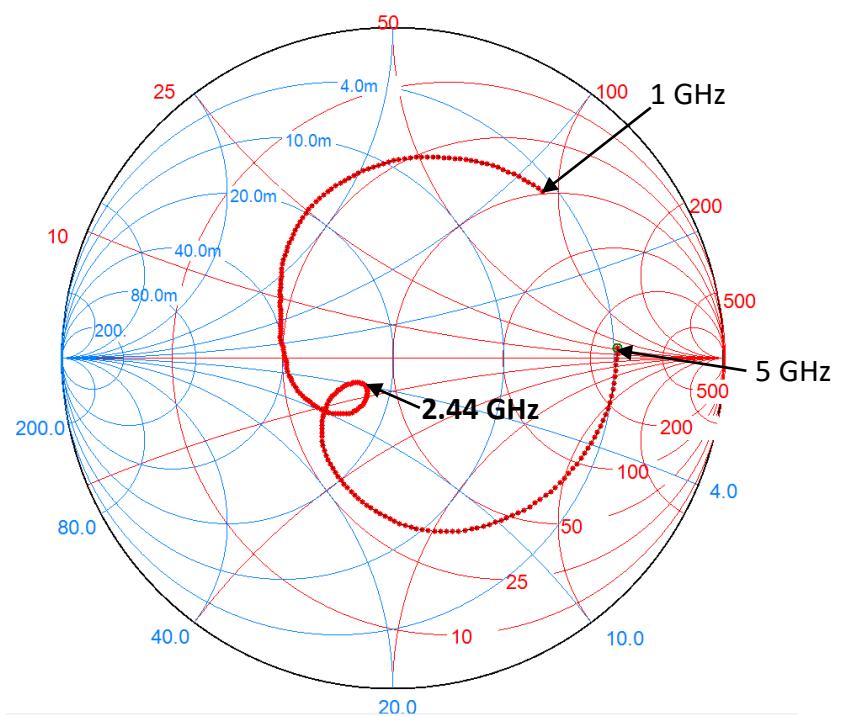
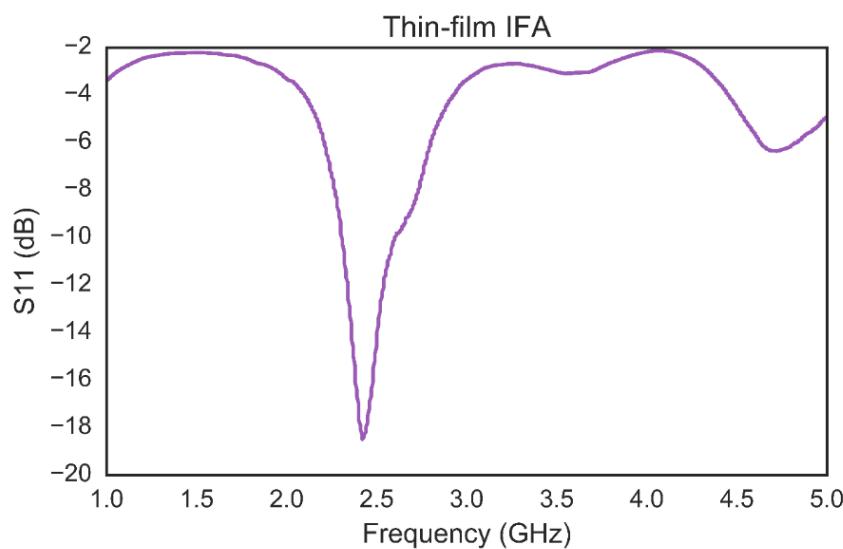
50 Ω is matched as long as the dimensions (hundreds of μm) are followed. Dielectric thickness does not matter.

Wireless S4



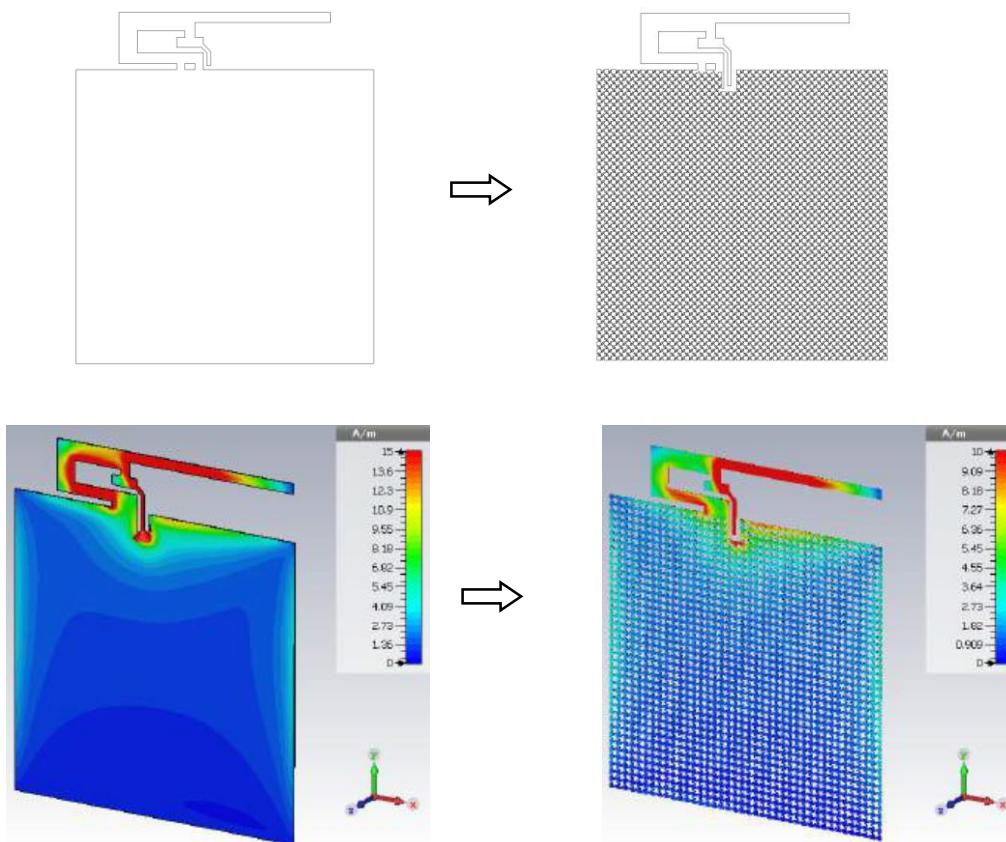
Wireless S4

S11 Measurements with VNA



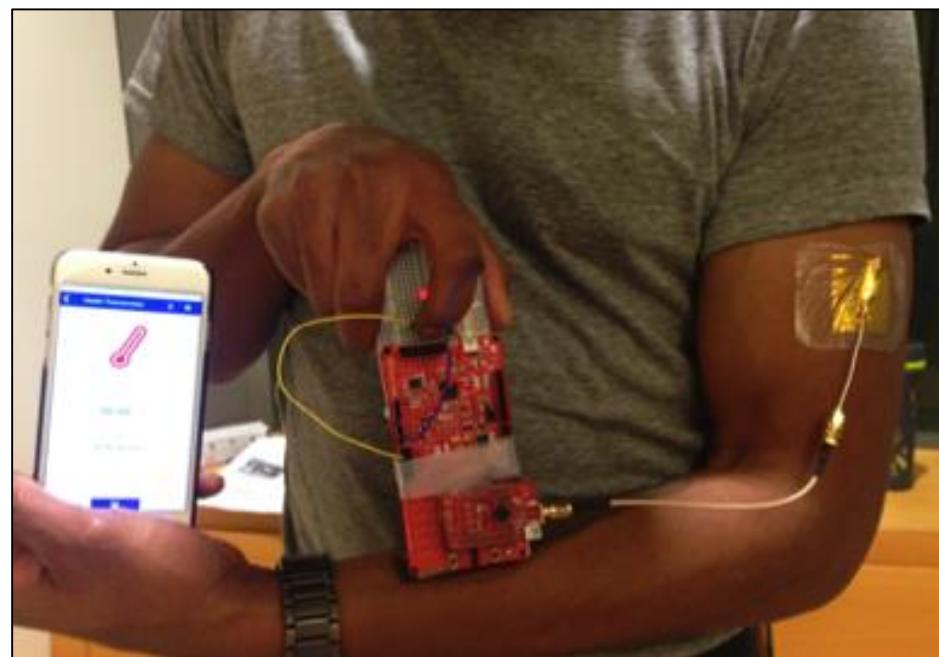
Wireless S4

Current Distribution



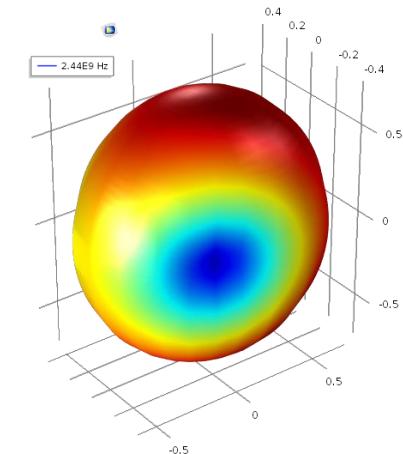
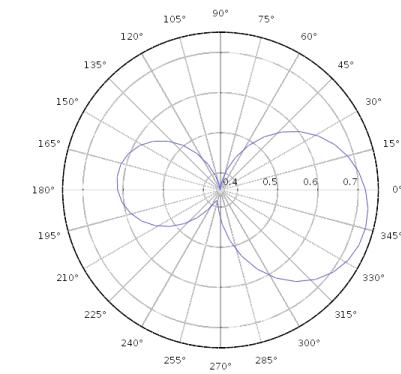
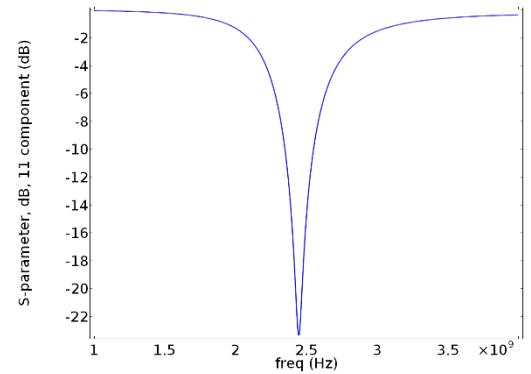
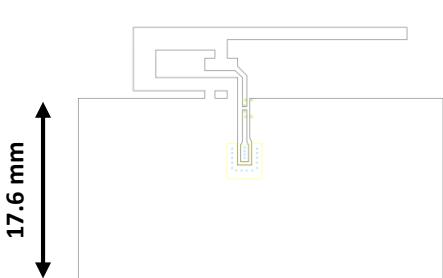
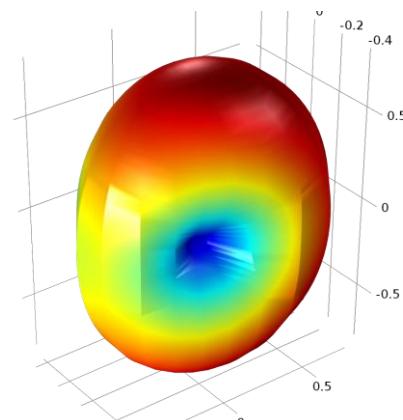
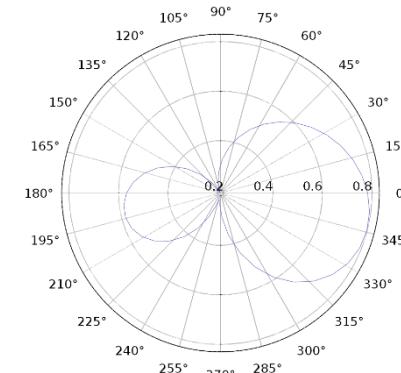
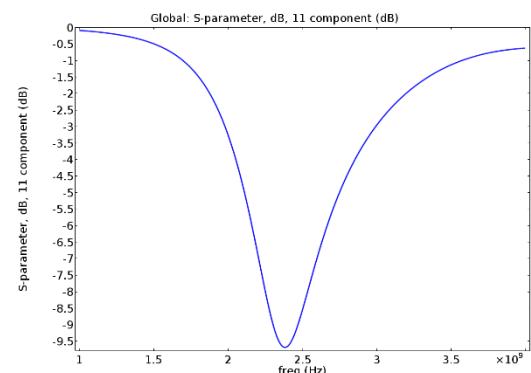
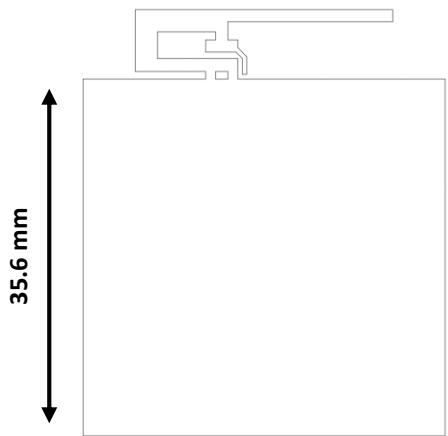
Wireless S4

Demonstration with BLE Development Kit



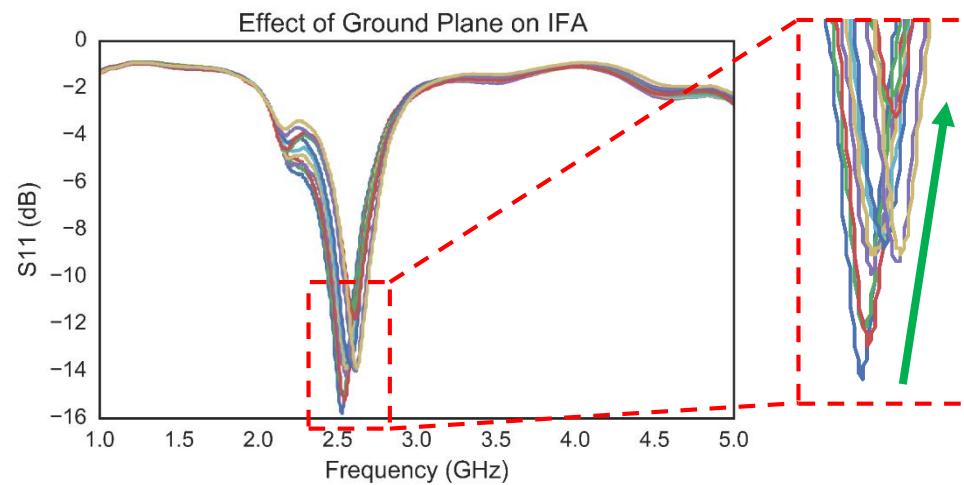
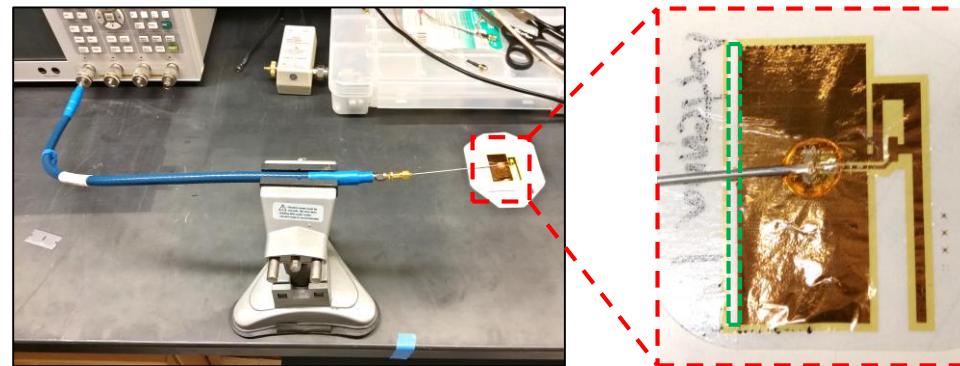
Wireless S4

Ground Plane Reduction (COMSOL simulation)



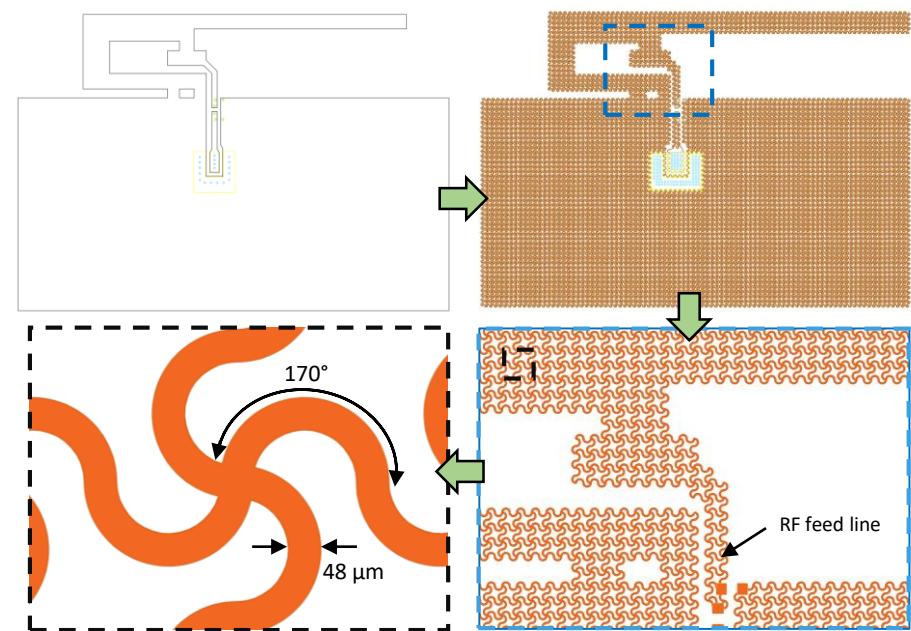
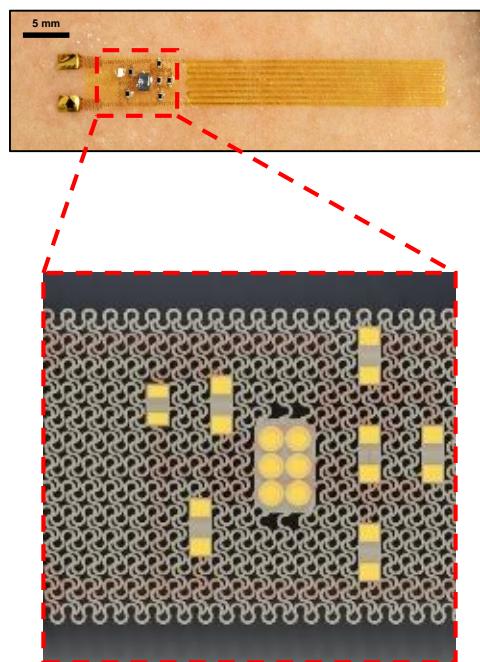
Wireless S4

Ground Plane Reduction (1/2 of original)



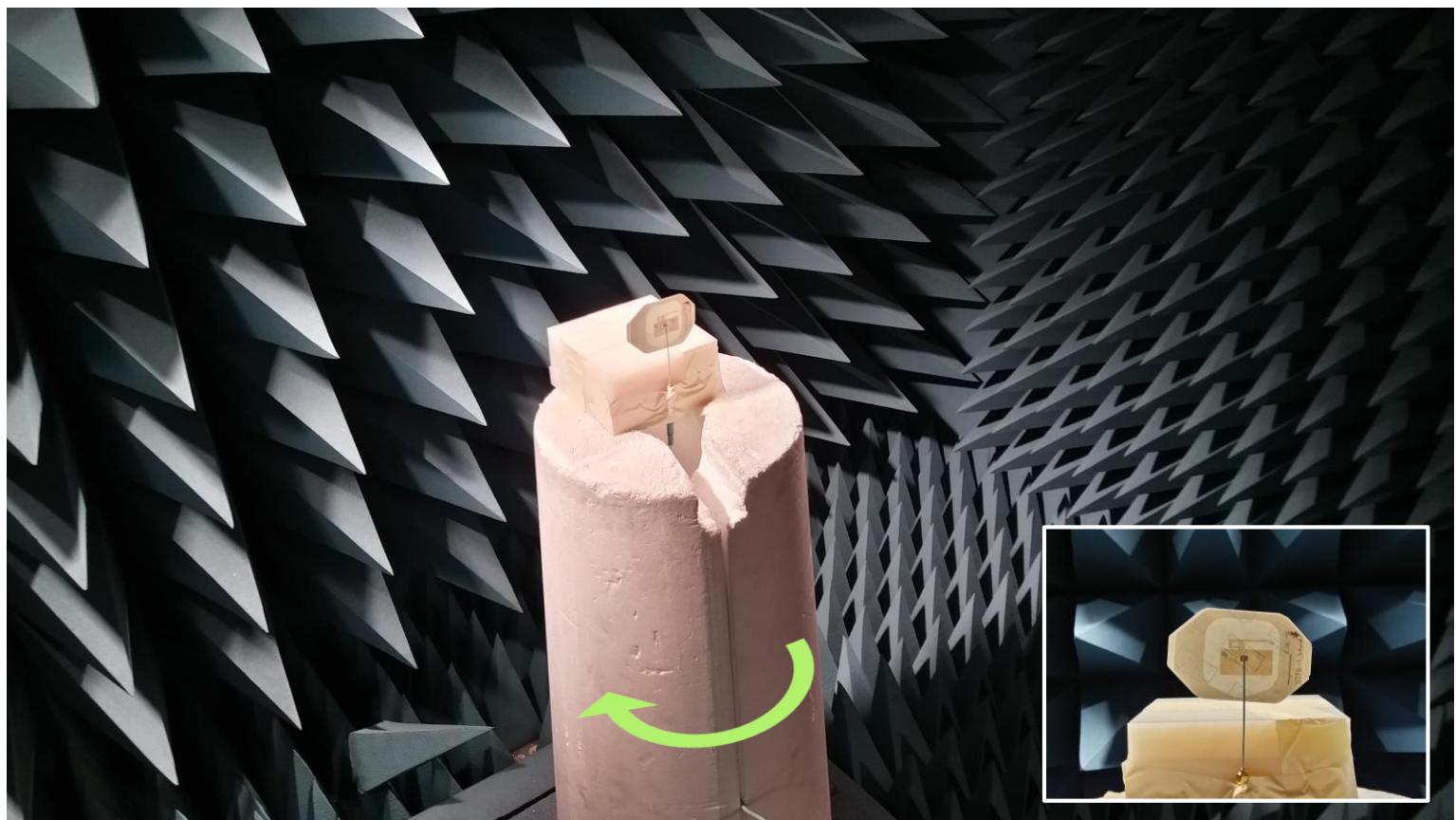
Stretchable Inverted-F Antenna (SIFA)

Applying the Mesh Network Layout



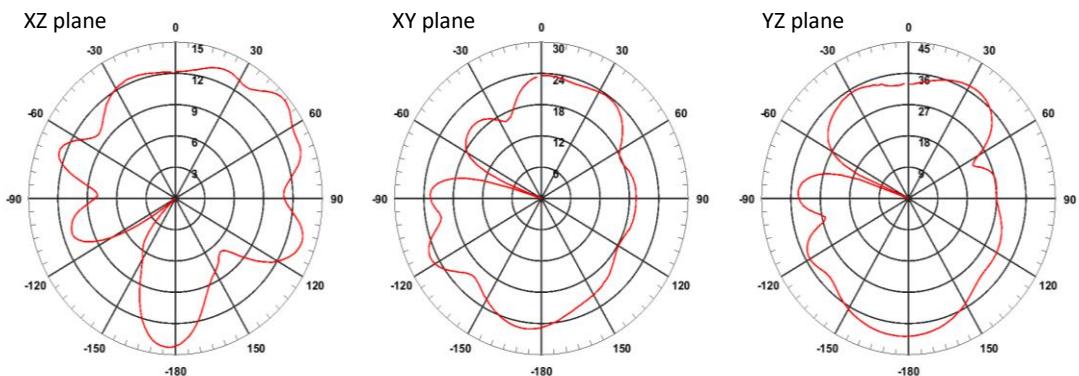
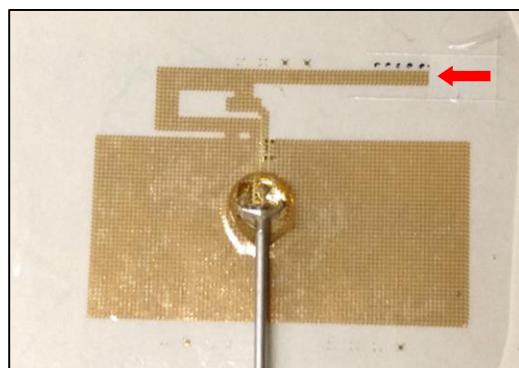
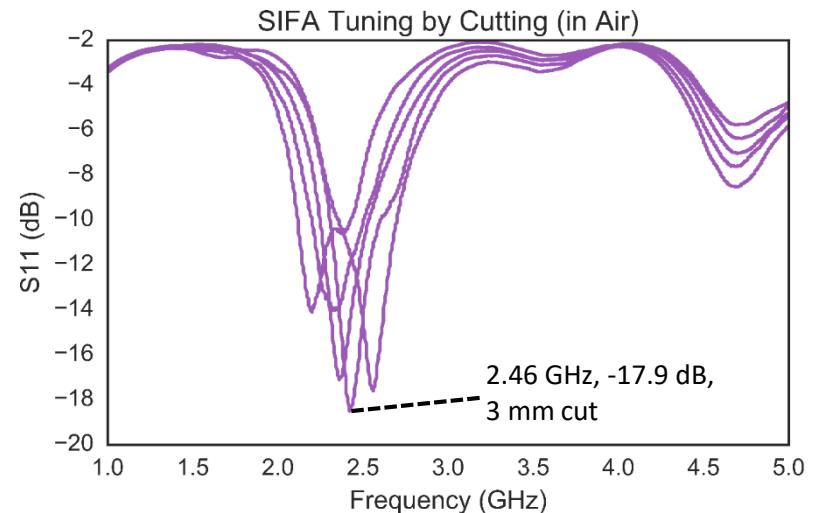
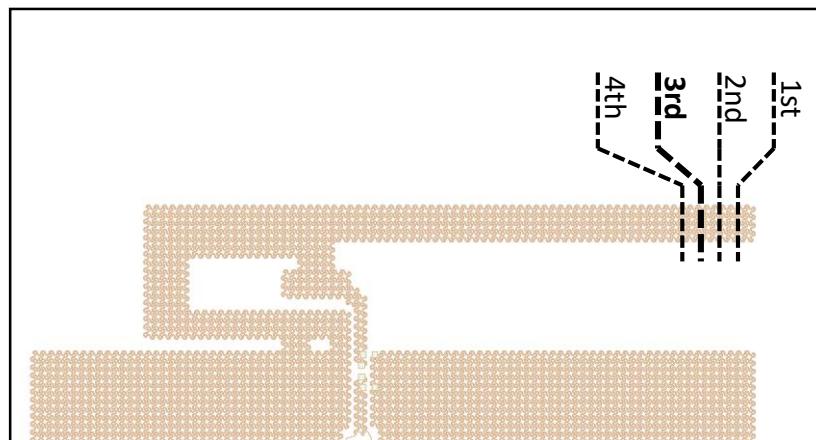
Stretchable Inverted-F Antenna (SIFA)

Anechoic Chamber Measurement



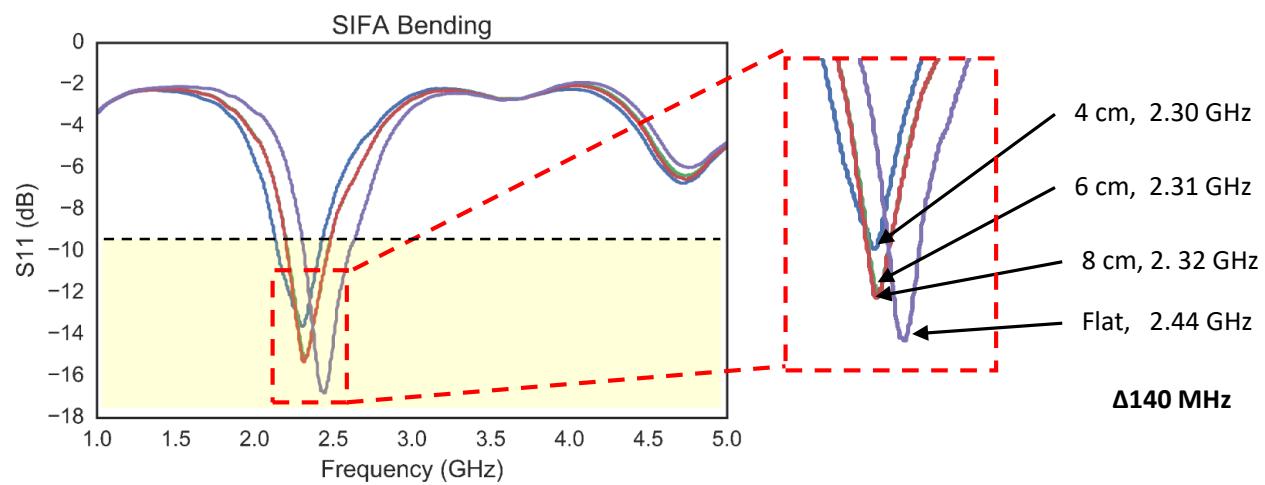
Stretchable Inverted-F Antenna (SIFA)

Tuning SIFA by Cutting



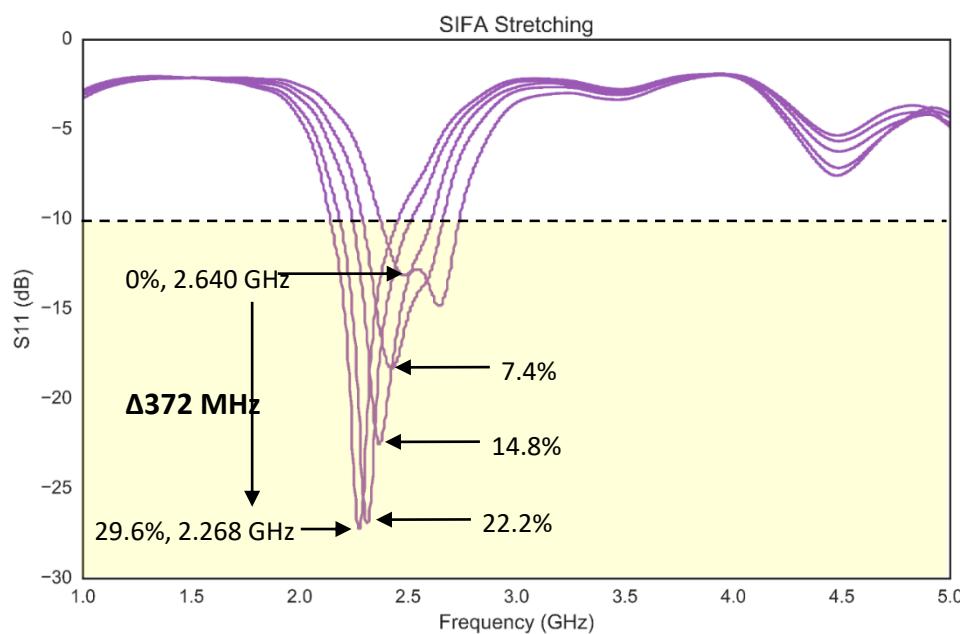
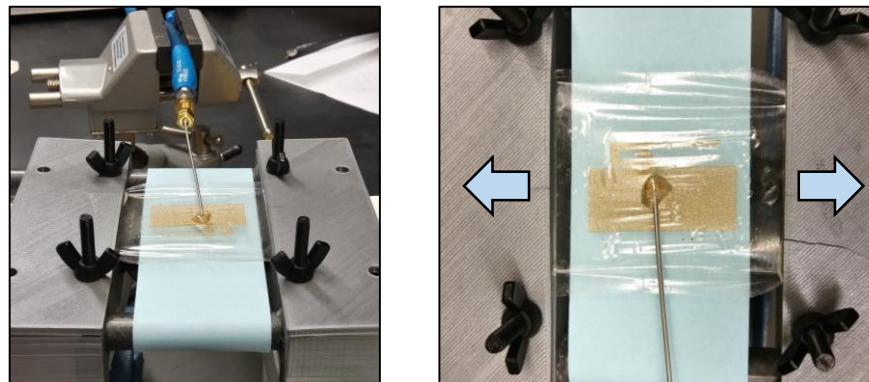
Stretchable Inverted-F Antenna (SIFA)

Effect of Bending



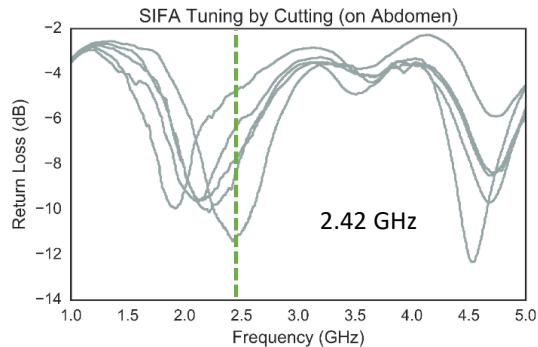
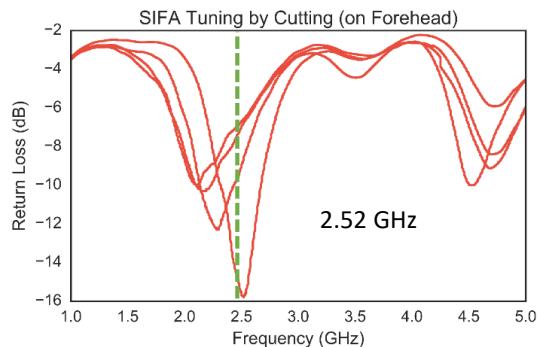
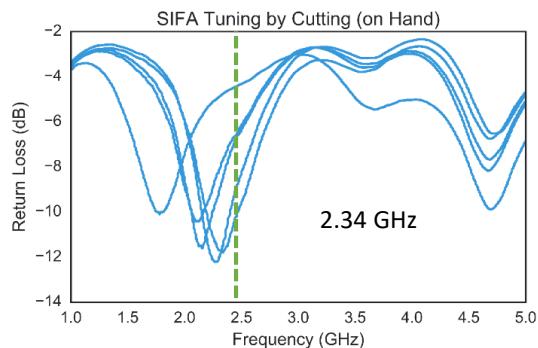
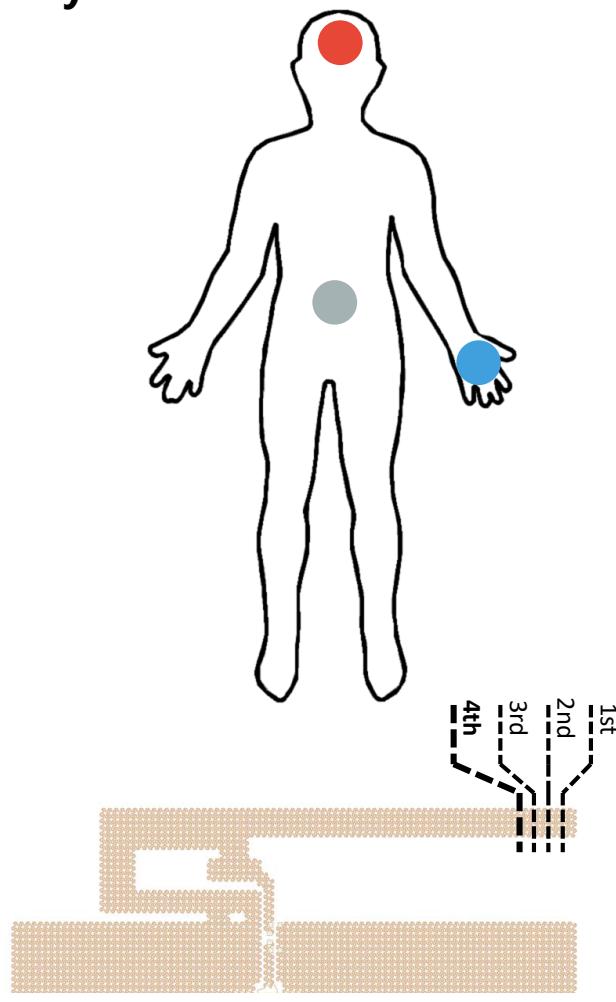
Stretchable Inverted-F Antenna (SIFA)

Effect of Stretching

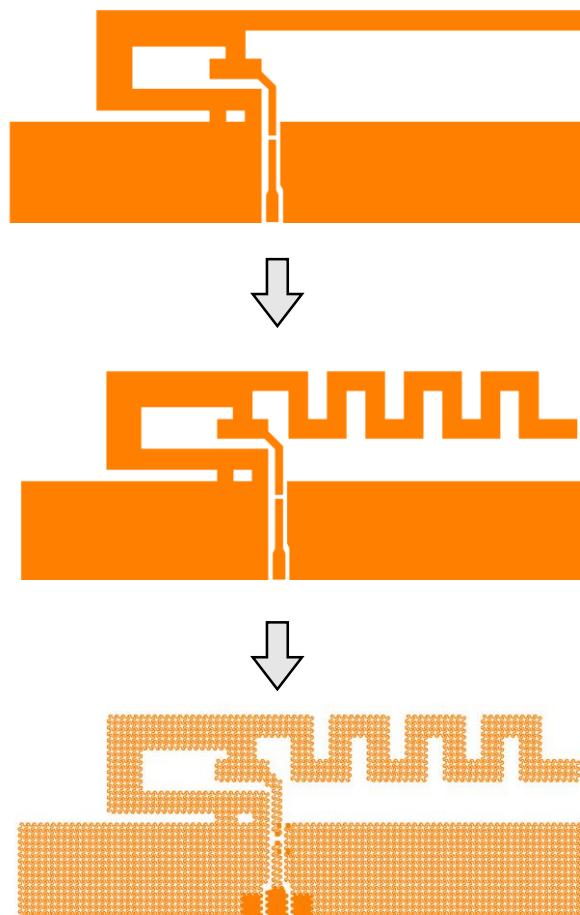


Stretchable Inverted-F Antenna (SIFA)

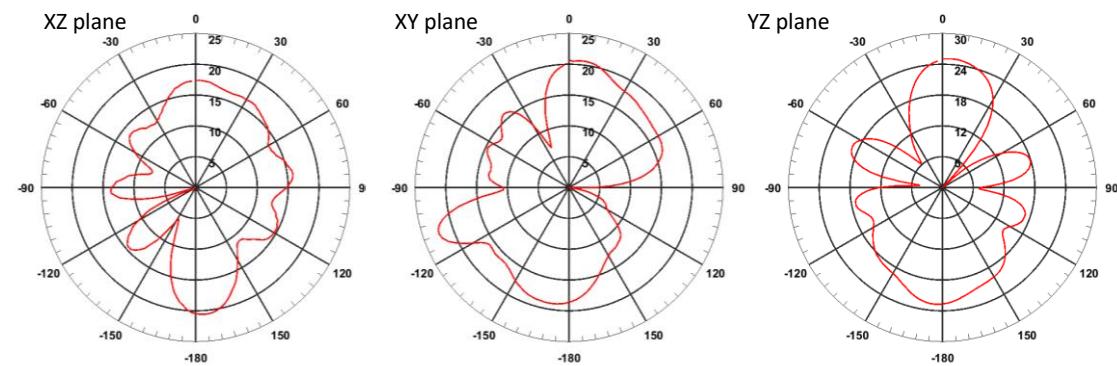
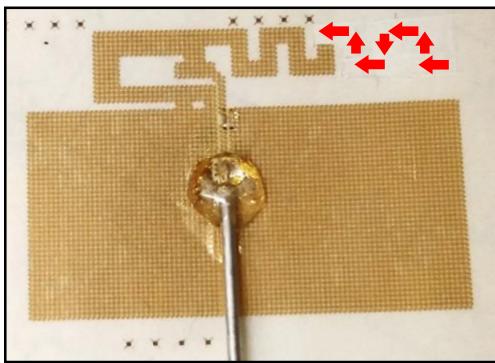
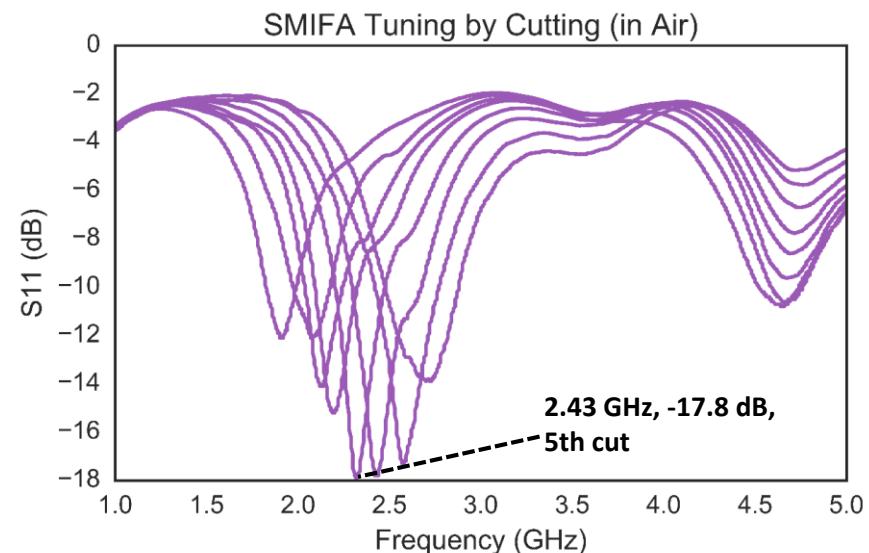
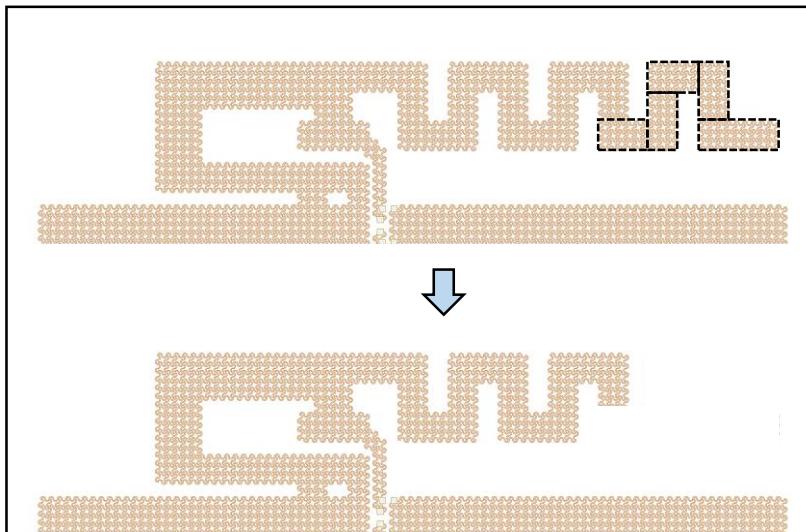
Effect of On-body Application



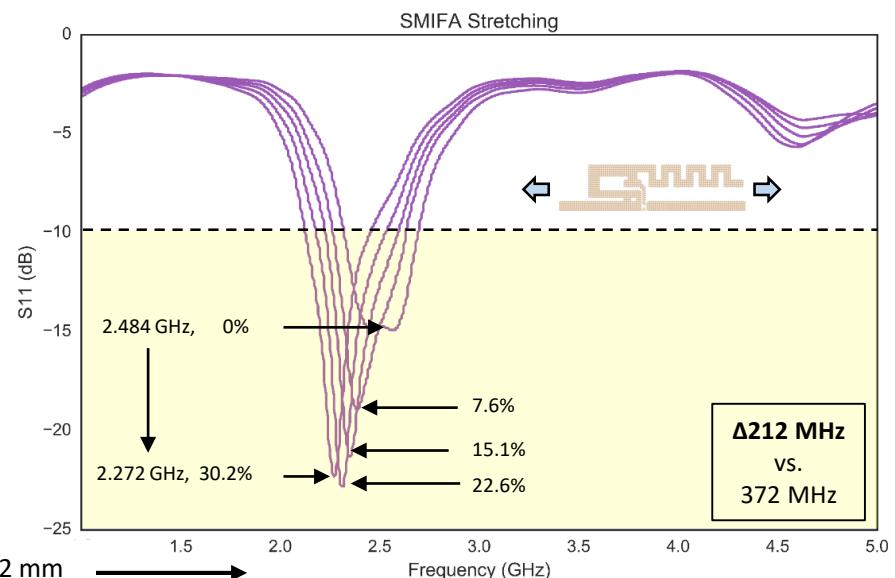
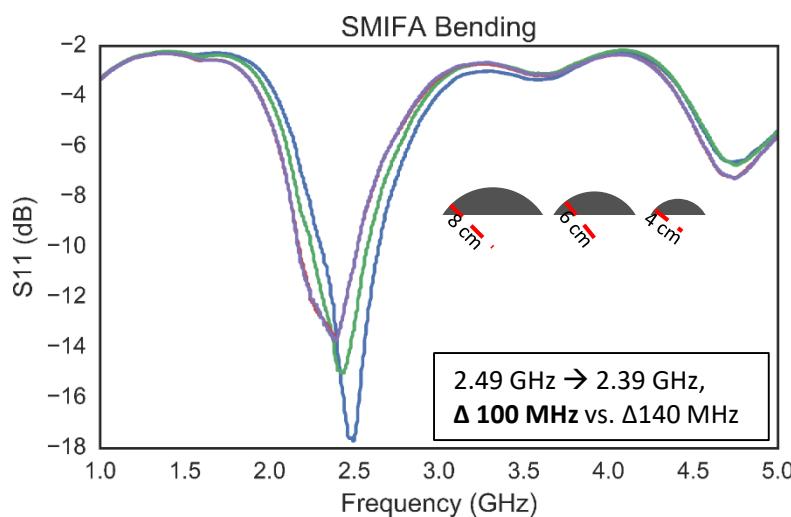
Stretchable Meandered Inverted-F Antenna (SMIFA)



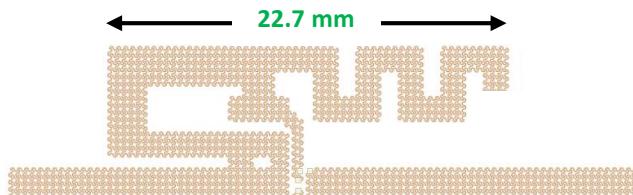
Stretchable Meandered Inverted-F Antenna (SMIFA)



Stretchable Meandered Inverted-F Antenna (SMIFA)



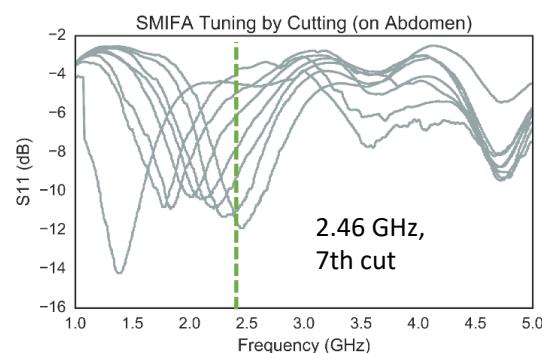
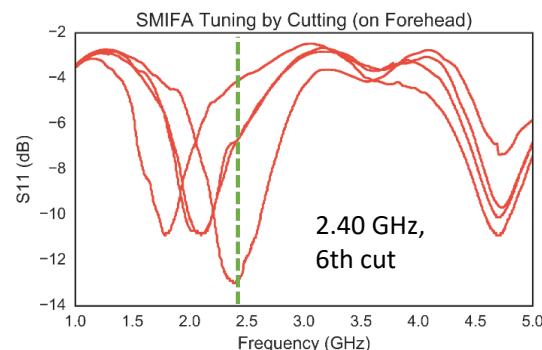
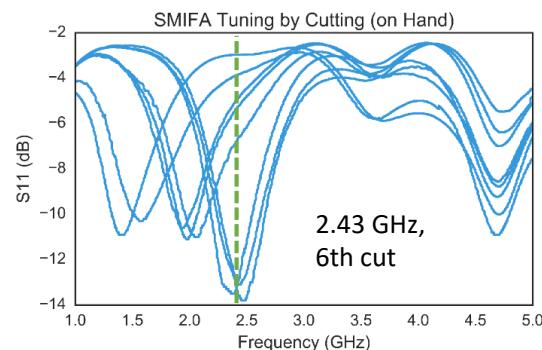
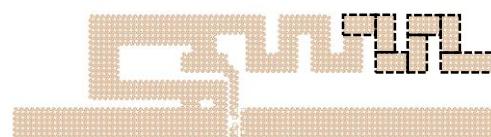
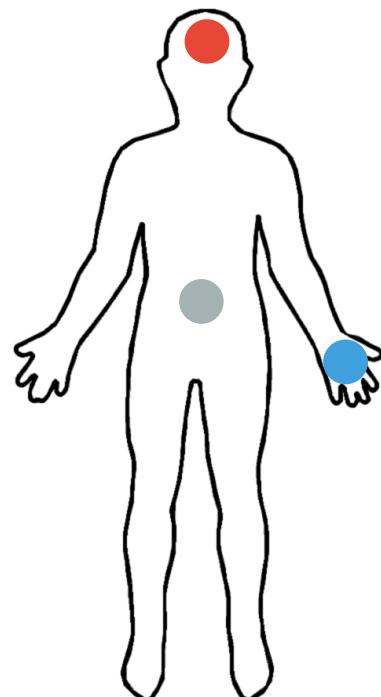
26.2 mm



22.7 mm

Stretchable Meandered Inverted-F Antenna (SMIFA)

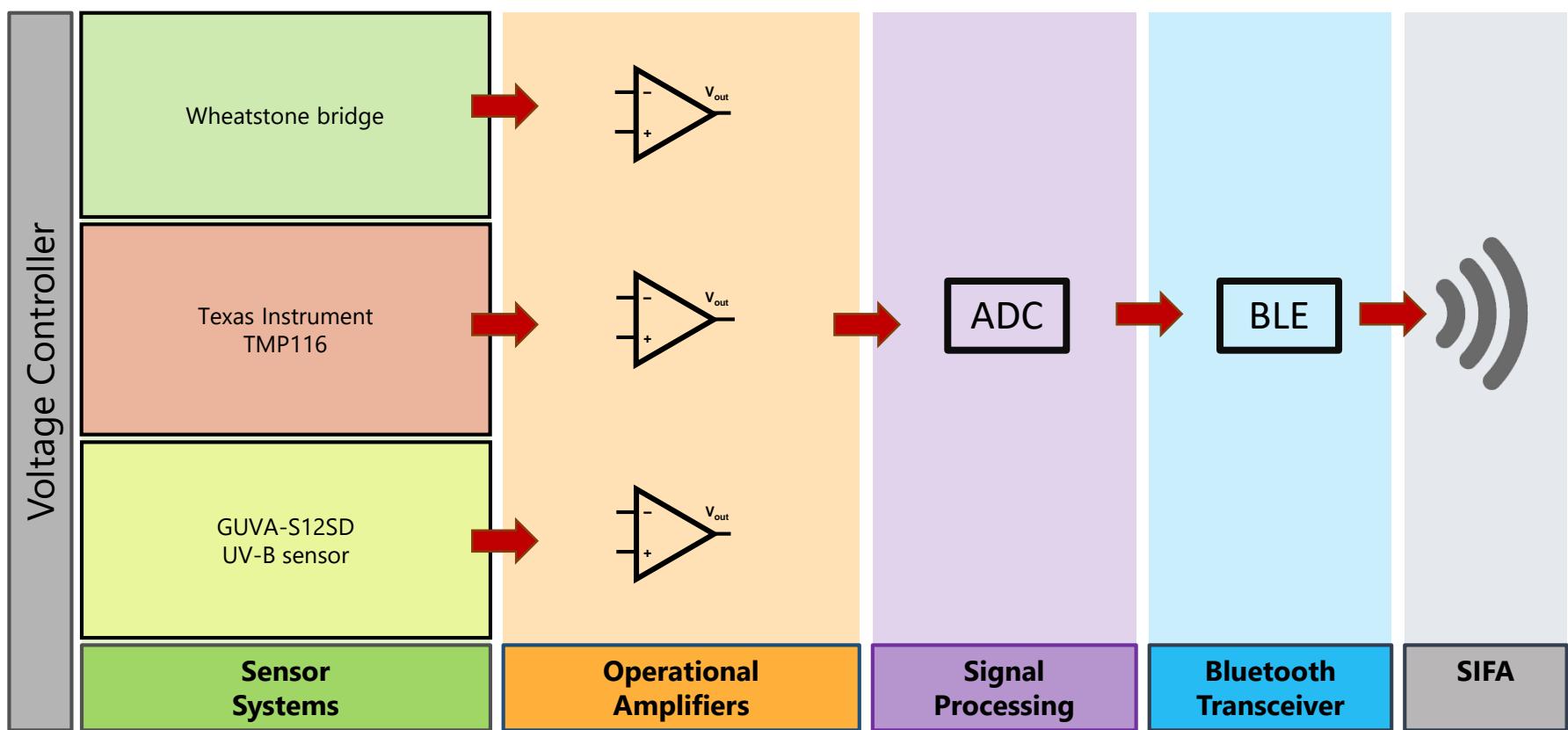
Effect of On-body Application



Overview

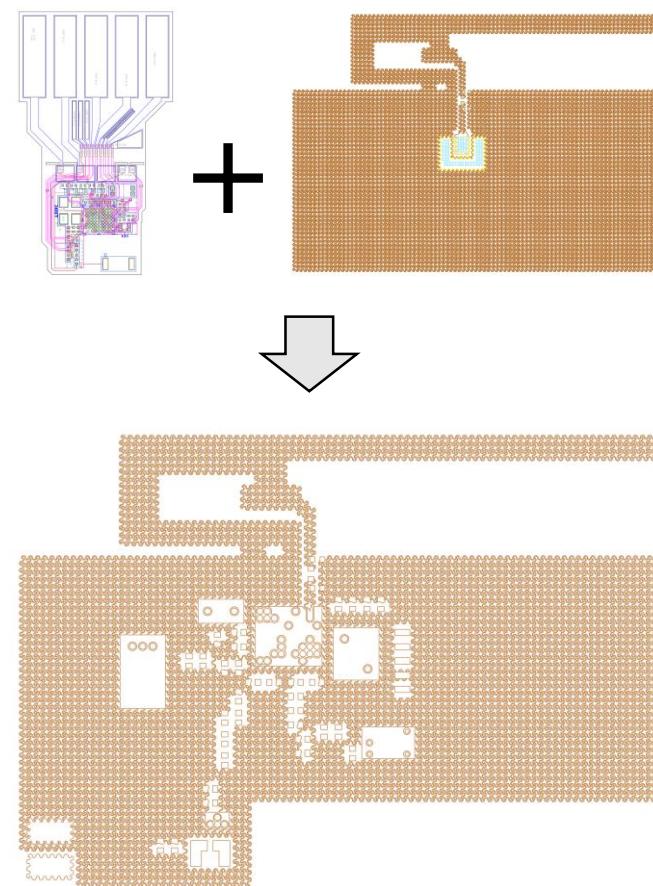
- About Me
- Motivation
- Development of Solderable Stretchable Systems
- Respiration Sensing Using Solderable Stretchable Sensing System (S4)
- Wireless S4
- Wireless S4 with an Integrated Stretchable Antenna
- Next Steps & Conclusion

S4-BLE-SIFA



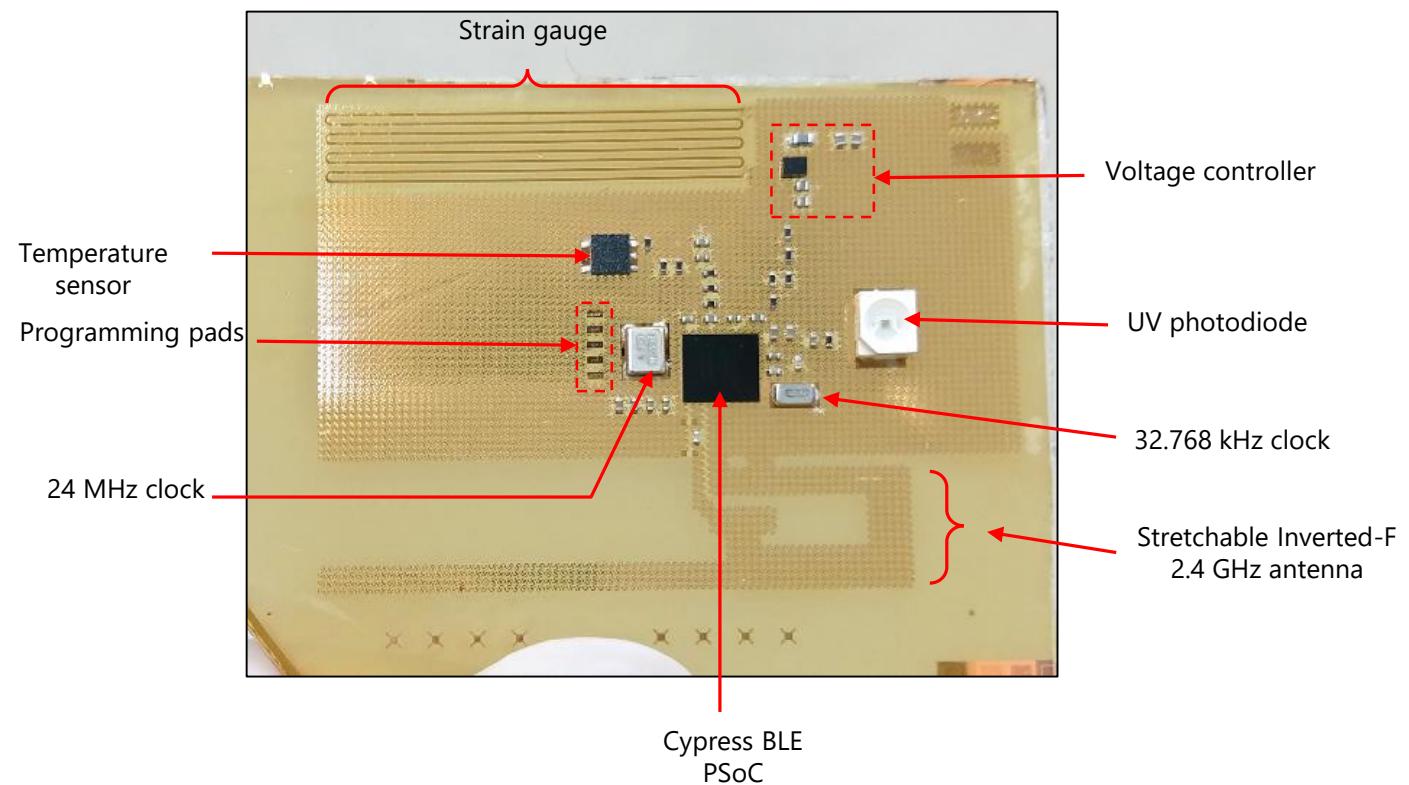
S4-BLE-SIFA

SIFA Integration with Ground Plane



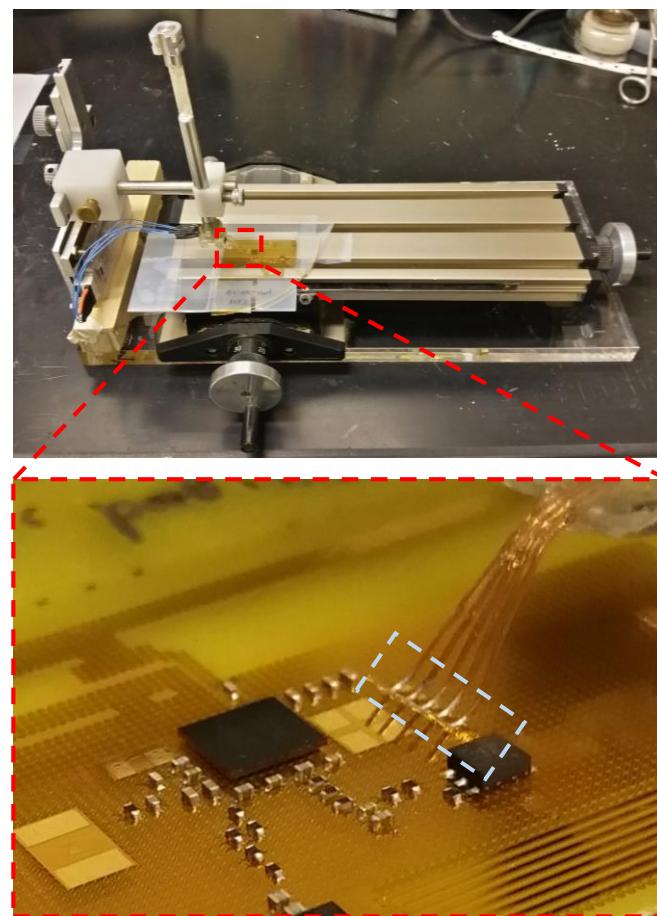
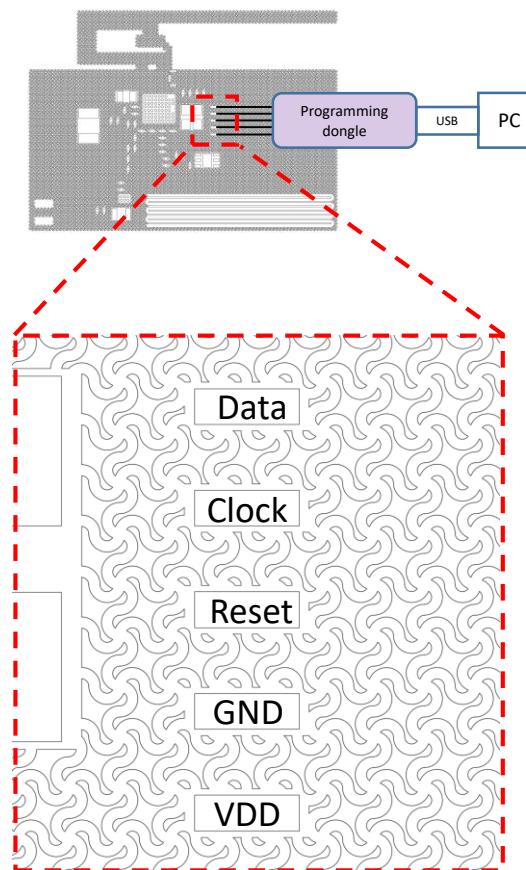
S4-BLE-SIFA

Assembly

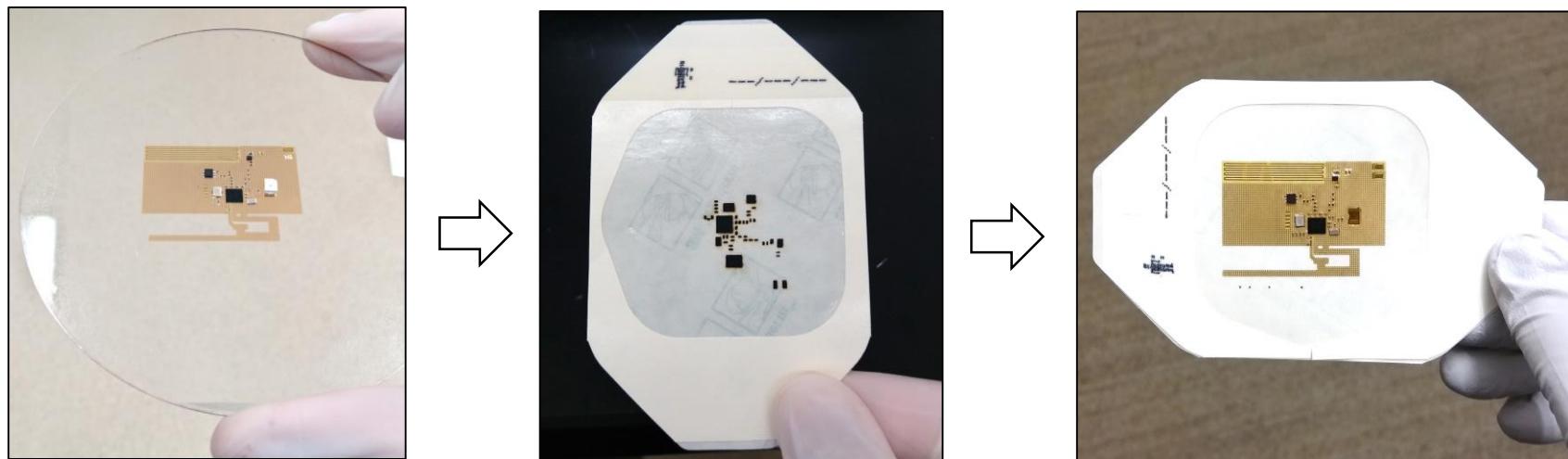


S4-BLE-SIFA

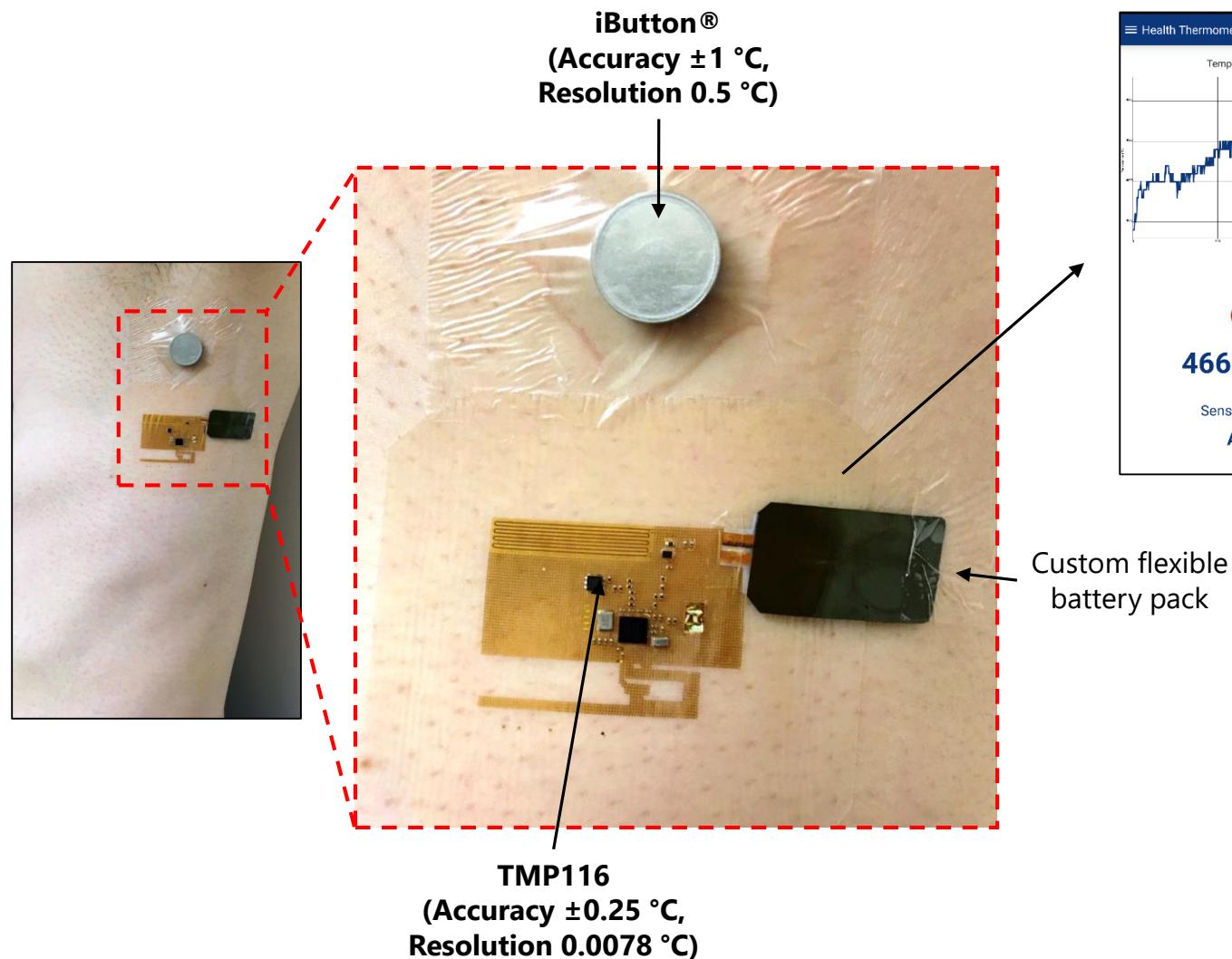
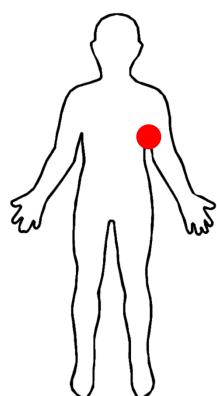
Programming with curved Cu wires



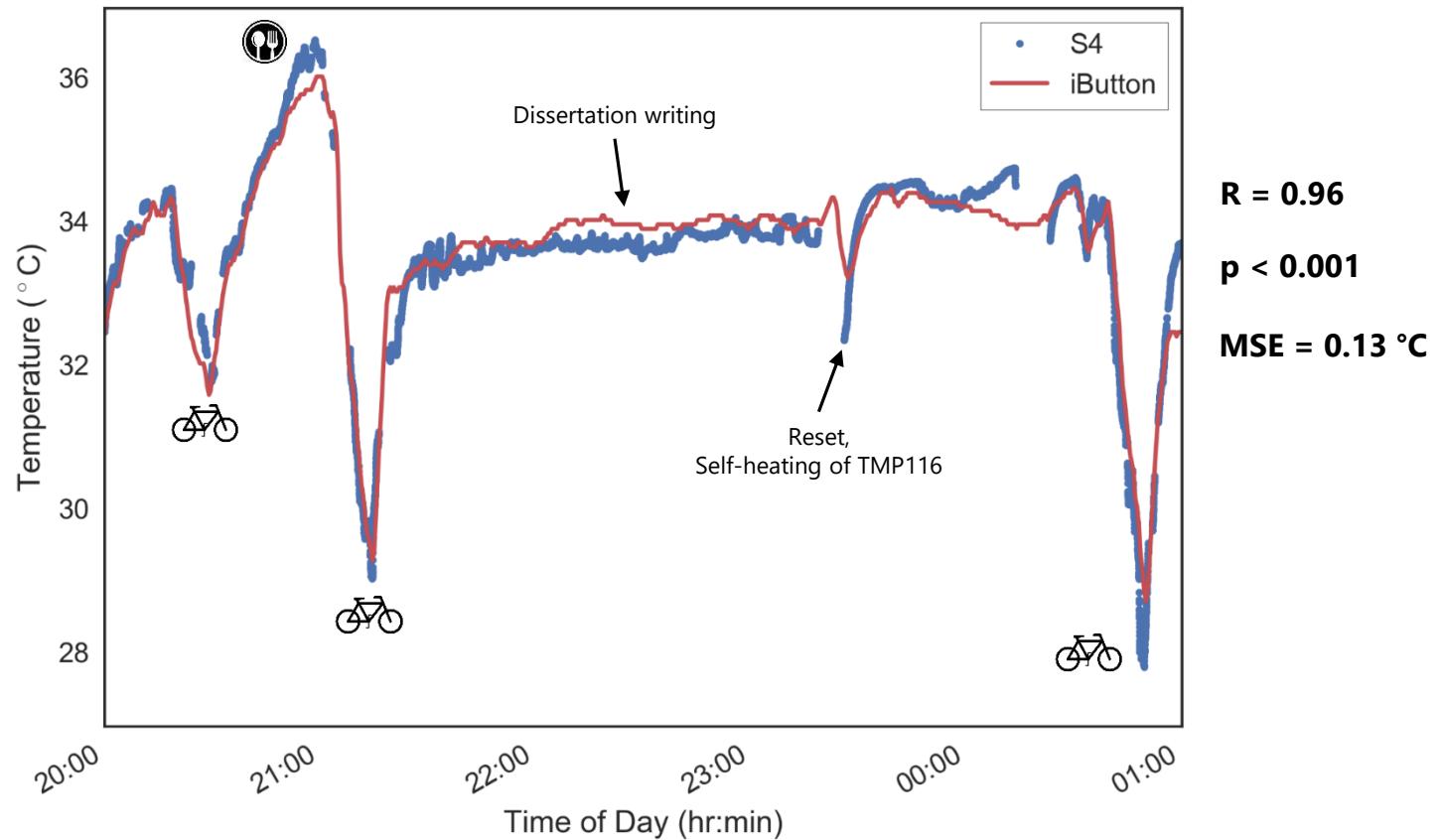
Validation of Continuous Temperature Sensing



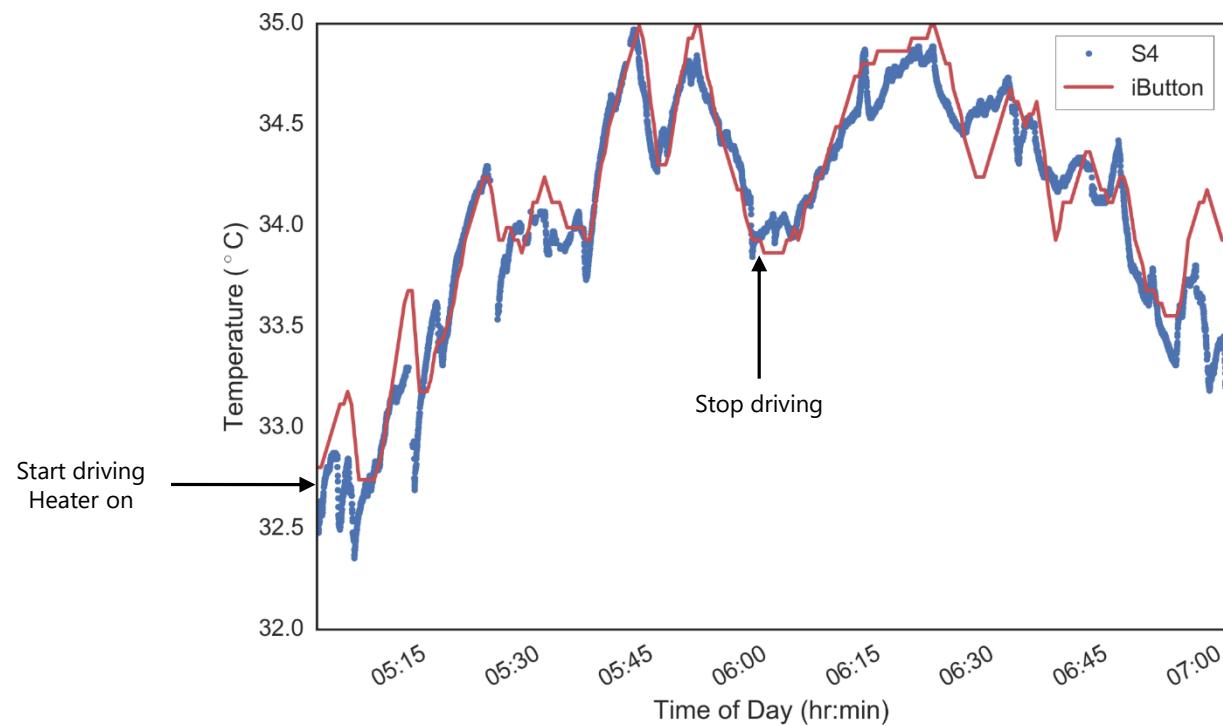
Validity Testing for Temperature Monitoring



Validity Testing for Temperature Monitoring



Validity Testing for Temperature Monitoring



$R = 0.95$

$p < 0.001$

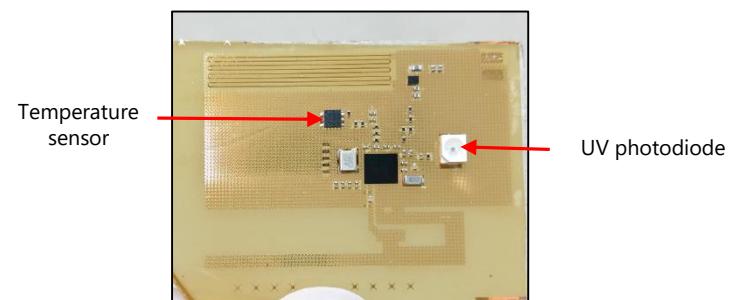
$MSE = 0.04\text{ °C}$

Next Steps

Monitoring UV exposure and thermoregulations in children

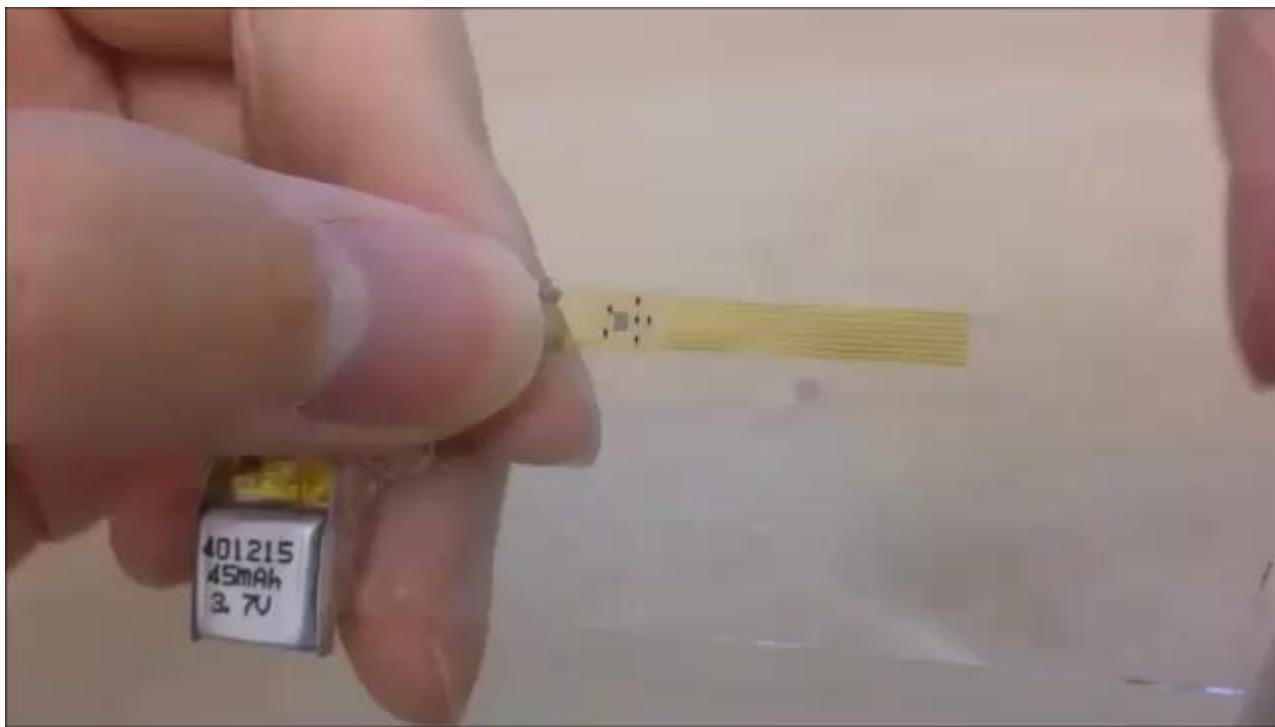


Dr. Jennifer Vanos

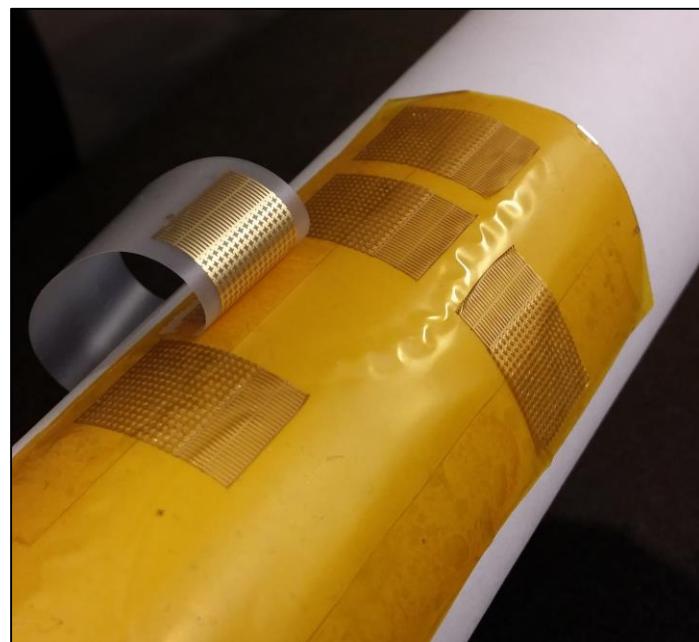


Next Steps

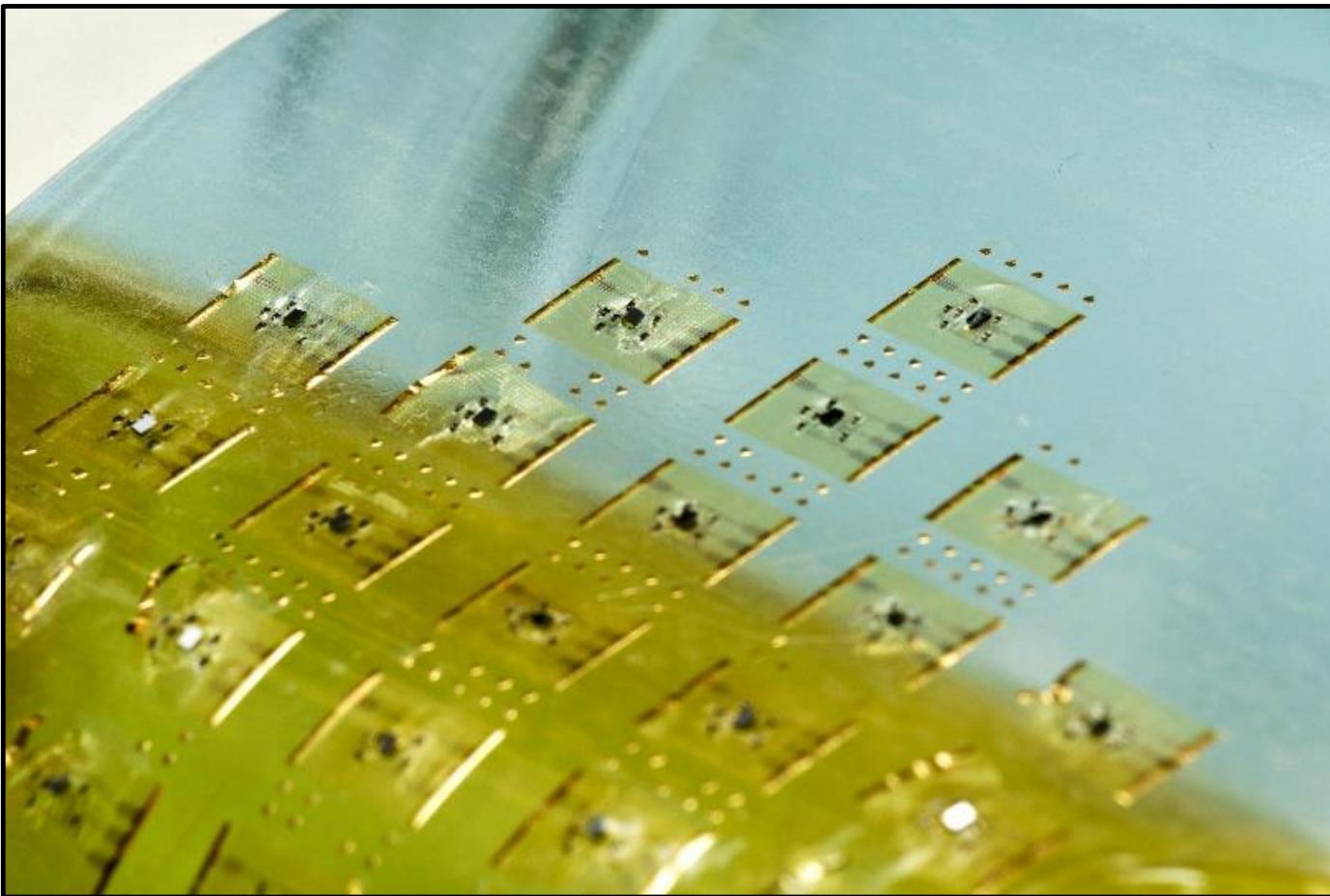
Alternative Packaging Materials



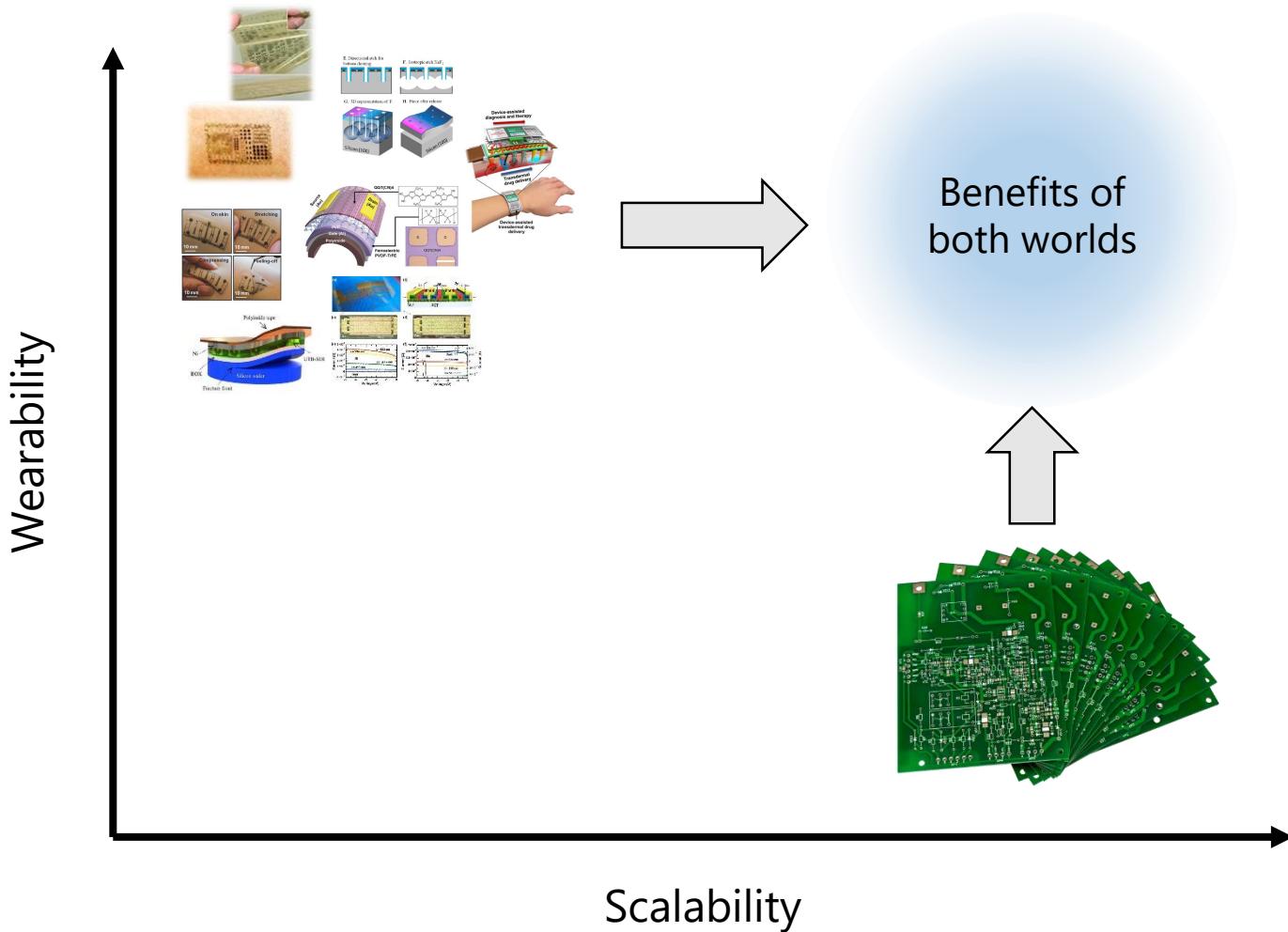
Next Steps



Next Steps



Conclusion



Conclusion

Energy Source

Thank you