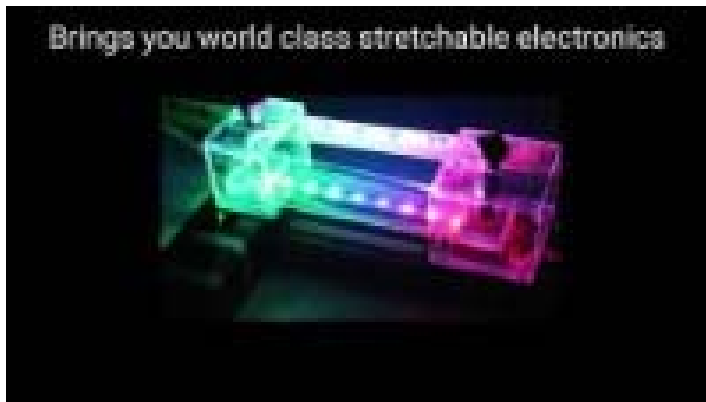


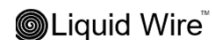
Liquid Wire, Inc.

- Founded in Portland, OR in 2016
- World leader in liquid metal wiring solutions
- Diverse team with backgrounds in advanced electronics, textiles, materials science, polymers and manufacturing
- Member of NextFlex flexible electronics consortium
- Ongoing partnerships with both industrial and academic teams

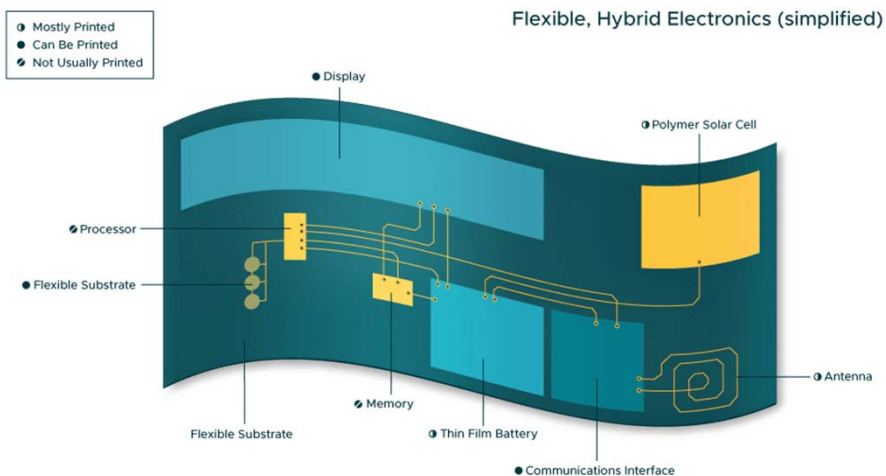


1

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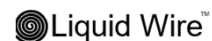
Flexible Hybrid Electronics



A depiction of an FHE device by the NextFlex consortium.

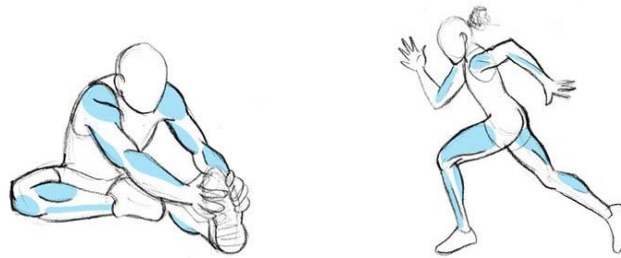
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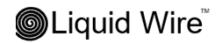
Matching Human Motion

Wearable applications benefit when electronics are able to conform directly to a user's motion, rather than a user putting up with an electronics package.



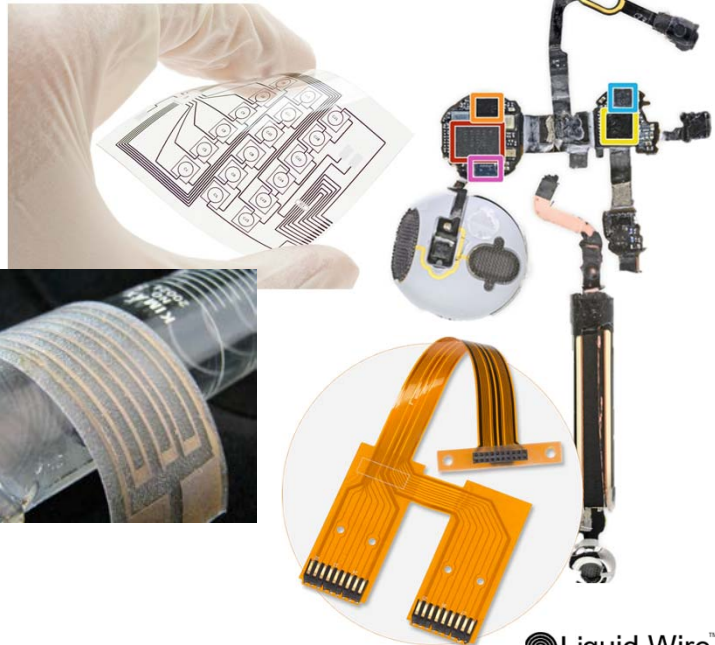
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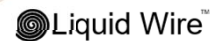
Printed Flex Circuits

- Many solutions for flexible circuitry
 - Polyimide
 - Copper foil
 - Printed silver inks
 - Conductive composites
 - Serpentine pathways



4

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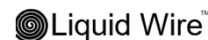
Introduction to Liquid Metals

- Gallium and gallium alloys have been extensively researched due to their interesting properties including:
 - Low melting point
 - High electrical conductivity
 - Low viscosity
 - Surface oxide

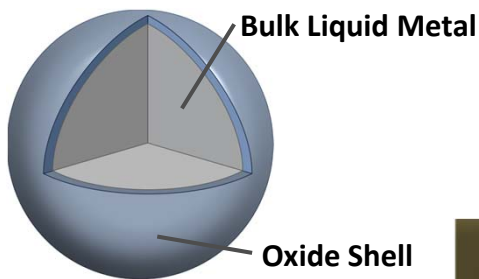


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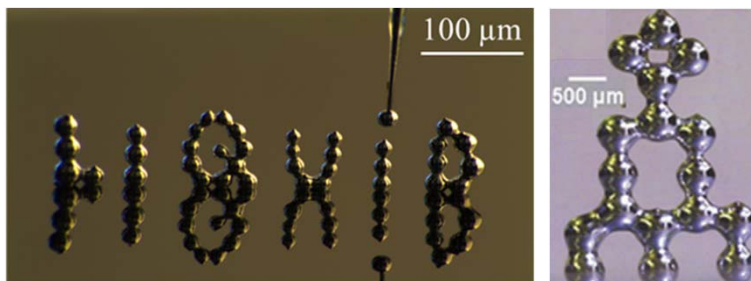
Oxides in Liquid Metals



- Oxide shell forms spontaneously in air
- Measured to be ~2-5 nm thick
- Provides mechanical stability
- Enables patterning of liquid metals in 2D and 3D



Chiechi, et al. *Angew. Chem.* (2007)



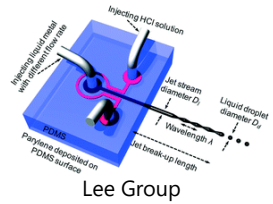
Ladd, et al. *Adv. Mat.* (2013)

6

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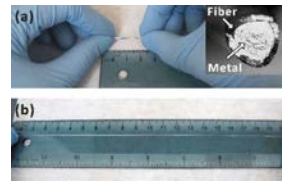
Academic Efforts



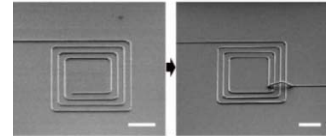
Lee Group
Chonnam National University



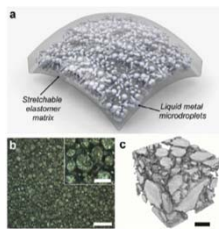
Air Force Research Labs



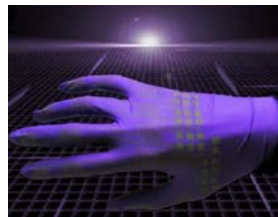
Dickey Group
North Carolina State University



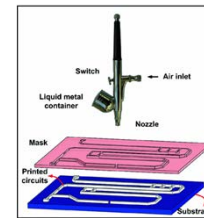
Park Group
Yonsei University



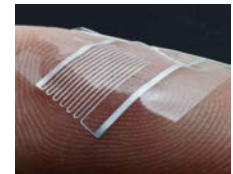
Majidi Group
Carnegie Mellon University



Kramer-Bottiglio Group
Yale University



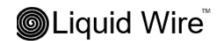
Liu Group
Chinese Academy of Sciences & Tsinghua University



Lacour Group
EPFL

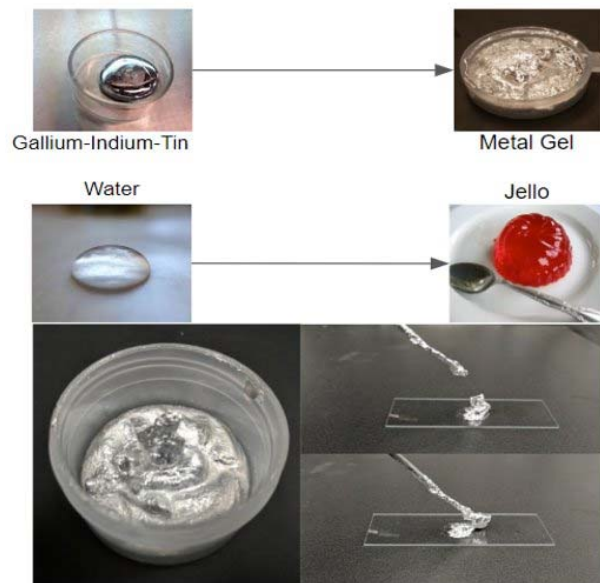
7

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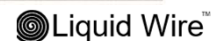
Metal Gel

- Proprietary, patented alloy of gallium-indium-tin
- Non-toxic, RoHS compliant
- High viscosity, shear thinning fluid
- Directly printable
- Flows and stretches with substrate
- Substrate and geometry agnostic
- Wide operating and processing temperature range
- Functions as both a conductor and a linear stretch/pressure sensor



8


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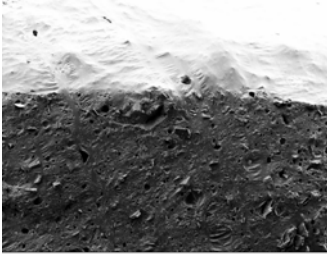
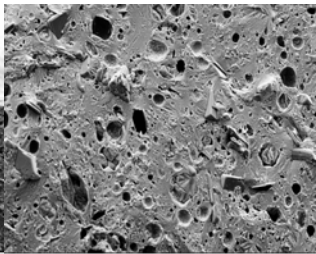
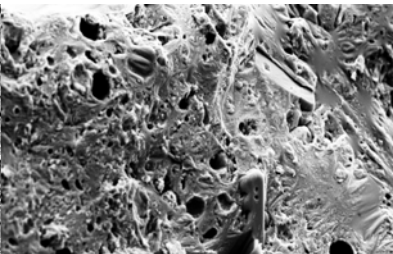


MW1
MD2
MW4
TNID1
MW5


Liquid Wire™ Tuned Rheology

- Oxides are distributed and crosslinked in the bulk of the liquid metal
- Oxides represent less than 1% of the metal gel
- Solid micron scale particles impart flow control
- Rheologically a Bingham Plastic
- Amorphous and self similar down to nanoscale



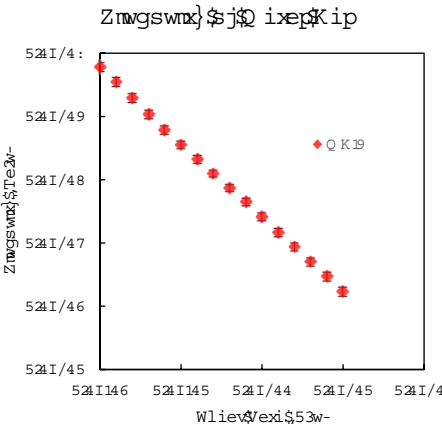




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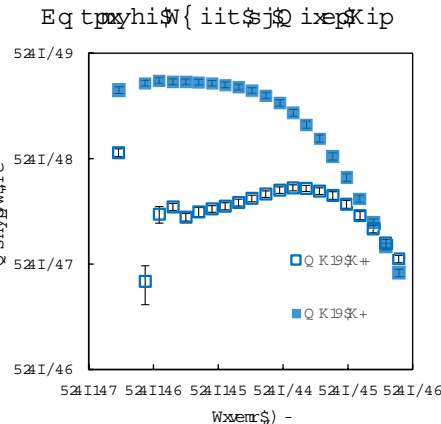


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Rheology of Metal Gel

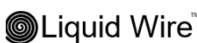


Znagswax\$}j\$Q i\$e\$K i\$P\$



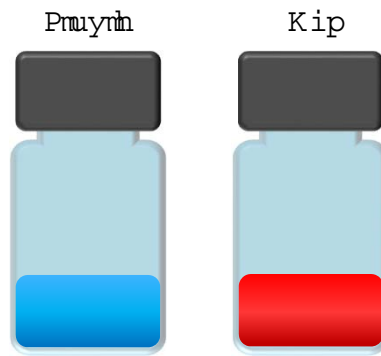
Eq t\$y\$hi\$N { iit\$}j\$Q i\$e\$K i\$P\$

Metal gel is a conductive, shear-thinning fluid with a yield stress.



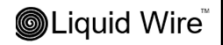
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Liquid Metal vs. Metal Gel

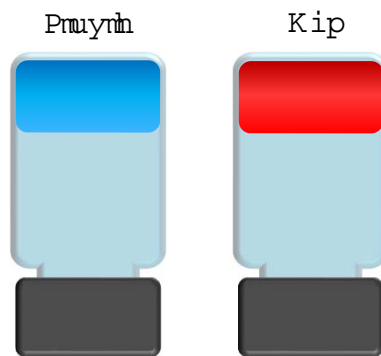


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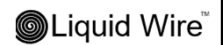


Liquid Metal vs. Metal Gel

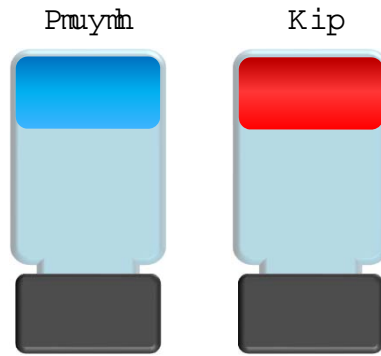


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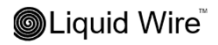


Liquid Metal vs. Metal Gel

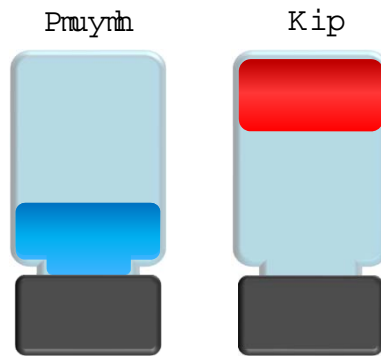


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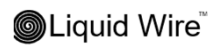


Liquid Metal vs. Metal Gel

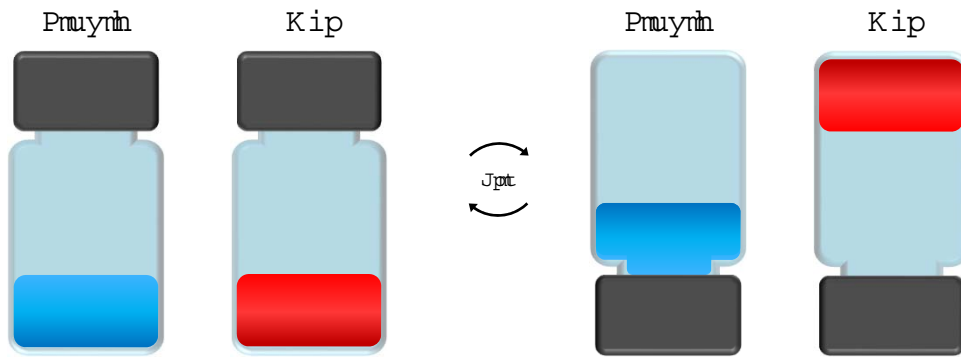


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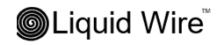


Liquid Metal vs. Metal Gel

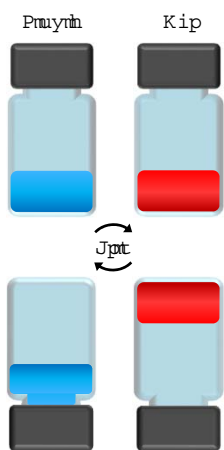


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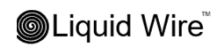


Liquid Metal vs. Metal Gel



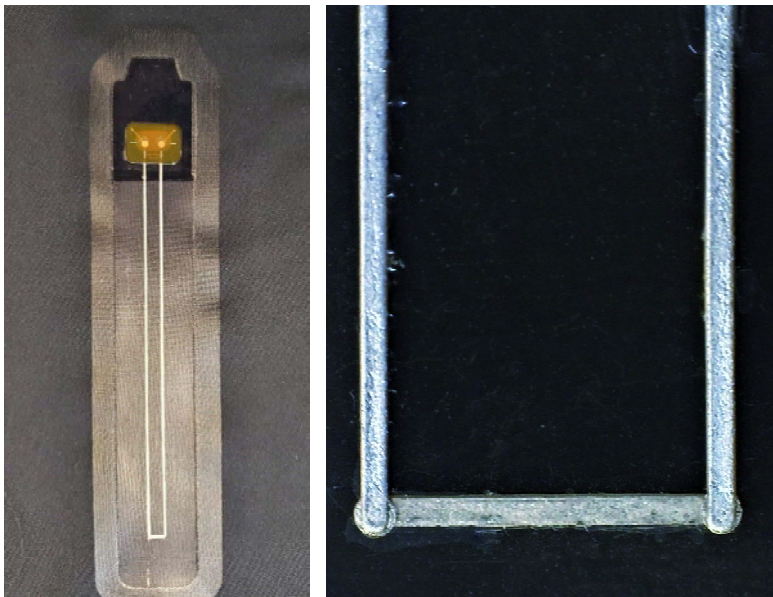
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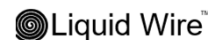
Patterning Metal Gel

- Metal gel can be patterned on a variety of materials, including:
 - Ceramics
 - Metallic surfaces
 - 3D printed resins
 - Silicones
 - Thermoplastic elastomers
- Stencil-in-place
 - Developed Specifically for Thermoplastic Laminates
 - Allows Multilayer circuitry
- Encapsulating layers are necessary for wearable devices



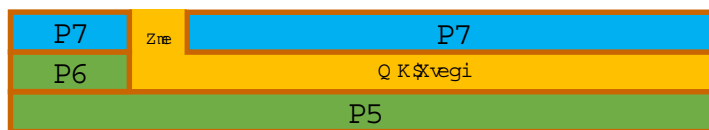
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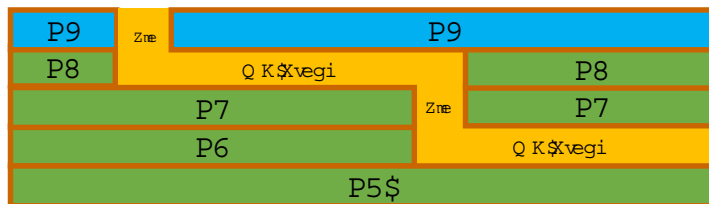
Cross-Section of A Circuit

Single-layer Circuit



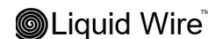
- Elastic Substrate
- Metal Gel
- Component layer

Multilayer Circuit



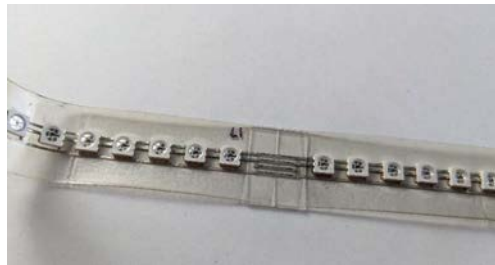
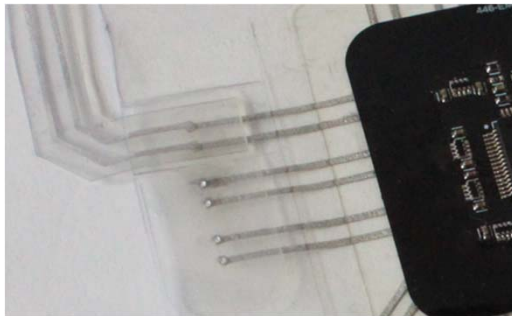
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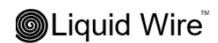
Lap Joint Connections

- Lap joints present a convenient way to connect two separate metal gel trace segments
- Metal gel layers connect through overlapping vias
- Trace segments can be fitted together to rapidly build up complex geometries

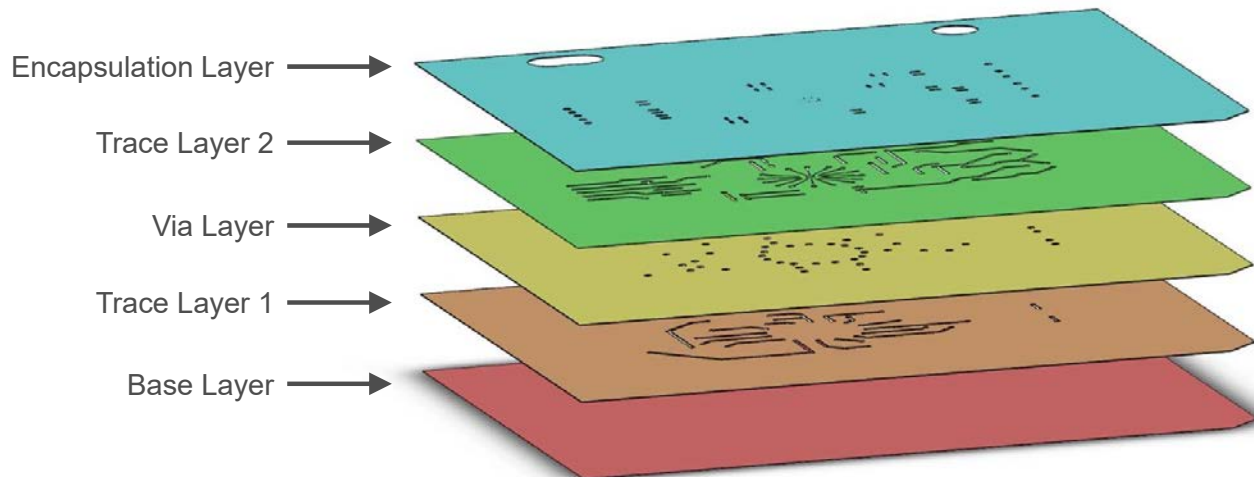


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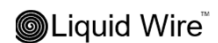


Breakout of a Circuit



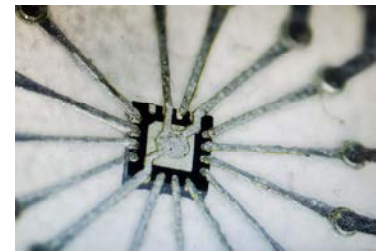
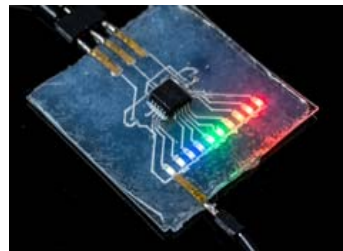
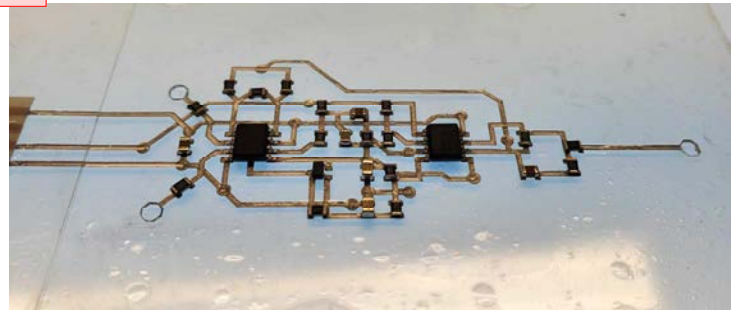
20

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Direct Component Attach MR4

- Components can be attached directly to metal gel traces via "soft solder" approach
- Substrate independence of metal gel allows for heterogeneous interconnects between dissimilar materials
 - This can be used for direct component attach or to connect traces from one substrate to another (e.g. flex to stretch)

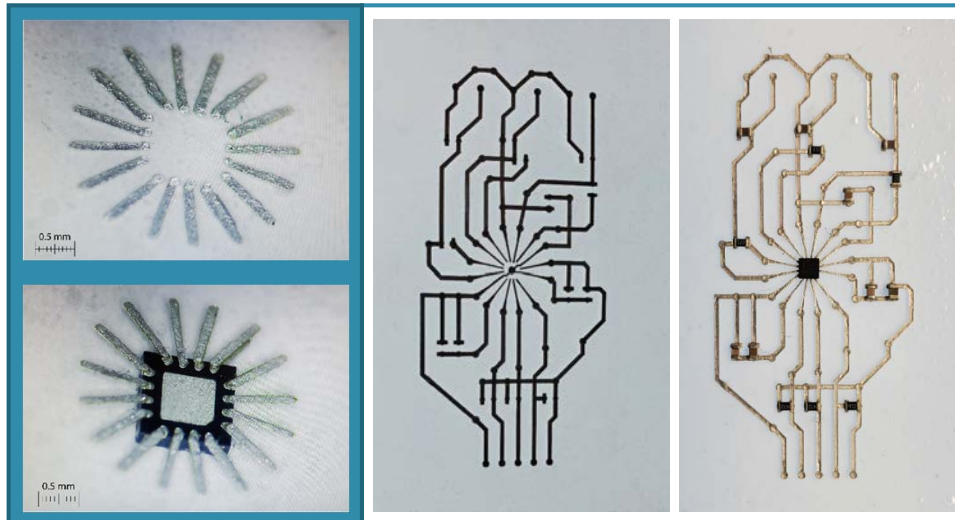


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Component Attach by "Soft Solder"

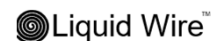


Features

- 52 Xst\$e}iv\$ iglermep}\$ ehliwiv\$sq tsrirxw\$tr\$ t\$egi
- 62 Q iex\$kip\$viexiw\$slq m}\$ gsrreg\$ ml\$sq tsrirx\$ teh
- 72 GXI\$u m}\$ egL\$zfvexsr}\$ wxem\$erh\$wliev\$ m\$rs}\$ hixegl\$ysq tsrirx\$ yrpww\$di}\$zivgsq i\$ ehliwzi\$fsrh
- 82 Wxziw\$miw\$ger\$fi\$ eq ipsvexih\$ ml\$tsxrk
- 92 Fypp\$wark\$vehm\$re}\$ WQ X\$siuyntq irx\$ ml\$ xssprk\$u shrtjexsr

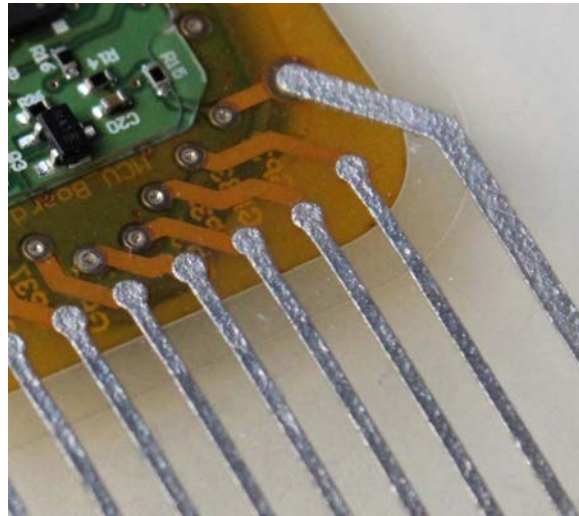
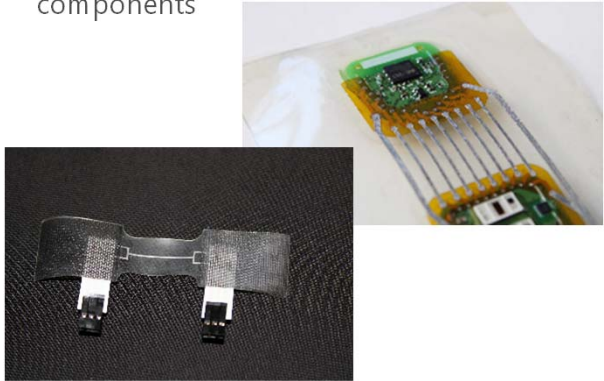
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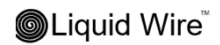
Heterogeneous Interconnects

- Metal gel readily forms Ohmic contacts to copper traces on a flexible board
- Metal gel is patterned through vias to connect with exterior electronic components

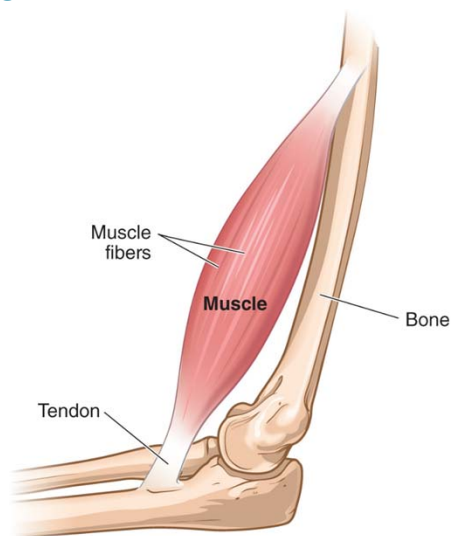


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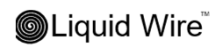


Rigid to Flex to Stretch

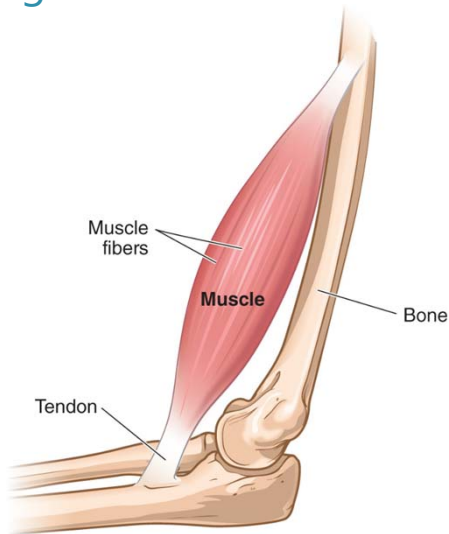


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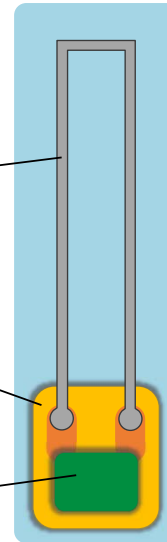
Rigid to Flex to Stretch



Stretchable Metal Gel Circuit

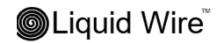
Flex Board

Rigid IC Component



25

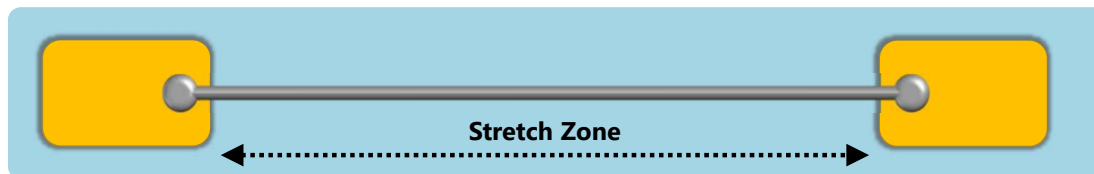
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Enabling Stretchability Between Rigid Components



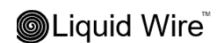
Flex Zone



Stretch Zone

26

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Metal Gel Laminate "Cores"

The diagram illustrates the structure of Metal Gel Laminate "Cores". It consists of three main layers: a Top Encapsulation Layer (yellow), a Trace Layer (brown), and a Base Encapsulation Layer (red). An inset box labeled "Hard to Soft Transition" shows a cross-section of a core with a purple top layer, a cyan middle layer, and a green bottom layer, with arrows indicating the transition between them.

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Island Architecture

- Stretchable metal gel traces connect rigid "islands" of traditional electronics
- IC modules provide high feature density
- Rigid components can be dispersed across a device in locations which make it easy to manufacture and comfortable to wear
- Metal gel interconnects allow for modularity of components

The 3D rendering shows a flexible, grey substrate with two rigid, gold-colored IC modules. These modules are interconnected by a network of stretchable, white metal gel traces that bridge the gaps between them.

28 Liquid Wire™

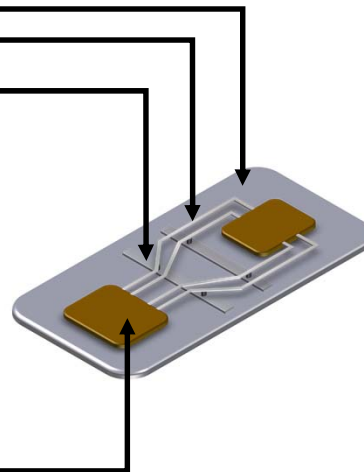
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Island Architecture

Pre-engineered TPU laminate complies with Liquid Wire DFM rules and has undergone extensive third-party testing revealing *orders of magnitude* better performance than silver ink layouts.

Metal Gel interconnects both tie together islands and serve as stretch/strain sensors.

Driven sensing elements such as dry electrode materials are attached directly to the pre-engineered laminate.

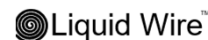


Modular Islands: Literally any SMT component can be hosted on these Polyimide islands:

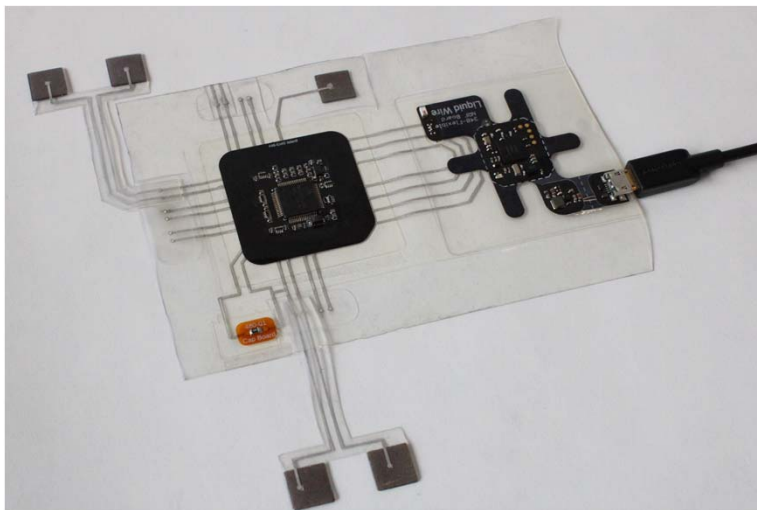
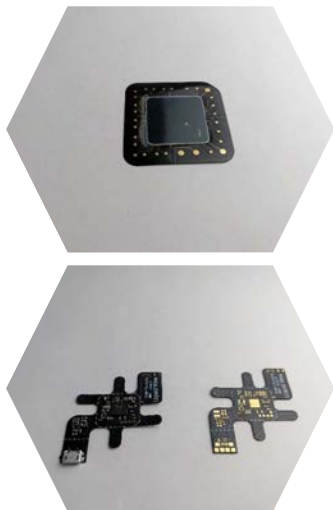
- Microprocessors
- Bluetooth Modules
- PPG sensors
- Temperature Sensors
- IMUs/Accelerometers/Gyros
- **Any Packaged Sensor**

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Hosting Functionality Example: EMG Array

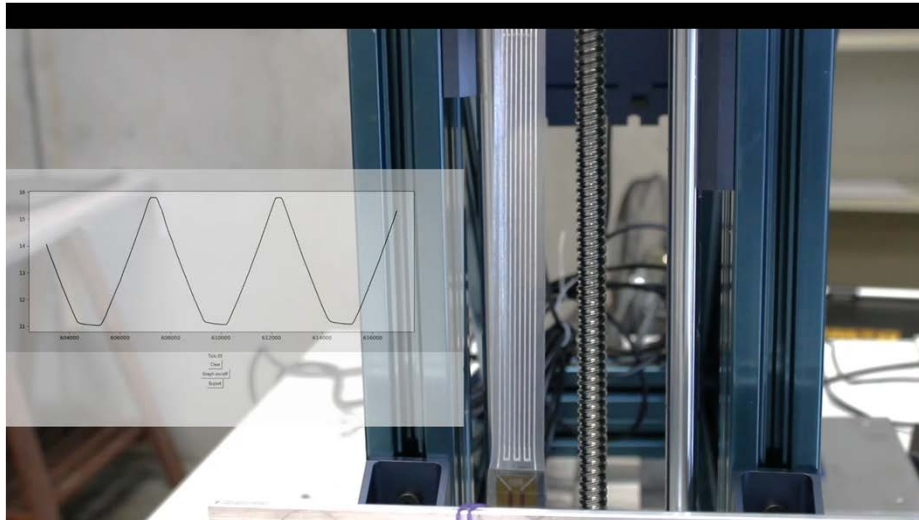


30

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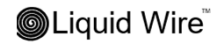


Metal Gel Sensor Cyclic Strain to 30%



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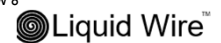
Metal Gel Sensor Cyclic Strain to 30%

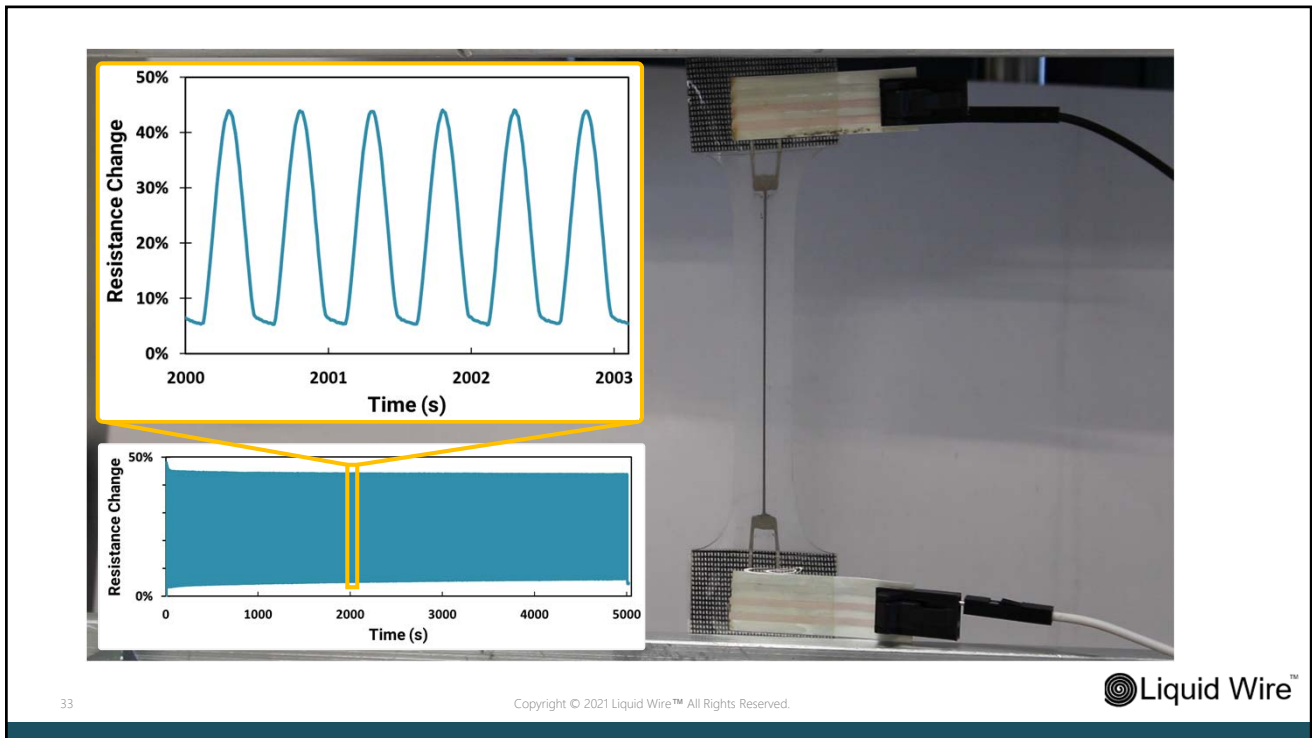


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32

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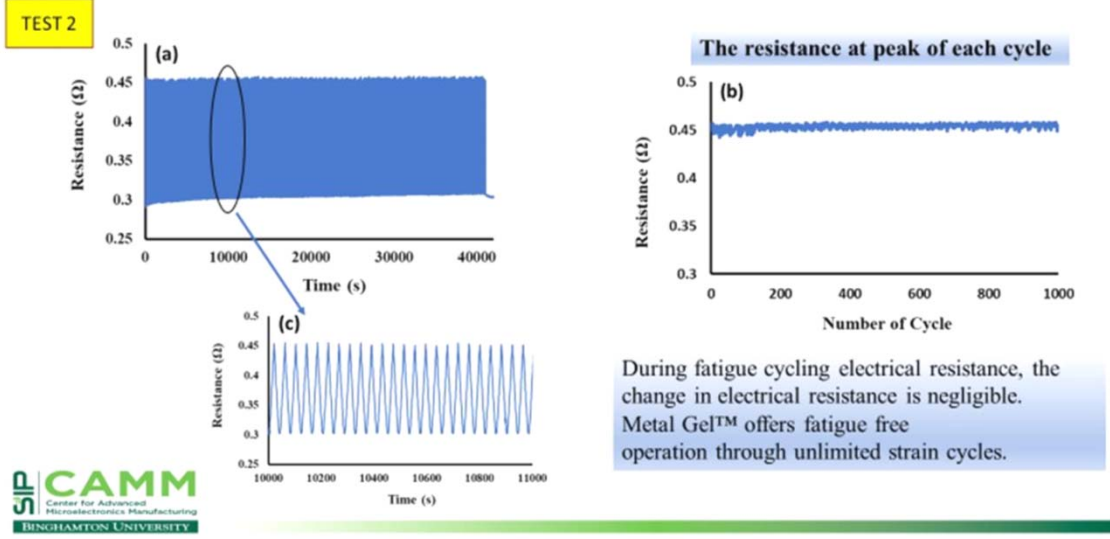


Strain Sensing

The image shows a black sensor board with a red LED indicator and a QR code. Two close-up photographs show the internal sensor cores. The 'Pressure Sense Core' is a small, clear, dome-shaped component. The 'Strain Sense Core' is a thin, flexible strip with a yellow adhesive layer. The Liquid Wire logo is in the bottom right corner.

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Cyclic Loading at 30% Strain at 0.5 mm/s Extension Rate for 1000 cycles



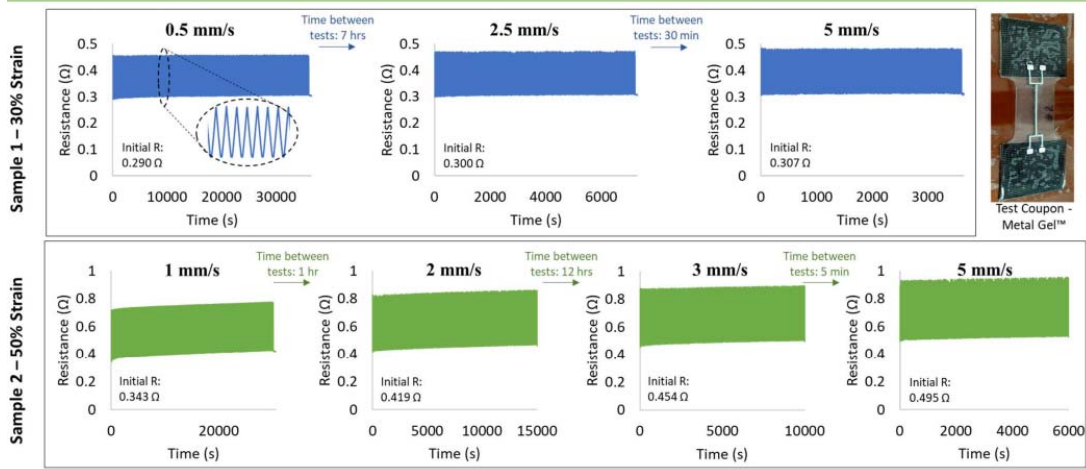
Courtesy of Binghamton University, Center for Advanced Microelectronics Manufacturing (CAMM), 6/2020

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Cyclic Loading at Different Extension Rates and Strain Amplitudes – 1000 Cycles

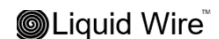


- During cyclic loading at strain amplitude of 30% the sample shows fatigue free behavior.
- Electrical resistance slightly increases from cycle to cycle during fatigue cycling at 50% strain amplitude.

Courtesy of Binghamton University, Center for Advanced Microelectronics Manufacturing (CAMM)

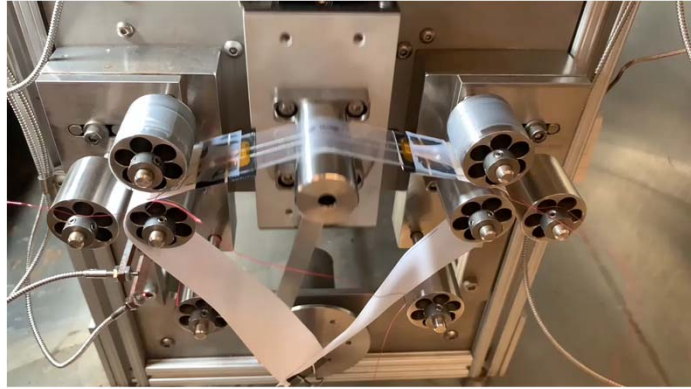
36

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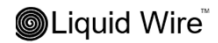
High Bend Radius/High Curvature

- Metal gel traces perform well under bending as well as under strain
- Bend testing done in collaboration with Binghamton University
- Bending radius: 0.5 , 1, 2, 3 and 4 inches
- Frequency : 1 Hz and 0.5 Hz



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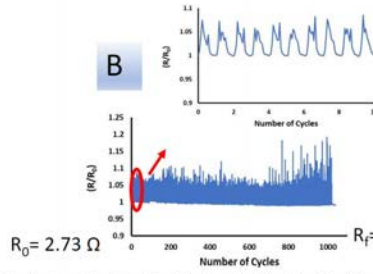
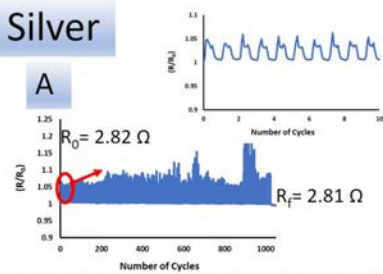
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Liquid Wire's conductor vs Commercially available silver paste- During 1000 Bending Cycles at 1Hz

TNP4

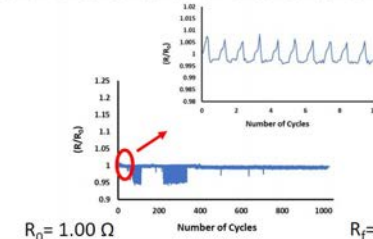
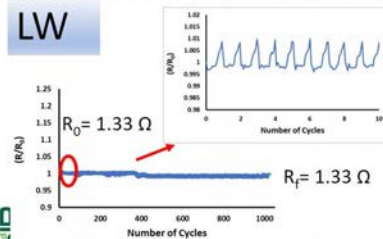
Silver



Bending radius: 0.1 inch



LW



Bending radius: 0.1 inch



BINGHAMTON UNIVERSITY

Courtesy of Binghamton University, Center for Advanced Microelectronics Manufacturing (CAMP)

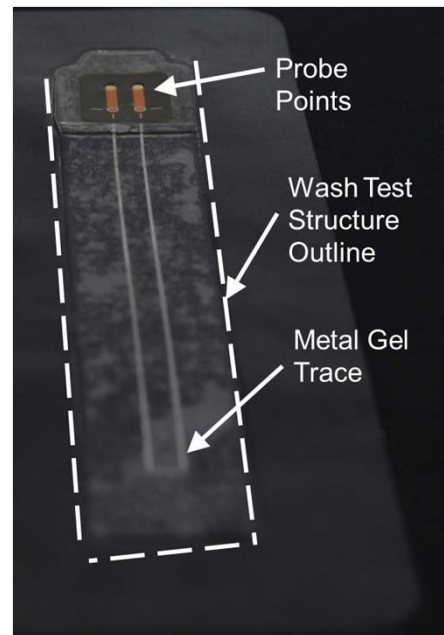
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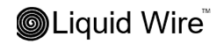
Integration with Textiles

- Metal gel circuits can be integrated directly with textiles using traditional textile manufacturing techniques such as heat pressing
- The circuit maintains integrity through extended use and over the course of multiple wash cycles



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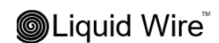


Washable and Seamless



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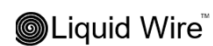


Wash Cycle Testing



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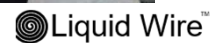


Modular Musculo-Skeletal Sensing Platform

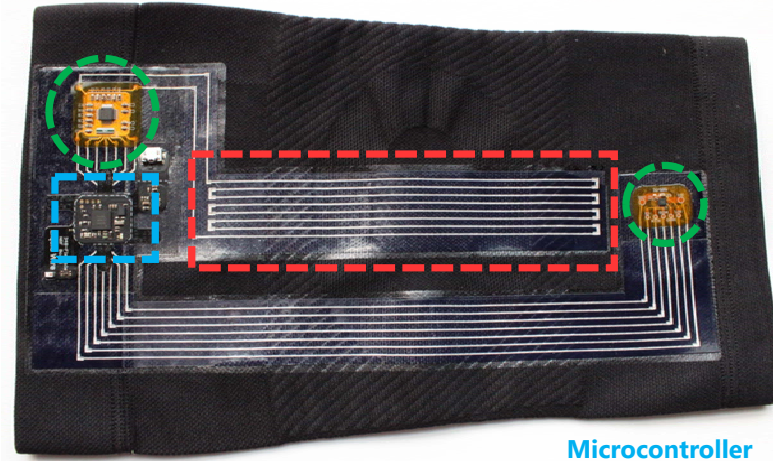


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Modular Musculo-Skeletal Sensing Platform

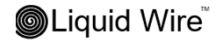


Microcontroller
Strain Gauge
Flex Boards

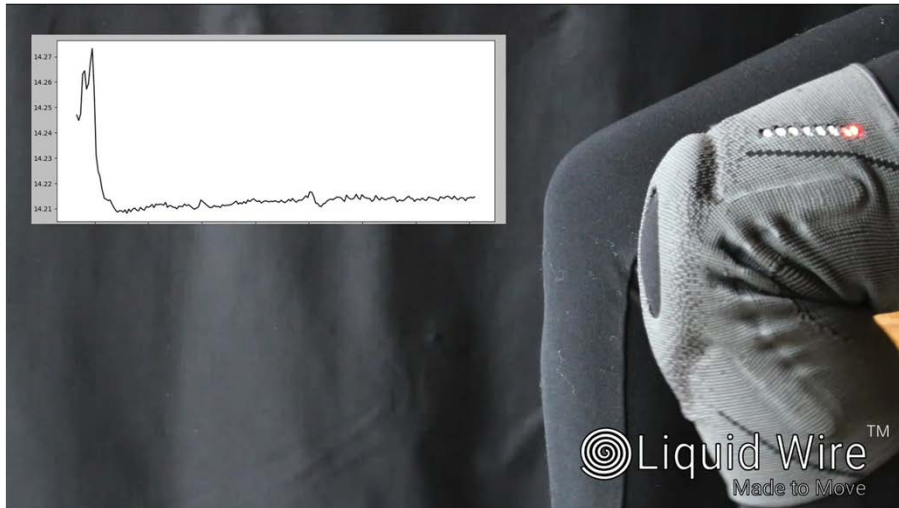


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Initial Proof of Concept



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