Innovative Ideas for Manufacturing Smart Apparels

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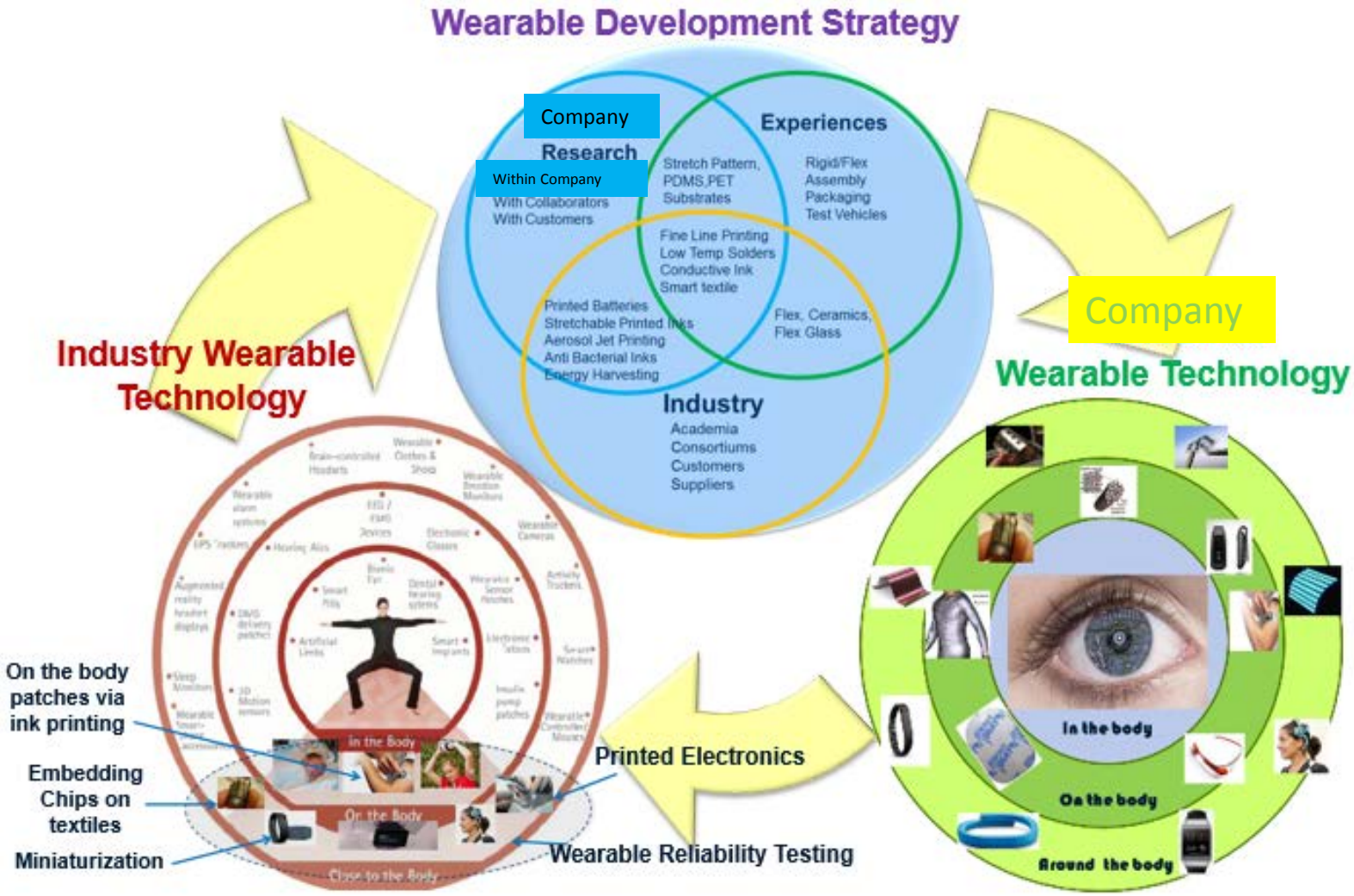
Wearable Technology Introduction



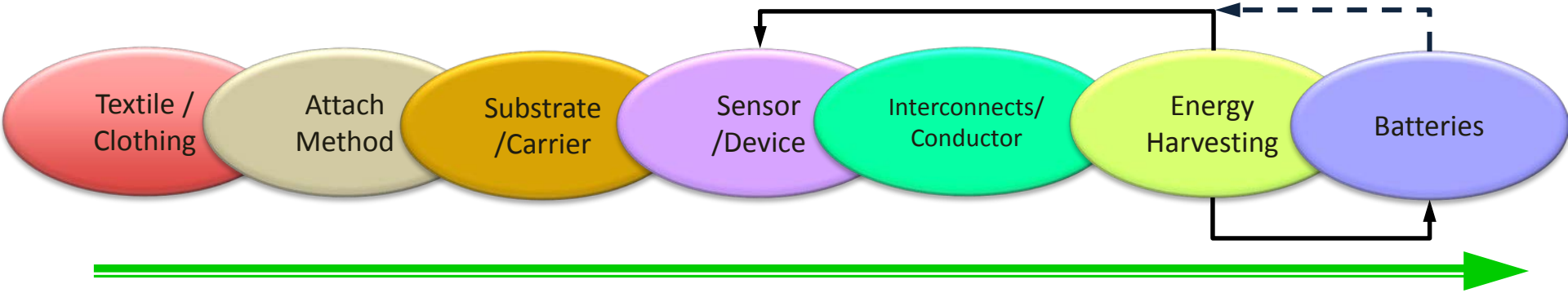
Wearable Sensors on Smart Jacket

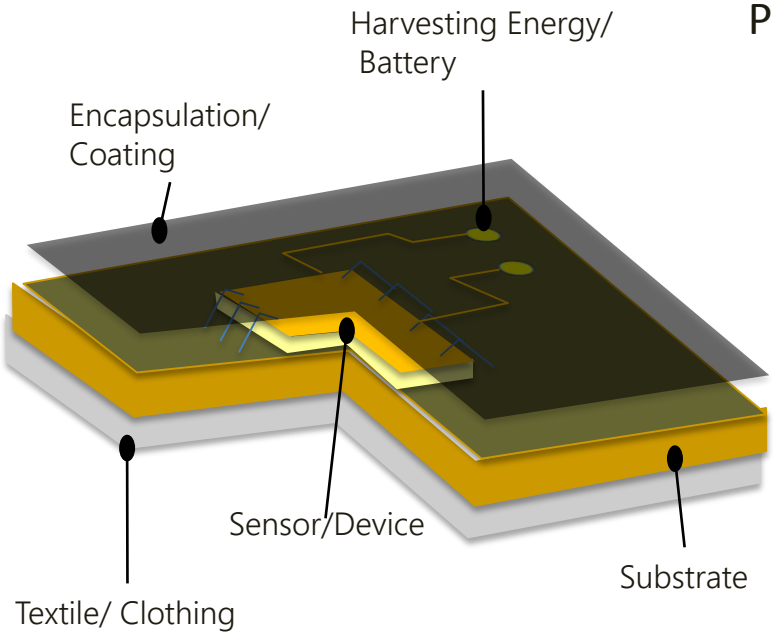
7 Section Wearable Sensor POC

- Energy Harvesting
- Navigation Sensor
- Security Sensor
- Activity Sensor
- Bio Sensor
- Stress Sensor
- Environmental Sensor

SENSORS	SENSOR APPLICATION	#	SENSOR PLACEMENT
Energy Harvesting	Flexible Solar Strap	1	Arm
	Piezoelectric	2	Elbow
	Textile Micro Spherical Solar Cells	3	Arm
Navigation	Ultimate GPS Module	4	Upper Back
		5	Front Chest
	GPS with Chip	6	Left Shoulder
		7	Forearm
		8	Waist
		9	Wrist Strap
		10	Wrist Strap
		11	Wrist Strap
		12	Wrist Strap
		13	Wrist Strap
		14	Wrist Strap
		15	Wrist Strap
		16	Wrist Strap
		17	Wrist Strap
		18	Arm
		19	Wrist Strap
		20	Arm
		21	Arm
		22	Arm
		23	Arm
		24	Arm
		25	Chest
		26	Left Chest
		27	Arm
		28	Back
	Humidity	29	Back
Ambient environment	Carbon monoxide	30	Right Chest
	Alcohol	31	Right Chest
	GAS	32	Left Chest
	UV	33	Right Chest
	Dust	34	Back
	Ozone	35	Shoulder
	Lux/Light	36	Back
	Color	37	Shoulder
	Flame detection	38	Back

Conceptual Framework POC





Proof of Concept (POC) Results Examples:

- TPU substrate with printed conductive silver with a maximum stretch of 20% and washable.
- Lamination of TPU to clothing with conductive traces
- Silver coated nylon thread used for interconnects
- Energy harvesting to power up WT sensors/ charge batteries
- Laser cut conductive clothing for interconnects/ conductors
- Coating / encapsulation to protect modules (spray, conformal, glob top and lamination).

Wearable Sensor Proof of Concept Overview

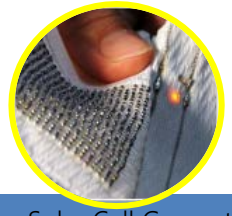
- Energy Harvesting
- Sensor/Devices
- Substrates/ Carriers
- Attach Process
- Electrical Interconnect / Conductors
- Encapsulation / Coating
- Batteries

WEARABLE
TECHNOLOGY
Proof of Concept

Energy Harvesting POC Mechanism

Solar

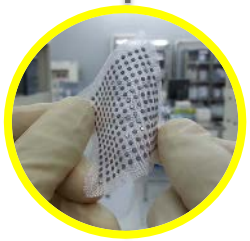
Flexible Solar



Micro Solar Cell Generator

Photovoltaic

Thermal



A thermoelectric device that can be worn and charge a battery using body heat, it can convert heat directly into electrical current.

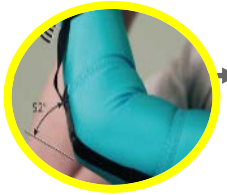
Thermoelectric

Motion / Vibration

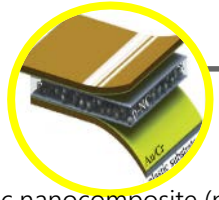
Plucking of flexible piezoelectric material that can be used to boost energy harvesting

Electromagnetic (Mechanical)

Electrostatic film measures all kinds of body position and can harvest energy



Electrostatic



Piezoelectric

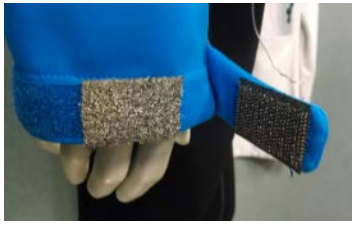
Piezoelectric nanocomposite (p-NC) layer between two metal-coated plastic substrates. It produces electricity from mechanical motion

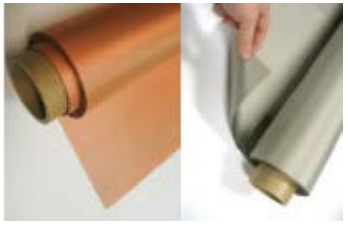
Proof of Concept Mechanism

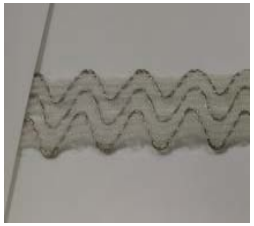
Interconnect/ Conductors

- Silver/carbon conductive ink
- Stretchable conductive cloth
- Non-stretchable conductive cloth
- Silver coated nylon thread
- Stainless steel thread
- Copper solderable strand
- Emerald copper wire
- Tinned copper plait (copper plait)
- Zipper interconnect
- Nickel and copper plated ripstop fabrics
- Polyester and Inox steel fiber
- Conductive ribbon
- Copper tape
- Z-axis conductive tape (ACF)
- Snap button
- Snap fastener
- Flexible conductive glue
- Conductive glue
- Velcro (conductive / Non-Conductive)
- Magnetic Switch
- Metal Crimping
- Miniaturize Connector

Method	Equipment/Tools	Challenges
Printed on TPU Substrate Different type of Stitching Lamination / steam press Snap Glue Dispensing / Bonding Soldering Crimping Curing Velcro / adhesion Coatings	Screen Printing Lamination / Steam Press Electric Sewing / Stitching Laser cut Electronics Cricut Snap/Hammer Driven tool Oven / UV Curing Laser Soldering / Iron	Washability Flexibility Stretchability High Temperature Tarnish of silver


Conductive Velcro


Conductive Cloth

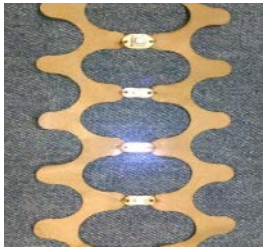

Stretchable Conductive Fabric


Stitch Conductive Wire


Conductive Wires/ thread


Isolated wiring


Fastener / Snap button

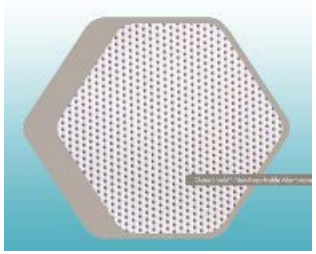

Conductive Copper Cloth

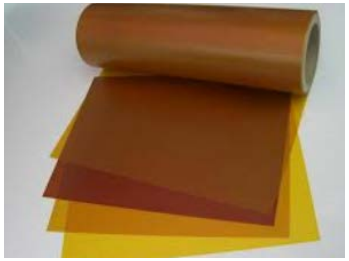
Substrates / Carrier

- TPU Film
- PTFE Membrane
- Polyurethane membrane
- Polycarbonate Plastic
- Polypropylene membrane
- Polyimide Film
- Viscose Rayon
- Nylon
- Stretchable Belt/ Strap
- Silk
- Polyester
- Flax (Linen)
- Heat Shrinkable Tubing
- PET
- Acrylic
- Modacrylic
- Leather
- Cotton
- Flax (Linen)
- Polyethylene Foam
- Fabric Tape
- Polyurethane Foam

Method	Equipment/ Tools	Challenges
Conductive ink printed on TPU Different type of Stitching Lamination Steam press Glue Dispensing / Bonding Hot air Crimping	Lamination / Steam Press Electric Sewing / Stitching Laser cut Electronics Cricut Snap/Hammer Driven tool Soldering Iron Punching cutter UV curing	Washability Flexibility Stretchability High Temperature Material compatibility


Thermoplastic polyurethane


PTFE Breathable Membrane


Polyimide Film


Polycarbonate substrate


Stretchable Nylon Strap


Polyethylene foam

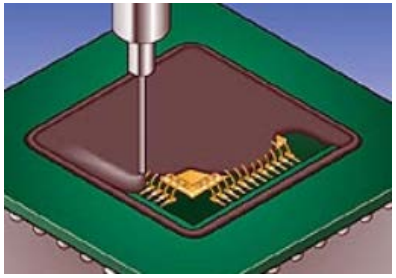

PET Substrate


Heat Shrinkable Tube

Coating/Encapsulation

- Dam and Fill
- Conformal coating
- TPU Lamination
- Spray coating
- Screen Printing
- Potting
- Hotmelt Coating on Fabric
- Underfill/NCP
- Potting
- Farbic waterproofing spray
- Parylene Coating
- Micromelt moulding
- Sogru Elastomer
- Shrinkable Rubber
- Elastomer patch

Method	Equipment/ Tools	Challenges
Spray Atomizing Dam and Fill Edge Bonding Glop Top Oven /UV Curing Low pressure moulding	Underfill Oven/UV curing Micromelt Potting Parylene Lamination	Flexibility Bendable Foldable Material compatibility



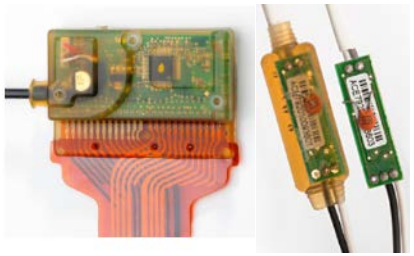
Dam and Fill

Potting

Edge Bonding

Conformal Coating

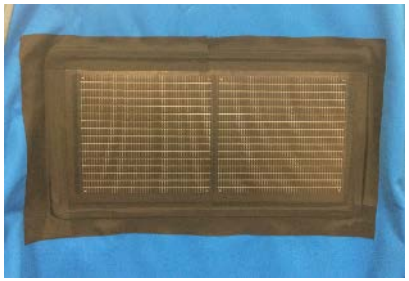
Hotmelt on Fabric



Macromelt LPM

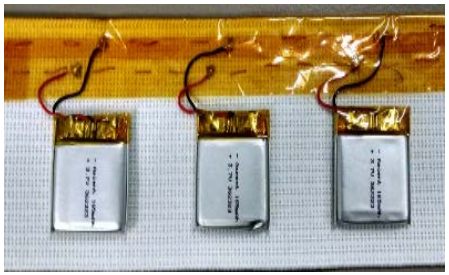
Power Source
Flexible Solar
Chain Battery
Stretchable Battery
Piezoelectric
Thermoelectric
Printed Batteries
Thin Batteries

Method	Equipment/ Tools	Challenges
Lamination Soldering Snap/ Fasteners	Laser Soldering/ Iron Laser cut Lamination	Washability Flexibility Stretchability



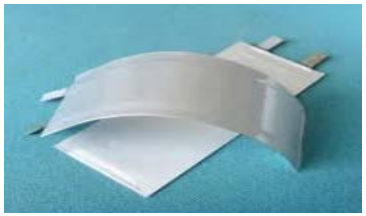
Flexible Solar

Stretchable Battery



Chain Battery

Piezoelectric



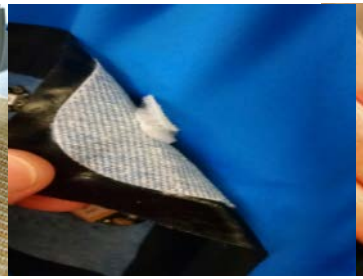
Thin Battery

Attach Process

- Lamination
- Braid Stitch
- Waiving Stitch
- Warp-Knitting Stitch
- Relief Embroidery
- Dispense Glue/Bonding
- Fabric Protector
- Curing adhesive
- Zigzag placement
- Ink screen printing
- Snapping
- Fastening
- Velcro
- Laser cutting
- Magnet attach
- Zipper interconnect
- Clip/ Staple
- Spray adhesive
- Pressure Sensitive Tape (PSA)
- Iron Soldering conductive thread
- Steam Press
- Cricut Electronic pattern
- Hotmelt
- ACF /Hotbar
- Laser soldering
- Etching on conductive fabric

Equipment/ Tools	Challenges
Lamination / Steam Press Electric Sewing / Stitching Laser cut Electronics Cricut Snap/Popper equipment Soldering Iron Punching cutter UV curing Low pressure moulding	Washability Flexibility Stretchability High Temperature Material compatibility

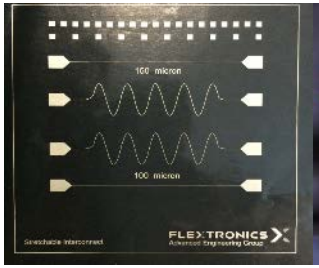
Popper Tools



Velcro

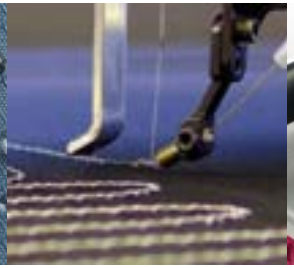
Soldering

Fasteners



Conductive Ink Printing

Fabric Protective Spray



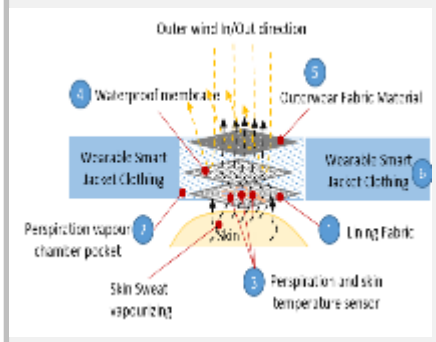
Stitching

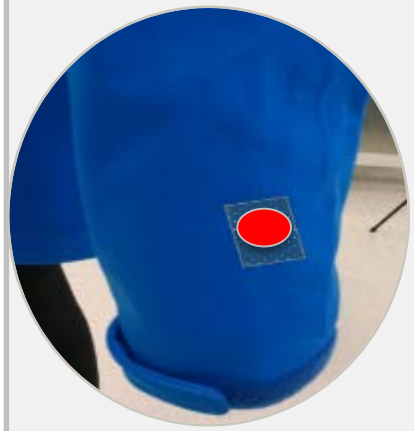
Steam Press

Sensor Integration	Application	Process Method	Future Works
GPS, LUX ,LED	**Navigation & light Sensor**	**Substrate** *Denim Fabric*	**Reliability Testing** *Stretchable* *Foldable* *Bending* *Washability*
	• **Components:** Flora control module, GPS module, Lux sensor, three LEDs	**Interconnects** *Silver conductive thread*	**Equipment / Tools** *Fabric Laser Cut* *Stitch Machine* *Screen Printing for conductive ink*
	• **GPS module**: at preset destination, LEDs will blink ,Lux sensor: at low lumens, the LED will light up	**Attach Process** *Stitch with conductive thread & pressure sensitive fabric* **Coating/ Encapsulation** *Protective Fabric Spray / Conformal Coating* **Energy Source** *Battery for indoor* *Flexible Solar - outdoor*	**Design Consideration** *Design Guidelines* *Test Method* *Module Miniaturization and use conductive silver ink for the traces*

Sensor Integration

Skin Perspiration & Temperature





Application

Biosensor
Fitness and Healthcare Monitoring

Measure skin perspiration, temperature and sensor size 2X2mm x0.8mm with low power consumption and operating voltage of 1.8V. Equip with apps and Bluetooth for data collection

Process Method

Substrate
Breathable Lining Fabric
Breathable Membrane Fabric
Breathable outerwear

Interconnects
Conductive Printed Ink

Attach Process
Sensor was place in between lining and breathable membrane fabric then stitch /laminate the membrane

Coating/ Encapsulation
Protective Fabric Spray / Conformal Coating on module

Energy Source
Coin battery

Future Works

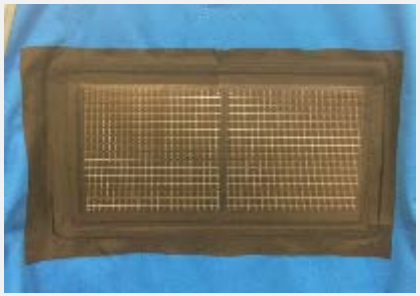
Reliability Testing
Stretchable
Foldable
Bending
Washability

Equipment / Tools
Fabric Laser Cut
Stitch Machine
Lamination
Screen Printing for conductive ink

Design Consideration
Design Guidelines
Test Method
Module Miniaturization and use silver ink for traces
Energy harvesting

Sensor Integration

Portable Flexible Solar



Application

Energy Source

Solar panel to power up sensor and charge batteries and it includes: USB adapter, USB charger, DC adapter and multiple adapters for charging phones and rechargeable lithium battery via solar panel

Process Method

Substrate
PET and pressure sensitive fabric

Interconnects
Stranded wire and connector

Attach Process
Use a patch and laminate the solar to fabric

Coating/ Encapsulation
Protective Fabric Spray / Conformal Coating

Energy Source
Outdoor application

Future Works

Reliability Testing
Stretchable
Foldable
Bending
Washability

Equipment / Tools
Stitch Machine
Lamination

Design Consideration
Design Guidelines
Test Method
Control Module
Miniaturization
Use conductive ink for the traces

Sensor Integration

Zipper Switch

Application

Conductive Switch

Zipper is connected with conductive wire and can be use to power on/off the sensor/LED.

Process Method

Substrate
Denim Fabric

Interconnects
Conductive cloth

Attach Process
Use a fastener to attach the conductive cloth to denim then use a strand wire for interconnects

Coating/ Encapsulation
Conformal Coating

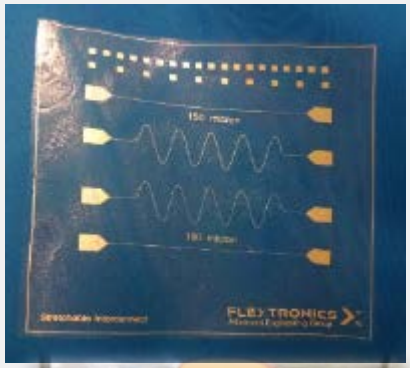
Energy Source
Outdoor application

Future Works

Reliability Testing
Stretchable
Foldable
Bending
Washability

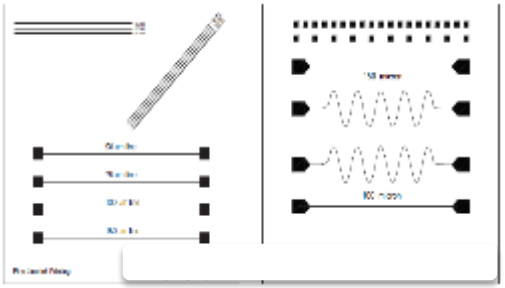
Equipment / Tools
Lay stitch Machine

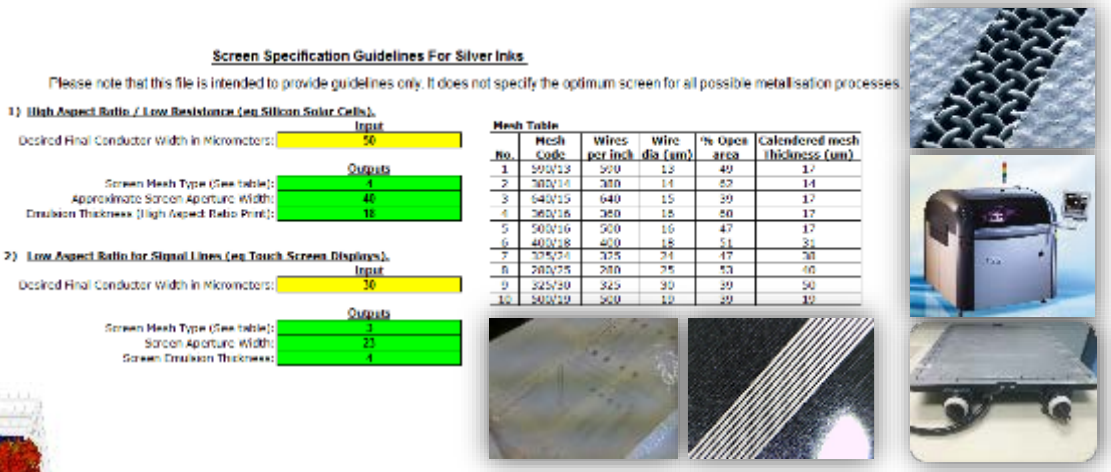
Design Consideration
Design Guidelines
Test Method

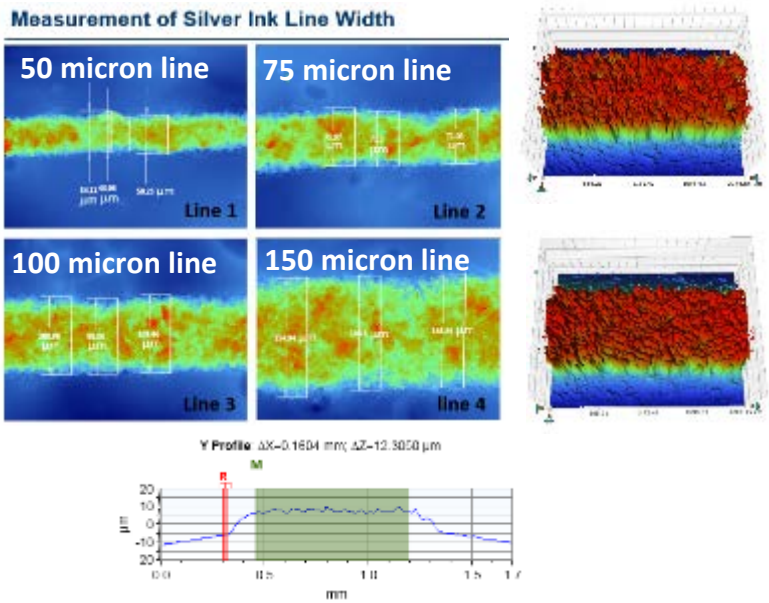
Sensor Integration	Application	Process Method	Future Works
Fine line Printing	**Conductive Traces**	**Substrate** *Stretchable TPU*	**Reliability Testing** *Stretchable* *Foldable* *Bending* *Washability*
 	**Fine line conductive ink printing with 50um, 100um, 150um printed to stretchable TPU substrate**	**Interconnects** *Conductive Ink* **Attach Process** *Laminated the stretchable TPU to fabric* **Coating/ Encapsulation** **Energy Source** *Solar / battery*	**Equipment / Tools** *Lamination* *Screen Printing for conductive ink* **Design Consideration** *Design Guidelines* *Test Method*

Fine Line Printing for Conductive Trace / Interconnects

Test Vehicle







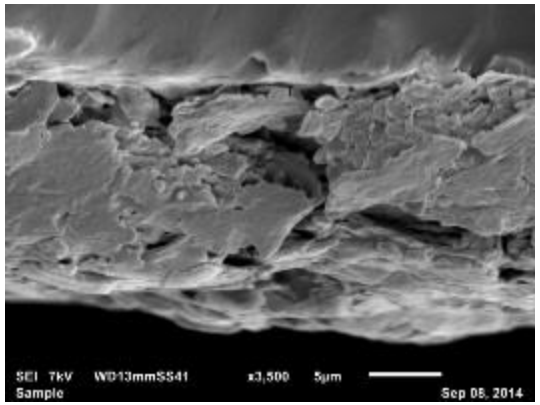
Screen can be designed based on fine line printing requirements (line width). There are several factors to consider for the screen design:

- **Screen material type: stainless steel or polyester.**
- **Screen thread diameter and mesh count**
- **Emulsion thickness**
- **Mesh angle**

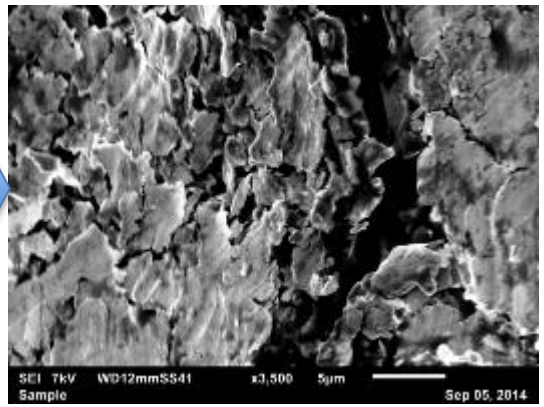
Demonstrated printability of 50, 75, 100 and 150 micron wide lines using screen printed stretchable silver conductive ink

Time Zero to 100% Strain - SEM Images

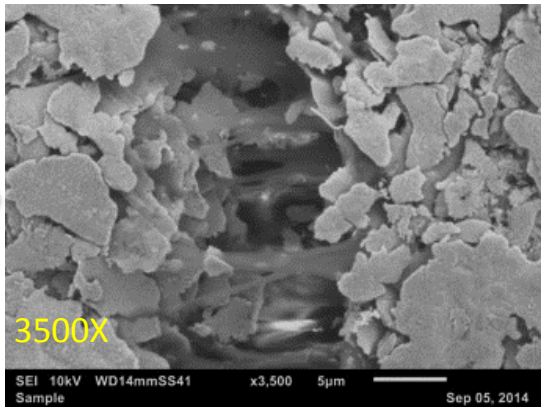
Time Zero



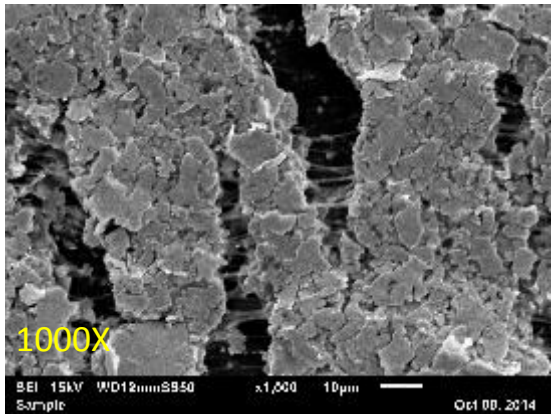
50% Strain



100% Strain



- From cross sectional view, the particle size ranges from 0.5 -15 um
- As strain increases the cracks in the printed ink becomes wider, although at 100% strain in 1000X magnification it shows there is still connectivity between silver flakes

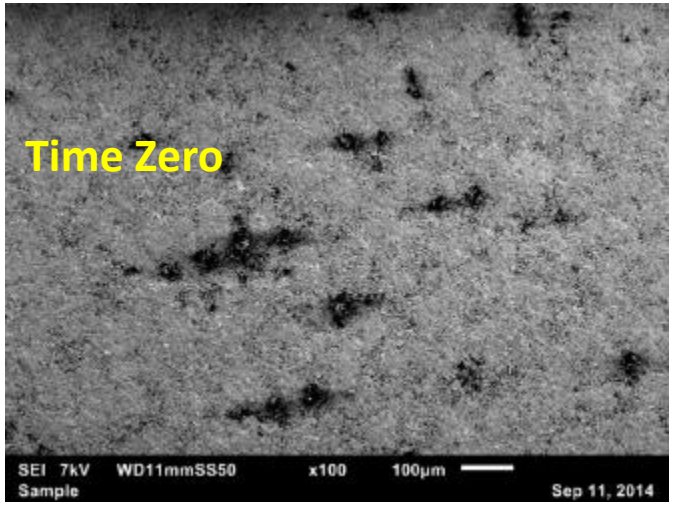


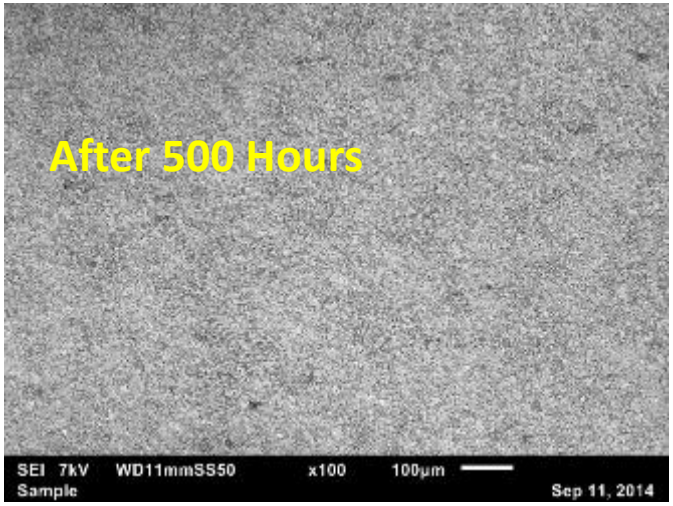
Remarks :

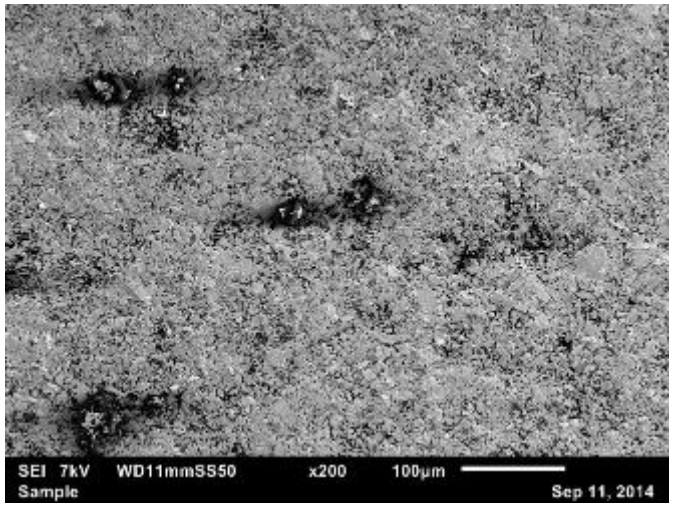
- Conductive silver ink was printed to TPU substrate with a 4 Mils thickness
- Oven Curing Parameter Setting : 10minutes @ 120 ^{0}C in accordance with conductive ink typical curing specification.
- Strain was performed in a customized stretchability test equipment development by our team.

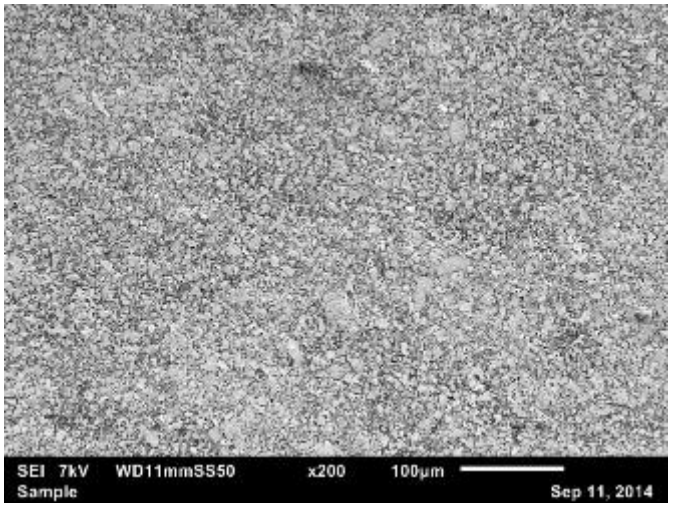
Customized Stretchability Testing

Time Zero and After 85%RH Humidity and 85C Temperature, 500 hours

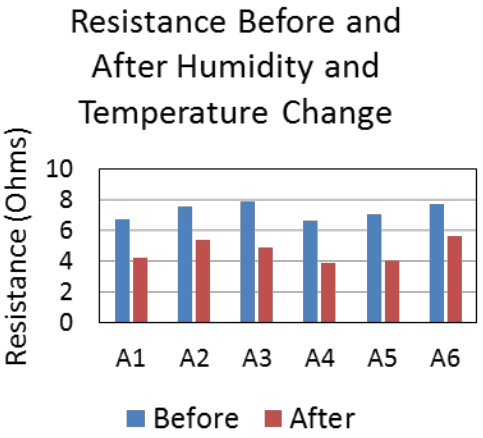






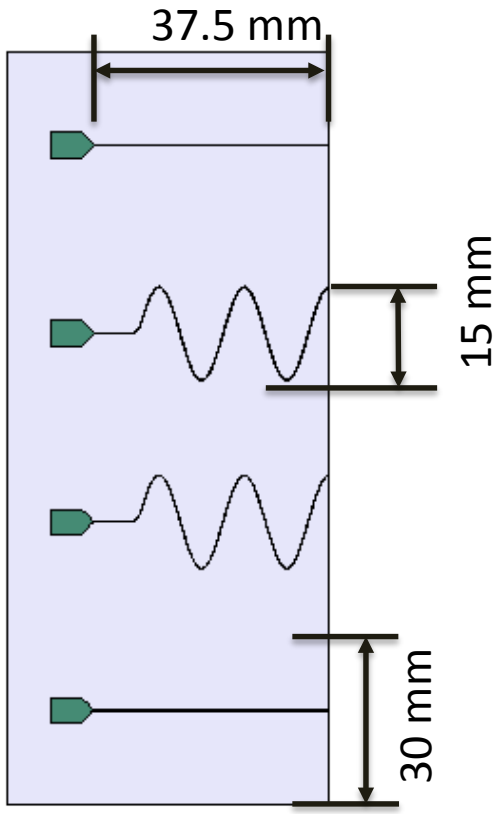


After 500 hours of 85%RH/ 85C, the discontinuity region reduces significantly, And the resistance reduces



Finite Element Analysis Modeling

- Half model deployed due to symmetry
- Critical dimension as shown



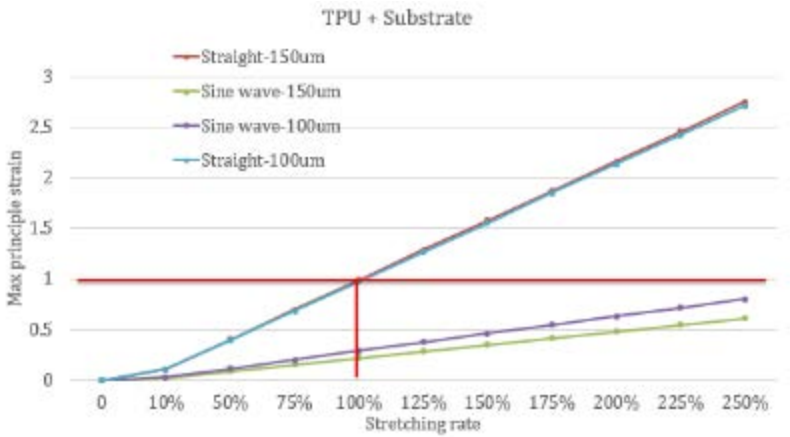
Thickness:

1) Ink:0.005mm
2) Substrate: 0.1mm

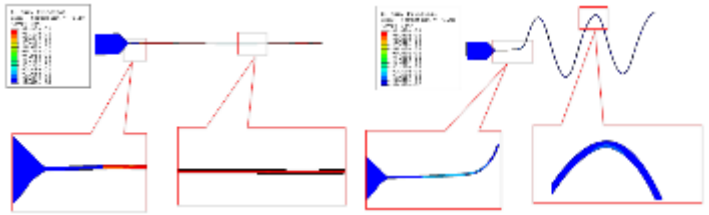
Material Name/Type	Substrate	Ink
Flexural Modulus (MPa)	5.6	11400
Poisson's Ratio	0.45	0.25
Density (ton/mm^3)	1.2e-09	2.2e-09
CTE, ppm/C	200	40
Elongation at break	550%	96%

Finite Element Analysis for Conductive Ink on TPU Substrate

Component	Elongation	Pattern	Max. Principal Strain
Ink (150um)	10%	Straight line	0.11
		Sine wave	0.0239
Ink (100um)		Straight line	0.109
		Sine wave	0.0318
Ink (150um)	250%	Straight line	2.76
		Sine wave	0.598
Ink (100um)		Straight line	2.71
		Sine wave	0.795

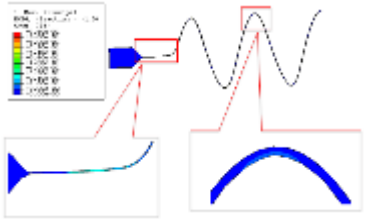


Principle strain at about 96% stretching

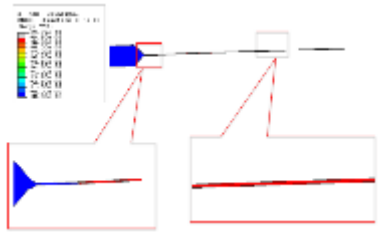


Straight Line : 150um

Sine Wave: 150um



Sine Wave: 100um



Straight Line : 100um

- The max principle strain of straight pattern is almost the same as stretching rate. It will crack as the stretching rate is about 96%.
- The sine wave pattern is safe even under 250% stretching.

Challenges

- Miniaturization of integrated sensors
- Display module to smart textiles
- Energy Harvesting
- Design evolution for flexibility, stretchable and foldable
- Water resistant and washability
- Equipment for integration to textile
- Fashionable Design

Future Work

- Create a stack up layer modeling simulation for the sensor integrated to clothing.
- Continue other integrated sensor for reliability testing, physical, environmental and washability test requirements.
- Process characterization and ranking summary for the attach and interconnects methods.
- Collaboration with equipment and material supplier to manufacture proof of concept study on wearable applications.
- Continue to work on energy harvesting, applicable to smart clothing.

Thank You