Government-Furnished Capabilities for IARPA SMART ePANTS

This material is based upon work supported by the Department of the Air Force under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of the Air Force.

Outline

- Overview of textile integration techniques
- Integration of electronics into fibers
- Fiber encapsulation
- Integration of fiber into the fabric
- Direct attachment of electronics to the fabric
- Electrical connection to electronics outside the garment
- Full garment construction
- Custom integrated circuit
- Custom optics

Overview

Approach #1

Integrate electronics into fibers

Integrate fiber into the fabric

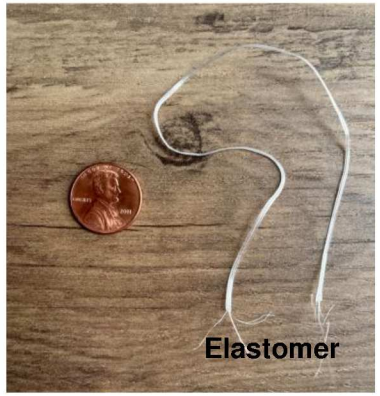
Approach #2

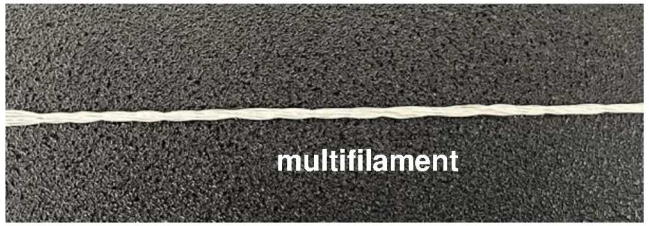
Integrate electronics directly onto the fabric

Fiber Design Space

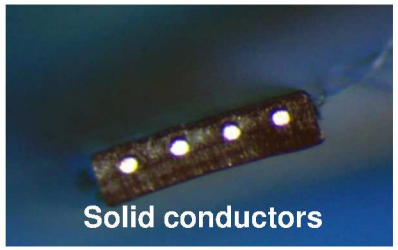
- Fibers can be made up of various cladding and component materials
- Connectorization to a fiber can be done in a variety of ways

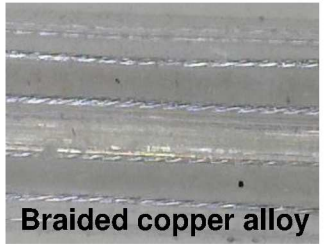
Cladding materials

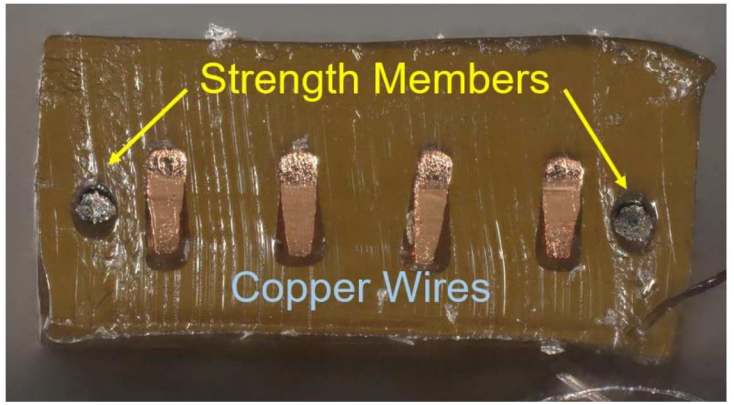




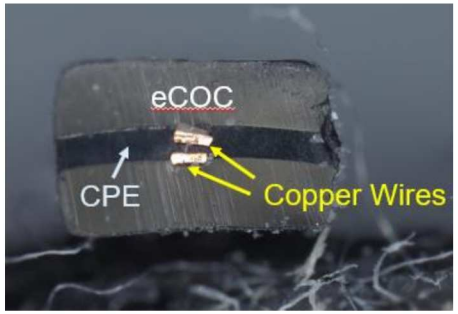
Component materials

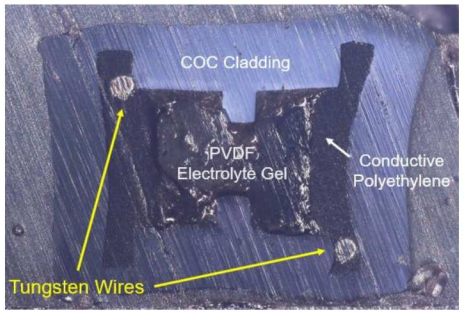






Multi-Material Fibers





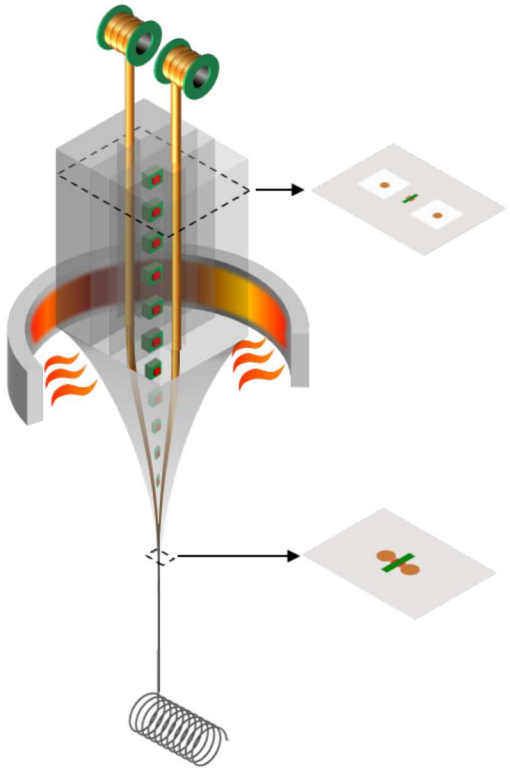
Connectorization

Flex Strips

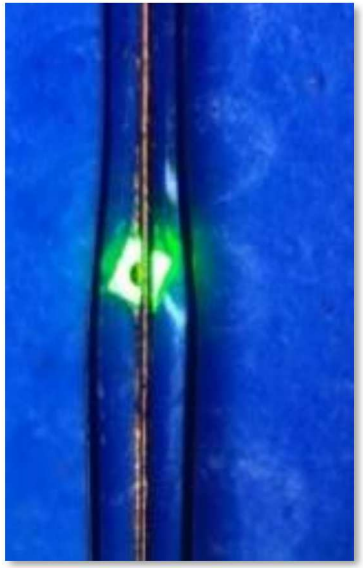
Conductive Yarn

Embedded Draw

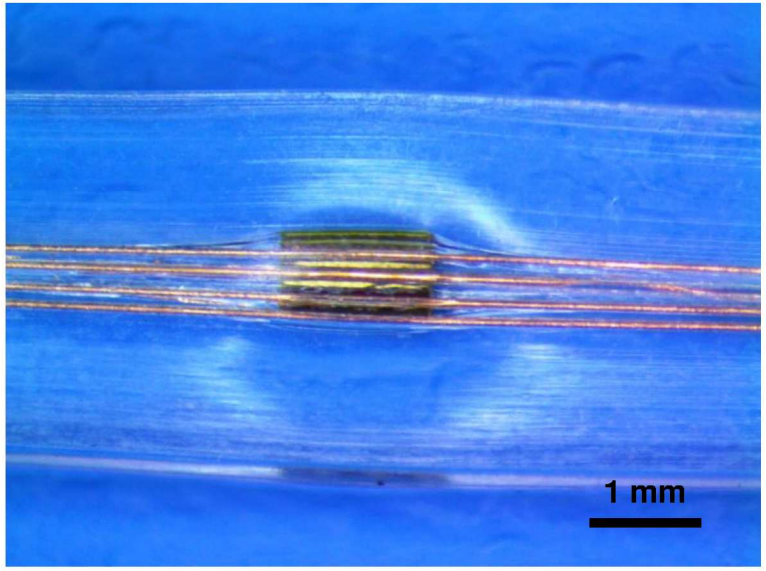
Integration of electrical components can be done during the draw process



Two-Wire Fiber with LED



Four-Wire Fiber with PCB



Rein et al, 2018, *Nature*, Vol 560

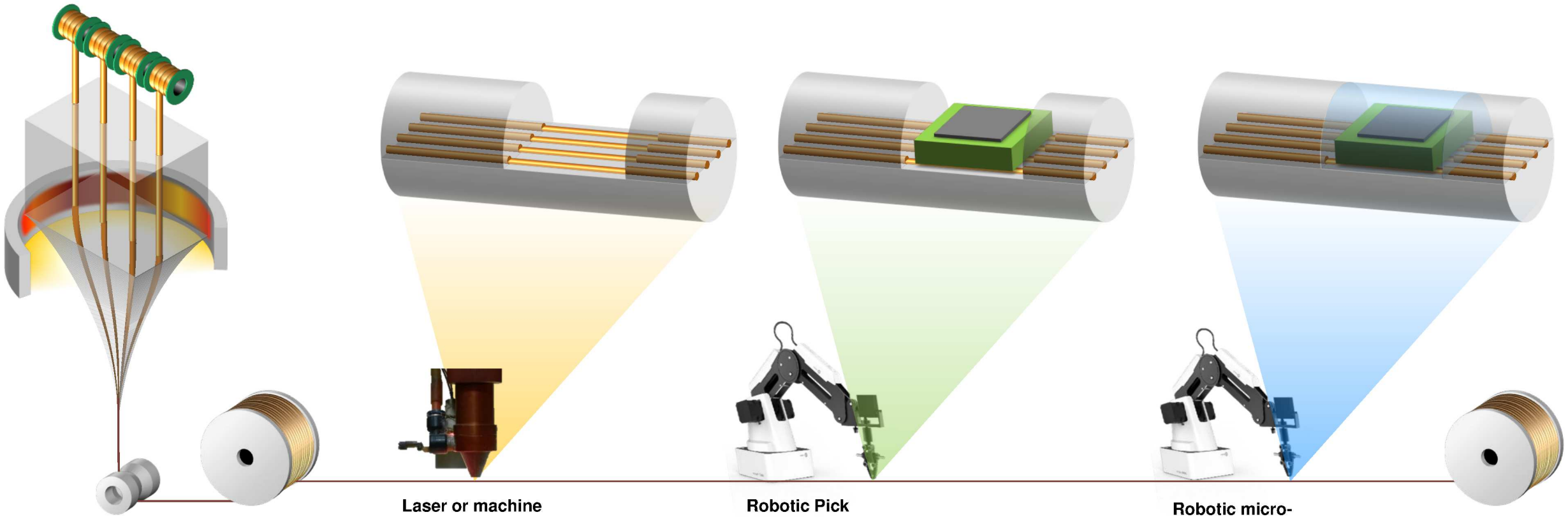
Post-Draw Integration of Electronics

STEP 1
Thermal draw of wiring board + cladding

STEP 2:
Cladding locally removed to expose wires

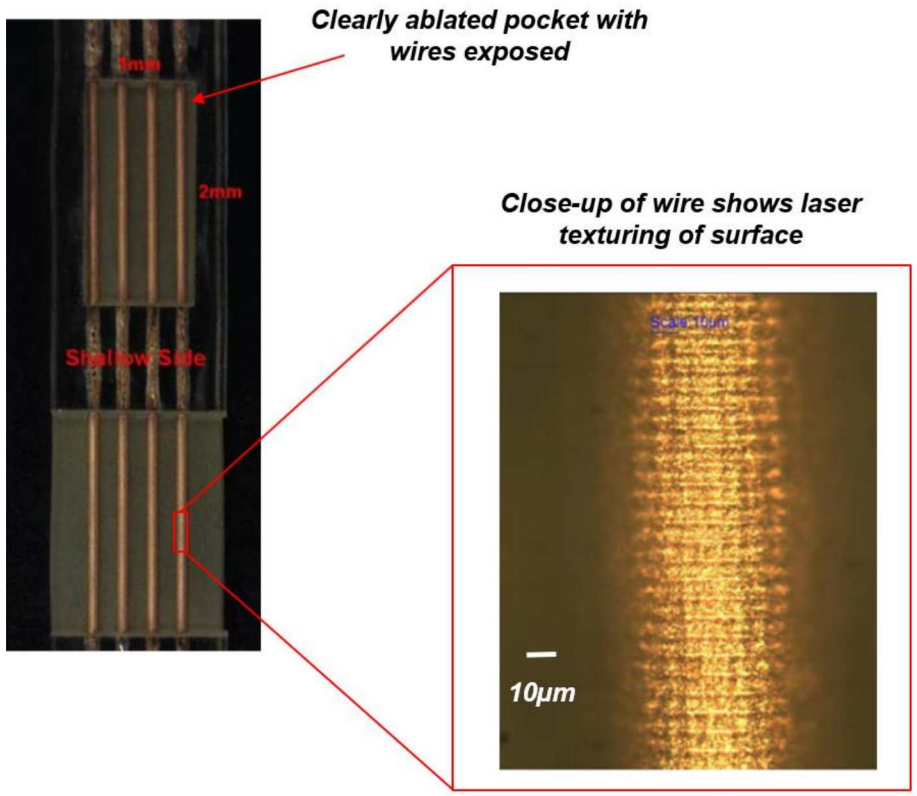
STEP 3:
Placement of chips with bottom solder bumps

STEP 4:
Coating applied and cured



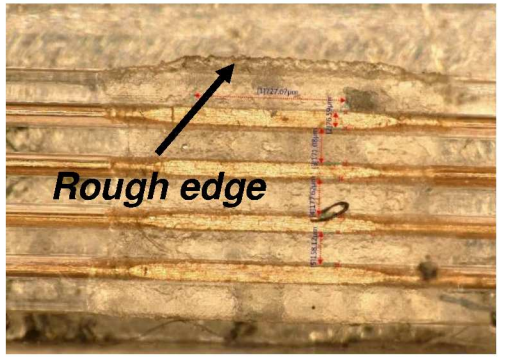
Exposing Copper Wires for Electronics Attachment

Laser Ablation

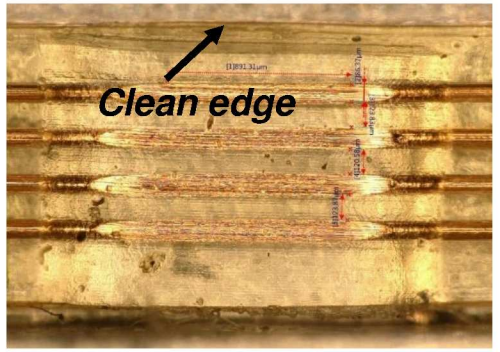


CNC Milling

Polycarbonate

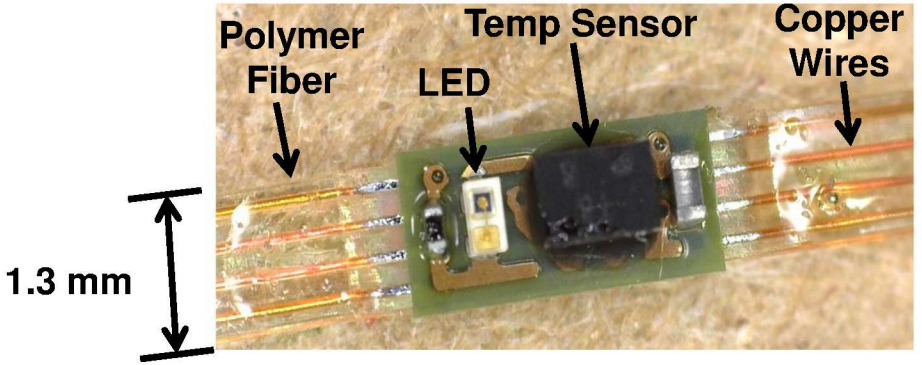


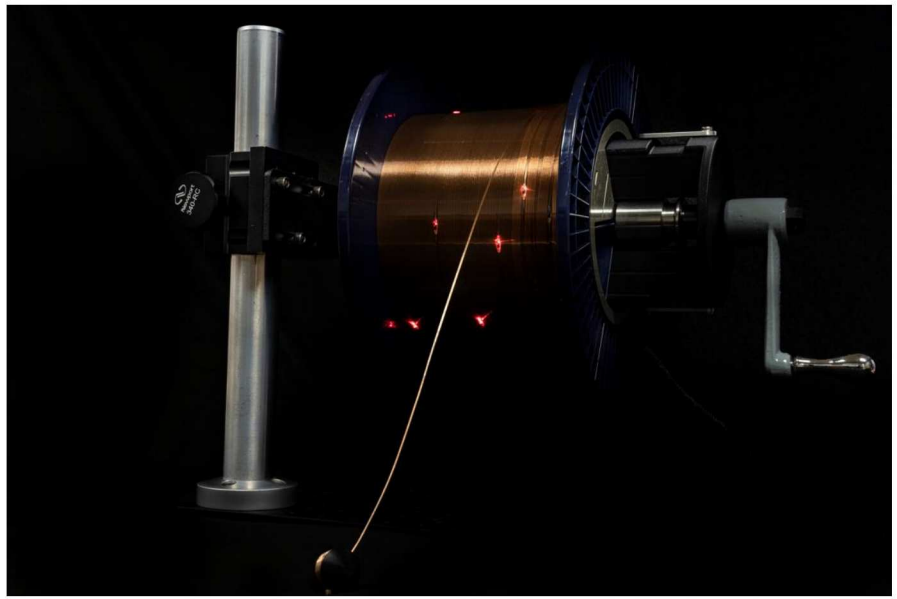
Ultem

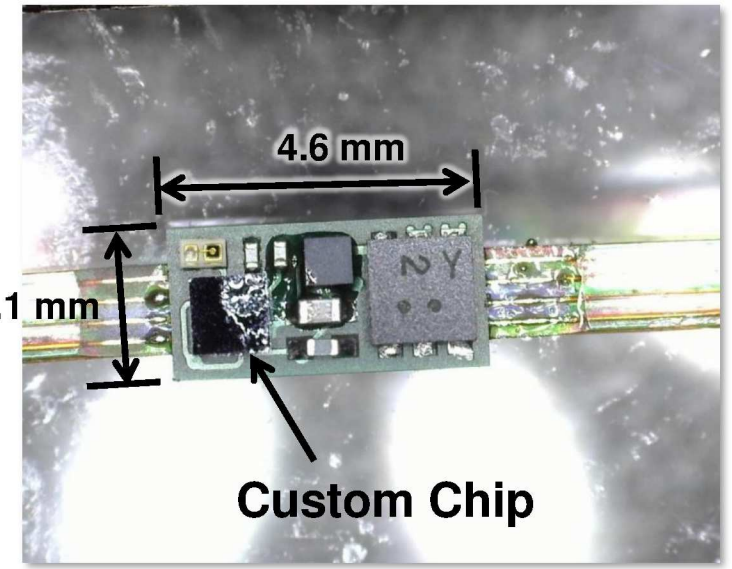


Interfacing Electronics to the Copper Bus

- Electronics are interfaced to the four-wire bus using an interposer PCB (green)
- The interposer can support a sensing element, processor, and memory
- The resulting fiber can then be integrated into a textile







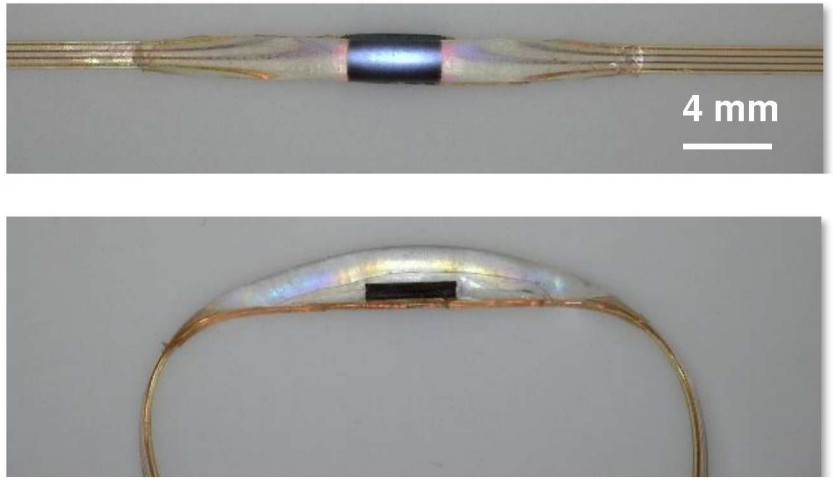
PCB: Printed circuit board

Integration of Interposer into Fiber

Fiber Encapsulation

- Electronics can be encapsulated for protection from water
- Encapsulation can be performed with a variety of methods and materials
- Overcoating of drawn fiber is also offered as a GFC

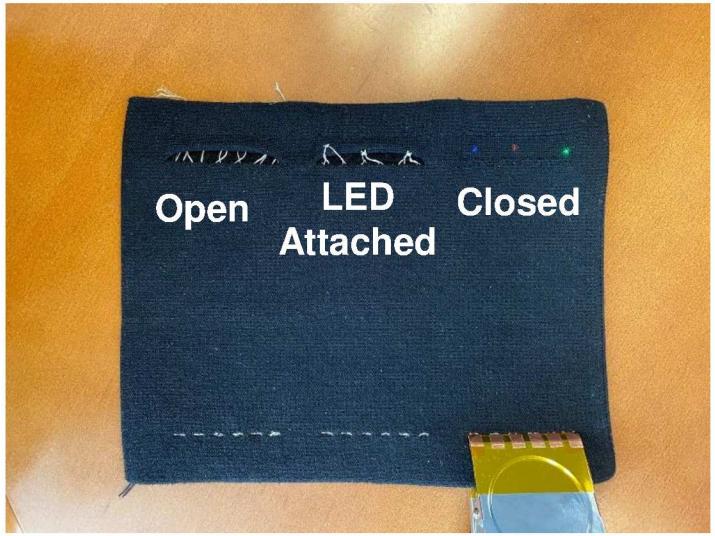
UV Curable Epoxy

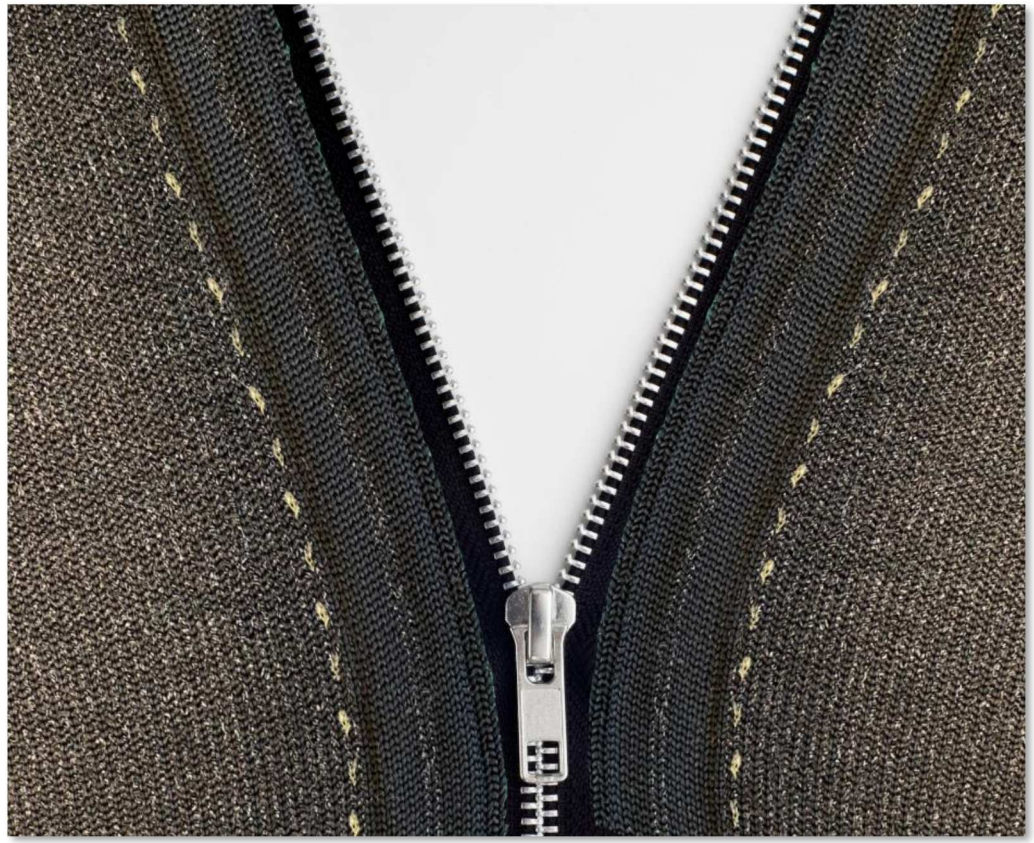


Inline Polymer Curing

Integration of Fibers into Knit Channels

- Knit channels can be used to enclose hardware
- Conductive yarn can attach to electronics for connectivity to battery or outside of fabric

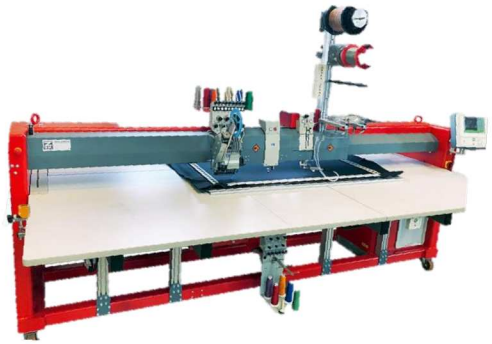


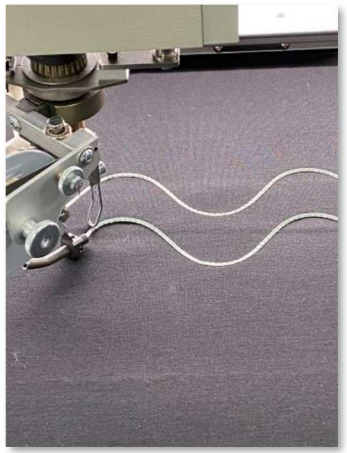


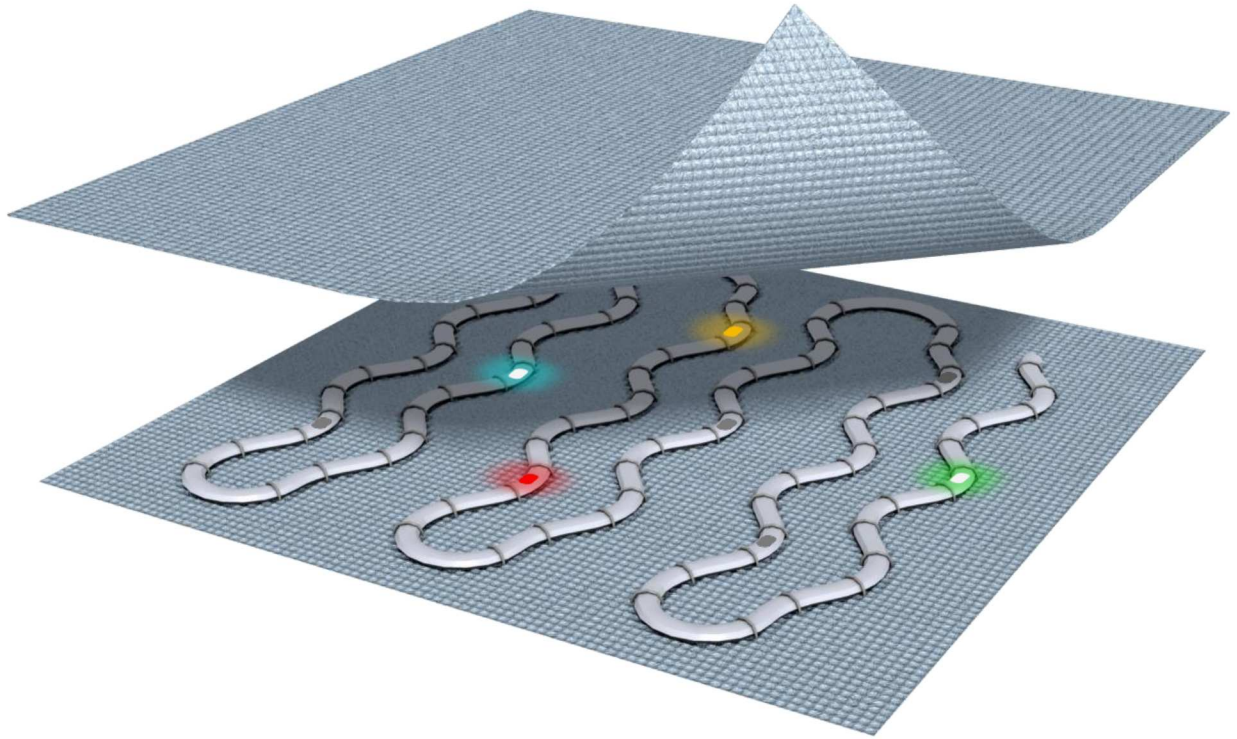
Embroidery of Fibers

- **Embroidery can be used to integrate polymer fibers into the textile**
- **We are currently testing with various polymer types and diameter**

Custom Embroidery Process

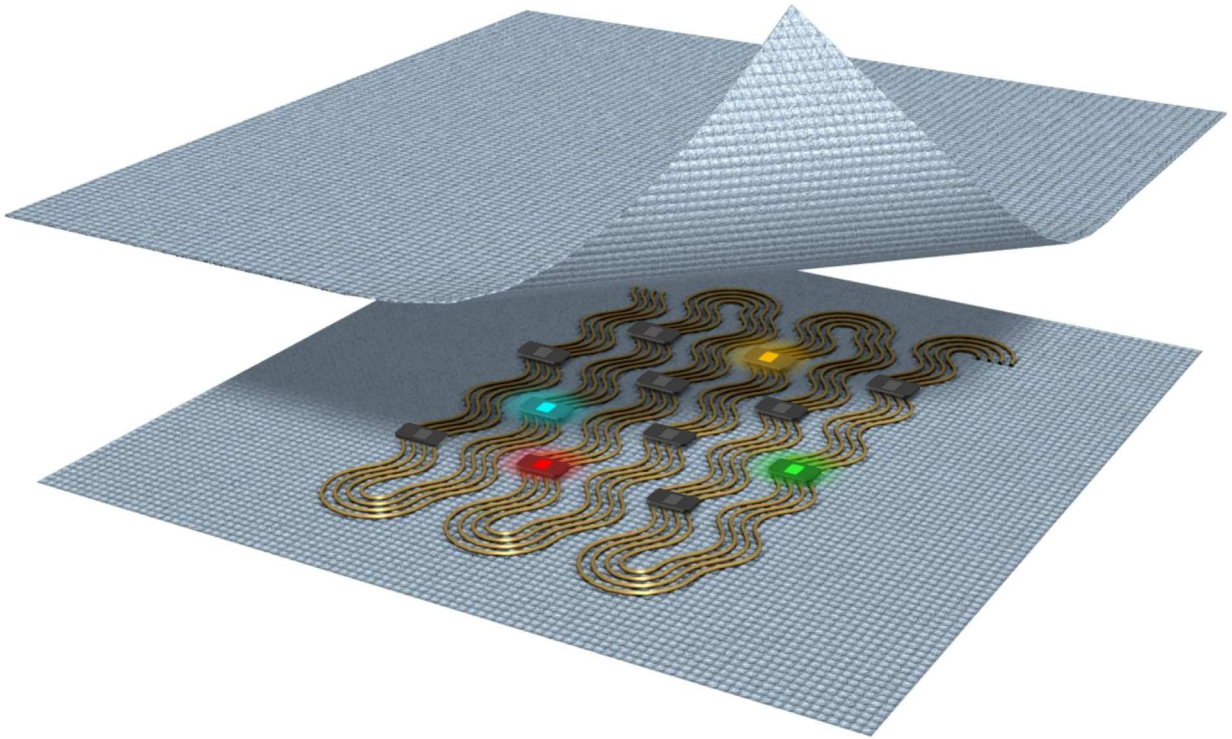






Direct Attachment to the Fabric

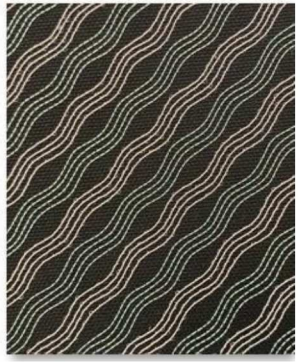
- **Electronics can be attached directly to traces in the fabric**



Conductive Traces on Fabric

- **Several methods are available for applying conductive materials to the fabric to acts as an electrical bus**

Embroidery



Sew wire & conductive yarns directly onto fabric

Knit

Conductive Yarns Knit

Laser Cut

Etch conductive fabric composite & peel away negative

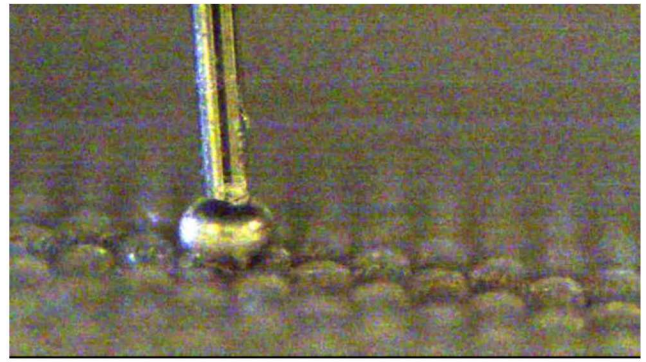
Screen Print

Conductive silver ink printed on laminate layer

Evaporated Metal

Aluminum

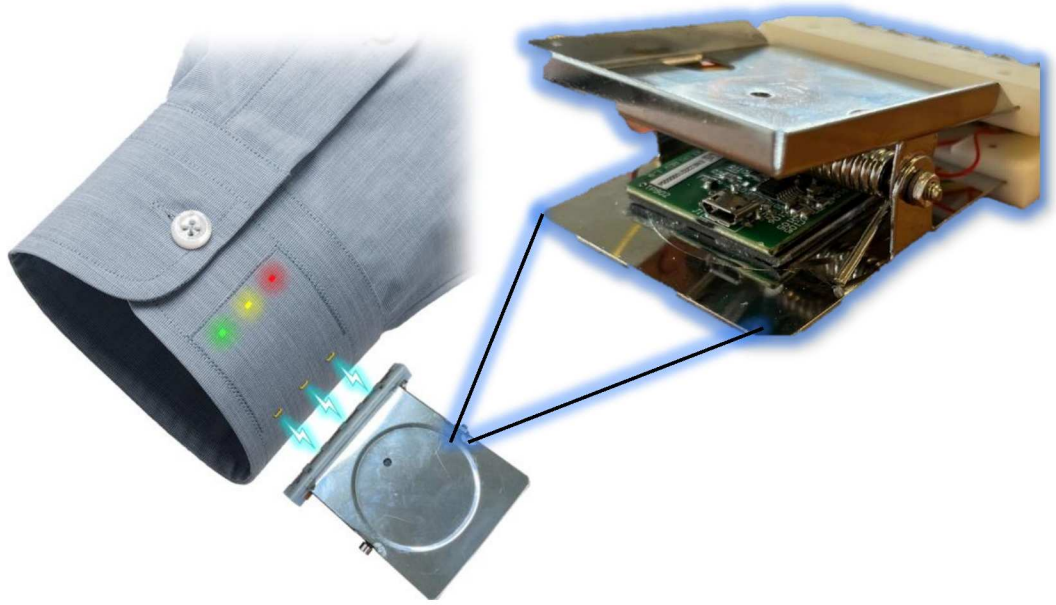
3D Printed Metal

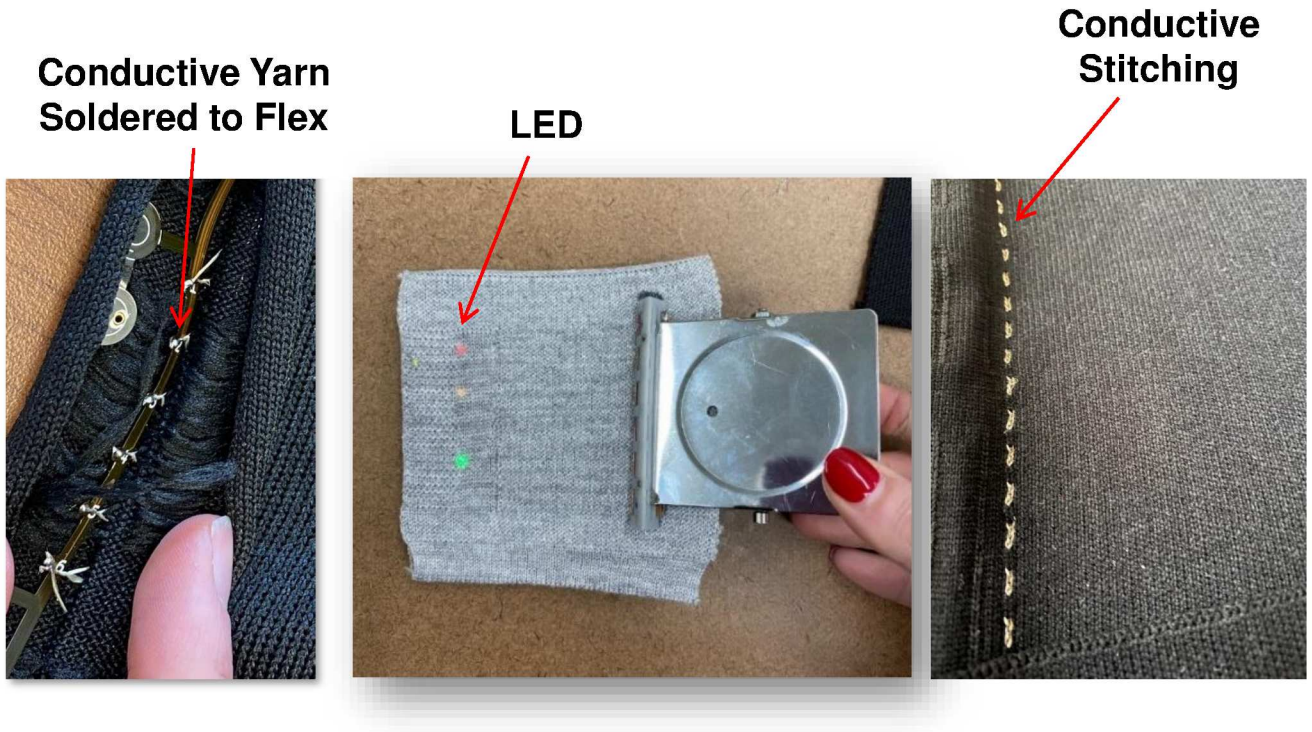


Silver Ink

Data Retrieval and Battery Recharge Method

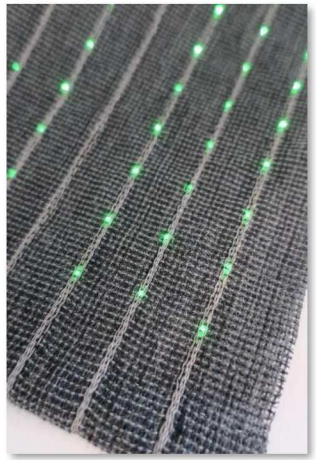
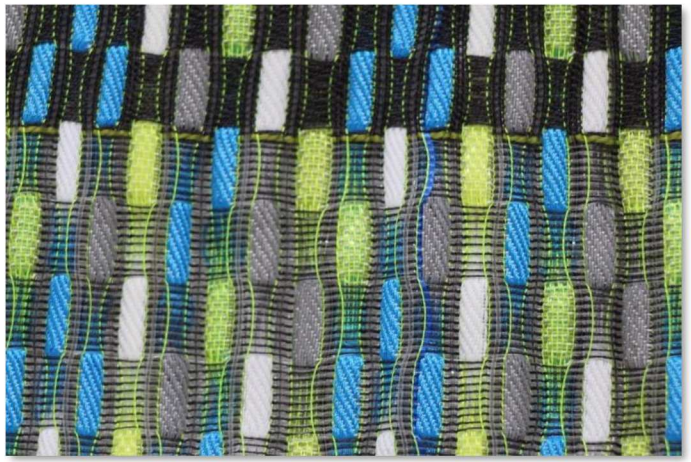
- Conductive yarns are used to interconnect the electronics
- A clip is used to make electrical contact to the fabric in order to retrieve data

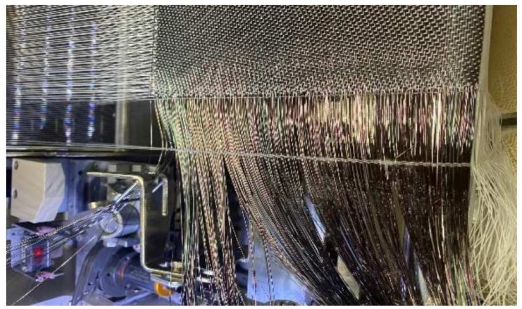




Textile Engineering

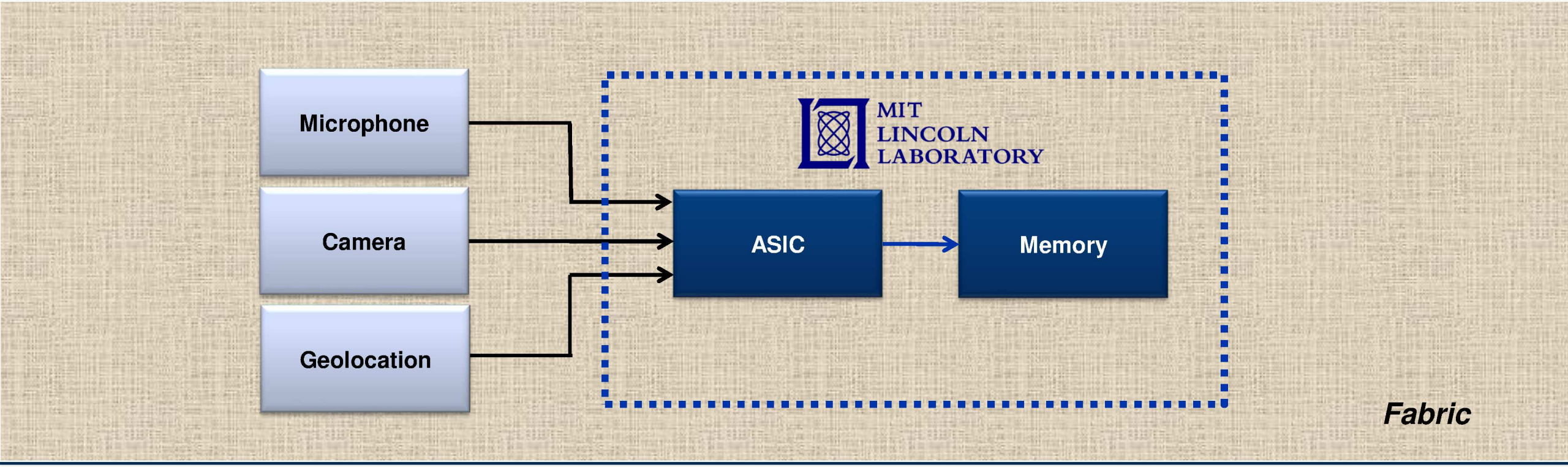
A variety of textile construction capabilities are available, including full garment construction



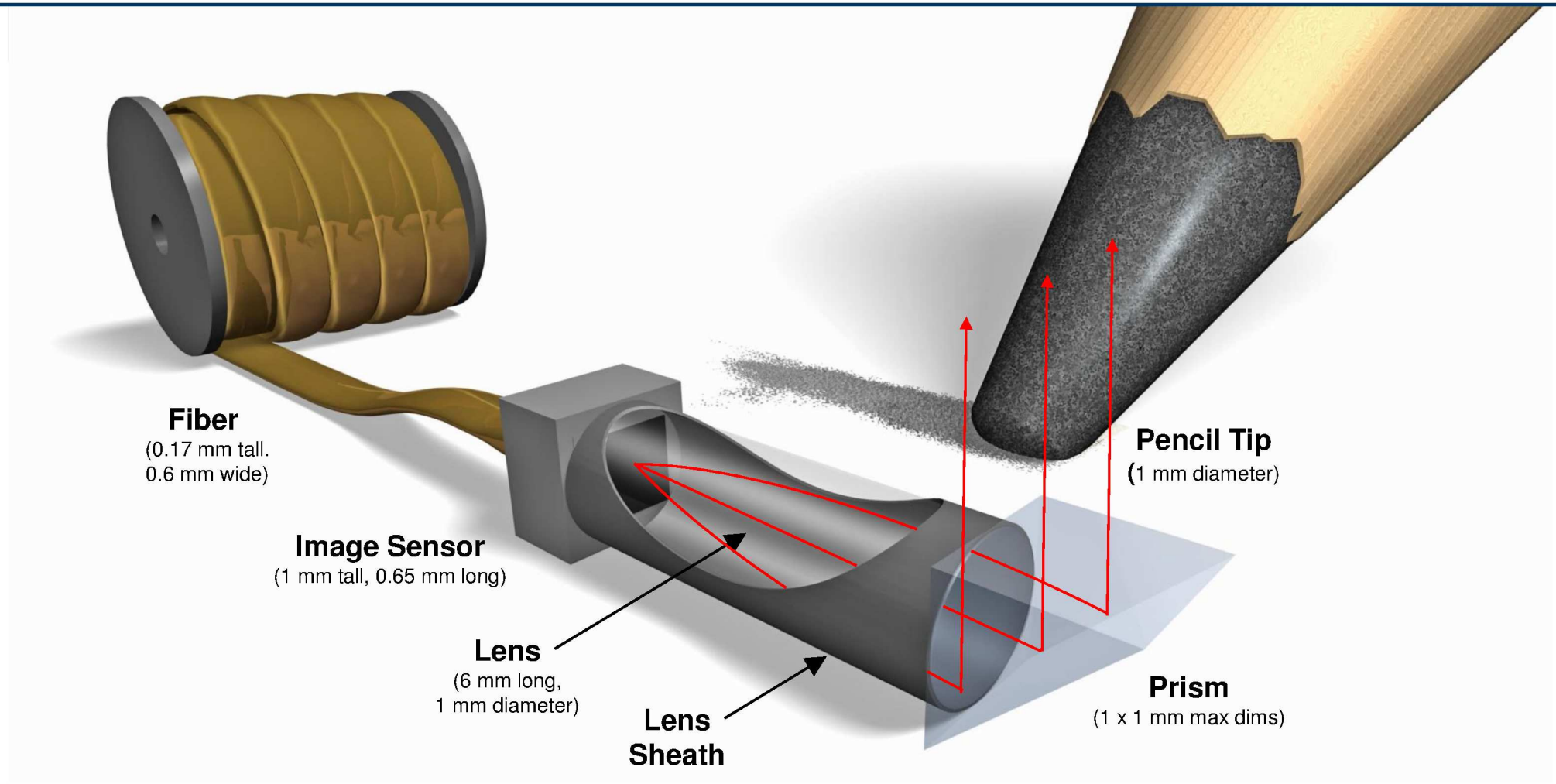

Back-end Electronics

- The electronics in the baseline designs can be integrated into a custom ASIC
- Performers who would like this capability will work with MITLL to establish a protocol for their interface



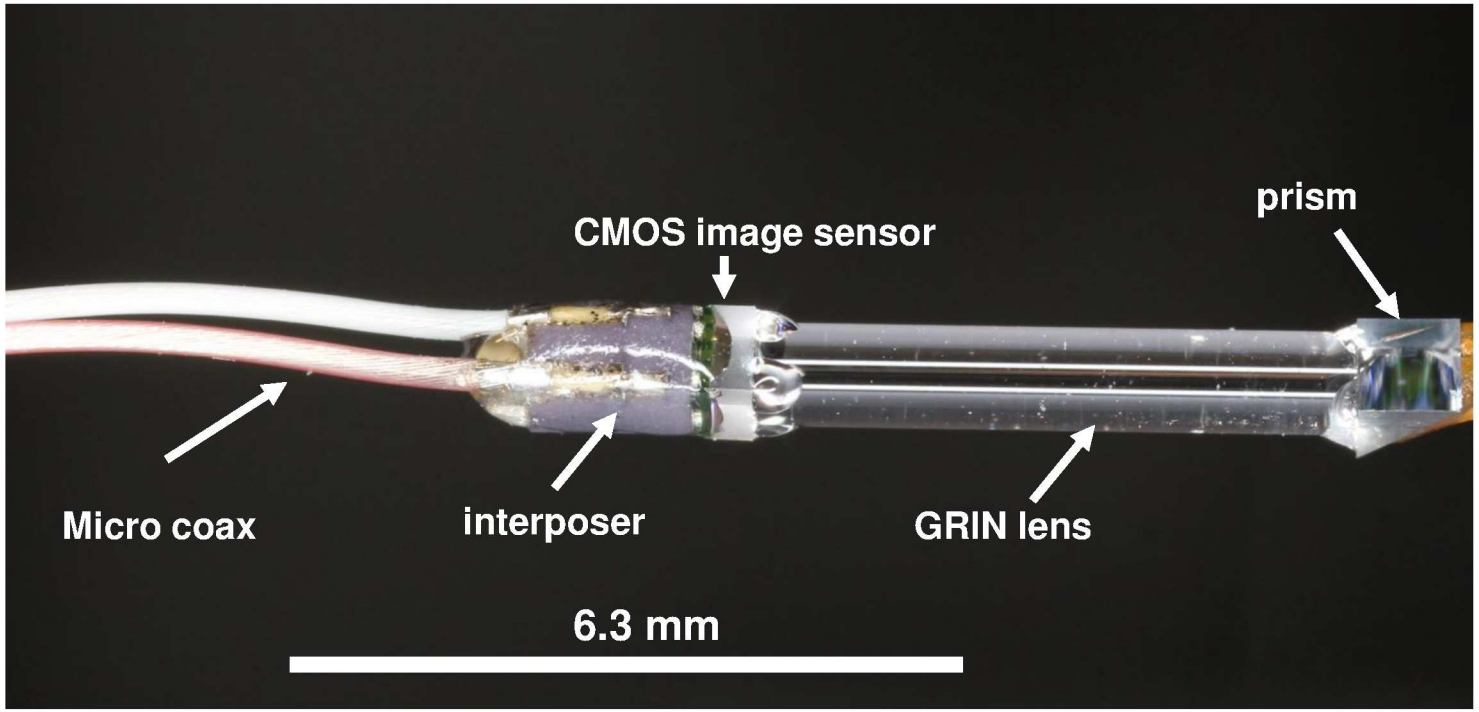
ASIC = Application-Specific Integrated Circuit

Custom Optics



Custom Optics

- Custom optics have been integrated into a garment and tested
- The geometry of the optics can be adjusted to fit the needs of the performer



Summary

- **Government Furnished Capabilities are being offered in a variety of areas:**
  - **Integration of electronics into fibers**
  - **Integration of fibers and/or electronic components into fabrics**
  - **Conductive yarns for interfacing with battery and/or data retrieval**
  - **Textile engineering and full garment construction**
  - **Back-end electronics, including custom integrated circuit**
  - **Optics design for integration with camera**

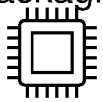
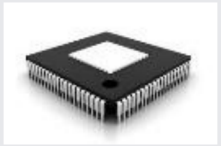
Backup Slides

Capability Matrix to Reference for GFC Requests

#	Process	Highest TRL*	Capability Description	*Tour Stop*
1	Filament Draw 	7	Thermally drawn polymer fibers containing wire buses	*1*
2	Yarn twisting 	5	Direct twist to ply custom yarns and fibers, includes core wrapping	*4*
3	Weaving 	6	Functional fiber & conductive yarn weaving, channel weaving, multi-layered fabric weaving	*4*
4	Knitting 	5	Stoll ADF Knit & Wear™ technology seamless weft knitting double bed 14gg/7.2 industrial machine. Shima Seiki Wholegarment™ technology seamless weft knitting double bed 10gg industrial accessory machine. Brother™ double handloom 7gg manual knitting machine.	*5*
5	Print 	5	Printing of various inks on fabrics	*6*
6	Embroidery 	4	Conductive thread through-hole board attachment; conductive thread bus laydown for subsequent component attach	*3*

**Specifics of components to be integrated may render a process step more or less risky.*

Capability Matrix, continued

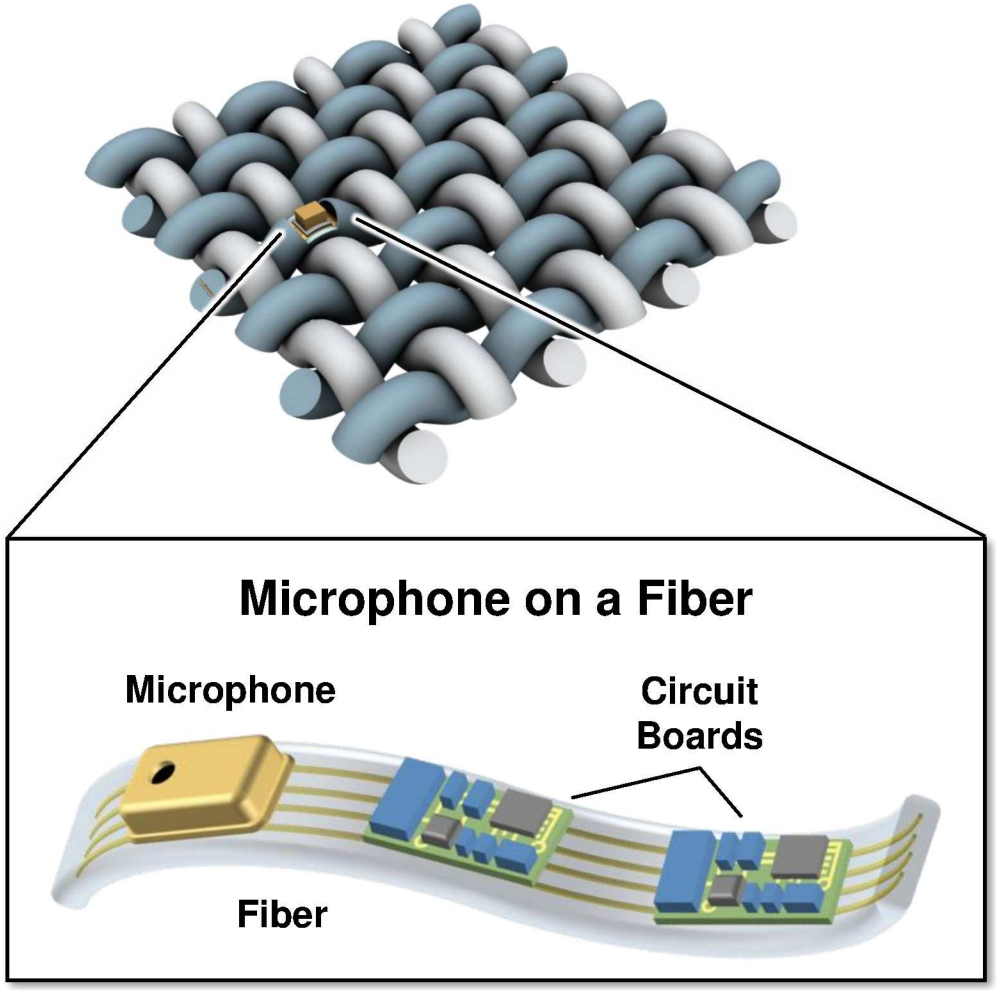
#	Integration Techniques	Highest TRL*	Capability Description	*Tour Stop*
7	Component Attach 	6	**Soldering, conductive adhesive, or embroidered attachment of components onto copper bus in polymer fiber**	*2*
8	Packaging 	8	**Range of packaging capabilities available**	*2*
9	Cut & Sew 	6	**Cut & sew expertise with necessary equipment (Juki, serger, embroidery machine etc.)**	*7*
10	Encapsulation 	6	**Epoxy-based, UV-curable encapsulation for water resistance**	*2*
11	Sensor Interfaces 	6	• **"Listen": Analog output (30 dB gain); digital output (I2C or I2S)** • **"Look": Digital output (MIPI CSI-2 or DVP); other protocols or analog output developed on prior U.S. Government programs open for discussion** • **"Locate": I2C for generic sensors (e.g. IMU); other protocols or analog output developed on prior U.S. Government programs open for discussion**	*N/A*

**Specifics of components or process to be integrated may render a capability more or less risky.*

Integrating Polymer Fibers into Textiles

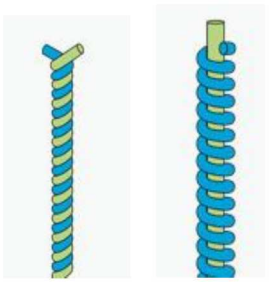
- **Fibers with electronic nodes can be integrated into textiles**
- **The fiber must remain flexible enough to crimp and bend during fabrication like traditional yarns**

Sub-mm fibers result in a more flexible fabric



Fabric Capabilities

Yarn Processing



Direct Twist Machine

Weaving Looms

Industrial Loom

Table Loom

Knitting Machines

Shima Seiki Knitting Machine

@ AFFOA - Stoll ADF Knitting Machine

Sewing Machines

Industrial Sewing Machine

Heavy Duty Industrial Sewing Machine (can handle thicker fabrics)

Team Infrastructure for e-Textile Integration

Industrial Sewing Machines

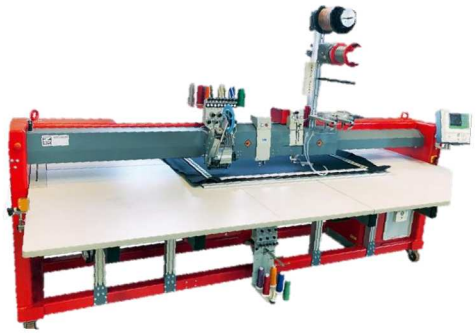
CCI Studio Industrial Loom

Shima Seiki Knitting Machine

Stoll ADF Knitting Machine

Direct Twist Machine

AIT 2024C Tabletop Fabric Laminator



ZSK JVGA Technical Embroidery Machine (AFFOA)

Titanium:Sapphire Laser