Integration Technologies for Smart Textiles

Rolf Aschenbrenner

Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM

Technische Universität Berlin

Gustav-Meyer-Allee 25

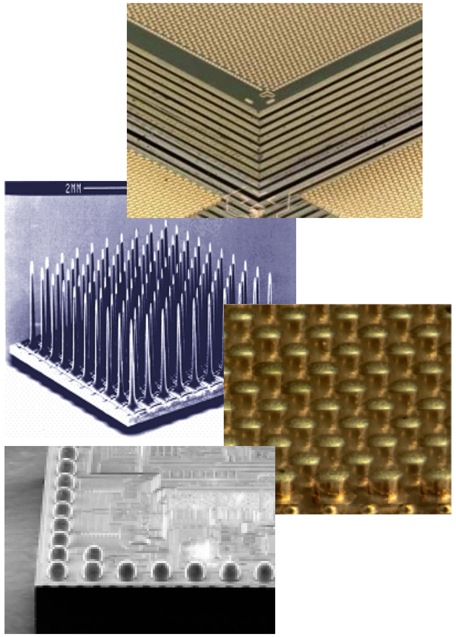
13355 Berlin

The Fraunhofer-Gesellschaft
Locations in Germany

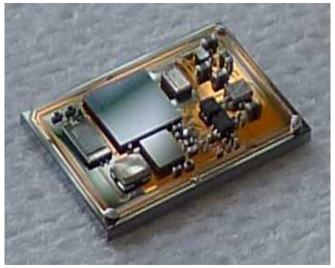
- **66 institutes and research units**
- **Nearly 24,000 staff**
- **More than €2 billion annual research budget totaling. Of this sum, around 1.7 billion euros is generated through contract research**

Fraunhofer IZM's Mission:
From Microelectronics and Microsystems towards Smart Systems

System Integration Technologies



2.4 GHz Sensor Node (15 x 10 x 2)



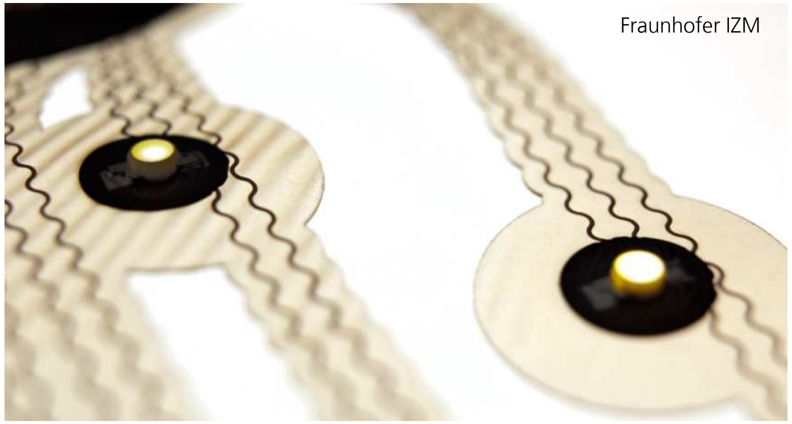
Fraunhofer Institut Zuverlässigkeit und Mikrointegration

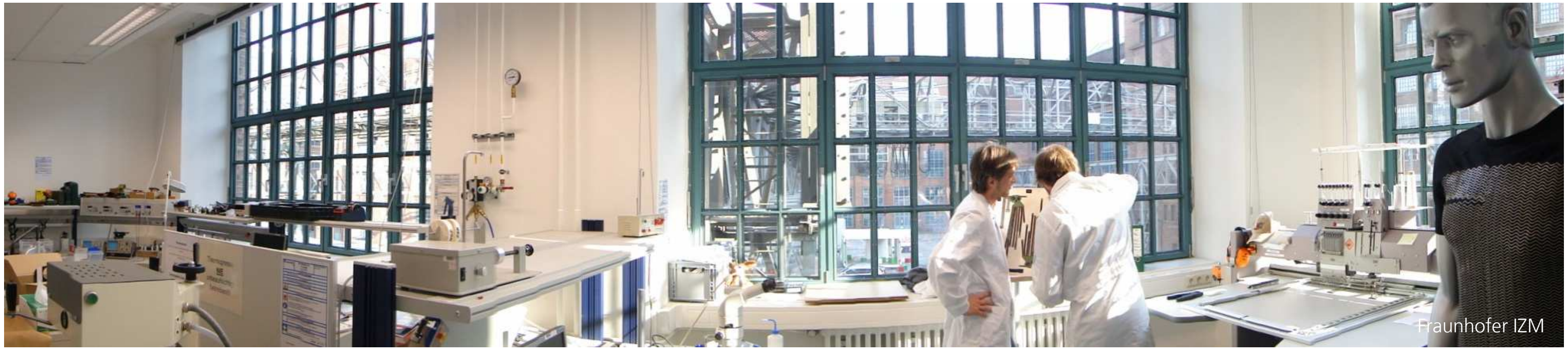
[nm], [µm] — [m]

Nanodimensions — to — Final Product Size

Outline

1. Introduction
2. Challenges for Design and Technology
3. Technology Overview
    - Conductors
    - Substrates
4. Interconnection Technologies
5. Application Examples

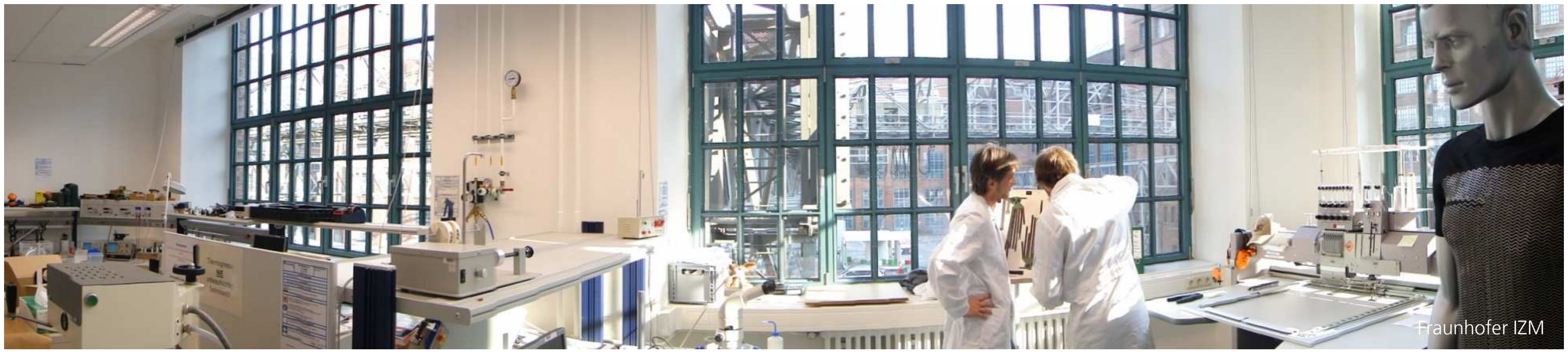




Fraunhofer IZM TexLab

- Conductor Integration and interconnection technologies
- Lighting Concepts for smart textiles
- System Design for Smart Textiles
- Electronics Manufacturing
- Reliability Testing

Team:
Christine Kallmayer
Christian Diels
Malte von Krshiwoblozki
Rene Vieroth
Bettina Otto
+5 Students



Wearables vs. Technical Textiles

wearable

ECG Shirt

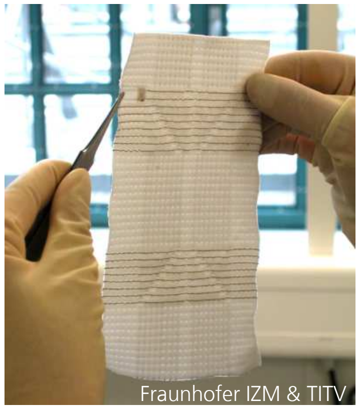
EMG Sensor

Klight Interactive Dress

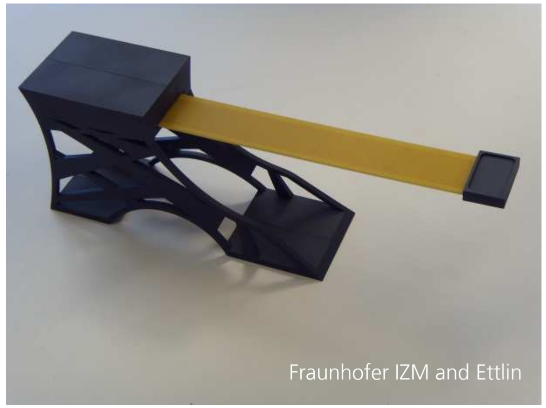
technical

SmartPixel

Automotive interior: lighting and control



Textile Transponder



Stress/Strain Measurement for Fiber Reinforced Plastics

Challenges for Design and Technology

System Design for Smart-Textiles

A New Way of Thinking

≠

Designing Systems for Smart Textiles is Totally Different
From Designing Systems for Conventional Electronics

System Design for Smart-Textiles

Nothing is Safe – The Seven Rules

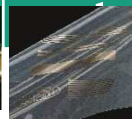
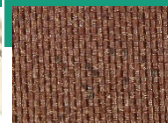
1. Every interconnection may break at any time (mechanical stress)
2. Any Isolation might conduct at any time (humidity)
3. Normally nothing is shielded (properly)
4. There are typically no wave guides (high data rates, signal integrity)
5. The user has its hands and body in the system
6. All conductors are extremely exposed to ESD
7. Excessive heat means excessive claims for compensation

➡ Years of theory and experience made us master this task

Technology Overview

Materials (conductors) for e-textiles

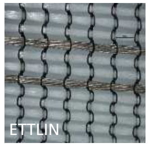
There is a huge diversity of conductive materials for e-textile applications on the market.

Coated fibers, yarns, threads	Stranded wires / litz wires	Hybrid wires	Inks / lithograph ic	Conductive Fabrics
			 	 
• Noble Biomaterials • STATEX • Imbut • Syscom Advanced Materials • …	• ELEKTRISOLA • Fisk Alloy • Bekeart • Karl Grimm GmbH & Co.KG • …	• ELEKTRISOLA • ZIMMERMANN (Novonic) • Yarn service provider • …	• Du Pont • Creative Materials • Fraunhofer IZM • QPI (SCB-Technology) • …	• STATEX • Metal Textiles (METEX) • …
textile character	**Conductivity (textile character)**		**Not textile**	**textile character**

Textile Circuit Manufacturing

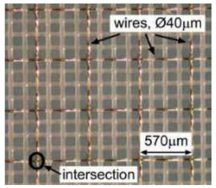
Conventional textile manufacturing processes can be used to generate conductive, textile circuits

Weaving	Embroidery	Knitting	Laser Structuring	Lithography (experimental)


ETTLIN


TITV / Fraunhofer IZM

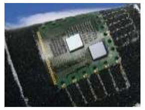
project: Jacquard



Source: SEFAR Petex

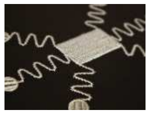

Fraunhofer IZM


Fraunhofer IZM




Source: TITV

Source: Forster Rohner



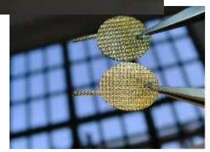

Source: STOLL


Source: Sensoria


Source: WLS


Source: WARMX


Fraunhofer IZM




Clothing plus / Myontec


Fraunhofer IZM


Fraunhofer IZM

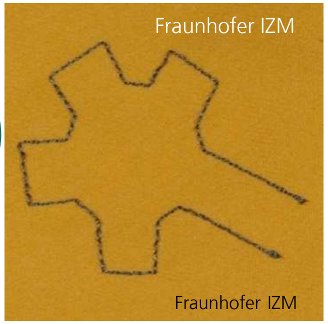

Fraunhofer IZM


Fraunhofer IZM

Interconnection Technologies

Textile-Integrated Electronic Systems

(1)

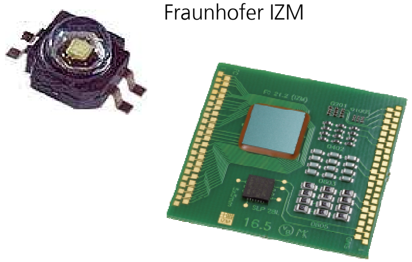


fabric with integrated conductors

- weaving
- knitting
- embroidery
- etc.

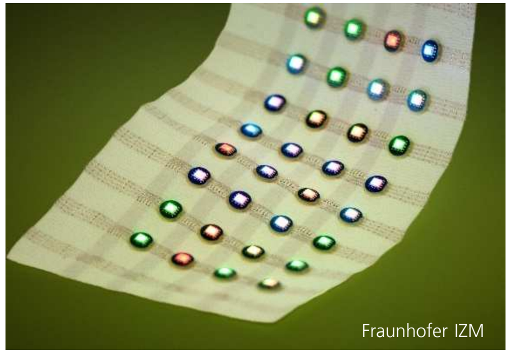
- wires
- conductive yarns
- etc.

+



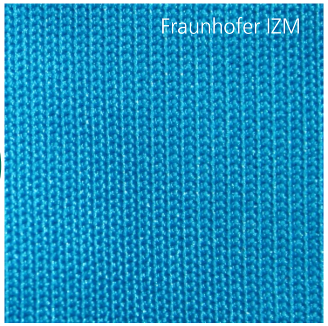
electronic components,
modules, systems

=



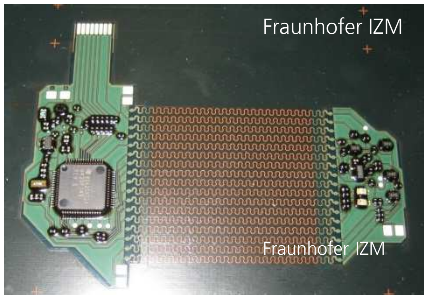
smart textile

(2)



basic fabric

+



Stretchable thermoplastic substrate
with electronic components

=

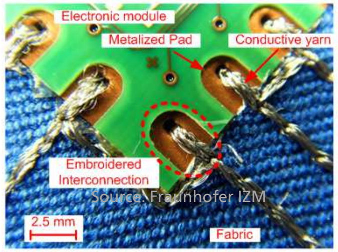
smart textile

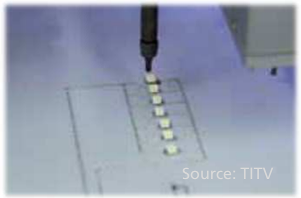
Fraunhofer
IZM

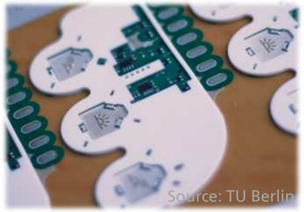
Integration Technologies – A Selection of Technologies

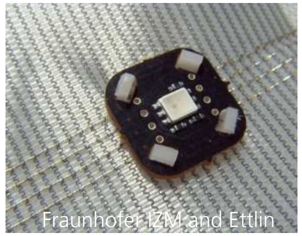
Soldering	Adhesive Bonding (ICA/NCA)	Force Fit

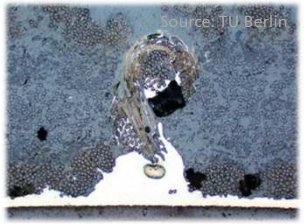
← Combination →

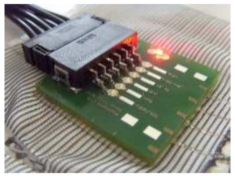




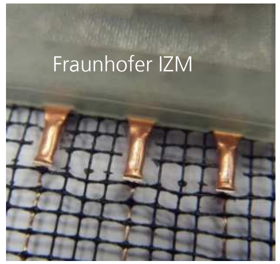








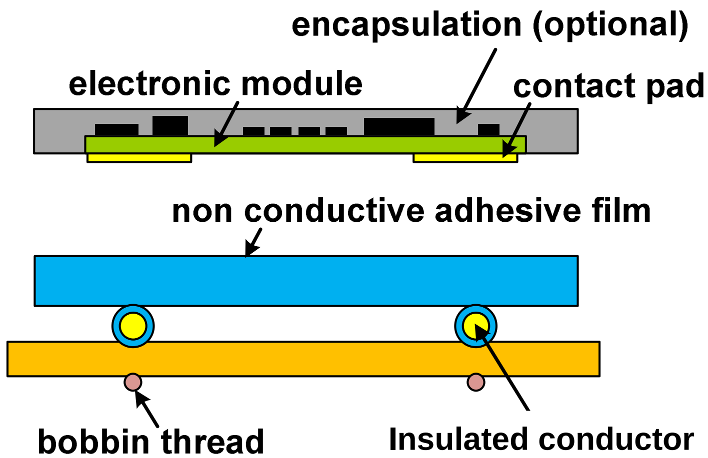
Snap fastener

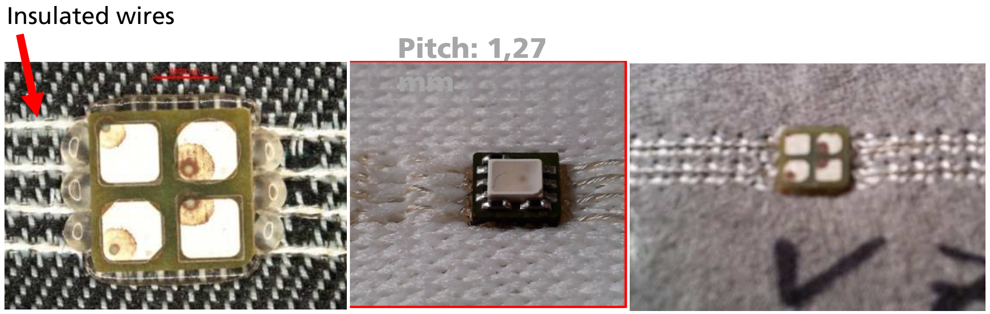


Interconnection Technologies:
Thermoplastic Adhesive Bonding (1)

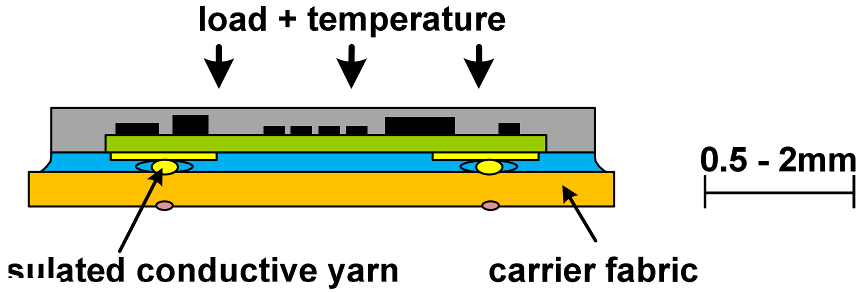
Bonding with Non-Conductive Adhesive

1. Pressure + Temperature
   - adhesive melts
   - contact pad and cond. yarn touch
2. Cooling without releasing pressure
   - adhesive solidifies and
   - keeps contact partners in contact
3. Release pressure
   - electronic module and fabric circuit are connected mechanically and electrically



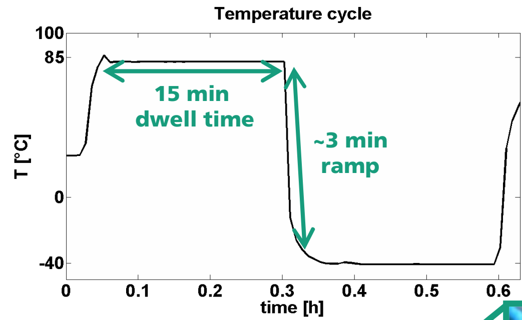


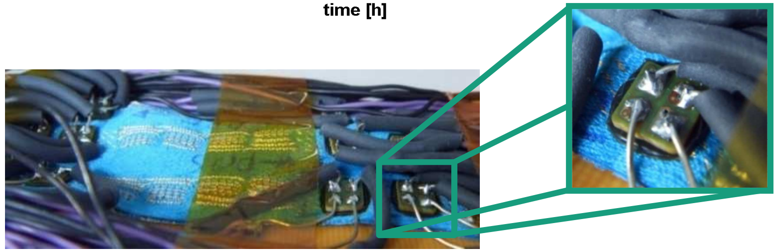
Woven substrate Knitted substrate Embroidered substrate (soutache)

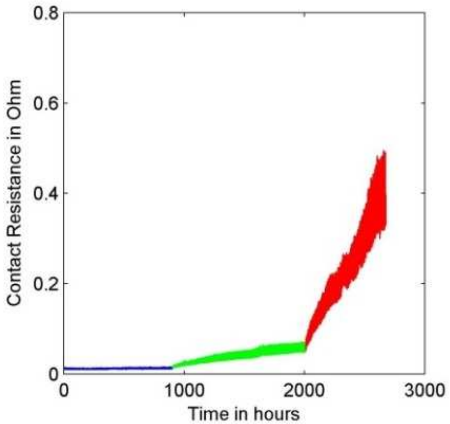


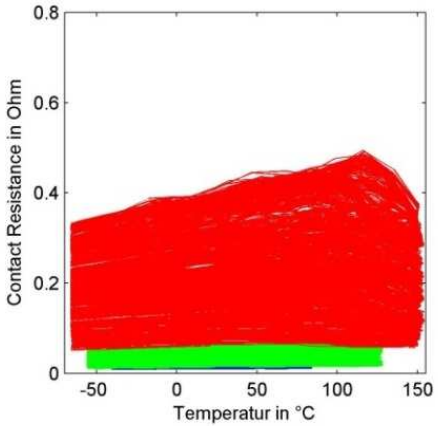
Interconnection Technologies:
Reliability Testing TA-Bonding

- Temperature cycling (JEDEC JESD22 A104C)
    - 1000 cycles at different ranges
- Humidity tests (JEDEC JESD22 A101B)(85°C/85%H)
    - 1000h
- Wash cycling tests (ISO 6330)
    - 20 cycles







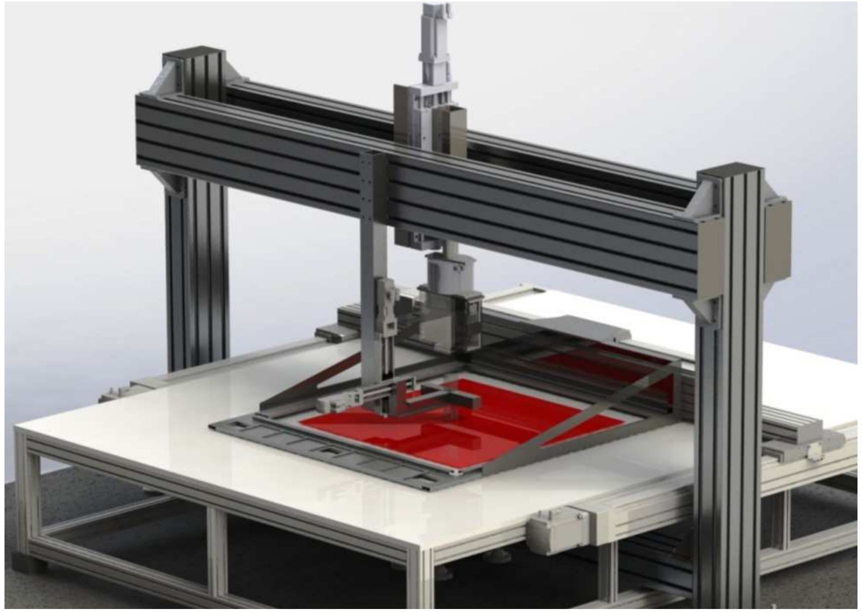


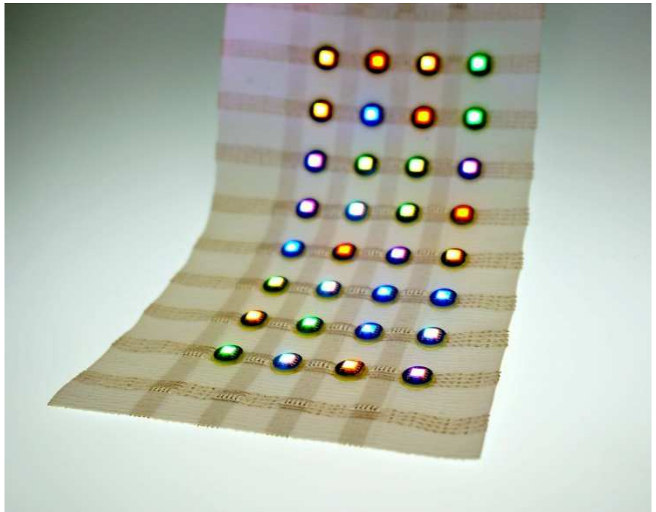
-40 °C – 85 °C | 1000 cycles
-55 °C – 125 °C | 1000 cycles (same samples)
-60 °C – 150 °C | 1000 cycles (same samples)

Interconnection Technologies:
Outlook: Large Area – High Precision Bonder

(1)

- Towards commercializing of thermoplastic adhesive bonding
- Prepared for large textile substrates (1x1 m² operation area)
- For bonding fine pitch circuitry modules

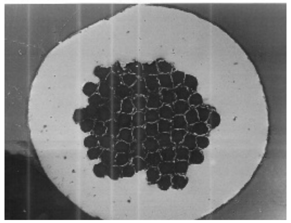




Overall length x width x height	3300 mm x 3400 mm x 2600 mm
working area on textile	1000 mm x 1000 mm
max./min. dimension of electronic parts	50 mm x 50 mm / 3 mm x 3 mm
max. heating temperature	350 °C / 623.15 K
Heating rate	80 K/s
Heating principle	Resistance heating
Cooling rate	20 K/s
Cooling principle	Liquid cooling
Heating and cooling	Can be applied from both sides
max. bonding force	2500 N
Accuracy translational/rotational	20 µm / 0,03°
Position control	dual machine vision

SIIT – System on Flex

Technologies: Crimping

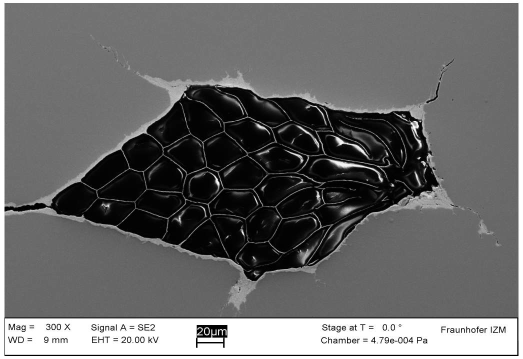


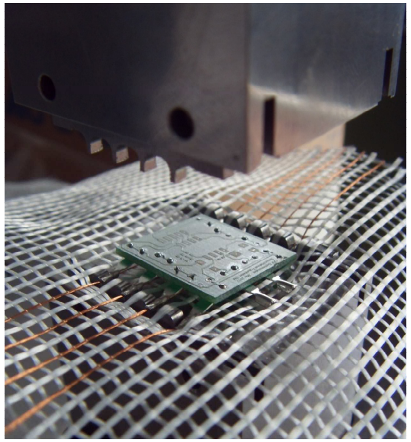
Advantages:

- Room temperature
- Mechanical opening of isolation layers
- Low contact resistance
- High reliability

Disadvantages:

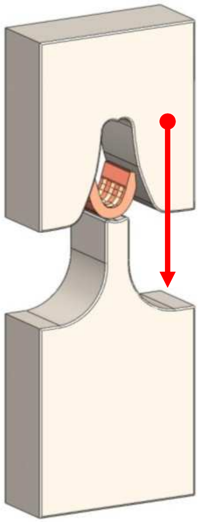
- High setup cost (tooling)
- Limited miniaturization (2 mm pitch)

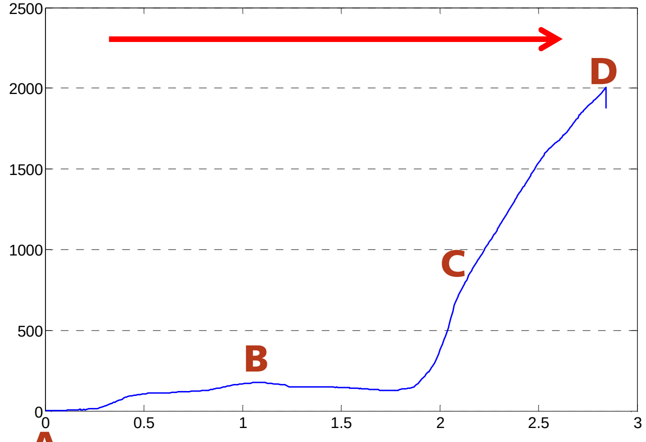




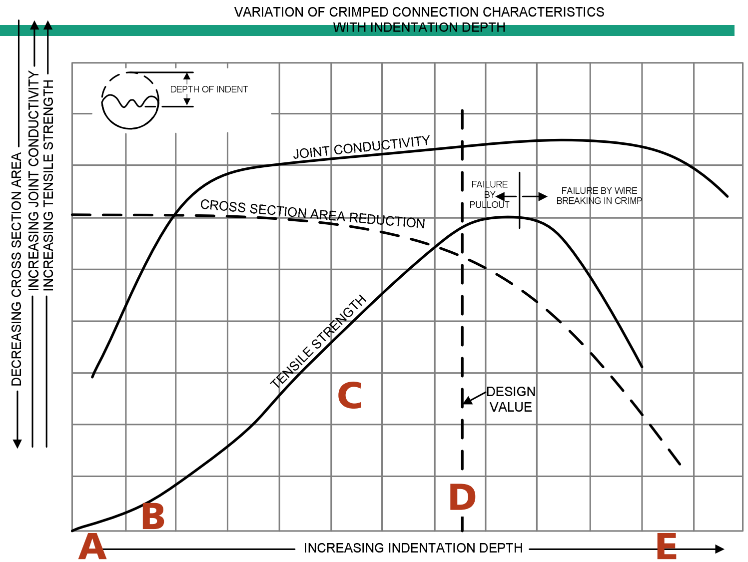
Christine Kallmayer

Crimp Technologie

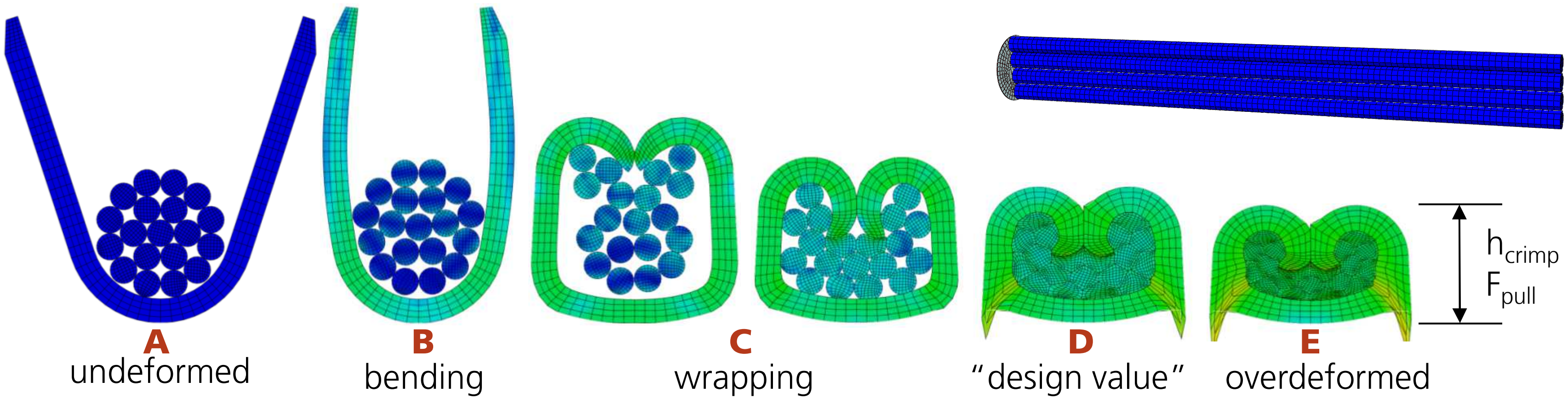




Crimp force over deformation



Variation of crimped connection characteristics with indentation depth [4]

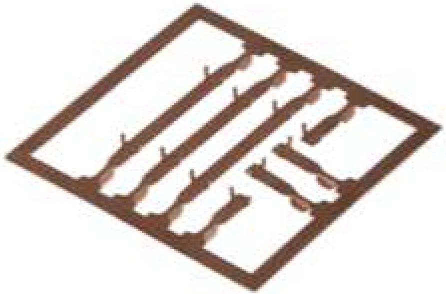


Cross-section view of a simulated crimp process

[4] J.H. Whitley, "The Mechanics of Pressure Connections", New York, 1964.

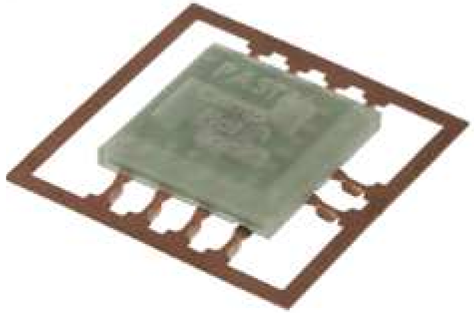
Technologies: Crimping

Application e.g. for sensor integration in textiles

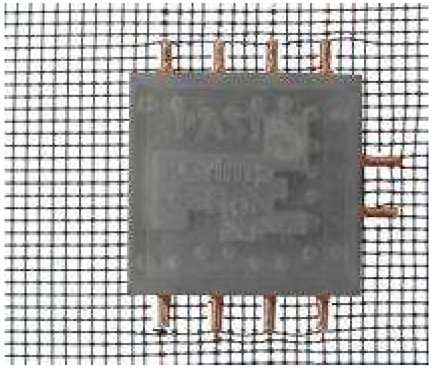


Lead frame

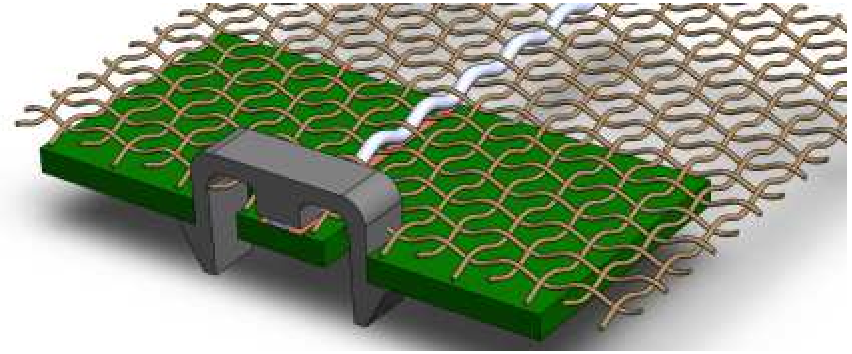
Lead frame with FR4



after encapsulation



Crimp package in textile

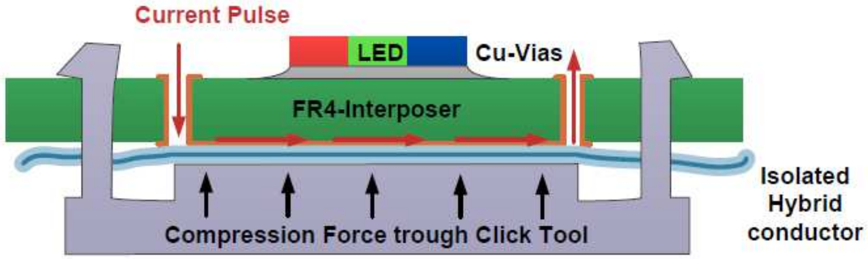


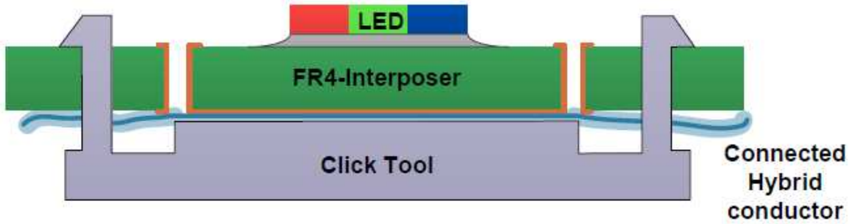
Alternative: Click bond

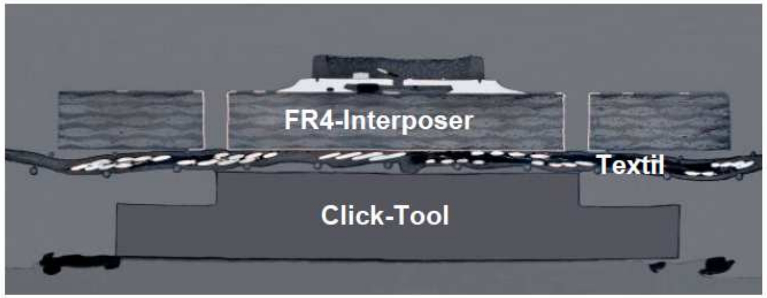
Christine Kallmayer

Interconnection by Click-Tool

- Combination of force-fit interconnection and non-conductive adhesive bonding
- Heat transfer through short current pulse for melting the thermoplastic isolation
- Compression force through Click-Tool

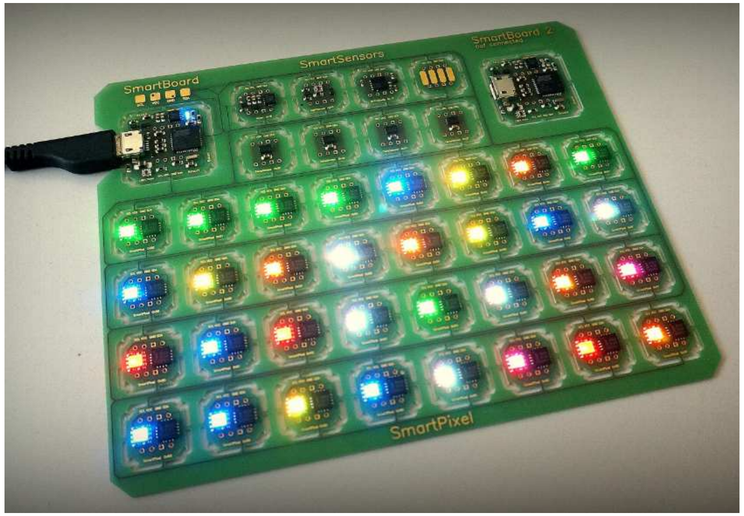


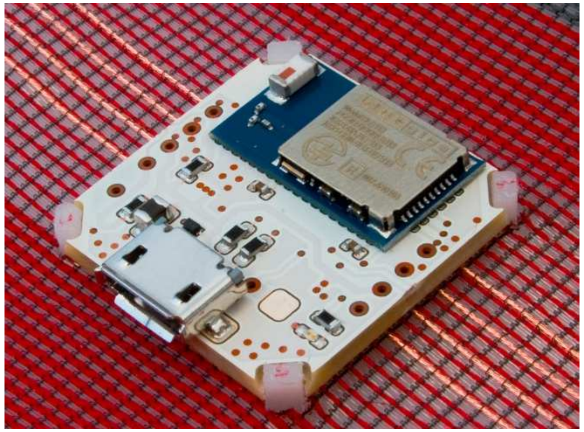


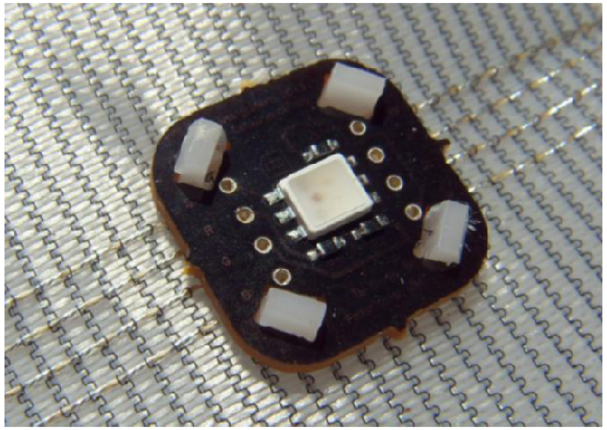


Wearables DIY-Kit

- IZM offers DIY-Kit for E-textile developers
- Boards are equipped with various sensors and LEDs
- Master Module is compatible to Arduino
- Designer is not bothered with BLE configuration

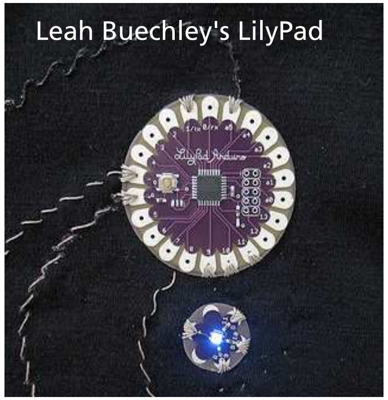




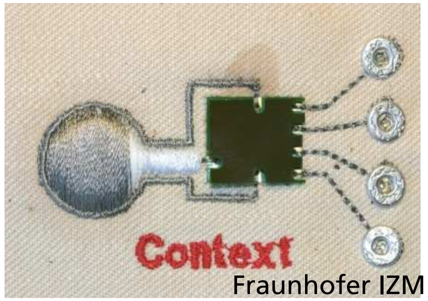


Embroidered Circuits and Interconnections

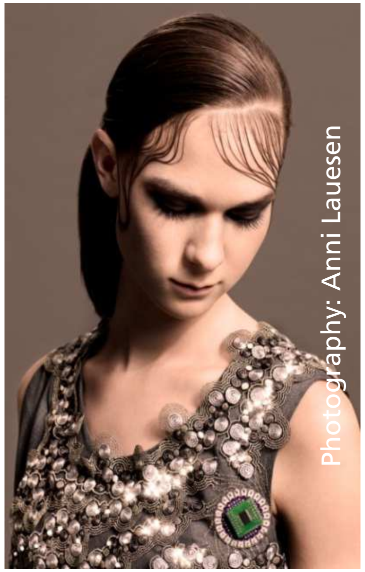
MIT Media LAB


Leah Buechley's LilyPad


Fraunhofer IZM



Fraunhofer IZM


Photography: Anni Lauesen


Diffus Design

Resistance of Embroidered Contacts

Contact Pressure $\sigma_{N,i}$:

$$\sigma_{N_i} \sim \frac{F_{yarn}}{r_i}$$

- F_{yarn} : tension along the yarn
- r_i: radius of local curvature

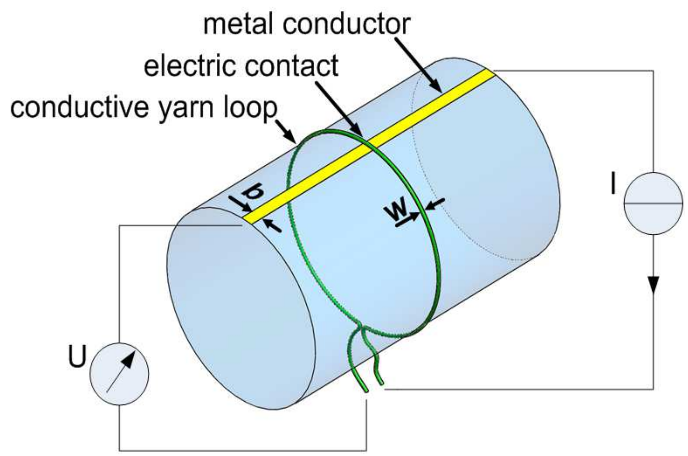
Local constriction resistance:

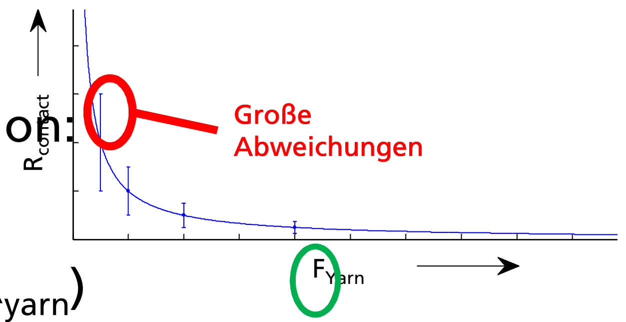
$$R_{C_i} = k_i' \left(\frac{r_i}{F_{yarn}}\right)^n$$

Contact resistance for specific configuration:

$$R_{Contact} \sim \left(\frac{1}{F_{yarn}}\right)^n$$

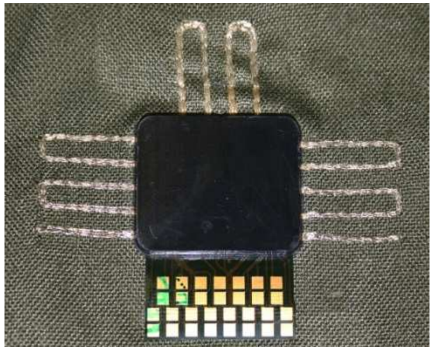
(neglecting R_{yarn})

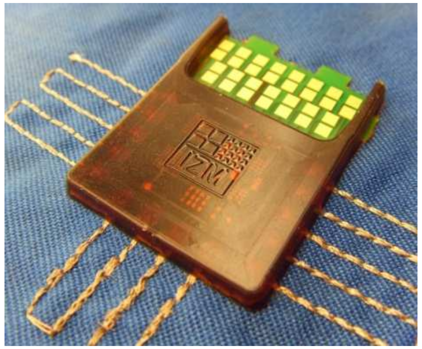




Phd Study Thorsten Linz

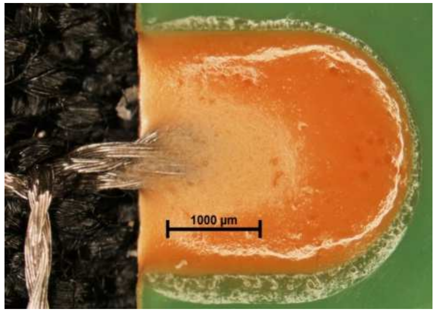
Protection of Embroidered contacts





Transfer Molding or
Hotmelt over the module

or



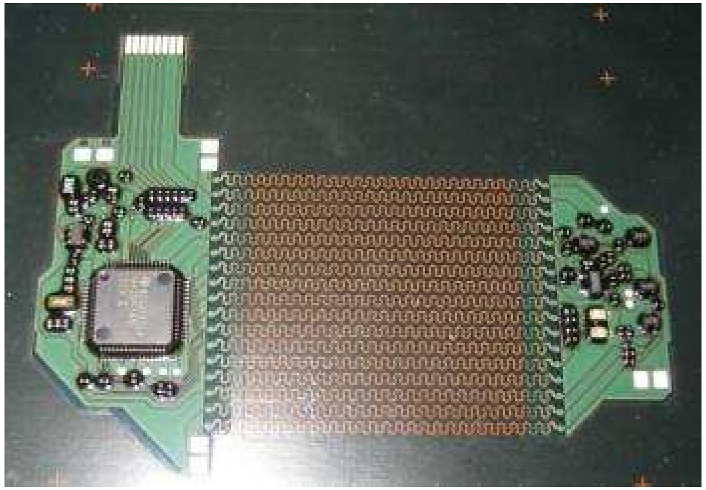
Deposition of Epoxy or ICA
locally at the contact

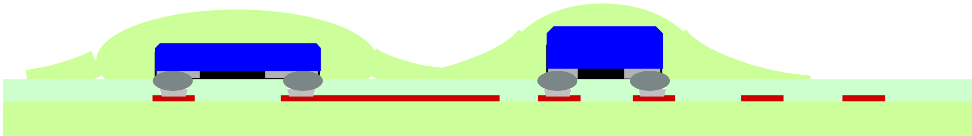
Or

Combination of local and
global encapsulation

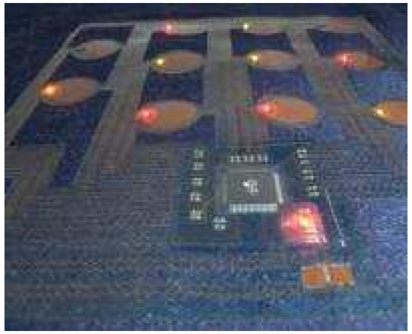
Technologies: Stretchable Circuit Board

- Stretchable Circuit board based on thermoplastic Polyurethane
- Meander structures for stretchable conductor lines
- Lamination on textile after complete assembly and test
- Textile and electronic processes are seperated as long as possible





Eingebettete Komponenten in TPU



Christine Kallmayer

Structuring of Polyurethane

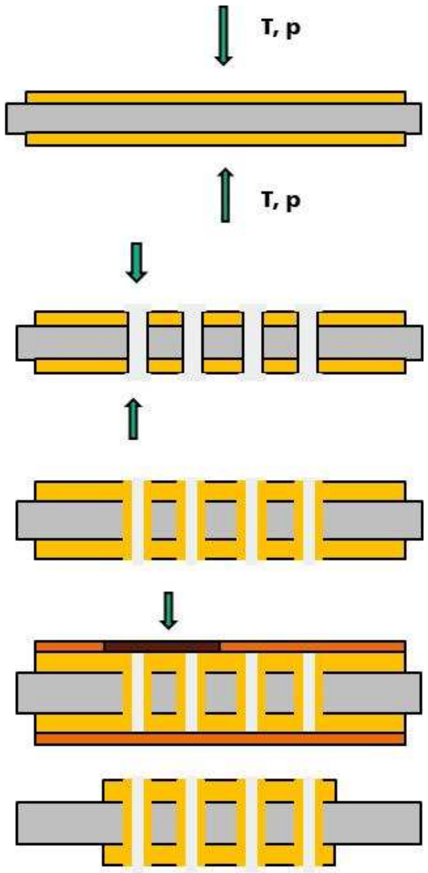
Cu lamination from both sides

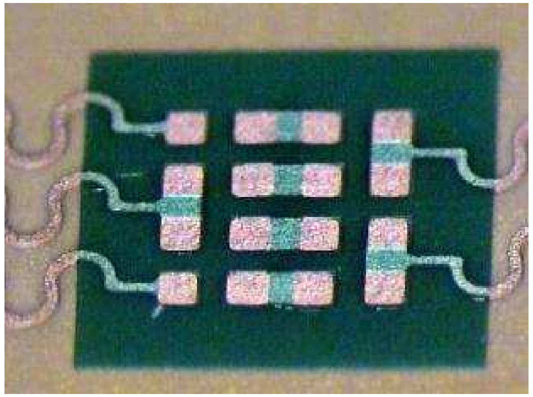
Via drilling

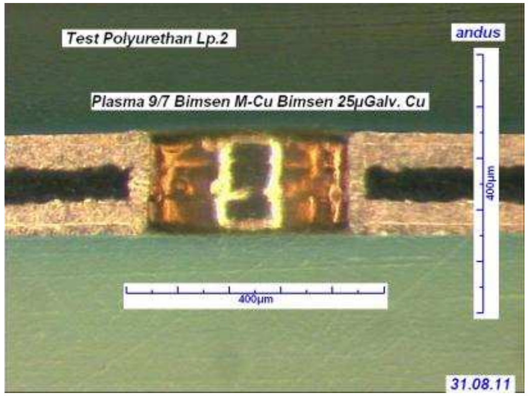
Electroplating

Photolithography

Etching /final metallization (opt.)

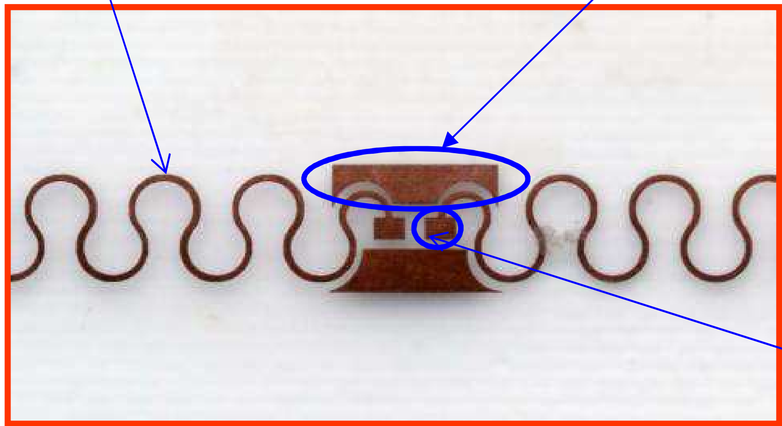


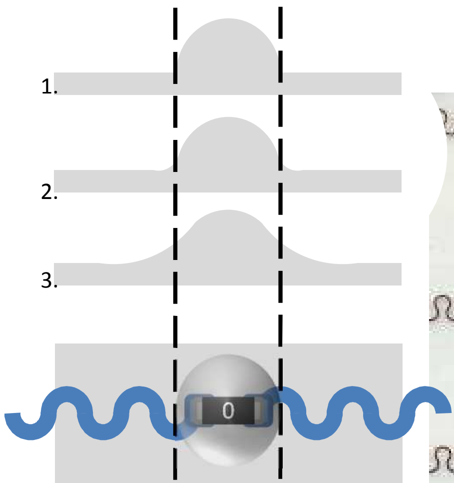


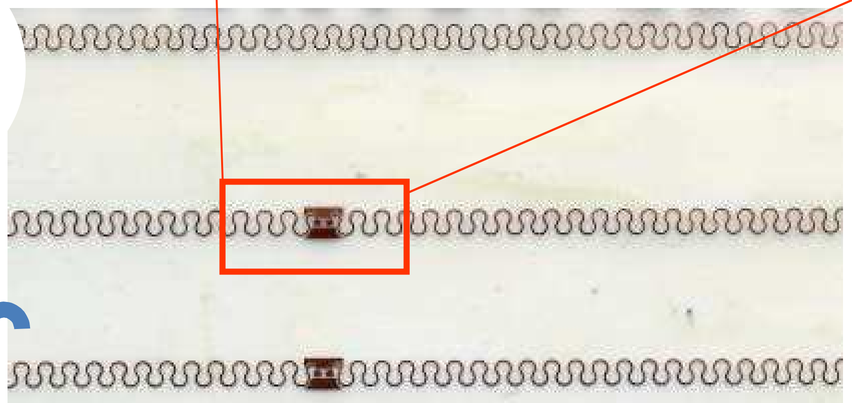


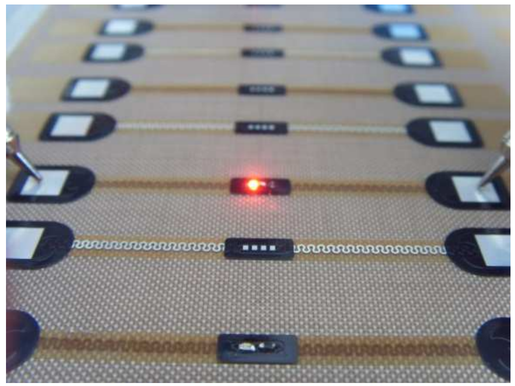
Via in thermoplastic polyurethane foil

Stretchable Circuit Board – Rigid stretch transition









SIIT – System on Flex

Lamination of SCB on Textile

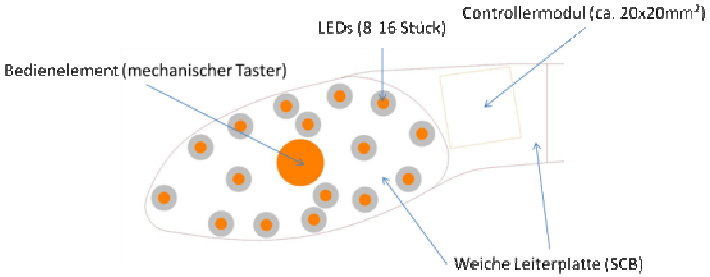
Ironing

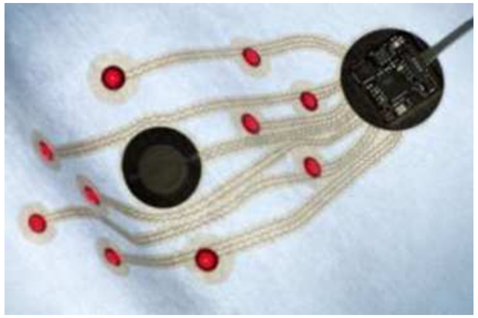
T=190 °C

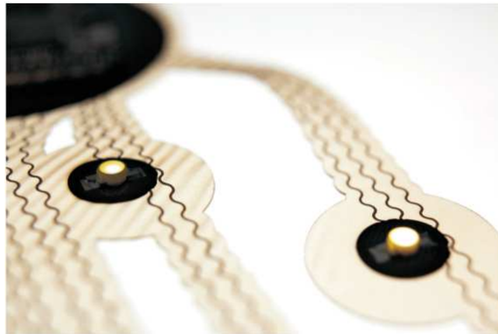
Textil Lamination

Application Examples

EasyLight Modular System

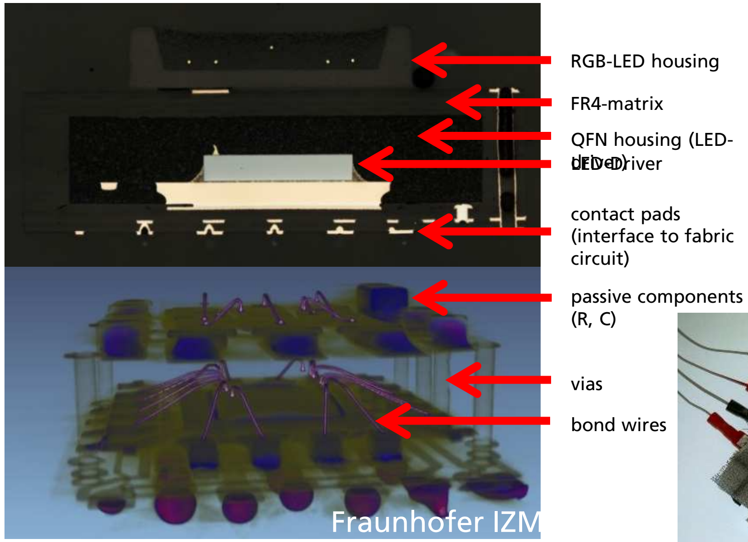


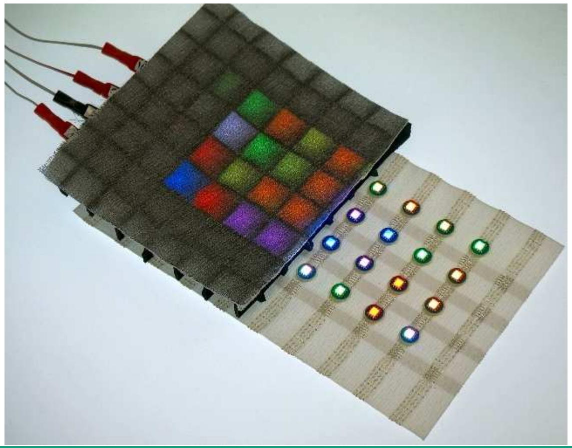




RGB display and lighting on textile

- Smart RGB pixel interposers bonded on conductive woven textile circuits
- 3D-fabrics for light diffusion



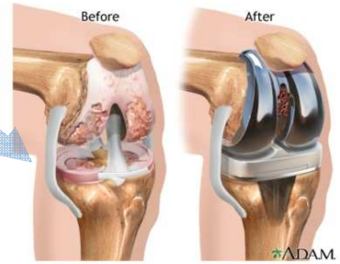


MOTEX
MOnitoring TEXtiles

Smart Textile based knee brace for accurate measurement/monitoring of the knee angles

Application fields:

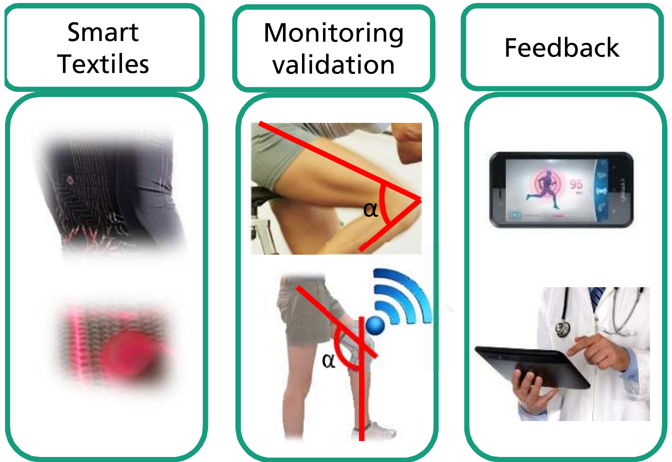
- Healthcare/medical: monitoring of rehabilitation trajectory of patients with total knee arthroplasty)
- Sport: monitoring of knee angles for cyclists to avoid wrong position which could lead to knee problems



Measurement principle: Inductive textile sensor with 1° resolution

Data will be collected by a Smartphone and transferred to

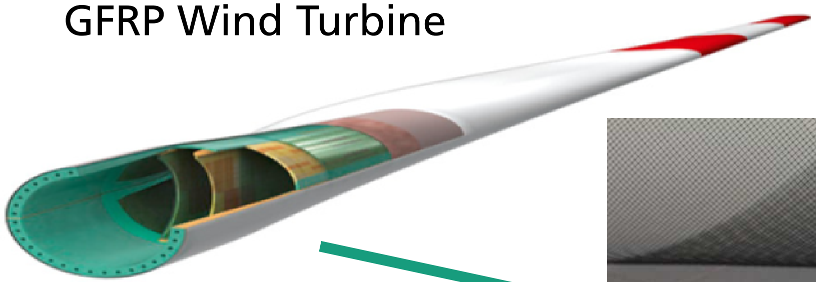
a cloud where it can be analyzed from doctors or coaches



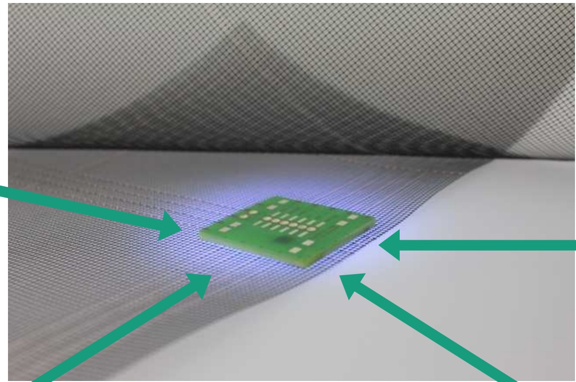
http://www.motex-research.eu/

Textile Sensor Integration for Structural Health Monitoring

GFRP Wind Turbine



Carbon
Prosthesis



Automotive CFRP Chassis

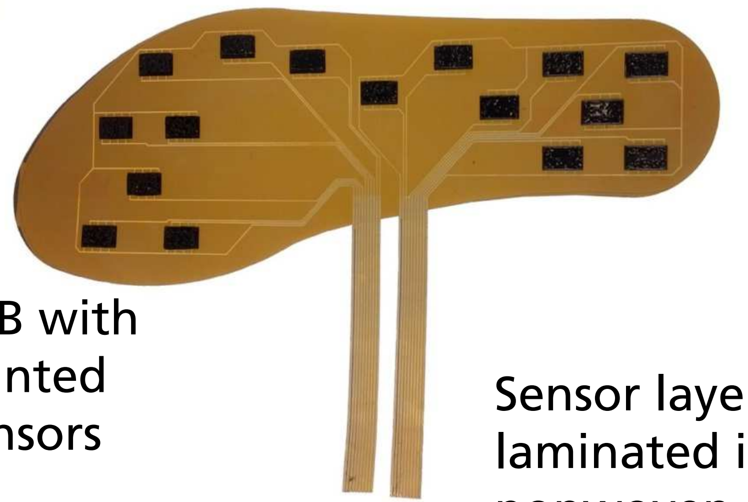
- Sensor integration in technical textiles for various applications
- Measurement of internal strain, temperature, humidity, anti-cut protection

Concrete Reinforcement

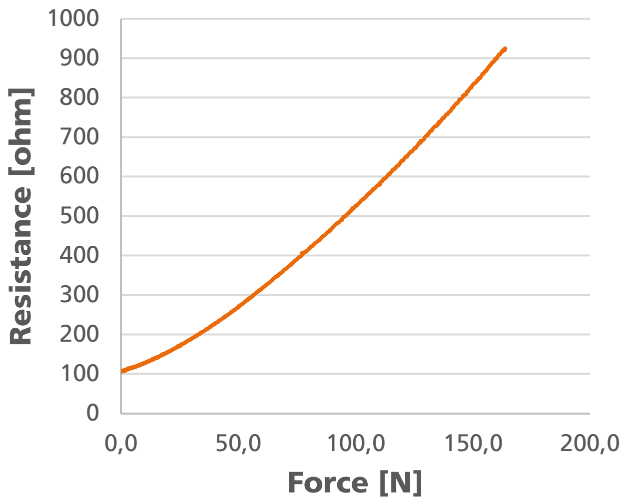
Application of Resistive Sensor Structures on SCB
Pressure Sensing Insole for Diabetes Patients

Goal: Measurement of pressure distribution with printed sensors

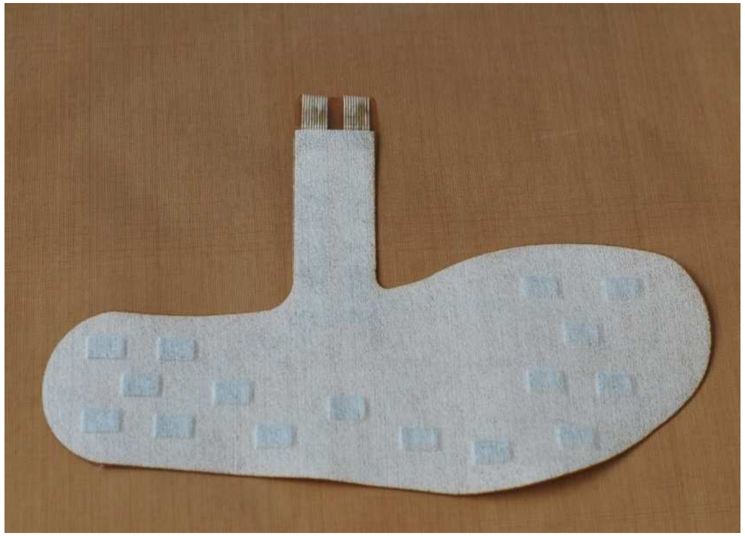
Principle: piezoresistivity of carbon filled elastomer



SCB with printed sensors



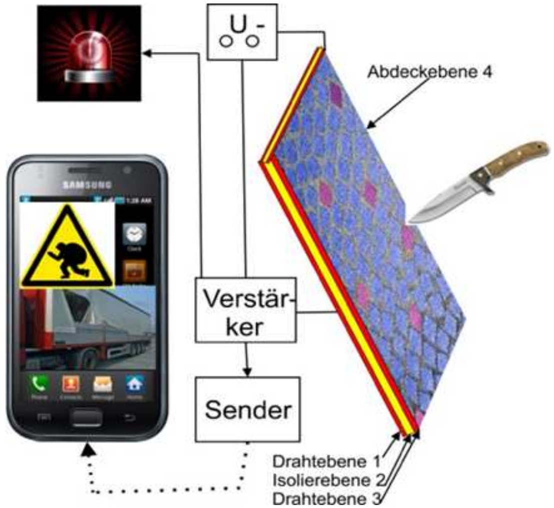
Sensor layer laminated in two nonwoven layers



E-Cargo bike
Extended safety features for green urban mobility

Adjustable textile based container

Anti-cut and anti-stitch fabric and large area alarm sensor layer with integrated electronics



Wireless communication:
control and notification
→ Driver will immediately be notified

Automotive interior trims

- Extensive use of fabrics as trim

Grupo Antolin is world leader in headliner trims. Its portfolio includes most vehicle interior trims.

- New styling & market trends and requirements
- Increasing number of illumination functions

SEVENTH FRAMEWORK PROGRAMME

Fraunhofer IZM

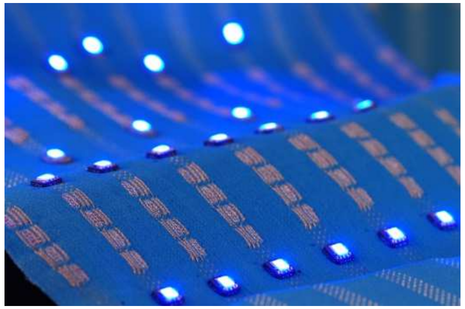
Self-Sustaining Emergency Shelter

morethanshelters

Autonomy:

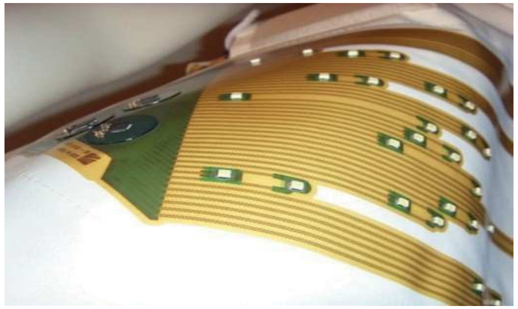
Energy harvesting with flexible solar panels for heating & cooking

Health:



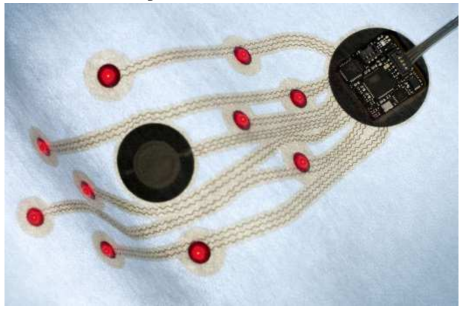
Water desinfection with UV-LEDs

Flexibility:



Flexible and bendable conductors by integrating metalized yarns or Stretchable Circuit Boards

Safety:



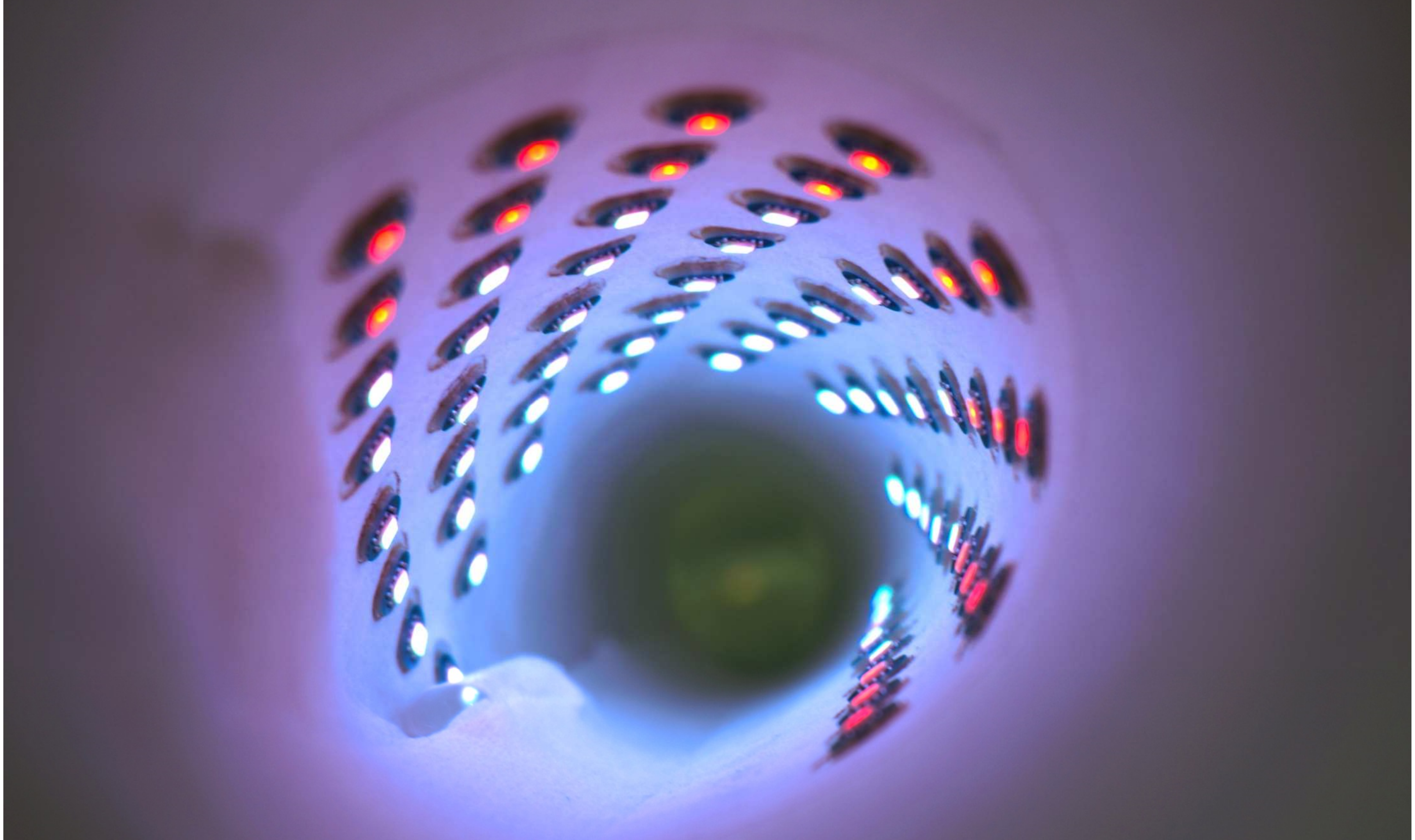
Lighting by textile integration of LEDs

TU berlin Fraunhofer IZM

Conclusion

- „Smart Textiles“ summarizes a wide range of applications from Wearables to technical textiles
- The requirements differ between the applications and are completely different from conventional electronics
- A large portfolio of materials and technologes has been developed with different TRLs
- Challenges still lay in:
  - „Simple“ applications
  - Standardization
  - Equipment for production

Thank you for your attention



Best Regards Your TexLab Team