Materials and Concepts for Textile Sensor Systems

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Fraunhofer IZM and university of Boras

The Fraunhofer-Gesellschaft
Locations in Germany

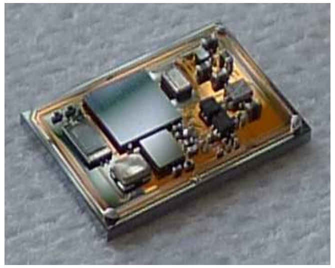
- **66 institutes and research units**
- **Nearly 24,000 staff**
- **More than €2 billion annual research budget totaling. Of this sum, around 1.7 billion euros is generated through contract research**

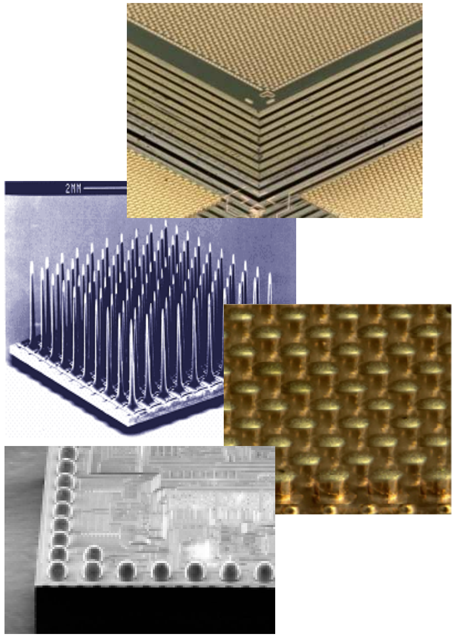
Fraunhofer IZM's Mission:

From Microelectronics and Microsystems towards Smart Systems

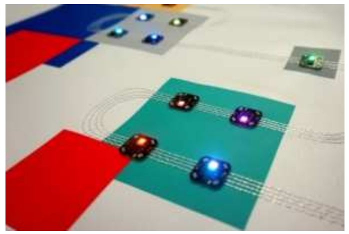
System Integration Technologies

2.4 GHz Sensor Node (15 x 10 x 2)





Fraunhofer Institut Zuverlässigkeit und Mikrointegration



[nm], [µm] to [m]

Nanodimensions to Final Product Size

Outline

I. Introduction and Motivation
II. Materials (conductors) for e-textiles
III. Textile Circuit Manufacturing
IV. Integration Technologies
V. Sensor principles
VI. Applications

Motivation

- E-Textiles can overcome the disadvantages (limited acceptance in healthcare sector, limited accuracy, lacking validation, limited operation place e.g. only wrist) of current gadgets and much more.

E-Textiles advantages and opportunities

Source: http://www.myontec.com

Source: http://www.warmx.de/index.php/start.html

- Physically flexible and also stretchable
  - adapt to the shape of the human body
    - Low signal body monitoring possible (ECG, EMG)
    - Treatment of multiple areas on the body (TENS, EMS, heat, ligh
- Breathable
  - ensures comfort
- Electronics as integral part of our everyday work cloth or outfit
- No size limitation
  - Textile electronic circuits can be produced in large area or simultaneously/batch wise

E-Textile Applications
Wearables vs. Technical Textiles

wearable | **technical**

ECG Shirt

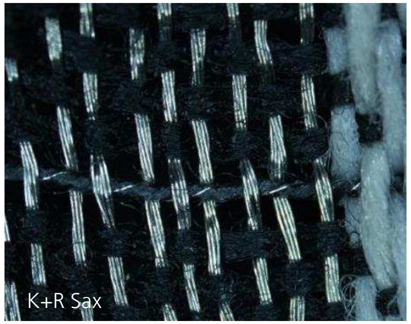
EMG Sensor

SmartPixel

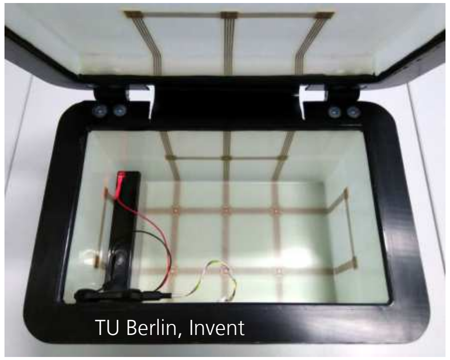
Automotive interior: lighting and control

Bicycle Jacket

Knee brace – Angle measurement



Cut protection fabric with cut detection

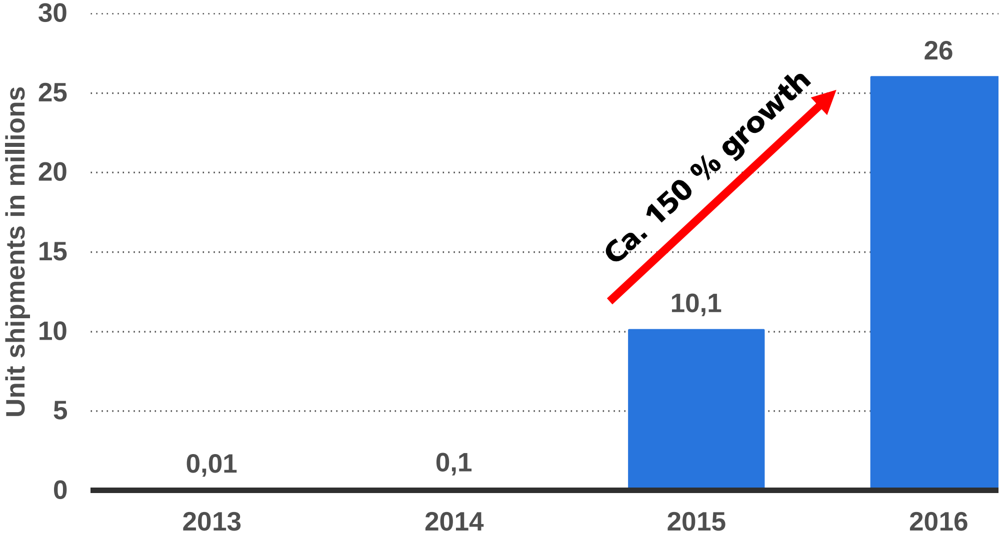


Composite materials

Motivation
(Market forecast, sections)

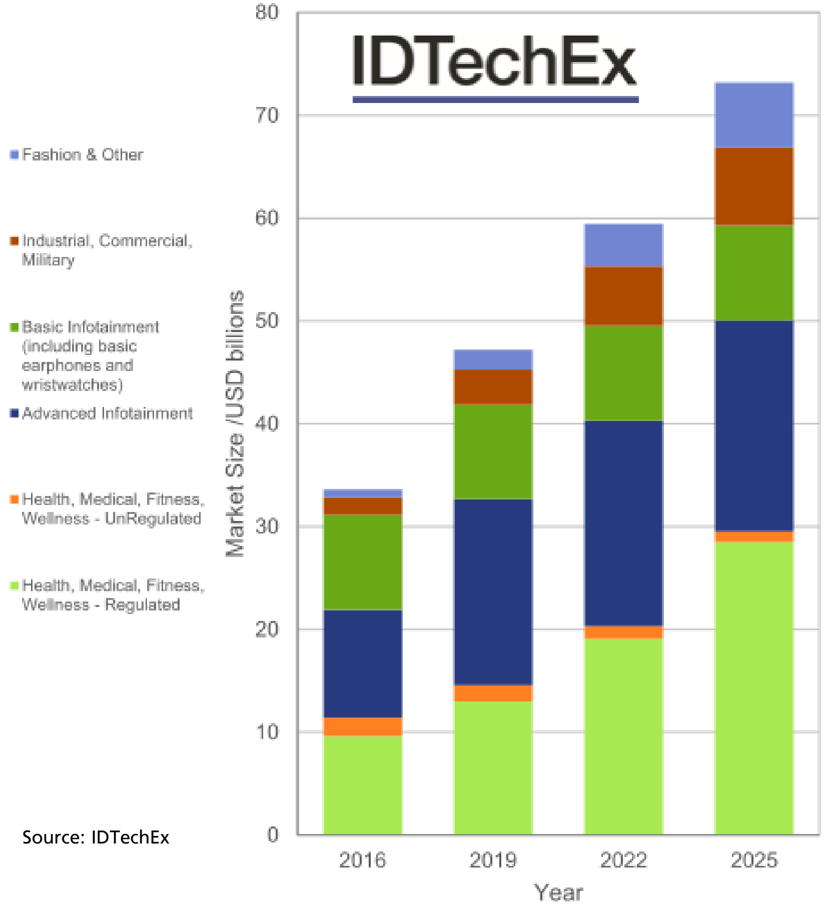
E-Textile products begin to penetrate the market (introduction phase), but it will need some time until acceptance.

Forecast unit shipments of smart garments worldwide from 2013 to 2016 (in million units)



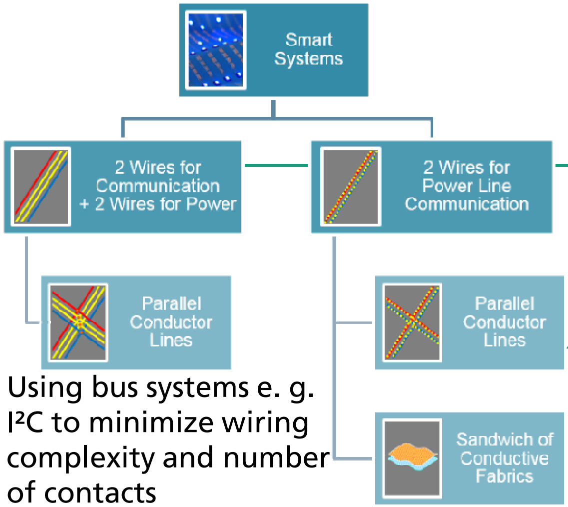
Source: statista (Gartner;ID 385757)

Wearables in general



Source: IDTechEx

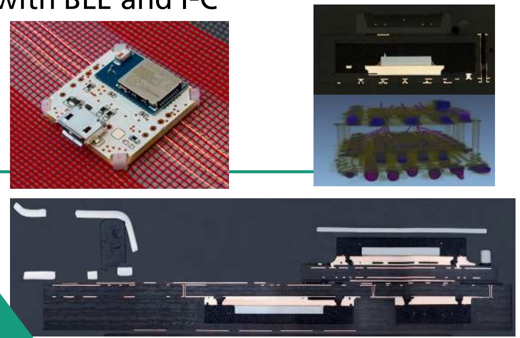
E-Textile Systems general observation



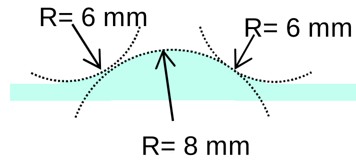
Using bus systems e. g. I²C to minimize wiring complexity and number of contacts (distributed tiny active sensors e.g. electrodes)

Textile RGB Display

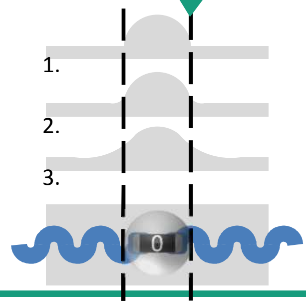
Control module with BLE and I²C



Miniaturization to reduce lateral space by keeping thickness → unobtrusive



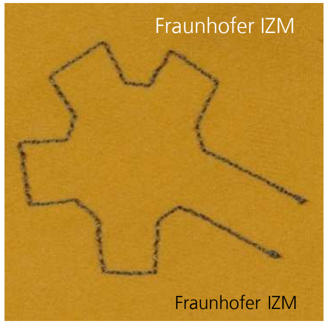
Engineering of Hard to soft transition area to increase minimal bending radii



Energy sources!
We need very small and reliable batteries for permanent integrated electronics.

Wireless Power?
External battery with antenna to couple Energy into textile antenna in the garment

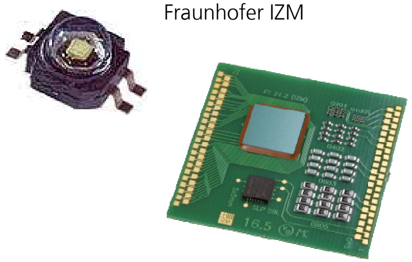
Textile-Integrated Electronic Systems



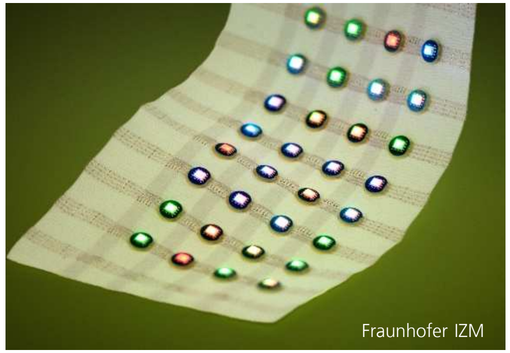
fabric with integrated conductors

- weaving
- knitting
- embroidery
- etc.

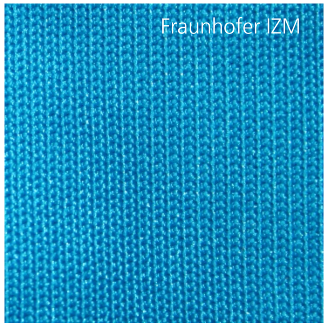
- wires
- conductive yarns
- etc.



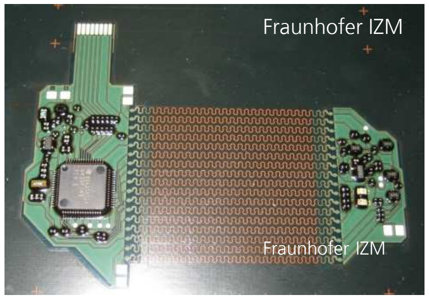
electronic components,
modules, systems



smart textile



basic fabric



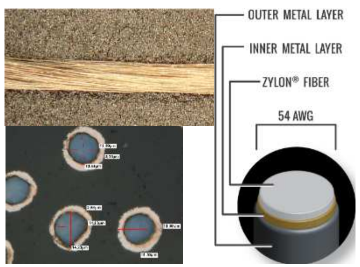
Stretchable thermoplastic substrate
with electronic components

smart textile

Materials (conductors) for e-textiles

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

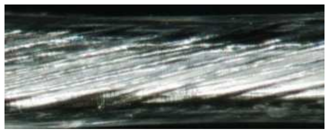
Coated fibers, yarns, threads



Source: Syscom Advanced Materials

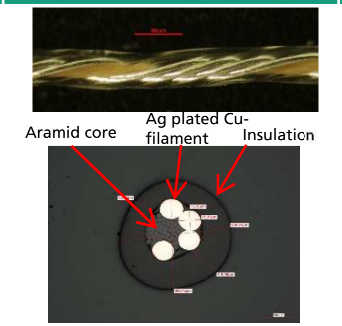
- Noble Biomaterials
- STATEX
- Imbut
- Syscom Advanced Materials
- …

Stranded wires / litz wires



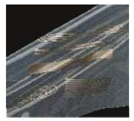
- ELEKTRISOLA
- Fisk Alloy
- Bekeart
- Karl Grimm GmbH & Co.KG
- …

Hybrid wires



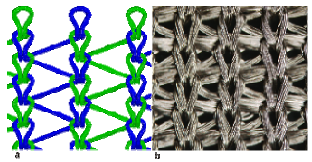
- ELEKTRISOLA
- ZIMMERMANN (Novonic)
- Yarn service provider
- …

Inks / lithographic materials



- Du Pont
- Creative Materials
- Fraunhofer IZM
- QPI (SCB-Technology)
- …

Conductive Fabrics



- STATEX
- Metal Textiles (METEX)
- …

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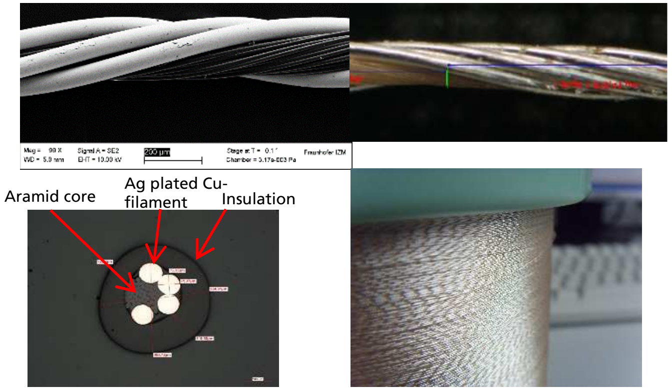
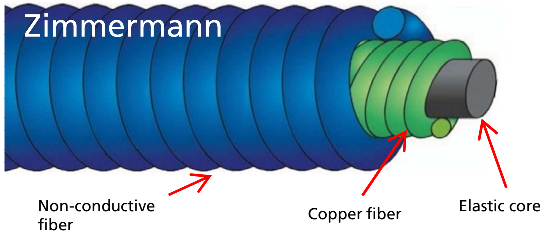
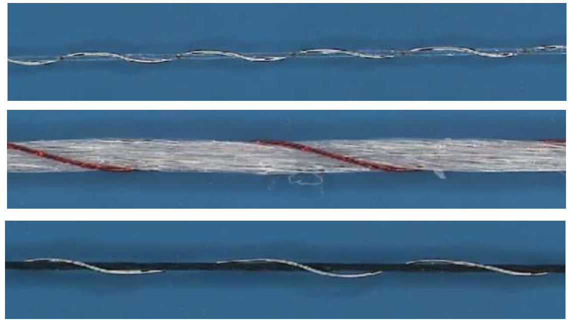
Materials: Hybrid wires

Copper litz wires with aramid core	Stretchable Constructions	Textile yarns combined with Copper filament
		

• No textile character
• Weaving, soutache embroidery
• Resistance: Highly conductive
    • E. g. 0,5 Ohm/m (depending on number and diameter of the filaments) → highly conductive
• Better flex life time
    • Thickness and number of filaments influence flex life time and conductivity
• For Power lines
• Insulation (filament or wire level)
• Surface finish (e. g. Silver recommended)
	• Very Stretchable up to 300%
	• Weaving, Knitting, soutache embroidery
	• Ca. > 10 Ohm/m
	• Handling and interconnection is a challenge
		• Conductive wire(s) spun around textile yarns
		• Textile yarns spun around conductive wires
		• Many different combinations
		• Characteristics vary with materials

Textile Circuit Manufacturing

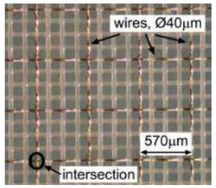
Conventional textile manufacturing processes can be used to generate conductive, textile circuits

Weaving


ETTLIN


TITV / Fraunhofer IZM

project: Jacquard



Source: SEFAR Petex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Embroidery


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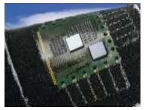
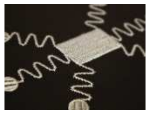


Source: TITV

Source: Forster Rohner



Knitting


Source: STOLL


Source: Sensoria


Source: WLS


Source: WARMX

Laser Structuring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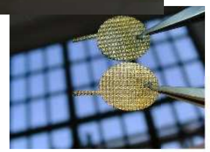


Clothing plus / Myontec


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Lithography (experimental)


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Textile Circuit Manufacturing: Weaving

E-Textiles advantages and opportunities

- Large area production → multiple circuits at the same time with subsequent separation e. g. laser cutting
- With modern Jacquard weaving machines the location of the conductive thread can be controlled (in the backside/midle of the fabric → comes only to surface if needed e. g. to form an electrode or contact pad)
- Limited in freedom of circuit design → only warp/weft (leno is more flexible in 1 direction)

✓ Coated fibers, yarns, threads
✓ Stranded wires, litz wires
✓ Hybrid wires
\- Conducive inks
\- Conductive fabrics

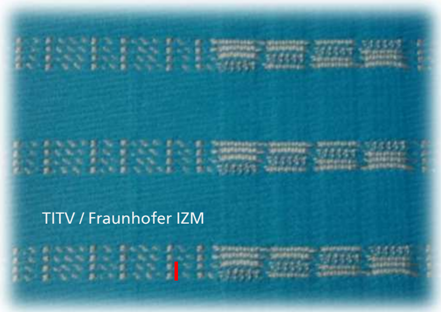
Source: Donier :DORNIER EasyLeno®

Leno weaved circuit (Conductors can be integrated in curved designs)

Source: Jakob Müller

Stretchable conductive ribbon (AMOHR) e. g. lead (narrow weave technology)

Jacquard weaved touch control panel (Google, TE Connectivity)



Jacquard weaved dual layer circuit with contact pads (pitch contact pads: 1.27 mm)

Integration Technologies – General challenges

The textile industry and the electronics industry are not alike. Production facilities as well as products differ totally in many ways.

Textiles	Electronics
Limp, dimensional unstable, often (anisotropically) stretchable → handling and alignment of components is challenging	Rigid (FR4) or foil often with support material to guarantee dimensional stability during manufacturing
Manufacturing environment is often full of particles (fibers)	Clean manufacturing environment (particles lead to errors)
Strong degradation or melting of most textile materials above 200 °C can be expected → contacting electronics is challenging	Peak temperature during reflow soldering above 250 °C (for std. solder)

- Suitable machinery to handle and manufacture e-textiles is still not available
- New technologies to enable a higher degree of integration are necessary (Customers want unobtrusive wearables, fully integrated)

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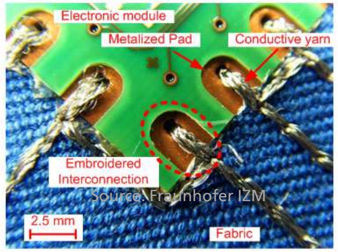
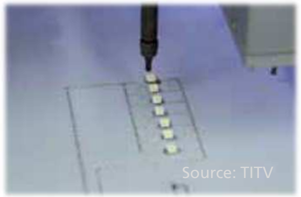
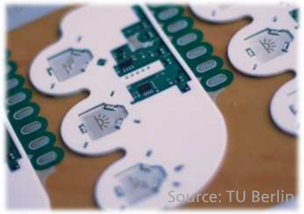
Integration Technologies – A Selection of Technologies

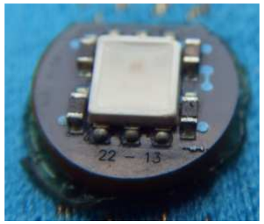
Soldering	Adhesive Bonding (ICA/NCA)	Force Fit

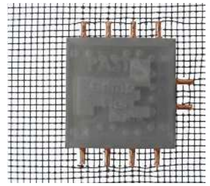
← Combination →

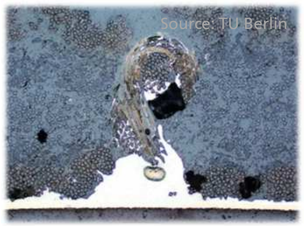


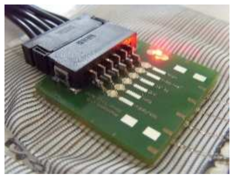












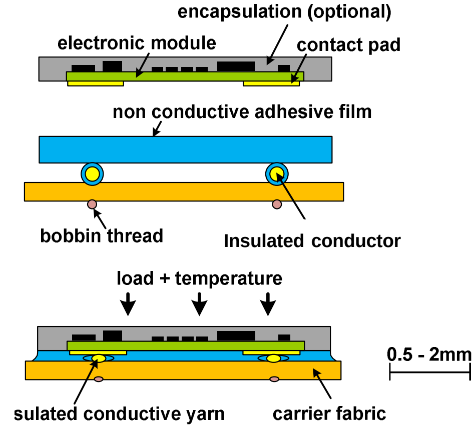
Integration Technologies: Adhesive Bonding (NCA)

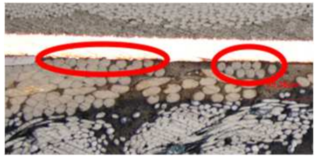
Adhesive Bonding (NonConductiveAdhesive)

- Electronic modules are connected electrically and mechanically in 1 step
- Contacts are protected below the module
- Compatible to different fabrics and conductors
- Contacts are reliable in terms temperature, humidity and washing
- No solder / expensive conductive adhesive necessary
- Low-priced thermoplastic adhesive
- Temperature load during bonding process is high → could be overcome with another reactive adhesive
- No machinery available for mass production → handling textiles automatically for component attachment is challenging

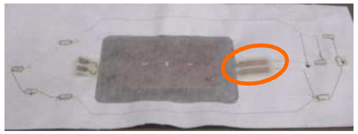
✓ Accessible conductors

✓ Insulated conductors (thermoplastic insulation)

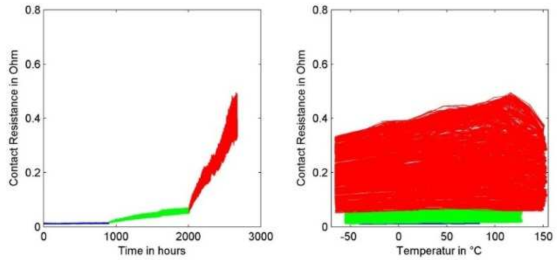




Cross section of a contact



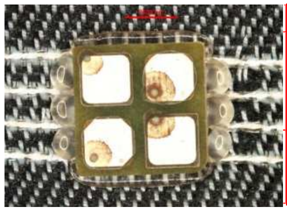
Bonded Stretchable electronic lighting – Sunvisor inlay



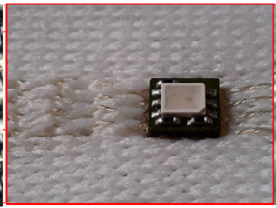
-40 °C – 85 °C | 1000 cycles

-55 °C – 125 °C | 1000 cycles (same samples)

-60 °C – 150 °C | 1000 cycles (same samples)



Woven fabric with insulated hybrid wires



Knitted fabric with insulated hybrid wires

Embroidered fabric with hybrid wires

Sunvisor

Textile display: Smart Pixel bonded onto Jaquard woven fabric

Stretchable Circuit Board

Base material: thermoplastic Polyurethane

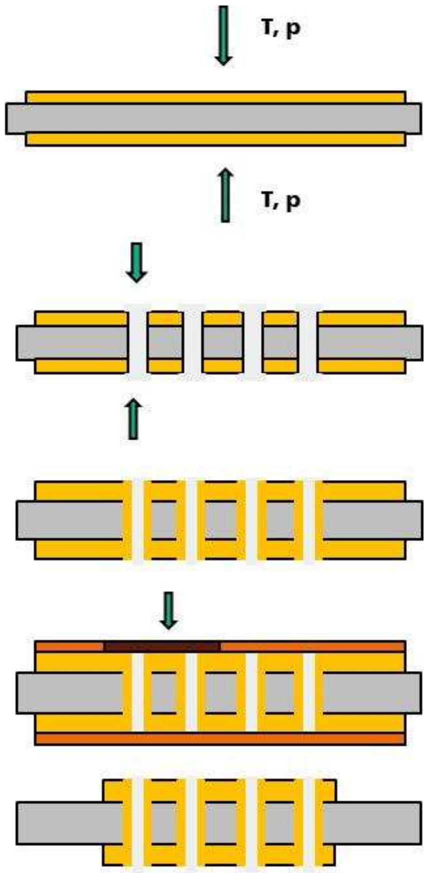
Cu lamination from both sides

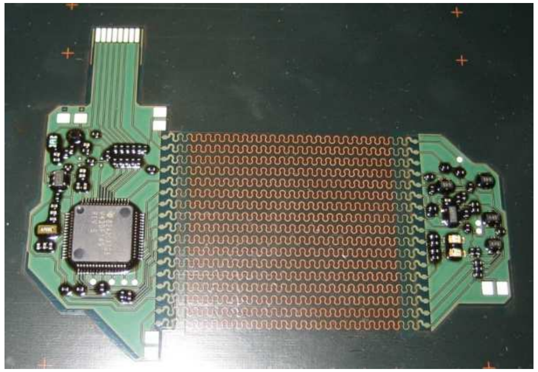
Via drilling

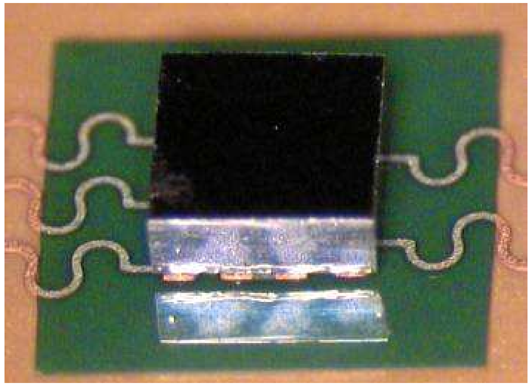
Electroplating

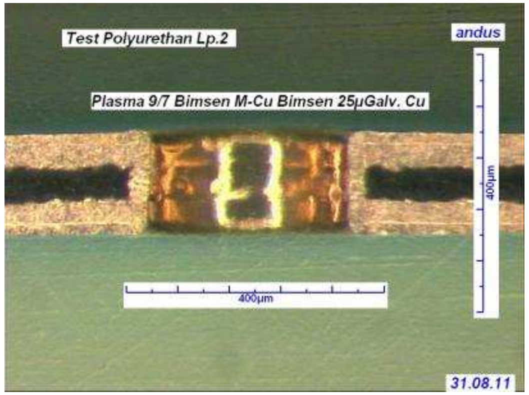
Photolithography

Etching /final metallization (opt.)









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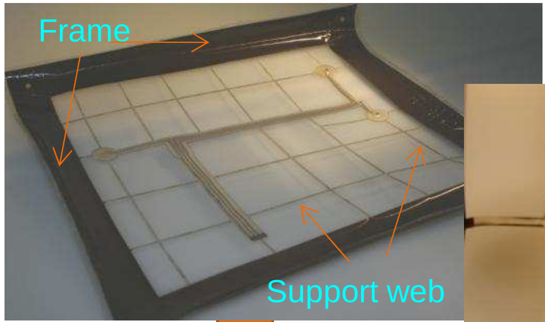
Stretchable Circuit Board – Integration into textiles

Embedding into a non-woven matrix



Cut Polyurethane matrix

Lamination into non-woven (textile)

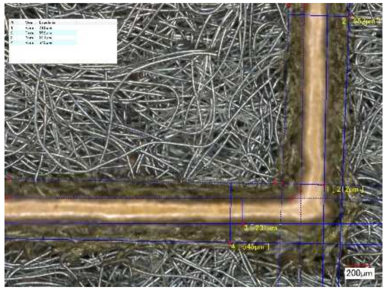
Lamination on Fabric

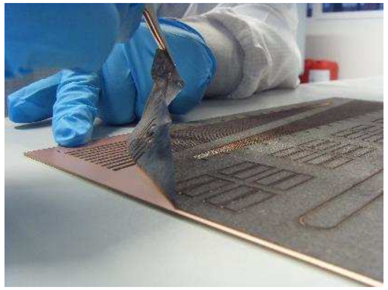
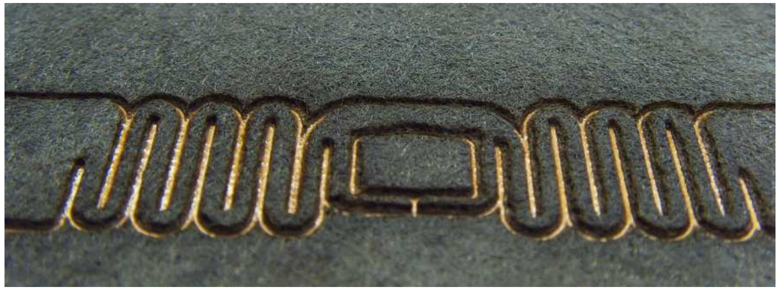
Electronics and fabric are combined in the last process step!

TexPCB Technology - ongoing

TexPCB futureTEX

- New cost-effective, flexible conductive non-wovens for dynamic application in continuous operation (Substitution of conventional FPCBs)
- Resource-saving process technology for the production of textile circuit boards by Laser structuring and lamination processes
  - High adhesion force between TPU film and conductive fabric > 15N/mm after vacuum lamination achieved
  - Low contact resistance <500mΩ for NCA bonded FR-4 interposer onto textile pads
  - Line pitch 250µm – 550µm depending on chosen materials after laser structuring
- Reliable interconnection technology (polymer US welding, NCA bonding)



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Measurement Principles for Textile Sensors

Principle	Technology	Damage	Strain	Pressure	Humidity
Resistance	Printed woven embroidered	X	X	X	X
Capacitance	Printed, SCB Woven		X	X	X
Inductance	Woven Embroidered		X	X	

Polymer based sensors typically show:

- hystheresis
- temperature dependance
- humidity dependance
- drift

→ Conventional sensors have to be integrated in textiles for high performance!

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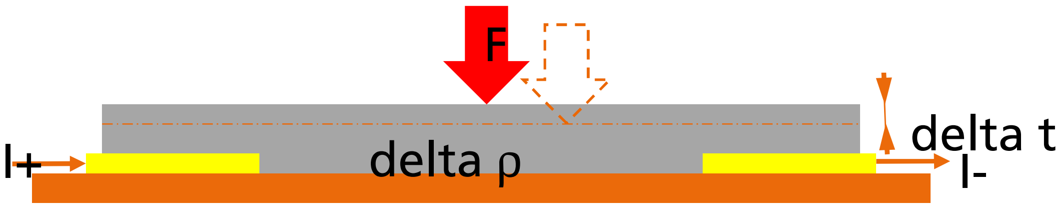
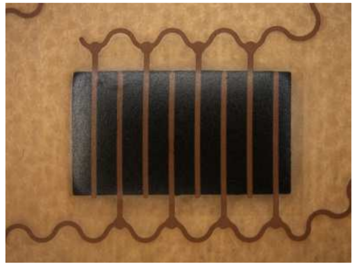
Sensor Principles: Resistive Sensors

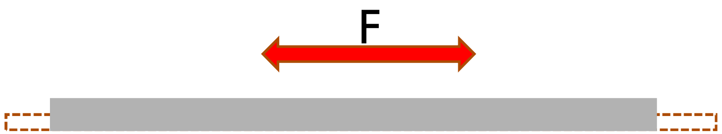


Piezoresistive material on single-layer electrode

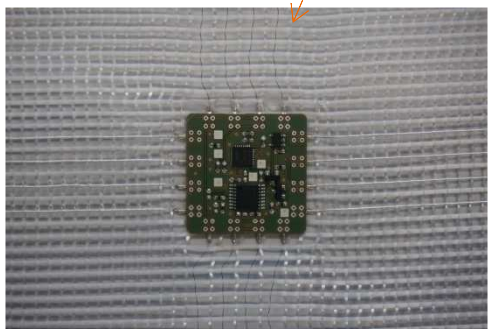


Increasing or decreasing resistance with pressure

Woven constantan wire

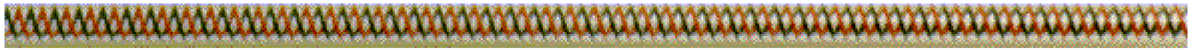


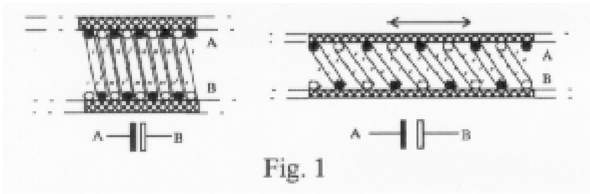
Conductive material, e.g. constantan



Increasing resistance with strain

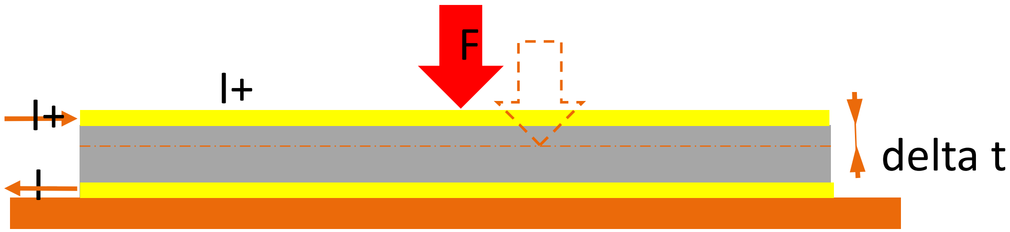
Sensor Principles: Capacitive Sensors





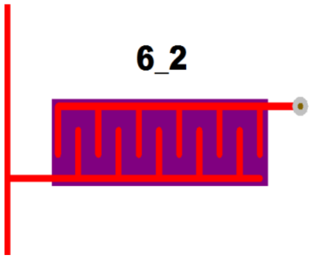
„Rubbery Ruler“

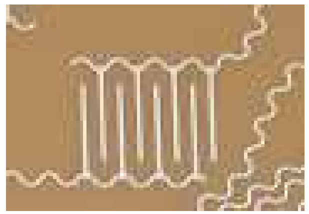
Strain



Spacer fabric

Pressure





Sensor structure on TPU

**Humidit
y**

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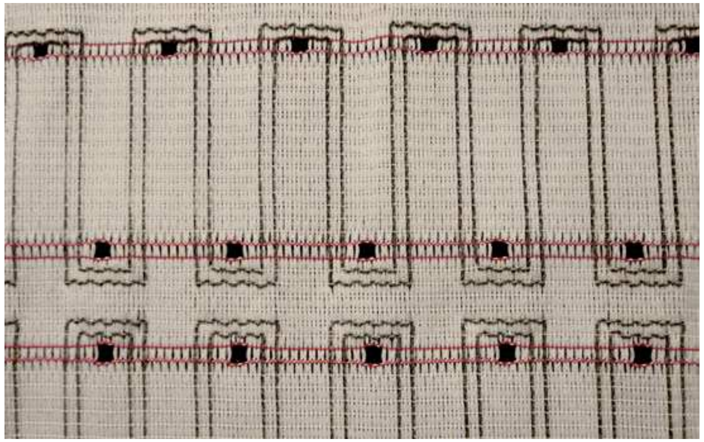
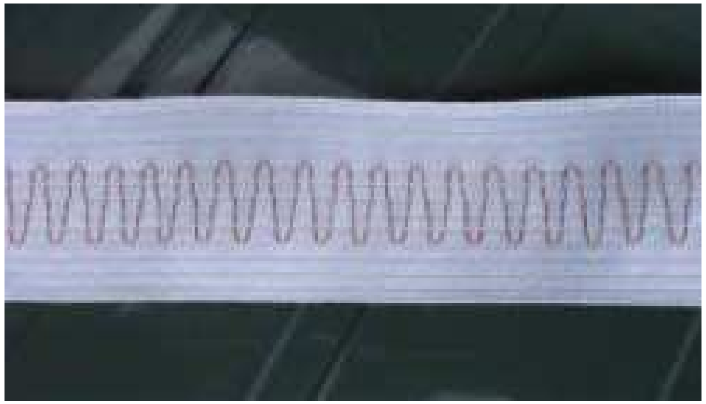
Sensor Principles: Inductive Sensors



Measurement of varying coupling factor between parellel woven inductivities

Strain / pressure

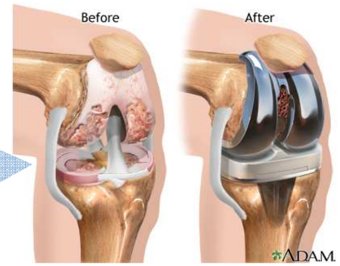


Measurement of varying inductance of meander structure (woven or embroidered)

Strain

Strain Measurement
MoTex - MOnitoring TEXtiles

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



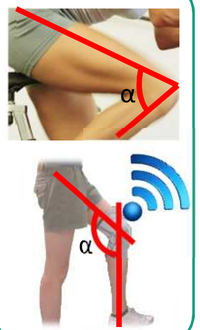
Application fields:

- 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

Data will be collected by a Smartphone and transferred to

a cloud where it can be analyzed from doctors or coaches

Smart Textiles	Monitoring validation	Feedback



Gefördert durch:

Bundesministerium für Wirtschaft und Energie

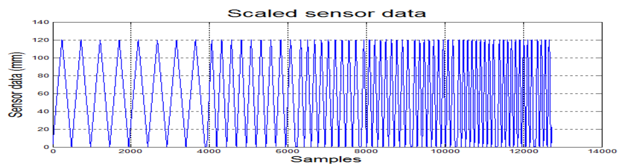
aufgrund eines Beschlusses des Deutschen Bundestages

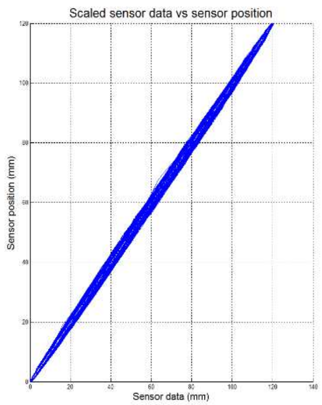
http://www.motex-research.eu/

MOTEX
MOnitoring TEXtiles

Artificial knee test bench

Force or way controlled cyclic stretch



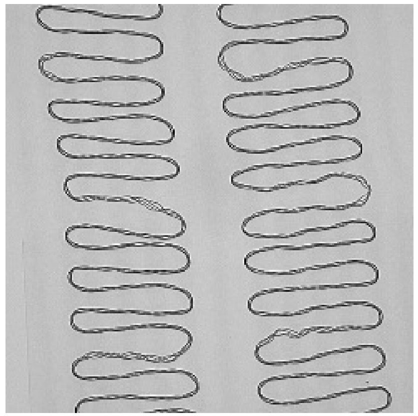


Sensor characterization:

Very good dynamic properties
Very good hysteresis properties

Reliability:

100k Stretch cycles at 50% stretch passed
Validated by Electrical, optical and x-ray inspection



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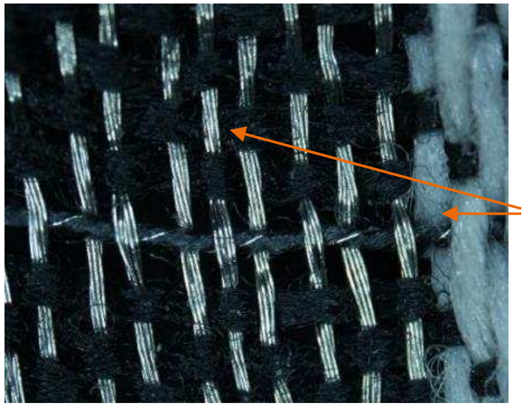
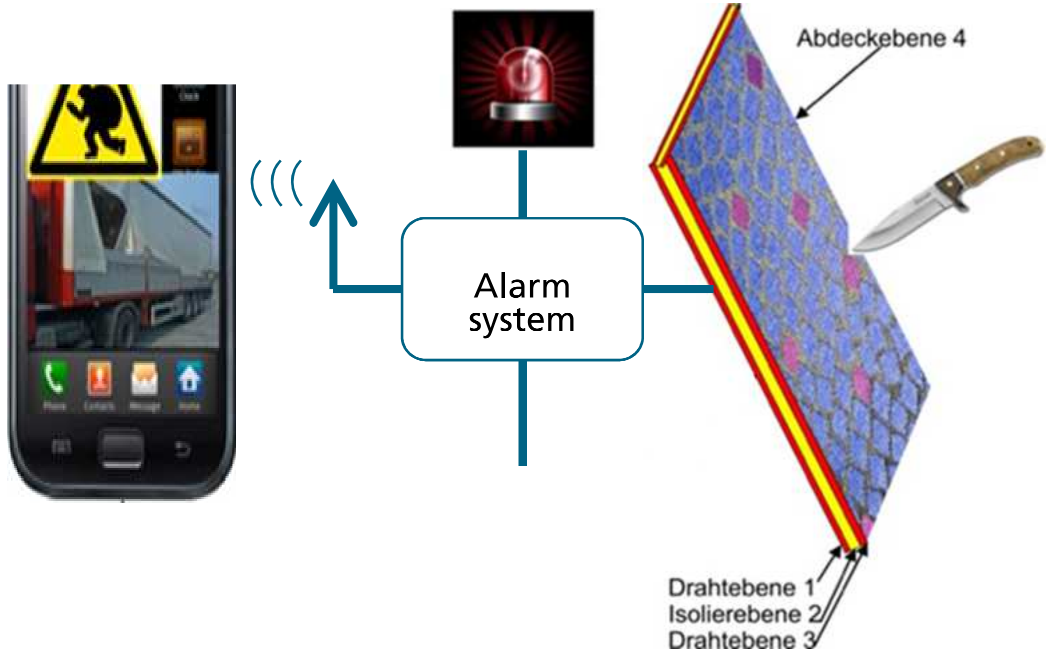
Damage DetectioneCargoBag

Extended Safety Features for Green Urban Mobility



Fabric with steel litz wire and Dyneema (Cut-protection)

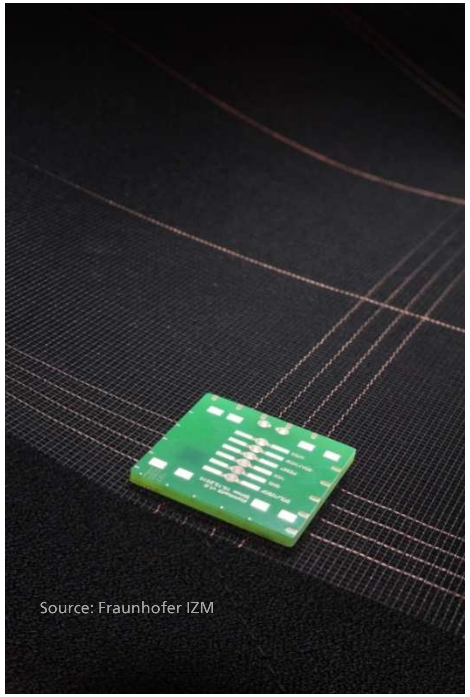
Foldable textile container with integrated sensors, protective layers and electronics



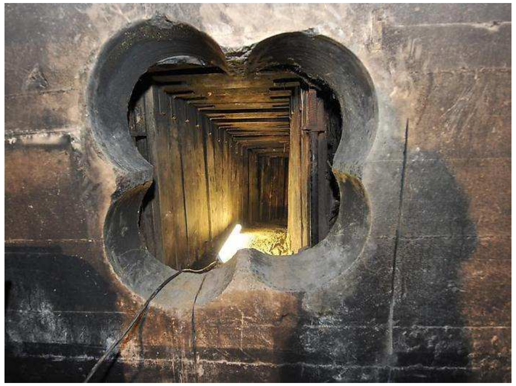
- Minimized weight
- Adaptable size
- Alarm
- GPS tracking

Damage Detection
AlarmTextil – Large Area Woven Alarm Device

- Woven conductive pattern (repeatable) in Polyester fabric
- Electronic module with embedded components assembled with nonconductive adhesive
- Basic structure detects damage at 16 Positionen
- Bus system enables free combinations of basic cell
- Integration in walls, floors, tarpaulins

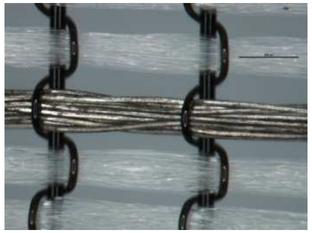


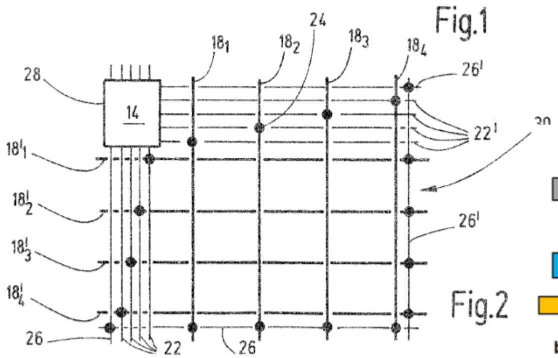
Alarm Textile controller module (12 contacts)

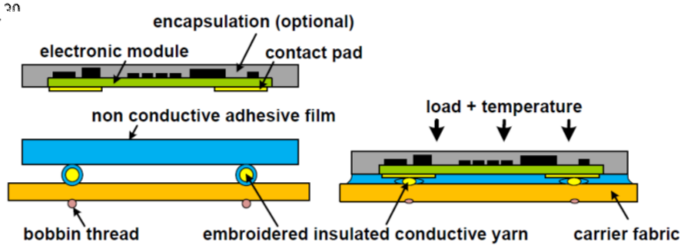


Bank robbery Berlin, Januar 2013

Quelle: Focus online; dpa/Paul Zinken







Strain Measurement

Composite embedded electronics – pasta Project

Woven Sensor fabric + electronics

Structural carbon and basalt layers

Shaping and stacking all layers

Epoxy injection under vaccuum

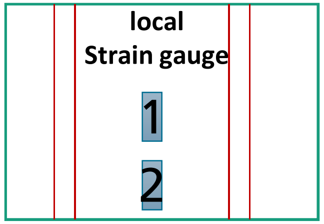
Testing of electronics and sensors

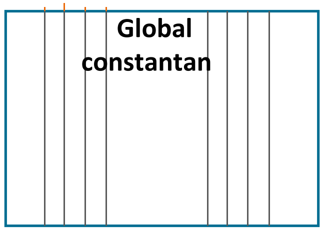
Final carbon blade

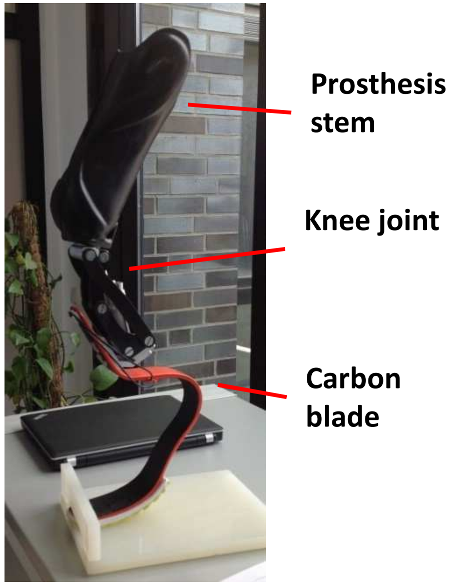
Sensortextil local stress (flex Strain gauge)

Electronic

Sensortextil global stress (sensor wires)







Final C-Leg with periphery (child)

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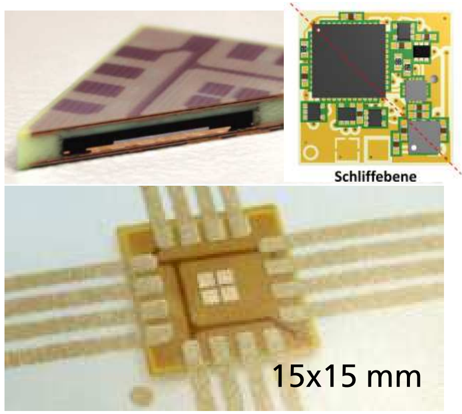
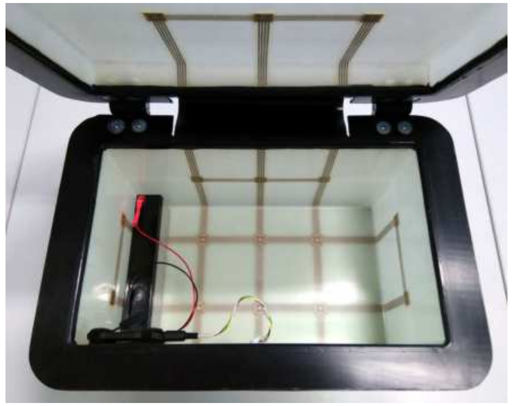
MoMiTeX: Composite Box for Battery Protection and Monitoring



Embedding in fibre reinforced Polymer

Forming of battery case



ESYS

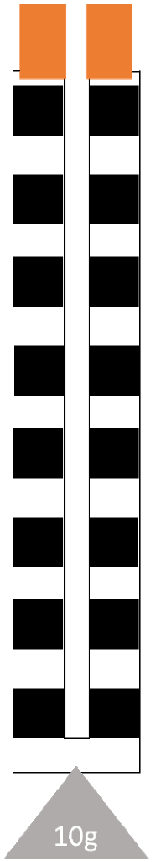
imbut

INVENT

- Number of sensors: 20
- Temperature sensor
- 3 axis accelerometer
- Damage detection and localization
- Self-Test of sensors
- Temperature range: -25 bis + 85°C
- Dimensions of sensor modules: max. 15 x15 x 2mm
- Printed bus structures
- Embedding of bus and modules in composite at high pressure/ temperature

TexPCB
Textile Humidity Sensor

Sensor length 63 cm / 97cm

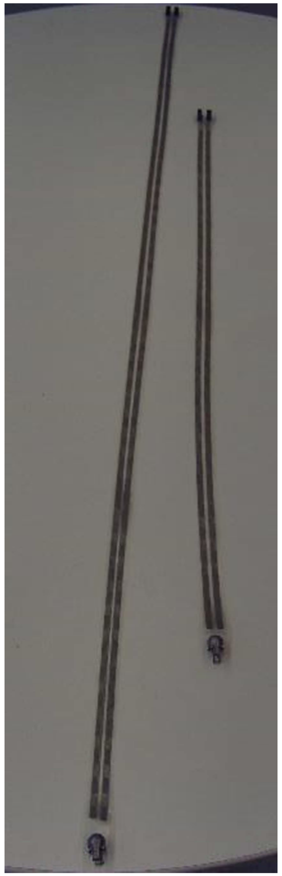


Crimped connectors to readout device

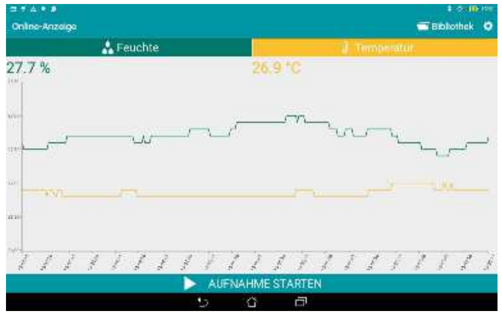
Conductive nonwoven In TPU with openings in TPU coverlay

Weight for positioning

Prototype



Readout device



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Conclusion

- Different simple textile sensor concepts allow the measurement of pressure, strain, humidity as well as the detection of damage
- Polymer and textile sensors are cost effective but show lower performance -> for high requirements conventional sensors have to be integrated
- The applications range from medical products to structural health monitoring in composite materials -> broad range of requirements
- Materials and technologies has already been developed to fulfill the various requirements but there are no standard solutions

Thank you for your Attention