FLEXO

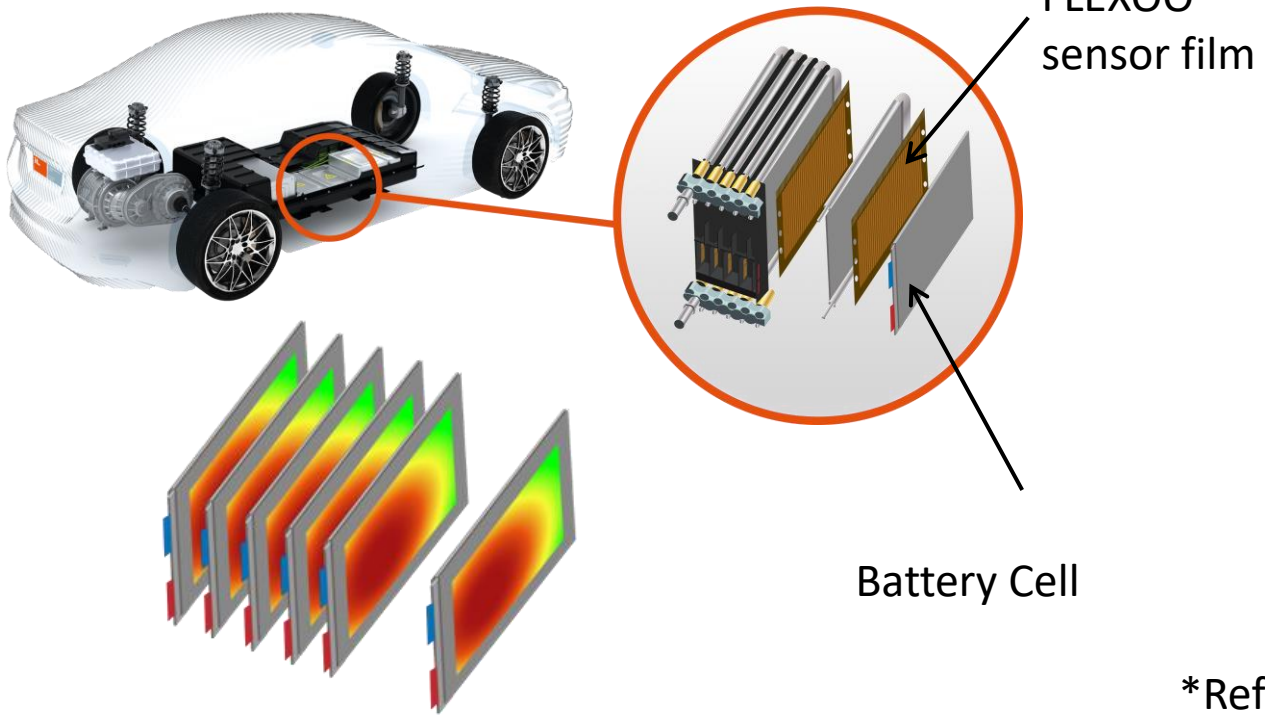
Battery Monitoring Solution
Context and Technical Info

Supplemental Information | July 2024

BaMoS – Battery Monitoring Solution

Lithium Ion Batteries: It is scientifically proven, that the local temperature and pressure within battery cells impacts the reliability and safety of the battery.*

FLEXOO provides a flexible sensor solution to acquire meaningful data from the inside of battery packs.



Conventional sensors (NTC) are integrated onto flex cable and cannot acquire data on battery-cell-level

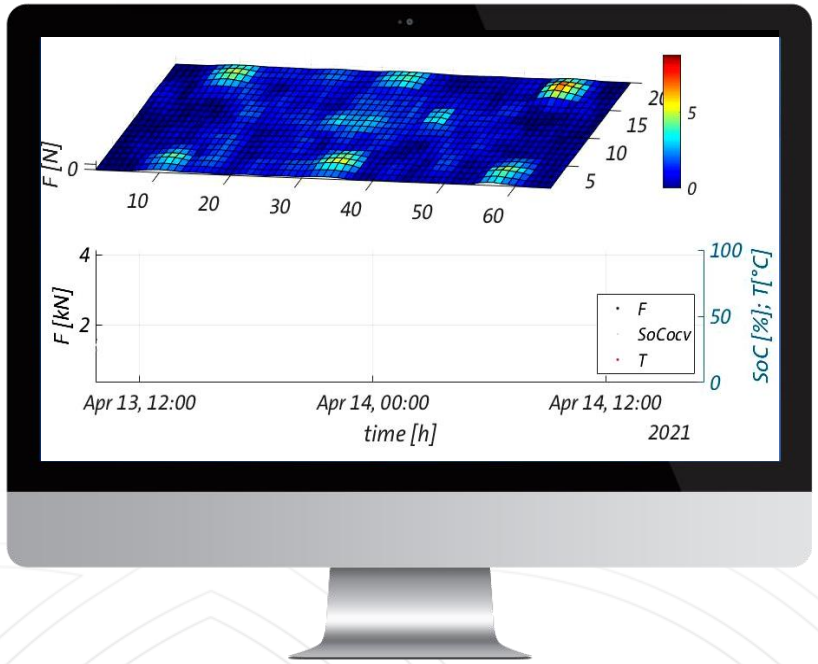
*Reference: Journal of the Electrochemical Society, Link

Measure temperature and pressure inside battery packs with cell-level resolution

FLEXOO's thin foil sensors are placed between the cells:

This allows to

- ✓ measure the state of charge (SoC) directly,
- ✓ implement preload and cell balancing measures,
- ✓ detect thermal runaway / propagation,
- ✓ gain additional information on state of health (SoH)
- ✓ and optimize performance and reliability



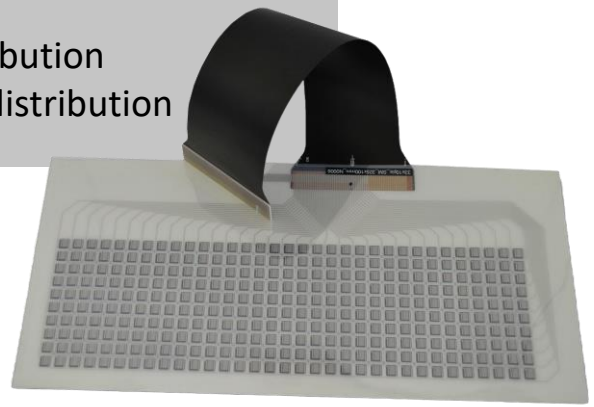
Foil sensors enable getting data from inside of the battery system. Both spatially & temporally resolved.

Animated Video: **Link**

Battery Monitoring Solution Overview

1. Sensor Foils:

- Pressure distribution
- Temperature distribution

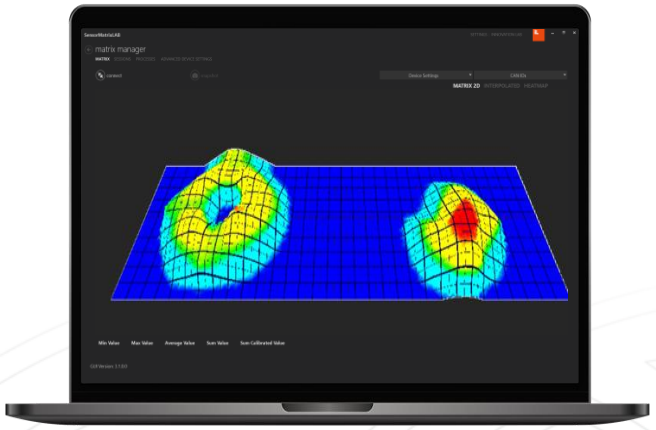


2. Read-out Electronics:

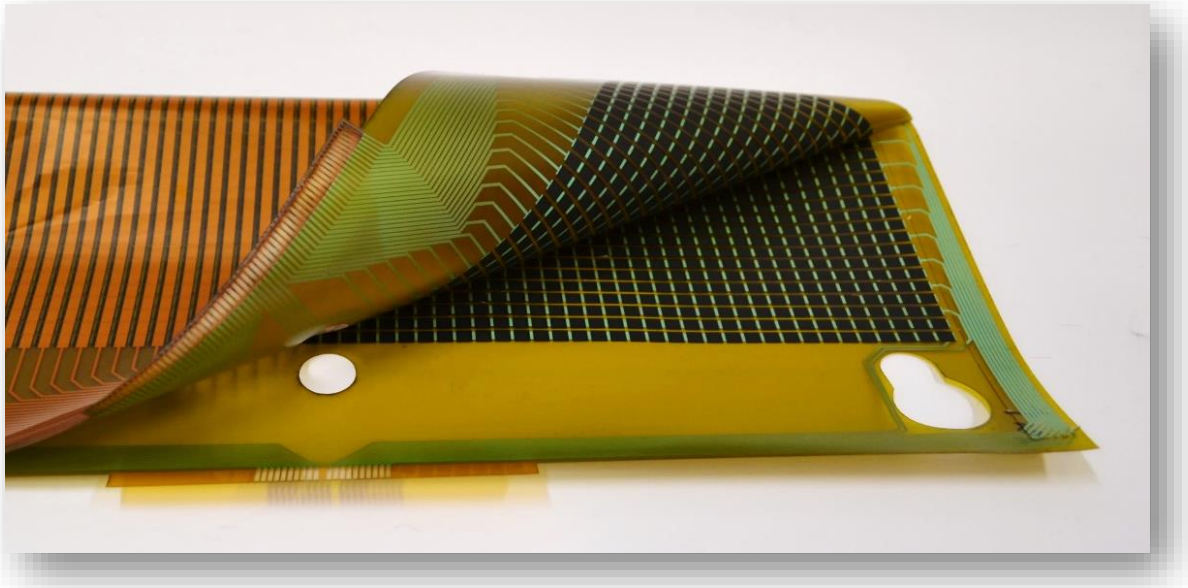
- State-of-the-art with reduced cross-talk
- 12-bit digital resolution
- Electro-magnetic interferrance protection
- Several communication interfaces

3. Software:

- Live 3D/2D data visualization, storage and analysis
- Data filtering
- Real-time streaming via API
- Calibration option

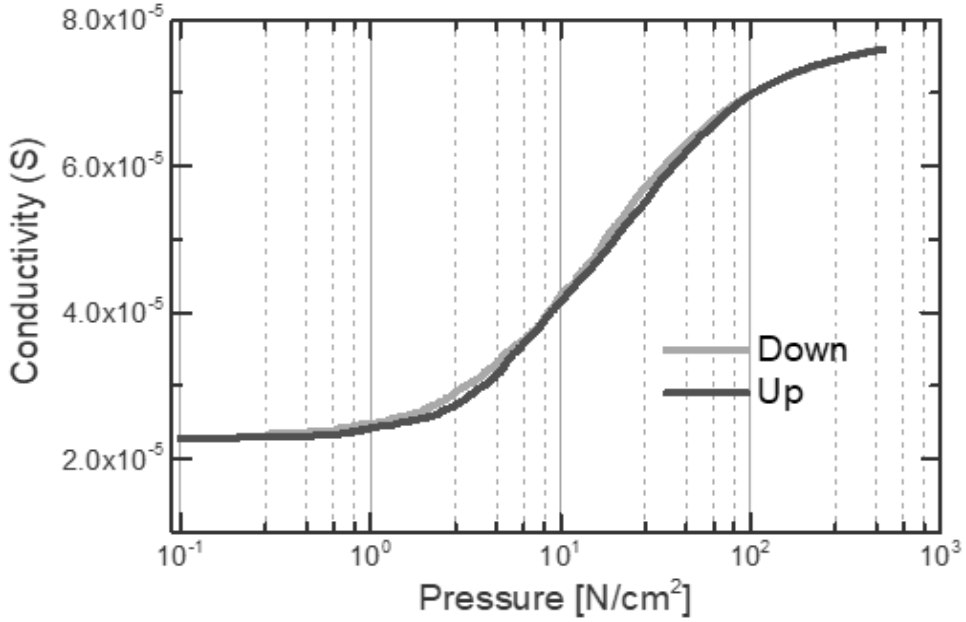


Pressure Mapping



Matrix of printed piezoresistive pixels on thin polyimide substrate.

High Performance (Prime Mode):



Strong performance:

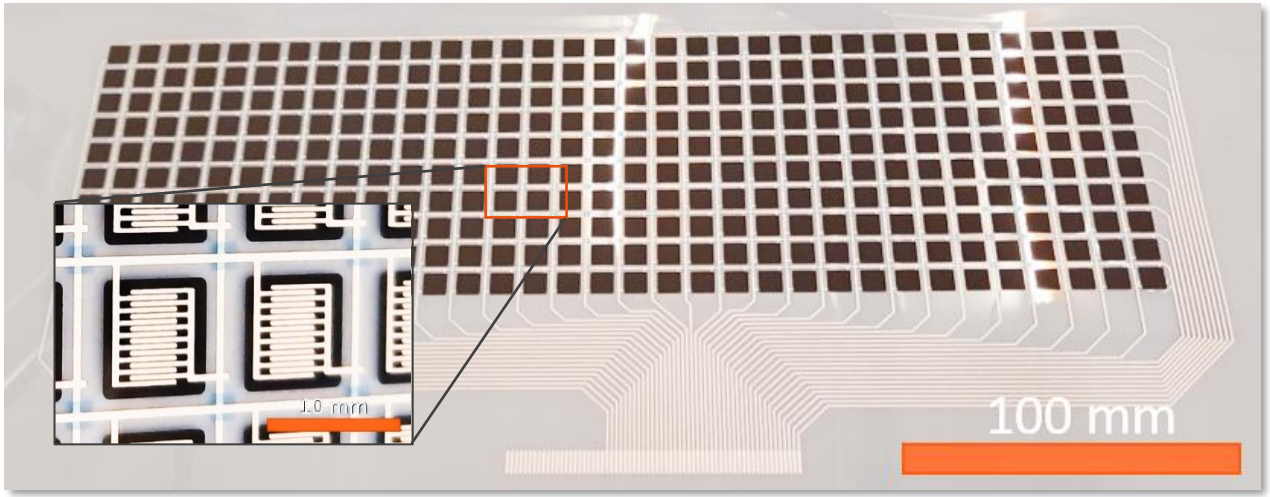
- ✓ **Huge measurement range:** 0.1 – 500 N/cm²
- ✓ **High accuracy:** 0.2% - 5 % (repeatibility error)
- ✓ **High durability:** < 5 % (loss after 1 Mio. Cycles of 150 N/cm² load)
- ✓ **Overall thickness:** 110 - 250 µm
- ✓ **Operating Temperature:** -20°C – 100°C

Pressure Mapping

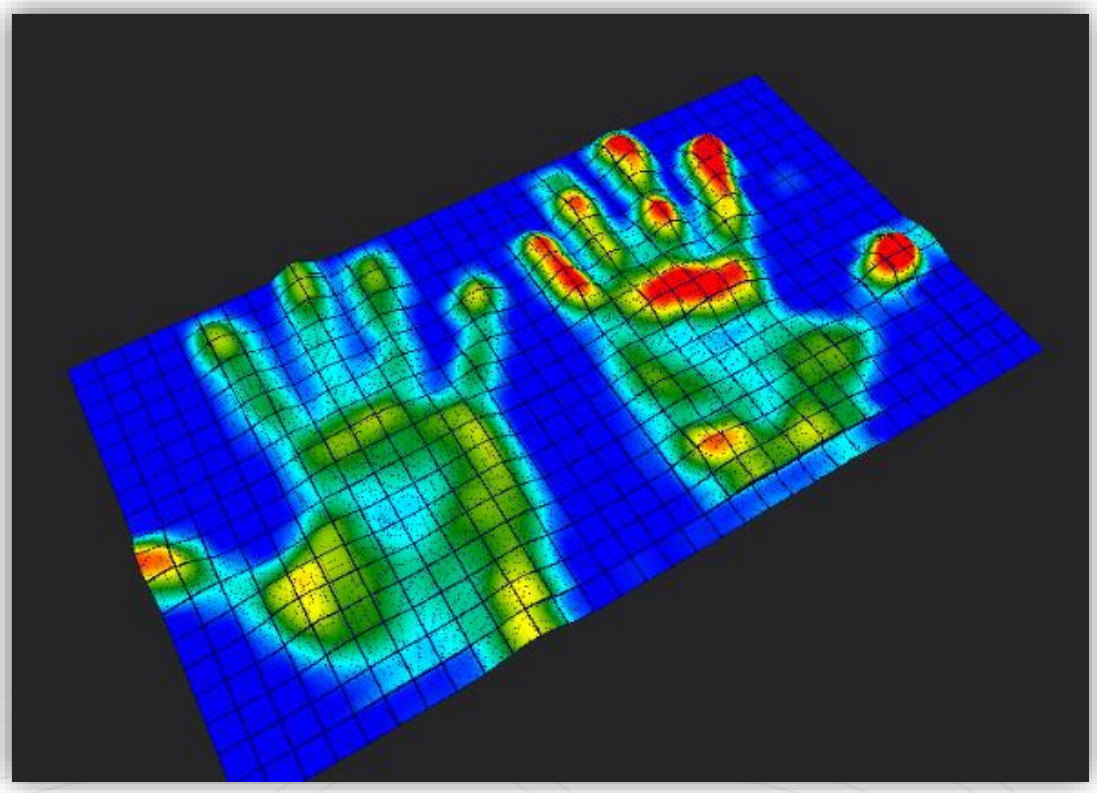
Portfolio:

	Type 1	Type 2	Type 3	Type 4	Type 5	Custom
						
Measurement Mode	Thru	Thru	Thru	Shunt	**Prime**	
Resolution (# of pixels)	29 x 17	64 x 20	64 x 20	32 x 10	32 x 10	up to 96 × 96
Active area (cm^2)	15 x 9	33 x 10	53 x 11	32 x 10	32 x 10	up to 40 × 60
Pixel size (cm^2)	0.32 × 0.32	0.30 × 0.30	0.50 x 0.32	0.62 x 0.57	0.5 x 0.5	down to 0.01 (Thru) down to 0.2 (Shunt) down to 0.25 (Prime)
Foil material	PI (2 x 50 µm)	PI (2 x 50 µm)	PI (2 x 50 µm)	PET (2 x 75 µm)	PET (2 x 100 µm)	PI, PET, PEN,…
Suitability for • low pressure • high pressure	 + +	 + +	 + +	 ++ +	 **++** **++**	

Temperature Mapping



Temperature-sensitive resistors printed on interdigitated electrode structures enable **spatially resolved temperature measurements** on very thin foils (< 80 µm).

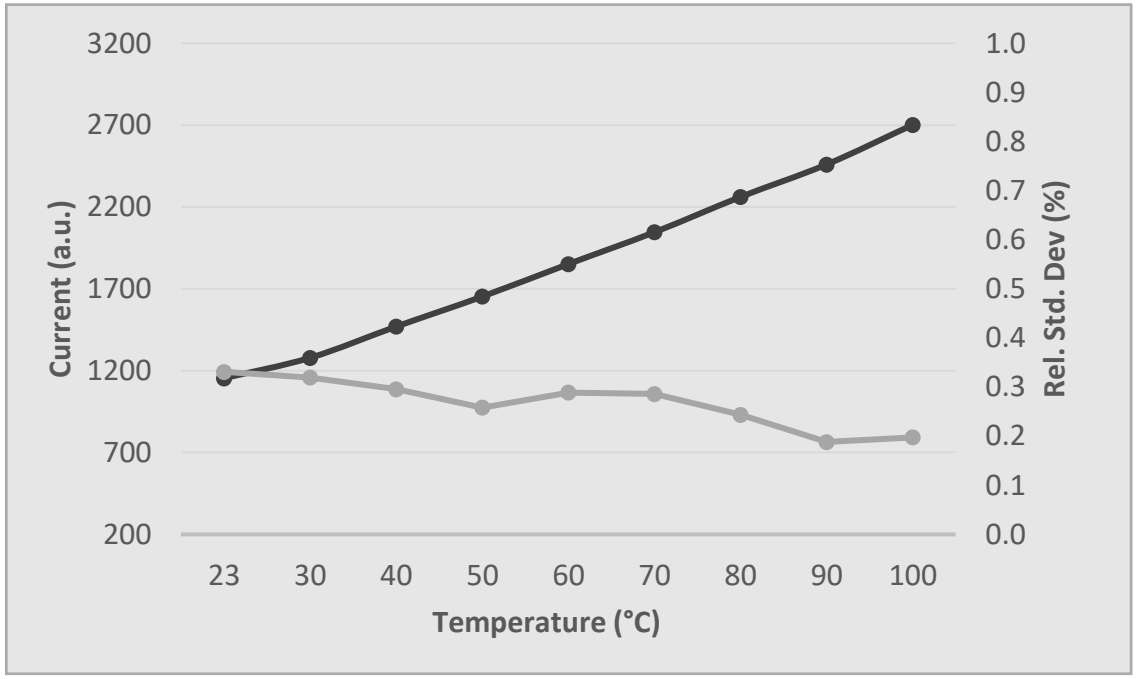


Color-coded image of the temperature distribution induced by a hand.

Temperature Mapping

Portfolio:

	Standard	Custom
Resolution (# of pixels)	32 x 10	up to 96 x 96
Active Area (cm^2)	32 x 10	up to 35 x 55
Pixel size (cm^2)	0.62 x 0.57	down to 0.2
Foil material	PET (2 x 75 µm)	PI, PET, PEN



Dependency of the measured current on the temperature. A clear linear behavior is observed.

Typical performance:

- ✓ Highly linear behavior
- ✓ Accuracy: < 1 °C
- ✓ Range: 10 - 100 °C and beyond
- ✓ Pressure independent

FLEXOO USPs

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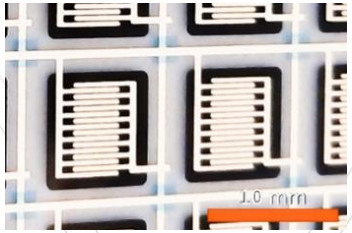
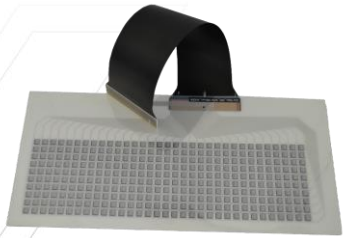
FLEXOO's Sensor and Manufacturing Technology

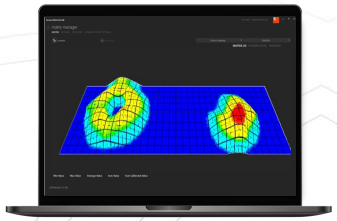
Multiple USPs

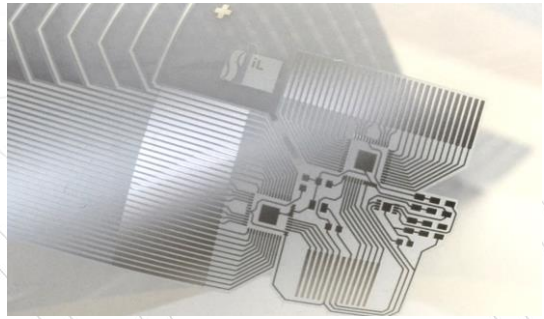
Materials	Patented architecture	Hardware/Software	Data interfaces	Analog to Digital	Modular System
Flexible and thinnest substrates Material sets for several sensor types Temperature Pressure Humidity pH value Gas/chemical species Flexible heaters	Best flexible temperature sensor on the market Best flexible pressure sensor on the market 3 x higher reliability 10 x higher accuracy 100 x dynamic performance Endless Sensor	Low-noise and cross-talk signals Highly-resolved ADC converting Ultrafast dynamic mode with 100 fps Standalone operation allows scaling	Data filtering and rendering Real-time streaming Customer system integration via API Real-time streaming, data filtering and rendering Sensor Calibration	Integration of ADC on flexible sensor Data is delivered on higher-level data layer Data quality is improved Data will be daisy-chained	Ready to use Multiple sensing methods combined Electronic readouts can be integrated into customer system Sensor count scales superlinear with module count

COUPLED BY MANUFACTURING EXCELLENCE









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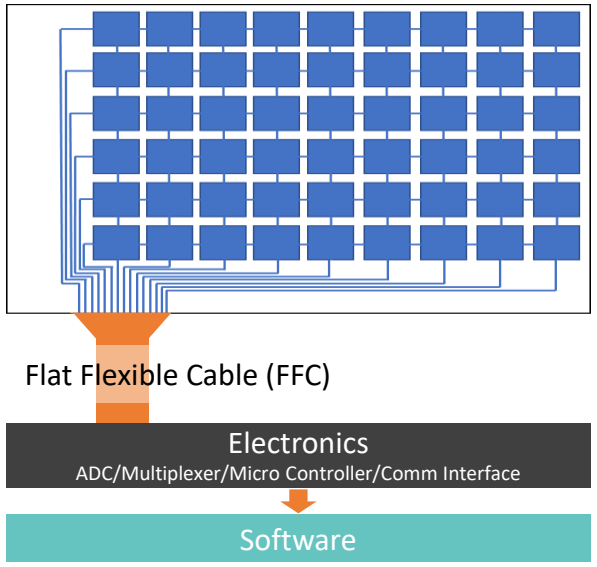
Technology Overview

Flexible sensors becoming smart

- Integrate Analog to Digital converting on flex…
- … allows “daisy-chaining” of smart sensors
- … delivers data to customer on a higher layer

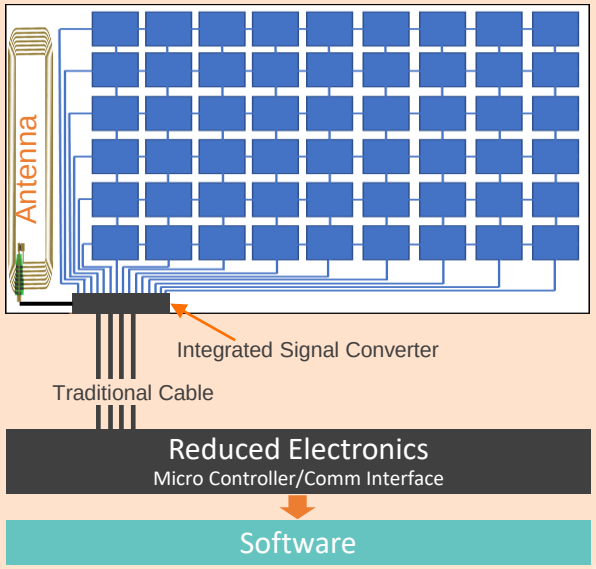
Flexible printed sensor solutions TODAY

Analog printed sensor (discrete or matrix design)



Our sensor solution TOMORROW

Digital printed sensor (discrete or matrix design)



FLEXOO core USPs already today

PERFORMANCE: Best data quality in the market

VERSATILITY: Sensing **pressure, temperature** in parallel

SIZE: **Up to 20 meters** long sensors

SOLUTION: **Complete system** of sensor, hardware and software

COST: **Roll-to-Roll manufacturing** delivering highest competitiveness

New disruptive USPs from 2025

PERFORMANCE: **Digital data** quality

VERSATILITY: **“Cut to size”** enables many new use cases

SIZE: **Sensors on >100m long reels**

SOLUTION: Daisy-chaining via **industrial interface protocols**

COST: Up to **75% cost reduction** vs**. today**

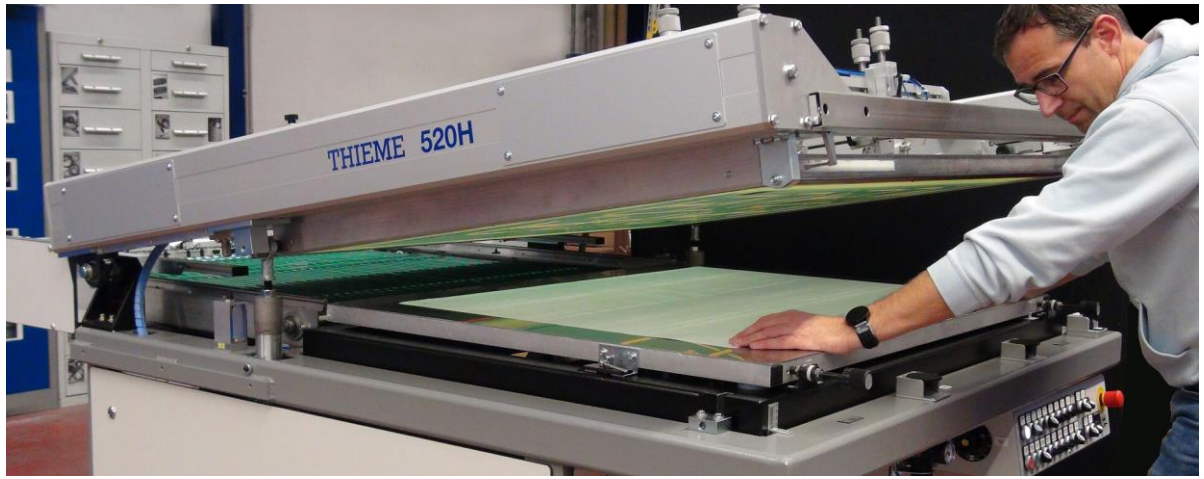
FLEXOO

USP: Manufacturing

FLEXOO's unique mass manufacturing advantage

- **High-performance flexible sensors are made from multiple layers of different materials**
- **Multilayer printing requires high accuracy**
- **Use of different materials requires process flexibility**

Competitors use S2S manufacturing to handle complexity



Manual production steps required
→ Low productivity
→ Low capacity
→ High quality cost

FLEXOO handles complexity in high-volume R2R manufacturing

Click Image for Video of Production Line

Fully automated production
→ Highest productivity
→ Highest accuracy
→ Superior quality control

USP: Manufacturing

FLEXOO's unique mass manufacturing advantage

- **High-performance flexible sensors are made from multiple layers of different materials**
- **Multilayer printing requires high accuracy**
- **Use of different materials requires process flexibility**

Click **here** for video of production of a 3-layer product on pilot line

→ Inline substrate cleaning and pre-treatment (0:10)
→ Conductive line printing (0:21) and curing (0:39)
→ Inline quality control (0:49)
→ Sensor material printing (0:58) and curing (1:05)
→ Insulating cover material printing (1:17) and curing (1:27)
→ Inline converting by slitting (1:43)

FLEXOO handles complexity in high-volume R2R manufacturing

Click Image for Video of Production Line

Fully automated production
→ Highest productivity
→ Highest accuracy
→ Superior quality control