

Printed electronics building blocks

Key considerations when
designing and scaling
printed sensor solutions

Scope and focus

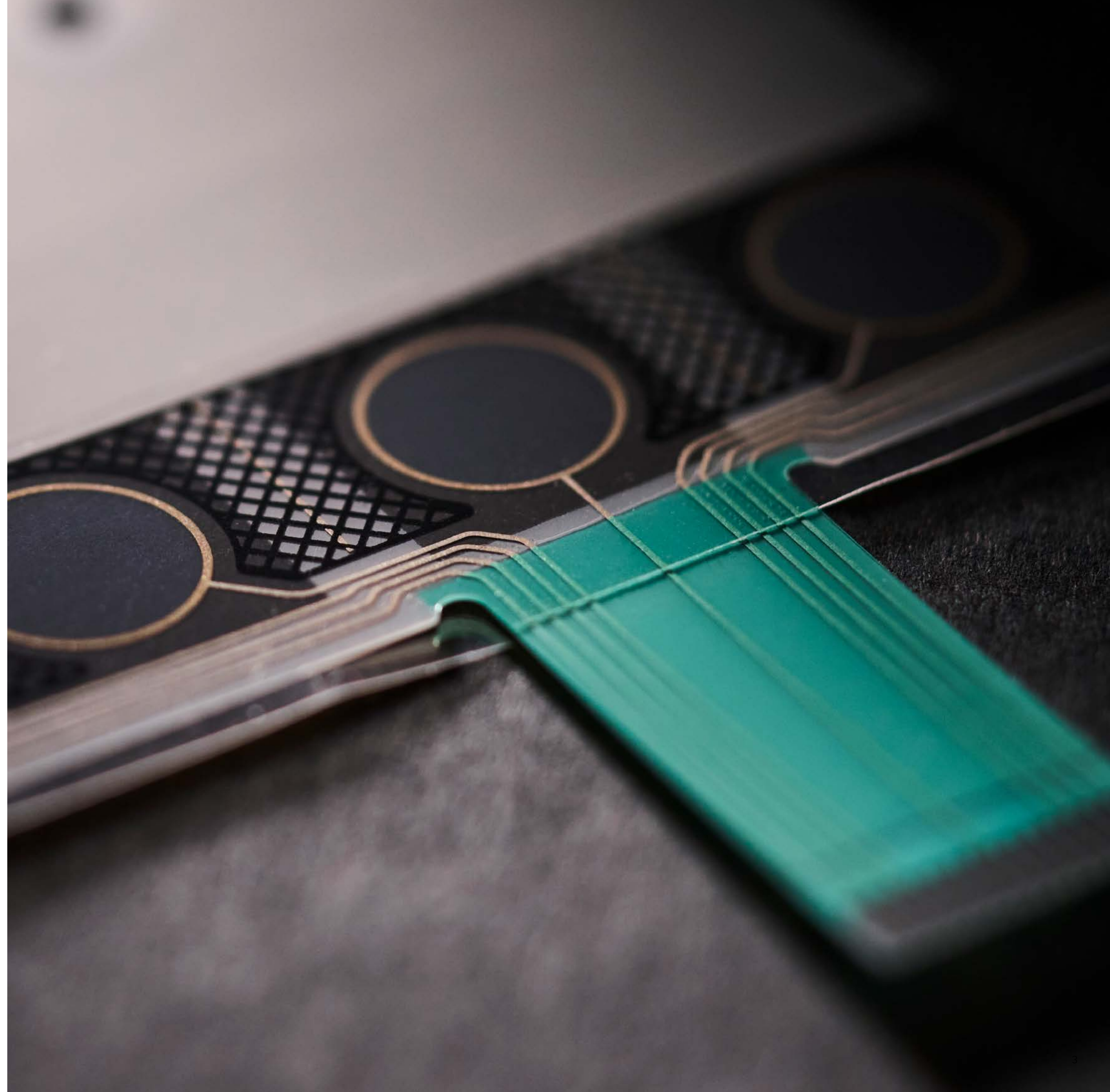
Printed electronics has advanced rapidly in recent years, driven by developments in substrate materials, functional inks, and high-precision industrial printing processes.

Research and development efforts continue to push the boundaries of what can be manufactured through printing, including the feasibility of producing functional electronic components such as capacitors, resistors, LEDs, and photovoltaic elements directly on flexible substrates.

While these emerging technologies show strong potential, this guide focuses on the industrially mature aspects of printed electronics - specifically the building blocks used in robust, high-volume printed sensor solutions suitable for scalable production.

This guide does not aim to replace detailed design documentation or material datasheets, but to provide a practical engineering framework for evaluating, designing, and industrialising printed sensor solutions.

A printed sensor with conductive traces and connector tail, illustrating how functional layers are combined on flexible substrates for thin, lightweight sensor solutions.





Roll-based printed electronics components highlighting scalable manufacturing.

Content

Technical reference range	Page 6
Indicative performance ranges for industrially mature printed sensor solutions, including sheet resistance, line width, substrate thickness, and operating temperature limits.	
System-level considerations	Page 8
Key system-level factors influencing the transition from concept to industrial production, including system alignment, interface optimisation, early design decisions, and prototype maturation.	
Printed sensor design considerations	Page 10
Core design dimensions affecting sensor performance and manufacturability, covering mechanical, electrical, optical, system integration, and manufacturing constraints.	
Layer stack-up and architecture	Page 12
Typical multilayer architectures used in printed sensors, explaining the function, materials, and role of each layer in capacitive, resistive, and functional sensor systems	
Layer overview and reference table	Page 14
Tabulated overview of common printed sensor layers, including typical materials, thickness ranges, and functional roles to support early design evaluation.	
Easy access to knowledge and manufacturing support	Page 16
Overview of engineering support across discovery, product engineering, process maturing, production engineering, and life-cycle optimisation.	
Printed sensor development checklist	Page 18
A practical, engineer-focused checklist summarising key considerations from application definition to validation, cost, and scalability.	
Your dedicated printed electronics partner	Page 20
Introduction to experience, capabilities, and collaborative approach to developing and scaling printed sensor solutions.	

Technical reference ranges

Printed electronics enables functional electronic structures through additive deposition of conductive, resistive, and dielectric materials. While performance is application-specific, the following ranges are representative for industrially mature printed sensor solutions.

Please note: Values are indicative and depend on material selection, layer stack-up, and process conditions. However, these ranges define practical design boundaries and should be considered early to avoid late-stage redesign.

These ranges define practical design boundaries and should be used early to assess feasibility, risk, and trade-offs before detailed design begins.

Sheet resistance (silver inks)
~50 mΩ/sq depending on layer thickness, curing profile, and ink formulation

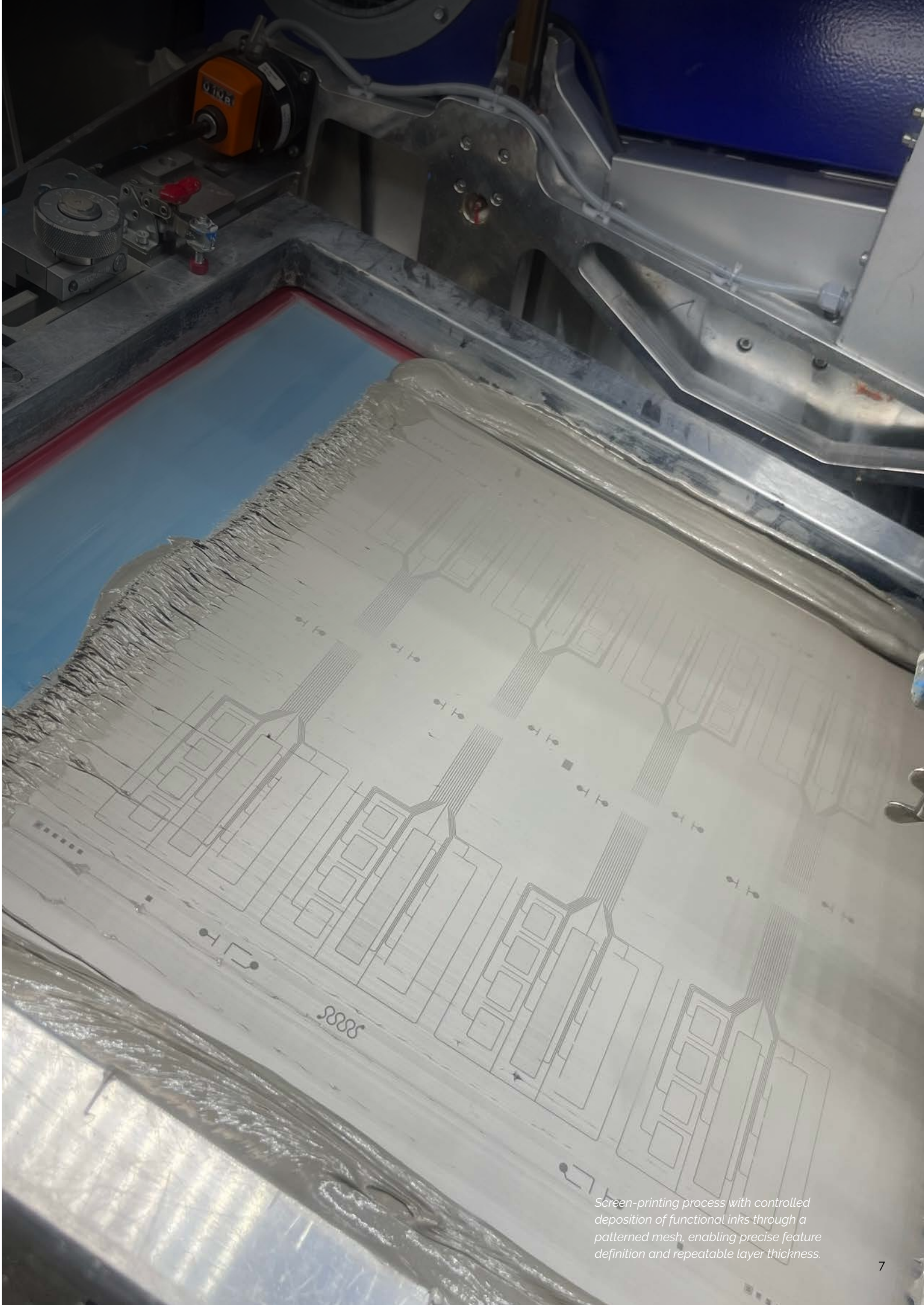
Typical line width
~50–300 μm

Substrate thickness
PET / PC: ~50–250 μm
PEN / TPU / Non-woven: Application dependent

Operating temperature limits
Typically –40 °C to +85 °C
Material stack dependent

	Printed Electronics	FPC	PCB
Typical thickness	< 0,5 mm	0.7-1.0 mm	> 1.5 mm
Bending radius	< 5 mm	5-10 mm	Not flexible
Mechanical integration	Direct to surface	Assembly required	Assembly required
Electrical integration complexity	Low (direct interface)	Medium	High
Unit cost at volume	Low	Medium	Medium / high

Comparative overview of printed electronics, flexible printed circuits (FPC), and conventional PCB solutions. The comparison highlights key differences in thickness, flexibility, integration complexity, and unit cost at volume.



Screen-printing process with controlled deposition of functional inks through a patterned mesh, enabling precise feature definition and repeatable layer thickness.

KEY CONSIDERATIONS

System-level

Printed sensors must be evaluated as part of a complete system rather than as isolated components. Successful industrialisation of printed sensors depends not only on sensor design, but on how the sensor is integrated into the complete system.

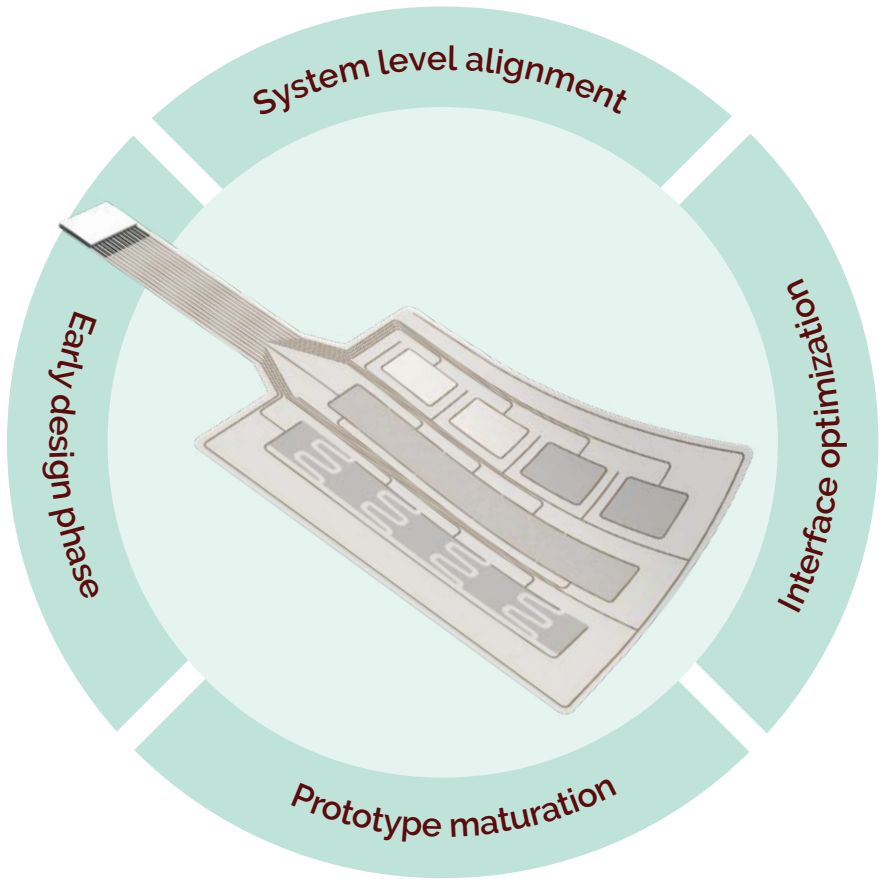
Electrical, mechanical, and environmental factors interact across multiple interfaces, and system-level alignment is critical to achieving stable sensor functionality and scalable industrial production.

To successfully transition from concept to high-volume manufacturing, several interdependent elements must be considered and aligned alongside the printed sensor design. These include

electronics, connector solutions, user interface implementation, and the surrounding system architecture.

Many system-level challenges do not emerge during prototype development but appear during volume production. Process variation, environmental exposure, and long-term use can reveal issues that were not visible at early stages.

Addressing system-level considerations early reduces costly redesigns and accelerates industrialisation.



Printed sensor integrated within a larger system context, illustrating how electrical, mechanical, and environmental interactions influence overall system performance.

DEFINES THE FRAME

1 System-level alignment

System-level alignment extends beyond the physical sensor and includes IT infrastructure, device interaction, firmware logic, and overall system integration. A mismatch at system level can compromise sensor performance even when the printed sensor itself functions as intended.

DECISIONS WITHIN FRAME

2 Early design phase

System-level performance is strongly influenced by decisions made early in the design phase. Design for manufacturability (DfM) and appropriate material selection help ensure that the sensor concept can be produced reliably at scale without introducing unnecessary process risk.

KEY RISK AREA

3 Interface optimisation

The electrical and mechanical interfaces between the printed sensor, connectors, and associated electronics are often critical points of failure. Interface optimisation focuses on ensuring stable electrical contact, mechanical robustness, and tolerance to process variation.

VALIDATION BEFORE SCALE

4 Prototype maturation

While early prototypes validate functionality, prototype maturation ensures that concepts can be scaled into high-volume production. This includes evaluating process repeatability, material consistency, and long-term performance under realistic operating conditions.

Sensor design

The functional performance of printed sensors is determined by a combination of material properties, geometric design, and process parameters established early in the development phase.

In contrast to conventional electronic components, printed sensors are inherently application-specific, as their electrical, mechanical, and optical characteristics are directly influenced by substrate selection, layer architecture, and manufacturing constraints.

The sensor behaviour emerges from the interaction between multiple design variables, where changes to one parameter may introduce trade-offs in others.

For example, increased conductive layer thickness may improve electrical conductivity while reducing mechanical flexibility, and modifications to dielectric thickness can affect both sensor sensitivity and process stability.

As a result, sensor performance and manufacturability are strongly coupled, and early design decisions play a critical role in determining long-term functionality, reliability, and scalability.

The following sections will elaborate on each design dimension, outlining the key technical parameters, typical trade-offs, and implications for sensor performance, reliability, and scalability.

Mechanical Requirements

- Deformation tolerance
- Strain limits
- Long-term mechanical stability

Mechanical requirements define the ability of the printed sensor to tolerate bending, strain, and long-term mechanical load without unacceptable performance drift.

Typical considerations include deformation under repeated bending, material-specific strain limits, and lifetime stability. Conductive and functional materials such as silver, carbon, and PEDOT exhibit different strain tolerances, where excessive strain may lead to gradual resistance drift rather than abrupt failure. Mechanical design must therefore balance flexibility requirements against long-term electrical stability.

Environmental requirements

- Temperature limits
- Humidity exposure
- Chemical exposure
- Long-term environmental stability

Environmental requirements define how the printed sensor performs under thermal, climatic, and chemical exposure throughout its lifetime. These conditions influence material stability, electrical drift, adhesion, and mechanical integrity, and must be considered early to avoid degradation during use.

Key considerations include operating and storage temperature limits, resistance to humidity and condensation, and exposure to chemicals. Environmental stress can lead to changes in conductivity, signal drift, delamination, or accelerated ageing if not addressed through material selection, layer stack-up, and protective dielectric or sealing layers.

Electrical Requirements

- Conductivity
- Resistance
- Sensitivity
- Electrical stability

Electrical requirements describe how conductivity, resistance, sensitivity, and stability are achieved within defined tolerances. In this context, sensitivity refers to the change in electrical response relative to mechanical, thermal, or capacitive input. Electrical performance is governed by material selection, printed layer thickness, and curing profile.

Increased layer thickness and curing temperature generally improve conductivity but may reduce substrate stability and flexibility. In capacitive sensors, sensitivity is strongly influenced by dielectric thickness, requiring careful optimisation of material systems and process parameters.

Optical Properties

- Transparency
- Opacity
- Integration of graphical elements

Optical properties are critical when sensors are visible to the user or integrated behind decorative or transparent surfaces.

Transparent conductive materials such as PEDOT typically provide 80–90% optical transmission, depending on formulation and thickness. A fundamental trade-off exists between transparency and sheet resistance, requiring balance between visual appearance and electrical performance.

System Integration

- Electrical and mechanical interfaces with connectors, electronics, and the surrounding system

System integration addresses how the printed sensor interfaces with connectors, mating electronics, and the surrounding system architecture. Stable electrical contact, mechanical robustness of connection regions, and compatibility with PCB input stages and signal conditioning are critical.

System-level considerations also include noise susceptibility, grounding, and interaction with firmware to ensure reliable signal transfer across the complete system.

Manufacturability

- Process capability
- Tolerances
- Yield
- Cost efficiency at scale

Manufacturability describes the ability to produce the sensor reliably and consistently at scale. It includes process capability, registration accuracy, curing constraints, yield, and cost efficiency. Design choices related to geometry, layer count, and material selection directly impact production stability.

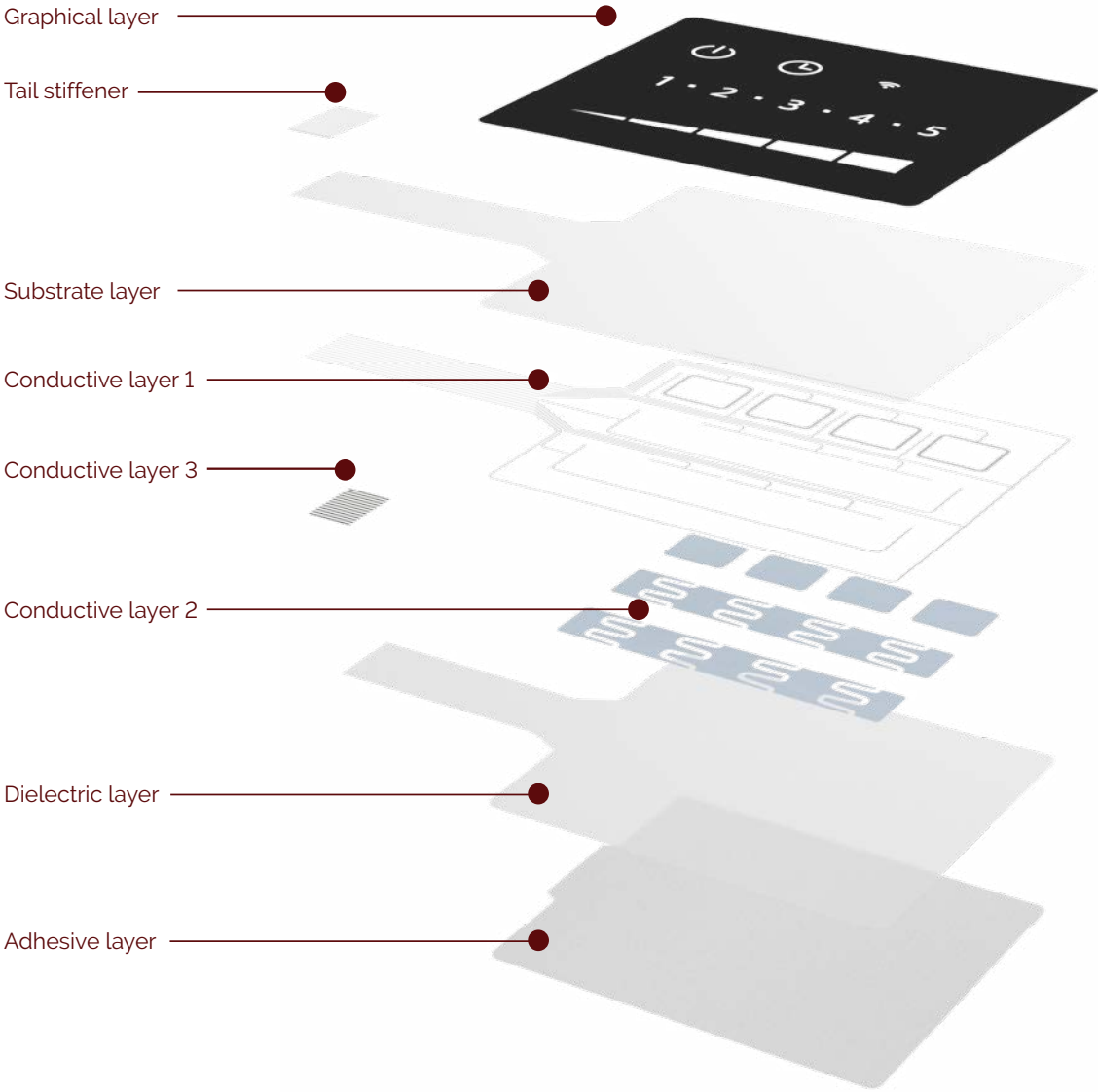
Early application of design-for-manufacturability principles enables controlled scaling from prototype to high-volume production and reduces late-stage redesign risk.

KEY CONSIDERATIONS

Layer stack-up

Printed sensors are typically constructed as multi-layer structures, where each layer serves a distinct mechanical, electrical, or functional purpose.

The exact layer configuration is application-specific; however, most printed sensors follow a common architectural principle in which functional conductive layers are combined with dielectric, graphical, and mechanical support layers.



Exploded view of a typical printed sensor layer stack-up used in capacitive, resistive, and functional sensor systems, showing the relative position and role of each functional, dielectric, and mechanical layer.

Substrate layer	<p>The substrate layer provides the mechanical base for all printed layers. Common materials are:</p> <ul style="list-style-type: none">Flexible structure: Polyester (PET), Polycarbonate (PC), Polyethylene Naphthalate (PEN)Stretchable structure: Thermoplastic Polyurethane (TPU), non-woven
Conductive layer 1	<p>The primary conductive layer is printed silver traces defining the electrical circuitry. Used for power distribution, electrodes, and signal paths.</p>
Conductive layer 2	<p>The secondary conductive layer is printed when the application requires specific electrical or optical properties.</p> <ul style="list-style-type: none">PEDOT: transparent conductive layer for capacitive touch sensorsAg/AgCl: for biosensing and healthcare electrodes
Conductive layer 3	<p>The third conductive layer is carbon. It is often applied to protect silver from oxidation, improve connector durability, or introduce specific resistive properties. It is frequently used at the connector tail to ensure robustness.</p>
Dielectric layer	<p>Printed or laminated dielectric layer protecting conductive traces. It prevents short-circuiting between layers. Supports tactile or capacitive designs requiring isolation.</p>
Tail stiffener	<p>Mechanical reinforcement of connector with a tail stiffener. Ensures proper thickness for ZIF insertion and improves handling strength.</p>
Graphic layer	<p>Optional printed graphic layer for button icons, branding, regulatory or identification markings.</p>
Adhesive layer	<p>An adhesive layer is typically laminated and used to integrate the sensor component onto plastic housings or other device structures.</p>

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Many performance and scalability issues are best addressed during early design, where engineering decisions have the greatest impact.

Tobias Holmgaard Stær
Mekoprint, Head of Printed Electronics

Preparation and handling of functional printing inks, where ink formulation and rheology influence achievable layer thickness, conductivity, and curing behaviour.

Layer overview

The overview below summarises the most commonly used layers in printed sensor designs, outlining typical materials, representative thickness ranges, and their primary functions.

Please note that not all layers are required in every sensor design. Thickness values are indicative and depend on material selection, process parameters, and application requirements.

This layered perspective supports early design evaluation by clarifying how material selection and layer thickness influence sensor performance, reliability, and manufacturability.

Layer	Material	Typical thickness	Function
Substrate	PET / PC / PEN Non-woven / TPU	75/175 µm	Mechanical base providing flexibility and dimensional stability
Conductive layer 1	Silver	5-10 µm	Primary signal routing and electrode formation
Conductive layer 2	PEDOT Ag / AgCl	1-5 µm	Transparent conduction or electrochemical interface for specific sensing functions
Conductive layer 3	Carbon	5-10 µm	Contact robustness, oxidation protection, and interface stabilisation
Dielectric layer	UV-cured lacquer Laminated film	10-30 µm	Electrical isolation and capacitive layer control
Graphic layer	Graphical inks	2-10 µm (typical)	Optical appearance, symbols, and graphical integration
Adhesive layer	Lamination Foam	application dependant	Bonding and integration to housing or carrier
Tail stiffener	PET / PC	100-300 µm (typical)	Mechanical reinforcement of connector interface

The table summarises commonly used layers, representative materials, indicative thickness ranges, and their primary functions. Actual layer combinations and thicknesses are application-specific and optimised during design.

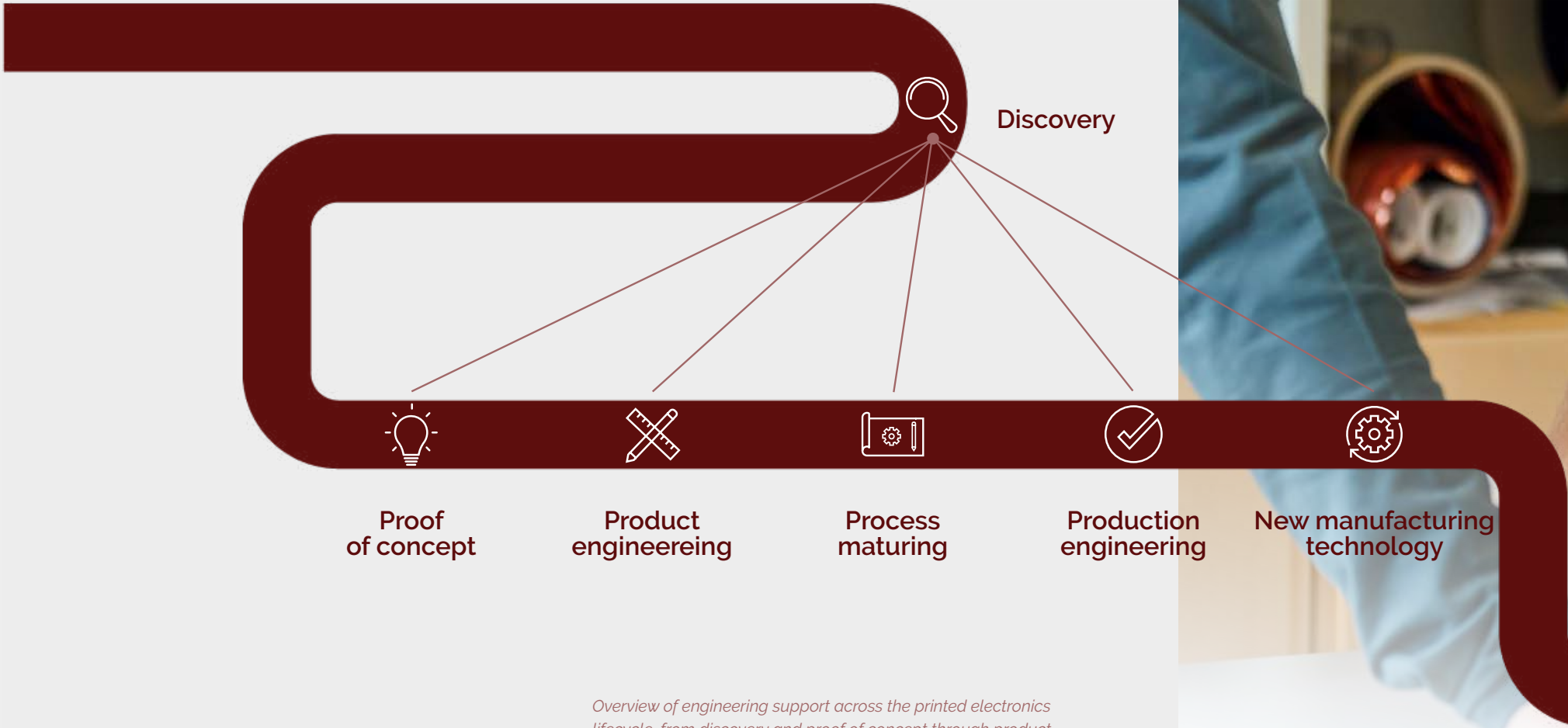
Easy access to knowledge and printed electronics manufacturing

We are here to assist you. You choose the level of involvement. Support can be provided across the entire development process, or selectively through targeted engineering and development services, depending on project needs.

Engineering decisions are driven by functional requirements, manufacturability, and total system performance.

Our focal point is always functionality, complexity, cost optimization, quality requirements, and your subsequent manufacturing process.

You can consider our development team an extended part of your organization. The depth of our collaboration is defined by your requirements and scaled according to your needs.



Overview of engineering support across the printed electronics lifecycle, from discovery and proof of concept through product engineering, process maturing, production engineering, and life-cycle and next-gen evaluation.



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Printed electronics does not follow a one-size-fits-all approach.

Within defined design rules, this enables cost-efficient creation of application-specific sensor designs and tailored functionality.

Tobias Holmgaard Stær
Mekoprint, Head of Printed Electronics

Checklist

Use this checklist during concept development, design reviews, and before design freeze.

Application & environment	<ul style="list-style-type: none"> Measured function defined (touch, force, temperature, humidity, bio-signal) Operating environment specified (temperature, humidity, chemicals, UV) Expected lifetime defined (cycles, hours, disposable vs. durable) Regulatory context identified (consumer, automotive, medical, industrial)
Mechanical requirements	<ul style="list-style-type: none"> Flexibility or stretchability requirement defined Minimum bending radius and cycle count specified Substrate selected (PET, PC, PEN, TPU, non-woven) Risk of mechanical fatigue and resistance drift evaluated
Electrical performance	<ul style="list-style-type: none"> Target resistance / capacitance defined Sensitivity and signal stability requirements set Layer thickness aligned with conductivity targets Curing profile compatible with electrical and mechanical limits
Optical properties	<ul style="list-style-type: none"> Transparency or opacity requirement defined Graphical or visual integration requirements specified Trade-off between transparency and sheet resistance evaluated
Layer stack-up	<ul style="list-style-type: none"> Substrate material and thickness defined Primary conductive layer (silver) defined Secondary layers required (PEDOT, Ag/AgCl, carbon) Dielectric thickness aligned with isolation and sensitivity Tail stiffener and adhesive requirements defined
Interface & system integration	<ul style="list-style-type: none"> Connector type selected (ZIF, snap-in, clip) Printed-to-connector contact resistance stabilised Sensor output compatible with PCB and MCU input Noise, grounding, and signal conditioning considered
Manufacturability (DfM)	<ul style="list-style-type: none"> Production technology selected early Achievable line width and tolerances verified Registration and curing constraints understood Process windows defined for stable production
Prototype maturation & scaling	<ul style="list-style-type: none"> Prototype validated beyond basic functionality Process repeatability evaluated Risks likely to appear at volume identified Yield expectations realistic for target volume
Testing & validation	<ul style="list-style-type: none"> Adhesion tested Temperature and humidity cycling defined Electrical stability over lifetime evaluated Mechanical durability tested under realistic conditions
Cost & viability	<ul style="list-style-type: none"> Key cost drivers identified Unit cost estimated at target volume Performance vs. cost trade-offs understood

Your dedicated printed electronics partner

Mekoprint has been a long-standing partner in the printed electronics industry, supporting both the development of new concepts and the maturation and scaling of high-volume printed sensor production.

Our dedicated team works closely with customers on a daily basis, assisting with everything from early design development to lifetime engineering and continuous optimization of running production to next generation conversations.

Mekoprint supplies printed electronics across a wide range of industries and applications. With this broad experience we are able to draw on

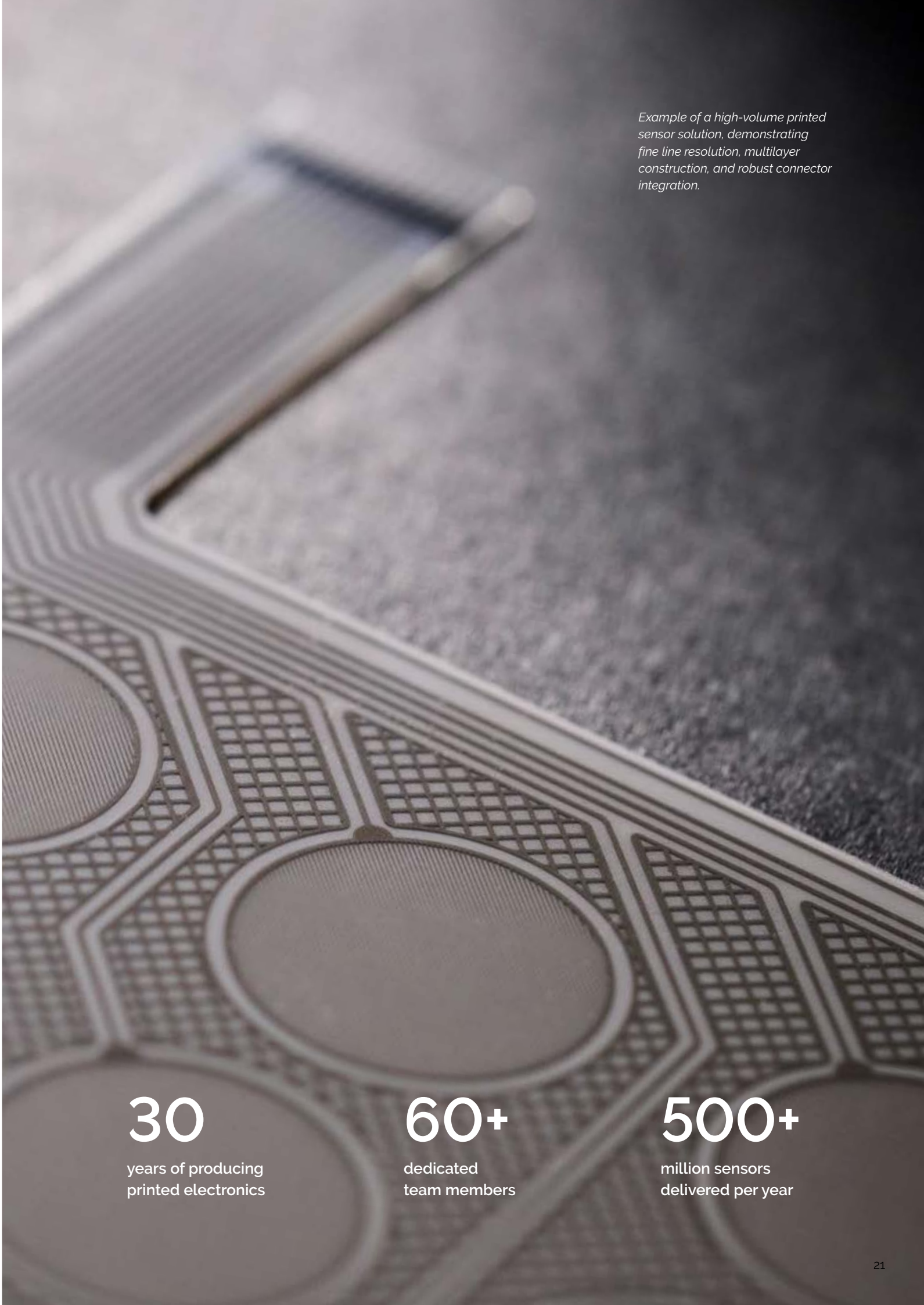
accumulated knowledge when supporting new projects - while still treating every design as unique and tailored to the specific functional requirements of the application.

Curiosity is a core value in our way of working, helping us understand your perspective, constraints, and opportunities at a deeper level.

We help translate printed electronics potential into robust, scalable, and industrially viable sensor solutions.



Engineering collaboration during printed electronics development and production, reflecting process knowledge, and industrial manufacturing experience.



Example of a high-volume printed sensor solution, demonstrating fine line resolution, multilayer construction, and robust connector integration.

30

years of producing printed electronics

60+

dedicated team members

500+

million sensors delivered per year

Pushing for progress Leading new ways™