

TECHNICAL REPORT

**Printed electronics –
Part 250: Material technologies required in printed electronics for wearable
smart devices**

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ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRINTED ELECTRONICS –

Part 250: Material technologies required in printed electronics for wearable smart devices

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IEC TR 62899-250 has been prepared by IEC technical committee 119: Printed electronics. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2016. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) added classification of e-textile integrated type;
- b) added Clause 5, "Verification of conclusions in IEC TR 62899-250:2016 (edition 1)";
- c) added explanation of 3D printed circuits;

- d) introduced trends in standardization activities, especially those after the first edition publication;
- e) added new issues that became clear after the first edition was published.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
119/509/DTR	119/536/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62899 series, published under the general title *Printed electronics*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

IEC TR 62899-250 (edition 1), published in 2016, discussed and summarized the applicability of printed electronics technology in the rapidly expanding area of wearable electronics and the concomitant need for standardization of new measurement methods. Many of the issues raised by the TR regarding the need for new standardization have actually been developed and have already been published as international standards.

The establishment of IEC/TC 124 in 2017 is a particularly noteworthy event in this standardization field. And multiple industrial organizations have progressed standardization activities in flexible electronics field that span both wearable and printed electronics.

During this period, the evolution of this technology field has accelerated, and new technologies are being introduced one after another. Therefore, there is no change in the situation where there is an ongoing need for new standards.

The second edition of this document, following the first edition, aims to provide guidance for future standardization work on wearable and printed electronic. And standardization activities in the field of both printed and wearable electronics are reviewed from a global perspective, in order to prevent standardization conflicts between different standardization organizations.

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PRINTED ELECTRONICS –

Part 250: Material technologies required in printed electronics for wearable smart devices

1 Scope

This part of IEC 62899, which is a Technical Report, explores a new technological field to establish standardization activities in TC 119 (Printed electronics) in particular, and to contribute to the development and market expansion of wearable smart device (WSD) technology.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

4 Wearable smart devices

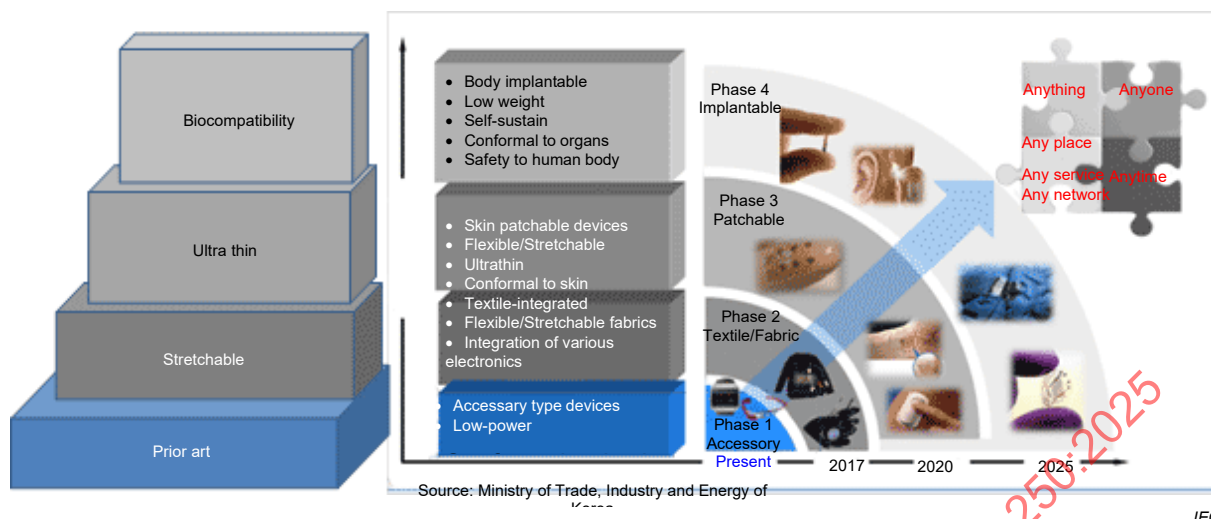
4.1 General

Wearable smart devices are a newly evolving electronic application field where standards for conventional electronic devices might not be smoothly applicable. In this new field, electronic devices are applied or attached directly to the human body like eyewear, contrary to conventional electronic devices, such as TV sets, that are most likely to be used away from the body. Due to the particular characteristics of the human body, these new devices are required to have new physical characteristics, such as flexibility and salt resistance (anti-sweat). In order to address those demands, the electronics industry has come up with new processes to produce those new devices.

NOTE The expression "wearable smart devices" is abbreviated as "WSD" in this document.

4.2 Categorization

Figure 1 shows an overview of WSDs, including categorization and examples. This graphic introduces categories based upon characteristics, such as "prior art", "stretchable", "ultra-thin" and "biocompatibility", and some examples in each category. Technologies and challenges for those examples are discussed in 5.2 to 5.5.



[SOURCE: Ministry of Trade, Industry and Energy of Korea]

Figure 1 – Wearable smart devices technologies and market¹

4.3 Accessory type devices

Accessory type devices are designed to be a good fit for the shapes of the human body. The major functions of these devices are to acquire vital data or movement, or both, of the body, and to transfer data to other devices or networks, or both, without human interaction, unlike cell phones or portable music players, which require human interaction. For example, the following WSDs are already commercialized:

- bracelets, watches and wristbands;
- eyewear and headmounted devices;
- earphones;
- finger rings, necklaces and the like;
- footwear in-soles

In order to realize these devices, adaptation of the following characteristics is required:

- a small footprint,
- lightness,
- low power,
- mechanical flexibilities to follow body movement, and
- if needed, display functions with high resolution or mechanical flexibilities, or both.

Obviously and most importantly, in addition to fulfilling these electrical or mechanical needs, additional safety requirements and regulations need to be developed, since WSDs will operate in close contact with the human body.

¹ Reproduced with the permission of Ministry of Trade, Industry and Energy of Korea.

4.4 Textile integrated type

Textile integrated type WSDs combine integrated biomedical signal acquisition functions with communication functions attached to clothing such as sportswear or underwear. This type of WSD needs complementary technologies compatible with the electronic components and textile products that make up the clothes. Specifically, highly flexible and stretchable wiring technologies are required. Furthermore, electronic components need to withstand stresses similar to those general clothing is subjected to, such as stresses which occur during washing and drying.

Textile-integrated WSDs are classified as follows, depending on the degree to which electronic components or devices are integrated on or into textile materials or products:

- Integration level 1 (removable solution)

The electronic (textile) component is attached in a way that it can be detached without destruction of the product. Examples for integration level 1 electronic textile systems are attachment of the electronic (textile) component by inserting in a dedicated pocket or by attaching it via, for example, close fasteners or push buttons.

- Integration level 2 (attached solution)

The electronic device is attached to textile in a way that it is not removable without destroying the products. Examples for attachment methods are stitching, welding, gluing.

- Integration level 3 (mixed solution)

The electronic textile system comprises an electronic device which consists of one or more electronic components which are made using textile or textile finishing technologies and which can be combined with permanently or non-permanently attached electronic components.

- Integration level 4 (full textile solution)

All components of the electronic device are made using textile or textile finishing technologies.

NOTE This level classification is based on [1] and [2]².

4.5 Skin patchable type

WSD types used in patches directly applied to the skin or mucous membranes of the body surface have been proposed. Such WSDs, in addition to the necessities of functional shape and flexibility, require technology for obtaining very thin electronic elements. Additionally, in order to evaluate the very thin electronic elements, new evaluation methods will be required.

Furthermore, because these types of WSDs are in continuous direct contact with the human body, they require resistance to secretions from the body such as sweat or saliva.

4.6 Body implantable type

In Figure 1, WSDs are shown to be expected to eventually develop into types which are implanted into the human body. High biocompatibility is required for WSDs at this stage.

² Numbers in square brackets refer to the Bibliography.

5 Verification of "conclusions" in IEC TR 62899-250:2016 (edition 1)

5.1 Current state of the standardization needs proposed in IEC TR 62899-250:2016 (edition 1)

The current state of the standardization needs proposed in IEC TR 62899-250:2016 (edition 1) is summarized in Table 1.

Some of the standardization needs were solved by developed and published by IEC standards. They are the result of IEC/TC 119 activities. In addition, the verification of conclusions in IEC TR 62899-250:2016 (edition 1) is summarized in Table 2.

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Table 1 – Wearable technologies map

Electronics technologies materials, process		Portable	Wearable smart devices								PE potential	Related standards organizations
			Portable	Accessory type				Textile-integrated	Skin patchable	Body implantable		
				Hands	Head, eyes	Ears	Others					
Examples		Mobile phone, tablet	Wristband	HMD eyeglass	Hearing aids	Ring necklace	Smart ware	Biosensors	Artificial organ			
Compact and lightweight	Small components	3	3	3	3	3			3	Thin parts	IEC/TC47, IEC/TC40(C&R), IEC/TC51WG9	
	High-density 3D electronics packaging	3	3	3	3	3			3	Multilayer PE	IEC/TC91, IPC JPCA, SEMI	
	Compact system	3	3	3	3	3			3	Thinner	IEC/TC100	
	Small and thin battery	3	3	3	3	3		3	2	Thin battery	IEC/TC21	
Low power consumption	Non-contact power supply	3	3	3	3	3	3	3	2		WPC: Wireless Power Consortium	
	High resolution	3	3								IEC/TC110	
High-definition curves display	Near the eye			1						Near eye display	IEC/TC110	
	Flexible display	1	1							Film substrate device	IEC/TC110, IEC/TC119WG5	
	High flexion	2	2	2			2	2		Film substrate device	IEC/TC91, IPC JPCA	
Free 3D design	3D molding and wiring		2	2	2	2			1	3D printer, 3D molding	(MID)	
	Deformation and stretch						1	2		Stretchable		
	Ultrathin						2	1		Ultra-thin device, process		
Adhesion	Skin contact							1		Ultra-thin device, process		

Electronics technologies materials, process		Portable	Wearable smart devices								PE potential	Related standards organizations	
			Portable	Accessory type					Textile-integrated	Skin patchable			Body implantable
				Hands	Head, eyes	Ears	Others						
Examples	Mobile phone, tablet		Wristband	HMD eyeglass	Hearing aids	Ring necklace	Smart ware	Biosensors	Artificial organ				
	EMC	3	3	3	3	3	3	3	2	2	IEC/TC77		
	Weather (light) resistance						2	2			ISO/TC38, ISO TC42 WG5		
	water resistant						2	2	1		ISO/TC38		
	Waterproof property	3	3	3	3	3			1		IEC/TC70		
Environmental compliance	The resistance to body fluids (sweat, blood, etc.)						1	1	1	Anti-sweat, anti-blood	ISO/TC38		
	Environmental pollution, 3R / LCA	3	3	3	3	3	3	3	2	Additive process	IEC/TC111		
	Electrical safety	3	3	3	3		3		2		IEC/TC108		
	Electromagnetic wave exposure, SAR	3	3	3			3		2		IEC/TC106, CISPR		
	Static electricity						2				IEC/TC101		
Safety	Optical and ultraviolet light exposure			2							IEC/TC108		
	Biological skin safty		2	2	2	2	2	1		Biocompatibility	IEC/TC62, ISO/TC194, ISO/TC210		
	In vivo safty								1		IEC/TC106, ISO/TC194, ISO/TC210		
Key													
1 High urgency													
2 Medium urgency													
Low urgency													

5.2 Circuits made with 3D printer

Using a 3D printer, three-dimensional modelling of insulating materials (e.g., polymer materials) and conductor (metal) can be made. The combination of the two will achieve a circuit with a 3D structure. 3D printers have attracted attention from the viewpoint of additive manufacturing. ISO/IEC JTC1 handles 3D Printing and Scanning and has published IEC/ISO 23510 [3]. ISO TC 261 handles additive manufacturing and has published several standards related to 3D printers. Since this field is related to many standardization activities, the Additive Manufacturing Standardization Collaborative (AMSC) has been created.

5.3 3D printed circuit

In addition to making circuits with 3D printers, other techniques for directly printing 3D forms are known, but their application to printed electronics is not yet common.

There are various 3D deforming technologies and the conductor pattern with a 3D shape requires an insulation treatment in the 3D structure. However, most insulation test methods of existing printed wiring are based on a 2D plane structure. It is expected that new test methods and standards will be required for insulation testing with 3-dimensional shapes.

One of the technologies is in-mould electronics (IME). Manufacturing steps typically include printing, surface mounting, thermoforming, and injection moulding. This means that substrates are transformed into 3D after printing (and surface mounting). Thus, test methods developed for 2D substrates can also be used.

There are some exceptions, and they are being addressed. IEC/TC 119 has published IEC 62899-202-10 [4]. The standard defines the terminology and measurement methods for characterizing the resistance change of conductive ink layers as a function of thermoplastic elongation.

5.4 Printed stretchable circuit

The basic evaluation method for the stretchable substrate for Printed Electronics (PE), the print conductor layer, and the insulating layer have been standardized in TC 119. Various forms of deformation of stretchable printed wiring are expected. In addition to simple tensile deformation and compressive deformation, there is a possibility that standards for evaluation methods and evaluation equipment will be needed for various deformations such as bending and flexing.

For textile-integrated devices, a method for evaluating durability against "washing" will be required.

5.5 Extremely thin printed circuit

It might not be possible for the extremely thin electric circuit realized by PE to apply electrodes or clips used in conventional test methods because of the lack of mechanical strength. As one of these responses to such issues, TC 119 has standardized non-contact sheet resistance measurement methods using an eddy current method.

However, the electrical connection method between the conducting track and test equipment to evaluate the extreme thin printed conductor track is not common. Technology development and standardization for this purpose are future challenges.

5.6 Safety issues

Standards regarding the safety of electronic products are covered by IEC/TC 108, which also covers wearable electronics products. ISO 10993-10 stipulates methods for evaluating the skin sensitization of medical devices and component materials, and these can be applied to wearable smart devices.

Table 2 – Verification of "conclusions" in TR 62899-250:2016 (edition 1)

Items to be standardized		Standards published after edition 1 (including those under development)	Standardized items to be developed in the future
a)	3D-formed and wired technologies by 3D printers,	The basic standards are handled by "ISO/IEC JTC 1 / WG 12 3D Printing and scanning".	there is no information on the standardization of materials and processing specific to 3D electronic circuits by 3D printers.
b)	3D circuit technologies in combination with printed wiring and in-mould technology	IEC 62899-202-10:2023 (edition 1), [4] Printed electronics – Part 202-10: Materials – Resistance measurement method for thermoformable conducting layer	Conductive ink for thermoformable conducting layer Insulating ink for thermoformable conducting layer
c)	materials for stretchable electronic circuits by PE.	IEC 62899-201-2:2021 (edition 1), [5] Printed electronics – Part 201-2: Materials – Substrates – Measurement methods for properties of stretchable substrates IEC 62899-202-4:2021 (edition 1), [6] Printed electronics – Part 202-4: Materials – Conductive ink – Measurement methods for properties of stretchable printed layers (conductive and insulating)	Durability evaluation method for various deformation modes other than simple tensile deformation
Matters to consider in standardization		Standards published after edition 1 (including those under development)	Standardized items to be developed in the future
a)	applicability to extremely thin devices	IEC 62899-202-3:2019 (edition 1) [7], Printed electronics – Part 202-3: Materials – Conductive ink – Measurement of sheet resistance of conductive films – Contactless method	Reliability evaluation method for extremely thin insulating films
b)	effects from the living body on electronic devices.	This issue is mainly dealt with by IEC / TC108. The following standard has been published from IEC/TC124. IEC 63203-406-1:2021 (edition 1) [8], Wearable electronic devices and technologies – Part 406-1: Test method for measuring surface temperature of wrist-worn wearable electronic devices while in contact with human skin	Evaluation method for the effects of biological substances such as sweat and saliva on electronic device elements

6 Current standardization activities for flexible electronics

As of 2016, the relationship between wearable electronics, smart textiles, and e-textiles could be illustrated with a simple Venn diagram, shown in Figure 2.

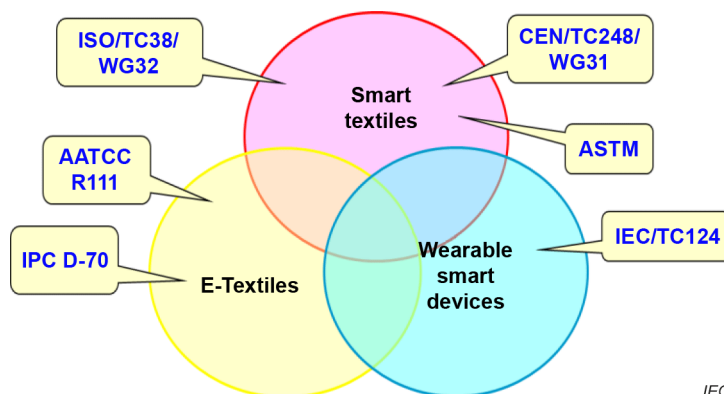


Figure 2 – Standardization activities from 2016 to 2018

Today, many more organizations are involved in standardization in the flexible electronics technical field, as shown below.

CEN/TC 248 Textiles and textile products/ WG 31 Smart Textiles – 2008

IEC/TC119 Printed Electronics – 2011

IPC D-60 Printed Electronics – 2012

ASTM Subcommittee Smart Textiles (D13.50) – 2016

AATCC R111 Electronically Integrated Textiles – 2016

ISO/TC38/WG32 "Smart Textiles" – 2018

IPC D-70 E-Textile Committee – 2017 D-73 Printed E-Textiles

IEC/ TC 124 Wearable Electronic Devices and Technologies (WSD) – 2017

JPCA E-Tex WG (E-Textiles) – 2020

SEMI Charter of Global Flexible Hybrid Electronics (FHE) Committee 2020

Their relationship is shown in Figure 3, but it is already difficult to represent it accurately in a Venn diagram.

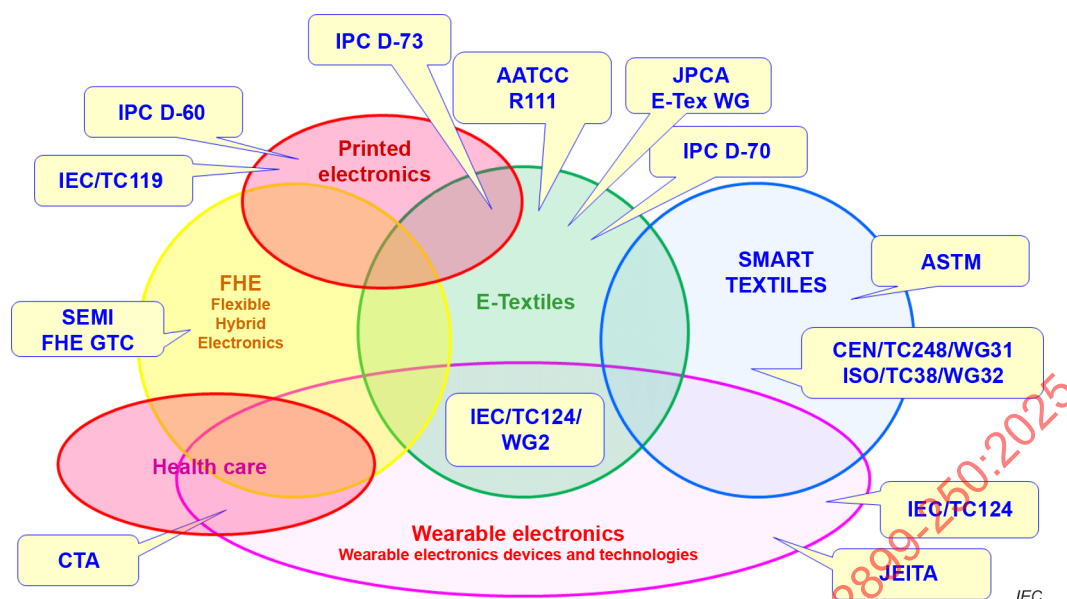


Figure 3 – Standardization activities in 2024

7 New challenges for printed electronics and needs for standardization.

7.1 Multilayer printing on fabric

The combination of textiles and printed electronics technology will naturally be considered as a means of realizing e-textiles. Generally, printing on fabrics has a long history as a method of giving graphic designs to fabrics. However, conventional printing on fabric differs from printed electronics in that, in principle, it does not involve multi-layer printing. Of course, the multilayer printing here is intended for a configuration in which insulating layers and conductive layers are alternately arranged.

7.2 Through-hole electrical connection without drilling

Fabrics, on the other hand, are porous, unlike the polymeric film substrates primarily used in printed electronics. This characteristic of the fabric suggests that it is possible to make the front and back of the fabric electrically conductive by permeating the conductive ink. In other words, double-sided through-hole printed wiring can be formed without drilling holes.

7.3 Transfer printing

The fabric is porous and at the same time has a large surface roughness compared to polymer film substrates. A high level of technology is required to form printed wiring that guarantees continuous electrical continuity on the fabric surface.

In order to solve this problem, there is a method of transferring printed circuit elements formed by printing on another substrate such as a polymer film to the fabric. These technologies are still under development, and standardization is also a future task.