International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

# A Review of Flexible Medical Sensors Using Polycrystalline Organic Electronics: Bridging Biomedical Engineering and Emerging Materials

**Sidra A. Shaikh**

PhD Researcher, Dallas, USA
Email: *sidraafzalshaikh[at]gmail.com*

**Abstract:** ***This review summarizes the application of polycrystalline organic semiconductors in flexible medical sensors, emphasizing their mechanical compatibility with soft tissues and the scalability of roll-to-roll fabrication. Key materials, such as TIPS-pentacene, DNTT, and poly(3-hexylthiophene), are discussed in terms of grain-boundary control for enhanced field-effect mobility and stability under bending radii less than 2 millimeters. Encapsulation approaches using perylene, hydrogels, and biodegradable PLA ensure device durability over tens of cm². Representative devices include pressure-sensitive diodes, piezoresistive RFID tags, amperometric lactate sensors, thermosensitive MOS capacitors, and near-field communication (NFC)- enabled ECG patches. This review provides design guidelines for integrating organic thin films into wearable and implantable diagnostic platforms.***

**Keywords:** flexible medical sensors, polycrystalline organic semiconductors, TIPS-pentacene, DNTT, grain-boundary morphology, organic electronics, roll-to-roll printing, biomedical engineering, wearable devices

## 1. Introduction

Over half a century of microelectronics development saw the first medical sensors fabricated on crystalline silicon, enclosed within rigid packages that are six orders of magnitude stiffer than soft brain or skin tissues. Such a mechanical mismatch provokes chronic inflammation. Activated microglial cells form an insulating capsule around the implant, which progressively degrades the signal and increases the risk of tissue damage (Li et al., 2023). Understanding this problem became the key impetus for transitioning from rigid microengineering to flexible, thin-film systems capable of accommodating microscale deformations of biological environments without causing trauma.

The economic and scientific dynamics confirm the irreversibility of this transformation. The global market volume for flexible sensors was estimated at USD 6.51 billion in 2024 and is projected to reach USD 11.01 billion by 2032, with a compound annual growth rate (CAGR) of 6.8% (Data Bridge Market Research, 2025). The narrowly segmented medical sensor sector is growing even more rapidly, reaching USD 42.6 billion in 2023 with an expected CAGR of 19.1% through 2030, reflecting high demand for wearable and remote diagnostics (Grand View Research, 2024).

The fundamental cornerstone of the new generation of devices has become polycrystalline organic semiconductors, which combine the mechanical compliance of polymers with charge-transport properties sufficient for sensor electronics. In TIPS-pentacene films formed by spin-coating, field-effect mobility reaches 0.65 $cm^2 V^{-1} s^{-1}$ with grain sizes exceeding one millimeter. In contrast, an average value of 0.48 $cm^2 V^{-1} s^{-1}$ is maintained even after bending samples to radii less than 2 millimeters (Lee et al., 2019). Based on this, flexible arrays of thousands of organic transistors have already been produced, demonstrating reversible photosensitivity and stable operation under repeated stretching, confirming the scalability of the technology for biosensor surfaces (Li et al., 2022).

Thus, soft polycrystalline organic materials become the critical link between materials science and clinical practice, as they simultaneously address the issue of mechanical compatibility and pave the way for roll-to-roll, mass fabrication of personalized medical sensors.

## 2. Materials and Methodology

The theoretical foundation comprises works on the mechanical mismatch between rigid silicon sensors and soft tissues (Li et al., 2023), which describe the mechanisms of chronic inflammation and the formation of an insulating capsule by microglia. To evaluate the electrical characteristics of the films, data from Lee et al. (2019) on field-effect transistors based on TIPS-pentacene formed by spin coating, as well as results from Li et al. (2022) on the scalability of organic OFET arrays with reversible photosensitivity, were utilized. Structural-morphological analysis relied on comparing grains ranging from hundreds of nanometres to millimetre scale and their influence on mobility under bending, using published average mobility values (Lee et al., 2019; Li et al., 2022).

Methodologically, the study merged three major approaches: material comparison, systematic literature review, and market indicator aggregation. The comparison examined the mechanical properties of stiff silicon bases against those of thin-film organic systems, emphasizing the latter's capability to emulate microscale deformations without degrading signals (Li et al., 2023). To electrically characterize the films, data on field-effect mobility, threshold voltage, and parameter stability at bending radii less than 2 millimeters were collected and critically analyzed (Lee et al., 2019; Li et al., 2022).

## 3. Results and Discussion

Polycrystalline organic semiconductors consist of a mosaic of oriented grains separated by nanoscopic boundaries. Within each grain, the molecules form well-ordered π-stacks, whereas in the grain boundaries, the disrupted packing creates energetic barriers and additional traps. Charge transport is directly influenced by grain size and texture: in flexible field-effect transistors on a plastic substrate, increasing the average pentacene grain size from several hundred to a thousand nanometres yielded a mobility increase from ≈0.1 to 0.3 $cm^2 V^{-1} s^{-1}$, while preserving device parameters even under bending to a radius of 4–5 mm—demonstrating that large-grain films can withstand mechanical stress without channel degradation (Sekitani et al., 2005). Scanning probe microscopy further shows charge accumulation and potential shifts precisely at the boundaries, confirming that they remain the dominant scattering centers and set the ultimate sensitivity limits of pressure and chemical sensors.

The energetic landscape of such films comprises two distributions: a broad Gaussian distribution associated with static disorder within the grains, and an exponential tail formed by deeper defects near the boundaries and at the dielectric interface. Direct comparisons between polycrystalline transistors and single crystals have shown that it is the grain boundaries that are responsible for fast hole traps; the steep rise in the density of states near the mobility edge has a characteristic slope of 10–20 meV, similar to that in amorphous silicon, emphasizing the universality of trapping mechanisms in disordered lattices (Kalb et al., 2010). Recent reviews of trap states confirm the same picture: deep traps are described by a Gaussian function with $\sigma \approx 70–120$ meV, while the tail states follow an exponential with a characteristic temperature T(C), which determines the slope of the exponential portion of the density of states and thus the activation component of the conductivity (Haneef et al., 2020).

A universal mobility law formalizes the transition from morphology to electrical response. Practically, this means that reducing the trap density by one order of magnitude nearly doubles the mobility, and any technique that increases grain size or passivates grain boundaries simultaneously lowers T(C) and reduces the steepness of the exponential tail.

Together, the grain-boundary structure, energetic traps, and the mobility law create a unified model: morphology defines the trap distribution, which, via the parameter T(C), governs the power-law increase in charge-carrier mobility with charge density. Deliberate control of each link—from the controlled growth of large-crystalline films to chemical passivation of boundaries—enables the precise tuning of the response of flexible polycrystalline sensors, integrating materials with circuit-modeling algorithms and paving the way toward reliable medical sensors capable of continuous deformation on the human body.

Polycrystalline organic semiconductors combine a low elastic modulus with transistor-level signal amplification, allowing flexible sensors fabricated from these films to conform to skin or soft tissue while still transducing minute biochemical or mechanical inputs, effectively linking emerging materials research with clinical monitoring needs. The latest review of flexible organic field-effect transistors highlights that their high charge mobility and printability enable millimeter-thin devices that maintain stable electrical performance under bending, making them natural candidates for wearable or implantable platforms (Liu et al., 2022).

All candidate sensors must first meet the biological safety requirements set by ISO 10993. Under ISO 10993-5, a material is classified as cytotoxic when it reduces L929 fibroblast viability below 70 % in either direct-contact or extract assays, thresholds that capture both acute surface toxicity and delayed effects of leachable residuals (Gatto et al., 2022). Because organic semiconductors often incorporate plasticisers, dopants, and residual solvents, running the full panel of ISO 10993-1 tests—cytotoxicity, sensitisation, irritation, and, where relevant, systemic toxicity—creates a data package that later accelerates regulatory review.

Sterilisation then becomes the next technical hurdle. Moist-heat autoclaves melt most organic films, and standard gamma doses of 25–50 kGy can cut polymer molecular weight by more than 50 %, with chitosan dropping from 275 kDa to 126 kDa at 20 kGy and to 77 kDa at 50 kGy, a level of chain scission that degrades charge transport (García et al., 2015). Vaporised hydrogen peroxide is now recognised by the FDA as an established Category A method, offering a lower-temperature option for battery-free patches provided residual moisture is carefully controlled (FDA, 2024).

From a regulatory perspective, flexible skin-worn sensors intended for continuous use up to 24 hours and equipped with active electronics typically fall into FDA Class II. They enter the market via the 510(k) pathway, which obliges proof of ISO 10993 biocompatibility, validated sterilisation, and software risk controls, as illustrated by recent clearances for continuous glucose and vital-sign biosensor systems. Simple single-use adhesive patches without active circuitry are often Class I and exempt from pre-market notification, though they must still comply with general controls such as good manufacturing practice. Implantable or life-supporting variants escalate to Class III, demanding a full Premarket Approval with clinical evidence because general and special controls alone cannot assure safety or effectiveness (FDA, 2025).

Aligning material selection, sterilisation chemistry, and risk-based regulatory strategy early in development therefore shortens the path from lab prototype to bedside deployment; each decision—polymer crystallinity, sterilant compatibility, or intended use duration—feeds directly into the evidence package that regulators require, ultimately speeding adoption of flexible organic sensors for more personalised and accessible healthcare.

The choice of a specific semiconductor is determined by how well it conducts charge in the presence of grain boundaries while remaining soluble, printable, and air-stable. For example, crystals of bis-(triisopropylsilylethynyl)-pentacene (TIPS-pentacene) grown on an ultrathin Mylar film (2.5 µm thick) retain mobilities of 0.1–0.4 $cm^2 V^{-1} s^{-1}$ even after repeated twisting to a radius of 200 µm, indicating that shear

deformation rather than brittle fracture of grain boundaries dominates, as shown in Figure 1 (Yi et al., 2012).

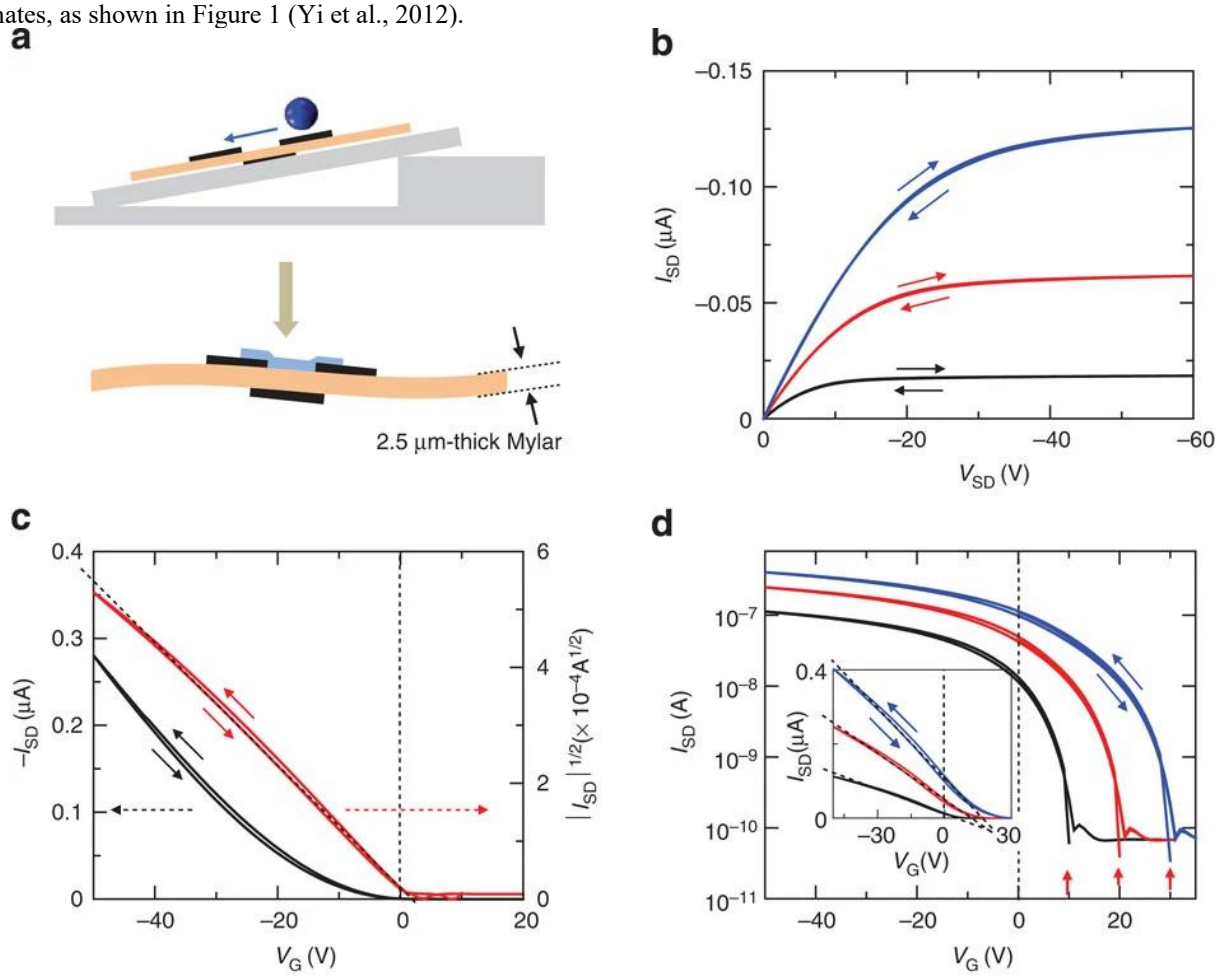


**Figure 1:** (a) The semiconductor solution (blue sphere) is drop-cast on an ultra-thin Mylar sheet with pre-deposited gate, source, and drain contacts, placed on a tilted glass slide. (b) The output characteristics of the resultant free-standing TIPS-pentacene OFET were recorded at VG=−10 V (black), −20 V (red), and −30 V (blue). (c) The saturation-regime measurements: ISD(VG) and ISD1/2(VG) were recorded at VSD=−50 V; saturation mobility is 0.14 cm2 V−1 s−1. (d) The linear-regime measurements: transfer characteristics ISD(VG) of the same device recorded at VSD=10, 20, and 30 V (black, red, and blue curves, respectively) (Yi et al., 2012)

For current-carrying channels with resistance < 1 kΩ, DNTT derivatives are preferred: 4H-21DNTT on a flexible substrate demonstrated a saturation mobility of 8.8 $cm^2$ $V^{-1}$ $s^{-1}$ with an on/off ratio > $10^6$, owing to its deep HOMO level and low contact resistance (Bilgaiyan et al., 2021). Polycrystalline polythiophenes complement small molecules where volumetric ionic control is required: poly(3-hexylthiophene) in a porous SEBS elastomer gel operates in organic electrochemical transistor (OECT) mode under 30 % strain, providing a transconductance of ≈6 mS, sufficient for biopotential amplification at low frequencies (Lu et al., 2025).

Scaling up to medical patches of tens of square centimeters demands an appropriate deposition technology. Inkjet and aerosol printing enable the solvent-free preparation of TIPS-pentacene blends with insulating polymers; fully printed NOT inverters based on this approach retain their parameters after three years of air storage (Luczak et al., 2022). The electrical scheme of the NOT logic gate with three printed inverters connected in series is presented in Figure 2.

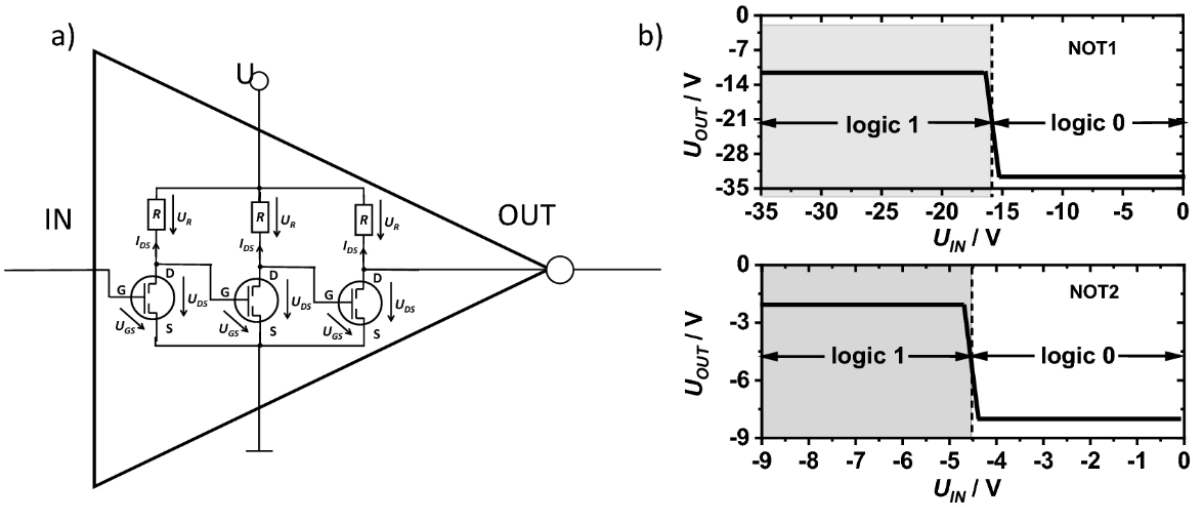


**Figure 2:** Electrical scheme of the NOT logic gate with three printed inverters connected in series (Luczak et al., 2022)

When oriented morphology is critical, meniscus-assisted bar coating forms centimeter-scale TIPS-pentacene grains, reduces the trap distribution, and brings experiments into agreement with the universal mobility law described in the previous section (Temiño et al., 2020). For DNTT and most polythiophenes, spin coating and blade coating remain relevant; however, direct gas-phase writing with a protective flow and electrostatic microjet printing are progressively combining high resolution with roll-to-roll throughput. Although stencil or screen printing is limited by line width, it remains indispensable for integrating silver, PEDOT:PSS, or carbon electrodes without damaging the organic layer.

The longevity of biosensors is determined by isolation from water, oxygen, and mechanical mismatch. Parylene C, deposited from the vapor phase at room temperature, forms a continuous barrier with low water uptake and Young's modulus comparable to that of hard tissue and has, therefore, long been the standard for implantable OTFT devices. The choice of the substrate then becomes critical: oriented PET provides a water-vapor transmission rate (WVTR) of approximately 14 g $m^{-2}$ $day^{-1}$ (12 µm), which is sufficient for skin patches but requires additional coating for subcutaneous applications, as shown in Fig. 3 (Kumari & Boora, 2024).

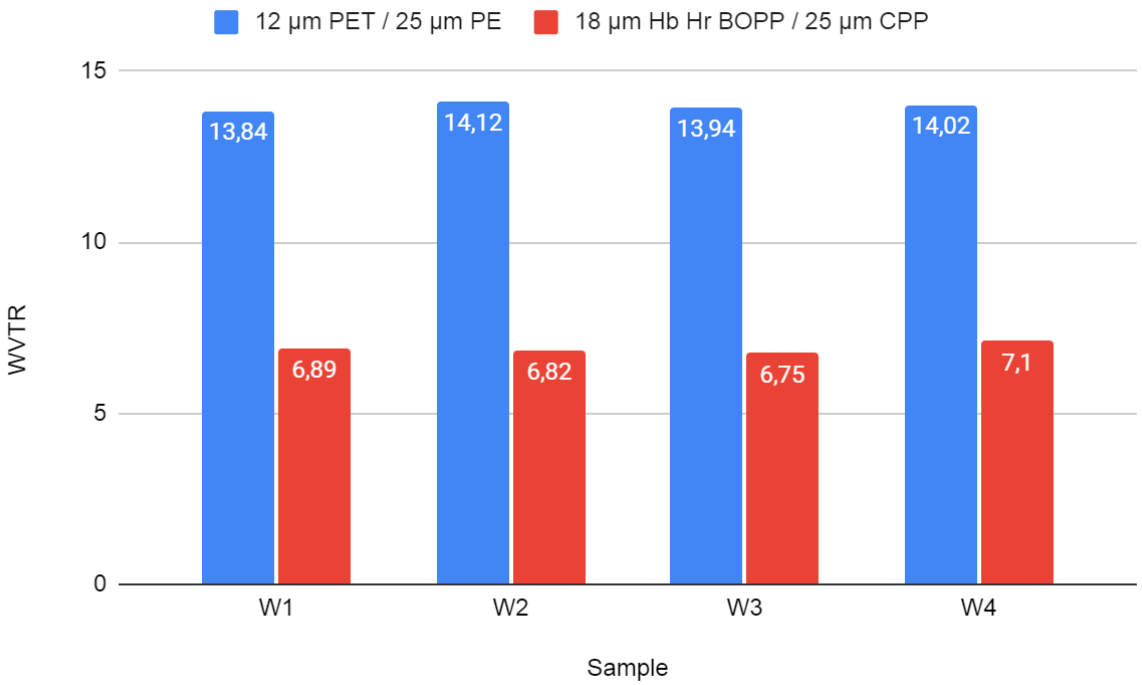


**Figure 3:** Comparative analysis of Water Vapour Transmission Rate (Kumari & Boora, 2024)

Biodegradable poly(lactic acid) (PLA) enables the development of temporary implants, including fully degradable pressure and deformation sensors based on PLA, which vanish after tissue healing, thereby eliminating the need for repeat surgery (Boutry et al., 2018). For organs with an ultra-low modulus, hydrogel interfaces with high water content are preferred, as they match mechanical impedance, serve as ionic electrolytes for OECT architectures, and withstand thousands of deformation cycles without delamination (Jiao et al., 2025). In practice, a multilayer construct—where the semiconductor sits on PET, is sealed on top with perylene, and locally replaces the active area with a

hydrogel window—combines the stiffness of plastic with the softness of biomaterials, forming a universal platform for next-generation flexible medical sensors.

The polycrystalline organic films described above not only dictate the physics of transport but also inform the design logic of flexible sensors. Each architecture exploits barrier or capacitive heterogeneities at grain boundaries, converting mechanical or chemical stimuli into an electrical response at micron-scale thickness and elasticity comparable to that of the dermis.

In inflatable tonometers, the patch primary element can be a Schottky diode, where mechanical pressure alters the microcrack area of the metal/semiconductor contact and, thus, the barrier height. In a spray-deposited Au/n-ZnO/p-TIPS-pentacene/ITO diode, the flexible Mylar substrate withstands repeated bending to 200 µm, preserving an exponential I–V characteristic with an ideality factor of $n \approx 11.6$ and a barrier height of 0.80 eV, thereby establishing sensitivity to normal stresses without the brittleness of brittle substrates (Mohd et al., 2015). Incorporating the diode into a passive frequency tag enables a fully wireless sensor: a piezoresistor on Velostat modulates rectification, and pressure changes from 0–80 kPa are encoded in the amplitude of the second harmonic, read by an RF reader so that the sensor operates without batteries or wires (Salvati et al., 2022).

For biochemical sensing, the key platform has been organic-transistor–based: a printed amperometric lactate sensor with LOx enzyme exhibits a linear range of 0–24 mM and a sensitivity of 68 µA $cm^{-2}$ $mM^{-1}$, retaining selectivity in artificial sweat—critical for sports medicine (Payne et al., 2019). The organic integrator responsible for electrode polarization, built from two OTFT inverters and printed in the same roll-to-roll process, delivers an amplification of $10^6$–$10^7$ V/A, outputting 1 V per mM lactate with a response time of ≈100 s; all electronics are implemented in pseudo-CMOS without rigid silicon ICs (Shiwaku et al., 2018). Such unification of material and circuitry reduces grain boundary mismatches, thus resolving mechanical incompatibility between the sensing element and the brain of the sensor.

Wound temperature monitoring relies on organic MOS capacitors: capacitance changes arising from the temperature-dependent density of states in pentacene yield a $\Delta C/C$ of over 3 %/K at voltages < 2 V, and the distributed uncover-area–covered-area model permits extraction of mobilities of 0.48–0.64 $cm^2$ $V^{-1}$ $s^{-1}$ directly from C–V measurements, simplifying calibration (Kimura et al., 2020). In a flexible bandage combining such a capacitor with a negative temperature coefficient (NTC) thermistor and a pH electrode, temperatures of 30–40 °C are tracked with an error < 0.2 °C; a rat model of Staphylococcus aureus infection demonstrated that an increase of 1–1.5 °C relative to the contralateral site predicts infection one hour before visual signs (Zhang et al., 2022). Thus, the organic MOS capacitor provides not only the sensor but also the circuit-level anchor for early warning.

A fully functional clinic requires a wireless link. Zinc-oxide–polyoxometalate TFT arrays on foil form an ECG patch that digitizes the signal and transmits it as Manchester-coded data at 105.9 kbps via NFC. At the same time, the analog front end consumes only 280 µW. The absence of rigid crystals renders the device practically imperceptible on the skin (Zulqarnain et al., 2020). The exact frequency is utilized by a battery-free cortisol patch, which supplies power and data via a smartphone, enabling continuous monitoring of the hormone's circadian rhythm in volunteers without requiring recharging or replacement (Cheng et al., 2021). Moreover, the diode architecture described above can be readily integrated into such tags, enabling passive tonometry—the same printing process yields sensor, logic, and antenna in one.

Together, these examples demonstrate how polycrystal morphology governs function at every level: the Schottky barrier converts pressure into a logarithmic current, OTFT-channel traps translate metabolite concentration linearly into voltage, and dielectric capacitors respond to microscopic thermal drift—all while the entire system is powered and communicates over the same flexible organic infrastructure, preserving the softness and reliability required for continuous on-body wear.

Thus, polycrystalline organic semiconductors demonstrate their key importance not only as materials for flexible sensors but also as a holistic platform that combines mechanical compatibility with biological tissues, scalable roll-to-roll manufacturing methods, and multifunctional circuit solutions. By controlling grain–boundary morphology and the films' energetic parameters, one can obtain pressure-sensitive, chemically sensitive, and thermally sensitive devices with operational stability under repeated deformation. Such unification of materials science and biomedical engineering opens new horizons for personalized diagnostics and monitoring, paving the way for the translation of flexible organic sensors from the laboratory to the clinic.

Moving flexible organic sensors toward clinical application will require systematic evaluation of long-term stability under physiological conditions including humidity, temperature and repeated mechanical stress, integration with power and data transfer modules that meet implantable device standards, and alignment with regulatory pathways through early engagement with agencies to define appropriate characterization and safety endpoints. Challenges remain in scaling up roll-to-roll processes while maintaining tight control over grain-boundary morphology and trap density, in developing biodegradable encapsulation schemes that balance hermeticity with timely resorption, and in establishing robust manufacturing quality controls for large-area arrays. A clear roadmap for clinical trials should encompass biocompatibility testing in relevant animal models, demonstration of reliable sensor performance in vivo, pilot human studies under an Investigational Device Exemption framework, and phased analysis of safety and efficacy metrics to support eventual 510(k) or CE-mark submissions.

## 4. Conclusion

This study demonstrates the comprehensive potential of polycrystalline organic semiconductors for creating flexible medical sensors that can operate efficiently under continuous microdeformations of biological tissues. The transition from rigid silicon platforms to thin-film systems based on TIPS-

pentacene, DNTT and polythiophenes not only eliminates mechanical mismatch (rigidity of implants versus softness of skin or brain) but also preserves high electronic performance—field-effect mobilities of 0.1–8.8 $cm^2 V^{-1} s^{-1}$, depending on composition and deposition method. At the same time, it is demonstrated that controlling grain-boundary traps and adjusting the energy landscape through morphology control reveals a general mobility law, enabling the prediction and optimization of a sensor's response when bent and stretched.

Roll-to-roll printing methods—in particular, inkjet, aerosol, and blade coating—have proven their usefulness in creating large-area sensor matrices while maintaining stability of parameters during long air storage. Complex multilayer constructs with parylene protection, localized hydrogel windows, and biodegradable PLA layers provide not only mechanical reliability but also long-term hermeticity for dermal and subdermal applications. This confirms that production scaling and device personalization for wearable and implantable diagnostics are practically achievable.

The functional diversity of organic sensors—from tonometric diodes and piezoresistive-RFID tags to amperometric biochemical detectors, thermal-sensitive MOS capacitors, and wireless ECG patches—underscores their universal architecture, in which every device element exploits grain boundaries or capacitive effects. Delivering sensitivity to mechanical, chemical, and thermal stimuli at signal levels comparable to rigid silicon counterparts, these devices demonstrate the full integration of materials science and circuit design within a single organic platform.

A key takeaway is that control of the grain–boundary morphology of polycrystalline films and the system's energetic parameters—whether via large-grain growth techniques, chemical passivation, or semiconductor selection—not only enhances charge-transport characteristics but also allows sensors to be tailored to specific clinical tasks. This unification of material and architecture lays a firm foundation for transitioning flexible organic sensors from laboratory prototypes to clinical trials, opening new horizons in personalized medicine and continuous physiological monitoring.

## References

[1] Bilgaiyan, A., Cho, S.-I., Abiko, M., Watanabe, K., & Mizukami, M. (2021). Flexible, high mobility short-channel organic thin film transistors and logic circuits based on 4H–21DNTT. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-021-91239-7

[2] Boutry, C. M., Kaizawa, Y., Schroeder, B. C., Chortos, A., Legrand, A., Wang, Z., Chang, J., Fox, P., & Bao, Z. (2018). A stretchable and biodegradable strain and pressure sensor for orthopaedic applications. Nature Electronics, 1(5), 314–321. https://doi.org/10.1038/s41928-018-0071-7

[3] Cheng, C., Li, X., Xu, G., Lu, Y., Low, S. S., Liu, G., Zhu, L., Li, C., & Liu, Q. (2021). Battery-free, wireless, and flexible electrochemical patch for in situ analysis of sweat cortisol via near field communication. Biosensors and Bioelectronics, 172, 112782. https://doi.org/10.1016/j.bios.2020.112782

[4] Data Bridge Market Research. (2025). Global Flexible Sensors Market Size. Data Bridge Market Research. https://www.databridgemarketresearch.com/reports/global-flexible-sensors-market

[5] FDA. (2024, January 8). FDA Facilitates Broader Adoption of Vaporized Hydrogen Peroxide for Medical Device Sterilization. FDA. https://www.fda.gov/news-events/press-announcements/fda-facilitates-broader-adoption-vaporized-hydrogen-peroxide-medical-device-sterilization

[6] FDA. (2025). Medical Device Exemptions 510(k) and GMP Requirements. FDA. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfpcd/315.cfm?GMPPart=872

[7] García, M. A., Pérez, L., de la Paz, N., González, J., Rapado, M., & Casariego, A. (2015). Effect of Molecular Weight Reduction by Gamma Irradiation on Chitosan Film Properties. Materials Science and Engineering: C, 55, 174–180. https://doi.org/10.1016/j.msec.2015.05.009

[8] Gatto, C., Ruzza, P., Giurgola, L., Honisch, C., Rossi, O., Romano, M. R., & Ragazzi, E. (2022). Comparison of Perfluorocarbon Liquids Cytotoxicity Tests: Direct Contact Versus the Test on Liquid Extracts. ACS Omega, 8(1), 365–372. https://doi.org/10.1021/acsomega.2c04697

[9] Grand View Research. (2024). Medical Sensors Market Size. Grand View Research. https://www.grandviewresearch.com/industry-analysis/medical-sensors-market

[10] Haneef, H. F., Zeidell, A. M., & Jurchescu, O. D. (2020). Charge carrier traps in organic semiconductors: a review on the underlying physics and impact on electronic devices. Journal of Materials Chemistry C, 8(3), 759–787. https://doi.org/10.1039/c9tc05695e

[11] Jiao, C., Liu, J., Yan, S., Xu, Z., Hou, Z., & Xu, W. (2025). Hydrogel-based soft bioelectronic interfaces and their applications. Journal of Materials Chemistry C, 13(6), 2620–2645. https://doi.org/10.1039/d4tc04150j

[12] Kalb, W. L., Haas, S., Krellner, C., Mathis, T., & Batlogg, B. (2010). Trap density of states in small-molecule organic semiconductors: A quantitative comparison of thin-film transistors with single crystals. Physical Review B, 81(15). https://doi.org/10.1103/physrevb.81.155315

[13] Kimura, Y., Hattori, Y., & Kitamura, M. (2020). Evaluation of organic metal-oxide-semiconductor capacitors based on a distributed constant circuit. Japanese Journal of Applied Physics, 59(3), 036503–036503. https://doi.org/10.35848/1347-4065/ab755b

[14] Kumari, S., & Boora, S. (2024). Comparison of the Optimum Barrier Properties of PET/PE and BOPP/CPP Laminate Structures. International Journal of Intelligent Systems and Applications in Engineering, 2024(22s), 1498–1503. https://ijisae.org/index.php/IJISAE/article/download/6672/5536/11856

[15] Lee, J. H., Seo, Y., Park, Y. D., Anthony, J. E., Kwak, D. H., Lim, J. A., Ko, S.-L., & Cho, K. (2019). Effect of Crystallization Modes in TIPS-pentacene/Insulating

Polymer Blends on the Gas Sensing Properties of Organic Field-Effect Transistors. Scientific Reports, 9(1). https://doi.org/10.1038/s41598-018-36652-1

[16] Li, H., Wang, J., & Fang, Y. (2023). Recent Developments in Multifunctional Neural Probes for Simultaneous Neural Recording and Modulation Microsystems & Nanoengineering, 9(1), 1–13. https://doi.org/10.1038/s41378-022-00444-5

[17] Li, M., Zheng, J., Wang, X., Yu, R., Wang, Y., Qiu, Y., Cheng, X., Wang, G., Chen, G., Xie, K., & Tang, J. (2022). Light-responsive self-strained organic semiconductor for a large flexible OFET sensing array. Nature Communications, 13(1). https://doi.org/10.1038/s41467-022-32647-9

[18] Liu, K., Ouyang, B., Guo, X., Guo, Y., & Liu, Y. (2022). Advances in Flexible Organic Field-Effect Transistors and Their Applications in Flexible Electronics. Npj Flexible Electronics, 6(1). https://doi.org/10.1038/s41528-022-00133-3

[19] Lu, L., Liu, X., Gu, P., Hu, Z., Liang, X., Deng, Z., Sun, Z., Zhang, X., Yang, X., Yang, J., Zu, G., & Huang, J. (2025). Stretchable all-gel organic electrochemical transistors. Nature Communications, 16(1). https://doi.org/10.1038/s41467-025-59240-0

[20] Luczak, A., Mitra, K. Y., Baumann, R. R., Zichner, R., Luszczynska, B., & Jung, J. (2022). Fully inkjet-printed flexible organic voltage inverters as a basic component in digital NOT gates. Scientific Reports, 12(1), 10887. https://doi.org/10.1038/s41598-022-14797-4

[21] Mohd, D., Seria, H., Mohamad, K., Rusnan, F., Ghosh, B., Alias, A., & Saad, I. (2015). Flexible Spray Coated TIPS-Pentacene Organic P-N Junction Diode. Journal of Advanced Research in Materials Science, 14(1), 2289–7992. https://www.akademiabaru.com/doc/ARMSV14_N1_P8_13.pdf

[22] Payne, M. E., Zamarayeva, A., Pister, V. I., Yamamoto, N. A. D., & Arias, A. C. (2019). Printed, Flexible Lactate Sensors: Design Considerations Before Performing On-Body Measurements. Scientific Reports, 9. https://doi.org/10.1038/s41598-019-49689-7

[23] Salvati, R., Palazzi, V., Cicioni, G., Simoncini, G., Alimenti, F., Tentzeris, M. M., Mezzanotte, P., & Roselli, L. (2022). Zero-Power Wireless Pressure Sensor based on Backscatterer Harmonic Transponder in a WPT context. Wireless Power Week. https://doi.org/10.1109/wpw54272.2022.9854038

[24] Sekitani, T., Kato, Y., Iba, S., Shinaoka, H., Someya, T., Sakurai, T., & Takagi, S. (2005). Bending experiment on pentacene field-effect transistors on plastic films. Applied Physics Letters, 86(7). https://doi.org/10.1063/1.1868868

[25] Shiwaku, R., Matsui, H., Nagamine, K., Uematsu, M., Mano, T., Maruyama, Y., Nomura, A., Tsuchiya, K., Hayasaka, K., Takeda, Y., Fukuda, T., Kumaki, D., & Tokito, S. (2018). A Printed Organic Circuit System for Wearable Amperometric Electrochemical Sensors. Scientific Reports, 8(1). https://doi.org/10.1038/s41598-018-24744-x

[26] Temiño, I., Basiricò, L., Fratelli, I., Tamayo, A., Ciavatti, A., Mas-Torrent, M., & Fraboni, B. (2020). Morphology and mobility as tools to control and unprecedentedly enhance X-ray sensitivity in organic thin-films. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-15974-7

[27] Yi, H. T., Payne, M. M., Anthony, J. E., & Podzorov, V. (2012). Ultra-flexible solution-processed organic field-effect transistors. Nature Communications, 3(1). https://doi.org/10.1038/ncomms2263

[28] Zhang, Z., Su, R., Han, F., Zheng, Z., Liu, Y., Zhou, X., Li, Q., Zhai, X., Wu, J., Pan, X., Pan, H., Guo, P., Li, Z., Liu, Z., & Zhao, X. (2022). A soft intelligent dressing with pH and temperature sensors for early detection of wound infection. RSC Advances, 12(6), 3243–3252. https://doi.org/10.1039/d1ra08375a

[29] Zulqarnain, M., Stanzione, S., Rathinavel, G., Smout, S., Willegems, M., Myny, K., & Cantatore, E. (2020). A flexible ECG patch compatible with NFC RF communication. Npj Flexible Electronics, 4(1), 1–8. https://doi.org/10.1038/s41528-020-0077-x