

Electrochemical Sensing and Biosensor Based on Functional Polymers

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Abstract

Functional polymers has great importance in the field of electrochemical sensing and biosensors due to adaptable chemical, electrical, and structural features, functional polymers are a significant class of materials that have been extensively used to create electrochemical biosensors. Additionally, conducting polymers can be made nanostructured, functional group-grafted chemically, or combined with other functional materials, like nanoparticles, to significantly enhance the sensitivity, selectivity, stability, and reproducibility of the biosensor's response to a variety of bioanalytes. Since these biosensors offer benefits such being affordable and having a low detection limit, they are anticipated to play an increasingly important role in providing diagnostic information and monitoring therapy. Because of this, this article begins with a description of the electroanalytical techniques (amperometry, potentiometry, conductometry, impedometry, voltammetry) used in electrochemical biosensors, and then moves on to a review of recent developments in the use of conducting polymers in the identification of bioanalytes that led to the development of enzyme-based biosensors, immunosensors, DNA biosensors, and whole-cell biosensors.

Keywords: Electroanalytical techniques, electrochemical biosensors, immunosensors, DNA biosensors.

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1-INTRODUCTION

Electrochemical sensing and biosensors have emerged as a result of a growing interest in the design and operation of analytical instruments for the identification, measurement, and monitoring of certain analytes. Because of their high sensitivity, specificity, and capacity for real-time analysis, these devices are effectively attracting an increasing number of receivers in the fields of medical diagnostics, environmental protection, and food safety. A receptor layer and a transducer are two closely related components that make up any ECS (electrochemical sensor)/biosensor. The receptor layer is made of material with bio recognition capabilities that may identify the required analyte. The transducer, on the other hand, transforms the biochemical signal produced by the interaction of the analyte with the receptor into a digital electrical signal [1]. Sensors can be categorized based on the type of transducer used, such as electrochemical or optical sensors. Electrochemical sensors, which utilize voltammetric transducers, measure the current produced when a product or substrate is oxidized or reduced with an increasing or decreasing potential [2].

On the other hand, optical sensors measure quantitative changes in parameters of light radiation, such as fluorescence. Although electrochemical systems are less sensitive and selective compared to optical systems, optical devices are more efficient, smaller in size, and resistant to electromagnetic waves. Moreover, they are highly sensitive and do not contaminate the reaction product during measurement. Numerous fluorescence and electrochemical-based sensors have been successfully employed for detecting heavy metal ions by researchers [3-5].

Functional polymers have been a subject of great interest since the discovery by Shirakawa *et al.*, in 1977 that halogen doping of polyacetylene significantly increased its conductivity [6]. This research was a major breakthrough and led to the development of other functional and conducting polymers that combine the properties of organic polymers with the electronic properties of semiconductors. Diaz *et al.*, also made significant contributions to this field by reporting the

electrodeposition of highly conductive, stable, and processable polypyrrole films [7-9].

Since then, numerous conducting polymers have been synthesized and used in various applications, such as polyacetylene, polypyrrole (PPy), polyaniline (PANI), polycarbazole, polythiophene (PTh), poly(3,4-ethylenedioxythiophene) (PEDOT), polyphenylene, poly(phenylene vinylene), and polyfluorene. These organic polymers are characterized by alternating single and double bonds and the presence of delocalized electrons across their entire conjugated structure. Doping these polymers by oxidation or reduction [10] significantly increases their conductivity from less than 10^{-6} S/cm in the neutral state to more than 10^5 S/cm in the doped state [11, 12].

The conductivity of the polymers is influenced by several factors such as the nature and concentration of the dopant [13, 14], temperature [15-17], swelling/deswelling [18], polymer morphology, pH and applied potential [19], and length of the polymer chain [20]. The mechanism of conduction for most heterocyclic polymers, such as PTh [21] or PPy [22], corresponds to p-doping, which begins with the removal of an electron from initial monomer, leading to the formation of an unstable radical cation known as a polaron. Bipolaron polymer is formed when second electron remove from the monomer or oligomer [23]. On the application of electric field the movement of electrons in bipolaron and polaron cause the conduction of charge along the chain of polymer [24].

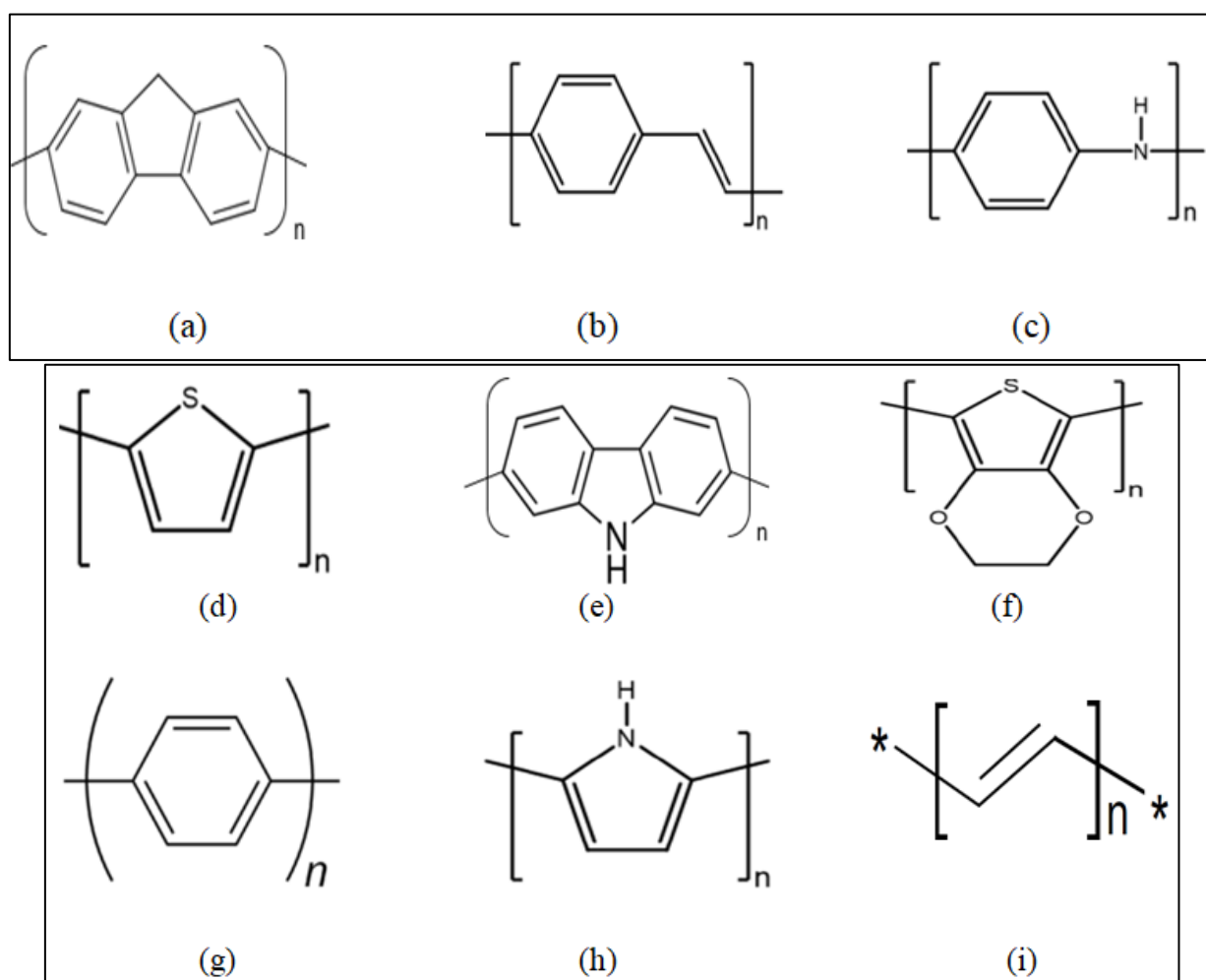


Fig-1: Structures some common functional/conducting polymers: polyfluorene, (b) poly(phenylene vinylene), (c) polyaniline, (d) polythiophenes (e) polycarbazole, (f) poly(3,4-ethylenedioxythiophene), (g) polyphenylenes, (h) polypyrrole, (i) polyacetylene

Functional polymers become now important class of polymer for material science due to its wide applications and properties (e.g plasticity, strength, flexibility, toughness or elasticity) with exceptional thermoelectric [25, 26], optical, electronic properties due to the π electrons conduction. These exceptional properties of polymers make them useful in the field of

electrochemical sensing, biosensor, photovoltaics with solar cells, anti-corrosion [36, 37] or electrochromic like use in the electrochromic display, LED (light emitting diode), supercapacitors and electro catalysis etc [27-39].

2- Mechanism and Potential Roles

2.1 Mechanism of Detection

The development of biosensors for LOC applications involves several aspects, such as fabrication, immobilization, and transduction, which require interdisciplinary research in chemistry, material science and biology. These biosensors offer high specificity and independence from physical limitations such as temperature or pH [40]. To ensure the appropriate performance of biosensors, it is crucial to select a suitable immobilization method that guarantees good operational and storage stability, high sensitivity, selectivity, short response time, and reproducibility. One of the critical challenges in designing enzymatic

electrodes is enhancing the speed and reversibility of charge transfer between electrode and the enzyme. Fortunately, using mediating particles, such as conductive materials for electrode modification (like polymers), can optimize the charge transfer in biosensors. These compounds improve electron movement/transport between the active site of enzyme and the surface of electrode, resulting in a biosensor with high sensitivity in short response of time. During the transfer of electronic charge, polymeric material provide micro environment for anchor of protein and transducer [41-43].

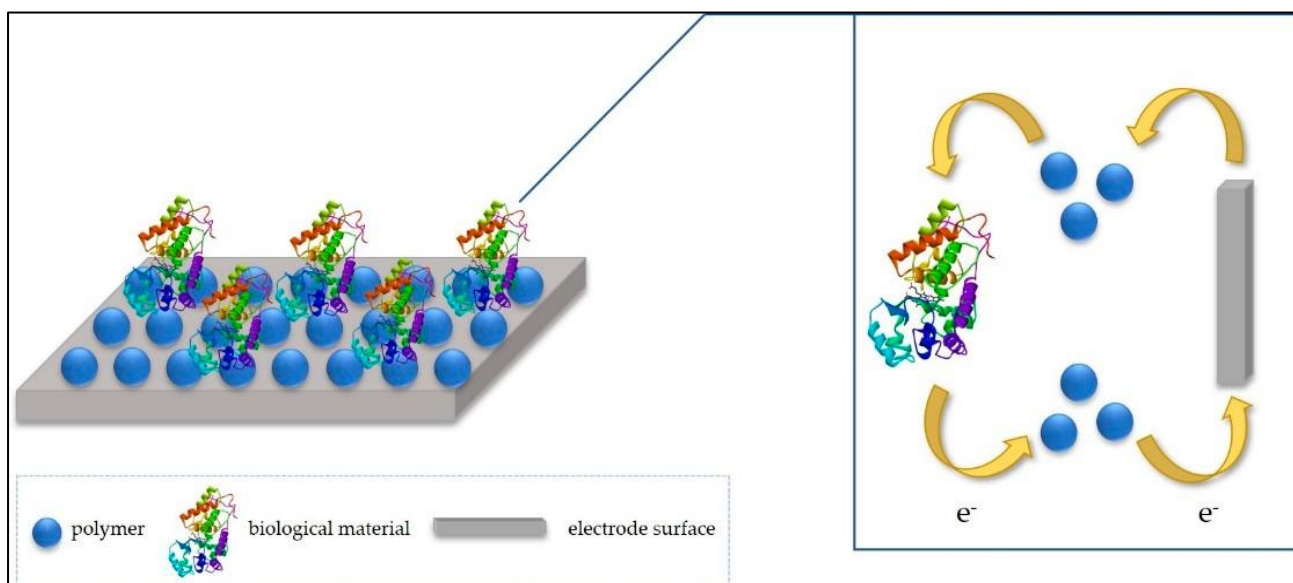


Figure-2: Mechanism of detection using the polymeric material

We cover a wide spectrum of frequently used polymeric materials for developing sensing platforms in this review. The most popular materials for different sensing methodologies include CPs, composites, and molecularly imprinted polymers (MIPs), which can also be utilised as a matrix for additional research detecting surface alterations. They have the potential to function as an integrated component in single-chip devices and other biodevices, such LOC, that are also discussed in this paper.

2.2 Electrochemical polymerization versus chemical polymerization

In 1912 first time polypyrrole was synthesized [44]. Using the conventional methods polypyrrole was synthesized in this method common solvent was insoluble due to the strong interactions present in inter-chain [45]. There are two main methods are used for the polypyrrole synthesis those are depend upon the polymerization induction by different methods (i) photo induced synthesis (ii) oxidative agents by chemical initiation (iii) anodic current by electrochemical activation [46]. Every polymer has its particular initiation method e.g oxidative agents by chemical initiation may be adopted if large amount of polypyrrole

is require for design of chromatography columns [47] or some other applications. By applying chemical and biochemical method Ppy particles are easy to synthesis and different sizes varies from nanometers to micrometer under controlled conditions. Moreover, this polymer can be uniformly overoxidized by chemical techniques, which is very interesting to affinity chromatography due to the possibility of producing molecularly imprinted Ppy, which could show selectivity to molecules ranging from small organics to big molecular weight macromolecules. Since it enables changes in synthesised Ppy morphology by changing the excitation light wave length, photo-induced Ppy synthesis is attractive in photolithographic applications of this polymer and theoretically might be used for the design of electronic chips. When compared to chemical or electrochemical polymerization, light-induced polymerization is still not used very frequently because of its sluggish rate of polymerization [48, 49].

Ppy is mostly formed in the bulk solution by chemically driven polymerization and only a little amount of synthetic polypyrrole coats the surface of added materials. In terms of depositing Ppy across some surfaces, it suggests that chemically induced

polymerization is not particularly effective. Additionally, Ppy is almost insoluble in common solvents [48-50], with the exception of some instances where it is doped with appropriate agents that increase this polymer's solubility. This means that deposition of this polymer from the solution containing dissolved polymer is possible at the stage when the polymer is still in the form of colloid particles, prior to its precipitation [51].

Electrochemical polymerization is used, all these drawbacks might be overcome. It permits Ppy to be deposited on top of electrodes that have been added to the electrochemical cell. Because of this, electrochemical polymerization has become a common method of deposition when thin Ppy layers are required. By applying a well-defined potential and a known current that passes through the electrochemical cell, this approach allows for the control of the thickness and morphology of the deposition of layer [52]. Ppy can be electrochemically deposited using a variety of solvents, including as acetonitrile, water, etc. The ability to synthesise Ppy from water solutions with neutral pH is crucial for the Nano structuring of this polymer since it allows for the trapping and/or doping of polypyrrole by a variety of biomaterials, including tiny chemical compounds, proteins, DNA, and even living cells

3. Electrochemical properties of conducting polymers

CPs have a high electron affinity and redox activity in contrast to ordinary organic polymers. The general physical characteristics of CPs are characterised in terms of their molecular weight as well as their size and length [54]. The majority of a polymer's chemical properties are determined by its polymer chains, which are insoluble in water. Typically, oxidising the monomer with oxidising chemicals or applying potential or current with electrodes yields CPs [55, 56]. Initially proposed by Diaz *et al.*, in 1981 [57], the original method of PPy synthesis promoted polymerization by continually expanding chains via side-to-side coupling of monomeric radical cations into oligomerradicals. Electrochemical growth of PANI, for instance, begins with the creation of oligomers before nucleation and polymer chain elongation take place. Electrochemical doping of CPs can result in oxidation of CPs producing a p-doped state and reduction of CPs producing an n-doped state. These redox reactions can also be used to regulate the CPs' conductivity. The characteristics, shape, conductivity, and thickness of the polymers can be controlled using electrochemical preparation techniques [58]. In Fig 2, the structures of the various CPs are shown. The electrochemistry of CPs was thoroughly explored in the early phases of this field by the Park and Shim groups, who also looked into the autocatalytic growth mechanism of PANI and its development kinetics on the electrode surface [58-61]. Also, the mechanisms of PANI, PPy, and polythiophene degradation prepared electrochemically were studied

[62, 63]. Several reports from the last few decades have discussed CP applications. To customise their properties, monomers and CPs can both be functionalized with various substances. The primary polymer chain's chemical and physical properties, particularly its electrical and mechanical properties, are improved by substituent addition in addition to improving functionalities. CP composites can be made from highly conductive nanomaterials and catalysts to enhance the characteristics of CPs.

4. The Thin CP Films

Generally speaking, minute structural variations among non-specific CPs-based sensing components enable differential interactions with analytes to produce distinctive and identifying response patterns. Linear discriminant analysis (LDA) and major component analysis can be used to identify between identical molecules as a result of these structural alterations (PCA). As a result of these algorithms, chemical compounds can be differentiated by highlighting and summarising the distinctive characteristics in vast data sets [64]. For instance, fluorescence sensors based on CPs function by analytically driven energy transfer. Excitons, the range of emission, and the process of quenching / enabling emissions are all controlled by different conformational changes and aggregation processes [65]. They depend on distance and demand robust CPs-analyte interactions, which are often made possible by the incorporation of receptors, or molecular recognition components, into or outwardly projecting from the CPs skeleton. The identification of the analyte quickly and selectively is still a topic of research. This calls for spatially distinct sensor units, each with a unique recognition component, made of inexpensive and secure materials.

In order to measure the amount of phenanthrene (PHE) in oil-polluted wastewater, Makelane *et al.*, published a unique dendritic star-copolymer sensor system based on three poly(propylenethiophenoimine) (G3PPT) and poly(3-hexylthiophene) (P3TH) on a gold electrode (Au|G3PPT-co-P3HT) in 2016 (Figure 3) [66]. The 3-hexylthiophene was electropolymerized on a gold electrode coated with G3PPT using cyclic voltammetry (CV) for 8 polymerization cycles to create the G3PPT-co-P3HT-modified gold electrode. An electrochemical cell solution containing acetonitrile, 3-hexylthiophene (monomer), and 0.1 M Bu₄NClO₄ was used to submerge the modified electrode. Because of its good sensitivity and limit of detection (LOD) of up to 107 M when utilised in electroanalysis, alternating current voltammetry (ACV) was used in the investigation. The study's findings revealed that the sensor's specifications include a limit of detection of 1.42 nM and a dynamic linear range (DLR) of application values of 2.78–37.65 nM. (0.253 ppb). The dendrimeric sensor for PHE has a

DLR of 0.7 ppb, which is under the WHO guideline

threshold for polyaromatic hydrocarbons (PAHs).

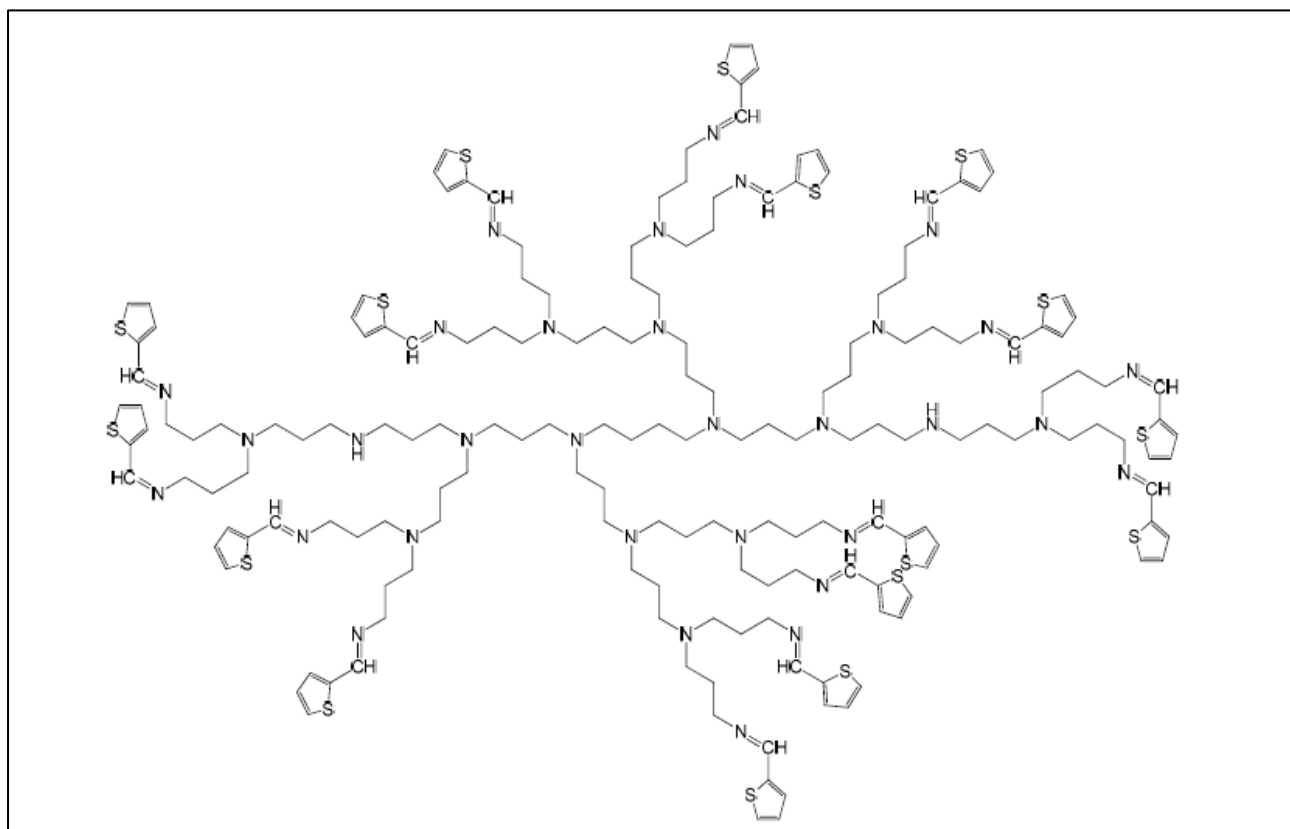


Figure-3: Chemical structure of dendrimer (G3PPT) 3 poly(propylenethiophenoimine)

Gurudatt and colleagues investigated the creation of a lipid-bonded polyterthiophene layer that was persistent and developed on the channel walls, offering a special surface property for interacting with cancer cells (Figure 4) [67]. They employed the electrochemical microfluidic channel for this purpose (EMFC). The carbon ink was screen printed onto a glass slide to create the EMFC. [2,20:50,2"-terthiophene]-30,40-diamine (DAT), the amine functionalized conducting polymer precursor, was electrochemically polymerized onto the channel walls to serve as a substrate material to enable the immobilisation of the lipid molecules (phosphatidylserine). Prior to separation, the tetracycline drug daunomycin (DM) had been specifically interacting with the cancer cell surface in order to detect the electrochemically inactive circulating tumour cells (CTCs). Via the mass and surface charge of the target species, fluid flow rate, AC amplitude, and AC frequency, different CTCs in the

blood were segregated and identified amperometrically at the carbon electrode put at the channel end. Using an electrochemical sensor placed at the channel end, the separated CTCs were specifically recognised by the oxidation of daunomycin adsorbed specifically at the cells. The isolation and identification of CTCs in human blood samples was used by the scientists to show that the device was successful in identifying various malignancies. The microfluidic channel walls' lipid-modified conductive polymer shown a striking increase in the specific interaction with DM-decorated cancer cells and was able to segregate and identify the CTCs in under 400 s. Two different cancer cells also displayed the greatest separation in the channel. The separation efficiency of the device was $92.0 \pm 0.5\%$ for a single cell. The findings of this investigation indicate a very promising cancer treatment strategy detected in the initial stages.

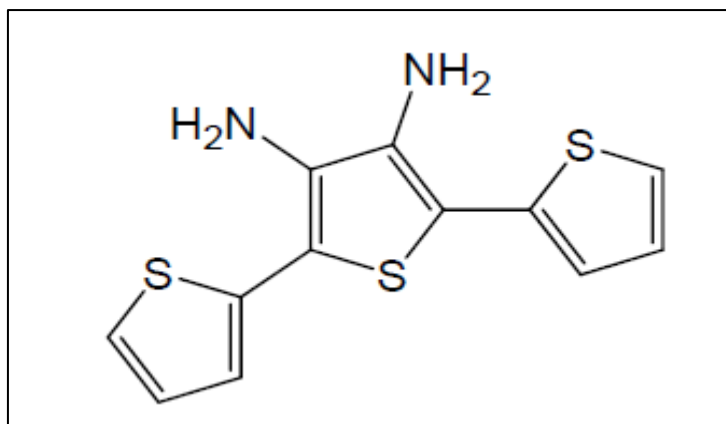
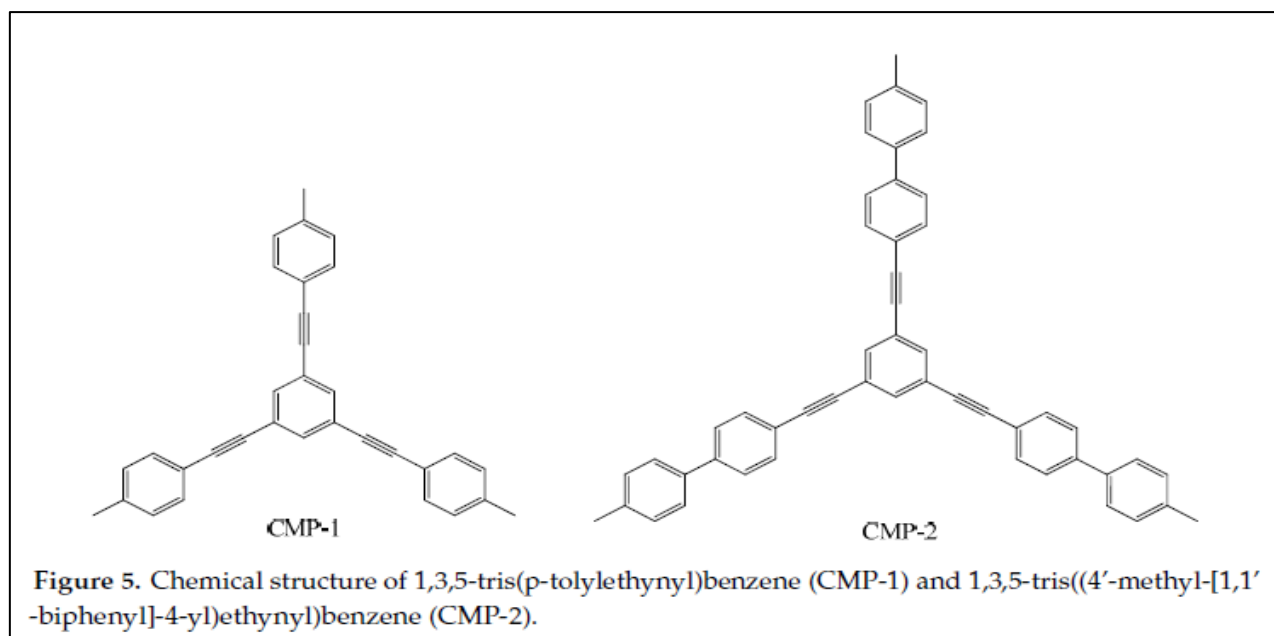


Figure-4: Shows the the structure of DAT

5. Conjugated Microporous Polymer (CMP)

Conjugated microporous polymer (CMP) is used to create the backbone of a three-dimensional polymer network. This material has many advantages over other materials, including excellent porosity, a stable backbone structure, and the potential to be used in a variety of scientific fields, including sensors, supercapacitors, and optoelectronics [67, 68]. CMP's practical applications are however constrained by their exceedingly poor processability and solubility as well as their severe fluorescence quenching as a result of aggregation. According to certain reports, conjugated organic microporous materials' performance can be enhanced by managing their shape [69]. CMPs are amorphous and lack long-range molecular order because they are generated under kinetic control. Not

with standing this order, J. X. Jiang and colleagues pointed out in 2007 that by adjusting the length of the stiff organic connectors, it is feasible to precisely control the micropore size distribution and surface area, as shown for ordered materials with the crystal structure (Figure 5) [70]. They pioneered the study of CMPs because, in contrast to metal-organic and covalent organic frameworks (MOFs and COFs), these polymers have exceptional chemical and thermal stability and offer a wide range of opportunities for robust anchoring of particular functionality to the networks. Due to the conjugated nature of the polymer networks, numerous opportunities exist to create microporous materials with advantageously linked electrical, chemical, or optical properties.



Wang and colleagues' work serves as an illustration of the application of CMP in sensors [71]. They revealed the Pd-catalyzed Suzuki coupling reactions' role in the synthesis of two multifunctional conjugated microporous polymers (CMP-LS7-8) that

include pyridine (Figure 6). The two polymers displayed exceptional porosity, pyridine unit N-donor sites, and extended -conjugated structures. The CMP-LS7-8 demonstrated outstanding performance in the detection and removal of tetracycline from water as

well as the collection of volatile iodine, with good reusability. CMP-LS8 has a higher iodine absorption than the majority of CMPs that have been studied so far. Additionally, this study demonstrates that CMP

materials made using Langmuir techniques can combine two functions—tetracycline removal and sensing—into a single material.

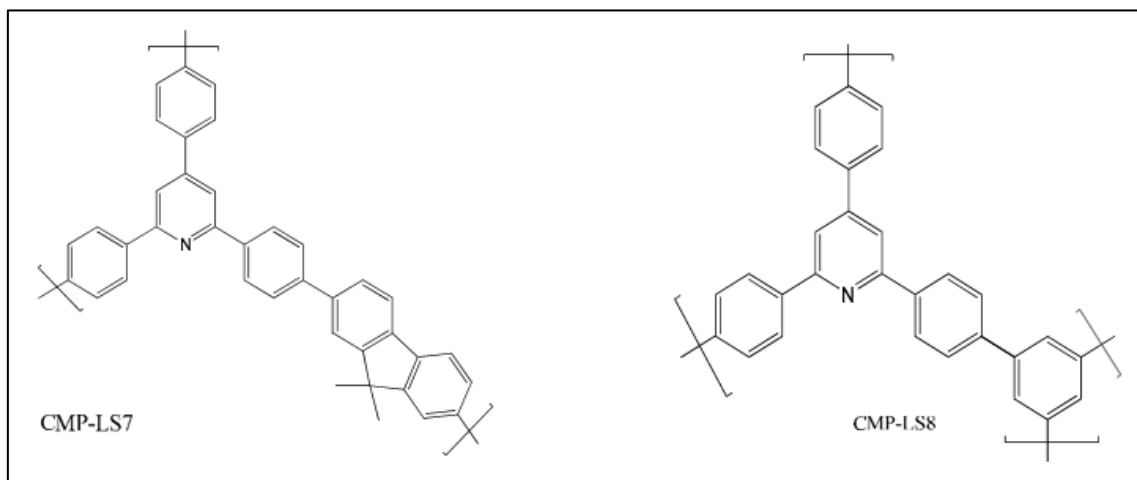


Figure-6: Structure of CMP-LS8 and CMP-LS7

The research team led by Liu created a novel dendrimer (TPETCz)-based high-luminescence CMP film with an aggregation-induced emission effect as its central component (Figure 7) [72]. Easy electropolymerization allowed for the quick fabrication of CMP films with high specific surface area. These CMP films display volatile organic compound sensitivity (VOCs). By changing the electrochemistry parameter, the researchers were able to modify the

morphology and thickness of CMPs. Additionally, a fluorescence array sensor was built using the various fluorescence responses of spin-coated and CMP films to VOC vapours, and LDA analysis was used to selectively identify 18 different types of VOCs. This is one of the publications on the precise detection of VOC vapours, and it demonstrates the wide range of potential uses for fluorescent arrays.

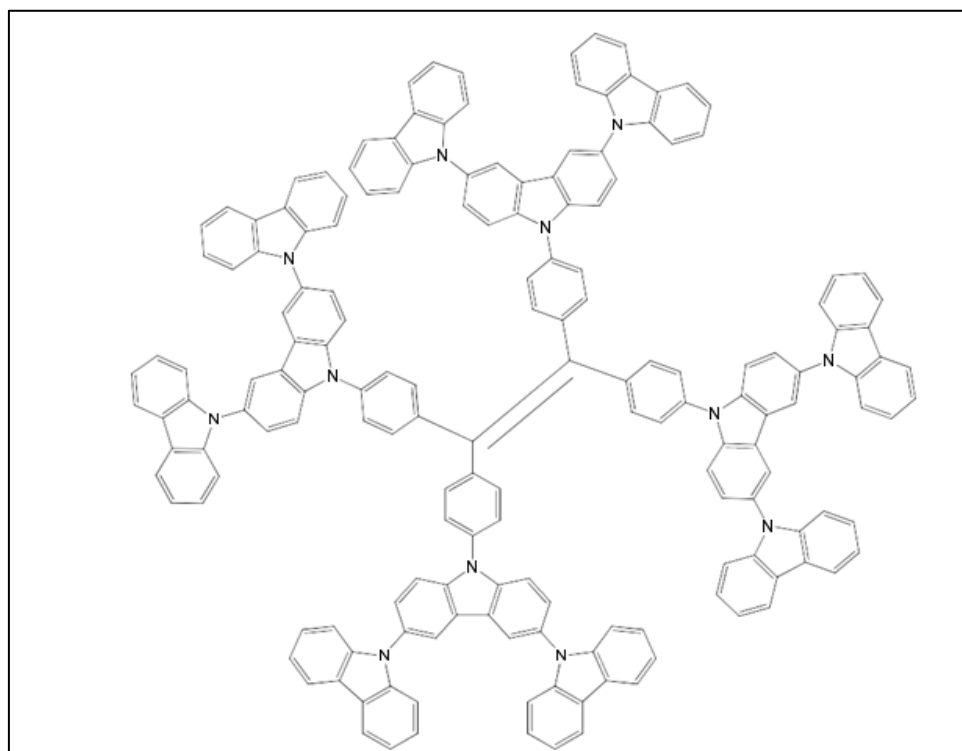


Figure-7: Structure of dendrimer TPETCz (1,1,2,2-tetrakis(4-(9'H-[9,3':6',9''-tert-carbazol]-9'-yl)phenyl)ethene)

7. Graphene Composite for the electrochemical sensing

A nanomaterial that resembles a sheet, graphene offers numerous exceptional qualities, including superb electron and thermal conductivity, high electron mobility, a huge surface area, and improved mechanical properties [73-74]. GO, RGO, and their related products were obtained using a variety of techniques to aid in the synthesis of graphene-based nanohybrids and derivatives. The distinctive structures and impurities of graphene and its derivatives—the source of electrochemical sensing applications—will be discussed in this section.

Nowadays, nanomaterials that could be combined with graphene include, in addition to carbon materials, polymers, peptides, metal nanoclusters, and metal compound nanoparticles [75-79]. Hybridization is used to enhance the chemical and physical characteristics of nanomaterials. The graphene nanohybrids as-prepared display a number of outstanding qualities, including superb conductivity, electrocatalytic activity, thermal stability, and biocompatibility [80-82].

For example, RGO-peptide nanofiber nanohybrid was created by Zhao *et al.* using in-situ intercalation polymerization. The GO flakes interacted strongly with the peptide nanofiber and diffused efficiently in the hybrid material. As a result, the nanohybrid exhibits exceptional mechanical strength, thermal conductivity, heat resistance, and electrical conductivity. Numerous studies revealed that graphene-based nanohybrids can be used as electrochemical sensors to detect a variety of substances, including hydrogen peroxide (H₂O₂), glucose, toxicants, DNA, and proteins. This is in addition to the broad applications of graphene-based nanohybrids in ion batteries, super capacitors, sensors, and biomedicine [83-88]. Zhao *et al.*, have reported on recent studies related preparation technologies of graphene-based hybrid films as well as their benefits and drawbacks. In the related sections of this review, some of the technologies are also discussed, including one-spot reactions and self-assembly. The systematic description of graphene/biomolecules nanohybrids for biological diagnosis would also go well beyond the purview of this review. These biomolecules include DNA, proteins,

and peptides. These introductions could therefore be aimed at Wang *et al* review.'s [89-91].

We mainly concentrate on various graphene-based nanohybrids and their potential uses as electrochemical sensors, as shown in figure 8, because it is well known that they are thought to be great candidates for sensing systems. Also, the difficulties that electrochemical sensing systems faced and their solutions were examined and remarked upon. This summary work is thought to be extremely important for the creation of possible applications for novel functional graphene-based hybrid materials in the sensing field.

Graphene is a densely packed material with a hexagonal 2D lattice made of single-layer carbon atoms. By hybridising the atoms [92], SP₂, which resembles a honeycomb, does so. The surface of GO has a lot more oxidised groups than the original graphene, including hydroxyl, carboxyl, and epoxy groups. According to analysis, GO has an oxygen concentration of about 40%. The surface of GO has an uneven distribution of these oxidised groups. Due to the presence of these oxygen-containing groups, the thickness of GO increased in comparison to G. RGO is then produced by reduction on GO flakes. As a result, the RGO surface has less oxidised groups than GO's [93-94]. Presently, the number of graphene layers, the average lateral dimension, and the carbon-oxygen atom are the three criteria for categorizing graphene-based nanomaterials ratio [95]. Carbon atoms occur in hexagonal configurations of sp₂ hybrids within the carbon material structure in the single-atomic-thickness sheet known as graphene. About 2 to 5 layers of graphene make up a few layer graphene material. About 5–10 layers of graphene make up a multi-layer graphene material [96].

Usually, a graphene nanosheet is one with a lateral dimension of less than 100 nm, and a graphene microsheet is one with a lateral dimension of between 100 nm and 100 mm. At the bottom end of the graphene nanosheet, graphene quantum dots (GQDs) typically have lateral dimensions of 10 nm or less (average: 5 nm) [97]. Moreover, GO is a high oxygen content, single-layered graphene substance that is categorized by the carbon/oxygen atom ratio. The C/O atomic ratio is below 3.0 and very nearly at 2.0. Compared to GO, RGO has a larger C/O ratio.

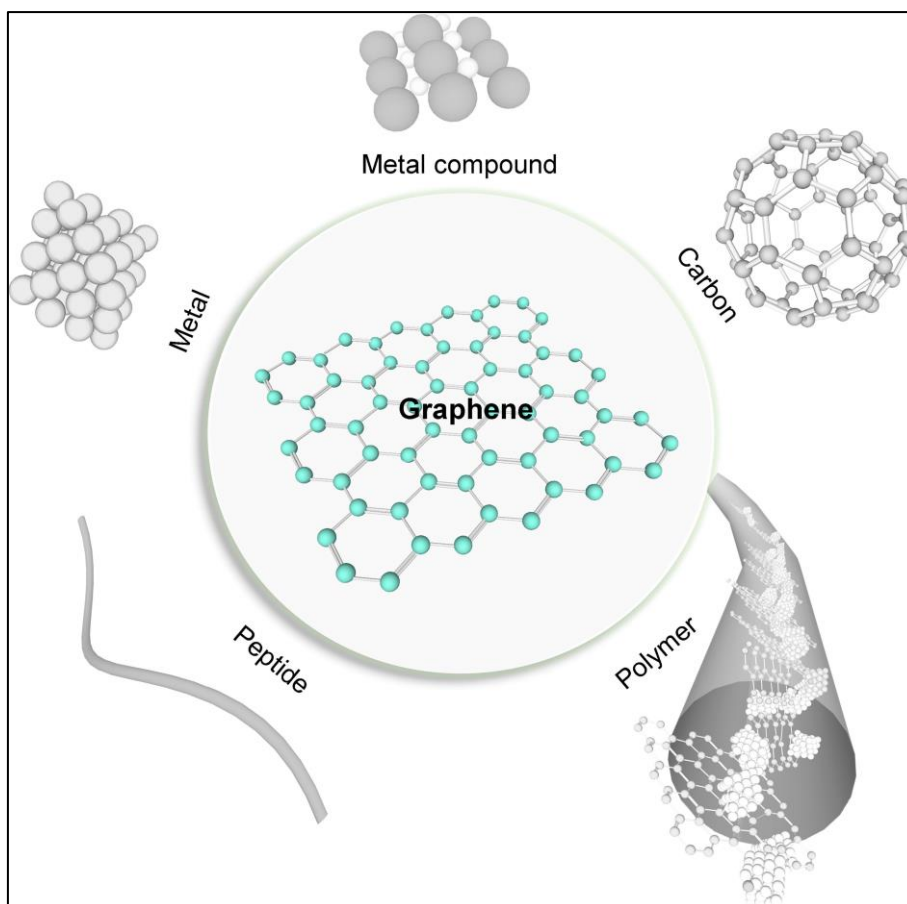


Figure-8: Graphene Composite for the electrochemical sensing

8. Recent Biosensor and Electrochemical sensing based on functional polymers.

The most recent research on sensor-based analyte detection is compiled in the Table 1 below.

Information about the functional monomer utilized, the electrode material used, the detection method, and the limit of detection are all included in the table.

Table 1: Shows Recent Biosensor and Electrochemical sensing based on functional polymers

Polymer (Monomer)	Template	Electrode Material	LOD	Detection Method	Reference
Pyrrole	tetracycline	SPCE/AuNPs	0.65 μ M	DPV	98
o-Phenylenediamine	testosterone	GCE	0.4 fM	EIS	99
Pyrrole	s-ovoalbumin	GCE	2.95x10 ⁻⁹ mg/mL	DPV	100
Phenol	serotonin	GCE/GQDs/2D-hBN	0.2 pM	DPV	101
Dopamine	PSA	Au	0.1 pg/mL	MOSFET	102
O-phenylenediamine	myoglobin	SPCE	0.006 ng/mL	DPV	103
Bis(2,2-bithien-5-yl)methane	human serum albumin	Au	0.25 pM	DPV	104
O-phenylenediamine	HIV	ITO	0.3 fM	ECL	105
TBA	hemoglobin	Au	82 nM	CA	106
2,2'-Dithiodianiline	ganciclovir	GCE/MWCNT/AuNPs	1.5 nM	DPAS	107
Nicotinamide	epinephrine	GCE/rGO	3 nM	DPV	108
Dopamine	E.coli	GCE	8 CFU/mL	ECL	109
O-phenylenediamine	dopamine	GCE/PPyNWs	33 nM	DPV	110
Pyrrole	B. cereus	CPE	102 CFU/mL	CV	111
Aniline	Azithromycin	GCE/GO/GNU	0.1 nM	DPV	112
Aniline	17_-estradiol	SPCE/MIP-Fe ₃ O ₄	0.02 μ M	SWV	113

A MIP-based approach that is both selective and sensitive was developed by Jafari *et al.* to measure azithromycin (AZT) concentration. Initially, GO and gold nanoruchins were used to modify GCE (GNU). On the surface of the GCE/GO/GNU electrode, MIP-film must be formed. Aniline, AZT, HNO₃, and H₂SO₄ were all present in the mixture in which the electrode was submerged. Five rounds of CV electropolymerization were performed on the MIP film. Finally, the electrode might be submerged in an aqueous media to extract the AZT molecules. Electrochemical techniques were used for the study, including CV, EIS, and field emission scanning electron microscopy (FESEM). The sensor was built in this fashion, and it demonstrated good selectivity and sensitivity, a broad linear range, and LOD that enabled the measurement of antibiotics down to 0.1 nM [114].

A quick and accurate electrochemical sensor for spotting *Bacillus cereus* spores was proposed by Lahcen *et al.*, The electropolymerization of pyrrole in a solution of LiClO₄ using CV for five scans formed the basis for the sensor fabrication. The bacterial spore solution was then added to the reacting mixture, and the CV was repeated for the following five scans. The spores were removed from the electrode surface in the last phase by sonication or incubation in a surfactant solution. All electrochemical measurements were carried out in a liquid media utilizing the CV, EIS, and DPV techniques. Such a built-in sensor allowed for detection with LOD at 102 CFU/mL and shown great affinity for *B. cereus* spores [115].

9. Application of electrochemical sensor and Biosensors

In present era electrochemical sensing and biosensors has extensive use in all sectors like medical, environmental, defense, Engineering etc. This all happened due to the attributes of sensor they are small, easy to use and short response time etc. Electronic signals that show changes in current, potential, and conductivity are produced by electrochemical sensors as a result of chemical reactions involving tar-get species on electrodes. According to Wang, who has made significant contributions to the fields of electrochemical sensors and biosensors, these sensors can be classified as voltammetric/ampereometric, potentiometric, and impedimetric sensors. Low detection limits, good selectivity, and a tiny sample volume are all advantages of electrochemical methods for obtaining signals. Electrochemical approaches allow for the measurement of turbid samples of whole blood, fat globules, red blood cells, and haemoglobin while spectrophotometric measurements of these systems typically result in interference effects. Two or three electrode systems make up electrochemical devices. A typical three-electrode cell has a working electrode made of platinum, gold, and/or carbon, a reference electrode that is typically an Ag/AgCl electrode, and a counter/auxiliary electrode made of platinum wire or

foil. In order to measure the current, a voltammetric sensor applies a voltage to the working electrode in relation to a reference electrode.

Voltammetry uses a potential sweep, whereas amperometry uses a potential step. This is the difference between the two measurements. Cottrell's equation provides the current, which is proportional to the concentration of the electroactive species in the sample at a given voltage. Because the oxidation or reduction potential used for detection is specific to the analyte species, amperometric sensors are more sensitive and selective. When there is little to no substantial current flowing, potentiometric sensors measure the potential difference between the working electrode and the reference electrode. In an electrochemical cell, the measured potential is primarily applied to calculate ion activity. The Nernst equation, where E_{cell} is the observed cell potential at zero current, can be used to compute the potential difference in potentiometric observations. Also known as the electromotive force, or EMF, is this value. Impedance sensors can be classified into two types, depending on the presence or absence of certain recognition elements. The first type of this sensor's operation is based on an impedance change brought on by the binding of targets to receptors (antibodies and nucleic acids) that have been immobilised onto the electrode; the response of the second type of sensor is based on surface changes brought on by the adsorption and desorption of target species as a result of growth.

CONCLUSION

This review summarizes the many approaches used to create electrochemical sensors and biosensors based on functional polymers, as well as the major developments in this area. Functional polymers can be used to create effective biosensors using a variety of techniques thanks to their charge transport capabilities and chemical adaptability, among other benefits. Additionally, the field of hybrid conducting polymer systems, which combines polymers and conducting inorganic materials, particularly metallic nanoparticles and carbon nanomaterials, is full of promising materials, each with unique chemical, electrical, and physical properties that have not yet been investigated for biosensing.

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