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A Study of Conducting Electrochemical Sensors Based on Molecularly Imprinted Polymer on Carbon Nanostructure Using Polypyrrole Film: A Review

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Abstract: **Conducting polymers are π- conjugated which possess a conjugate structure of alternate carbon-carbon single and double bond for the delocalization of π electrons. Such types of polymer are highly efficient but few of them are naturally conducting polymers and the rest of all they are nonconducting which acts as an insulator. For the incorporation of such type of non-conducting polymer doping process or by mixing of two or more materials (composites) are used in electrochemical sensors or biosensors which lead to increase in demand of sensors in various fields. In biosensors, the bio element which is used is mostly like enzyme, antibody, etc which on exposure harsh environment and the extreme temperature has low stability cannot be used for detection at that time Molecularly Imprinted Polymer(MIP) are most promising and reliable because of their remarkable properties like high selectivity, sensitivity, great reliability, low cost, reusable, can be stored at room temperature for a longer period, mechanically, chemically, and physically stable, when such type of MIPs on combining with nanocomposites their properties increases tremendously it not only used for bioanalysis but also in environmental monitoring, drug delivery, drug abused, medicinal diagnosis, etc. In this review we will discuss conducting polymers, and they're characteristic when combining with nano MIPs using pyrrole as their monomer with their recent research and future aspects for electrochemical sensing.**

Index Terms: **Conducting polymers (CPs), Carbon-based Nanomaterial (Carbon nanotube, graphene), Molecularly Imprinted Polymers (MIPs).**

I. Introduction

A sensor is a device that responds to a physical stimulus, such as heat, light, sound, pressure, magnetism, or movement, and transmits a resulting electrical impulse as a means of measuring the change of any intrinsic property of the constituent material. The origin of the word sensor comes from the Latin sentire, which means to feel (Simões, & Xavier, 2017). These electrochemical sensors belong to electrochemistry which plays a significant role in the field of science and technologies. They are considered as a class of chemical sensors in which the electrode is a transducer element, converts the response to a detectable electrical signal, which can be correlated with the analyte concentration and nature in the chemical solution (Pan, & Mondal, 2014). The development of electrochemical sensors has received a great deal of scientific interest in the past few decades. Due to their high selectivity and sensitivity (Raj, M. A. & John S. A 2019). These sensors are widely used for environmental monitoring, clinical analysis, the safety of drugs, detection of toxic gases in industries, and harmful pesticide used in the agriculture field. Therefore a variety of designs has been developed to increase the sensitivity, specificity, and selectivity of electrochemical sensors which are affordable and user-friendly. The best example for this is 'polymers' which have been started using as sensors i.e. conducting polymers which bring a drastic change in sensing various parameters since the discovery in 1977 (Shirakawa, H et al., 1977).

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A. Electrochemical Properties of Conducting Polymer

The conducting polymers are π- Conjugated which possess a conjugated structure of alternating single and double bonds for the delocalization of π-electrons this brings excellent electronic properties like, easy synthesis procedure, tunable properties, flexibility, and environmental stability. As CPs are good for chemical sensing they can be synthesized by chemical or electrochemical oxidation with corresponding monomers. They are further classified into two types intrinsically conducting polymer and extrinsically conducting polymer. In the polymers, most of them are non-conducting which acts as an insulator. Their conductivity can be incorporated by the doping process. In the doping process, the polymers are doped with doping ions introduced into the polymer system, when oxidation occurs in the CPs positive holes are called p-type doping and when reduction occurs in CPs creates a no hole but more electrons are called n-type doping. This effect can be reversed by removing the charge carrier called dedoping. For oxidation (p-type doping), Lewis acids and halogens are employed and for reduction (n-type doping), Alkali metals are best suited (Persaud, K. C. 2005). Doping of such polymers gives rise to semiconducting material. This charging site interacts with free radicals formed as polaron which are highly unstable and can be stabilized by further oxidation to form bipolaron. polaron can be cationic or anionic but oxidation removes the electron from the system forming a dication (Moliton, A., & Hiorns, R. C. 2004) which cause defects in the polymer and these make the conducting polymer interesting for chemical sensing (Persaud, K. C. 2005). Another method can also be used to increase their conductivity i.e. conductive element filled polymer in which the polymer act as a binder to hold the conducting element (such as carbon black, metallic fibers, metallic oxides, etc), and also blended conducting polymer which is obtained by blending a conventional polymer with a conducting polymer.

B. Electrochemical Sensors and Biosensors

The CPs on combining with electrochemical sensors which convert chemical information into an electrical signal can further be used for the detection/identification of analyte. The measurement of the signal can take place by a different electrochemical technique which is most commonly used such as potentiometry, Amperometry, voltammetry, and conductometry (Rahman, Md. A et al. 2008). It consists of a three-electrode system one of which is a working electrode where conducting polymers are coated the second one is a reference electrode (commonly used are saturated calomel electrode or a silver-silver chloride electrode) and the third one is a counter electrode (Bai, Hua; Shi, Gaoquan. 2007).

A biosensor is an analytical device that consists of two components: a bioreceptor and transducer, the bioreceptor is a biomolecule where the target analyte is recognized and the transducer converts the recognized analyte into a measurable signal. The main feature of a biosensor is that the two components are united into one single sensor without using a reagent (Davis, J. et al. 1995). The signals that are generated are directly proportional to the concentration of the analyte. Herein recognized analytes are enzymes, proteins, and antibodies. According to the International Union of Pure and Applied Chemistry (IUPAC), biosensors are classified in two ways: one is transducer including mass-based electrochemical and optical biosensors and the second is a type of bio element including biocatalytic affinity sensors.

The biocatalytic sensors are fabricated by immobilization of cell tissue and enzyme that helps to identify the target analyte to generate an electroactive molecule and the affinity sensors depend upon the binding interaction between the analyte and the immobilized bio element (Joong-Min, et al 2018). As there was increased demand in the field of biosensors modifications are also made to provide flexible and viable options to replace complex, expensive, and time-consuming experiments, but the bio element like enzyme, antibody-based immunoassay that has been used as a functional matrix for recognition of the target analyte is not stable in harsh environments like acid or base, organic solvent, and high-temperature (Mohammadali et al, 2020). So at that time molecularly imprinted polymers (MIP) have emerged as one of the remarkable methods for detection and diagnosis.

II. MOLECULARLY IMPRINTED POLYMER

A molecularly imprinted polymer was first developed by Polyakov in the 1930s, with further research Wulff and Sahan highlighted the strategy of polymerization in presence of a target template (Canfarotta, F et al. 2018). The molecular imprinting polymers are formed by one or more functional, cross-linking polymers and target molecules i.e. templates are polymerized in an appropriate porogenic solvent through covalent non-covalent interaction. During polymerization, there is a complex formation between the functional monomer and the template which is surrounded by a surplus crosslinking monomer which yields a three-dimensional polymer network (Cheong, W. J et al, 2013).

After polymerization, the targeted molecule is removed from the polymer matrix which retains recognition cavities that are complementary to the template in terms of size shape functionality of the structure (Canfarotta, F et al. 2018, Cheong, W. J et al, 2013). Hence the working mechanism of MIPs is similar to lock and key which is quite similar to antibody-antigen interaction (Zaidi, S. A. 2017). It is also called plastic antibodies because they are not sourced from an animal. Therefore MIPs are specifically designed to use as a sensor in biosensors and as a sorbent in sample preparation (Mohammadali et al, 2020).

MIPs show remarkable properties such as high selectivity, sensitivity, great reliability, low cost, reusable, and can be stored at room temperature for a longer period, mechanically, chemically, and physically stable. These properties of MIPs have evoked great application in the field of protein detector, chromatographic separation, capturing of hazardous radioactive waste, recognition of biomolecule, recognition element for electrochemical and biosensors, solid-phase extraction, and drug delivery (Zaidi, S. A. 2017). After their phenomenal discoveries, MIPs evoked enormous interest in the researchers of the various field like nanoscience. from the last two decades nanomaterial used as composites in MIPs which show extraordinary features like high surface to volume ratio, robust mechanical strength, electrical and optical properties, susceptible for determination of an analyte, easy removal of the template, functionalization, surface modification, good dispersion and handling capacity (Mohammadali et al, 2020). Mostly the structure of the nanoMIPs which are formed by one or more layer with hexagonal configuration e.g., the carbon atom is sp2 hybridized which are connected to another atom in different dimension forming allotropic form (Terrones, M. et al 2010).

III. CARBON NANO TUBE BASED MIP COMPOSITES

Carbon-based nanomaterial like carbon nanotube, graphene, and many others which possess the capacity to hybridized into sp,sp2,sp3 configuration with a narrow gap between the 2s and 2p electronic shell this association is responsible for versatile design in carbon-based nanomaterial for sensitive detection (Adhikari, B. R., Govindhan, M., & Chen, A. 2015). The carbon nanotube was first discovered by Sumio Iijima, a Japanese physicist in 1991. It has a carbon wall structure that has a diameter of less than 100nm and is mostly studied in nanoscience and nanotechnology. CNTs are classified by the number of layer of the cylindrical tube formed by graphite i.e. single-walled carbon nanotube (SWCNTs) and multiwalled car bon nanotube (MWCNTs) which are interconnected by van der Waal force of attraction. This MWCNT is mostly used because of its high conductivity and facilitating electron transfer. Furthermore, CNTs have remarkable properties electric conductivity, high thermal stability, robust mechanical strength, biocompatibility, high surface-to-volume ratio, and chemical stability (Adhikari, B. R., Chen, & A Govindhan, M., 2015). Because of all these unique properties CNTs are used in electrochemical sensors. Also, the most important properties of nanomaterial are surface-to-volume ratio, higher the surface-to-volume ratio excessive sites will be available in modification

Table I. Molecularly imprinted polymer in combination with carbon nanotube-based electrochemical sensor

ELECTRODE	TEMPLATE / ANALYTE	DETECTION	SAMPLE	LOD	REFERENCE
MIPs/ MWNT/GCE	Dopamine	DPV	-	60nm	X. Kan, et al 2012
MIPs/MWNTs/PGE	HTC	SEM	Serum and pharmaceuticals	0.10nm	A. Nezhadali, M. Mojarrab, 2014
MIPs/MWCNTs/PGE	Triamterene	DPV	serum and pharmaceuticals	3.35nm	A. Nezhadali, M. Mojarrab, 2015
MIPs/MWCNTs/PGE	Metoprolol	DPV	serum and pharmaceuticals	2.88nm	A. Nezhadali, M. Mojarrab, 2016
MIPs/f-MWCNTs/GCE	Tramadol	EIS	Human urine and pharmaceutical	0.03nm	B. Deiminiat et al, 2017
MIPs/MWCNTs/PGE	1,4-DAQ		Serum and plasma	4.15nm	A. Nezhadali, et al, 2016
MIPs/PtNPs/POM/MWCNTs/GCE	simazine	SEM	wastewater	0.02nm	B. Ertan, et al, 2016

with MIPs. For the synthesis of molecularly imprinted polymers, electropolymerization is used. In electropolymerization, the conducting polymers are coated on the working electrode or supporting substrate material of the desired template (Crapnell RD et al, 2019). Generally, the sensors are characterized are by the following technique like Electrochemical Impedance Spectroscopy (EIS), Cyclic voltammetry (CV), Scanning electron microscopy (SEM), Atomic force microscopy (AFM), and transmission electron microscopy (TEM). Among all the monomers that are used in nanoMIPs polypyrrole are the most widely applied because of its unique property for detection of different analytes in different samples some of the example are shown above in Table I.

IV. GRAPHENE BASED MIP COMPOSITES

Graphene was discovered by Novoselo in 2004. It has gain enormous attention in material chemistry at the nanoscale because of its physicochemical properties and theoretically highspecific surface area which are higher than the activated carbon or carbon nanotube (CNTs).and it also shows excellent electrical and thermal conductivities, chemical stability, and mechanical strength (Zaidi, S. A. 2017). The electrocatalytic effect of NP on the surface of graphene sheet shows rapid transport of electrons which formed in an increased number of sites that play a fundamental role in the development of MIP sensors. the best example is AuNP which is most widely used on GR sheets as nano MIPs (F.W. Campbell, R.G. Compton, 2010). Generally, graphene existed in two oxidation states graphene oxide(GO) and reduced graphene oxide(RGO). Graphene oxide consists of a single layer of carbon atom closely packed in a honeycomb lattice derived from graphene (X. Lin, et al 2013). GO is obtained from graphite and a strong oxidizing agent which on oxidation produce numerous oxygen group that acts as the catalytic active center in electrochemical process and also provide sites for covalent and noncovalent functionalization (J. Xu, Y. Wang, S. Hu, 2017). Graphene reduce oxide (RGO) is a derivative of graphene which is obtained from the reduction of GO by deoxygenation. As RGO is sparingly soluble in water and different solvent which lead to extreme electrical conductivity. Thus both of the graphenes are extensively used to show remarkable properties that lead to the development of nanoMIPs (Zaidi, S. A. 2017). Thus in electrochemical sensors, as many conducting polymers are used as a monomer in the coating from all of its pyrrole are considered as a most compactable and stable polymer with graphene nanocomposites for detection of different analytes like BSA (Bovine Serum Albumin), Quercetin, Trimethoprim etc in different sample from which some of them are shown in Table II.

Table II. Molecularly imprinted polymer in combination with graphene/graphene oxide/reduced graphene oxide-based electrochemical sensors

ELECTRODE	TEMPLATE	DETECTION	SAMPLE	LOD	REFERENCE
MIP/GR/GCE	Trimethoprim	EIS/CV	Urine	0.13μM	H. da Silva, et al 2014
MIP/GR/GCE	BSA	DPV	-	-	F. Li, et al 2013
MIP/GO/GC	Quercetin	DPV	Apple juice	48nm	S. Sun, et al 2013
MGO/β-co@AuNPs/MIPs/GCE	chrysoldine	DPV	water	17nm	X. Wang, et al 2014
MIPS/GP/CE	4-Nonylphenol	DPV	Rain and lake water	3.5pg mL^{-1}	H.J. Chen, et al 2013
MIP/graphene-Ag/CE	Bisphenol	CV/DPV	Plastics	3.2pM	R. Cai, et al2014
MIP/NiNP/RGO-GCE	Myo-inositol	DPV	Sugarcane vinasse	76pM	M.A. Beluomini et al 2018
MIP/ERGO/GCE	Melamine	EIS	milk	0.83nm	M. Shamsipur, et al 2018

V. POLYPYRROLE POLYMERS IN MOLECULAR IMPRINTING

In conducting organic polymer such as polypyrrole is mostly studied in MIPs because of its distinctive properties like easy synthesis, stability in oxidized form, high electrical conductivity, good redox properties, compact thin and can be easily deposited on the various substrates. Their conductivity can be increase by the doping process which occurred by removing the electron by chemical or electrochemical oxidation (p-type) which create a positive charge on the polymer backbone thus polymer chain keeps going (Bai, Hua; Shi, Gaoquan. 2007) and a conducting band is formed by delocalization of π-electron in the backbone of PPy and it can be undoped by reduction of the polymer chain. But its conductivity can be decreased by overoxidation and also the N-H group that is present in pyrrole can easily attach to the OH group of carbon-based nanomaterial functionalized and to the target molecule. Because of all these properties, pyrrole film can be easily coated on the transducer surface by electropolymerization.

Conclusion

The review here discussed the development of MIPs that can be used when it is combined to the nanomaterial. As nanomaterials have a high surface to volume ratio it acts as excellent composite material by combining it with MIPs by electropolymerization. This technique has evoked tremendous application by using different monomers i.e. pyrrole, aniline, phenol, carbazole but most of the time pyrrole largely applied as a monomer coating on electrodes. The nanomaterial that is applied is carbon-based nanomaterial i.e. carbon nanotube (CNTs) and graphene. The carbon nanotube and graphene show high electrical conductivity which tends to increase their sensitivity. Because of the remarkable properties of carbonaceous nanomaterial which leads to an increase in the sites of electrodeposition of MIPs that allows for better absorption of molecules on the surface of electrodes. Thus nanoMIP based sensors have emerged to be beneficial in the growth of the material in different areas not only in protein sensing but also in various areas from environmental to disease detection which create a new era for detection and diagnosis.

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