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A Review: Electrochemistry in Nanomaterials

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Abstract

Electrochemistry is a science that involves the application of highly complex systems. For these applications, it is cruicial to use various chemicals and develop as well as implement ideal forms. This review article focuses on carbon-based nanomaterials and their diverse application areas for electrochemical sensors. Carbon plays a vital role in numerous applications across distinct fields. In this publication nanostructured materials are a hot topic of research. Electrochemical applications, catalytic applications, optical applications and biological labeling some of the areas where nanomaterials provide significant advantages. In electroactivity applications, nanowires, nanotubes, and nanocomposite materials are highly favored nano-electroactive materials. Carbon nanomaterials exhibit exceptional compatibility with highly active electrodes which exhibit rapid catalytic activity. Additionally, thermotropic polymorphism is a notable property of certain fullerene derivatives, making them valuable in various advanced applications. In terms of shape, fullerenes resemble an ellipsoid or hollow sphere. They have a caged frame and resemble a soccer ball in appearance. Electrons can be present in a variety of places. Also, in this study, carbon nanotubes are also mentioned as well. Electro-sensors, electrocatalytic experiments, electrical circuits, and electrochemistry are just a few of their areas of excellence. Their conductivity and catalytic activity are notably high. They also exhibit good solid stability and can participate in both covalent and non-covalent modifications. Due to these properties, it has become an important player in the electrochemical field. C_{60} molecules in the fullerene class are known as C_{60}/QD hybrid nanorod, which contain 60 carbons. It has high solid stability properties and can take part in covalent and non-covalent modifications. The surface area of the electrodes is important in calculating the current. Au, Pt, or nickel bimetallic nanowires are used in anodic reactions. It is important to set the reference electrode potential to determine the electrode potential for nanomotors.

Keywords: *Electrochemistry, nanomaterials, catalytic activity.*

1.Introduction

The term “nano” means “dwarf” in Latin, and 1 nm corresponds to 10^{-9} meters [1], [2], [3]. Based on this, nanotechnology refers to the research and use of structural properties of nanostructure that lie between atoms and bulk materials [4]. Nano-structured materials are an important subject of study in the field of nanotechnology [5], [6]. Numerous studies with nanocomposite materials have been reported in the literature [7]-[35]. The term “nanotechnology” was first introduced by *Feynman* in one conference in 1959 [36]. Since nano-structured materials are nano-sized in terms of structure, they play an important role in performing the desired studies by reaching or adapting to the specific target point quite easily.

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Nanocomposites are highly preferred in electrochemistry for observing properties such as catalytic activity studies, energy storage, and conversion [37], [38]. Since the structures of nanomaterials are highly regular and controlled, reports on the working of electrochemistry with nanomaterials together with sensitive electrodes have taken place in the literature.
Today, nanomaterials are preferred as electrocatalyst materials to accelerate catalytic activity in electrochemical applications. Nanowires, nanotubes, and various nanocomposite materials are highly preferred nano-electroactive materials in electroactivity applications. In other words, nanomaterials increase the surface kinetics of electrodes modified by electrochemical reactions, accelerate electrocatalytic reactions, increase the adsorption of the materials to be analyzed on the electrode surfaces. For this purpose, commonly used nanomaterials used in the literature are generally graphene, carbon nanotubes, quantum dots, metal/nonmetal nanoparticles, and their oxides [39].

2. Nanomaterials used in electrochemistry

Nanomaterials are highly versatile materials for electrochemical applications, catalytic applications, optical and biological labeling. Examples include carbon nanomaterials [40], [41], quantum dots [42]-[47], metal nanowires [48] and nanoparticles [45]-[47], and as well as electroactive enzymatic structures [41] used for this purpose [49]-[51].

2.1. Carbon nanomaterials

Carbon nanomaterials are preferred for use in electrochemical applications due to their reliability, scalability and high compatibility [52]-[54]. They exhibit very high compatibility with highly active electrodes and provide rapid catalytic activity [55]. The carbon nanomaterials used in electrochemistry are shown in Figure 1.

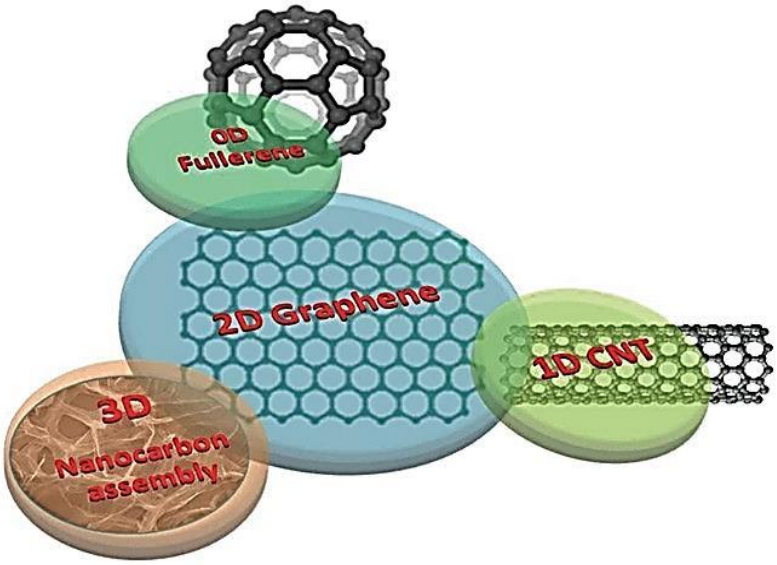

Fig. 1. Carbon nanomaterial derivatives are used in electrochemical applications [56]. *"Reprinted (adapted) with permission from [56] Copyright (2024) Wiley Advanced Energy Materials".*

2.1.1. Fullerenes

Some fullerene derivatives have thermotropic polymorphism properties [57]. Fullerenes are in the form of an ellipsoid or hollow sphere in terms of structure. It looks very similar to a soccer ball and has a caged structure [56], [58]. Carbon atoms are positioned at every corner of the polygons [59]. In the case of crystals, the radius is 1.1 nm. At the core, the core- core has a diameter of 0.71 nm. It is a great advantage to have a cage [59], [60]. Because electrons are found exactly at the surfaces of fullerenes Filling of a given boundary [61]-[70]. Thus, they provide energy transfer by providing electron interaction [71]. It has good electron acceptor properties. Therefore, its oxidation and electrocatalytic activities are strong [56]. The structure of a fullerene molecule is given in Figure 2.

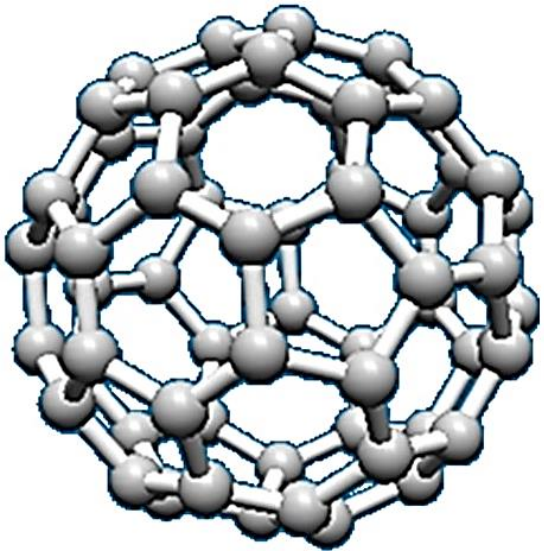

Fig. 2. The structure of a fullerene (C_{60}) molecule.

Fullerenes generally contain 60 carbons atoms, although larger fullerenes such as C_{70}, C_{76}, C_{78}, C_{80} also exists. Amog these C_{60} is the most common molecule in the fullerene class [72]. Fullerene molecules are depicted in Figure 3.

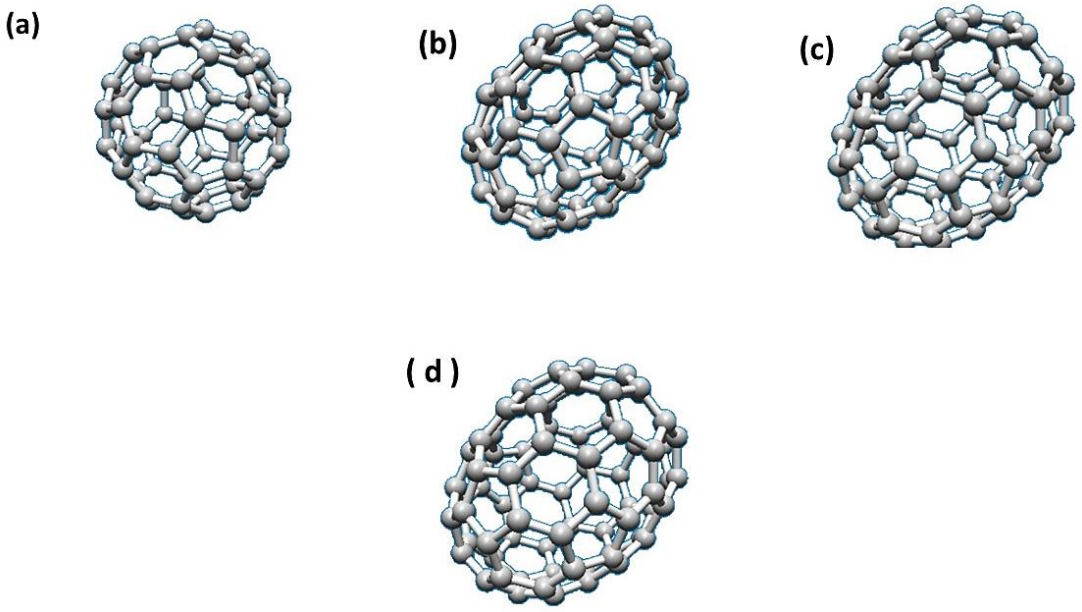

Fig. 3. The structure of fullerene molecules (a) C_{60}; (b) C_{70}; (c) C_{72}; (d) C_{76}.

The emission life of fullerene nanorods is approximately τ = 18.41 ns and the electron transfer efficiency is 40.21% [73]. Researchers have synthesized the ZnO nucleus and synthesized the C_{60} / QD hybrid structure and reported it in the literature [74], [75]. Fullerenes at high temperatures give strong dehydrogenation catalytic reaction. Fullerenes play a radical role in these reactions [76]. Thus, they play an important role in electrochemistry by providing a catalytic reaction with the active electrons that switch to the radical state.

2.1.2. Carbon Nanotubes

Carbon nanotubes are 1D-sized and tubular nanomaterials [56]. The diameter is greater than 1 nm and the length is micrometer [56], [77], [78]. In academic studies, especially in electrochemical applications, researchers work with carbon nanotubes as multi-walled carbon nanotubes (MWCNTs) and single-walled carbon nanotubes (SWCNTs). The structure of carbon nanotubes (MWCNT) is shown in Figure 4. Particles of carbon nanotubes adhere to each other by Van der Waals forces and there are π-πbond stacking occurs between these particles [56]. SWCNTs exhibit a hollow structure between their particles, unlike MWCNTs which lack gaps between layers. As a result, the specific surface area of MWCNTs is comparatively lower [6], [60], [79]. Both SWCNTs and MWCNTs demonstrate a very excellent catalytic activity and robust performance in the electrons transfer [56], [80], [81]. Their catalytic activities and conductivity are high, and they exhibit high solid stability properties [60], [79], [82]. Furthermore, the can participate in both covalent and non-covalent modifications [56], [83]-[87]. These properties have made them an important agent in the electrochemical field. They have working performances in almost every field of electro-sensors, electrocatalytic studies, electronic devices, and electrochemistry [88]. Numerous electrochemical and electrocatalytic studies on carbon nanotubes have been documented in the literature [21], [22], [89]-[94].

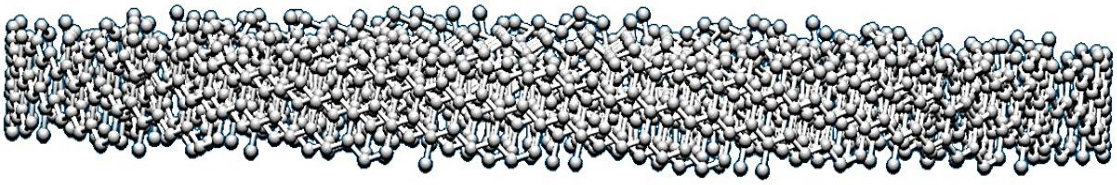

Fig. 4. The structure of multi-walled carbon nanotubes.

According to reports in the literature, SWCNTs are produced with three different basic methods: laser ablation [95]-[100], electric arc-discharge [101]-[104], and catalytic decomposition of gaseous hydrocarbons [105]-[107]. The parameters for the **synthesizing** SWCNTs using these methods are detailed in **T**able 1. The structure of SWCNT is given in **F**igure 5. When carbon nanotubes come into contact with another electric field, they function as highly efficient transistor [105], [108]. The holes in the structure and surface of carbon nanotubes act as charge-bearing nanomaterials enhancing catalytic activity. Furthermore, they are unaffected by power voltage drop of the system [54].

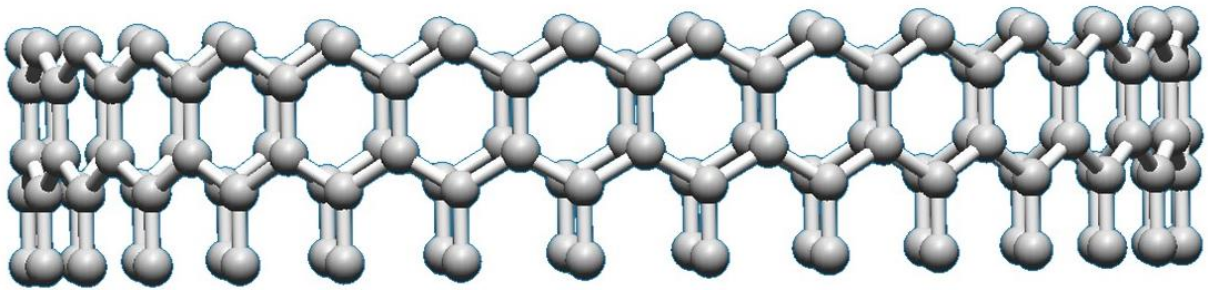

Fig. 5. The structure of a SWCNT.

Table 1. The production and parameters of SWCNTs.

Synthesis method	Principle	Average diameter of the tubes	Maximum production rate
Electric arc- discharge	Carbon atoms are generated through an electric arc discharge at T>3000 ^{o}C between two graphite rods. Nanotubes are formed in the presence of suitable catalyst metal particles (Fe, Co, or Ni).	1.3-1.4 nm	120g.day^{-1}
Laser ablation	Generation of atomic carbon	1.4 nm	50 kg.day^{-1}

	T>3000 ºC through laser irradiation of graphite, which contains appropriate catalyst particles (Fe, Co, or Ni) is followed formation of nanotubes.		
Catalytic decomposition of gaseous hydrocarbon	Decomposition of gaseous hydrocarbons source (e.g., an alkane or CO) is catalyzed by metal nanoparticles (Co or Fe). Particles are prepared by pyrolysis of suitable precursors (e.g., $Fe(CO)_5$ at 1000-1100 ºC under high pressure.	1 nm	50 $kg.day^{-1}$

2.1.3. Graphene

Graphene is a very fine, pure 2D carbon nanomaterial. It is also defined as single-dimensional graphene oxide layers [56], [109]. Due to its exceptional morphological properties, graphene can be wrapped into fullerenes, graphite, and carbon nanotubes. Graphene serves as the main source of fullerenes, carbon nanotubes, and graphite allotropes, which are formed through the sp^2 hybridization of carbon atoms [110]-[119]. In contrast diamonds are formed through sp^3 hybridization.

Graphene structures can exist in single-layer forms as well as in double, triple, or multi-layer forms (Figure 6) [56], [120]. Because graphenes are very thin, they have an almost transparent morphological structure and conducts light, conducts heat, and electricity well [56]. Studies have demonstrated that graphene has high electron mobility in charge transfer under ambient conditions, reported as 15,000 $cm^2\ V^{-1}\ s^{-1}$ [56], [121]. Graphenes have an important place in electrochemistry like other carbon nanomaterials with their energy transfer, storage, and transformation properties. Graphene plays an essential electrocatalytic role by reducing oxygen in electrochemical applications [122].

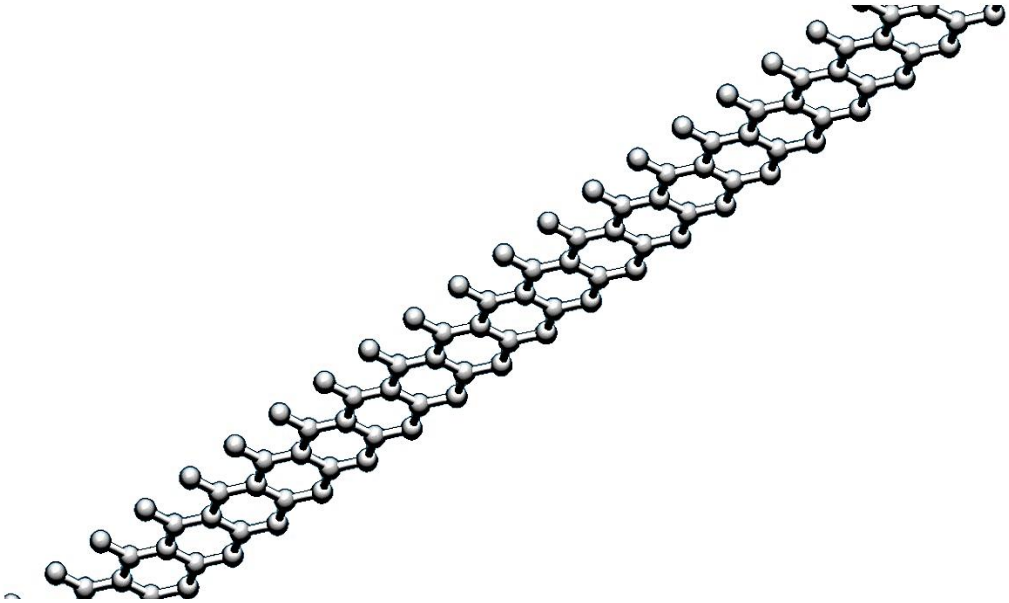

Fig. 6. The morphology of graphene.

2.1.4. 3D Nano carbons

Unlike graphene and carbon nanotubes, 3D nanocarbon materials extend over a very large area and are available in various sizes. Examples includemesoporous nano carbons and activated carbons [30], [123]. Sponges [124], foams [125], and aligned carbon nanotubes [126] are examples of 3D carbon nanomaterials based on carbon nanotubes [30].

3D nano carbons play a very important role in electrochemical applications due to their excellent conductivity (electron transfer charge conduction), electrocompatibility, and large surface area, and their electrocatalytic performances are very good [30].

2.1.5. Metal nanowires and nanoparticles

Metal nanowires and nanoparticles, including tjose made ofgold, silver, platinum, nickel, palladium, can be synthesize in ethanol solution and studies on this subject have been widely eported in the literature [127]-[129]. These nanoscale materials exhibit unique properties distinct from bulk materials and play a vital role in catalytic reactions.

In electrochemical applications, nanoparticles enhances electrocatalytic reactivity [116]-[119], [130]-[132]. During this process, the nanoparticles are attached to a non-electrocatalytic support material (electrode), enabling the electrode to act as a charge flow bridge while also preventing the agglomeration of nanoparticles. For example, studies have shown that gold nanoparticles outperform carbon-supported gold nanoparticles in the oxidation of carbon dioxide. Similarly, titanium - platinum nanoparticles exhibit loweractivity than carbon-supported platinum nanoparticles [133].

3. Electrochemical aspects

Electrochemical methods and working procedures are widely used due to their ease of experimentation, rapid results, cost-effectiveness, and time-saving features. Techniques in the production of nanorobots are divided into 2. These techniques are template-based and template-less techniques [134]**.** These techniques are shown in Figure 7.

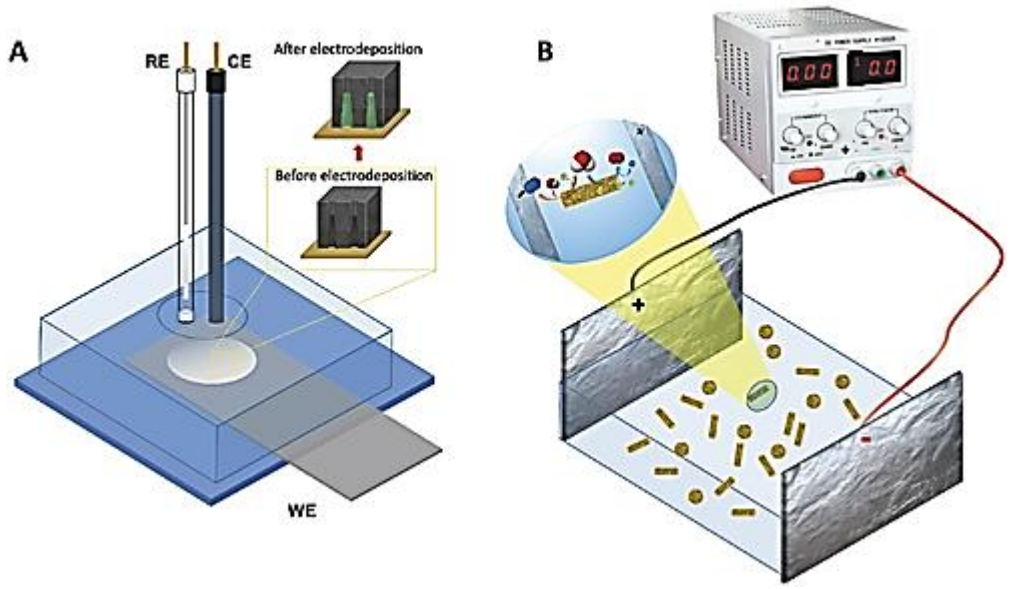

Fig. 7. The schematic procedures of nanorobots (a) template-based; (b) template-less [135].*"Reprinted (adapted) with permission from [135] Copyright (2024) Wiley –Advanced Functional Materials".*

These techniques are shown in Figure 6. As can be seen in Figure 6, a triple electrode system was used for the formation of nanorobot devices in the template systems [135]. These electrodes are shaped like working electrodes, reference electrodes, and counter electrodes. The working electrode is covered with a conductive layer and has a porous structure, such as a glassy carbon electrode or carbon paste. Gold-based electrodes can also be used in rare cases. Ag / AgCl, calomel mercury, and hydrogen electrodes are used as reference electrodes [136]-[147]. A platinum wire is generally used as the counter electrode. The surface area of the electrodes is important in calculating the current. While the working electrode provides the charge current of the electrons, the reference electrode provides the protection of metal structures against cathodic reactions. The counter electrode, on the other hand, is an electrode that complements the cell circuit (Figure 6A).

The first nanomotors produced by electrodeposition are shown in Figure 6B. Porous membranes are used here as templates. Au, Pt, or nickel bimetallic nanowires are used in anodic reactions [135]. A significant work has been done so far for electron conversion. biological reactions developed by oxidation and reduction at the electrode surface; involve electrons being transferred to the electrode using intermediate nanoparticles after reducing or oxidizing the substrate. After the electrode surface is in contact with the particles, the nanomaterials are directly reacted to electrode oxidation or reaction, and the electrode can be turned into micro or nano-sized micro or nano measurements with interlocking sequences [148].

In the electrochemical studies of nanomaterials, it is the surface reaction that takes place in the electrodes in the template systems [149]-[160]. Working electrodes play an important role in characterizing the structural and ionic properties of the substrate to be analyzed [161]-[174]. Electrode potential, electrochemical cell, and concentration, participation of the analyte in the reaction, oxidation and reduction parameters, current and potential are uncontrollable closely related to the results. Setting the reference electrode potential is crucial. While taking the electrochemical characterizations, the characterization current results are measured based on the experimenter and external factors. Cell potential difference is indicated by the symbol "E" and determines the free energy exchange. Negative cell potential indicates that the electrochemical cell gives off charges more easily than the electrode, while the positive cell potential indicates that the electrochemical cell accepts charges more easily than the electrode [175], [176].

Electrochemical cells are systems that induce signals to record voltages and currents. As explained above, the most common electrochemical systems consist of a working electrode, a reference electrode and a counter electrode. The outline of the electrochemical cell is shown in Figure 8.

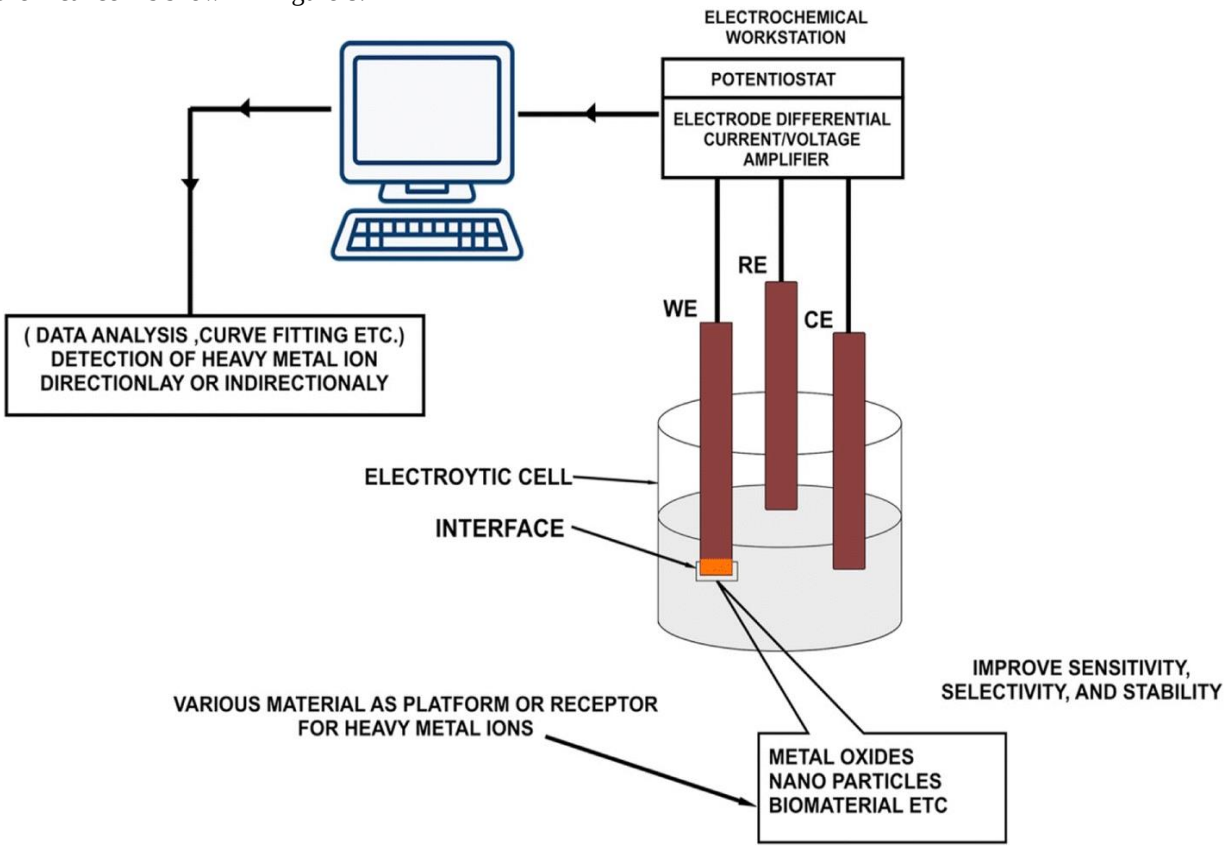

Fig. 8. The outline of an electrochemical cell system [177].*"Reprinted (adapted) with permission from [177] Copyright (2024) Springerr* – Journal of Analytical Science and Technology".

Fuel cells are a frequently studied and preferred subject within electrochemical studies [178], [179]. Fuel cells are a very effective, healthiest, and most useful energy source because they convert chemical energy directly to fuel energy [180]. The types of fuel cells include alkaline (AFC), molten carbonate (MCFC), phosphoric acid (PAFC), proton exchange membrane (PEMFC), and solid oxide (SOFC) fuel cells [181]. Oxygen electroplating (ORR) provides efficiency in a fuel cell. The thermodynamic equilibrium potential at ORR is 1.23 V. This is the case against the reversible hydrogen electrode. Especially for platinum group metals, potentials below 0.9 V are measured [182], [183]. In ORR mechanism, the reduction reaction takes place by oxygen accepting 4 electrons. Hydrogen peroxide formation in this mechanism is a disadvantage for the system because it reduces the flow and contaminates the environment of the catalyst. For this reason, the platinum electrode is preferred. Oxygen-oxygen breakdown occurs on the platinum electrode surface, resulting in a healthier and more effective performance for the system.

In this review article, we will mainly refer to the interaction of electrochemistry's potentiometry and voltammetry processes with

electrochemical cell systems with nanomaterials.

4. Theoretical Process of nano-electrochemistry

According to the report published by *Robbs* and *Ree* in the literature, as the radius of an electrode decreases below 10 nm, the *Butler-Volmer* and *Marcus-Hush* formalizations may fall behind the definition [184]. The theoretical process of electrochemistry has been described in detail in the literature [185]-[188].

The diffusion of the layer between the nanoscale electrode and the electrolyte can be suggested as:

$\delta_{eff}=r_0/A$ (1) [188].

δ_{eff} :the diffusion of the layer,

r0: the nominal electrode radius,

A: 1, or $4/\pi$ for spherical and planar electrodes [188].

The equation depending on the supporting electrolyte concentration of the electrical double layer is as follows:

$K^{-1} = (RT\mathcal{E}\mathcal{E}_0 / \Sigma\varrho e^2 z_i^2)^{-1/2}$ (2) [188].

R and T: The usual meanings of concentration

(c_0), $\mathcal{E}$: the dielectric constant,

$\mathcal{E}_0$: vacuum permittivity,

ϱ_i: the number density of ionic types *i* of charge z_i [188].

As we emphasized in this article, the electrode field affects charge/electron conduction and accelerating catalytic reactions by affecting its velocity. The kinetic parameters of charge conductivity for nanoelectrodes do not exactly coincide with the classical Butler-Volmer approach [188], [189]. BV formalism is considered in small potentials (η). So the BV approach is suitable for nano and microelectrode measurements. The quantum Marcus – Hush (MH) and Marcus – Hush – Chidsey (MHC) formalisms are suitable for the potentials (η) of larger size nanoelectrodes, and results can be predicted based on these data. The quantum Marcus – Hush (MH) and Marcus – Hush – Chidsey (MHC) formalisms predict large-scale reorganization energies (λ) more accurately. If the inequality is correct, the results are not known precisely (3) [188].

$\log_{10}\gamma > 2- \lambda/20\ K_BT$ (3) [188].

If the relationship is as in (4) the results will be different.

$\log_{10}\gamma < 1- \lambda/10\ K_BT$ (4) [188].

4.1. Chemical actions at a nanoscale electrodes

Since its introduction in the 1980s, the voltammetric usage of operating electrodes of micrometer dimensions —typically 1–25 μm diameter— has grown to be a significant field of study in electrochemistry [146], [147], [190], [191]. Reducing the size of the working electrode has several effects [192], [193]. A number of these have to do with how electrochemical studies are restricted by the combination of an electrode's electrical double-layer capacitance (CEL) and the electrolyte solution's uncompensated ionic resistance (RUNC) [189], [194]. A microelectrode's tiny size reduces CEL, which in turn lowers the time constant RUNCCEL, allowing for the adjustment of the working electrode potential and allows for nanosecond time scale studies [195]. Experiments in media with extremely large RUNC, such as solvents without purposefully added electrolytes and ionic liquid semisolids, are also made possible by smaller RUNCCEL values [196].

Additionally, the tiny electrode size makes voltammetry possible in incredibly small places, creating significant gaps in voltammetry. In comparison to linear diffusion, the quicker radial diffusion flow to microelectrodes can improve current signal-to-noise ratios and the electroanalysis at low analyte concentrations [189], [103]. This piece will concentrate on electrodes with sub-micrometer dimensions, or what are often known as nanoelectrodes, which have diameters in the lower range of nanometers [189]. The initial illustration was a nanoband with widths of 5-2300 nm and macroscopic lengths [197], [198] . These include the following: reactions of molecules with electrode interfaces of similar dimensions; quantum size effects of smaller electrodes (similar to quantized double layer charging, QDL, see above); the structure of the double layer itself; the reactant/product crowding attentive to acutely radial (fast) transport conditions; and a better understanding of the atomicscale [189].

4.2. Electrochemistry of nanoparticle multilayered coatings

In theory, creating molecular or nanoparticle monolayers is usually simple, but in practice, it might be more challenging [189], [199]. Therefore, the advanced literature on multilayer MPC films is not unexpected. As previously mentioned, films with multiple layers have been employed in voltammetric tests where, electrolyte solutions are applied to them, as well as in a "dry" condition when the film is submerged in a nonionic or gaseous medium [96].

4.2.1. Electrolyte solution-wet films

By first adsorbing bromide-stabilized 6 nm diameter Au nanoparticles onto conductive indium tin oxide (ITO, optically transparent) sheets and then bathing the nanoparticles in a solution of 1,4-benzenedimethanethiol, the nanoparticles were dithiol-linked together to create an early multilayer Au MPC film [189], [200]. Ellipsometric spectroscopy was used to monitor the film creation when the aforementioned process was repeated to create multilayer films that were thicker than 30 nm A modulated optical transmittance spectrum of the nanoparticle film was produced when it was put in an aqueous KCl electrolyte and a modulating ac potential was supplied [201], [202]. This may be taken into consideration in light of the optical theory of metals.

Spectral shifts indicated that only the outer layer of nanoparticles participated in the electrolytic injection of charge into the film.When utilized as an electrode, the film was sufficiently conductive to produce a well-characterized cyclic voltammetry of $Fe(CN)_6^{4-}$ [96].

Subsequent investigations utilizing multilayer nonlinked-together films of smaller Au MPCs revealed that the aqueous medium's doping with an organic component and the selected aqueous electrolyte had a significant impact on the electroactivity of these particles. Only with certain electrolytes that could certainly permeate to MPC sites below those initially present at the MPC/aqueous interface, together with some accompanying solvent, could multilayer voltammetry reflective of Au QDL charging be seen. Multilayer Au MPC films could act as working electrode surfaces only at potentials near the inherent redox energies of Au nanoparticles, not at potentials within the band gap of these molecule-like nanoparticle, as demonstrated by *Ranganathan et al* [203].

4.2.2. Dry films electronic conductivity

As noted earlier, studies of the electrical conductivities of MPC films when not in contact with electrolyte solutions, have been conducted in a variety of ways to better understand these films' conductivity, the structural elements that affect them, and their potential uses as organic gas sensors [189], [204]. Measurements of conductivity on films of unlinked 2.4 nm core diameter Au MPCs (cast on IDAs) with alkanethiolate (C_8, C_{12}, C_{16}) monolayers generated well-formed AC impedance semicircles indicative of frequency-independent film resistance and capacitance. They also exhibited linear current-potential responses at low potentials [189], [205]. As the length of the alkanethiolate chain increases, these films' conductivities and electron hopping rates fall and their activation energy barrier consistently rises [206]. Based on density measurements on solid samples, the average spacing between MPC core edges is a useful metric to analyze the dependence of electron hopping rate on alkanethiolate ligand. This separation is near the length of a single chain. This spacing is approximately the length of a single chain. Extensive intercalation or bundling of the alkane chains of adjacent MPC monolayers was observed, consistent with theoretical predictions [96].

4.3. Fabrication and characterization of nanoelectrodes

The advancement of nanoelectrode research is closely linked to advancements in their manufacture and characterization, as one might anticipate [207]. Since they control the mass transfer of electrode reactants and, therefore, the correct interpretation of currents and current-potential curves, electrode geometry and that of the insulating shroud encircling the electrode are concerns that are just as significant as electrode size [189], [112]. Researchers have studied various geometries and fabrication techniques for nanoelectrodes, their arrays, and microelectrodes (disks and other shapes such as bands and rings) [189]. Glass encapsulation, micropipette pulling technology, electrochemical or chemical etching followed by photoresist, polyimide, teflon, or electrophoretic paint deposition, as well as carbon nanotubes with both single and multiple walls, have all been used to produce single nanoelectrodes with submicron dimensions [208]-[213]. A perfect hemisphere encircled by a flat shroud at the level of the hemisphere's rim is the optimum shape of a microelectrode and a nanoelectrode from the perspective of uniform flow of mass transport of reactants to it and uniform current density across its electrode/electrolyte interface [214]. For a band electrode, the optimal shape is a hemicylinder, enclosed by a flat insulating surface, or shroud[215], [216]. A hemispheric electrode that has been flattened to varying degrees, an oval electrode shape as opposed to a circular electrode shape, and random roughening are examples of experimental departures from this geometry [217], [218].

The insulating shroud may extend as a rim sticking out over the working electrode, or it may be flat on one side but not the other [219], [220]. Through the later "shroud effect," radial channels of mass transfer are closed, reducing nanoelectrode currents [221-[224]. At the limit, mass transport changes from being radial to linear when the rim of a projecting shroud surrounding the electrode creates a cylindrical pore with the working electrode at the bottom. A bigger diameter "lagoon" of solution forms under a pore mouth in another extreme shroud geometry [68]. Ignoring these factors can significantly overestimate electron transfer rate constants. Rather than being detrimental, some of these non-ideal geometries can be helpful in the design of model nanopore structures and the construction of ultrasmall collection/generation cells for single molecule studies, as will be covered later.

5. Electrochemistry studies of nanomaterials

Electrochemistry studies bridge chemistry and electricity, establishing relationships between electric current and chemical systems [225]-[227]. Modern electrochemistry is categorized into 2 parts as bulk electrochemistry and interfacial electrochemistry

[228], bulk electrochemistry deals with homogeneous systems [229], whereas interfacial chemistry deals more with heterogeneous systems. surface electrochemistry differs from bulk electrochemistry with the thermodynamic parameters of reactions occurring in the intermediate phase and the characteristics of the internal properties [68], [230]-[232]. Nanoelectrodes are instrumental in investigating reaction kinetics parameters in heterogeneous charge conduction. Researchers have suggested that classical theory predicts biased sonatas in the behavior of experiments and research with macro electrodes and microelectrodes [2], [3], [235]. In laboratory studies, the electric fields of rotation symmetric electroactivity electroactivities are calculated by the diffusion bounded equation [236]. This equality is as follows:

$I_{ss} = AnFDcr$ (5) [237].

A = the geometries of different electrodes, n = the number of transferred electrons,

F = faraday constant,

D = the diffusivity of the redox probe,

c = the concentration of the bulk.

r = the radius of the electroactive disk [234]

There are numerous electrochemical studies on nanomaterials in the literature [238], [239]. Bare platinum and graphene oxide (Mw-PtNPs@GO) decorated with platinum nanoparticles synthesized by microwave were used as electrodes in solar fuel cells to measure dye sensitivity [31]. Chitosan-cobalt nanoparticles (CTS-Co NPs) synthesized in another electrochemical study were used as catalysts and 3.3' 5.5 tetramethylbenzidine (TMB) was used in sensor studies and CV curves are as in Figure 9. TMB studies were tested in aptamer-based sensor studies by synthesizing mesoporous silica nanoparticles (MSNPs) (Figure 10).

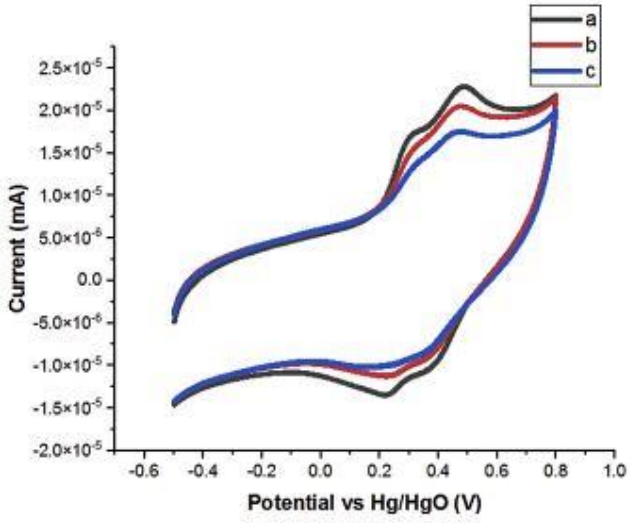

Fig. 9. Cyclic voltammogram measurements of TMB sensor studies (a) without CTS-Co NPs; (b) 10 mg CTS- Co NPs; (c) 20 mg CTS-Co NPs [238]. *"Reprinted (adapted) with permission from [238] Copyright (2024) Elsevier – Chemosphere"*

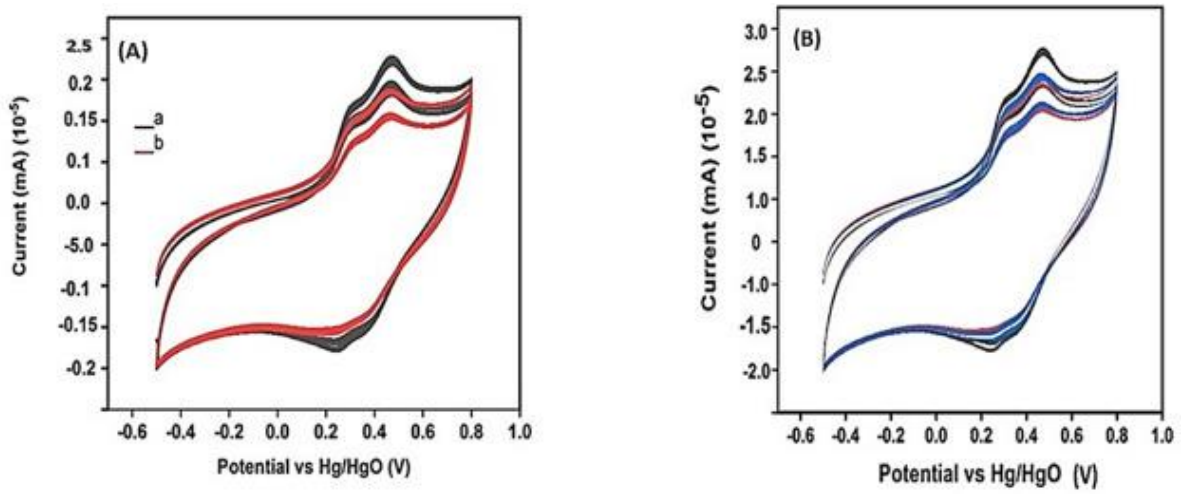

Fig. 10. (**a**) TMB CV curve in aptamer-overlayed MSNP and; (b) CV curve of TMB(ox) released from MSNPs after aptasensor development after 5 min CV

curve of TMB(ox) released from MSNPs after aptasensor development (at 5 min intervals, 100 mV/s scan rate) [240]*"Reprinted (adapted) with permission from [240] Copyright (2024) Elsevier – Chemosphere"*

In another academic study, a sensor study was performed by looking at glucose sensitivity of functionalized palladium-nickel nanoparticles on MWCNT (Pd–Ni@f-MWCNT) by electrochemical measurements (Figure 11). f-MWCNT functionalized with the synthesized palladium-nickel nanoparticles showed a significant electrocatalytic activity.

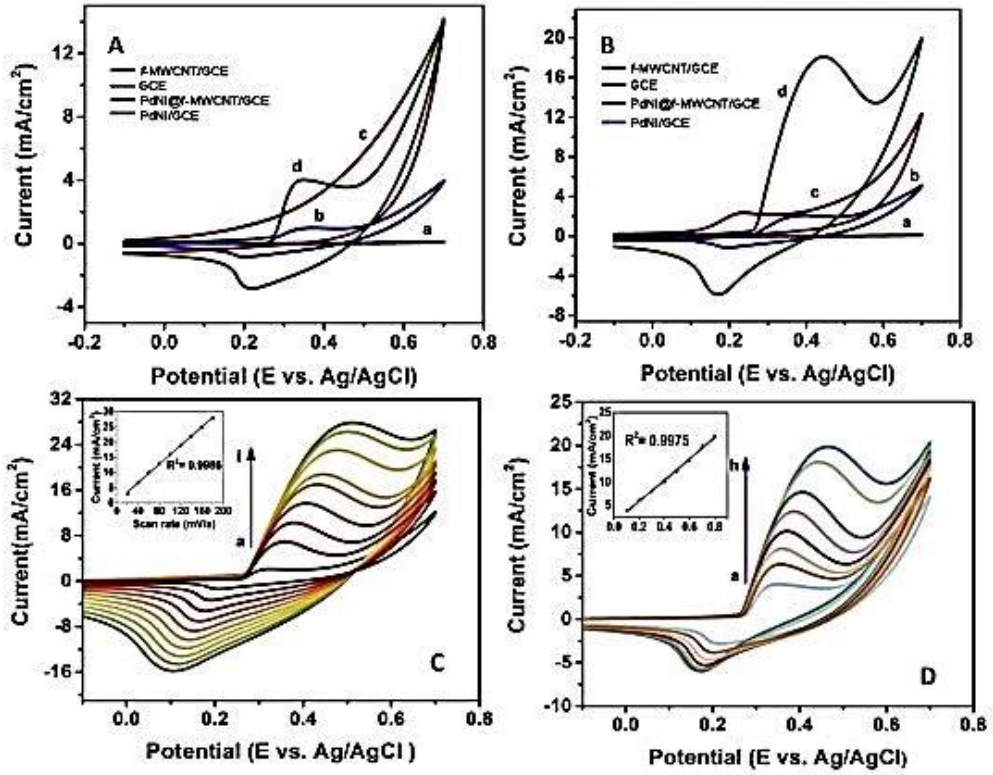

Fig. 11. 3 Cyclic voltammogram measurements (a) without glucose; (b) with 0.1 mM glucose in 0.1 M NaOH solution; (c) for1 mM glucose at Pd–Ni@f-MWCNT/GCE [241].*"Reprinted (adapted) with permission from [241] Copyright (2024) Elsevier- Materials Chemistry and Physics"*

In another academic study, carbon nanoparticles were synthesized by electrochemical methods and formation conditions were observed under 30-40 mA current. Then the carbon nanotubes were immobilized by casting graphene and (4-ferrocenylethyne) phenylamine (FEPA) onto the GCE surface with a ferrocene derivative suspension to form a stable modifier film (Nafion-FEPA-CNP-GR / GCE) [242].

In the literature, articles reporting the catalytic activities of nanoparticles and nanomaterials with numerous electrochemical studies have been reported [243-[253].

6. Conclucion

Nano-structured materials are an important subject of study in the field of nanotechnology. Nanomaterials are highly versatile and find applications electrochemical applications, catalytic applications, optical and biological labeling. Among these, nanowires, nanotubes, and nanocomposite materials are highly preferred nano electroactive materials in electroactivity applications. Carbon nanomaterials demonstrate excellent compatibility with highly active electrodes and exhibit rapid catalytic activity. Some fullerene derivatives possess thermotropic polymorphism properties.

Fullerenes structurally, are shaped like an ellipsoid or hollow resembling a soccer ball. They have a distinctive caged structure where electrons are localized at the surfaces and provide energy transfer through electron interaction. They exhibit excellent electron acceptor properties and have strong electrocatalytic activities. In electrochemistry, fullerenes play a significant role by enabling catalytic reactions involving active electrons transitioning to the radical state. At high temperatures, they exhibit remarkable dehydrogenation catalytic activity.

Carbon nanotubes are one-dimensional (1D) tubular nanomaterials with diameters typically greater than 1 nm and the length is micrometer. They have working performances in almost every field of electro sensors, electrocatalytic studies, electronic devices, and electrochemistry. Fullerenes at high temperatures give strong dehydrogenation catalytic reaction. They play a radical role in

these reactions and are an important agent in the electrochemical field.

Nanowires and nanoparticles of metals such as gold, silver, platinum, nickel, palladium can be synthesized in ethanol solution. These nanoscale materials exhibit unique properties compared to their bulk counterparts, making them critical in catalytic reactions. In electrochemical applications, nanoparticles accelerate electrocatalytic reactivity. In this process, the nanoparticles are attached to another non-electrocatalyst support material.

C60 molecules a subclass of fullerene are known as C60/QD hybrid nanorod, and consist of 60 carbon atom. These molecules are highly stable in solid form and can undergo covalent and non-covalent modifications. This review also covers their applications in energy technologies. Accordingly, the working electrode is often coated with a conductive layer and has a porous structure in the form of a glassy carbon electrode or carbon paste. The surface area of the electrodes is important in calculating the current. Au, Pt, or nickel bimetallic nanowires are used in anodic reactions.

Key parameters such as electrode potential, electrochemical cell, and concentration are critical and often uncontrollable. The outcomes of these applications are closely tied to these factors. Setting the reference electrode potential is vital for accurately determining the electrode potential for nanomotors in nanomaterials. Characterization of current results depends on experimental conditions and external factors, which influence the free energy change. This study provides a comprehensive review of the role of nanomaterials in electrochemistry, emphasizing their diverse applications and critical contributions to the field.

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None

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