

REVIEW

A Brief Review on Fundamentals of Conductive Polymer (CPs)

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ABSTRACT

Polymers are huge compounds made up of numerous monomers (repeated subunits). They have similar macro and micro properties, as well as electrical transport qualities, semiconductive capabilities, and optical features. With the advent of conductive polyacetylene, conductive polymers have gotten a lot of interest. These conductors have a wide range of electrical conductivity, which may be produced by doping, while being mechanically flexible and having a high thermal stability. Polymers may be created using a variety of methods, including chemical and electrochemical polymerization. With advancement in material stability and greater property control, an increasing variety of new applications are now being investigated.

1. Introduction

A polymer is a natural as well as manmade substance consisting of large molecules called macromolecules that are multiples of minor chemical units known as monomers. Polymer is derived from the Greek words Poly, means many, and Mers, means parts^[1].

Conducting polymers or more precisely, intrinsically conducting polymers (ICPs) are organic polymers that conduct electricity as a result of delocalization of electrons. The polymer becomes good conductors of electricity only when one electron is withdrawn from the valence

band by oxidation process, called p-doping or introduced to the conducting band by reduction, called n-doping. The concentration of charge carriers i.e. number of charges per unit volume and their mobility μ , or how quickly they can travel in the material, determine a material's conductivity. Temperature has a significant impact on conductivity. Conductivity reduces with rising temperature of metals, but that increases for semi-conductors. Fine tuning of the electrical characteristics is achieved by modified organic synthesis and sophisticated dispersion methodology^[1].

Conducting polymers have a wide range of applications in the field of variety of innovative technical gadgets, in-

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cluding electrochromic displays, photovoltaic devices, and biosensors. Conducting polymers or organic metals may one day replace traditional inorganic metal in a number of key applications [2]. Certain features of inorganic metals, such as their lack of environmental friendliness and high toxicity, that's why these organic metals could be useful as alternatives. Conducting polymers have light emitting properties, for this reason it can be used in LEDs, Diodes, Photovoltaic cells etc. In our previous studies, Sardar et al. said the light emitting behavior of perovskite was tuned and also the water degradability studies reveal that conducting polymers enhanced the life time of perovskite [3].

Conducting polymers shows high optical and electrical properties when it is irradiated with visible light having high photon adsorption co-efficiency. Thus, it can be used in the degradation of soluble toxic materials present in water [4,5]. Midya et al. had synthesized by in-situ carbon dot (CDs) deposited functionalized chitosan (polypyrrole grafted chitosan) with increased photocatalytic activity towards degradation of hazardous 2-chloro phenol (2-CP) into tiny molecules [6].

2. History of Conducting Polymers

Conductive polymers are a sub-gathering of a bigger, more established gathering of natural and inorganic electrical conductor. Indeed, as soon as 1862 H. Letheby of the College of London Hospital, by anodic oxidation of aniline in Sulfuric corrosive, got a somewhat conductive material which was likely polyaniline [7]. In the mid 1970s, it was tracked down that the inorganic explosion polymer, poly(sulphur nitride) (SN)_x, was superconductive at amazingly low temperatures (T_c=0.26 K).

Polyacetylene (PA)

Polyacetylene (PA) was unintentionally manufactured by Shirakawa in the 70's. It is the very first polymer prepared to do directing electricity. It is a natural polymer with the rehashing unit (C₂H₂)_n. The creation of exceptionally directing PA prompted the fast mission in research for the disclosure of new conductive polymers [8-10].

Poly (thiophene)

Another Poly (thiophene) subsidiary was created by two researchers at the Bayer AG research labs in Germany in 1980. Poly (thiophene) (PTh) that makes the naturally and thermally stable materials utilized as electrical super capacitor, non-straight optics, PLEDs, electrochromics, photo resists, solar cell, antistatic coatings etc. [11-15].

Polypyrrole (PPy)

Polypyrrole (PPy) is a sort of natural polymer shaped by pyrrole polymerization. It was demonstrated to be a conductive polymer in 1968. Among the various leading polymers, PPy has been generally examined, because of its simplicity of readiness, unrivaled redox properties balanced out oxidized structure, ability to give transcending conductivity, water dissolvability, industrially available and important electrical and optical properties. In 1963 Weiss and collaborators clarified the pyrolysis of tetraiodopyrrole to manufacture shockingly conductive materials. In 1979, a superior electrochemical procedure was utilized to incorporate detached movies with sufficiently great mechanical properties to concentrate on this framework as a conductive polymer [16-20].

PEDOT

Poly (3,4-ethylenedioxythiophene) (PEDOT) is a directing polymer in view of 3,4 - ethylene dioxylthiophene monomer. PEDOT enjoys a few benefits which remembers optical straightforwardness for meager, oxidized movies, high strength, sensible band hole and low redox potential. It has used in many fields like transparent electrodes for thick-film electroluminescence, source gate and drain in the quickly developing organic semi-conductors [21-24].

Poly (phenylene vinylene) (PPV)

Poly (phenylene vinylene) (PPV) is a diamagnetic substance, equipped for electroluminescence and has amazingly low electrical conductivity. PPV is exceptionally glasslike, precisely solid and naturally steady. The conductivity is improved by doping with iodine, ferric chloride, soluble base metals or acids however with less steadiness [25,26-30].

Polyphenylene and Polyparaphenylene (PPP)

Polyphenylene and Polyparaphenylene (PPP) are predecessors to a rigid-rod polymeric host family conductive polymer made up of repeating p-phenylene units that is transformed to its conducting state using an oxidant or a dopant. PPP was doped in 1980 to achieve conductivity equivalent to PA. It's the first time a nonacetylenic hydrocarbon polymer has been doped with either an electron donor or an electron acceptor to provide conducting characteristics [31-34].

The chemical structures of the mentioned conductive polymers were illustrated in Figure 1.

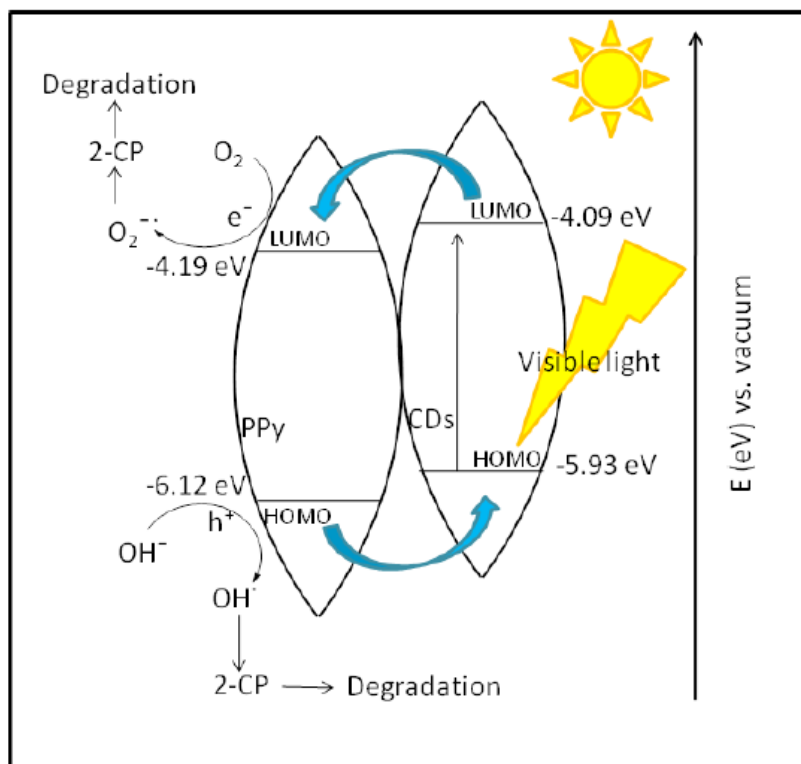


Figure 1. Proposed photocatalytic degradation mechanism of 2-CP using Ch-g-PPy@CDs under sunlight exposure, Reprinted with permission from ref. ^[6]

3. The structures of Conducting Polymers

Conductors or metals, insulators, and semiconductors are the three primary categories of materials. They are distinguished by their capacity to conduct current or allow current to flow through them. The structures of various conducting polymers have been shown in Figure 2. Although certain strongly conducting polymers, such as polyacetylene, fall into the metal range, conducting polymers are often categorised as semiconductors. The physical characteristics of conducting polymers as follows in Table 1 ^[2].

Table 1. Properties of conducting polymers

Property	Conducting polymers
Electrical conductivity(S/cm)	$10^{-11} - 10^3$
Carriers	Electrons of conjugated double bonds
Concentration of carriers per cm^3	$10^{12} - 10^{19}$
Effect of impurity	Impurities of 0.1% - 1% change conductivity by 2 to 3 orders of magnitude
Magnetic properties	Paramagnets

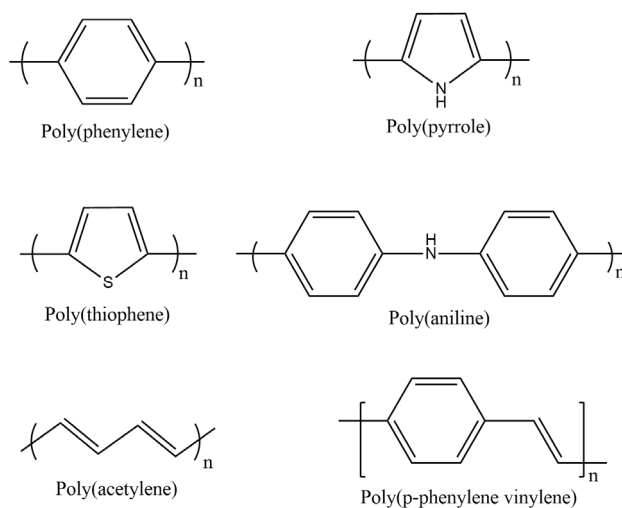


Figure 2. Chemical structures of conducting polymers

4. What is Electrical Conductivity?

Conductivity defined by the Ohm's law that is,

$$V = IR$$

Where R is the resistance, I is the current and V is the voltage present on the material. The conductivity depends on number of charge of the material and their mobility.

There are three types of conduction.

i) Intrinsic conductivity: conduct electricity in pure form by present of electrons and holes.

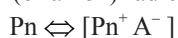
ii) Extrinsic conductivity: by adding external impurities called as doping. Several doping methods have used to make conjugated double bonds, like redox doping, non redox doping, photo doping, charge injection doping.

iii) Holes: created by removal of electrons on doping^[35].

Conducting mechanism

While “doping” refers to the addition of a donor or acceptor molecules to a polymer, the reaction that occurs is really a redox reaction.

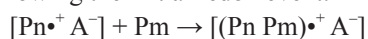
The production of a soliton or polaron, which is a cation (or anion) radical, is the first stage.



This phase may be referred to as the second electron transfer, resulting in the production of a bipolaron dication (or dianion).



When feasible, charge transfer compounds may develop between energized and neutral portions of the polymer following the initial redox event.



5. Synthesis of Conducting Polymers

1) Chemical synthesis: Conducting polymers are created chemically by oxidising or reducing monomers and polymerizing the matching monomers. The main benefit is the possibility of mass manufacturing at a reasonable cost. Several studies have been conducted to improve the quality and quantity of manufactured products produced using the oxidative polymerization process. The employment of electrochemical techniques is not mandated by the principles of chemical methods. Poly (3-hexylthiophene), for example, is the most researched conducting polymer that is virtually always made chemically. Chemically, PPy and PANI may be synthesized. After conjugation, the most important need for chemical polymerization is stability. Oligomers and low molecular weight polymers must be reactive and soluble enough to polymerize for chemical polymerization to be successful. If an oligomer precipitates out of solution, polymerization should proceed in a heterogeneous manner, which is becoming increasingly implausible as monomer and reactive polymer concentrations decrease.

2) Electrochemical synthesis: Conducting polymers are made electrochemically by either anodic oxidation or cathodic reduction of suitable electroactive functional monomers. Because of its simplicity, cost-effectiveness, and ability to accomplish the process in a single section glass cell, electrochemical synthesis of conducting polymers is a very essential approach. Typically, the potential for

monomer oxidation to lead to polymerization is greater than the potential for oligomeric intermediate polymerization. Alternate chemical and electrode reaction stages are used in a simplified method of electro polymerization of an electro active monomer, such as pyrrole or thiophene.

3) Photochemical method: Photochemical preparation has been claimed to have a number of advantages as a consequence of its rapid and low-cost process, as well as the fact that it is not harmful to the environment. The process can be used to create certain conductive polymers. Pyrrole, for example, has been successfully polymerized to Poly pyrrole by irradiation with visible light, either as the photosensitizer or as an electron acceptor. Currently, horseradish peroxide is used to begin aniline polymerizations in the presence of hydrogen peroxide via oxidative free radical coupling reactions. When compared to chemical and electrochemical approaches, aniline polymerization may be accomplished under more benign conditions.

4) Metathesis method: Metathesis is a chemical process in which one portion of each substance is swapped, resulting in the formation of two new compounds. Ring-opening metathesis of cyclo-olefins, acyclic or cyclic metathesis of alkynes, and diolefin metathesis are the three types of metathesis polymerization.

5) Concentrated emulsion method: The emulsion technique of polymerization is a heterophase approach with three segments: water, latex particle, and monomer droplet. A radical polymerization is the main process at work. Bulk and solution polymerization have one segment in the arrangement, with the monomer as the solvent and the initiator in the same segment. Until significantly changed, the produced polymer remains soluble in either the monomer or the solvent. A micelle-forming surfactant, a water-soluble initiator, and a water insoluble monomer are all used in this method.

6) Inclusion method: At the atomic or molecular level, inclusion polymerization creates composite materials. This sort of polymerization can pave the way for one-of-a-kind low-dimensional composite materials with huge promise. An electroconductive polymer, for example, may be used to make a molecular wire. On this point, organic hosts have been used to create composites of such polymers. This polymerization, according to Miyata et al., may be regarded as a common space-dependent polymerization and should not be viewed just through the lens of stereoregular polymerization.

7) Solid state method: Solid State polymerization is a process in which the lengths of polymer chains are lengthened by heat in the absence of oxygen and water, either by vacuum or by removing by-products with an inert gas. Temperature, pressure, and the diffusion of by-products

from the pellet's core to the shell govern the reaction. It's frequently used after melt polymerization to improve polymer mechanical and rheological characteristics before injection blow moulding. The solid state approach is widely used in the manufacturing of bottle-grade PET, films, and sophisticated industrial fibres in industry. The use of simple and inexpensive apparatus, as well as the avoidance of some of the issues associated with traditional polymerization techniques, are the main advantages of solid-state polymerization.

8) Plasma polymerization: Plasma polymerization is an unique method for producing thin films from a variety of organic and organometallic precursors. Plasma polymerized films are insoluble, thermally durable, chemically inert, and mechanically robust because they are pinhole-free and strongly cross linked. Such films are also exceedingly coherent and sticky to a variety of substrates, including traditional polymer, glass, and metal surfaces. They have been widely employed in recent years for a variety of applications, including perm selective membranes, protective shells, biological materials, electrical, optical devices, and adhesion supports, due to their exceptional qualities^[36-38].

9) Vapour phase polymerization: Vapour phase polymerization (VPP) is a well-known method for introducing a monomer in vapour form to an oxidant-coated substrate. At the oxidant vapour contact, polymerization occurs. VPP is a method for immobilizing materials on a modified electrode surface^[39,40].

6. Characterization

Conducting polymers, like many other polymers, may be described using a number of analytical methods. There are several examples in the literature, including:

a) Cyclic voltammetry - in order to better understand redox processes in conjugated polymers and to assess prospective cell and electrochromic window component choices. Murugappan et al. had synthesized a conducting polymer poly (3,4-ethylenedioxythiophene) (PEDOT) by electrochemical procedure and characterized by cyclic voltammetry method. The decrease of the polymer generated on the surface as a result of process I causes the peak at roughly 0.8 V. A new peak occurs at roughly +0.4 V on the second CV scan (red trace). This peak is caused by polymer oxidation, which did not occur until after polymer synthesis during the initial CV scan (black)^[41]. Li et al. in one of their studies revealed the synthesis of three 3,4-bis(alkylthio)pyrroles by a nonclassical pyrrole ring formation reaction followed by alkylation of the dithiol-2-one functional group. The synthesized polymers were investigated by cyclic voltammetry study. The CV study shows that the monomers have much less oxidation poten-

tials than that of virgin pyrrole^[42].

b) Nuclear magnetic resonance - for determining the structure of the insoluble organic conducting polymers, solid state NMR spectroscopy can be employed. Zujovic et al. had studied the molecular dynamics in complex and diverse material using solid state NMR (SSNMR) technology for polyaniline (PANI) SSNMR can offer crucial information on the structure and conformation of the polymer backbone, as well as the type and distribution of charge carriers, when applied to PANI^[43]. Wahane et al. studied the structure of poly pyrrole by using various spectroscopic analysis techniques. High resolution NMR Spectroscopic methods have emerged into the most powerful tool for studying the structure of such conducting polymers in solution and in solid form. Chemical oxidation polymerization in non-aqueous media was used to make several PPy / Metal Oxide composites, which were then analysed by NMR^[44].

c) Raman analysis - Hiragond et al. synthesized polythiophene (PTh), polypyrrole (PPy) and polyaniline (PANI) by oxidative coupling method. CdS/polythiophene (CdS/PTh), CdS/polypyrrole (CdS/PPy) and CdS/polyaniline (CdS/PANI) hybrid nanocomposites had been synthesized. The interaction of CdS with these conjugated polymers in the current hybrid nanocomposites was further validated by Raman spectroscopy of all samples. Raman spectra of CdS/PTh, CdS/PPy, and CdS/PANI nanocomposites in the range of 100-1800 cm^{-1} . Various peaks of vibrational Raman active modes were identified in all samples, with two peaks in the area of 300-400 cm^{-1} matching to fundamental optical phonon modes (LO and 1LO+E2) of CdS QDs^[45]. Xu et al. synthesized PANI/Bi₁₂O₁₇Cl₂ composites at room temperature via a green and simple approach. The as-prepared PANI/Bi₁₂O₁₇Cl₂ composite was also tested using Raman spectroscopic technology. The distinctive bands at 149 cm^{-1} and 94 cm^{-1} in the Raman spectra of Bi₁₂O₁₇Cl₂ corresponded to the A_{1g} internal Bi-Cl and E_g internal Bi-Cl stretching modes, respectively^[46].

d) Electroluminescence - to see if it might be used in light-emitting diodes (LEDs). Krishnaswamy et al. had deposited high quality P-type Polypyrrole (PPy) on ITO by Pulse Laser deposition (PLD) technique. Optical characteristics were investigated in depth. The thin film had a transmittance of 59.7% and a reduced band gap of 1.73 eV. The PPy thin sheet has an optical conductivity of 0.27 S/cm. The dielectric characteristics of the PPy thin film were thoroughly examined. The photoluminescence spectra of a PPy thin film at room temperature showed three peaks at 373 nm, 425 nm, and 486 nm, corresponding to electronic transitions, polarons, and bipolarons, respectively. PPy thin films with high luminescence efficiencies can be

employed as an excellent hole transport layer [HTL] in electroluminescence devices [47].

(e) X-ray analysis, including Rutherford backscattering - to acquire insight into the conducting process by understanding the crystal structure and obtaining elemental thickness profiles [2]. Sardar et al. studied the synthesis of a smart composite from poly (3-bromothiophene) (PTBr) and graphene quantum dot (GQD) through facile in-situ and ex-situ routes. The crystallographic structure of the composites were analyzed by XRD. The diffraction pattern of neat poly (3-bromothiophene) (PTBr) was broad, indicating that it was mostly amorphous (low percentage crystallinity of 26 percent). It had a reflection peak at 2-26 degrees, which corresponded to the reflection from the (002) plane. The reflection angle in the in-situ composite was lowered to 24.8 °, whereas it was further reduced to 23.4 ° in the ex-situ sample [3].

7. Applications of Conductive Polymers(CP)

Drug delivery

Current drug-delivery technologies are effective in delivering pharmaceuticals in a regulated manner, and it is depicted in Figure 3. The application, however, is still limited to cell clusters instead of individual cells. Developing innovative medicine delivery methods will open up new possibilities that were previously unavailable due to the limitations of existing oral formulations. The use of conductive polymers in bioanalytical sciences is gaining a lot of attention because of their biocompatibility, which allows them to be used in in vivo biosensor applications for constant monitoring of medications or metabolites in bodily fluids.

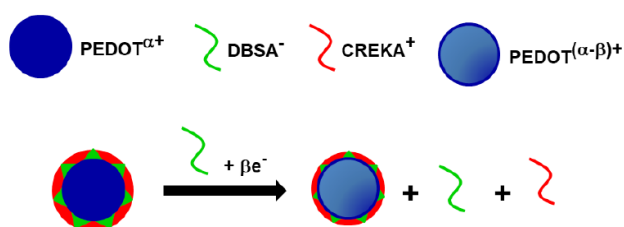


Figure 3. The mechanism of peptide release from CREKA/PEDOT NPs. Reproduced with permission from ref. [48]

Tissue engineering

The medical sectors is one of the sectors that might be transformed by the uses of conductive polymers, particularly in tissue engineering and biosensors. Electrospinning allows for the creation of 3D scaffolds made of conductive polymers. Because conductive polymers are a good biocompatible matrix for biomolecules, they're of particular interest. PEDOT, on the other hand, has lately attracted a

lot of attention due to its improved electrical conductivity and chemical stability. Now a days PEDOT uses by growing neural cells in an in vitro dorsal root ganglion model, in film and nanotube morphology.

Bioactuators

Bioactuators are mechanical force-generating gadgets that may be utilised to construct artificial muscles. Bioactuators have been built using the phenomena of change in the volume of the CP scaffold when electrical stimulation is applied. Two layers of CP are used in a triple layer configuration in artificial muscle operations, with the intermediate layer consisting of a non-conductive substance.

Smart textiles

Fabrics that can sense exterior situations or stimuli such as chemical, thermal, electrical, photonic, magnetic, and the like are known as smart textiles. It can intelligently respond to and adapt to external behaviour. Conductive polymers have been intensively studied for smart textiles in recent years. There are now around twenty five conducting polymers being investigated for such uses [39,40]. Because of their reduced weight, high control can be done, cheap cost, tunable electrical conductivity, bio compatibility, and customise ability to provide a sensing and actuating function, these polymers were chosen [49].

Self-healing conductive material

Self-healing materials are intelligent materials that can regain some or all of their properties after being injured from the outside. Self-healing properties are a potential technique to make materials more durable and dependable. Extrinsic and intrinsic self-healing mechanisms are two types of self-healing mechanisms. In extraneous self-healing instrument, mending process is relying upon the microcapsules/pipelines containing recuperating specialist and intrinsic self-recuperating component, recuperating process relies upon the powerful reversible substance bond making capacity of the framework upon the feeling of an outer boost, for example, temperature, dampness, light, electrical flow through reversible sol-gel progress. The highly conductive PEDOT: PSS is being investigated as a self-healing conductive material. Adding a little quantity of the quasi surfactant plasticizer Triton-100 ($C_{14}H_{22}O[C_2H_4O]_n$) to PEDOT ($n = 9-10$): PSS resulted in a high level of self-healing abilities [2].

Conducting polymer as wearable: The need for flexible and wearable next-generation electronic gadgets that can bend and stretch under mechanical deformation is increasing. Because of their large-area synthesis, cheap

cost, low toxicity, great flexibility, and customizable electronic characteristics, energy harvesting technologies have heavily invested in organic and polymeric semiconducting materials. Electrically conductive p-conjugated polymers, for example, have been studied in various thermoelectric technologies for producing stretchable, wearable, and light-weight thermoelectric devices that can harvest energy from a temperature gradient and produce electricity without polluting the environment or requiring moving parts^[50]. Conducting polymers have also antifouling property and the mechanism which it follows is shown in Figure 4.

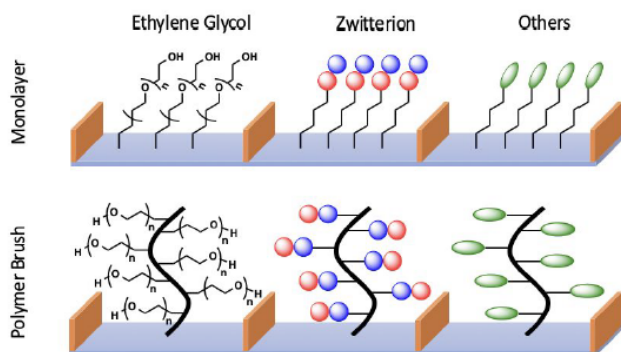


Figure 4. Design and classification of conducting polymers with an antifouling property. Reproduced with permission from ref.^[51]

Supercapacitors and electrolytic-type capacitors are two further possible uses for conductive polymers. As a consequence of their multiple protonation and oxidation forms, several conductive polymers, including polyaniline, exhibit a wide range of color. Their electrochromic capabilities can be exploited to make “smart windows” that absorb solar energy in the summer. Polymers have the benefit of being produced in big sheets with limitless visual angles, as opposed to liquid crystals^[52-55].

Kraft et al. (2019)^[56] had synthesized PEDOT: PSS conducting polymer which has conductivity of 700 S cm^{-1} . The use of printable elastic conductors in large-area fabrication of wearable electronics and prosthetics opens up new possibilities. Furthermore, by placing sensor arrays close to the skin, they have the potential to advance health monitoring and continuous diagnostics. These devices must be comfortable to wear and must be able to withstand strains and deformations like twisting and stretching. The introduction of a conductive polymer ink for elastic interconnects and electrodes. Inkjet printing’s processability allows for versatile, contactless, and maskless large-area processing. The printed PEDOT:PSS-based interconnects have conductivities of up to 700 S cm^{-1} , can withstand strains of up to 100%, and are stable in air (less

than 5 percent change in resistance in 1 month). The conductivity is among the greatest recorded for inkjet-printed PEDOT:PSS, making it useful not only for stretchy circuits, but also for printed flexible and rigid PEDOT: PSS-based applications such solar cells, organic light emitting diodes, and electrochemical sensors.

Jeong et al. (2019)^[57] synthesized organic and perovskite light-emitting diodes (LEDs), an ideal conducting polymer anode (CPA) requires a high electrical conductivity k , a high work function WF , and the avoidance of exciton quenching between the anode and the overlaying emitting layer. Due to their trade-off connection, boosting the k and WF at the same time has been a difficult unresolved challenge. Previous efforts to increase the WF have lowered the films’ k and vice versa. To tackle this basic problem, careful molecular scale control of conducting polymer compositions is necessary. They presented a molecular scale control approach for decoupling the WF from k in a CPA while keeping exciton quenching blocking capabilities. In green polycrystalline perovskite LEDs, this adjustment resulted in a high current efficiency of 52.86 cd A⁻¹ (10.93 percent ph el-1). Their findings offer valuable insight into the development of effective CPAs for high-efficiency organic and perovskite LEDs.

Bilal et al. (2014)^[58] synthesized poly (o-toluidine) (POT), a methyl-substituted derivative of PANI, by inverse emulsion polymerization. The dispersion media was a combination of 2-butanol and chloroform, the oxidant was benzoyl peroxide, and the dopant and surfactant was dodecylbenzenesulfonic acid (DBSA). POT was collected in its salt form and found to be totally soluble in a variety of organic solvents, including DMSO, chloroform, toluene, THF, acetonitrile, and ethanol (so far the most solvents). Cyclic voltammetry, in situ UV-Vis spectroelectrochemistry, viscosity and in situ conductance measurements, FTIR, and TGA were used to characterise the produced polymer. POT has a high conductance that is comparable to electrochemically synthesised POT, according to conductance measurements. The electrochemical activity of the POT film dip-coated on a gold electrode was very stable in air; even after 14 days in the open, there was no discernible decline in the film’s electrochemical activity. Thermal analysis reveals a very good thermal stability up to 513 °C. POT works as a very efficient corrosion protection layer on steel, according to potentiodynamic polarisation studies, with a 77 percent protection efficiency.

Tuken et al. (2004)^[59] in a LiClO_4 containing acetonitrile solution, electrochemical polymerization of polythiophene (PTh) was examined on a nickel covered mild steel (MS) electrode. A 1 mm thick nickel coating was depos-

ited galvanostatically from a suitable bath solution. The PTh film was then synthesised using the cyclic voltammetry technique in 0.1 M thiophene containing ACN-LiClO₄. Electrochemical impedance spectroscopy (EIS) and anodic polarisation curves were used to study the corrosion performance of nickel coated samples with and without polymer top coatings in a 3.5 percent NaCl solution. MS was protected from corrosion by the nickel coating, which acted as a physical barrier. However, its barrier properties deteriorated with time, and it was unable to protect MS patients. The PTh top coat significantly increased the barrier performance, and good protection against MS corrosion was achieved over a long period of time in such a hostile environment.

Marzocchi et al. (2015)^[60] synthesized poly (3,4-ethylenedioxythiophene) poly (styrene sulfonate) (PEDOT: PSS). Conducting polymers are interesting materials for tissue engineering applications because of their electrical conductivity and reversible doping, they may both offer a biocompatible scaffold for physical support of live cells and convey electrical and mechanical stimuli. Thin films of poly (3,4-ethylenedioxythiophene) poly (styrenesulfonate) (PEDOT: PSS), one of the most promising materials for bioelectronics applications, are prepared using two different techniques, spin coating and electrochemical polymerization, and their oxidation state is then changed electrochemically with the application of an external bias.

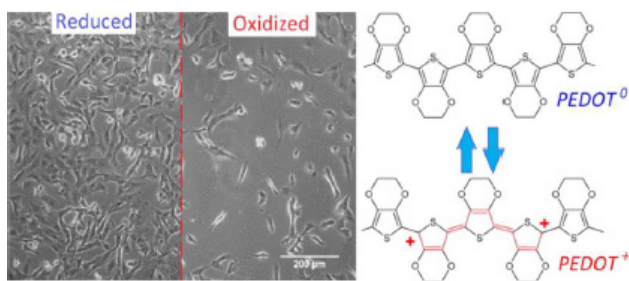


Figure 5. Structure of oxidized and reduced form of PEDOT. Reproduced with permission from ref.^[60]

The electrochemical characteristics of the various kinds of PEDOT are as follows: The efficacy of the oxidation process and its stability over time are assessed using cyclic voltammetry and spectrophotometry on PSS. Their physical qualities on the surface and their relationship to PEDOT's redox state: Atomic force microscopy (AFM), water contact angle goniometry, and sheet resistance measurements are used to investigate PSS. The structure of the oxidized and reduced form of PEDOT is shown in Figure 5. Finally, primary human dermal fibroblasts (hDF) and human glioblastoma multiforme cells (T98G) are cultivated on PEDOT: PSS films with various oxidation states, revealing that the influence of the substrate on cell

growth rate is substantially cell-dependent: T98G growth is aided by reduced samples, but hDF development is aided exclusively by oxidised substrates with significant chemical interactions with the cell culture medium.

8. Conclusions

In this paper we have described a variety of conductive polymers, as well as new synthetic processes that have been developed to synthesize those polymers. Among all the routes of synthesis of conducting polymers it can be concluded that chemical polymerization techniques are beneficial from the standpoint of mass manufacturing, but we must also limit by-products and waste materials in order to maintain a clean and healthy global environment. The characterization along with some vivid examples has been incorporated to have a better clarity in this regard. It has also been found that the conducting polymers have better light emitting properties. The electrical properties have been showcased by cyclic voltammetry study by scientists around the world. The wide range of applications has been included in this review. It can be said that in future these conducting materials could find its way in this smart world as we have seen that no one can think of storing for security purpose in storage device which is nothing but the contribution of these conducting materials. The LEDs have already replaced the power giant 100 W bulb and more to see in future. The smart material could also find its way into medical fields. The catalytic polymerization technique is a desirable candidate for an environmentally friendly reaction mechanism. At this moment, catalytic studies should be enhanced in order to get a more accurate conducting polymer. The authors anticipate that this study will spur more research into conductive polymers and new catalytic methods for their production.

Conflict of Interest

The authors declare no conflict of interest.

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