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Conductive Polymer Coated Textile and their Applications

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Abstract

Conductive polymers can be defined as cationic and anionic salts of highly conjugated polymers. Cation salts result from chemical oxidation and electrochemical polymerization while anion salts are produced through electrochemical reduction or chemical reduction using reagents such as sodium naphthalide. This article reviews the preparation and development of conductive polymers, mechanism of conductivity. Different methods for applying conductive polymers to the surface of textiles are described here (chemical polymerization, electrochemical polymerization, vapor phase polymerization, Solution coating process, polymerization in supercritical fluid) along with their relative advantages and disadvantages. Various applications of electrically conductive fabrics based on conductive polymer are presented, such as electrochromic fabrics, smart fabrics, sensors, and electrically conductive fabrics for protection against electromagnetic radiation and flame resistance.

Keywords: Conductive polymer, smart textile, electrochromic, cotton, electromagnetic

Introduction

Commodity polymers are inherently non-conductive. The discovery of conductive polymers began with the groundbreaking observation that halogen-doped polyacetylene (-CH=CH-)n exhibits high electrical conductivity, leading to the 2000 Nobel Prize in Chemistry award. Since then, several other conjugated polymers have been studied, such as polyaniline (PANI), poly(phenylenevinylene), PPy and polythiophene (PT). Conducting polymers possess backbones that feature alternating double and single bonds. These structures give rise to semiconductor characteristics. In semiconductors, there is a small energy gap between the HOMO (highest occupied molecular orbital or valence band) and LUMO (lowest unoccupied molecular orbital or conduction band). Electrons can be excited thermally or electrically over this gap where they become free to delocalize over the LUMO level or conduction band. If there are enough small band gaps present, a large delocalized band appears across the lattice; electrons flow in the conduction band while vacant holes of positive charge flow in the valence band resulting in current flow.[1]

Conductive polymers can be defined as cationic and anionic salts of highly conjugated polymers. Cation salts result from chemical oxidation and electrochemical polymerization while anion salts are produced through electrochemical reduction or chemical reduction using reagents such as sodium naphthalide. An oxidized conducting polymer has electrons removed from its backbone resulting in a cationic radical whereas a reduced conducting polymer has electrons added to its backbone producing an anionic radical. [2-4]

The mechanism behind conduction in conductive polymers involves solitons, polarons and bipolarons making it very complicated. Conductive polymers exhibit insulative properties (conductivity of 10^{-10} S/cm) when neutral but upon oxidizing (p-doping) or reducing(n-doping) their conjugated backbone it leads to high conductivity values(up to 10^2 S/cm depending on polymer system type/extent of doping). Doping is achieved by partially adding/removing electrons from/to p-systems within their respective backbones via chemical/ electrochemical means[1]

In chemical doping processes for example, conductive polymers are oxidized by exposing them to oxidizing vapors like iodine gas - p-bonds(p-p*) being partially localized under normal conditions-excitation across these bands creates self-localized excitations known as polarons, bipolarons, and solitons which generate localized electronic states after relaxation processes when neutral polymer is oxidised.After saturation with polarons,a bipolaron forms by removing another electron from one

polaron. Influencing factors for conductivity include polaron length/conjugation length/overall chain length & charge transfer between adjacent molecules. These factors find explanation through models based on intersoliton hopping, hopping assisted by lattice vibrations, intra-chain hopping of bipolaron variables range hopping & three-dimensional limited -hopping charging energy ductingtunneling between con. [5]

Electron hopping refers to the movement of charge along and between chains, due to electron attraction in one repeating unit towards neighboring nuclei. This results in electrical conductivity as charge carriers move along the conjugated backbone. A smaller distance between the conducting band and valence band (band gap) leads to a higher conductive state, which can be influenced by factors such as dopant, oxidation level/doping percentage, synthesis method, and temperature. The aim of synthesizing conducting polymers is to create novel structures with increased order in the polymer backbone for easier processability and synthesis while maintaining stability in both conducting and non-conducting states. Additionally, solubility in certain solvents and a more defined three-dimensional structure are sought-after features. Electrically conductive polymeric materials have recently garnered significant attention from academic and industrial researchers due to their potential in applications such as sensors, biomedical wireless communication, patch antennas, energy harvesting, and energy storage. Conductive polymers are lightweight and flexible and can be applied to textiles without affecting their flexibility. Solution-based conductive polymers are especially convenient for roll-to-roll processing, which can easily be integrated with current textile technologies like dyeing and printing. [1, 5]
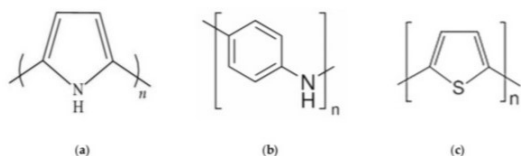

Figure1: chemical structure of the most common conductive polymer: (a) polyrrole , (b) polyaniline ,(c) polythiophene.

Conductive polymers and mechanism of conductivity

The boundaries of conductivity among conductive materials, semiconductors, and electrical insulators are hazy and imprecise. The conductivity of conductive polymers falls within the conductivity range of semiconductors. [6] These polymers are widely used because of their enormous potential for developing new uses. Figure 1 displays the

conductivity of polymers in comparison to other materials. [7, 8] The advantageous qualities of metals and traditional polymers are combined in conductive polymers. They exhibit excellent electrical characteristics and conduct electrical charges. [9]
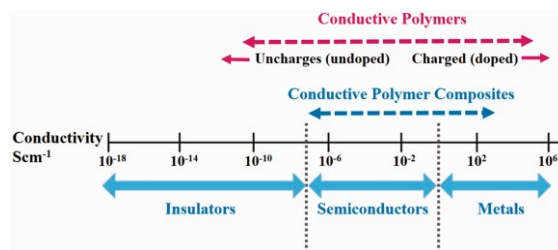

Figure 2. Conductivity range of polymers compared to other materials conductivity. [8]

Conductive polymers can be divided into two classes: [8] extrinsically and inherently conductive polymers.

Conjugated polymers and synthetic metals, commonly referred to as intrinsically (or inherently) conductive polymers (ICPs), display intriguing electrical and optical characteristics that were previously exclusive to inorganic systems. [10] It is possible to create many kinds of ICPs with conductivities ranging from 10^{-10} to 10^{+5} Scm^{-1}. [11-14] Among these polymers, polyaniline (PANI), polypyrrole (PPy), and poly(3,4-ethylenedioxythiophene) (PEDOT), which is a derivative of polythiophene (PTh), are the most appealing. They are easily synthesized, exhibit good electrical conductivity and environmental stability, but have subpar mechanical qualities. [15, 16]

The process of blending (melt mixing) an insulating polymer matrix, thermoplastic or thermosetting plastic, yields extrinsically conductive polymers (ECPs), also known as conductive polymer composites (CPCs). using conductive fillers. The three most significant conductive fillers are ICPs (PPy, PANI), metal powders and their compounds (indium tin oxide (ITO) and aluminum zinc oxide (AZO), and carbon (carbon black (CB) and carbon nanotubes (CNTs). Good mechanical, electrical, and thermal conductivity, as well as resistance to corrosion, are among the unique qualities of ECPs. They find application in solar collectors, electronics, corrosion-resistant coatings, ESD materials, and conductive and semi-conductive polymer fibers. Depending on the application, their conductivity values range from 10^{-5} to 10^3 Scm^{-1}, which is significantly lower than that of ICPs. [13, 15, 17, 18]

Polymers can become conductive under two circumstances. Conjugated double bonds, which are alternating single and double bonds, are the initial

requirement for conductive polymers. These connections have a Strong chemical bonds are formed by localized "sigma" (σ) bonding. Furthermore, every double bond furthermore consists of a weaker, less firmly localized "pi" (π) bond as shown in (Figure 3).
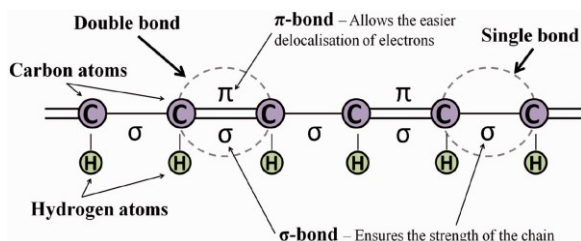

Figure 3. Simplified schematic of a conjugated backbone: a chain containing alternating single and double bonds. [9]

Nevertheless, the polymer material needs more than just bond conjugation to be conductive. Therefore, the second need is that the polymer structure must be altered, either by adding or withdrawing electrons (oxidation or reduction). The terms "p-doping" and "n-doping" refer to the processes. They may have an impact on the bulk structural characteristics (volume, porosity, and color) of the surface. [9, 19-21]

In organic conjugated polymers, doping is a charge transfer reaction that is better categorized as a chemical redox reaction. Table 1 shows typical characteristics changes of conductive polymers as a result of doping. [9, 22, 23]

Temperature, doping material presence, charge carrier density, mobility, and direction are all factors that impact polymer conductivity. [17, 20, 21]

Table 1: Properties changes of conductive polymers in response to redox transition.

Oxidized	reduced
More conductive	Less conductive
More capacitance	Less capacitance
Less transparent	More transparent
Less hydrophobic	More hydrophobic
Expanded	Contracted
Higher modulus	Lower modulus

Conductive polymers have a special stretched π-conjugation that makes them suitable oxidized or reduced state conductors. A conductive band is formed by π*-orbitals, while the valence band is made up of overlapped π-orbitals. Conductive polymers undergo chemical or electrochemical oxidation, which removes electrons from the

valence band. This results in the presence of charge on the conductive polymer, which is delocalized over a number of monomer units and causes the polymer geometry to relax into its most stable form. Dopants can be retrofitted or added to the polymer during synthesis. They could be bigger polymers, ClO4-, Na+, or other anions or cations. poly(styrene sulfonic acid) (PSS), poly(vinyl sulfonic acid) (PVS), and polyelectrolytes are examples of such particles. The ratio of counterions to monomers in a polymer is represented by the degree of doping. [24]

It was found in 1977 that doping polyacetylene with iodine could raise its conductivity. Heeger, MacDiarmid, and Shirakawa were granted the 2000 Nobel Prize in Chemistry in recognition of their discovery of conductive polymers. [25]

Polyenes have specific excitations that are connected to solitons and solitary waves. [20, 21, 26] Three simple carbon compounds—polyacetylene, graphite, and diamond—can be compared with interest. They can be thought of as one-, two-, and three-dimensional carbon materials.

Whereas one hydrogen atom is bonded to each carbon atom in polyacetylene, diamond and graphite are modifications of pure carbon. Diamond is an insulator and has only σ bonds in it. High symmetry results in isotropic characteristics. Because of their mobile π electrons, graphite and polyacetylene are very anisotropic conductors. [7]

Principles of conduction mechanisms in polymers are illustrated by polyacetylene, the simplest conjugated polymer that can be produced by polymerizing acetylene. [7] Two analogous polyene chains, L and R, are interconverted by a soliton as a required result of the asymmetry of the polyacetylene ground state. As a mobile charge, neutral defect, or "kink" in the polyacetylene chain, the soliton spreads along the chain and lowers the interconversion barrier, as shown in (Figure 4) .

In n-doped polyacetylene, the charge carrier is a resonance-stabilized polyenyl anion with a length of roughly 29–31 CH units, the maximum amplitude of which is located in the center of the defect. Bipolaron hopping mechanism explains soliton migration from one end of the sample to the other. [7]
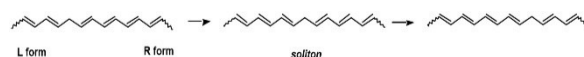

Figure 4. Soliton intervention through the polyacetylene chain [7]

The instabilities of polyacetylene in air (covalent interactions between carbon and oxygen atoms reduce polyacetylene's conductivity) prompted a greater focus on the investigation of alternative conductive polymers. [25]

P-type conduction, electron inter-chain hopping, and anions' or cations' internal movement are the main causes of conductivity in PPy. Up to 7.5×10^3 Scm^{-1} of conductivity can be found in PPy. The "disorder" in the PPy backbone is the main factor limiting PPy's conductivity. The slow degradation of conductivity can be caused by redox switching, exposure to oxygen, or water, which can result in the formation of more of these flaws. Because of its excellent adhesion, strong conductivity, outstanding environmental stability, and non-toxicity, PPy is one of the most significant conductive polymers used in smart textiles. This polymer has been investigated for use in brain tissue engineering, biosensors, microelectronics, and surgical instruments, among other uses. [9, 24]

PANI has drawn a lot of Due to its chemical and thermal stability, it is of global interest. [18, 27-29] It can be readily doped with organic and inorganic acids to create the conductive form, and its production costs are minimal. [18] PANI has better thermal stability than other ICPs. The conductive nature of emerald base PANI is limited to a range of 10^{-10} Scm^{-1}, whereas the conductive salt formed by altering the base's oxidative state has a conductivity of 30 Scm^{-1}. The polymer chains are coiled in their base state, but when they are in their salt form, the extra positive charges in the polymer oppose.one another, causing the chains to lengthen. Since form electrons delocalize more easily in longer coils, conductivity increases. [9] PANI is used in a wide range of sensing applications, including EMI shielding, ammonia sensors, and precious recovery of metals. [24] PANI is being researched for tissue engineering, controlled medication delivery, and brain probes. [9]

PSS is a water-dispersible polyelectrolyte that was used to get around the solubility issue with PEDOT. During the oxidative polymerization of the 3,4-ethylenedioxythiophene (EDOT) monomer, PSS is utilized as a charge-balancing counterion to produce the polymer complex poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT: PSS). With sizes of several tens of nanometers, the polyion complex is easily distributed in water as colloidal gel particles and exhibits great stability. [29, 30] The aqueous coating mixture can be modified to enhance the mechanical characteristics and coatability of the polymer on hydrophobic substrates by including organic co-solvents, surfactants, and wetting agents. [31] Small amounts of secondary dopants, such as sorbitol, dimethyl sulfoxide, and glycerol, are employed (ethylene glycol (EG), N-methylpyrrolidone (NMP), DMSO, etc.). [31, 32] The PEDOT:PSS polymer combination finds application as a hole transport layer in organic light emitting diodes and as an electrode material in organic thin film transistors. This complex has the ability to cover stretchy substrates like textiles, fibers, and other hard surfaces, including microelectronics. [24]

Polymers can be modified in a variety of ways, including blending, grafting, and curing (Figure 5). The physical combination of two (or more) polymers to achieve the desired properties is called blending. In curing, an oligomer mixture is polymerized to form a coating that is physically linked to the substrate, while in grafting, monomers are covalently bonded onto the polymer chain.
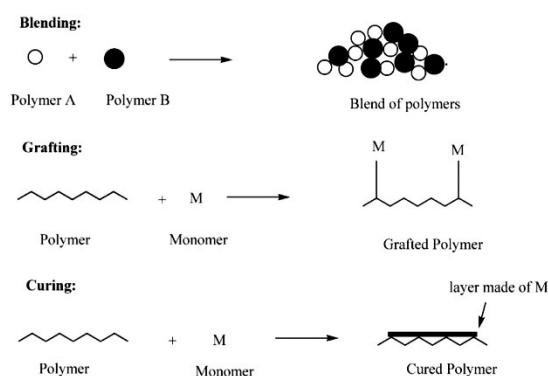

Figure 5. Schematic representation of the methods of polymer modification. [34]

Techniques for graft co-polymerization of various monomers on polymeric backbones have been the subject of extensive research. These methods include enzymatic grafting, photochemical, radiation, chemical, and plasma-induced methods.

The conductive polymers need to go beyond a few obstacles in order to produce a material that can be used in a variety of technologies (such as poor mechanical qualities, processing issues, and instability under the appropriate environmental conditions). Through grafting, conductive polymers become more processable and offer the opportunity to acquire the specific characteristics needed for a given application.

A water-soluble PPy is produced by grafting self-doped conductive polymers together. The desired attribute of water-soluble 2-acrylamido-2-methyl-1-propane sulphonic acid-N-(4 aniline phenyl) methacrylate co-polymers is obtained by grafting pyrrole (Py) onto p-amino diphenylamine moieties. Another method for making PANI soluble was to polymerize aniline in an aqueous blend of poly(p-amino styrene) to create a graft co-polymer that is solvent-soluble (Figure 6(a)). Grafting can also lessen the polymer chain's stiffness, which allows the solvents to solvate and impart solubility. [33]

Using azoisobutyronitrile (AIBN) as an initiator, styrene and 4-chloromethyl styrene were co-polymerized to create a styrene-based composite.

The Py moiety was then grafted onto the co-polymer matrix by re-mixing the mixture overnight with an added potassium pyrrolate solution in tetrahydrofuran (THF) medium. In Figure 6(b), the reaction scheme is displayed. The composite has a conductivity of about 10 Scm−1.
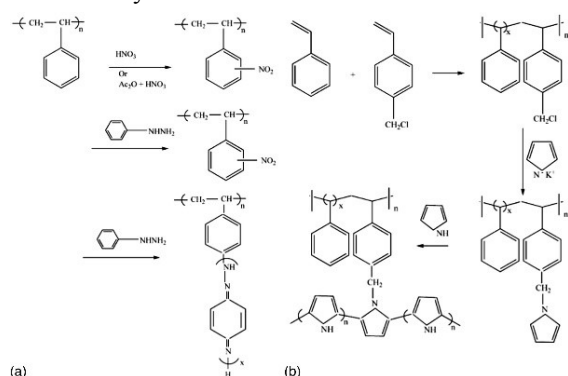

Figure 6. Reaction scheme for preparation of: (a) polyaniline based graft co-polymer, (b) pyrrole-styrene graft co-polymers. [33]

Grafting also serves the purpose of altering the conductive polymer's surface. By grafting hydrophilic monomers, such as acrylamide, acrylic acid, or the Na salt of 4-styrene sulphonic acid, the hydrophilicity of the PANI film surface can be increased. This can be accomplished by treating the emeraldine films with Ar plasma or an ozone/oxygen combination, which will graft co-polymerize the monomers. Grafted PPy is useful as ion-sensor as well; for instance, it is capable of detecting ions in a solution . [33]

By grafting PANI onto chitosan in an acidic environment with persulfate acting as an initiator, an intrinsically anisotropic graft copolymer was created (Figure 7). Similar to PANI, the grafted biomaterial demonstrated electrical conductivity and pH switching behavior. Good processability, enhanced solubility, mechanical strength, and regulated electrical characteristics are offered by PANI-grafted biopolymer. Consequently, chemical and biosensor applications can make advantage of it. [33]

Coating methods for depositing conductive polymers onto textiles

One of the key prerequisites for synthesizing conductive polymers is maintaining their conjugated nature throughout the process. Due to strong intermolecular interactions within the polymer chains, they are insoluble and resistant to melting, rendering it challenging to spin them into filaments or fibers. Additionally, their lack of thermal stability makes them unsuitable for hot molding processes and difficult to apply onto textiles. [24, 34, 35] In situ polymerization methods have been identified as optimal techniques in this

regard. Electro-conductive textiles can be fabricated using various approaches such as in situ chemical, in situ electrochemical, in situ vapor phase polymerization, in situ polymerization in supercritical fluids, solution coating processes and more. [36]
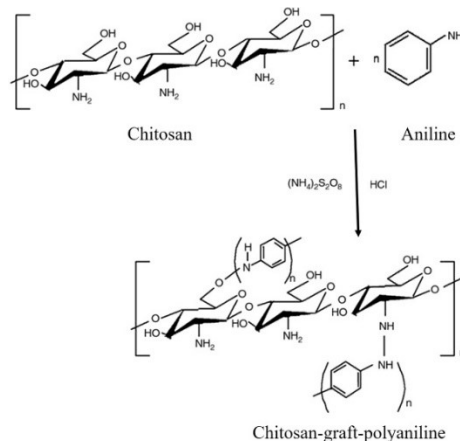

Figure 7. Chitosan-graft-polyaniline synthesized through the oxidative-radical graft copolymerization. [37]
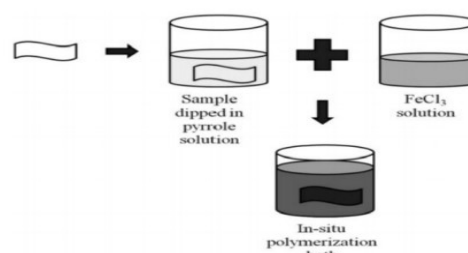

Figure 8: In situ chemical polymerization by single-bath process

In situ chemical polymerization

In situ chemical polymerization is a straightforward process that requires the monomer to be soluble. To initiate this process, solutions of the monomer and an appropriate oxidant (such as FeCl3) are mixed together and continuously stirred for an extended period. Oxidative polymerization occurs, resulting in the formation of bulk polymers. The application of conducting polymers, such as polyaniline, PPy, polythiophene, and their derivatives, to various materials can be achieved through in situ chemical polymerization. This method can be performed using either a single or double-bath approach. In the single-bath method, both the monomer and oxidant solutions are blended in one container while simultaneously immersing the textile substrate into it, illustrating this process. For the double-bath approach, treatment with a monomer solution takes place first before immersion into an oxidant solution or vice versa, as shown in this procedure. As

polymerization commences during both methods, some polymers deposit on the textile substrate due to adsorption, while others remain present in bulk within the solution, causing its color to change to greenish-black, which denotes that polymer formation has occurred. [38, 39] Compared to other forms of in situ polymerization techniques available today, this particular technique is simpler, with easy-to-follow experimental setups suitable for laboratory preparation as well as mass production of conductive textiles, provided PPy exhibits some affinity towards. [38]
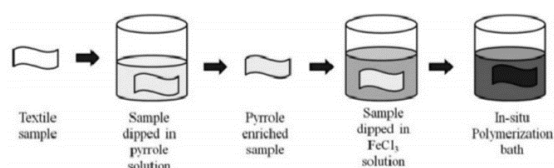

Figure 9: In situ chemical polymerization by double-bath process.

In situ electrochemical polymerization

Electrochemical polymerization is typically conducted in a one-compartment cell that contains two electrodes, such as an anode and cathode, which are connected to an external power supply. The cell is filled with a monomer solution containing suitable electrolytes and dopants. In most cases, the electrolytes also act as dopants. When the monomer undergoes electrochemical oxidation, it forms polymer films on the surface of the anode. If the anode surface is covered by a textile substrate, then polymers will deposit on it. The rate and yield of polymerization depend on various factors such as electrode material, solvent type, electrolyte composition, voltage supplied, temperature and time . Different types of electrolysis techniques can be employed including potentiostatic (constant potential), galvanostatic (constant current) and potentiodynamic (potential scanning or cyclic voltammetry) methods. Potentiostatic and galvanostatic methods are particularly useful for investigating nucleation mechanisms and macroscopic growth of polymers while potentiodynamic techniques like cyclic voltammetry provide information about redox processes during early stages of polymerization reaction along with examining electrochemical behavior after deposition. However this process has limitations due to the size constraint imposed by sample preparation. Chemical vapor phase deposition can be used to produce conducting polymers through. [39]

In situ vapor-phase polymerization

This, and dopant, followed by drying before exposing them to monomer vapors for subsequent polymeric coating formation through chemical reactions at fiber surfaces. The vapor-phase preparation process involves impregnating textiles in aqueous solutions containing oxidant. Fabrics exhibit highly uniform coatings, resulting in reduced variability in surface resistivity while improving fastness properties towards light exposure and washing effects, despite the complicated equipment setup and difficulties in controlling it. [40, 41]

Solution coating process

Conducting polymers are insoluble in most of the solvents available. But by grafting some functional groups in the polymer chain, it can be made soluble in some selected solvents. Synthesis of soluble PPy can be possible in the form of a PPys, which increases with the increase in the length of the alkyl chain attached. Pyrroles can be pre-packaged in aerosol cans or be commercially available to the pyrrole ring without significantly affecting the conductivity. These soluble alkyl paints can be applied directly to any surface in any desired pattern for intelligent textile applications. The main advantage of soluble conducting polymers is that they can be directly applied to any substrate, which avoids exposure of the surfaces to damaging oxidizing agents and fulfills the requirements for controlled laboratory conditions. [42, 43]

In situ polymerization in supercritical fluid:

As discussed above, textile materials can be successfully coated with conducting polymers. However, washing conductive polymer-coated textiles remains problematic, as the polymers lose conductivity after washing. Improved washing conductivity has been achieved by using in situ polymerization of polyaniline and PPy in supercritical CO_2 onto polyester and polyamide fibers. The main advantage of using this technology is that the environment of supercritical fluid during polymerization helps the substrate polymer to expand, allowing the pyrrole monomer to penetrate it. As a result, a much more durable electro-conductive textile can be prepared. However, this process is costly and the setup is complicated. [44-47]

Conductive polymers for smart textile applications

Durable superamphiphobic (superhydrophobic and superoleophobic) electrically conductive fabric was created by Wang et al. using a one-step vapor phase polymerization of EDOT in the presence of fluorinated alkyl silane (FAS) and fluorinated decyl polyhedral oligomeric silsesquioxane (FD-POSS). The substrate was made of plain-weave,

commercial polyester weighing 168 g/m2. The surface resistance of the PEDOT was not significantly affected by the addition of FD-POSS and FAS. It can give the PEDOT coating long-lasting liquid repellency and the capacity to recover itself after suffering chemical harm. It was discovered that FD-POSS significantly improved the coating's capacity for self-healing, cleaning, and abrasion resistance.[45]

Research progress in conductive polymer-based electrochromic fabrics

Because of their flexibility, light weight, high degree of controllability, and wide range of color change, conductive polymer-based electrochromic fabrics offer promise for use in novel intelligent displays, flexible smart wearables, and military camouflage. The optoelectronic characteristics of metals and semiconductors are combined with the elastic mechanical and processing properties of polymers to create conductive polymer-based electrochromic materials. These materials also offer the benefits of easy synthesis, cheap material costs, quick response times, and a broad color tunability.The current electrochromic fabric research focus is conductive polymer-based electrochromic fabrics (CP-ECFs), which show significant promise for new applications such smart wearables, military camouflage, detection, and ornamentation. The military environment as well as the welfare of human civilization can both profit immensely from these applications. [48]

Conductive polymers used in CP-ECFs

Thiophene derivatives are the focus of most research, and numerous fruitful outcomes have been attained. Among thiophene derivatives, poly3, 4-ethylene dioxythiophene (PEDOT) is one of the more researched conductive polymers because to its superior qualities, which include excellent electrical conductivity, good film formation, high stability, and facile color modification of the film. [48] The conjugated π-bond structure of PEDOT: PSS undergoes a color change due to a change in electron energy gap. When ions and electrons are driven by an external voltage to migrate reversibly in and out of the PEDOT: PSS molecular chain, they introduce carriers such polaritons and dipolaritons. [49] This results in a change in the molecular structure of PEDOT: PSS, which alters the size of the energy gap Eg. This causes a change in PEDOT: PSS's ability to absorb visible light, which is shown as a color shift. [50, 51]

Research progress of CP-ECFS

There are now two primary approaches to the research of CP-ECFs. Two methods are available for creating electrochromic materials: the first involves forming them into thin films and laminating them with electrode and electrolyte layers to create ECFs; the second method involves forming electrochromic materials directly into fiber filaments and then knitting or weaving them into fabrics to create ECFs. The four types of CP-ECF designs that are covered in this part are layered, single-layer, laterally designed, and CP-ECFs based on electrochromic fiber design. In light of this, the current state of CP-ECF research is evaluated.[44]

Single-layer design CP-ECFs

By depositing conductive polymers onto the fabric's surface, single-layer CP-ECFs can be created, resulting in conductive fabric with superior characteristics. [52],[53] Nevertheless, because they aren't put together into full devices, their color-changing effect is limited to the electrolytic cell. In order to create the single-layer design CP-ECFs, some early research used fabrics as substrates and deposited conductive polymers on fabric surfaces by chemical oxidation, electrochemical oxidation, and chemical vapor deposition.81 Li et al. [54] for instance, created PEDOT/PET conductive textiles by chemically oxidizing PEDOT onto PET fibers. The platinum wire was wrapped around PEDOT/PET as the working electrode using a three-electrode method: a platinum electrode served as the counter electrode, a saturated glycerol electrode served as the reference electrode, and 0.1 mol/L solutions of HClO4 acting as the electrolyte. An application of voltage ranging from -0.42 V to 1.0 V might cause the cloth to shift from grayish blue to dark blue-black.

The same year, the team applied voltage to the cotton fabric using the three-electrode approach and deposited PANI on it to create PANI/CTT conductive fabric. The fabric could transform from yellow-green to dark green with good cycle reversibility when a voltage of -0.45 V to 1.0 V was applied.83 In order to create PANI/PET conductive fabric, Molina et al.84 synthesized PANI on the surface of PET fabric by electrochemical oxidation. The PANI/PET conductive cloth was sandwiched between a platinum sheet, which served as the working electrode, and stainless steel wire, which Ag/AgCl as the reference electrode, 0.5 mol/L sulfuric acid solution as the electrolyte, and the counter electrode.the fabric can shift from yellow-green to dark green when a voltage of −1 V to +2 V is applied. In order to create P3MT/PET conductive fabric, Mokhtari et al.85 chemically oxidized 3-methyl thiophene (P3MT) onto the surface of PET fabric. When 0–12 V was applied, the color of the fabric changed from yellow to red. In order to create P3MT/PET and P3HT/PET conductive fabrics, Jahan et al.81 applied poly (3-methyl thiophene) (P3MT) and poly (3-hexylthiophene)

(P3HT) by chemical vapor deposition on the surface of PET fabric. The P3MT/PET conductive fabric turned red when applied from 0 to +12 V The yellow-green P3HT/PET conductive cloth turned a dark green color. [55]

Layered design CP-ECFs

As single-layer CP-ECFs lack an assembled electrolyte layer, their color-change effect can only take place within an electrolytic cell and they cannot be considered true ECDs. Hence, at this stage, CP-ECFs are frequently designed with a layered structure. In earlier research on layered CP-ECFs, researchers commonly utilized a transmissive structure, For example, Beaupré et al., based on a transmission-type structure with ITO-coated polyester plastics as working electrodes, conductive fabrics as opposites, conductive polymer PT (BuTPA) films as electrochromic layers, and LiClO$_4$-PMMA-PC gel electrolytes as electrolytes, assembled the various layers of materials to obtain flexible CP-ECF. The final product can change color at different voltages, as shown in . Chang et al. prepared CP-ECFs with PET/ITO as the transparent electrode, PANI as the electrochromic layer, PMMA-based gel electrolyte as the electrolyte layer, and copper-coated conductive fabric as the conductive fabric and found that the fabric color changed reversibly between primary color, black, and brown when the voltage across the fabric varied from −1.5 to +1.5 V.[55]

Lateral design CP-ECFs

When the structure is mechanically bent, the two laminated electrodes in a layered-design CP-ECF are prone to making contact. As a result, there is a short circuit, and the laminated structure is more likely to separate and slip. Researchers have used a lateral structure to get around the aforementioned problems in order to tackle this challenge; its basic structure is displayed in . For instance, Yu et al. created side-by-side conductive ITO electrodes by spraying ITO liquid over the fabric's surface while wearing a mask. The working electrode was subsequently created by spraying conductive polymer PG3 on one of the electrodes; the counter electrode was the electrode that did not have PG3. In order to create laterally organized CP-ECFs, the gel electrolyte was finally placed dropwise over the two electrodes, as demonstrated in. Consequently, the When the positive voltage was applied, the working electrode's color changed from green to earth brown, and when the negative voltage was applied, the working electrode's color returned. Furthermore, as demonstrated in, these CP-ECFs kept their good electrochromic qualities even after undergoing numerous bending and twisting cycles. The CP-ECFs' lateral design is incredibly flexible

and stable, maintaining the fabric's natural lightness and thinness while showcasing electrochromic capabilities. All of these features make the design extremely useful. [55]

CP-ECFs based on fiber design

The majority of CP-ECFs with the aforementioned structure have coatings made of conductive polymers applied to the fabric's surface. In general, CP-ECFs have low air permeability. However, CP-ECFs designed with an electrochromic fiber have attracted attention because of their great flexibility, which makes it easier to weave them into different textiles and helps to address the low air permeability problem. [56] The three forms of electrochromic fibers are core-shell structure, intertwined structure, and parallel structure, which are based on the relative positions of the working electrode and counter electrode. [57]

Studies on electrochromic fibers with core–shell architectures are somewhat scarce. Sheng et al. [58] used a straightforward cosolvent evaporation technique to phase separate and create monodisperse BisDDLC-Ms with core–shell topologies and interface migration behavior in O/W emulsion. The Short-range dye-doped liquid crystal (DDLC) configurations make up three-dimensional (3D) network structures, and paraffin in microcapsules gives DDLCs a sufficient and adjustable anchoring force. The microcapsules exhibit outstanding bistable photoelectric stability (lasting over a week) and a reversible color-change performance from gray-red to colorless, all thanks to their unique construction and a reduced driving voltage of approximately 7.4 V. The optimized microcapsules and fibers can exhibit reversible changes in optical appearance between colored and colorless states based on the applied electric field. [45]

Conductive polymer-based electro-conductive textile composites for electromagnetic interference shielding:

Preparation of textile EMI shield

We can shield ourselves from electromagnetic radiation by enveloping ourselves in an electroconductive material that has the ability to produce and transfer free charges. It is well known that synthetic textile fibers, including cellulose-acetate, acrylic, polyester, and polyamide, have extremely low electrical conductivity and are hydrophobic by nature. Static charge is produced and builds up on the fibers when these fiber masses are brushed. [59, 60] Natural fibers with comparatively higher electric conductivity and a higher hydrophilic property—such as cotton, wool, and silk—help dissipate static charges. They work

well for dissipating static charges, but they are ineffective as an electromagnetic shield. [61] Metallic fibers, or fibers coated in a metal, are frequently utilized as an electrically conductive material for this purpose. [62-65] Furthermore, Electro-conductive yarns are made by staple spinning with metal fibers. [65, 66] The fiber coated with a polymer dope comprising particles of silver and carbon black, or other electrically conductive materials, is also deemed undesirable due to the high cost of the coating procedure and the ease with which the coated layer can separate from the fiber during processing. [67] Based on the weight of the fiber matrix polymer, at least 15% of carbon black is needed when using it in dope mixing with polymer to spin a conductive filament. Because of the high concentration of carbon black, the process of manufacturing fibers is challenging, intricate, and costly. Furthermore, carbon black cannot possibly be contained inside natural fibers. It is possible to effectively get around several of these processability, flexibility, and durability constraints by coating or applying conducting polymers like polyaniline. textile substrates containing polypyrrole (PPy) and polythiophene. [68] These conductive polymer-coated textile materials are thought to be promising for electromagnetic radiation shielding due to their flexibility, toughness, simplicity of preparation, and ease of application. [69, 70]

Conductive polymer-coated woven fabrics for electromagnetic shielding

In situ chemical polymerization is used to polymerize aniline and pyrrole on insulating materials such as polyester, glass, and high silica materials. conducting polyaniline-coated polyester textiles have a shielding performance in the range of 30–40 dB in the radio frequency range of 100 to 1000 MHz. According to conductance experiments on polyaniline-coated cloth, 2% of the energy is reflected back and 98% of the energy is absorbed in the UV, Vis, and NIR range. Whereas 82% of the energy is absorbed and 18% is reflected back in polythiophene-coated fabric, 96% of the energy is absorbed in PPy-coated fabric and just 4% is reflected back . A good shield should absorb all energy and allow for no reflection. The efficiency of the shielding 89.9% at 18 GHz is reported for PPy-coated nylon/lycra fabric produced with an anthraquinone-2-sulfonic acid dopant. [71] On a polyester woven fabric, PPy is sequentially polymerized chemically and electrochemically to create a composite with an extremely low electrical resistance of 0.2 Ωcm. As seen, the EMISE measured with this composite is around 36 dB throughout a broad frequency range up to 1.5 GHz. Researchers discovered that the composite EMI shielded by both absorption and reflection, that EMI

shielding by reflection rises with electrical conductivity . [72] and that the composite absorbs 7% of the input electromagnetic wave's power. [66] On the surface of insulating materials, conducting PPy sheets with excellent adhesion and conductivity are successfully polymerized. chemical polymerization of epoxy resin substrates, those films demonstrate EMISE in the practical range of roughly 30 dB over a broad frequency range from 30 to 1500 MHz. At a frequency of 101 GHz, PPy-coated polyester and silica cloth exhibit EMISE values of 21.48 and 35.51 dB, respectively. [66]In the 800–2400 MHz frequency range, the conductive fabric made from PPy coating on glass fiber textiles with resistivity ranges < 500 Ω/Υ demonstrated 98.67% to 99.23% signal loss. [66] samples with low resistivity or high conductivity exhibit higher shielding efficiency than samples with high resistivity. These textiles are suggested for use as shields for wireless phones, FM/AM radio broadcast sets, and home appliances. cell phones, PCs, structures, hidden chambers, and other electrical devices with a 2.4 GHz operating frequency. [66] Silver (Ag) is thermally vacuum-evaporated on the surface of PPy–polyester complexes in a different investigation. As the area of the Ag evaporation layer rises, so does the EMISE of fabric complexes. The EMISE is 29 dB at 0.5 GHz when the Ag is partially (around 37%) evaporated on one side of the fabric complexes, and 33 dB in the same frequency range when the Ag is evaporated on the entire sample. the area and array of the low conducting PPy layer and the high conducting Ag layer can regulate the EMISE and absorbance/reflectance of the shielding material. It is discovered that PPy/Al2O3 textile nanocomposite is appropriate for an efficient EMI shield in the 8–12 GHz frequency range and might have the capacity to absorb almost 53% of microwave radiation. [66]

Conductive polymer-coated nonwoven fabrics for electromagnetic shielding

In the frequency range of 100 to 800 MHz, the EMISE of PPy-coated polyester hydro-entangled nonwoven fabrics is investigated. [66] It is discovered that there is a positive association between certain nonwoven fabrics' surface conductivity and SE. The sample with the lowest surface resistivity, 3 Ω/Υ, had an EMISE of 37 dB. [66] PPy-coated polyester nonwoven composite fabrics exhibit an effective EMISE of 20 dB at 1 GHz frequency in another investigation. [73] The EMISE of these nonwoven textiles can be improved by up to 55 dB by coating them with Ag particles, and the EMISE of their multilayer complexes can reach up to 80 dB. Because of their high absorption and low reflection, PPy-coated nonwoven textiles are suggested as superior radio frequency and

microwave absorbers. PPy-coated textile textiles are said to exhibits a strong EMISE of absorption in low conductivity samples and a dominant EMISE of reflection in high conductivity samples. [74] According to published research, EMISE of certain conductive textile materials suggested as an efficient shield.

PEDOT:PSS-Based Conductive Textiles and Their Applications

PEDOT:PSS Based Conductive Polymer Composites

PEDOT:PSS is widely recognized for its exceptional conductivity and its use in conductive fabrics. It has demonstrated promising outcomes in a variety of applications. Unfortunately, the brittleness of pure PEDOT:PSS now limits its usage. As previously said, utilizing conventional commodity polymers to create a composite can enhance its mechanical flexibility. Hilal and Han created graphene (G) and PEDOT:PSS composites that have enhanced electrical conductivity by 63% over a pristine PEDOT:PSS for solar cells. [75] Giuri et al. produced GGO-PEDOT composites with thermal stability up to 270°C for super capacitors. [76] A thermoelectric PEDOT:PSS/PU blend with enhanced ductility and acceptable conductivity was reported by Taroni et al. Silver flakes, PEDOT:PSS, phosphoric acid, and polyvinyl alcohol (PVA) that Houghton et al. discovered that it can withstand approximately 230% strain before breaking .Additionally, to improve the electron transport via the PEDOT:PSS matrix, an electro-active bacterium was embedded inside a conductive three-dimensional PEDOT:PSS matrix to create a PEDOT:PSS-based multi-layer bacterial composite PSS. [77]

Methods of Treating Textiles with PEDOT: PSS

PEDOT: PSS can be applied to textile materials using either a polymer PEDOT: PSS dispersion placed onto a textile substrate or an in-situ polymerization of 3,4-ethylenedioxythiophene (EDOT) on the textile substrate in the presence of PPS. PEDOT based conductive textiles can generally be made by putting the polymer into a polymer solution during fiber spinning, coating/dying textile substrates (fibers, yarns, fabrics), and/or printing textile fabrics. [77]

Spinning of Conductive Fibers

This method creates conductive fibers or filaments by adding PEDOT: PSS to a traditional polymer solution during fiber wet spinning or electrospinning. Alternatively, PEDOT: PSS can be spun into a fiber on its own. Okuzaki and Ishihara first reported on the production of 4.6 to 16 μm

PEDOT:PSS microfibers with an electrical conductivity of 0.1 S/cm using wet-spinning in 2003. [78] The generated microfibers had a Young's modulus of 1.1 GPa, a tensile strength of 17.2 MPa, and an elongation at break of 4.3%, respectively. By post-treating the fibers with ethylene glycol, Jalili et al. described a simpler wet-spinning method for continuous PEDOT:PSS fibers that demonstrated a conductivity of up to 223 S/cm. [79] In Using a different strategy, they combined PEDOT:PSS and poly(ethlylene glycol) in an aqueous blend, and the fibers' conductivity rose 30-fold (from 9 to 264 S/cm) without the requirement for a post-treatment. Through wet-spinning, Okuzaki et al. produced PEDOT:PSS microfibers with a diameter of around 5 μm. [70] They next dipped the fibers in ethylene glycol, increasing the electrical conductivity of the fibers from 74 S/cm to 467 S/cm. The dip-treatment also enhanced the microfibers' mechanical qualities; their tensile strength and Young's modulus rose from 3.2 GPa and 94 MPa to 4.0 GPa and 130 MPa, respectively. Zhou et al. used wet-spinning followed by post-spinning to further increase the electrical conductivity of wet spun PEDOT:PSS microfibers to 2804 S/cm. hot-drawing and ethylene glycol treatment. [80] The combined effects of the vertical hot-drawing method and the ethylene glycol doping and dedoping of the microfibers are responsible for this high conductivity. Additionally, they possessed exceptional mechanical properties with a Young's modulus of up to 8.3 GPa, a tensile strength of up to 409.8 MPa, and a significant elongation before failure of 21% at a semiconductor metal transition at 313 K. Moreover, J. Zhang et al. performed a wet spinning of PEDOT:PSS fiber and, by employing a fine gauge needle to reduce the fiber diameter, improved the conductivity of the PEDOT:PSS fiber to 3828 S/cm .Figure 4a illustrates the modifications made to the wet-spinning setup. Additionally, Liu et al. created composite conductive fibers based on wet blending of PEDOT:PSS with polyacrylonitrile. [81] rotating. Conductivity in fibers containing 1.83 weight percent PEDOT:PSS was 5.0 S/cm. In order to create an electrically conductive and highly stretchable PU/PEDOT:PSS fiber, Seyedin et al. scaled up the process of fiber wet-spinning . These fibers were then utilized to weave a prototype knee sleeve that would be used for personal training and injury rehabilitation. The fiber demonstrated a wide strain sensing capacity up to 260 % strain and a conductivity of 166 S/cm, very similar to pristine PEDOT: PSS film.

PEDOT Polymerization on a Textile Substrate

Using EDOT and suitable chemicals such as oxidants, the PEDOT monomer can be electrochemically polymerized on the textile

substrate (fiber, yarn, fabric, or garment form) via vapor phase, in situ, or electrochemical polymerization. [82] This process involves coating the textile with PEDOT polymerization.

The chemistry of the fiber and its surface roughness both affect how PEDOT adheres to the fabric's surface. Even though direct PEDOT polymerization on textiles appears simple, controlling the conditions is challenging. Additionally, it is a difficulty for industrial applications and employed for small sample sizes. Five cycles of PEDOT in-situ polymerization were performed by Hong et al. on poly(trimethylene terephthalate) textiles in after butane treatment, ferric chloride and ferric p-toluenesulfonic acid were present as oxidants, and an electrical conductivity of 3.6 S/cm was obtained. [83] In the presence of Fe (III) chloride hexahydrate oxidant, Bashir et al. reported the oxidative vapor phase polymerization (VPP) coating of PEDOT on an electrically conductive polyester fabric with an electrical resistance of around 2000 Ω. Using the same method, they were also able to produce nylon, aramid, and viscose fabrics that conduct electricity. In a different study, they used oxidative chemical vapor deposition to create a conductive viscose yarn with an electrical resistance of 6 kΩ. However, before the oxidant enrichment and polymerization stages, they eliminated contaminants such acetone and ethyl acetate [81]. Additionally, Trindade et al. used VPP to coat a polyester cloth with PEDOT and saw a decrease in Fe (III) chloride hexahydrate concentration can be increased to achieve a sheet resistance of around 20 °C/sq [82]. Depending on the porosity of the fabric, L. Zhang et al. coated textile fabrics (silk, linen, wool, pineapple, and bamboo rayon) with PEDOT by VPP and got a sheet resistance ranging from 200 to 9.46 kΩ [83]. Porous fabric yields a greater sheet resistance than tight-fabric. In general, the concentration of oxidants, the pretreatment and posttreatment of the conductive fabric, the kind and form of the textile substrate, and the polymerization conditions all affect the electrical and mechanical properties of conductive textiles.[84]

Textile Coating and Dyeing with PEDOT: PSS

Using the proper auxiliary chemicals, the suitable type of cloth is immersed or dipped in a PEDOT: PSS dispersion in order to apply the coating or dyeing technique. This technique imitates the continuous dyeing procedure or exhaust dyeing method used in commercial textile manufacturing. This is the approach that is most frequently used to create conductive fabrics using PEDOT:PSS. The textile's functional group determines both the consistency and depth of the coloring or coating. By impregnating cotton, cotton/polyester, polyester, and nylon/spandex fabrics with PEDOT: PSS, Ding et al. demonstrated that materials that swell well in water have better conductivity . Using PEDOT: PSS, Ryan et al. were able to color silk yarn up to 40 m in length with a conductivity of about 14 S/cm, making it resistant to machine washing . The rationale behind washing The dyeing effect and the presence of the fluorosurfactant Zonyl FS-300, which is employed during dyeing, are what cause PEDOT: PSS to be durable on silk. The cotton became very frail after dying it using the same technique because the highly acidic PEDOT: PSS hydrolyzed the cellulose. In addition, the same group showed how to continuously dye more than 100 meters of silk thread with PEDOT:PSS to create a functional thread that is resistant to wear and washing and has a conductivity of roughly 70 S/cm. [85] PU fibrous nonwoven was created by Ding et al. and dip-coated with PEDOT:PSS . By changing the number of dip-coating times, the PEDOT: PSS@PU nonwovens demonstrated sheet resistance of 35–240 Ω/sq (electrical conductivity of 30–200 S/m). The surface resistivity of this conductive nonwoven was not compromised. potential for wearable applications, with up to 50% strain. Moreover, Tadesse et al. treated polyamide/lycra elastic fabric once with PEDOT: PSS, demonstrating a sheet resistance of approximately 1.7 Ω/sq. Up to washing cycles, the cloth retained a reasonable conductivity and was stretchable up to approximately 650%. In this instance, the dyeing effect—which results from a chemical interaction between the fiber and PEDOT: PSS—also contributes to the washing durability. [1]

Printing of PEDOT: PSS on Textiles

Printing is a sophisticated industrial textile processing technique that applies PEDOT:PSS to the textile structure while thickening agents are present to achieve the right paste or ink viscosity. Guo et al. showed how to create all-organic conductive wires by applying PEDOT:PSS to nonwoven polyethylene terephthalate (PET) using patterning techniques like inkjet printing and sponge stencil. This allows for a wide range of resistance, from tens of kΩ/sq to less than 2 Ω/sq, which can be customized to a particular application [88]. Screen-printed PEDOT:PSS electrocardiography (ECG) circuitry was integrated on completed textiles by Sinha et al. They also recorded an ECG signal similar to Ag/AgCl coupled to copper wires. Zhao et al. additionally employed screen-printing to create a disposable electrochemical sensor based on carbon and PEDOT:PSS for the sensitive and targeted measurement of carmine . A PEDOT:PSS conductive polymer composite was coated on a knitted cotton fabric by Tseghai et al. using flat screen printing, yielding a sheet resistance of 24.8

kΩ/sq . Up until the point at which stretching occurs, the conductive textile fabric remains conductive. [1]

Applications for PEDOT

Conductive Textiles Based on PSS

As previously mentioned, PEDOT: PSS has good biocompatibility, strong electrical conductivity, thermal stability, and solution processability. A variety of textile-based applications, such as sensors, energy harvesting, and storage devices, find it appealing because to these intriguing features. [1]

Sensors

Because textile-based sensors are lightweight, flexible, and washable, there is a growing market for them. Textiles based on PEDOT:PSS have found extensive application as a biopotential, temperature, pH, humidity, strain, and humidity sensor. In order to create conductive, breathable, and lightweight mercerized cotton fabrics, Zahid et al. used graphene nanoplatelets dispersed in PEDOT:PSS solutions. These fabrics demonstrated a highly consistent and stable response to cyclic deformation tests at 5% and 10% strain rates for up to 1000 cycles, with approximately 90% viscoelastic recovery levels following cessation . As an illustration of bio-potential sensors, Kang reported on a resistive memory graphane-PEDOT:PSS coated nylon thread with a strain response for wearable applications . A strain sensor was created by Seyedin et al. using PU/PEDOT:PSS fibers with 9.4 S/cm conductivity . This textile sensor's resistance holds steady for up to 500 cycles and 160% strain. Upon stretching, the highly conductive textile-based hybrid demonstrated excellent stability. For bio-potential recordings conducted on humans, Pani et al. created a novel textile ECG electrode based on woven fabrics coated with PEDOT:PSS. The electrode was assessed in terms of skin contact impedance and the quality of ECG signals collected both at rest and during physical activity . The electrode's ability to function in both wet and dry environments was discovered, which could represent a significant advancement in wearable cardiac monitoring. Ankhili et al. created an ECG sensor electrode using cotton fabric that had been screen-printed with PEDOT:PSS, and they were able to acquire distinct ECG wave amplitudes up to 50 washings cycles [94]. With a similar outcome to silver-plated cotton fabric at 12.8 wt% of PEDOT:PSS to pure cotton, the same group also produced washable screen-printed cotton textile electrodes with and without lycra of different PEDOT:PSS concentration, offering a medical-quality ECG signal to be used for long-term ECG measurements

. Using PEDOT:PSS textile electrodes, Niijima et al. created "hitoeCap" to secure electromyography of the masticating muscles . [66]

Flexible and wearable actuators

Antenna, organic light-emitting diodes (OLEDs), and flexible, wearable actuators are highly needed. Fabricating these devices on fabrics is excellent because of the intrinsic characteristics of PEDOT:PSS. For example, Li et al. used PEDOT:PSS as a patch and ground on polyester fabric to create a screen-printed textile patch antenna that can function at 2.4 GHz . Because of its flexibility and breathability, the antenna is a good fit for wearable technology.

Another area where smart fabrics are being used is in actuators. By applying alternating square-wave voltages between 0 and 8 V, Miura et al. created a foldable PEDOT:PSS/PVA fiber through wet spinning that displays a reproducible contraction motion at air . By screen printing silver as the bottom electrode, barium titanate as the dielectric, copper-doped zinc oxide as the active layer, and PEDOT:PSS as the top electrode on polyester fabric, Verboven et al. produced an OLED with preserved textile qualities . This OLED requires a 3–5 V power source. With an OLED thickness of only 0.5 µm on the textile fabric, it makes for a viable platform for wearable applications. [76]

Fabrication, Properties, and Operation of Conductive Materials: Cotton and PANi

The flame-resistant properties of cotton and pani fabrics

We examined these materials' ability to withstand flames by 20-cm-long yarns were suspended from them, and the bottom end of the strands was burned. In contrast to the control cotton, the yarns produced incredibly positive outcomes. Table I presents the findings.

After adding polyaniline, it took a lot longer to bum the samples than it did for the control samples. It should be noted that the treated fabric took a while to begin burning and burnt extremely slowly once the flame was applied. The cloth that was treated with polyaniline exhibited strong thermal stability and also developed good flame resistance. Observe that despite the For a given combination of monomer and oxidant concentrations, the time required to burn a certain length of the sample was constant, as were the diffusion and polymerization times. It was, nevertheless, greater for samples treated with antineole at higher doses (0.5/0.5) as opposed to lower quantities (0.05/0.05).

The samples exhibit good flame retardancy even with delayed ignition, although they are not completely fireproof. Table I demonstrates the

exceptional flame retardancy of these fabrics by showing that there was a larger than 100% increase in the time taken to burn, even for relatively modest loadings or incorporations of conducting polymer. Furthermore, at a leading level of roughly 7-9% of the conducting Starting from roughly 2%, the sample bummed up to a further 100% in time. [86]

The effectiveness of cotton + PANI fabrics for EMI shielding

The frequency range used and the diffusion/polymerization time have a significant impact on shielding efficiency. For all concentrations and frequency ranges, the shielding efficiency generally declines as the diffusion time or polymerization time decreases. This demonstrates that a decrease in polymerization time results in a decrease in the amount of transformed monomer. In comparison to the sample generated with a longer diffusion period, we can say that polymer production is less as the diffusion time reduces since the diffused monomer concentration is decreasing on its own. Additionally, given the frequency for every frequency band examined, the efficiency falls.

Following two hours of redoping the fabric samples with 1 M HCI and a 24-hour drying period in ambient settings, we also conducted EMI shielding studies because the conductivity of the cotton + PANi fabric samples increased after redoping. Table I displays the EMI shielding efficiency values for the fabric samples before and after redoping. For all treatments, these values have increased after redoping. [86]

Using PANI and Cotton Composite Materials as Gas Sensors

Examining how well these composite conductive fabrics work in terms of gas detection is fascinating. This is the guiding idea for these kinds of responses: the arriving gaseous molecules' electronic cloud interacts if the molecule contains atoms that are electron-donating in nature, such as NH3, or greater delocalization if the molecule contains atoms that are electron-accepting in nature, such as oxygen, with the charged species present on the conducting polymer backbone. Observe that the current drops noticeably as the ammo-nia fumes enter the chamber and then stabilizes for ten minutes. When the gas supply ceases and the pumping begins, the Once more, current values begin to rise, although not as much as those of the composite conducive fabric that is not exposed. This behavior is comparable to that of PANi prepared by the conventional approach and exposed to ammonia gas, implying that the reason for the reaction is The cellulose molecules interact with the Pnrri molecules, and the cellulose structure is not readily altered. SEM analyses show that the material is deposited quite uniformly and densely

PANi molecules, even following a rigorous cleaning. Cotton textiles impregnated with PANi exhibit superior thermal stability, according to thermal studies. The conductivity studies unequivocally demonstrate that, despite being integrated into a nonconducting insulating matrix, the conduction mechanism is that of the virgin conducting polymer. The outcomes of the tests conducted on washability, redoping, flame retardancy, and EMI shielding with 1 M HCI demonstrate that these conductive fabric samples are superior materials suitable for use in industry, stealth technology, and specific anti-flammable apparel. [86]

Development of conductive textile fabric using Plackett–Burman optimized green synthesized silver nanoparticles and *in situ* polymerized polypyrrole

It can be difficult to strike a compromise between producing environmentally friendly e-textiles and high-performing ones. This paper describes the composite of conjugated polymer polypyrrole (Ppy) with green produced silver nanoparticles (AgNPs) to produce an inexpensive conductive textile fabric. For the purpose of synthesizing AgNPs, lime peel extract (LPE) mediated reduction was optimized using a Plackett–Burman design of experiment. The size and UV-vis absorption maxima of the LPE-synthesised AgNPs were shown to be significantly influenced by the concentration of silver nitrate, with reaction temperature also having an impact on these parameters. The optimized AgNPs that were produced had a consistent size range of 40–80 nm and dispersity of PDI = 0.250. AgNPs produced with LPE are combined with linen textile to create an AgNP-Ppy nanocomposite, which results in an e-textile with low resistance to electricity (37 Ω). [87]

Experimental design extract from lime peel

Finely chopped lime peel (LP) was cooked in distilled water to 100°C for 20 minutes before being filtered.

Experimental design

PB stands for Placket-Burman experiment design.

Silver nanoparticles synthesis

LP extract added to silver nitrate solution according to PB defined parameters.

Synthesised silver nanoparticles (AgNPs) characterised.

E-textile development

E-textile sample added to AgNP and pyrrole solution [88]

Polymerisation initiator added

Reaction left to progress

E-textile analysis

E-textile sample removed from solution to air dry before characterization [87]

Concluding remarks

The goal of this endeavor was to create a dependable and uniform process for creating e-textiles while reducing adverse environmental effects. AgNPs were developed using a plant-based textile fabric and a green synthesis technique. Utilizing a Plackett–Burman DOE, the LPE synthesis was optimized. It was discovered that in the lime peel-mediated AgNP synthesis, AgNO3 concentration and reaction temperature were statistically significant. This work has demonstrated that homogeneous AgNPs with a PDI of 0.250 that are tailored to a size between 40 and 80 nm may be synthesized efficiently using LPE. AgNPs that were synthesized via LPE were combined with Ppy to create an e-textile that had a low electrical resistance of 9.56×10^1 Ω/sq. elemental inorganic After removing the Ppy and linen fabric, the examination showed that PAL-11, the sample with the lowest electrical resistance, had a 92% chlorine content (caused by the Cl− counterions in Ppy) and 1% silver content, showing that the AgNP-Ppy linen e-textile had been successfully doped. The e-textile sample grew more electrically resistant during the wash testing process, but it did not lose its electrical conductivity. The electrical characteristics of the e-textile sample persisted even after it was bent, suggesting that it could find utility in sensing. All things considered, these findings point to AgNP-Ppy based e-textiles as a viable path toward the creation of highly conductive, environmentally friendly e-textiles that can be made with straightforward, scalable procedures. To improve percolation, more research on the physicochemical structure of AgNP-Ppy on linen and on Ppy production using AgNP would be beneficial network and robustness in terms of washing. [87]

Conclusion

The preparation and development of conductive polymers are reviewed in this article. Here are several techniques for adding conductive polymers to textile surfaces, along with a comparison of their benefits and drawbacks. Applications to electrically conductive textiles and woven and non-woven fabrics coated with conductive polymer are taken into consideration.

Conflict of Interest

The authors declared no competing interests in the publication of this article

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المنسوجات المطلية بالبوليمرات الموصلة وتطبيقاتها

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المستخلص:

يمكن تعريف البوليمرات الموصلة على أنها أملاح كاتيونية وأنيونية للبوليمرات عالية الاقتران. تنتج أملاح الكاتيون عن الأكسدة الكيميائية والبلمرة الكهروكيميائية بينما يتم إنتاج أملاح الأنيون من خلال الاختزال الكهروكيميائي أو الاختزال الكيميائي باستخدام الكواشف مثل نفثاليد الصوديوم. تستعرض هذه المقالة إعداد وتطوير البوليمرات الموصلة ، آلية الموصلية. يتم وصف طرق مختلفة لتطبيق البوليمرات الموصلة على سطح المنسوجات هنا (البلمرة الكيميائية ، البلمرة الكهروكيميائية ، بلمرة طور البخار ، عملية طلاء المحلول ، البلمرة في السائل الحرج الفائق) إلى جانب مزاياها وعيوبها النسبية. يتم تقديم تطبيقات مختلفة للأقمشة الموصلة كهربائيا القائمة على البوليمر الموصل ، مثل الأقمشة الكهرومغناطيسية والأقمشة الذكية وأجهزة الاستشعار والأقمشة الموصلة كهربائيا للحماية من الإشعاع الكهرومغناطيسي ومقاومة اللهب.

الكلمات المفتاحية: بوليمر موصل ، نسيج ذكي ، كهرومغناطيسي ، قطن، كهرومغناطيسي..