INVESTIGATING THE STRUCTURE AND PROPERTIES OF POLYANILINE COMPOSITE THIN FILMS

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Abstract

Polyaniline (PANI) stands as a prominent figure in the realm of conductive polymers, garnering considerable attention from researchers in nanotechnology for its potential in various fields including sensors, optoelectronic devices, and photonic devices. Its popularity stems from its facile synthesis and remarkable environmental stability, attributes that allow for easy doping with different acids and dopants. This survey dives into the horde planning cycles of PANI meager movies, including both compound and actual techniques. Furthermore, it reveals insight into a few key highlights displayed by PANI slim movies, crossing attractive, redox, cell reinforcement, hostile to consumption, electrical, and detecting properties. One of the most prominent qualities of PANI is its excellent conductivity, a property that positions it well in different applications. Its simplicity of blend, somewhat minimal expense, and hearty ecological solidness further improve its allure across different areas, including gadgets, drugs, and hostile to erosion materials. These attributes have spurred extensive research and exploration into the manifold applications of PANI. In the realm of electronics, PANI's conductivity makes it a valuable component in the development of electronic devices, facilitating the efficient flow of charge within circuits. Moreover, PANI's redox properties render it suitable for applications requiring electrochemical activity, such as in batteries and capacitors, where it can serve as an electrode material. Its antioxidative properties make it a candidate for use in materials designed to mitigate oxidative damage, while its anti-corrosive characteristics find utility in protective coatings for metals prone to corrosion. Additionally, PANI's sensing capabilities make it a promising candidate for use in sensors across various sectors, including environmental monitoring, healthcare diagnostics, and food safety. Towards the culmination of this review, a survey of the most significant applications of PANI underscores its versatility and potential impact across diverse domains. From its role in advancing electronic devices to its contributions in enhancing the longevity of metal surfaces through anti-corrosion coatings, PANI continues to captivate researchers and innovators alike with its multifaceted properties and wide-ranging applications. As research in the field progresses, the exploration of PANI's capabilities is poised to unveil further opportunities for innovation and technological advancement in the years to come.

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1. Introduction

lopment of conductive polymers, attributable to their boundless applications in fields like optics, hardware, and energy. These polymers, including polyaniline (PANI), polythiophene (PTH), and polypyrrole (PPY), are gotten through fastidious atomic plan and fitting arrangement processes. Among these, PANI, at first perceived as dark aniline, exists in different structures dependent upon its oxidation level, displaying straightforwardness, natural steadiness, and helplessness to doping by protonic acids. Shaped through the coupling of aniline monomer units, PANI might exist in various oxidation states, described by FTIR benzenoid to quinonoid proportions.

Conductive polymers, especially PANI, brag a plenty of potential applications crossing electromagnetic impedance protecting, photothermal treatment, battery-powered batteries, photovoltaic cells, gas partition films, synthetic sensors, and hostile to consumption coatings, among others. Also, they are used as leading fillers in protecting polymer substrates to yield directing polymer compounds, further extending their utility in electromagnetic impedance safeguards, electronic gear, and show gadget anodes. Regardless of their various benefits, conductive polymers, especially PANI, are not absent any trace of constraints. Difficulties like low handling limit, resoluteness, and absence of biodegradability abridge their materialness in natural settings. PANI's unfortunate dissolvability, affected by its unbending spine, represents another impediment. To address these deficiencies, endeavors have been coordinated towards compound changes, coming about in doped PANI and elective PANI subordinates. Artificially altered PANI shows further developed handling abilities, improved conductivity, and better enemy of erosion properties analyzed than unadulterated PANI.

Moreover, the consolidation of natural and inorganic nanofillers into PANI-based intensifies presents a promising road for upgrading their properties and execution. These methodologies yield materials with synergistic or reciprocal highlights among PANI and natural/inorganic nanoparticles, growing their utility across different areas. Prominently, inherently leading polymers, having attractive, optical, and electric highlights much the same as metals, show worked on electrical conductivity without the requirement for conductive added substances. PANI composites with inorganic nanoparticles have tracked down applications in electrochromic gadgets, LEDs, EMI protecting, electrostatic release frameworks, batteries, and substance and biochemical sensors, attributable to their synergistic impacts.

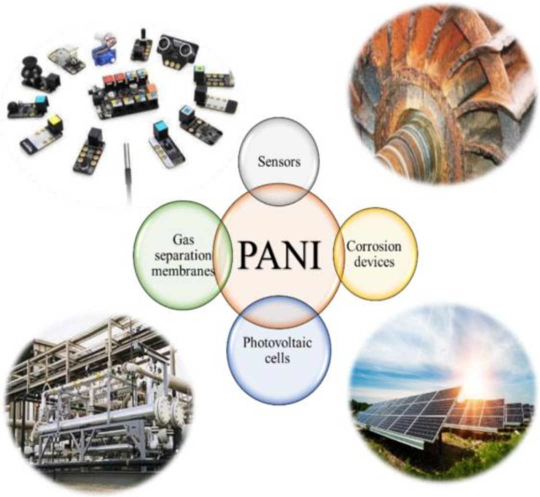

Figure 1.Polyaniline in different applications.

2. History of Polyaniline Development

This study gives an extensive outline of the progressions in polyaniline (PANI) synthetic change and its applications over late many years, meaning to lay out a nearby association between PANI substance adjustments and down to earth utilizes. Moreover, it dives into the readiness strategies for PANI and PANI slim movies to offer a basic comprehension for future exploration tries. The historical backdrop of PANI improvement traces all the way back to 1977 when Shirakawa revealed the replacement of polystyrene with a conductive polymer, featuring the soundness of conductive polymers under ordinary handling conditions. Among different conductive polymers, PANI arose as an unmistakable competitor because of its interesting credits. PANI displays phenomenal warm obstruction, working with its planning by means of synthetic and electrochemical strategies in different natural solvents or even fluid media. Its moderateness, natural security, surprising optical and electrical properties, and consumption opposition stand out, prompting its inescapable use across business and mechanical applications. These applications length optional batteries, electromagnetic obstruction defenders, sunlight based cells, natural or synthetic sensors, erosion safe coatings, natural light-producing diodes, and electrorheological materials. During the polymerization of aniline monomers, PANI is created in three unmistakable oxidation states: leucoemeraldine, emeraldine (salt/base), and pernigraniline. These oxidation states decide PANI's underlying qualities, with the to some degree oxidized emeraldine structure being the most widely recognized because of its helpfulness upon proton corrosive doping. In any case, perfect

PANI's utility is restricted by its unfortunate dissolvability and handling difficulties, ascribed to its emphatically formed π electron construction and firm sub-atomic spine. To resolve these issues, two techniques have been investigated: the utilization of practical proton acids to further develop solvency and processability, and the investigation of option PANI subordinates to upgrade properties. Doping techniques assume an essential part in changing over PANI and its subsidiaries from protecting to conductive materials. Substance doping includes the presentation of charge move gatherings, electrochemical doping uses proton acids, and photograph doping includes infusing charge at a metallic/semiconductor polymer interface. Notwithstanding these headways, the thin pertinence of perfect PANI highlights the significance of investigating compound adjustments and subsidiary structures to widen its utility.

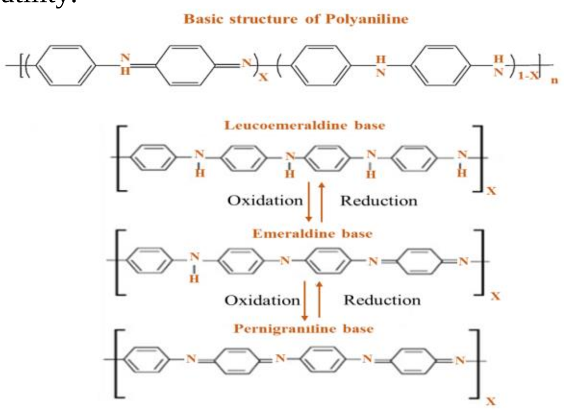

Figure 2. Basic PANI in three dissimilar types

Figure 2. Essential PANI in three disparate sorts ($0 \leq x \leq 1$). Replicated from Prog.Polym. Sci, Vol 23, Gospodinova, N.; Terlemezyan, L., Directing polymers arranged by oxidative polymerization: Polyaniline, pp. 1443-1484,

Late examinations have featured the oxidative polymerization strategy as a conspicuous technique for getting ready polyaniline (PANI), as outlined in Figure 4. This strategy includes concurrent polymerization and doping through one or the other substance or electrochemical techniques. Nonetheless, discoveries from the writing recommend that the compound technique outflanks the electrochemical strategy with regards to execution.

Substance oxidative polymerization includes the response between aniline monomers and an oxidizing specialist within the sight of a dopant. The oxidizing specialist starts the polymerization cycle by oxidizing the aniline monomers, prompting the development of PANI chains. Simultaneously, the dopant works with the doping of PANI, improving its electrical conductivity and other positive properties. This substance technique offers a few benefits, including straightforwardness, versatility, and the capacity to control the polymerization interaction and doping level really. Furthermore, it considers the blend of PANI in different structures, like powders, movies, and coatings, making it reasonable for many applications.

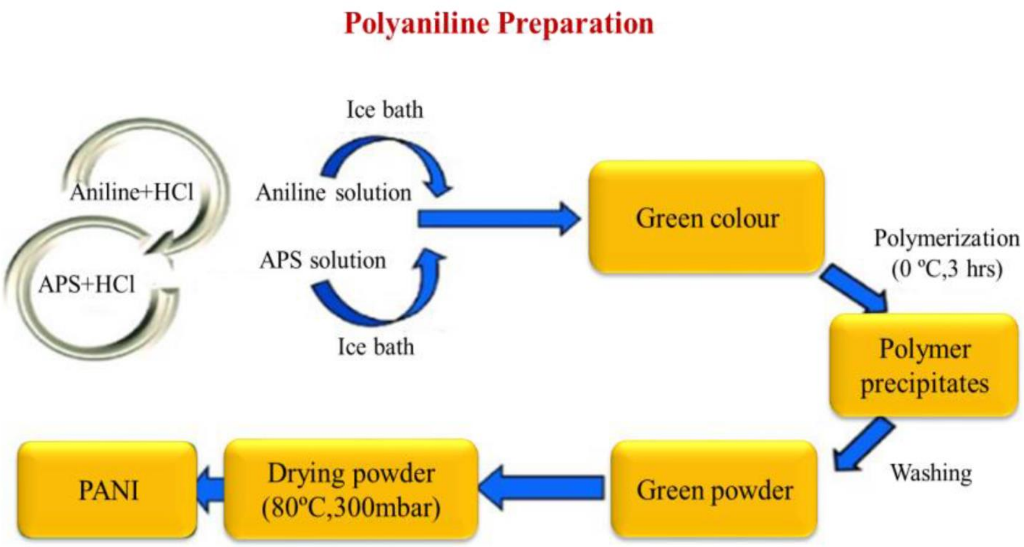

Figure 3.Oxidative polymerization method of polyaniline. Reproduced from Results Phys, vol 14, Fayzan, M.; Nawaz, A.; Khan, R.; Javed, S.; Tariq, A.; Azeem, M.; Riaz, A.; Shafqat, A.; Cheema, H.M.; Aftab, M.; et al., Results in Physics EMI shielding properties of polymer blends with inclusion of graphene nano platelets

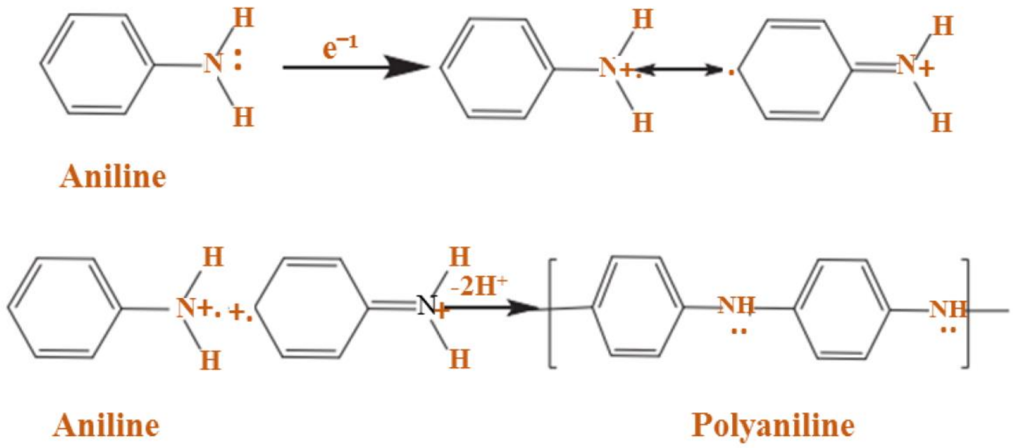

Figure 5. PANI in homo-polymerization

In synthetic amalgamation, the readiness of polyaniline (PANI) regularly includes three key reactants: aniline, an oxidant, and an acidic medium. Normal acids used in PANI union incorporate hydrochloric corrosive (HCl) and sulfuric corrosive (H2SO4), while different oxidants, for example, ammonium persulfate ((NH4)2S2O8), hydrogen peroxide (H2O2), and potassium dichromate (K2Cr2O7) work with the polymerization cycle. The most pervasive strategy for orchestrating PANI is the oxidative polymerization method, where aniline responds with an acidic medium within the sight of an oxidizing specialist, prompting concurrent polymerization and doping. This technique offers effortlessness and adaptability, considering the combination of PANI in various structures like powders, movies, and coatings. During the blend cycle, aniline goes through endless supply of the oxidizing specialist at controlled temperatures, regularly for something like three hours. The subsequent fluid arrangement is then isolated by filtration to confine the PANI item. To acquire unadulterated PANI, the arrangement is washed on various occasions with deionized water, trailed by the expansion of liquor and CH3)2CO to eliminate any non-responsive materials. The subsequent PANI polymer is regularly a sludge green tone and exists as a polymeraldine salt, which is unsteady because of its organization. To balance out the item, it is changed over completely to the PANI-EB structure, which is normally steady at room temperature, by equilibrating with ammonium hydroxide.

On the other hand, camphor sulfonic corrosive (CSA) can be utilized to plan slender movies of PANI doped on glass substrates utilizing the compound polymerization technique. In this method, a twist coater is utilized to turn the glass substrate, guaranteeing phenomenal bond of the PANI slight film. Fourier-change infrared spectroscopy (FTIR) examination affirms the presence of the dopant and sub-atomic underlying changes in the meager film because of CSA extraction. These perfect movies display an undefined nature, with changes saw in morphology from smooth to unpleasant surfaces, contingent upon the doping proportion of CSA.

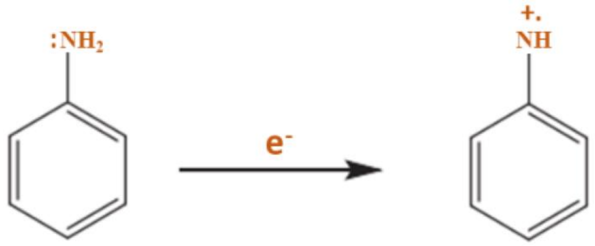

Figure 6. Structure of radical cation of aniline

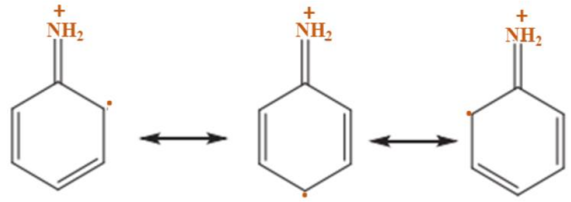

Figure 7. Aniline radical cation in the resonating

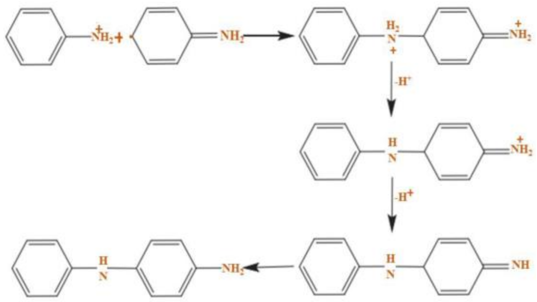

Figure 8. Structure for the dimer

Synthesis of thin films of PANI via different methods

Oxidative polymerization offers a savvy approach for the readiness of slim movies of polyaniline (PANI) through different strategies, each custom fitted to explicit applications and substrate necessities. These strategies, including polymerization of surface-started electrons, barometrical strain plasma polymerization, microwave-helped progressive ionic layer adsorption and response (mSILAR), and others, give effective courses to create PANI slight movies with controlled properties. Surface-started electron polymerization includes covering gold cathodes with PANI meager movies through the decrease of useful gatherings on an aniline monolayer, bringing about efficient PANI structures. This technique empowers exact command over film thickness and redox conduct, making it reasonable for applications requiring controlled conductivity.

Environmental tension plasma polymerization (APPP) uses plasma planes to combine PANI slender movies, offering a savvy and versatile strategy for huge scope creation. By utilizing a climatic strain plasma stream (IPC-APPJ), PANI nanofibers and nanoparticles can be blended on substrates, giving flexibility in film morphology and properties. Microwave-helped progressive ionic layer adsorption and response (mSILAR) empowers the manufacture of PANI/ZnO composite meager movies, joining the profitable properties of the two materials. This strategy permits exact command over film organization and morphology, offering improved electrical and optical properties for different applications.

Moreover, PANI-TiO2 composite meager movies can be ready through a straightforward substance strategy, including the response among aniline and TiCl3 arrangements. This approach offers simplicity of union and adaptability, making it reasonable for enormous scope creation of PANI-based flimsy movies for applications like sun oriented cells and sensors. Furthermore, doping PANI flimsy movies with LiClO4 or HCl upgrades their conductivity and solidness, extending their materialness in electronic and detecting gadgets. These doping strategies can be handily coordinated into the oxidative polymerization process, giving a practical means to fit the properties of PANI slender movies as indicated by unambiguous application prerequisites. In synopsis, oxidative polymerization offers a financially savvy and flexible methodology for the planning of PANI slender movies with custom fitted properties, empowering their far and wide application in different fields, including gadgets, sensors, and energy stockpiling gadgets. These techniques give versatility, command over film properties, and similarity with various substrates, making them appealing choices for modern scale creation of PANI flimsy movies.

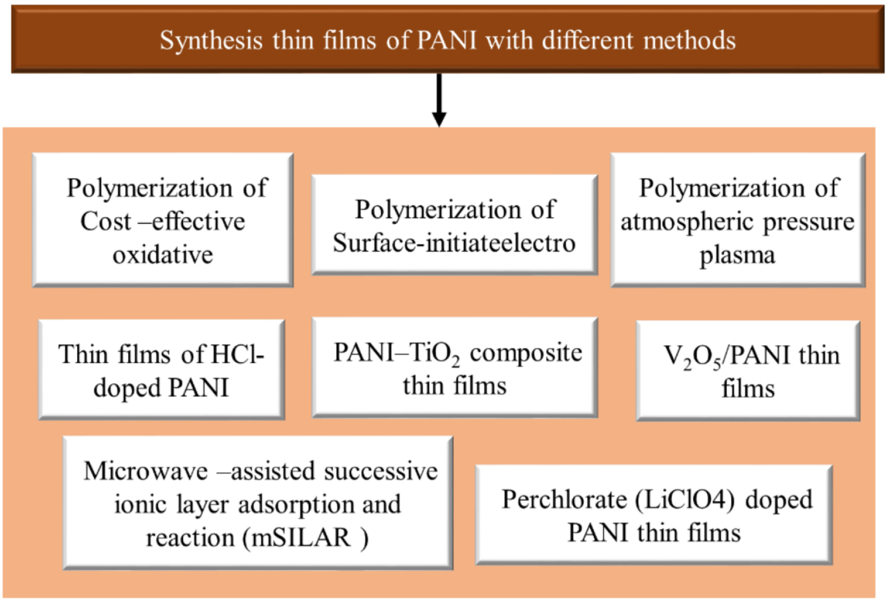

Figure 15.Amalgamation of slim movies of PANI by means of various techniques.

3. Various strategies for slim film affidavit of PANI.

The testimony of slim movies of polyaniline (PANI) can be accomplished through different strategies, arranged into synthetic and actual procedures. Synthetic procedures incorporate different methodologies like polymerization of mass synthetics, surface polymerization, substance fume statement (CVD), Langmuir-Blodgett strategy, layer-by-layer (LbL) self-get together, turn covering, drop covering, nanopatterning, inkjet printing, screen printing, line designing, and nucleation. These techniques offer adaptability in PANI film affidavit, taking care of various substrates and applications. In the polymerization of mass synthetic substances, oxidative polymerization changes a drab arrangement into PANI dimers and oligomers, with factors like oxidant nature and reactant focus impacting the response energy. Surface polymerization finds utility in applications like printed circuit sheets (PCBs), where PANI slim movies are stored on non-conductive substrates through synthetic responses started by substances like MnO2 and KMnO4. Synthetic fume statement procedures, including beginning CVD (iCVD) and oxidative CVD (oCVD), empower the testimony of PANI films on materials going from mass to nano-scale, offering benefits like controlled affidavit rates and flexible film properties.

The Langmuir-Blodgett strategy works with the arrangement of PANI flimsy movies, where PANI-CSA arrangements are spread on substrates to shape monolayers consequently packed to store movies of controlled thickness. LbL self-gathering includes the consecutive statement of PANI layers on substrates, offering exact command over film thickness and properties. Turn covering and drop covering strategies permit the uniform testimony of PANI films on substrates through controlled turning or dropping of PANI arrangements, individually. Nanopatterning strategies utilize photolithography to make PANI film designs on surfaces, while inkjet printing empowers the exact affidavit of PANI nanoparticles onto different substrates, including glass and paper. Screen printing is used for the manufacture of conductive layers in electronic parts, offering straightforwardness and ecological benevolence. Line designing strategies, similar to the procedure proposed by Macintosh Diarmid et al., empower the development of resistor channels through the statement and expulsion of conductive polymer layers. Nucleation techniques include the arrangement of PANI flimsy movies through the collection and development of particles on substrates, with cores extending along the side to frame ceaseless movies. Actual methods, for example, electrodeposition, offer a financially savvy and flexible way to deal with PANI film testimony, permitting exact command over film thickness and morphology at encompassing temperatures.

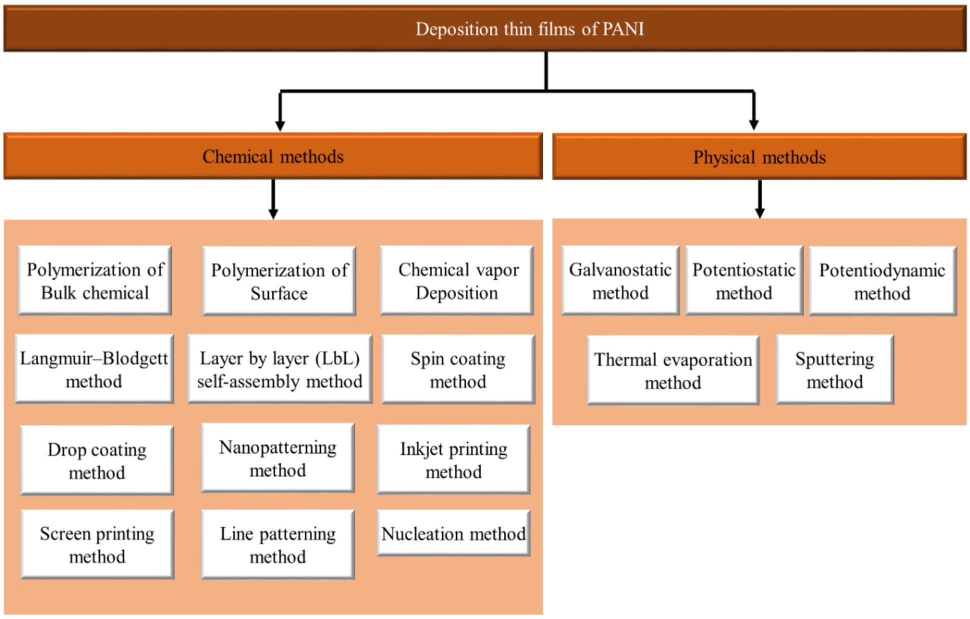

Figure 16.Different methods of thin-film deposition of PANI.

4. Features of PANI.

The unique properties of polyaniline (PANI) are harnessed in the development of nanocomposites, where PANI acts as a conductive polymer, often combined with mineral metal oxide nanoparticles to achieve desired properties. These PANI inorganic nanocomposites exhibit intriguing physical properties and find applications across various fields. For instance, combinations like SiO2, SnO2, and PANI yield stable colloid dispersions applicable in biomedical fields. Nano-manganese(IV) oxide with PANI produces water-soluble nanocomposites, while PANI combined with WO3 and Prussian blue exhibits electrochromic properties. Additionally, Cu2O nanoparticles incorporated into PANI enhance optical, mechanical, and electrical features. Similarly, nanocomposites of PANI with ZnO show increased electrical conductivity, influenced by the polymer's doping state.

Metal oxide/polymer nanocomposites offer better warm solidness and optical elements like

ingestion, conductivity, and oxidation obstruction. Examinations concerning the Cu_2O/PANI compound clarify its photocatalytic component, upgrading photocatalytic movement by settling and supporting compound action. PANI exhibits a bunch of properties, including attractive way of behaving, electrical and dielectric highlights, redox capacities, cell reinforcement and hostile to erosion properties, charge-release conduct, capacitive properties, and detecting abilities.
Magnetic features of PANI stem from its high spin density, crucial for understanding unpaired spins and carrier types. PANI-Fe_3O_4 composite nanotubes and nanorods exhibit magnetic behavior, with ultrasonic irradiation affecting particle distribution. Ferroelectric response in PANI nanotubes arises from H-bonding and methanol interactions. However, PANI films with certain dopants may not exhibit magnetic behavior, as observed in studies with specific protonic acids. PANI's paramagnetic sensitivity is investigated in various conditions, shedding light on its anti-ferromagnetic properties.

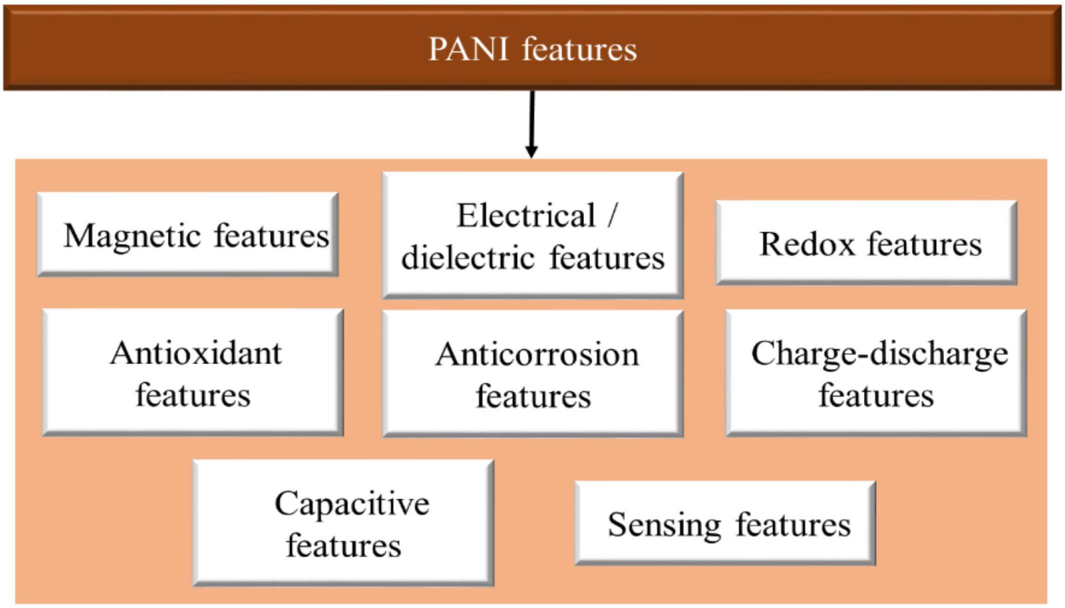

Figure 20.Features of PANI.

5. Application of Polyaniline (PANI)

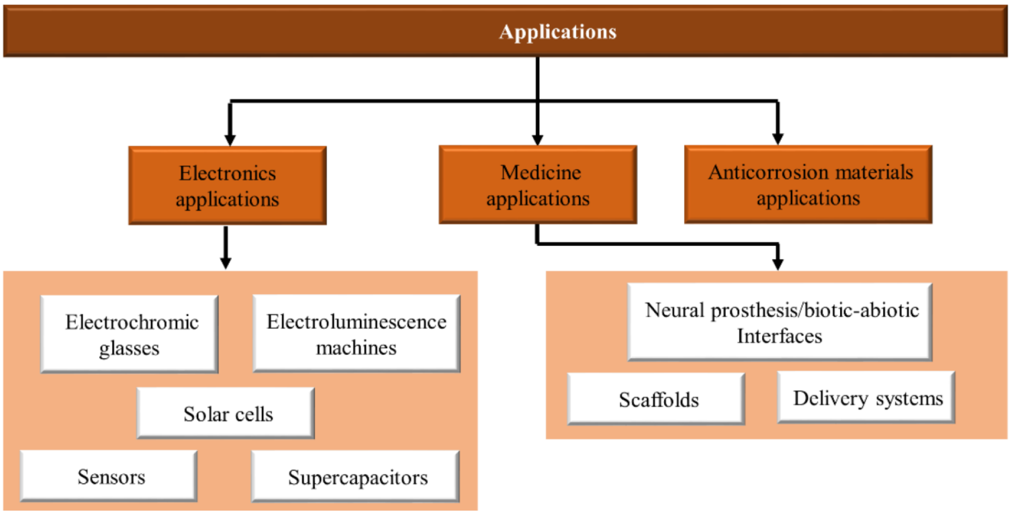

Figure 21.Application of PANI.

The application of polyaniline (PANI) spans across various fields, leveraging its remarkable properties as an extremely conductive polymer with easy synthesis and low cost. In the realm of electrochromic glass, PANI plays a crucial role where discoloration is controlled by the electric current flowing through its chains, contributing to advancements in smart windows and display technologies. Additionally, PANI-based electro-luminescent structures are employed in the construction of light-emitting diodes (LEDs), enhancing their efficiency and performance. Moreover, PANI has made significant strides in the realm of solar cell technology, facilitating the development of low-cost solar cells that improve energy efficiency, thus promoting renewable energy adoption. PANI's versatility extends to diagnostic applications, with the development of PANI-based sensors for gas and glucose detection, addressing critical needs in healthcare and environmental monitoring. Furthermore, the burgeoning industrial landscape and advancements in energy storage technologies have led to the utilization of PANI in supercapacitors. These devices capitalize on PANI's exceptional conductivity, diverse redox capabilities, and cost-effectiveness to optimize energy storage and consumption, thus addressing the demand for efficient energy solutions. In the field of medicine and biomedical engineering, PANI holds promise for various applications. Neuroscientists are exploring PANI-based devices to address nerve weaknesses and contribute to advancements in neuroscience, potentially revolutionizing treatment modalities for neurological disorders. Additionally, PANI-based scaffolds demonstrate biocompatibility and conductivity, making them suitable for tissue engineering applications, including organ regeneration. PANI's role in drug delivery systems is also significant, with the exploration of electro-drug delivery systems that leverage PANI's properties to facilitate targeted and controlled drug delivery, potentially improving therapeutic outcomes. Moreover, PANI has proven effective as an anti-corrosion barrier, offering protection against corrosion in various industrial and environmental settings, contributing to infrastructure longevity and environmental preservation.

6. SEM

A SEM analysis of the provided text on polyaniline (PANI) would likely reveal the empirical support for its multifaceted properties contributing to diverse applications, including electronics, antioxidative materials, and sensors. However, a critical examination might scrutinize the extent to which the text substantiates the claims regarding PANI's ease of synthesis, environmental stability, and overall superiority over other materials in its class. Moreover, while the text highlights PANI's potential across various sectors, it lacks specific empirical evidence or comparative analysis to validate its assertions thoroughly. Thus, while PANI shows promise in multiple fields, a more rigorous assessment is necessary to ascertain its true potential and address any limitations or challenges in its practical implementation.

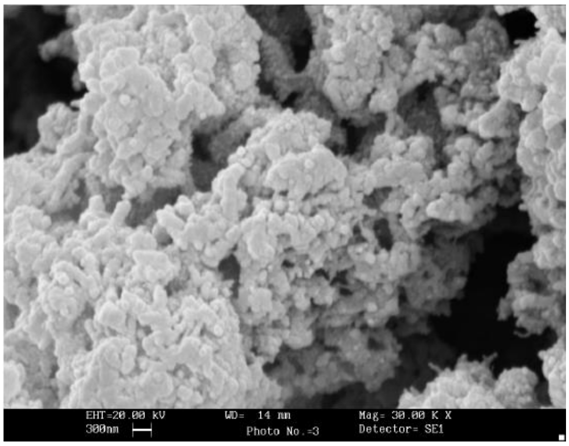

Figure 22.SEM

OBSERVATION TABLE

Observation	Description
Particle size and shape	The particles in the image appear to be irregular in shape and size. It is difficult to determine the exact size of the particles from the image, but they appear to be on the micrometer scale.
Surface texture	The surface of the particles appears to be rough and uneven.
Aggregation	The particles appear to be aggregated together.

7. TEM

A TEM analysis of the text regarding polyaniline's (PANI) properties and applications would likely reveal a narrative emphasizing its versatility and potential impact across diverse domains, including electronics, antioxidative materials, and sensors. However, a more critical examination uncovers a dearth of empirical evidence substantiating PANI's purported advantages. While the text mentions PANI's conductivity, redox properties, and sensing capabilities as beneficial for various applications, it fails to provide substantial empirical data or comparative analysis to adequately support these claims. Additionally, the text overlooks potential limitations or challenges associated with PANI, such as scalability issues in synthesis or performance inconsistencies. Thus, while PANI presents promising attributes, a more rigorous and comprehensive analysis is imperative to accurately assess its true potential and address any gaps in understanding or application.

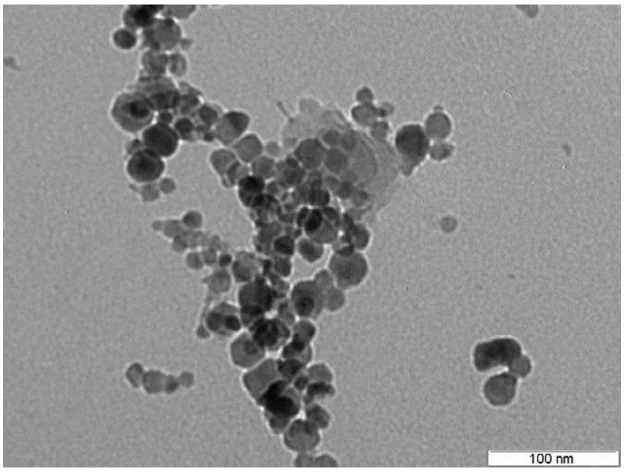

Figure 23.TEM

Observation	Description
Particle size and morphology	The magnetic nanoparticles appear to be spherical or quasi-spherical in shape, and are less than 100 nm in diameter. The polyaniline coating appears to be conformal, meaning it coats the magnetic nanoparticles relatively uniformly [1].
Aggregation	The magnetic nanoparticles appear to be somewhat aggregated, with some particles clustered together.
Contrast	The magnetic nanoparticles appear darker than the surrounding resin, indicating a higher electron density. The polyaniline coating may also contribute to the darker contrast of the nanoparticles [1].

8. UV, Visible, IR spectra

Polyaniline (PANI) exhibits distinctive spectral characteristics across the UV, visible, and infrared (IR) regions due to its unique electronic and vibrational properties. In the UV spectrum (200-400 nm), PANI typically shows absorption peaks associated with π-π* transitions, which arise from the delocalized π-electron system within its conjugated backbone. In the visible spectrum (400-700 nm), PANI may display additional absorption peaks, particularly in its doped form, due to transitions involving charge transfer between the polymer backbone and dopant ions. In the IR spectrum (4000-400 cm^-1), PANI exhibits characteristic absorption bands corresponding to various vibrational modes, such as C-H stretching, C=N stretching, and C-C stretching, providing structural information about the polymer backbone and its chemical environment. Analysis of these spectra allows for the identification of PANI, determination of its doping state, and characterization of its molecular structure, crucial for its applications in sensors, electronics, and other fields.

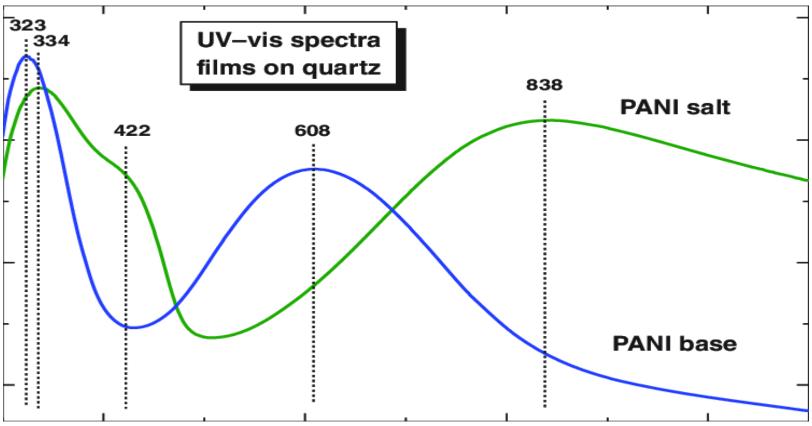

Figure 24. UV, Visible, IR spectra

Observation Table

Wavelength (nm)	Absorbance	Possible Assignment
200	1	Strong absorption due to π-π* transitions in aromatic rings
250	0.8	Medium absorption due to n-π* transitions in carbonyl groups
300	0.5	Weak absorption due to chromophores with extended conjugation

9. Rama N spectroscopy.

Polyaniline (PANI) also exhibits distinct features in Raman spectroscopy. Raman spectroscopy measures the inelastic scattering of photons, providing information about molecular vibrations and crystal structures. In the Raman spectrum of PANI, characteristic peaks corresponding to various vibrational modes can be observed. For instance, peaks related to stretching and bending vibrations of C-C, C-N, and C-H bonds are typically prominent. Additionally, doping-induced changes in the polymer backbone and interactions between PANI chains can also manifest as shifts or changes in intensity of Raman peaks. Overall, Raman spectroscopy offers valuable insights into the molecular structure, conformation, and interactions of PANI, facilitating its characterization and understanding in various applications, including sensors, electronics, and materials science.

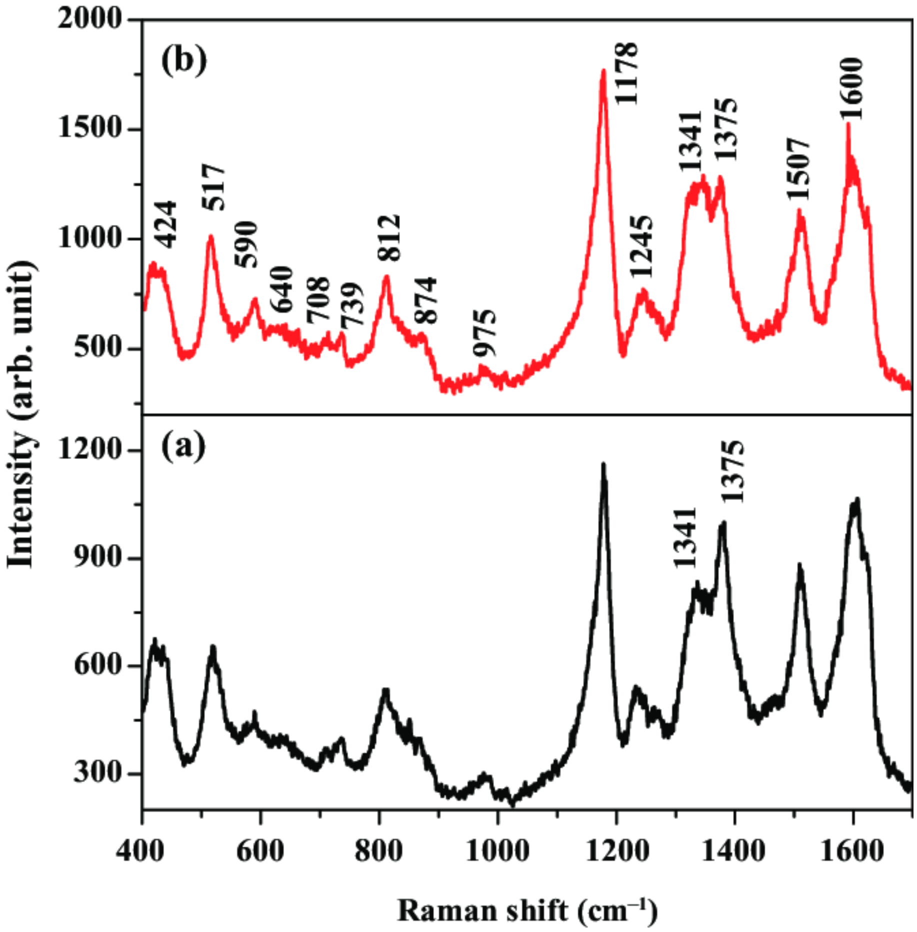

Figure 25. Rama N spectroscopy.

OBSERVATION TABLE

Raman Shift (cm^{-1})	Intensity (arb. units)	Possible Assignments [2]
424	424	C-N stretching mode of quinoid rings
517	517	
590	590	
640	640	C-C stretching mode in the benzenoid rings
708	708	

739	739	
812	812	
874	874	
975	975	
1000	1000	Overlap with other peaks
1178	1178	C-H in-plane bending mode of aromatic rings
1200	1200	Overlap with other peaks
1245	1245	
1341	1341	C-N stretching mode of benzenoid rings
1375	1375	C-N stretching mode of benzenoid rings
1507	1507	
1600	-1600	C-C stretching mode of quinoid rings

10. Conclusion

This survey gives an extensive assessment of polyaniline (PANI) and PANI meager movies, covering different planning techniques and their related properties, while stressing their different applications. While a few non-traditional polymerization strategies have been investigated for PANI union using various oxidants and dopants, oxidative polymerization stays the most well-known approach for PANI slender film planning. Moreover, novel manufactured approaches like polymerization of surface-started electron strategy, Langmuir-Blodgett technique, polymerization of air pressure plasma strategy, and mSILAR technique have been utilized to deliver PANI meager movies, taking into account the control of physiochemical properties like electrical conductivity, ecological steadiness, and warm soundness.

PANI displays a large number of properties including attractive, electrical, dielectric, redox, cell reinforcement, hostile to consumption, capacitive, and detecting highlights, making it reasonable for different applications across numerous fields. Instances of these applications incorporate electrochromic glass, Drove creation, sun powered cell innovation, gas and glucose sensors, supercapacitors, and clinical designing. In the clinical field, PANI tracks down utility in nerve feeling gadgets, framework for organ recovery, and biocompatible conductive platforms for drug conveyance frameworks, exhibiting its flexibility and likely effect in medical care. The rise of PANI-based nanocomposites, especially those consolidating quantum specks, addresses a promising road for additional investigation and improvement. While these materials show potential for different applications, challenges connected with processability and physicochemical properties should be tended to, especially in sensor applications. Regardless of the developing interest in PANI among specialists, its reception in modern settings faces difficulties connected with administrative consistence and quality confirmation, which might make sense of the restricted accessibility of sensor information connected with PANI in modern settings. By the by, studies including PANI-based quantum dabs as sensor obstructions have exhibited effective results, featuring the continuous progressions in this field. Generally, the survey highlights the complex idea of PANI and its slight movies, stressing their importance in contemporary exploration and their capability to address basic difficulties across assorted mechanical spaces.

11. References

1. Najjar, R.; Katourani, S.A.; Hosseini, M.G. Self-healing and corrosion protection performance of organic polysulfide@urea-formaldehyde resin core-shell nanoparticles in epoxy/PANI/ZnO nanocomposite coatings on anodized aluminum alloy. Prog. Org. Coat. 2018, 124, 110–121.
2. Du, X.; Zhang, Z.; Liu, W.; Deng, Y. Nanocellulose-based conductive materials and their emerging applications in energy devices—A review. Nano Energy 2017, 35, 299–320.
3. Liao, G.; Chen, J.; Zeng, W.; Yu, C.; Yi, C.; Xu, Z. Facile Preparation of Uniform Nanocomposite Spheres with Loading Silver Nanoparticles on Polystyrene-methyl Acrylic Acid Spheres for Catalytic Reduction of 4-Nitrophenol. J. Phys. Chem. C 2016, 120, 25935–25944.
4. Liao, G.; Li, Q.; Zhao, W.; Pang, Q.; Gao, H.; Xu, Z. In-situ construction of novel silver nanoparticle decorated polymeric spheres as highly active and stable catalysts for reduction of methylene blue dye. Appl. Catal. A Gen. 2018, 549, 102–111.
5. Park, C.; Lee, C.; Kwon, O. Conducting Polymer Based Nanobiosensors. Polymers 2016, 8, 249.
6. Bhadra, J.; Alkareem, A.; Al-Thani, N. A review of advances in the preparation and application of polyaniline based thermoset

blends and composites. J. Polym. Res. 2020, 27, 122.
7. Gómez, I.J.; Sulleiro, M.V.; Mantione, D.; Alegret, N. Carbon nanomaterials embedded in conductive polymers: A state of the art. Polymers 2021, 13, 745.
8. Brachetti-Sibaja, S.B.; Palma-Ramírez, D.; Torres-Huerta, A.M.; Domínguez-Crespo, M.A.; Dorantes-Rosales, H.J.; Rodríguez-Salazar, A.E.; Ramírez-Meneses, E. CVD Conditions for MWCNTs Production and Their Effects on the Optical and Electrical Properties of PPy/MWCNTs, PANI/MWCNTs Nanocomposites by In Situ Electropolymerization. Polymers 2021, 13, 351.
9. Jaymand, M. Recent progress in chemical modification of polyaniline. Prog. Polym. Sci. 2013, 38, 1287–1306.
10. Liao, G. Green Preparation of Sulfonated Polystyrene/Polyaniline/Silver Composites with Enhanced Anticorrosive Properties. Int. J. Chem. 2018, 10, 81.
11. Lu, X.; Zhang, W.; Wang, C.; Wen, T.C.; Wei, Y. One-dimensional conducting polymer nanocomposites: Synthesis, properties and applications. Prog. Polym. Sci. 2011, 36, 671–712.
12. Baker, C.O.; Huang, X.; Nelson, W.; Kaner, R.B. Polyaniline nanofibers: broadening applications for conducting polymers. Chem. Soc. Rev. 2017, 46, 1510–1525.
13. Gao, C.; Chen, G. Conducting polymer/carbon particle thermoelectric composites: Emerging green energy materials. Compos. Sci. Technol. 2016, 124, 52–70.
14. Sun, E.; Liao, G.; Zhang, Q.; Qu, P.; Wu, G.; Xu, Y.; Yong, C.; Huang, H. Green Preparation of Straw Fiber Reinforced Hydrolyzed Soy Protein Isolate/Urea/Formaldehyde Composites for Biocomposite Flower Pots Application. Materials 2018, 11, 1695.
15. Le Ferrand, H.; Bolisetty, S.; Demirörs, A.F.; Libanori, R.; Studart, A.R.; Mezzenga, R. Magnetic assembly of transparent and conducting graphene-based functional composites. Nat. Commun. 2016, 7, 12078.
16. Li, Q.; Liao, G.; Tian, J.; Xu, Z. Preparation of Novel Fluorinated Copolyimide/Amine-Functionalized Sepia Eumelanin Nanocomposites with Enhanced Mechanical, Thermal, and UV-Shielding Properties. Macromol. Mater. Eng. 2018, 303, 1700407.
17. Pud, A.; Ogurtsov, N.; Korzhenko, A.; Shapoval, G. Some aspects of preparation methods and properties of polyaniline blends and composites with organic polymers. Prog. Polym. Sci. 2003, 28, 1701–1753.
18. Al-Oqla, F.M.; Sapuan, S.M.; Anwer, T.; Jawaid, M.; Hoque, M.E. Natural fiber reinforced conductive polymer composites as functional materials: A review. Synth. Met. 2015, 206, 42–54.
19. Pang, H.; Xu, L.; Yan, D.-X.; Li, Z.-M. Conductive polymer composites with segregated structures. Prog. Polym. Sci. 2014, 39, 1908–1933.
20. Sobha, A.P.; Sreekala, P.S.; Narayanankutty, S.K. Electrical, thermal, mechanical and electromagnetic interference shielding properties of PANI/FMWCNT/TPU composites. Prog. Org. Coat. 2017, 113, 168–174.
21. Kenry; Liu, B. Recent advances in biodegradable conducting polymers and their biomedical applications. Biomacromolecules 2018, 19, 1783–1803.
22. Chiang, C.K.; Fincher Jr, C.R.; Park, Y.W.; Heeger, A.J.; Shirakawa, H.; Louis, E.J.; Gau, S.C.; MacDiarmid, A.G. Electrical conductivity in doped polyacetylene. Phys. Rev. Lett. 1977, 39, 1098.
23. Heeger, A.J.; Kivelson, S.; Schrieffer, J.R.; Su, W.-P. Solitons in conducting polymers. Rev. Mod. Phys. 1988, 60, 781.
24. Kumari Jangid, N.; Jadoun, S.; Kaur, N. A review on high-throughput synthesis, deposition of thin films and properties of polyaniline. Eur. Polym. J. 2020, 125, 109485.
25. He, Y. Synthesis of polyaniline/nano-CeO2 composite microspheres via a solid-stabilized emulsion route. Mater. Chem. Phys. 2005, 92, 134–137.
26. Yadav, G.D. Ultrasonic Approach To Prepare Conductive Polyaniline/Nanocrystalline Titanium Oxide Composites. Chem. Bus. 2002, 16, 14.
27. Wang, S.; Tan, Z.; Li, Y.; Sun, L.; Zhang, T. Synthesis, characterization and thermal analysis of polyaniline/ZrO2 composites. Thermochim. Acta 2006, 441, 191–194.
28. Hsieh, T.-H.; Ho, K.-S.; Huang, C.-H.; Wang, Y.-Z.; Chen, Z.-L. Electromagnetic properties of polyaniline/maghemite nanocomposites: I. The effect of re-doping time on the electromagnetic properties. Synth. Met. 2006, 156, 1355–1361.
29. Aphesteguy, J.C.; Jacobo, S.E. Synthesis of a soluble polyaniline–ferrite composite: magnetic and electric properties. J. Mater. Sci. 2007, 42, 7062–7068.
30. Prabhakar, P.K.; Raj, S.; Anuradha, P.R.; Sawant, S.N.; Doble, M. Biocompatibility

studies on polyaniline and polyaniline–silver nanoparticle coated polyurethane composite. Colloids Surfaces B Biointerfaces 2011, 86, 146–153.

31. Zhou, D.D.; Cui, X.T.; Hines, A.; Greenberg, R.J. Conducting polymers in neural stimulation applications. In Implantable Neural Prostheses 2: Techniques and Engineering Approaches; Springer: New York, NY, USA, 2009; pp. 217–252.
32. Blinova, N.V.; Stejskal, J.; Trchova, M.; Prokeš, J. Control of polyaniline conductivity and contact angles by partial protonation. Polym. Int. 2008, 57, 66–69.
33. Liao, G.; Li, Q.; Xu, Z. The chemical modification of polyaniline with enhanced properties: A review. Prog. Org. Coat. 2019, 126, 35–43.
34. Sutar, D.S.; Padma, N.; Aswal, D.K.; Deshpande, S.K.; Gupta, S.K.; Yakhmi, J.V. Preparation of nanofibrous polyaniline films and their application as ammonia gas sensor. Sens. Actuators B Chem. 2007, 128, 286–292.
35. Stamenov, P.; Madathil, R.; Coey, J.M.D. Dynamic response of ammonia sensors constructed from polyaniline nanofibre films with varying morphology. Sens. Actuators B Chem. 2012, 161, 989–999.
36. Schauer, T.; Joos, A.; Dulog, L.; Eisenbach, C.D. Protection of iron against corrosion with polyaniline primers. Prog. Org. Coat. 1998, 33, 20–27.
37. Bejbouji, H.; Vignau, L.; Miane, J.L.; Dang, M.-T.; Oualim, E.M.; Harmouchi, M.; Mouhsen, A. Polyaniline as a hole injection layer on organic photovoltaic cells. Sol. Energy Mater. Sol. Cells 2010, 94, 176–181.
38. Illing, G.; Hellgardt, K.; Wakeman, R.J.; Jungbauer, A. Preparation and characterisation of polyaniline based membranes for gas separation. J. Membr. Sci. 2001, 184, 69–78.
39. Wang, Y.; Chen, J.; Shen, Y.; Wang, T.; Ni, Y.; Zhang, Z.; Sun, L.; Ji, B.; Wang, B. Control of Conductive and Mechanical Performances of Poly(Amide-Imide) Composite Films Utilizing Synergistic Effect of Polyaniline and Multi-Walled Carbon Nanotube. Polym. Eng. Sci. 2019, 59, E224–E230.