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REVIEW ARTICLE

A NOVEL ROUTE FOR THE FORMATION OF GAS SENSORS

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Abstract

The rapid development of conductive polymers shows great potential in temperature chemical gas detection as their electrical conductivity is often changed upon spotlight to oxidative or reductive gas molecules at room temperature. However, the relatively low conductivity and high affinity toward volatile organic compounds and water molecules always exhibit low sensitivity, poor stability and gas selectivity, which hinder their practical gas sensor applications. In addition, inorganic sensitive materials show totally different advantages in gas sensors like high sensitivity, fast response to low concentration analytes, high area and versatile surface chemistry, which could harmonize the conducting polymers in terms of the sensing individuality. It seems to be a good option to combine inorganic sensitive materials with polymers for gas detection for the synergistic effects which has attracted extensive interests in gas sensing applications. In this appraisal the recapitulation of recent development in polymer inorganic nanocomposites-based gas sensors. The roles of inorganic nanomaterials in improving the gas sensing performances of conducting polymers are introduced and therefore the progress of conducting polymer inorganic nanocomposites including metal oxides, metal, carbon (carbon nanotube, graphene) and ternary composites are obtainable. Finally, conclusion and perspective within the field of gas sensors incorporating conducting polymer inorganic nanocomposites are summarized.

Keywords: Gas sensor, conducting polymer, polymer-inorganic nanocomposites; conducting organic polymers nanostructure, synergistic effect, polypyrrole (PPY), polyaniline (PANI).

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Introduction

Conducting polymers have undergone rapid development and shown great potential in temperature chemical gas sensors since their electrical conductivity are often changed upon spotlight to oxidative or reductive gas molecules at temperature(Ibanez et al, 2018; Wu, 2019) . In general, the conducting polymers with typical π conjugated structures show pi type conductive behaviors. Upon interaction with gas molecules, they act either as an electron donor or an electron acceptor, which may end within the rise or decrease of carrier concentration, hence the change in electrical conductivity or opposition of the detecting polymers. Conducting polymers reported as sensitive materials within the literature mainly include polyacetylene (PA), polyaniline (PANI), polypyrrole (PPy), polythiophene (PT), poly(3,4¬ethylenedioxythiophene) (PEDOT), poly (phenylene vinylene) (PPV) and their derivatives (Figure 1). within the undoped state, conducting polymers are either electrical insulators or semiconductors. to extend their conductivity, a doping process like protonic acid doping or redox doping is applied to polymers, which is amid removing the electrons on the backbones. Positive charges remained within the backbone act because the charge carriers, which could increase the conductivity from the low level of an insulator or semiconductor (10¬10¬10¬ 5 S/cm) to the conducting level (1¬105 S/cm). The unique tunable electrical properties, along with easy synthesis, structural diversity, facial functionalization and suppleness of those conducting polymer materials enable diverse energy and device applications(Park, S.J. 2017) Particularly, this unique doping/dedoping process allows conducting polymers to be explored as promising candidates for temperature gas sensor applications.

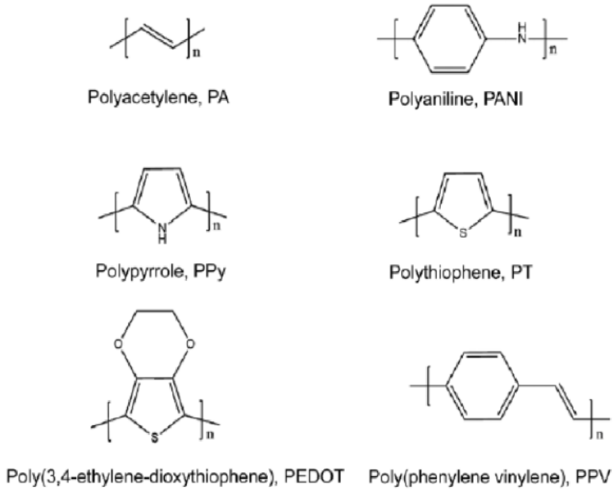


Figure 1. Chemical structures of representative conducting polymers.

With significant efforts within the past decades, there has been a huge research evolution in conducting polymers-based room temperature gas sensors. However, credit to their relatively low conductivity and high affinity toward volatile organic compounds (VOCs) and water molecules; they always exhibit low sensitivity, poor stability and gas selectivity, which hinder their practical gas sensor applications. Numerous endeavors are made for detecting execution upgrade including expanding the dynamic region, redox doping, functionalization, and so on for example (Huang et al.2004) showed a profoundly permeable detecting layer made out of one-dimensional (1D) PANI nanofibers with unrivaled detecting exhibitions including high affectability, selectivity, and fast reaction because of its higher region contrasted and mass movies. Such gas detecting upgrade impacts emerging from the low-dimensional designs likewise are accounted for in other directing polymers including PPy, PT, and so on. Nevertheless, although the sensing responses are greatly improved, the gas sensing behaviors aren't highly reversible and reproducible, which may be a present concern for practical sensor applications(Zhang et al.2014) illustrated (+)-camphor-10-sulfonic corrosive (HCSA) doped polyaniline Page 1 nanofibers by electrospinning strategies, which displayed extraordinarily further developed reaction/recuperation practices to 500 ppm NH3. In addition, (Kwon et al.2010)demonstrated that PPy functionalized with the carboxyl groups (-COOH) showed specific selectivity to dimethyl methylphosphonate (DMMP) gas credit to the intermolecular interactions between -COOH groups and phosphoryl groups of DMMP molecules.

However, although the gas sensing performances were improved, their limitations like low sensitivity, reversibility and selectivity remained a challenge for practical use in gas sensors. Rather than directing polymers, inorganic touchy materials show entirely unexpected benefits in gas sensors, i.e. metal oxides always show high sensitivity thanks to oxygen stoichiometry and active surface charge (Yang, G. 2019), however, the requirement of heat for operation always hinders its wide applications; metal nanostructures are taken on as affectability advertisers by substance and electronic refinement impacts (He, L.2013)One-dimensional (1D) or two-dimensional (2D)materials display quick reaction to low fixation analytes at temperature because of their low electronic noise, high surface area and versatile surface chemistry, which could complement the conducting polymers in terms of the sensing characteristics (Zhou and Azumi 2016; Giampiccolo, 2013). the utilization of conducting polymer inorganic nanocomposites may end in high-performance gas sensors thanks to their synergistic effects, which has attracted extensive interests in gas sensing applications. In the nanocomposite framework, the host natural and visitor inorganic stages are connected by powerless van der Waals or hydrogen holding, or covalent or ionic covalent holding, which could give upgraded or novel synthetic and actual functionalities. Such synergetic/complementary effects within the nanocomposite could help to eliminate their inherent drawbacks and also utilize the benefits of their individual constituents in gas sensing fields, which could result in high-performance sensitive materials and gas sensors. During this section, we'll sum up the new improvement in polymer-inorganic nanocomposites toward superior gas sensors. In area 2, we initially present the jobs of inorganic nanomaterials in further developing the gas detecting exhibitions of directing polymers. In section 3, we mainly describe the progress of conducting polymer inorganic nanocomposites including metal oxides, metal, carbon However, although the gas sensing performances were improved, their limitations like low affectability, reversibility and selectivity stayed a test for useful use in gas sensors. As opposed to directing polymers, inorganic touchy materials show entirely unexpected benefits in gas sensors, for example metal oxides always show high sensitivity thanks to oxygen stoichiometry and active surface charge (Yang et al., 2019b), however, the requirement of heat for operation always hinders its wide applications; metal nanostructures are adopted as sensitivity promoters by chemical and electronic sensitization effects (He, L. et al.2013b); One-dimensional (1D) or two-dimensional (2D)materials exhibit fast response to low concentration analytes at temperature due to their low electronic noise, high surface area and versatile surface chemistry, which could complement the conducting polymers in terms of the sensing characteristics (Zhou and Azumi 2016; Giampiccolo, 2019)The utilization of conducting polymer inorganic nanocomposites may end in high-performance gas sensors thanks to their synergistic effects, which has attracted extensive interests in gas sensing applications. In the nanocomposites system, the host organic and guest inorganic phases are interacted by weak van der Waals or hydrogen bonding, or covalent or ionic covalent bonding, which could provide enhanced or novel chemical and physical functionalities. Such synergetic/complementary effects within the nanocomposites could help to eliminate the inherent drawbacks and also utilize the benefits of their individual constituents in gas sensing fields, which could result in high-performance sensitive materials and gas sensors. During this section, we'll sum up the new advancement in polymer-inorganic nanocomposites toward elite gas sensors. In area 2, we initially present the jobs of inorganic nanomaterials in further developing the gas detecting exhibitions of leading polymers. In area 3, we mostly portray the advancement of directing polymer inorganic nanocomposites including metal oxides, metal, (carbon nanotube, graphene) and ternary composites, separately. Finally, we provide a conclusion and a perspective in the sector of gas sensors incorporating conducting polymer inorganic nanocomposites.

2. Comprehensive roles of inorganic nanomaterials in gas sensing enhancement effects

2.1 Constructing P-N or Schottky hetero junctions

The gas sensing responses of the conducting polymer inorganic nanocomposite-based sensors are obtained by footage the time reliant film resistance changes as a function of target gas concentration. The film obstruction esteem changes upon the openness of lessening/oxidizing gas, and bit by bit reestablishes to the primary state when the objective gas stream is taken out. The gas sensing response arises from the physical incorporation of target analyte molecules onto the sensing films and the electron capture/donation process of the polymer matrix embedded with the inorganic nanomaterials, which is improved by the connection effects at the conducting polymer inorganic interfaces. At the point when the leading polymer lattice is installed with inorganic nanomaterials, a PN or Schottky heterojunction is shaped at the directing polymer/inorganic interfaces, contingent on the idea of inorganic nanomaterials (Pirsaand Alizadeh 2010: Li, S., Liu and Yang 2019.). Taking it for a model, when n type metal oxide nanostructures are brought into the polymer lattice, a PN heterojunction is shaped at the polymer metal oxide interfaces, going with with the formation of depletion area in both polymer and metal oxides (Li et al., 2019) The interaction of the target gas molecules and the nanocomposite film surface leads to the decrease/increase of electrons within the polymers and thus the change within the width of the consumption region, which could limit/broaden the conductive pathway of the polymers. Considering the concentration of doped metal oxide nanostructure to the conducting polymers is low, in the order of 0.110 wt. %, which brings about the way that the nanocomposite film opposition is predominantly constrained by the leading polymers. The synergistic effects of the changed conductivity and conductive pathway of polymers in the nanocomposite films results in the enhanced sensitivity of the nanocomposite films toward the target analyte.

2.2 Modulating film morphology

In addition to the surface interactions, economical gas molecule absorption is additionally a very important facet to attain high sensing response as a result of the physical absorption of gas molecules onto the film is the beginning for the gas detection. An extremely porous layer with massive extent, high pore volume and desired pore size might introduce additional active sites and increase the gas molecule absorption. By introducing inorganic nanomaterials, the film morphology of the nanocomposite films and therefore the gas sensing performances can be adjusted freely (Jian, et al., 2020; Li, et al., 2019, Liu and Yang 2019; Wang, etal.,2020]. The inorganic nanomaterials may be a model for the chemical change of conducting polymers, wherever the nanocomposite morphology could be determined by the inorganic nanomaterials and polymerization strategies. Therefore, with a nanocomposites development effort, Associate in Nursing economical methodology for performance sweetening is used to style new nano composite material systems and develop new artificial strategies to well manage the morphology of the nanocomposite films.

2.3 Improving electrical conductivity

The electrical conductivity of the delicate movies is additionally significant for accomplishing high detecting reaction. For accomplishing high detecting reaction, charge transporters endless supply of gas atoms ought to move effectively and be gathered at the anode. Because of the low conductivity of natural materials, hardly any charge transporters arrive at the anodes, which bring about helpless detecting reaction. The doping methods have been reported to enhance the electrical conductivity of conducting polymers. Particularly, nano composite of conducting polymers and conducting inorganic nanomaterials may be a simple and effective technique to enhance the intra and interchange mobility of charge carriers within the polymer chains Kaushik et al.,2015; Shirsat, et al.,2009.]. Legitimate choice of inorganic nanomaterials can alter the electrical conductivity to an ideal level for high detecting reaction. The inorganic nanomaterials with high electrical conductivity could make up for the low conductivity of directing polymers to forestall loss of electrical signs, consequently acquiring a huge detecting reaction.For example, Shirsat et al. decorated PANI nano wires with Au nanoparticles (NPs) (~70120 nm) to achieve enhanced gas sensing behaviors (Shirsat et al.,2009). The PANI Au nano composite chemiresistive sensor showed an altogether upgraded recognition limit with great selectivity and reproducibility, which has been credited to the response between H2S molecules and Au and enhanced conductivity of PANI induced by the electron transfer from PANI (donor) to Au (acceptor).

3. Conducting polymer-based nanocomposites gas sensing

3.1 Metal oxide-conducting polymer nanocomposites

Conducting polymers are unit wide used as effective species for gas detection because of their wonderful chemical science and electronic properties, yet because of the blessings of low value, long-term stability and simple synthesis. However, the disadvantages of their performance like low sensitivity, slow response and recovery method, poor thermal stability and property conjointly limit their any applications in gas sensors. Fortunately, scientists have verified that polymer/metal chemical compound nanocomposites cannot solely scale back the defects of chemical compounds or metal chemical compounds, however conjointly effectively improve their sensitivity, thermal stability and time interval. Through in-depth research, individuals have a better understanding of the mechanism of raising the gas sensing performance. it's believed that the amendment of small morphology and also the formation of P-N junctions will effectively improve the conduction of nanocomposites and promote their sensing method. With the try of various forms of preparation strategies, a variety of conducting polymer/metal chemical compound nanocomposites with sort of skinny films (Tai et al.,2007), particles (Barkade, et al., 2013;Shu and Tian., 2017), fibers (Gong, J., Li and Hu, 2010 : Shu, et al., 2017), irregular shapes (Li, and Yang, 2018), sheets (Park, et al., 2013) short rods (Vellaichamy et al., 2017), tubes (Yin et al., 2018), flowers (Xiang et al., 2015), networks Andre et al., 2017: Kulkarni et al., 2018; Zhang et al., 2019) and core at shells (Zhang et al., 2019; Gerard et al., 1999) are synthesized and applied to gas sensors in turn.

Taking PANI primarily based nanocomposites for instance, as early as 2007, (Jiang et al. 2007) with success ready gas sensors for NH3 detection victimization hybrid PANI/TiO2 nanocomposites. They ascertained that compared with mono-phase PANI primarily based sensors, hybrid nanocomposites primarily based sensors showed higher sensitivity, faster responsiveness, higher stability and shorter recovery time. After that, totally different forms of nano structured metal oxides together with SnO2 (Deshpande et al., 2019; Bai et al., 2016; Koncki et al., 2000; Harsanyi et al., 1999; Lepsenyi et al., 1999), TiO2 Gong et al., 2010., Fe2O3 (Liu et al., 2017) GeO2(Liu et al., 2018; Wang et al., 2014), ZnO (Li et al., 2018) WO3 Xiang et al., 2015; Andre et al., 2017; Zhang et al., 2019; Gerard et al., 1999), Nb2O5 and MoO3 (Vellaichamy et al., 2017) area unit tried to be combined with PANI for gas detection. In 2010, sensors supported PANI/TiO2 nanofiber structures were first off according by (Gong et al., 2010) for dilute NH3 detection (Figure 2). They obtained the Ti4+ containing microfiber precursor by electrospinning methodology and so calcined the precursor at 600 °C for four hours to arrange TiO2 microfibers. After that, the P-N heterojunction nano hybrids with PANI Nano-grain encashed TiO2 microfibers were shaped through a polymerized reaction. The PANI/TiO2 primarily based sensors showed high sensitivity to fifty ppt of NH3. Within the nanocomposites, the PANI NPs entrenched on the surface of TiO2 microfibers acted as nano-switches. Once the NH3 molecules were adsorbed onto the PANI/TiO2 nanocomposites, the PANI NPs shut down the present loop, and once the gas molecules were desorbed, the circuit was reconnected. The NH3 gas sensitivity was considerably improved because of the fast increase of device resistance. Following year, (Wang et al., 2014) fabricated NH3 gas sensors victimization core-shell CeO2 at PANI structure. The sensors exhibited a high response of half-dozen. 5 to 50 ppm beneath NH3 detection and nice long stability. The internal mechanism of device performance improvement was analyzed thoroughly. It is incontestable that the enlarged sensitivity and stability benefited from the P-N heterojunction of nanohybrids. The electron-donating NH3 changed the first area charge region at the equilibrium condition, which diminished the opening concentration within the PANI and distended the reduction region from Wp to Wp-NH3. The physical phenomenon ways therefore reduced from the thicker emeraldine salt (ES)shaped shell painted in inexperienced to the thinner emeraldine base (EB)shaped shell painted in blue. Since the inherent resistance of CeO2 was very high, the entire resistance of hybrid system enlarged finally (Figure 3).

In recent years, the manufacture of electronic devices based on organic/inorganic hybrid systems on flexible/ductile substrates has become a replacement analysis hotspot. Compared with normal physical science, versatile physical science will adapt to totally different operating environments to a definite extent, and meet the deformation needs of the kit. In 2017, (Bai et al., 2017) according nanorod like α-MoO3/PANI primarily based triethylamine (TEA) sensors. The sensors were invented on a versatile synthetic resin terephthalate (PET)substrate with the PANI film lined onto the MoO3 nanorod framework (Figure 4). During this work, comparative experiments were tried to optimize the standard of hybrid system and connected device performance (Figure 5). The optimized sensors have an incontestable high property and smart sensitivity of five.5 to ten ppm TEA at temperature. They considered that the improved response once adding MoO3 nanorods into PANI was presumably caused by two factors. On one hand, the PANI embedded within the surface areas of MoO3 robs shaped a network that provided an oversized variety of α-MoO3/PANI interfaces, which increased the sorption efficiency of gas molecules. Additionally, the new shaped structure was contributory to the diffusion of gas molecules in the nanocomposites system.

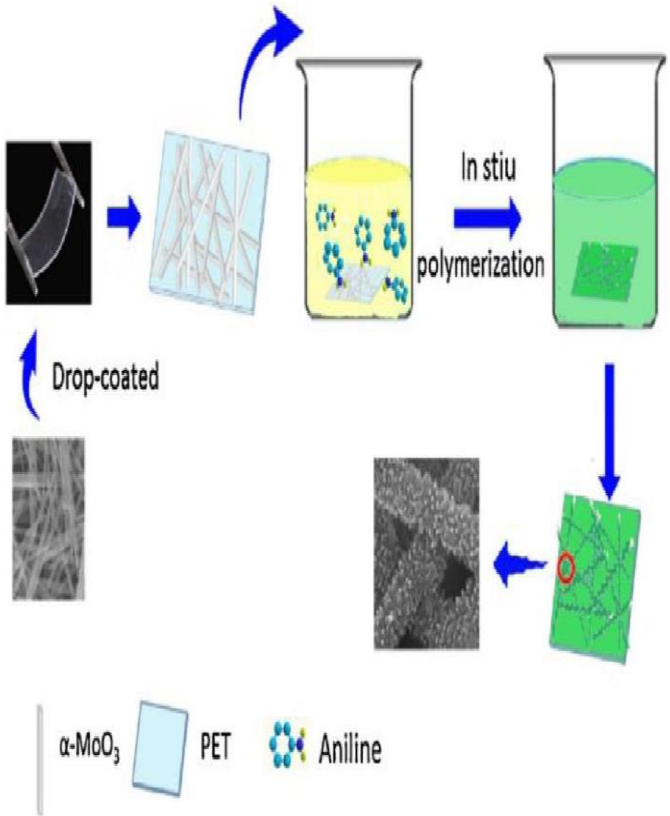


Figure 2 Schematic diagram of fabrication process of α- MoO3/PANI nanocomposites.

Be that as it may, the more significant issue for upgrading the detecting reaction was new framed P-N hetero intersections, which decreased the actual property and initiation energy of actual sorption of gas atoms, prompting savvy electron-donating qualities.It is cost referencing that gas sensors upheld mixture PANI/WO3 nanocomposites on adaptable PET substrates were additionally agreeing by Li et al. Blossom like (Xiang et al., 2015) and hollow spheres (Gerard et al., 1999) WO3 at PANI nanocomposites were designed and applied in sensors for temperature NH3 detection. The highest response was twenty-one for flower-like WO3 at PANI and twenty-five for hollow sphere WO3 at PANI to a hundred ppm NH_3 at temperature.

In summary, there are two main benefits of doping metal chemical compounds into conducting compounds to make the heterostructure. On one hand, the introduction of metal oxides will alter the electrical properties of conducting polymers and create a singular tangency with chemical electron physical phenomenon properties. On the other hand, nanostructures of metal oxides with numerous morphologies will be simply introduced into semiconducting polymers, therefore greatly increasing the surface areas of the mixture. In Table 1, the notable samples of the sensors supporting the hybrid system of conducting polymers and metal oxides developed in recent decades are listed, and their main sensing properties are summarized.

Table 1. Conducting polymer/metal oxides hybrid composites used in gas sensors

Polymer	Metal oxides	Target gas	Concentration (ppm)	Response	Response/recovery	T (in degree Celsius)	Ref.
PANI	TiO2	NH3	23	1.67	18~58	25	[25]
		CO	140	~1.9			[25]
		NH3	50 ppt	0.4%		RT	[25]
	SnO2	NH3	100		15~80		[26]
		NO_2	50 ppb		5~15 (min)	25	[26]
		SO_2	2				[30]

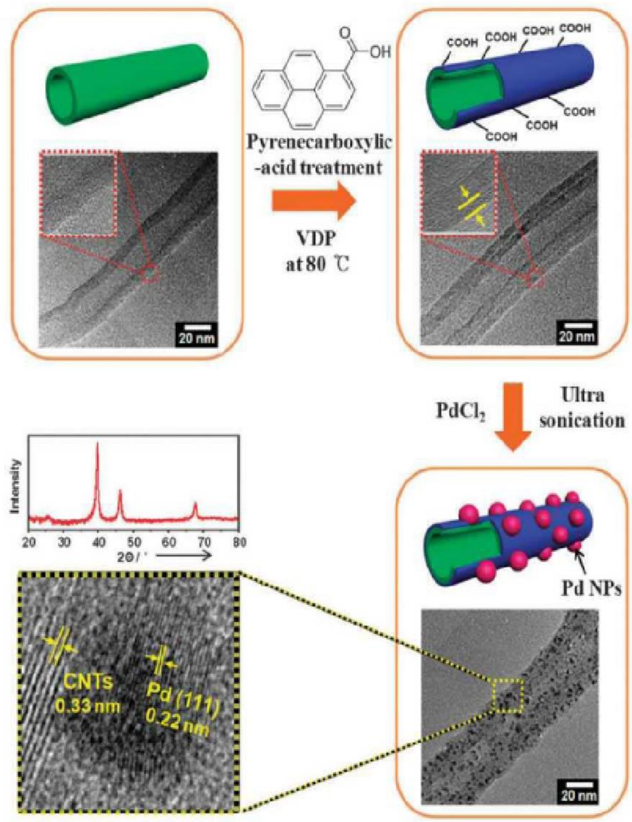
		NO_2	37		17~25	140	[31]
		NH_3	100	29		21	[27]
		NO_2	10	~2			[27]
		NO_2+NH_3	10	~5			[27]
		CO	25	15		30	[31]
	Fe_2O_3	LPG	50	0.5	< 60	28	[31]
		NH_3	10.7	30.70%		20	[31]
	GeO2	NH3	50	6.5		RT	[28]
		NH3	50	262.7%		25	[28]
		NO2	50	~40%			[28]
		HCHO	50	~20%			[28]
		H2S	50	~13%			[28]
		CO	50	~10%			[28]
		SO2	50	~5%			[28]
		O2	50	~5%			[28]
	WO3	NH3	5 2	4%	136~137	RT	[31]
		NH3	100	158%			[31]
		NO2	100	40%			[31]
		H2S	100	6%			[31]
		CH3OH	100	3%			[31]
		C2H5OH	100	1.5%			[31]
		NH3	10	7.1 %			[31]
		NH3	100	25 %			[31]
		NH3	1	9 %			[31]
	MoO3	TEA	10	5.8 %		RT	[30]

3.2 Polymer based ternary nanocomposites

As mentioned on top of, the binary hybrid system composed of metal oxides, metal NPs, CNTs or graphene with conductive polymers shows smart synergistic impact, which is conducive to optimizing the sensing characteristics. In order to further enhance the sensing performance, the analysis of ternary hybrid systems has attracted additional and additional attention in recent years. varied gas sensors supported ternary nanocomposite are synthesized recently for gas sensing analysis, primarily embrace metal particles-metal oxide conducting polymers (Sun et al., 2017; Liu et al., 2017) metal particles-carbon nanotubes-conducting polymers [33], metal particles graphene-conducting polymers (Jiang et al., 2013; Liu et al., 2015) metal oxide graphene-conducting polymers(Shu et al., 2017; Li et al., 2018; Park et al., 2013; Vellaichamy, et al., 2015; Yin et al., 2018), metal oxide-metal Oxide-conducting polymers (Yin et al., 2018) metal oxide-metal oxide metal oxide-conducting polymers Andre et al., 2017). In 2017, (Kulkarni et al., 2018) applied an associate degree unaltered self-assembly method to fabricate Au-TiO2-PANI ternary nanocomposites thin film primarily based NH3 gas sensors (Figure 6). They tested response characteristics to NH3 concentrations starting from ten to fifty ppm at temperature. The outcomes showed that, contrasted and the PANI-TiO2 parallel film, the sensors fundamentally dependent on PANI-TiO2-Au ternary composites played out the following reaction worth of forty-eight.6% to 123% and more limited time interval of fifty-two to 122 s, yet as higher property and changeableness, which may be attributed to the natural process of nanojunctions and the combined impact of Au nanorods chemical change.

Due to the success of CNTs and metal nanocomposites applied in gas sensing, researchers began to couple the metal NPs and CNTs with conductive polymers to get new composite sensing materials with higher gas sensing properties. For instance (Zhang et al., 2019) presented a totally exceptional and straightforward method for preparing carboxylate polypyrrole (CPPy)/CNTs/Pd nanocomposites for NH3 location (Figure8). Through correct material proportion and experimental condition improvement, the sensors possessed the minimum detection limit as low as one ppm to H2 and exhibited glory.

Figure 3 Fabrication process of the (CPPy)/CNTs/Pd nanocomposites



Reproducibility and changeableness. In 2019, (Zhang et al. 2019) synthesized a form of ZnO/GQDs/PANI nanocomposites through unaltered polymerization. Once exposed to solvent atmosphere at room temperature, ZnO/GQDs/PANI nanocomposites sensors exhibited high sensitivity concerning a pair of to five hundred ppb solvent, short response/recovery time of 15/27 second, reliable repeatability, outstanding property, yet as exceptional long-term stability. It ought to be noted that the ternary material mixture system supporting conductive chemical compounds isn't a simple random combination. So as to comprehend the synergistic reinforcement impact of varied materials, process compatibility, morphology and structure, composition magnitude relation and function distribution ought to be thought-about comprehensively. Table four lists the notable samples of conducting ternary nanocomposites primarily based on sensors developed in recent decades and summarize their main sensing performance.

Table 2. Conducting polymer/multicomponent nanostructures hybrid composites used in gas sensors

Polymer	Multicomponent		Target gas	Concentration (ppm)	Response	Response/ recovery Time (s)	T (^{0}C)	Ref
PPy	Ag	SnO2	NH3	0.02	3.15%		RT	[32]
	Au	TiO2	NH3	0.02	3.2%		RT	[32]
	Pd	CNT	H2	10	~4.5	% < 1	RT	[33]
	TiO2	Gr	NH3	50	102.2%	36~16	25	[34]
			CH3OH	50	~11			[34]
			CO	50	~5			[34]
			H2S	50	~4			[34]
PANI	ZnO	SnO2	TEA	100	69		21	[35]
	Au	TiO2	NH3	10	48.6 %	52~122	RT	[36]
			NO2	50	19 %			[36]
			CO	50	16 %			[36]
	MoS2	MWCNT	NH3	0.25	11%	32~36	RT	[37]
			NH3	6	40%			[37]
			C2H5OH	6	~13%			[37]
			C6H6	6	~5%			[37]
			CH4	6	~2.5%			[37]

4. Application of conducting polymers as a gas sensor

4.1 For Health Care

Various reports on immobilization of glucose oxidase in leading polymers for glucose assessment are accessible in writing (Fortier and Belanger, 1991; Foulds and Lowe, 1986; Ramanathan, 1995a; Ramanathan et al., 1995b, c, 1996b; Umana and Waller, 1986). It has been investigated that the polymers containing *para*- and *ortho*-quinone groups as electron transfer relay systems for oxido-reductases can effectively catalyze the electro-oxidation of glucose. Ramanathan et al. (1995c) have immobilized GOD after control of the pore size in polypyrrole to work on the stacking of the catalyst. A trade of para-toluene sulfonates and ferricyanide particles with a more modest particle like chloride in arrangement has been applied for making polypyrrole more permeable empowering improved stacking of GOD. An endeavor has been made to covalently couple glucose oxidase (GOX) to poly (o-amino benzoic corrosive) (PAB), a carboxy bunch functionalized polyaniline (Ramanathan et al., 2000). Interceded (with ferrocene carboxylic corrosive and tetrathiafulvalene) and unmediated frameworks have been used for glucose focuses.

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4.2 Urea biosensors

Most of the urea biosensors available in literature are based on detection of NH_4^{+} or HCO_3 sensitive electrodes (Koncki et al., 2000; Hirose et al., 1983; Cho and Huang, 1998; Pandey and Mishra, 1988; Gambhir et al., 2001a). Osaka et al. (1999) built an exceptionally delicate and quick stream infusion framework for urea investigation with a composite film of electropolymerized inert polypyrrole and a polyion complex. .Gambhir et al. (2001a) have recently co-immobilized urease and glutamate dehydrogenase on electrochemically prepared polypyrrole/polyvinyl sulfonate for the fabrication of urea biosensor.

4.3 DNA Biosensors

Not many reports of association of DNA with leading polymers are accessible (Saoudi et al., 1997; Chehimi et al., 1996; Bruno et al., 1994). Livache et al. (1995) announced one-venture electrodeposition of PPY films functionalized by a covalently connected oligonucleotide. Another possibility is to dope DNA probes within electropolymerized polypyrrole films and monitor the current changes incurred by the hybridization (Wang et al., 1999). Gambhir et al. (2001b) have reported the results of the studies relating to the characteristics of physically adsorbed DNA (Calf thymus) on conducting PPY/PVS films. Immobilization of DNA on a conducting polymer matrix facilitates the detection of a signal (amperometric or potentiometric) generated as a result of interaction of proteins or drugs with DNA.

4.4 For environmental monitoring

The conducting polymer-based gas sensor for environmental monitoring is based on the fact that upon exposure to vapor, the polymers show rapid conductivity changes, which are generally reversible at room temperature. The change in conductivity probably results from a reversible reduction of the polymer on exposure to the organic vapor as well as change in the moisture content of the film. (Harsanyi et al., 1999; Bartlett and Ling-Chung, 1989a, b; Krutovertsev et al., 1992).

5. Conclusions and outlook

Outstanding accomplishments have been achieved in conducting polymer-based gas sensors in the past decades. However, to realize future commercialization, future efforts to increase the gas sensing performance including high sensitivity, long-term stability, high selectivity and high reversibility are still necessary. To date, in order to improve gas sensing responses, a great number of doping inorganic nanomaterials and doping methods have been developed to construct P-N or Schottky heterojunctions, improve electrical conductivity and modulate film morphology. Here, the recent advances of conducting polymer inorganic nanocomposites-based gas sensors with excellent gas sensing performances. Up to now, inorganic nanomaterials including metal oxides, metal, carbon nanotube, graphene, and parallel nanocomposites (like metal/metal oxide, metal oxide/carbon) to shape directing polymer-inorganic nanocomposites have been accounted for, which have been found to be an excellent platform for high performance room temperature gas sensing. Here, it clearly demonstrates that the sensing characteristics of the nanocomposite depend both on the composition and structural characteristics of individual constituents and the synergistic effects between them.

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