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Review Article

Advancements in Synthesis Strategies and Optoelectronic Applications of Bio-Based Photosensitive Polyimides

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With the rapid development of information, energy, and materials industries in China, the demand for high-performance polymers is gradually increasing. Photosensitive polyimide (PSPI) has emerged as an ideal choice for high-performance optoelectronic materials due to its outstanding thermal stability, mechanical strength, and low dielectric constant. In particular, bio-based photosensitive polyimide prepared from bio-based chemicals, as a green polymer material, not only reflects the advantages of environmental protection and resource efficiency but also contributes to carbon neutrality. However, how to improve the photolithography efficiency while maintaining the thermodynamic performance and environmental friendliness and how to balance the pros and cons of low-molecular-weight matrixes are still challenges in the research. This review systematically summarizes the synthesis and performance characteristics of photosensitive polyimides, bio-based polyimide, and bio-based photosensitive polyimides and further explores the future application prospects of bio-based polyimides in the field of high-performance optoelectronic materials.

1. Introduction

Polyimide, due to its excellent comprehensive performance, such as high thermal stability [1, 2], mechanical strength [3, 4], chemical resistance [5, 6], dielectric properties [7, 8], and biocompatibility [9–11], is widely used in microelectronics [12, 13], sensors [14–16], energy storage [17–19], biomedical engineering [20–22], aerospace [23, 24], and other industries. In particular, photosensitive polyimide, as a unique high-performance polymer, has both the function of photoresisting and can be used as a dielectric insulation layer [25]. It can independently complete the patterning, saving material costs and simplifying the integrated circuit manufacturing process, thereby improving the accuracy and yield of photolithography patterns [26–28], as shown in Figure 1. However, traditional polyimides mostly originate from fossil raw materials, which not only cause environmental pollution and fossil fuel consumption but also may pose a carcinogenic risk to experimental personnel. In the current "dual carbon" context, it is particularly important to develop bio-based polyimides with raw materials partly or wholly derived from biomass [29–31]. At present, bio-based polyimides are limited to adding bio-based content, which is far from the early goal of complete substitution. This limitation is mainly attributed to the design contradiction between bio-based sources and polymer performance. Since polyimides are generally prepared by condensation of dianhydrides and diamines, the application performance of polyimides can be changed by designing the structure of bioderived monomers [32, 33]. For example, Sawada et al. used isosorbide [34] to synthesize a series of polyimides with excellent optical transparency, a low refractive index, a low dielectric constant, and small birefringence. Zhang et al. used furan-containing t-butyl oxy-carbonyl glycine (BOC-glycine) and furan-containing 2,5-furan dimethanol to synthesize BOC-glycine 2,5-furan dimethyl ester, which was further

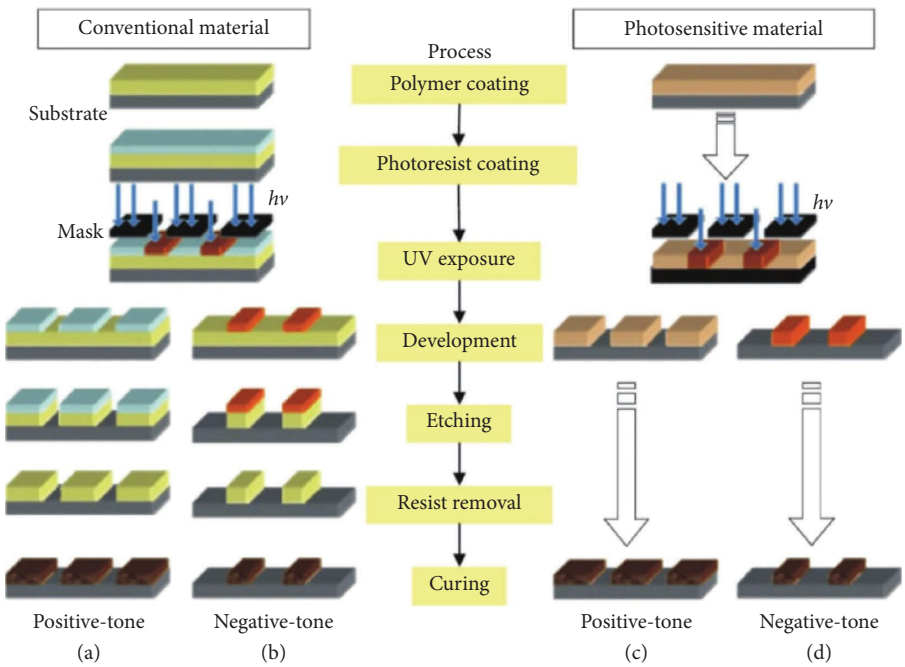

Figure 1: Comparison of the lithography patterning process using an ordinary photoresist and photosensitive polyimide [28].

applied to the synthesis of furan-based diamines and prepared polyimides with excellent thermal stability and smooth surface [35]. Gong et al. used dihydrogenated soybean saponins and diamine to prepare polyimides with relatively excellent mechanical properties, thermal properties, light transmittance, and fluorescence characteristics [36]. Also, the bio-based content reached 53%, providing a possible way to break through the limitations of bio-based content in the future. This article aims to systematically review the research progress of photosensitive polyimides and bio-based polyimides, describe their main performance, and explore the potential application of bio-based photosensitive polyimide in the field of high-performance optoelectronics.

2. Photosensitive Polyimides

The research and development of photosensitive polyimides (PSPIs) mainly focus on the innovation of their synthesis routes. The traditional synthesis method involves the polymerization of dianhydride and diamine monomers, first generating polyamic acid (PAA), and then undergoing a cyclodehydration reaction to imidize [37–39]. In order to introduce photosensitivity into polyimides, researchers have adopted three main strategies.

2.1. Method of Introducing Photosensitizing Functional Groups into Diamine and Dianhydride Monomers. Specifically, the strategy of introducing photosensitive groups usually revolves around two core goals: one is to ensure the effective introduction of photosensitive groups to achieve the desired photoresponsiveness; the other is to maintain or optimize the basic performance of PSPI, such as solubility, thermal stability, and optical properties. In the research, a successful method is to use the dianhydride of N-methylpyrrolidone (NMP) to condense with aromatic diamine with photoreactive ester groups [40], as shown in Figure 2. The advantage of this method is that it avoids the use of acid acceptors such as pyridine or triethylamine and can be carried out under lower reaction conditions. When exposed to ultraviolet light, this polyimide will change from weak cross-linking to heavy cross-linking and will not swell during the development process, thus ensuring excellent stability and resolution. However, simply introducing photosensitive groups is often not enough to meet all the needs in practical applications. For this purpose, Song [41] further introduced ethylene glycol chains of different lengths into the diamine monomer, which not only provided more choices for researchers but also helped to optimize the solubility and stability of the polyimide. By this method, they successfully prepared PSPI containing a nitrobenzyl ether (Nb) photosensitive group. It is worth noting that the solubility of a polyimide is directly related to the length of its ethylene glycol chain.

In order to further improve the performance of polyimides, researchers have adopted more complex and innovative design strategies. For example, a study reported the design and synthesis of a series of novel photosensitive polyimide coating [42]. These materials broke through the traditional design framework, achieving both excellent photoresponsiveness and improved thermal stability and dimensional stability at high temperatures. In exploring the improvement of optical transparency and thermomechanical properties, a study [43] creatively developed a novel aromatic diamine unit, called MABTFMB, and copolymerized it with BTDA and standard TMMDA, as shown in Figure 3. Thus, a series of optimized PSPIs were successfully developed. These novel fluorinated PSPI systems (FPI-2~FPI-7) which

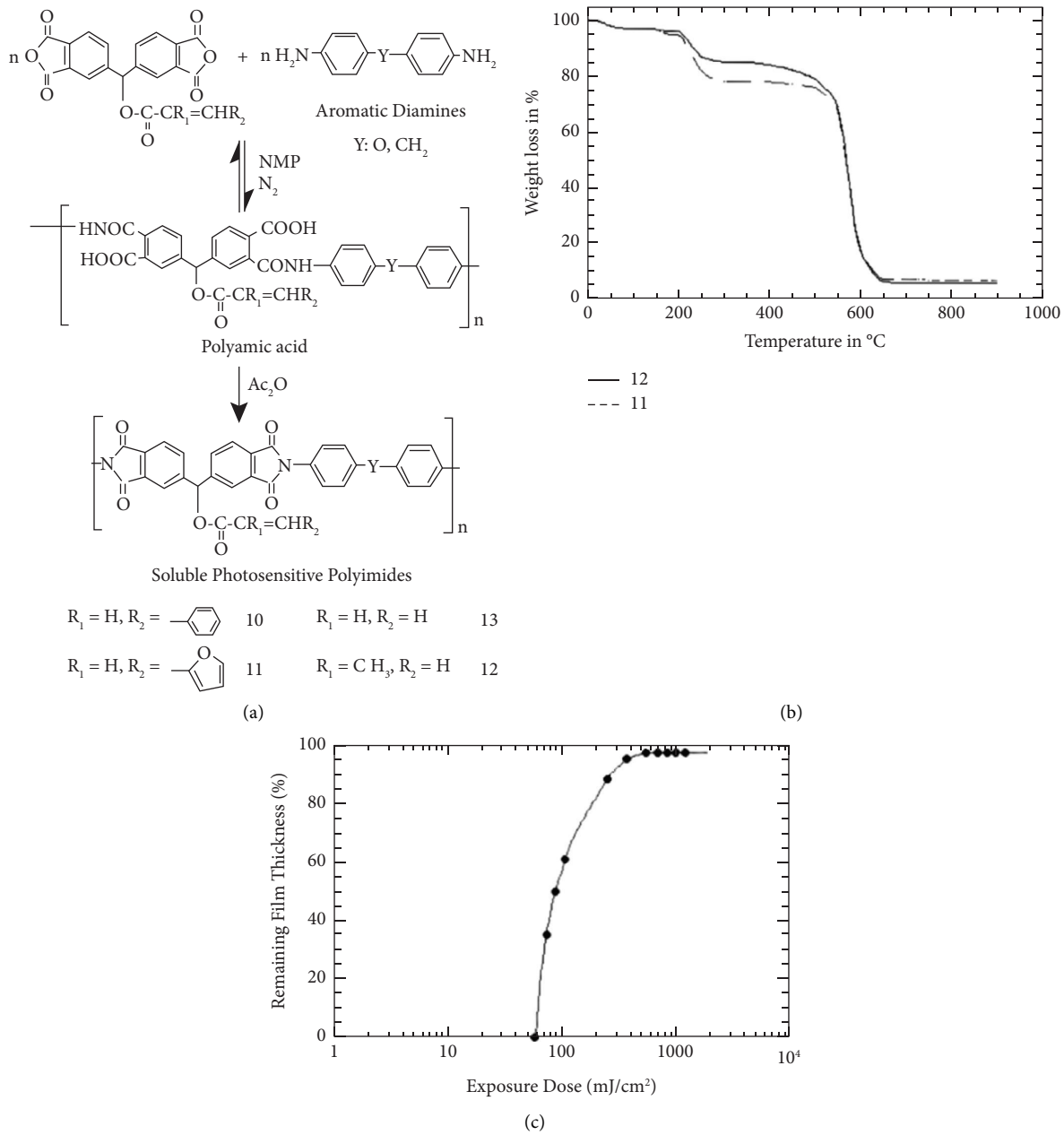

Figure 2: (a) Synthesis of soluble photosensitive polyimide, (b) thermogravimetric curves of photosensitive polyimides 11 and 12, (c) exposure characteristic of 12 (initial film thickness of 30 μm) [40].

showed similar solubility to the benchmark PI-1 (BTDA-TMMDA) system in specific solvents. In the spectral range of 365–436 nm, they exhibited superior optical transparency, especially at 436 nm, where the transmittance reached 78.3–81.3%. In addition to the improvement in optical properties, these PSPIs also showed significant improvement in their coefficient of thermal expansion (CTE), indicating their excellent stability under high temperature conditions.

Next, Zhong et al. [44] adopted the Diels–Alder reaction strategy and successfully synthesized two new cycloaliphatic dianhydride monomers: MBTA and DMBTA. Combining these new monomers and with modified diamine monomers (such as 4,4′-ODA and TFMB), the synthesized polyimides showed excellent performance, especially in thermal stability. The introduction of methyl substituents enhanced the performance of polyimides and effectively prevented the reverse Diels–Alder reaction at high temperatures, thereby enhancing the thermal stability of these polyimides.

In summary, although adding photosensitive functional groups through dianhydrides or diamine is relatively intuitive, the complexity of reaction conditions must be considered, which may make the distribution control of photosensitive functional groups in polyimides difficult. At the same time, ensuring the compatibility and stability of

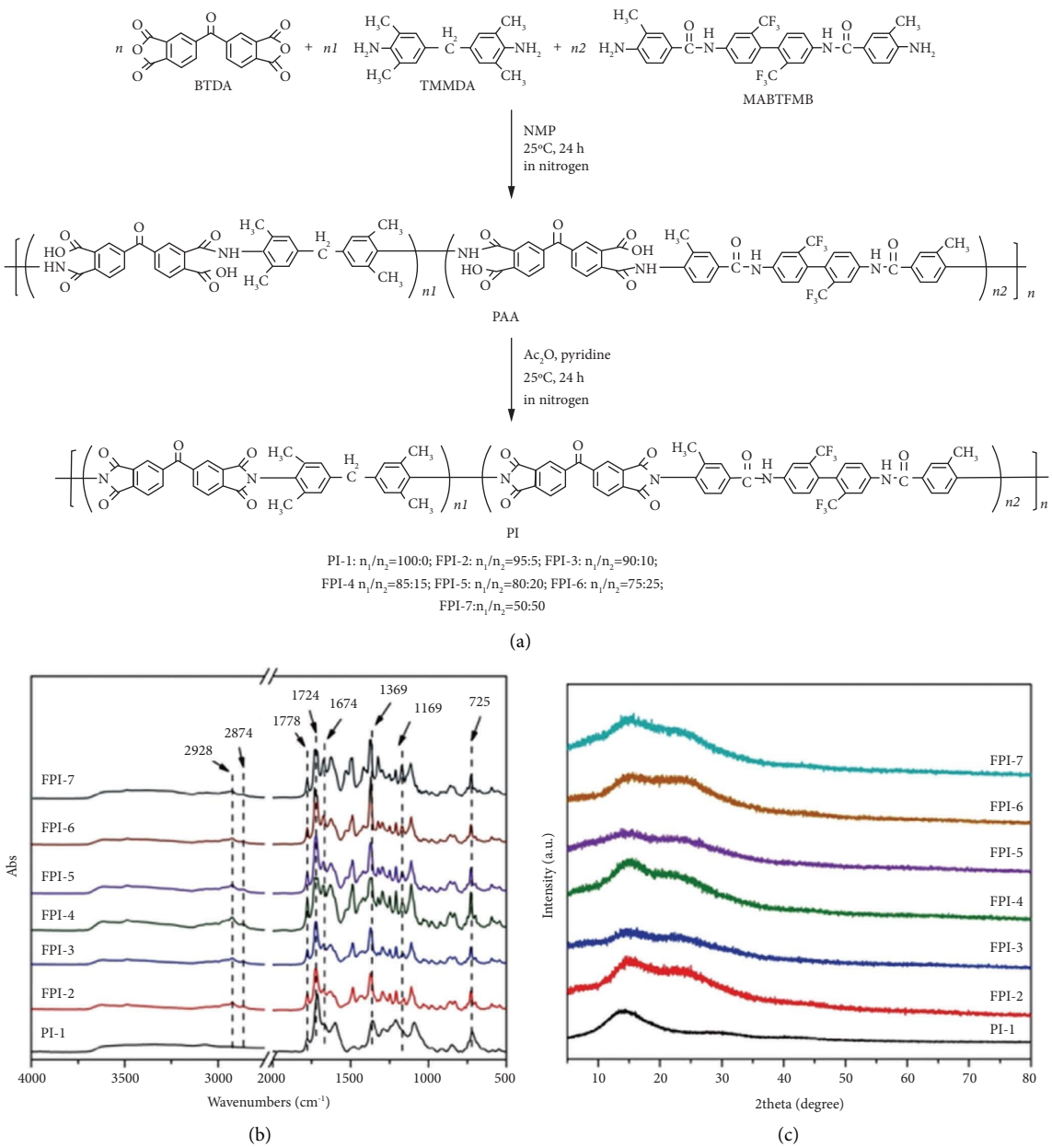

Figure 3: (a) Preparation of standard photosensitive PI-1 (BTDA-TMMDA) and fluorine and benzamide bridged FPI-2-FPI-7 resins, (b) FTIR spectra of PI and FPI films, (c) XRD spectra of PI and FPI polymers [43].

photosensitive functional groups on the main chain is also the key to avoid reducing the overall performance or causing early photo-induced reactions [45–47].

2.2. Methods of Postpolymerization Modification of PAA. This method mainly introduces photosensitive functional groups after the formation of polyamic acid (PAA), thus preparing photosensitive polyimides [48, 49].

Ogura et al. [50] synthesized semialicyclic polyamic acid (PAA) by 3,3′,4,4′-biphenyltetracarboxylic dianhydride and trans-1,4-cyclohexane diamine and combined DNCDP as a photobase generator, successfully developed a negative-type photosensitive polyimide (PSPI) based on semialicyclic PAA. In this system, the mass ratios of PAA and DNCDP were 80% and 20%, respectively. The PSPI had a high sensitivity of 70 mJ/cm^2 and a high contrast of 10.3 under 365 nm light. After baking at 190°C and specific development treatment, the PSPI could form clear negative images, including 6 μm lines and space patterns. In particular, its coefficient of thermal expansion was much lower than that of the traditional polyimide prepared by 3,3′,4,4′-biphenyltetracarboxylic dianhydride and 4,4′-oxydianiline.

Yao et al. [51] synthesized polyamic acid by BPDA and ODA, and then used DIBOC for end-capping, obtaining PAA with a controllable molecular weight. The PAA could undergo chain extension reaction in the curing stage, as shown in Figure 4. Using PAA polymerization solution,

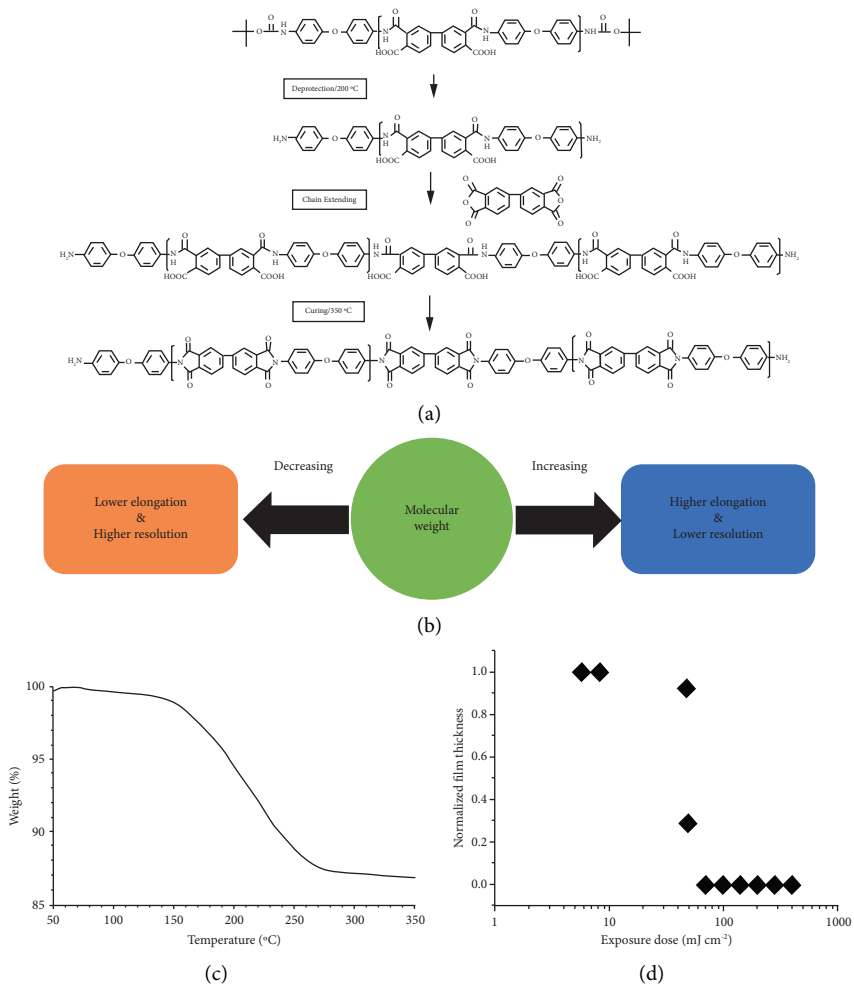

Figure 4: (a) Deprotection and chain extension of N-Boc, (b) effect of molecular weight on mechanical properties and pattern resolution, (c) TGA curve of N-Boc-023 at a heating rate of 10 C min-1, (d) PAA/TPVE/PTMA (83/13/wt/wt/wt) corrosion inhibitor system at 5 μ characteristic photosensitive curve at m film thickness [51].

thermally decomposable cross-linker TVEB, and photoacid generator PTMA, they successfully developed a positive-type photosensitive polyimide based on chain extension. This postpolymerization-modified PAA with photosensitive functional groups introduced provided a beneficial inspiration for developing high-performance photosensitive polyimides.

In a pioneering study, Tseng et al. [52] synthesized polyamic acid (PAA) through the polycondensation of p-phenylenediamine (PDA), 3,3′,4,4′-biphenyltetracarboxylic dianhydride (BPDA), and 4,4′-(hexafluoroisopropylidene)diphthalic anhydride (6-FDA). The polyimide (PI) obtained via thermal imidization exhibited superior thermal and mechanical properties. Furthermore, they formulated a chemically amplified, alkaline-developable negative-type PSPI from PAA (PDA-BPDA/6-FDA) and a photobase generator (PBG). This PSPI demonstrated high sensitivity and resolution and robust thermal and mechanical stability, signifying a promising direction in the development of high-performance photosensitive polyimides.

This method of postpolymerization modification of PAA has its own advantages in selecting different photosensitive properties and controlling the number and position of photosensitive functional groups. However, some undesirable side reactions are inevitable during the modification [53–55]. Moreover, because it requires extra steps to introduce photosensitive groups, it causes unnecessary waste of time and cost.

2.3. Methods of Postpolymerization Modification of PI Polymers. This method further introduces photosensitive functional groups after the formation of polyimide (PI) [56].

Wang et al. [57] successfully developed a positive chemical amplification photosensitive polyimide composed of t-butyl carbonate-protected polyimide (t-Boc-PI), a photoacid generator (PAG), and other additives and solvents. By introducing t-Boc, protecting groups, PI, polymer, and PAG were combined to form a novel photosensitive polyimide, as shown in Figure 5. Its characteristics are that, while maintaining high

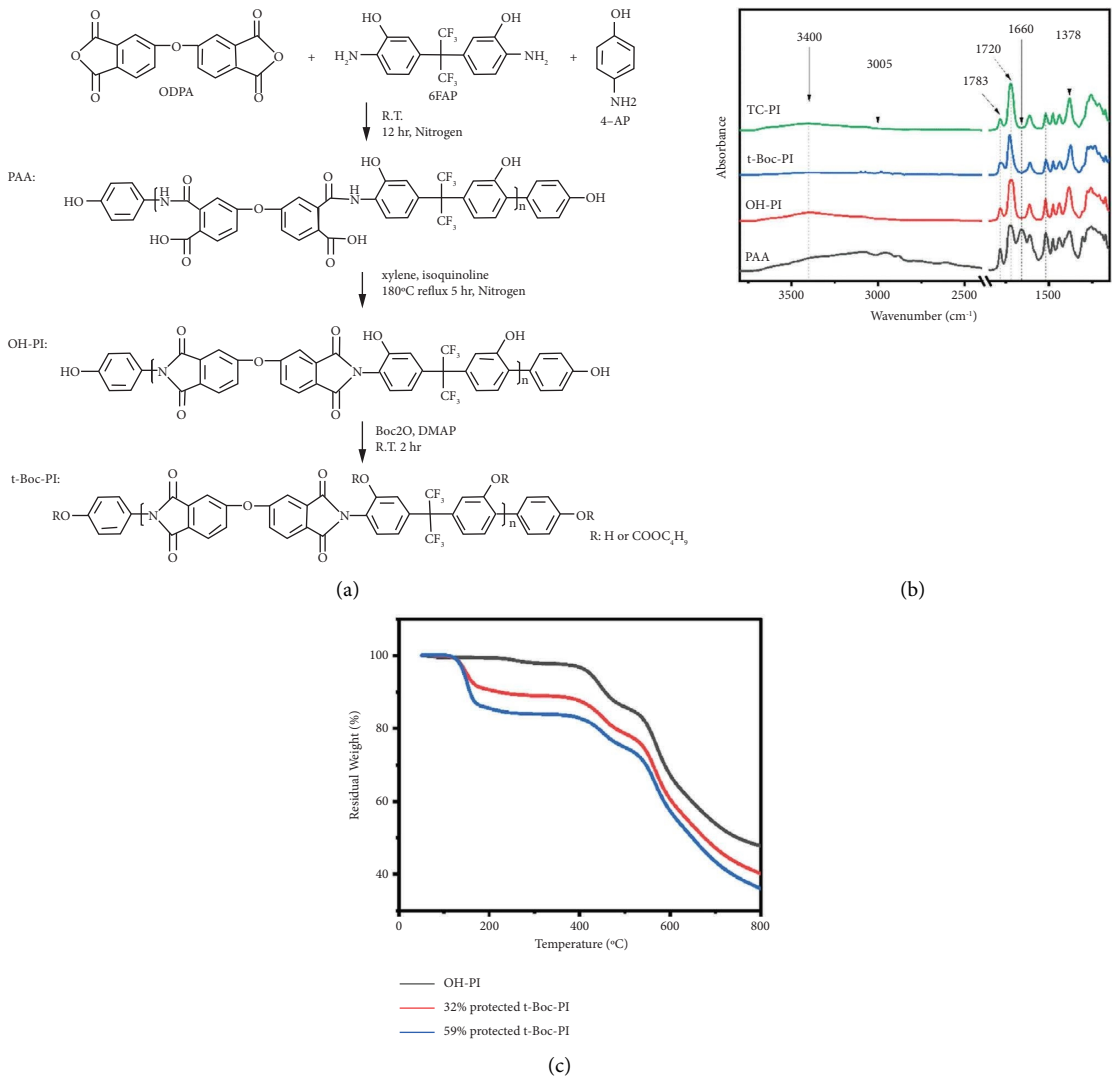

Figure 5: (a) Preparation of OH-PI and t-Boc-PI resins, (b) FT-IR spectra of hydroxylated PI (OH-PI), t-Boc protected PI (t-Boc PI), and 300°C thermally cured PI (TC-PI), (c) TGA curves of p-ca pspi with different protection ratios [57].

resolution, the cone angle can be widely adjusted to 11–53°. This PI polymer also exhibited high tensile strength, modulus, fracture elongation, and thermal stability. In general, by adding photosensitive groups to the PI polymer, it was successfully postpolymerization modified, which opened up new possibilities for further optimizing its performance and expanding its application range.

The method of postmodification of PI polymer is easier to customize the modification according to the specific properties and needs of the polymer. It also shows enough flexibility in different specific application directions [58–60]. However, this method still needs to be further improved in terms of efficiency and structural stability. In addition, besides the above strategies, new technologies and methods are also being developed and applied to further improve the performance of photosensitive polyimide.

For example, a study used ultraviolet-assisted electrospinning (UVAES) technology [61] to perform in situ photopolymerization during the spinning process, significantly improving the solvent resistance of PI ultrafine fiber membranes (UFMs). Using unsaturated double bond side chain modified photosensitive polyamic ester (PSPAE), as shown in Figure 6, PI and UFMs were prepared, and the PSPAE fibers after ultraviolet irradiation maintained their structure and morphology under high temperature treatment.

In summary, whether introducing photosensitive groups into dianhydride or diamine monomers, or modifying PAA after polymerization, or modifying PI after polymerization with photosensitive groups, they can all improve the performance of photosensitive polyimides to some extent [62, 63]. However, they all have different drawbacks and you need to choose the most suitable strategy according to the actual application requirements.

3. Synthesis Methods for Bio-Based Polyimides

Bio-based polyimide originates from raw materials partly or wholly provided by biomass (such as isosorbide, furan, dicarboxylic acid, gallic acid [64–66], benzoxazine [67–69], soybean isoflavone [70, 71], natural camphor [72], and

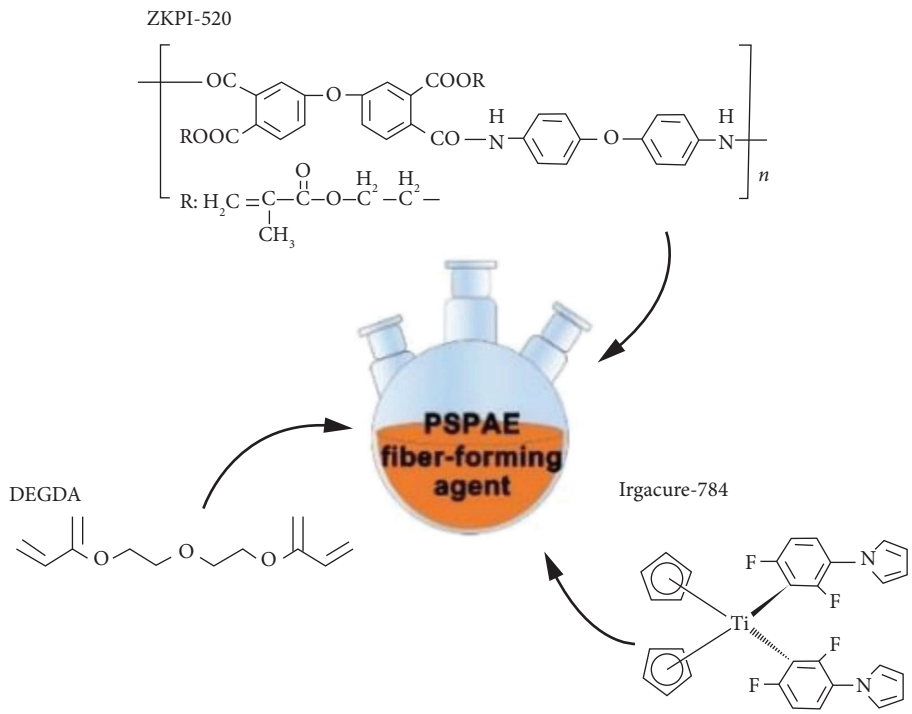

Figure 6: Components of the PSPAE fiber-forming agent [61].

lignin-derived degradation small molecules). This novel material has excellent emission reduction potential and has been identified as one of the key research and development projects during the "14th Five-Year Plan" period. It is worth noting that the performance of bio-based polyimides is directly affected by the structure of the selected monomers. Therefore, by rationally designing the bio-derived monomers before polymerization, green bio-based polyimides with specific properties can be produced.

However, it is crucial to understand that, while the bio-based nature of these polyimides suggests potential biocompatibility, most of the referenced studies have not explicitly addressed this aspect. Biocompatibility is a complex issue that can be influenced by various factors, including the chemical structure of the monomers used and the specific synthesis method employed. Furthermore, the absence of comprehensive clinical trials in the referenced research also contributes to the lack of explicit discussion on biocompatibility [10].

To further explore this material, we will divide the discussion into two parts: (1) introducing bio-based groups into diamine monomers and (2) introducing bio-based groups into dianhydride monomers. In these sections, we will focus on the synthesis and properties of the resultant polyimides without speculating on their potential biocompatibility due to the aforementioned reasons.

3.1. Methods to Introduce Bio-Functional Groups into Diamine Monomer. Diamine monomers play a core role in the synthesis of bio-based polyimides, as they not only affect the main chain structure of polyimides, but are also the key to achieve the introduction of bio-based groups [41]. To explore in depth, we will focus on two major strategies: directly using bio-sourced diamines and incorporating bio-based groups into diamines by chemical modification. The choice of these strategies will be based on the demand characteristics of the target polyimides and the characteristics and structure of the bio-based groups. Next, we will show the advantages and disadvantages of various strategies and share some cutting-edge research results.

Bio-sourced diamines are mostly obtained from biological resources such as plants, animals, and microorganisms, usually through biotransformation and extraction. This process typically has the characteristics of environmental friendliness, sustainability, and greenness, which is in line with the current trend of environmental protection and sustainable development.

For example, a study on bio-sourced diamines [73] adopted a unique strategy, using cashew nut shell liquid (CNSL) as raw material, successfully synthesized a triphenylamine-containing diamine 4,4′-diamino-4′-pentadecyltriphenylamine, as shown in Figure 7. The diamine was condensed with aromatic dianhydride in solution to produce novel polyimides containing part bio-based triphenylamine, which had excellent solubility and film-forming characteristics, and excellent thermal performance. Further studies showed that these bio-based polyimide devices exhibited superior performance in some applications. In summary, this study showed how to start from bio-sourced materials and successfully synthesize novel bio-based polyimides, providing a valuable reference for future research.

In addition, Jiang et al. [74] started from natural citric acid and designed and synthesized two novel biosourced diamines, OAC and OOD, as shown in Figure 8. Using these diamines and commercial dianhydrides for polymerization, they obtained a series of polyimides with special optical properties

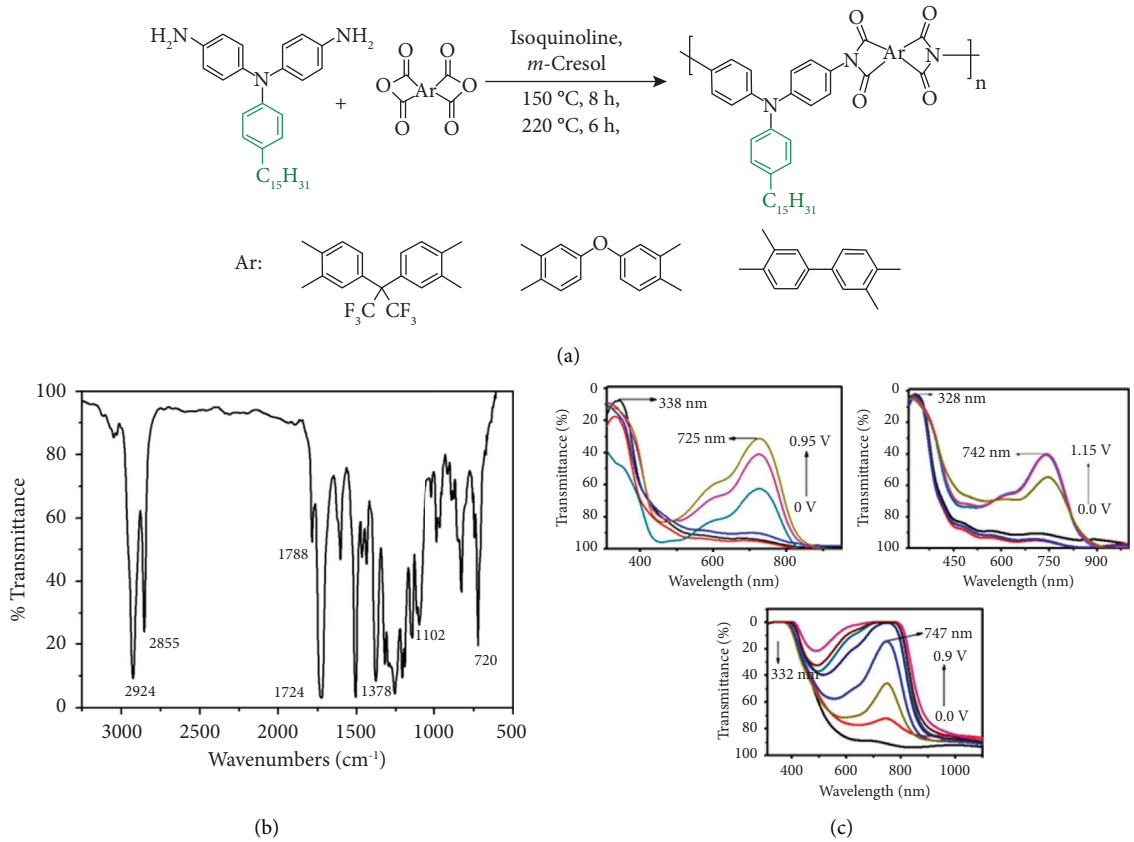

Figure 7: (a) Synthesis of polyimide containing triarylamine, (b) FT-IR spectra of PI-6FDA (thin film), (c) (A) electrochromic behavior of PI-6FDA (B) PI-ODPA and (C) PI-BPDA thin films [73].

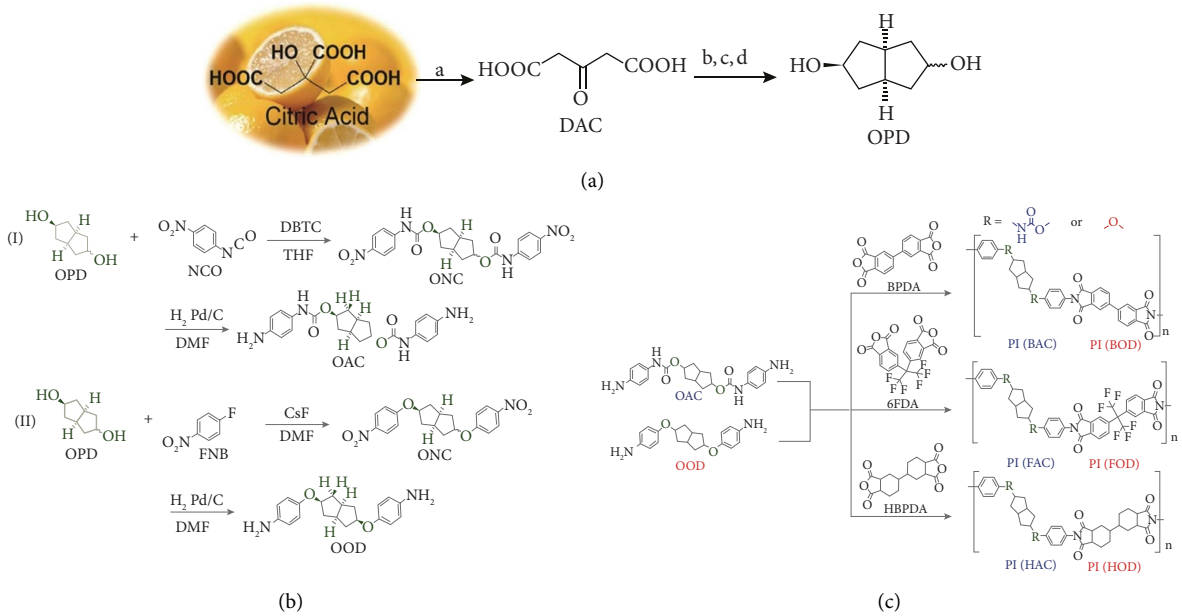

Figure 8: (a) Citric acid synthesis of octahydropentanediol (OPD), (b) OAC and OOD synthesis routes, (c) biomass, oac pi, and ood pi synthesis routes [74].

and good optical activity. After in-depth research, they found that after treatment under specific conditions, the molecular weight of one of the polyimides would be greatly reduced, which provided a potential way to solve the environmental problem of polyimides. This also proved the core role of bio-sourced diamines in developing environmentally friendly and high-performance new polyimide materials.

Beyond diamines directly derived from biological resources, there exists a distinct category of diamines synthesized chemically. These diamines may have their roots in petroleum or bio-based feedstocks. Importantly, the term "bio-based" in this context signifies that the introduced moieties originate from biological sources, such as bio-based alcohols, acids, or esters [75]. Via chemical synthesis, these moieties are proficiently grafted onto the diamine molecules, bestowing upon them novel properties. For example, in the study conducted by Noda et al. [76], bio-based diamines with distinct bending angles were successfully synthesized using 4-nitrobenzoic acid derivatives, especially the β-type and δ-type truxinic acids. These diamines were subsequently subjected to an amide reaction with tetracarboxylic dianhydride, yielding δ-type polyimides that exhibited commendable solubility and thermal stability. With the prevailing emphasis on environmental sustainability, there has been extensive research into bio-based polyimides within the realm of flexible and renewable electronics. Chen et al. [77] harnessed isosorbide to generate bio-based diamines, which were then reacted with three variants of terephthalic dianhydride to successfully synthesize polyimides with a biomass content of up to 53%. These polyimides not only showcased excellent thermal stability but also exhibited high levels of transparency, underscoring the immense potential of bio-based polyimides in the landscape of a sustainable economy.

Further research indicates that hexa-substituted cyclotriphosphazene (HVP) with bio-based characteristics can be synthesized starting from vanillin derived from lignin [78]. This discovery further substantiates the immense potential of utilizing bio-based raw materials in polymer synthesis. Subsequently, researchers employed various diamines to cure HVP using chemical methods, successfully developing a high-performance polyimide glass with dynamic imide covalent bonds. This breakthrough unveils a novel avenue, paving the way for the fabrication of high-performance polyimide glasses with superior flame retardancy and acid degradability.

In summary, the intersection and integration of bio-based diamines and chemically synthesized diamines have opened up new perspectives in polyimide research, providing beneficial insights for future directions.

3.2. Methods for Introducing Bio-Based Moieties into Dianhydride Monomers. Dianhydride monomers play an indispensable role in the synthesis of polyimides, although diamine monomers are equally important. By modifying dianhydride monomers, we can introduce bio-based moieties into the polyimide structure. In the following, we will delve into how to achieve this goal, expounding on the advantages and limitations of related methods, and providing representative research in recent years.

Certain studies have demonstrated the use of bio-based anhydrides in gas separation membranes [79]. For example, guaiacol (a lignin-based biomaterial) has been used to synthesize novel dianhydrides such as MMDA and FDDA. When imidized with diamines containing Troger's base (TB), two polyimides, bio-TBPI-1 and bio-TBPI-2, were obtained. They not only have excellent thermal properties but also exhibit excellent gas separation properties.

Moreover, the selection and derivation of dianhydride monomers are crucial in the synthesis of fully biobased polyimides. The TAKADA team [80] derived trimellitic anhydride from maleic anhydride and 2,5-dimethylfuran, as shown in Figure 9. By combining with the dimer of 4-aminocinnamic acid, they achieved the synthesis of fully bio-based polyamic acids. This strategy not only provides a new route for the design and preparation of fully bio-based polyimides, but also indicates the vast application potential in the field of bio-based materials. TAKADA [81] synthesized a series of bio-based polyimides with specific structures. Among them, the water solubility of polyimides was achieved through treatment with potassium hydroxide, thereby producing materials with high optical transparency.

4. Synthesis of Bio-Based Photosensitive Polyimides

With the progression of time, carbon emissions are increasing day by day. From the perspective of human health and green development, the design and development of bio-based photosensitive polyimide materials from bio-based raw materials (chemicals) hold significant importance. They not only promise the high-value utilization of biomass resources but also aim to reduce carbon emissions, aiding the green transformation and sustainable development of traditional chemical and new material industries [82–84].

Li et al. [85] elaborately described a method for synthesizing a bio-based photosensitive polyimide (PIMC). This method involves an esterification reaction between chloromethylated polyimide and cinnamic acid derived from cinnamon bark. This new type of photosensitive polyimide, due to its unique properties, is considered an ideal material for the manufacture of liquid crystal displays (LCDs). More importantly, its bio-based origin could effectively reduce the carbon footprint of LCD production. Further research shows that PIMC films exhibit enhanced chemical resistance under ultraviolet (UV) light, along with exceptional thermal stability and transparency, making it suitable for LCD industry applications. PIMC also demonstrates good solubility in various organic solvents and excellent adhesion, ensuring it can be effectively coated on various substrates. These characteristics further emphasize the vast application potential of bio-based photosensitive polyimides in the field of optoelectronics and optics.

Simultaneously, S. J. Do's team from the Korea Institute of Chemical Technology [86] utilized partially bio-based triarylamines to prepare a new positive photosensitive polyimide-carbon black composite material. The Π-Π interaction between triarylamines and carbon black significantly enhances its optical density, showing promising potential for application in organic light-emitting diode displays, as shown in Figure 10.

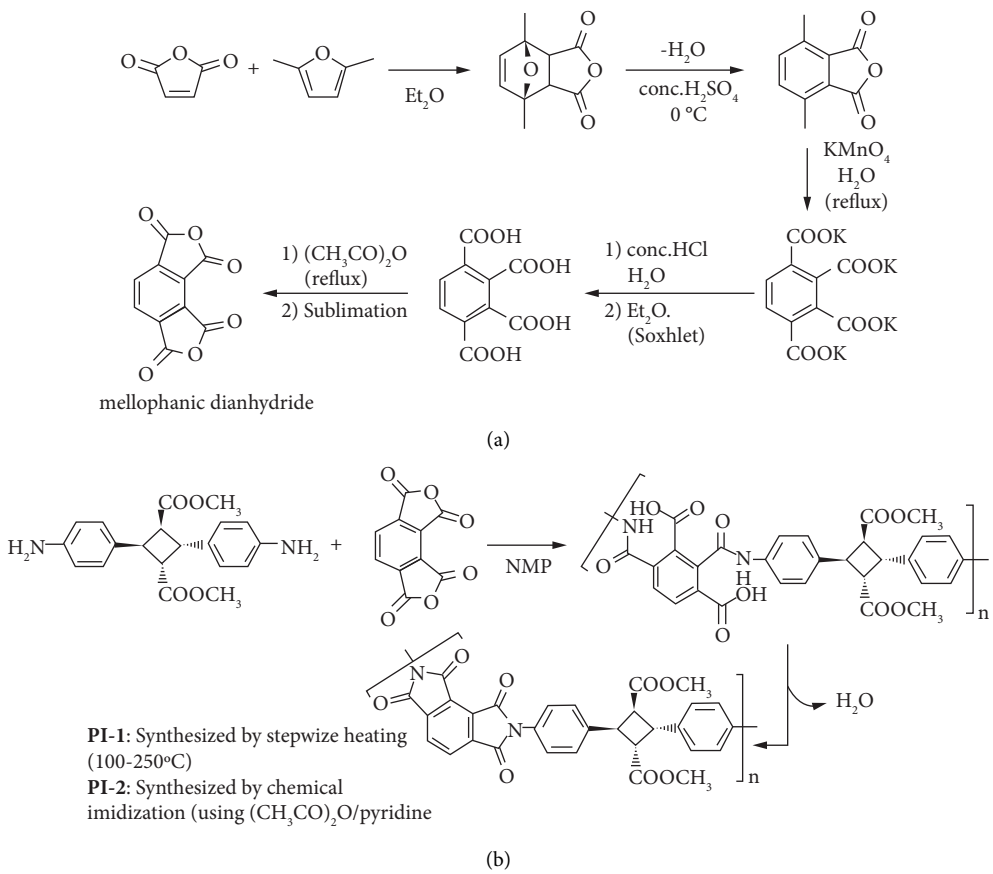

Figure 9: (a) Synthesis of methylphosphodianhydride using maleic anhydride and 2,5-dimethylfuran as biological compounds, (b) 4,4′-diamino-α synthesis of all bio-based aromatic polyimides using trimethyl truxilic acid and toluene dianhydride as monomers through thermal or chemical acylation methods [80].

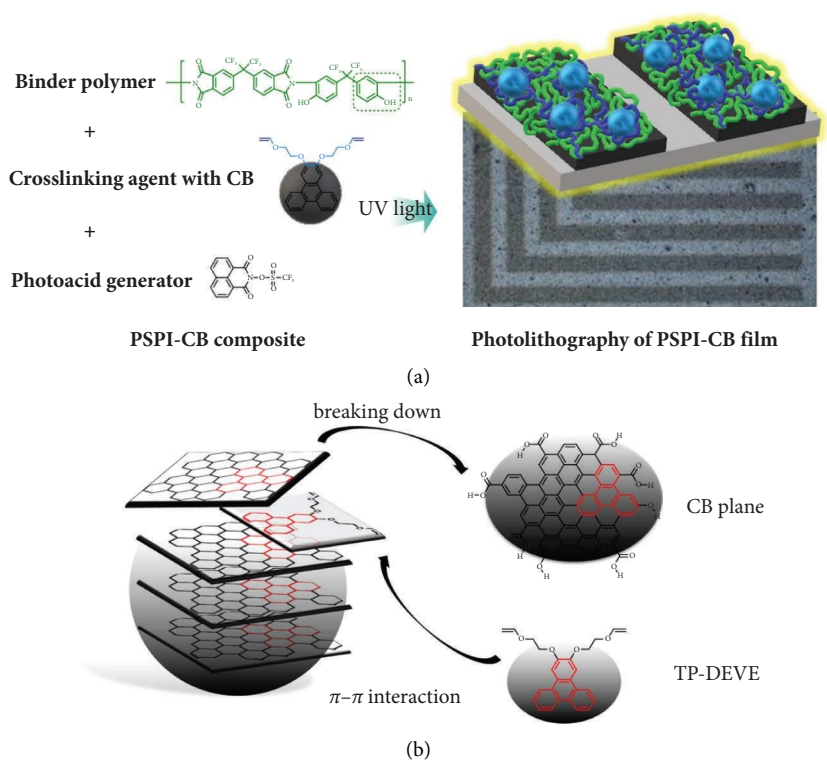

Figure 10: p-PSPI lithography system doped with aromatic vinyl ether cross-linker modified carbon black; (a) system composition and lithography image; (b) π-π Interaction between polybiphenyl structure and carbon black molecular plane [86].

In summary, these achievements demonstrate the feasibility of the synthesis route for bio-based photosensitive polyimides using bio-based raw materials, and the resulting bio-based photosensitive polyimides also possess excellent comprehensive properties. Therefore, the development and design of structurally controllable bio-based photosensitive polyimides lay a solid foundation for the design of high-performance, eco-friendly materials in the future.

5. Application of Bio-Based Polyimides in High-Performance Optoelectronic Materials

The research and application of high-performance optoelectronic materials is an important frontier in current technological development, which has significant impacts and contributions to various fields such as information technology, new energy, and environmental protection. Among these, bio-based polyimides have become a focus of research due to their unique properties.

5.1. Flexible Optoelectronic Devices. Polyimides (PI) play a crucial role as flexible substrates in areas such as advanced integrated circuits, optoelectronic displays, wearable devices, and flexible electronics. As electronic devices trend towards miniaturization, ultra-thinness, and high power density integration, the problem of thermal failure due to the accumulation of Joule heat becomes increasingly severe, becoming a key issue limiting the further development of electronic devices [87–90]. Therefore, there is an urgent need to develop PI films with high thermal conductivity.

Hung and colleagues [91] successfully synthesized polyimides with high thermal stability and low water absorption using the biomass resource isosorbide, making a contribution to the sustainability of flexible electronic devices. These polyimides not only show excellent thermal/mechanical stability, but their glass transition temperature also exceeds 300°C, surpassing most biopolymers and Kapton engineering plastics. Moreover, flexible transistors based on PI-1 show electrical performance comparable to traditional silicon-based devices, demonstrating their great potential in the optoelectronics field.

In a pioneering development, Wang et al. [92] fabricated a network of silver nanowires (AgNWs) on a bio-polymer base derived from sodium alginate using a spray method. This significantly enhanced the composite film's conductivity and optical transmittance. They are expected to replace commercial polyimides given their environmentally friendly properties and excellent performance. The resultant CA/AgNWs/CA composite film showcases exceptional electromagnetic interference (EMI) shielding efficiency and optical transmittance. Its excellent durability and adaptability pave the way for its potential applications in wearable devices, marking a significant advancement in flexible electronics.

Madden et al. [93] further advanced research in this field by developing a flexible laser-engraved graphene carbon-based lactate biosensor using bio-based polyimide as a substrate. Through electro-deposition of platinum and subsequent dual casting as well as modifications with chitosan and lactate oxidase, this sensor can accurately measure lactate and demonstrate excellent operational and storage stability. The sensor was also successfully fixed on a flexible polyimide substrate with a curvature of $0.14\,\mathrm{mm}^{-1}$, proving its potential for integration with oral care products such as oral swabs. Furthermore, lactate at different concentrations was successfully measured in artificial saliva and sterile human serum samples, further demonstrating the great application value of bio-based polyimide in the preparation of high-performance optoelectronic materials, especially flexible biosensors.

5.2. Waveguides and Optical Fibers. In the development of high-performance optoelectronic materials, polyimides and their derivatives play a crucial role. Particularly, in the realm of waveguides and optical fibers, polyimides, with their unique physical and chemical properties, are extensively utilized in the fabrication of electro-optical devices [94–96].

Saranyoo's research focuses on the development of bio-based polyimides, which are synthesized from renewable diamine and various dianhydride monomers [97]. The resulting materials form transparent films that exhibit remarkable thermal and electrical resistances. Through Fourier-transform infrared spectroscopy, these films are confirmed to possess excellent transparency and low birefringence. Such attributes not only make them perfect for panel displays but also indicate potential applications in the field of waveguides and optical fibers. Saranyoo's study, therefore, provides a significant contribution to the understanding of the high-performance bio-based polyimides and their potential in optical technology.

This research, spearheaded by Huang et al. [98], delves into the synthesis of a novel bio-based polyimide, 4ATA-PI, which is derived from 4,4′-diamino-α-truxilic acid (4ATA) and alicyclic dianhydrides (BCDA). The strategic inclusion of carboxylic acid groups within the PI chains paves the way for organic-inorganic bonding. This, in turn, facilitates the creation of highly transparent and flexible bio-based polyimide hybrid films with TiO_2 and ZrO_2. These hybrid films showcase intriguing optical properties, including adjustable transparency, refractive index, and an appreciable Abbe number. The team further delves into the memory behavior of these films. The unique characteristics of these bio-based polyimides, particularly their tunable optical properties and memory behavior, underscore their considerable potential in waveguides and optical fibers. This study, therefore, represents a significant stride in the realm of bio-based materials, highlighting the potential of bio-based polyimides in revolutionizing optical applications.

In conclusion, bio-based polyimides have garnered significant attention from researchers as they are emerging as potential candidates for future high-performance electro-optic polymer waveguide materials. This is largely attributed to their nonlinear optical effects, exceptional thermal stability, excellent processability, and low optical transmission loss. The unique combination of these properties inherent in bio-based polyimides underscores their potential in addressing the demands of advanced optical applications.

5.3. Photomasks and Photolithography. In the field of optoelectronics, the pursuit of new materials with high stability and superior performance is a focal point of research [99, 100].

The fabrication of flame-retardant transparent films is pivotal for the advancement of electrical devices. In this study spearheaded by Jakkapon [101], high-optical transparency films were developed using biopolyimide (BPI) salt with embedded aluminum (BPI-COOAl) and copper ions (BPI-COOCu). The BPI-COOAl showcased a lower total heat release and peak heat release rate compared to its precursors. These films strike a balance between flame retardancy, thermomechanical stability, and transparency, underscoring the promising potential of bio-based polyimides in the fields of photomask and photolithography.

Recently, Mai et al. [102] developed a bio-based polyimide with commendable thermoelectric properties and high transparency, utilizing raw materials derived from microbial sources. Further research has discovered that this polyimide possesses stable chemical and mechanical characteristics under conditions of light radiation. This paves the way for its potential application in photomask and photolithography technologies.

5.4. Biomedical Field. In the biomedical field, bio-based polyimides with excellent biocompatibility present wide-ranging application prospects [103–105].

Specifically, retinal prostheses, serving as a crucial tool for treating vision loss, often incorporate photosensitive polyimide films, especially Durimide. However, current research on the response of retinal cells to Durimide is still lacking. Recent research [106] indicates that Durimide films demonstrate good biocompatibility when interacting with retinal cells. Furthermore, the properties of this film positively contribute to supporting cell growth and function, further substantiating its potential applications in the biomedical field.

6. Conclusions

Development prospects of bio-based photosensitive polyimides (BPI) are promising, yet their research and application still face numerous challenges. From the preceding discussions, we can outline the future development directions of bio-based photosensitive polyimides in the following aspects:

(1) Structural design of photosensitive groups and polyimides: Enhancing the photosensitivity and graphic film performance of photosensitive polyimides by improving the design and selection of photosensitive groups, thereby increasing their application value in high-performance optoelectronic materials.

(2) Optimization of film-forming process: The photolithography resolution of photosensitive polyimides can be improved by optimizing the film-forming process, such as controlling the relative molecular weight of polyimides. At the same time, it can also enhance the heat resistance and sensitivity of its photolithographic patterns.

(3) Utilization of bio-based materials: By increasing the bio-based content and applying renewable biological resources in the preparation of polyimides, the environmental impact of the preparation process can be mitigated, aligning with the current trend of green and sustainable development.

(4) Resolving the contradiction between bio-based sources and polymer performance: New strategies or methods need to be sought due to the design contradiction between bio-based sources and polymer performance, aiming to enhance the bio-based content as much as possible while ensuring the excellent comprehensive performance of polyimides.

(5) Realizing the full substitution of bio-based polyimides: Despite the current limitations in the use of bio-based polyimides, their significant value in science and technology, environmental protection, and human life will spur ongoing research and improvement by scientists, aiming to fully replace traditional polyimides with bio-based ones.

In summary, the development of bio-based photosensitive polyimides requires simultaneous breakthroughs in material design, process optimization, and the utilization of bio-based materials. In the future, with the advancement of related research, we can anticipate the wide-ranging application of bio-based photosensitive polyimides in science and technology, environmental protection, and human life.

Data Availability

No underlying data were collected or produced in this study.

Additional Points

Highlight. (1) Comprehensive Exploration: Systematically reviews synthesis methods and optoelectronic applications of photosensitive and bio-based polyimides, offering valuable insights for future research. (2) Meticulous Synthesis Analysis: Detailed examination of synthesis strategies for photosensitive and bio-based polyimides, provides a clear separation and comprehensive understanding of each type. (3) Promising Future Directions: Outlines future development directions, emphasizing optimization of structural design, film-forming processes, utilization of bio-based materials, and environmental impact mitigation. (4) Significant Environmental Contribution: Highlights the importance of utilizing renewable biological resources in polyimide synthesis for environmental sustainability, aligning with green development trends.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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