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Light-emitting polymer semiconductors in flexible electronics: strategies, challenges and future perspective

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Light-emitting polymer semiconductors (LPSs) represent a cornerstone material for next-generation flexible electronics, including wearable displays and health-monitoring devices. However, a fundamental trade-off exists between their mechanical flexibility, essential for stretchable applications, and their optoelectronic performance, governed by rigid conjugated structures. This perspective article critically reviews the recent advancements in strategies developed to resolve this conflict, which are categorized into three primary approaches: intrinsic flexibility engineering (through backbone and side-chain modifications), external plasticization (using small-molecule additives), and elastomer blending. We delve into the implementation mechanisms of each strategy, highlighting their respective merits and limitations in achieving stretchable and efficient light-emitting films. Despite significant progress, key challenges persist, particularly in balancing electrical, optical, and mechanical properties, managing phase separation and interfacial defects, and ensuring interlayer compatibility in full devices. Looking forward, we emphasize that the future development of flexible LPSs hinges on a deeper mechanistic understanding of structure–property relationships and the innovation of functionally elastic and recoverable materials. Overcoming these hurdles will be pivotal for unlocking the full potential of LPSs in practical, durable, and high-performance flexible electronic systems.

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1 Introduction

Flexible light-emitting polymer semiconductors (LPSs) hold significant promise for applications in flexible displays, wearable devices and intelligent healthcare.[1–12] The performance of flexible devices critically depends on both the stretchability and efficient electroluminescence (EL) properties of polymer films. However, the rigid structure required for carrier transport channels and the soft segments required for mechanical flexibility are contradictory.[13–17] Indiscriminate enhancement of flexibility in polymer films often leads to degraded electrical properties. Moreover, mechanical strain can induce microstructural rearrangements in the polymer film, resulting in the degradation of optoelectronic performance.[18–21] Therefore, achieving an optimal balance between mechanical flexibility and EL properties of LPSs is crucial for the development of flexible electronics.

To address these challenges, a variety of flexible functionalization strategies have been developed over the past decade. These strategies can be broadly categorized into three groups: intrinsic flexibility strategy, external plasticization strategy, and elastomer blending strategy (Fig. 1).[1,9,10,22–24] The intrinsic flexibility strategy enhances the stretchability and reduces the modulus of polymer films through backbone or side chain structure modification. The external plasticization strategy incorporates small-molecule additives to modulate chain stacking and free volume, thereby improving segmental motion of polymer chains. The elastomer blending strategy controls the morphology and phase structure of blended films by introducing elastomers to impart high flexibility. While these strategies have proven effective in improving the mechanical compliance of LPSs, the synergistic mechanism of mechanical, optical and electrical interactions within LPS films remain inadequately understood. This is particularly critical for blue LPSs, where low-energy band defects formed at rigid–flexible interfaces significantly restrict the practical application of existing strategies.

In this perspective article, we first review recent advances in flexible LPSs, with a particular focus on the implementation of flexible strategies. We aim to deepen the understanding of the underlying mechanism of governing the interplay between mechanical and optoelectrical properties. Subsequently, we discuss the remaining challenges in achieving practically viable and mechanically robust LPS materials and devices. Finally, we put forward the future perspective on the development direction of flexible LPSs.

Wei Huang

Prof. Wei Huang received his PhD from Peking University in 1992. In 2001, he was appointed as a chair professor at Fudan University, where he founded and chaired the Institute of Advanced Materials (IAM). After that he became the vice president of Nanjing University of Posts & Telecommunications, and then president of Nanjing Tech University. He was elected as Academician of Chinese Academy of Sciences in 2011. His research interests include organic/plastic/flexible electronics, nanomaterials and nanotechnology, and so forth.

2 Design and modification of flexible LPSs

2.1 Intrinsic flexibility strategy

The intrinsic flexibility strategy improves the mechanical flexibility of LPSs by introducing flexible units into polymer structures to tune the microstructure and interchain interaction. According to the specific site within the polymer structure where the flexible units are incorporated, it can be subcategorized into backbone functionalization and side-chain functionalization. The following sections discuss these two strategies in sequence.

2.1.1 Backbone flexible functionalization. Kuo *et al.* (2020) synthesized a polyfluorene-*b*-polyisoprene (PF-*b*-PI) block copolymer *via* reversible addition–fragmentation chain transfer (RAFT) polymerization, which have a deep-blue emission at 421 nm.[25,26] PF-*b*-PI inherits the high stretchability of PI, with the crack-onset strain (COS) exceeding 150% as the proportion of PI increased. Furthermore, the block copolymer retained a stable photoluminescence quantum yield (PLQY) after 500 cycles of stretching under 150% strain. The following year, a stretchable touch-responsive light emitting diode was developed using similar block polymer, PF-*b*-PDL, composed of PF and poly(δ-decanolactone) (PDL).[27] These studies demonstrate that block copolymerization of conjugated monomers and elastomeric segments can significantly improve the flexibility of LPSs, with the extent of enhancement dependent on the chemical structure and length of the flexible segment. Despite this advantage, a high content of flexible segments can dilute the interchain interactions among conjugated components, ultimately compromising device performance.[28] Moreover, microphase separation between flexible and rigid blocks is often observed in block copolymer systems, yet the relationship between phase structure and optoelectronic properties remains insufficiently explored.

The conjugation-break strategy represents another effective method for backbone flexile functionalization. Our group introduced non-conjugated segments into the backbone of fluorene-based polymers, developing a series of blue LPSs.[29,30] These flexible linkers disrupt the continuity of the rigid conjugated backbone, endowing the polymer (N2) with a wider bandgap (3.9 eV), lower glass transition temperature (T_g, 114 °C), reduced modulus (113 MPa), and improved ductility (above 60%) compared to the fully conjugated polymer PODPF. This enhanced flexibility mitigates stress concentration and helps prevent interlayer separation in devices under strain. In

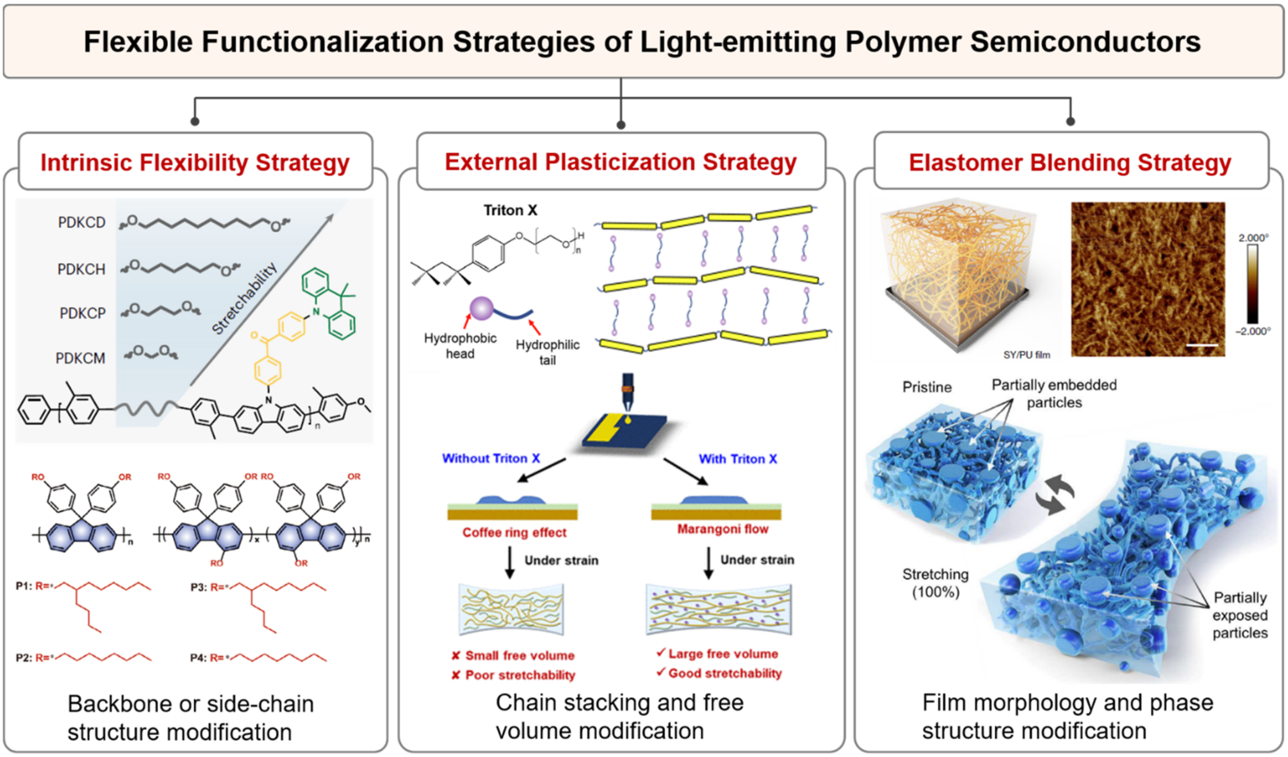

Fig. 1 Flexible functionalization strategies of LPSs. Intrinsic flexibility strategy, including backbone and side-chain structure modification. Reprinted with permission from ref. 9. Copyright 2023 Springer Nature. Reprinted with permission from ref. 22. Copyright 2024 John Wiley and Sons. External plasticization strategy, using small-molecule additives to modulate chain stacking and free volume. Reprinted with permission from ref. 23. Copyright 2021 AAAS. Reprinted with permission from ref. 24. Copyright 2024 American Chemical Society. Elastomer blending strategy, introducing elastomers to controls the morphology and phase structure of blended films. Reprinted with permission from ref. 1. Copyright 2022 Springer Nature. Reprinted with permission from ref. 10. Copyright 2023 AAAS.

addition, the broken conjugation suppresses interchain exciton coupling, contributing to a high PLQY of 89.2% and a high maximum external quantum efficiency (EQE$_{max}$) of 2.4% in N2, whereas the PLQY and of EQE$_{max}$ PODPF is 42.5% and 0.8%, respectively. However, the discontinuous conjugation also leads to reduced charge carrier mobility and a higher interlayer energy barrier in polymer light-emitting diodes (PLEDs). Under identical conditions, PODPF-based flexible PLEDs achieved a maximum luminance (L_{max}) of 2700 cd m^{-2}, whereas N2-based devices reached only 550 cd m^{-2}. To address this limitation, Liu *et al.* (2023) introduced such conjugation-break structure into thermally activated delayed fluorescence (TADF) polymers (Fig. 2a).[9] By leveraging the donor–acceptor charge-transfer characteristics of TADF emitters, these polymers can maintain interchain carrier transport capability through hopping. Since charge transport relies on hopping rather than extended conjugation, it remains less affected by chain elongation during stretching. As a result, stretchable PLEDs using these TADF polymers maintain stable performance up to 50% strain. Moreover, the ability of TADF emitters to harness triplet excitons enabled the EQE$_{max}$ exceeding 10%. The conjugation-break strategy effectively improves the mechanical flexibility of light-emitting polymers, with the COS can be enhanced by increasing the length of non-conjugated segments. Nevertheless, the impact of broken conjugated backbone on electrical performance remains a critical consideration, as evidenced by the relatively low EQE$_{max}$ (around 1%) in blue and red TADF based PLEDs.

2.1.2 Side-chain flexible functionalization. Side-chain flexible functionalization is achieved by modifying the side chain structure to enhance the mechanical flexibility of films, accompanied by changes in crystallization behavior, interchain

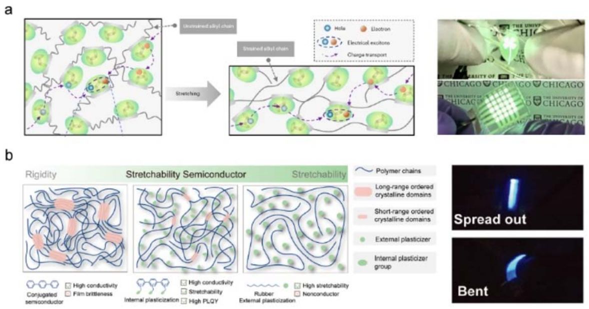

Fig. 2 Intrinsic flexible strategy for flexible LPSs. (a) The conjugation-break strategy used in TADF-based polymers to fabricate high-efficiency flexible PLEDs. Reprinted with permission from ref. 9. Copyright 2023 Springer Nature. (b) Balancing the mechanical and electrical properties of LPSs through controlling FCD. Reprinted with permission from ref. 35. Copyright 2023 John Wiley and Sons.

stacking, conformation, and aggregation behavior. For instance, Wei *et al.* (2023) developed a series of stretchable red-light-emitting indacenodithiophene (IDT) based polymers.[31] The copolymer with phenylhexyl side chains (IDT-2T-Ph) have a higher relative degree of crystallinity (rDOC) compared to the copolymer with hexyl-side-chains (IDT-2T). As a result, IDT-2T exhibited twice the COS of IDT-2T-Ph, albeit with only half the charge carrier mobility. In earlier work, our group introduced amide group into polyfluorene side chains to improve the stretchability.[32] The hydrogen bond between amide groups enhances the side-chain interaction, raising the yield point of polymer films from 7% to 25%. However, increasing the amide side-chain content from 0% to 40% also elevated the tensile modulus from 200 MPa to 400 MPa. Moreover, strong interchain interactions promoted polymer aggregation in solution, leading to solution gelation. Beyond side-chain chemistry, the length and substitution symmetry of side chains also critically affect mechanical flexibility. Our group systematically studied these factors in polyfluorene systems, introducing the parameter flexible chains density (FCD), which is defined as the weight fraction of flexible chains in the polymer structure, to quantify the effect of side-chain length.[22,33] Long alkyl side chains act as internal plasticizers, enhancing the segmental motion, which lowers the T_g of LPSs and improves the ductility.[34] While increasing FCD generally enhances stretchability, it also reduces the packing density of conjugated backbones, often at the cost of electrical performance (Fig. 2b).[33,35] For example, PODPF, PODOF and PODOPF have FCD value of 29.1%, 68.8% and 55.3%, with corresponding tensile modulus of 785 MPa, 222 MPa and 322 MPa. Under the same conditions, the $L_{\max}$ of the PLEDs are 4352 cd m^{-2}, 1561 cd m^{-2} and 2218 cd m^{-2}, respectively. Therefore, only moderate FCD can achieve a balance between the electrical and mechanical properties, which is about 50% in polyfluorenes. Additionally, asymmetry side-chains substitution can weaken the π-stacking between polymer backbones while promoting side-chain entanglement. In a recent work, our group prepared three polyfluorenes, PODPF, PFPO, and POPOF with varying side-chain symmetries.[36] As asymmetry increased, the elongation at break rose from 11% (PODPF) to 72% (PFPO). The change in the interchain interaction mode also altered aggregation morphology from spherical to shuttle-like assemblies. The resulting anisotropic rod-like aggregates of conjugated polymer chains promoted strong capillary interactions and further suppressed the coffee-ring effect, enabling uniform film deposition during printing, which is an advantageous feature for solution-processable device fabrication.

The intrinsic flexibility strategy offers the most fundamental approach by directly tailoring polymer chemistry. Backbone engineering (*e.g.*, block copolymers, conjugation-break spacers) provides a direct handle on the trade-off between conjugation length (affecting charge transport) and chain mobility (affecting stretchability). A key insight is that while increasing flexible segment content improves mechanical compliance, it often dilutes charge transport pathways. The introduction of TADF emitters within a conjugation-break framework represents a clever compromise, utilizing intermolecular hopping for transport less sensitive to chain distortion. Side-chain engineering, quantified by parameters like FCD, provides a more subtle means to tune interchain packing and entanglement. However, its effectiveness is inherently limited by the rigid conjugated core. Crucially, both sub-strategies require sophisticated synthesis and may not be universally applicable across different polymer families. Their primary advantage lies in yielding materials with well-defined and reproducible properties, which is essential for fundamental studies and high-performance devices where purity and homogeneity are paramount.

2.2 External plasticization strategy

External plasticization, a well-established approach for reducing modulus and enhancing ductility in non-conjugated polymers, has been increasingly applied to polymer semiconductors in recent years.[37–49] Kim *et al.* first introduced this strategy into LPSs in 2021 by blending the small-molecule nonionic surfactant Triton X with the conjugated polymer Super Yellow (SY) to form an intrinsically stretchable emission layer (is-EML).[23] The plasticizer increases free volume of the conjugated polymer by reducing interchain interactions, shifting the aggregation morphology from spherical to rod-like aggregates. As the weight ratio of Triton X increases, the blended films exhibit reduced modulus, lower T_g, and improved COS. When the weight ratio of SY to Triton X is 2 : 1 (ST2), the blended film showed optimal charge carrier mobility, and the resulting fully stretchable PLED achieved a $L_{\max}$ of 2500 cd m^{-2} (Fig. 3a). Beyond mechanical enhancement, Triton X also improves the inkjet-printability of SY. Lv *et al.* (2024) demonstrated that Triton X addition enhances both film uniformity and

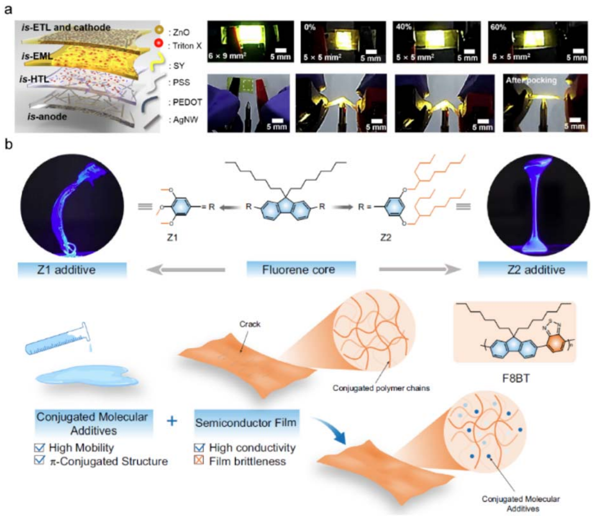

Fig. 3 External plasticization strategy for flexible LPSs. (a) Fully stretchable PLED prepared by is-EML, which is composed of SY and Triton X. Reprinted with permission from ref. 23. Copyright 2021 AAAS. (b) Fluid conjugated-molecule plasticizers used for flexible LPSs enable blended films with high EL performance and mechanical flexibility. Reprinted with permission from ref. 50. Copyright 2023 Springer Nature.

stretchability in printed layers.[24] The surfactant reduces solution surface tension, inhibiting the coffee ring effect during solvent evaporation. Moreover, its amphiphilic structure allows it to intercalate between polymer chains, providing additional free volume that facilitates chain motion and alignment under strain. As a result, PLEDs with Triton X-modified emission layers retained 70% of their luminance under 100% strain, compared to only 33% for devices without the additive. In contrast to conventional small-molecule plasticizers, our group developed a class of fluid conjugated-molecule plasticizers for use in LPSs (Fig. 3b).[50,51] The structural similarity between polymer matrix and fluid conjugated molecules ensures good compatibility, resulting in smooth films with no phase separation even at high blending ratios. As a result, the elongation at break of the blended films can be increased by 50% at a weight ratio of 50%. Furthermore, the conjugated backbone of these plasticizers provides a specific bandgap, enabling efficient Förster Resonance Energy Transfer (FRET) between the host matrix and additive when properly designed. By leveraging this FRET process, the $\mathrm{EQE}_{\max}$ of PLEDs can be enhanced by approximately 40%. Additionally, stretchable PLEDs incorporating these conjugated plasticizers maintain stable EL performance under repeated mechanical stretching.

External plasticization stands out for its simplicity and process compatibility. By blending small-molecule additives, it decouples the material design (synthesis of the LPS) from the flexibility tuning (post-synthesis blending). This allows rapid screening and optimization of mechanical properties using commercial or easily accessible polymers like SY. The use of amphiphilic surfactants (*e.g.*, Triton X) or specially designed fluid conjugated molecules addresses compatibility concerns to varying degrees. However, this strategy faces significant challenges regarding long-term stability. Potential issues include additive migration, phase separation under thermal or mechanical stress, and volatility. Therefore, its application might be more suited to proof-of-concept devices or systems where operational lifetime requirements are moderate. Its greatest utility may be in improving printability and processing of existing high-performance LPSs for flexible fabrication.

2.3 Elastomer blending strategy

The earliest blending of LPSs with elastomers can be traced back to the polymer light-emitting electrochemical cell (PLEC) prepared by Pei *et al.* in 1995.[52] The active layer of the PLEC contained poly[5-(2′-ethylhexyloxy)-2-methoxy-1,4-phenylene vinylene] (MEH-PPV), polyoxyethylene (PEO) and lithium trifluoromethanesulfonate (LiOTf), where PEO, a thermoplastic elastomer serving as the ion-transport matrix, accounted for up to 50 wt% of the blend. The high elastomer content significantly facilitated the realization of flexible devices, and the first flexible PLEC was demonstrated by Fang in 2009.[53] Since then, PLECs have evolved into a variety of flexible devices, including intrinsically stretchable PLECs, flexible paper PLECs and flexible light-emitting fibers.[54–60] The structural simplicity of PLECs underscores the advantage of the elastomer blending strategy, highlighting its effectiveness for flexible and wearable displays.[61] However, due to the different operation mechanisms, applying this approach to PLEDs requires careful consideration of issues such as material compatibility, film morphology, and interfacial properties.

In contrast to PLECs, the elastomers employed in PLEDs do not require the ion-transport ability. This distinction affords a broader selection of elastomers for fabricating flexible PLEDs. Commonly used elastomers include polydimethylsiloxane (PDMS), polystyrene-*block*-polybutadiene-*block*-polystyrene (SBS), polystyrene-*block*-polyethylene-*block*-polybutylene-*block*-polystyrene (SEBS), polystyrene-*block*-polyisoprene-*block*-polystyrene (SIS) and polyurethane (PU).[1,10,62,63] Zhang *et al.* (2022) blended LPSs with PU to fabricate stretchable all-polymer light-emitting diodes (APLEDs, Fig. 4a).[1] This elastomer blending strategy markedly enhanced the mechanical properties of the films: with 70 wt% PU blended into SY, the elongation at break increased to 350% and the tensile modulus decreased to 205 MPa. Furthermore, at low blending ratio, the charge-trapping-dilution effect dominated, substantially improving both current density and luminance in SY-based PLEDs. As a result, the stretchable PLEDs maintained stable device performance under mechanical strain. Through rational material design and optimized device fabrication, the authors successfully realized APLEDs that are both highly stretchable and efficient. In addition to mechanical enhancement, the special phase structure formed between elastomers and LPSs plays a critical role in determining device performance. Jeong *et al.* (2023) developed stretchable PLEDs emitting the three primary colors by blending SEBS with various LPSs.[10] The structural disparity between the elastomer and the LPSs induced a multidimensional hybrid phase separation within the blend films. When the LPS content exceeded 40 wt%, the resulting spherical and rod-like LPS nanodomains interconnected, forming a nanoweb-like architecture. This island–bridge structure facilitated efficient vertical and horizontal charge transport even under strain, without inducing

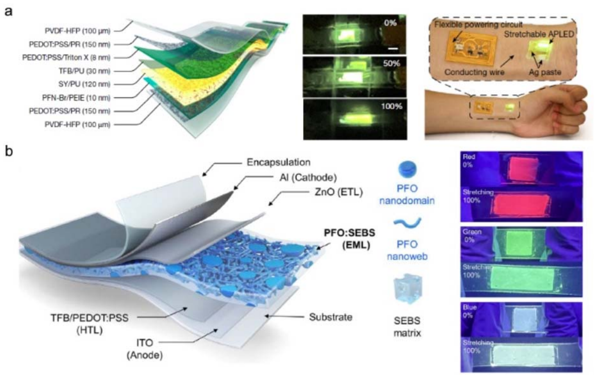

Fig. 4 Elastomer blending strategy for flexible LPSs. (a) Stretchable APLED fabricated by blended films with PU. All substrates and functional layers were composed of polymers and polymer composite films. Reprinted with permission from ref. 1. Copyright 2022 Springer Nature. (b) Intrinsically stretchable three primary light-emitting films and PLEDs enabled by SEBS blend. Reprinted with permission from ref. 10. Copyright 2023 AAAS.

mechanical failure. The COS of all blend films with blue, green and red LPSs can reach over 100%. Based on these results, the authors fabricated stretchable three primary PLEDs with a high luminance value (>1000 cd m^{-2}) up to 100% strain at low V_{on} (<5 V) and these values have even maintained for 10 000 multiple stretching cycles. These outcomes underscore the considerable application potential of the elastomer blending strategy in flexible electronics.

Elastomer blending is arguably the most effective method for achieving extreme levels of stretchability (often >100% strain) by leveraging the intrinsic properties of high-performance elastomers. It facilitates the creation of beneficial phase-separated morphologies (*e.g.*, island-bridge, nanoweb structures) that can maintain percolation pathways for both charge and light under strain. This strategy is highly versatile, compatible with a wide range of LPSs, and benefits from the vast existing knowledge of polymer blends and elastomers. The central drawback is the inherent complexity of multiphase systems. Controlling the nanoscale morphology is challenging and sensitive to processing conditions (solvent, ratio, annealing). The typically large compositional and mechanical mismatch between the LPS and the elastomer can lead to severe interfacial defects, particularly problematic for blue emitters. Success in this strategy is heavily reliant on empirical optimization and advanced characterization to understand and control the blend microstructure.

3 Challenges

The development of intrinsic flexible PLEDs is critically dependent on advances in flexible LPSs. Although various design and modification strategies have been developed to impart compliant mechanical properties to LPSs for practical applications, these approaches also introduce new challenges. Compared to other polymer semiconductors, flexible LPSs require careful consideration of the impact on EL performance. Thus, the central challenge lies in achieving high EL performance in flexible and stretchable PLEDs.

The first challenge is the balance between mechanical, optical and electrical properties. In most cases, enhancing mechanical flexibility compromises EL performance. On the one hand, increasing the content of flexible components tends to raise the non-radiative transition rate, thereby reducing the PLQY.[22,33] On the other hand, the flexible segments are often non-conjugated and cannot facilitate charge carrier transport within the device.[13,14,64] Although strategies such as external plasticization and elastomer blending have demonstrated that low blending ratios can dilute exciton trap density in films, EL performance continues to decline significantly at higher blending ratios.[10,23] We propose that a promising pathway to reconcile this conflict lies in the synergistic enhancement of the intrinsic flexibility and the molecular weight (chain length) of the polymers. Recent studies indicate that for many conjugated polymers, electrical performance (*e.g.*, charge carrier mobility) improves with molecular weight up to a critical point, as longer chains reduce inter-grain hopping and improve connectivity.[31,65] Importantly, when the polymer backbone is inherently more flexible, the mechanical benefits of high molecular weight—such as increased entanglement and toughness—can be realized at a lower critical molecular weight threshold. For instance, work on stretchable red-light-emitting IDT-based polymers showed that optimizing both the side-chain design (for flexibility) and achieving high molecular weight led to simultaneously improved ductility and charge carrier mobility.[31] Therefore, future molecular design should aim not only at incorporating flexible units but also at developing polymerization techniques that reliably yield high-molecular-weight, defect-free LPSs with tailored chain architectures. This dual focus could shift the trade-off curve, enabling high performance at greater levels of stretchability. Furthermore, improving the intrinsic flexibility of the polymer can lower this critical molecular weight, thereby facilitating the attainment of both high mechanical stretchability and desirable optoelectronic performance.

The second challenge involves phase separation and interface interactions. The intrinsic incompatibility between rigid conjugated structures and flexible segments often induces severe phase separation in blended films, leading to diverse morphological patterns.[62,63,66–68] These phase-separated morphologies are closely influenced by the chemical structure, blending ratio, and processing conditions of the system components. However, a clear qualitative relationship between phase morphology and overall film performance has not yet been established. Moreover, interfacial defects frequently arise at the boundaries between the rigid and soft phases. Under mechanical strain, such defects can degrade color purity and compromise spectral stability. Especially in blue LPSs, complex interfacial interactions often promote the formation of low-energy emission traps, manifesting as undesirable green emission bands in the spectrum and significantly undermining EL stability. Moving from describing to managing phase separation requires advanced characterization and smart material design. *In situ* characterization techniques, such as grazing-incidence X-ray scattering (GIXS) under tensile strain or *in situ* atomic force microscopy (AFM), are crucial for dynamically probing morphological evolution under operational conditions.[69,70] These techniques can reveal how microphase domains deform, connect, or fracture, directly correlating structure with optoelectronic performance loss. From a design perspective, the use of compatibilizers—molecules or block segments that localize at the interface between the rigid LPS and the soft phase (elastomer or plasticizer)—could be a powerful tool. For example, designing block copolymers where one block is conjugated and the other is miscible with the elastomer, and using them as a minor additive in a blend, could reduce interfacial tension and stabilize finer domain sizes. Recent work on ternary blends has begun to explore such concepts to achieve more controllable and stable phase-separated morphologies in stretchable films.[71–73]

The final challenge concerns interlayer adaptability in flexible devices. Under mechanical strain, stress concentration and interfacial issues often arise between functional layers, leading to significant performance degradation.[30,74–76] In many cases, flexible devices with the same structure as their rigid counterparts exhibit less than half of the efficiency, largely due to poor interlayer adhesion and mismatched mechanical properties. Notably, flexible functionalization strategies can change the interfacial characteristics of flexible LPSs, such as and surface energy.[36,63,77] By consciously designing these modified interfacial properties, it is possible to mitigate stress-induced failures and enhance both the efficiency and operational stability of flexible devices. Different flexibility strategies distinctly alter the interfacial properties of the LPS layer, which must be strategically leveraged. Intrinsic flexibility strategies, particularly side-chain engineering, directly modify surface energy and adhesion. For example, introducing polar amide groups or long alkyl chains can significantly alter wetting behavior against adjacent charge transport layers.[18,22,33] External plasticization with surfactants like Triton X can migrate to the film surface, creating a low-surface-energy top layer that may hinder hole or electron injection if not accounted for. Elastomer blending introduces a composite surface whose properties depend on the phase-separated morphology; elastomer-rich surface domains may cause poor adhesion. Therefore, device optimization must include interfacial engineering as a co-design parameter. This could involve: (1) tailoring the surface energy of adjacent layers to match the modified LPS film, (2) using crosslinkable or adhesion-promoting interlayers that bond chemically or physically to both sides, and (3) designing the flexible LPS layer to have a gradient structure where the surface composition is optimized for interface stability while the bulk is optimized for stretchability and emission.

4 Future perspective

Polymer semiconductors have undergone nearly half a century of development since their emergence. While they generally underperform relative to inorganic semiconductors in terms of electrical conductivity, environmental stability, and operational reliability, their future advancement should capitalize on their unique strengths—particularly their compatibility with flexible and stretchable electronic systems. The rapid growth of flexible electronics represents a significant opportunity for polymer semiconductors, especially LPSs, which show broad application prospects in flexible displays, wearable devices, intelligent healthcare, and interactive systems. Looking forward, research efforts should focus on enhancing the durability, stability, and sustainability of LPS-based devices. We envision several concrete research directions: first, the development of functionally elastic and recoverable LPS layers is critical. This goes beyond mere stretchability to include full, rapid, and fatigue-resistant recovery after repeated deformation. This requires new polymer architectures (*e.g.*, incorporating dynamic covalent bonds or supramolecular motifs) that allow energy dissipation and network reformation. Second, a deeper mechanistic understanding facilitated by advanced *operando* and *in situ* characterization is needed. Techniques that can map local strain, morphology, and optoelectronic response simultaneously, such as coupled mechanical testing with photoluminescence microscopy or the scanning probe methods referenced in recent studies, will be indispensable.[69,78] Third, material design must evolve to explicitly manage interfaces and phase boundaries. This includes the synthesis of tailored compatibilizers and the exploration of multi-component blends with precisely controlled morphology. Finally, exploring novel device architectures that intrinsically accommodate strain, such as fiber-based, kirigami-patterned, or self-healing devices, can circumvent material-level limitations. Overcoming these hurdles will be pivotal for unlocking the full potential of LPSs in practical, durable, and high-performance flexible electronic systems.

Author contributions

Xiang An and Wenyu Chen are attributed equally to this work. Xiang An: methodology, formal analysis, writing – review and editing and funding acquisition. Wenyu Chen: writing – original draft. Man Xu, Zhiyang Sun and Hong Ren, Xiao Luan and Shigang He: writing – review and editing. Jinyi Lin and Wei Huang: conceptualization, supervision, project administration and funding acquisition. All authors have read and approved the final manuscript.

Conflicts of interest

There are no conflicts to declare.

Data availability

No primary research results, software or code have been included and no new data were generated or analyzed as part of this perspective.

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