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Rise of intrinsically stretchable electroluminescent materials: toward free-form displays

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Intrinsically stretchable light-emitting diodes (LEDs) are foundational components for next-generation free-form displays. Here, we present recent advances in electroluminescent materials for intrinsically stretchable LEDs, including molecular plasticizer–light-emitting polymer blends, elastomer-light-emitting polymer integration, thermally activated delayed fluorescence polymers, and inorganic semiconductor nanocrystals–elastomer composites. Critical challenges—improving luminous efficiency, stability, patterning, and developing stretchable electrodes and transport layers—are discussed, providing clear pathways toward practical applications.

Stretchable displays have attracted significant attention, driven by the growing demand for wearable, deformable, and skin-attachable electronics[1–5]. Early approaches for fabricating stretchable displays relied heavily on integrating rigid electroluminescent (EL) materials into structurally stretchable design[6–8]. However, these approaches exhibited inherent limitations, including restricted mechanical deformation and degraded image quality. For instance, displays utilizing "wrinkled" designs based on ultrathin light-emitting diodes (LEDs) can accommodate various deformations by minimizing bending strain but often result in image distortion[9–13]. Similarly, "island-bridge" structures, where rigid LED islands are connected by stretchable interconnection bridges, suffer from reduced fill factors of light-emitting areas under stretching due to the rigidity of the pixel components[14–16]. This inevitably leads to decreased resolution and brightness during mechanical deformations, highlighting the need for innovative material solutions to overcome these limitations.

To address these challenges, intrinsically stretchable displays, built from inherently stretchable materials, have emerged as a promising solution[17,18]. Intrinsically stretchable LEDs technologies are central to this advancement. Unlike their rigid counterparts, intrinsically stretchable LEDs provide exceptional mechanical compliance and user comfort, enabling applications such as wearable electronics, interactive displays, health monitoring devices, and soft robotics[19]. However, a critical challenge remains: the development of EL materials that achieve both robust stretchability and high luminous performance. Traditional organic and inorganic EL materials, due to their high crystallinity and inherent rigidity, often fail under mechanical stress by stretching deformations or experience significant performance degradation, emphasizing the need for breakthroughs in material design and engineering.

This perspective review article highlights recent advances in intrinsically stretchable EL materials, specifically focusing on four state-of-the-art material categories for stretchable LEDs: light-emitting polymers blended with molecular plasticizers (Fig. 1a), light-emitting polymers integrated with elastomers (Fig. 1b), thermally activated delayed fluorescence (TADF) polymers engineered for intrinsic stretchability (Fig. 1c), and inorganic semiconductor nanocrystals (e.g., colloidal quantum dots (QDs) and perovskite nanocrystals) embedded in elastomeric matrices (Fig. 1d). While phosphorescent powder-based alternating current electroluminescence devices also offer intrinsic stretchability, their operational mechanism (field-induced excitation) fundamentally differs from that of LEDs (direct electrical carrier injection). Thus, this article exclusively focuses on EL materials suitable for intrinsically stretchable LEDs. Furthermore, we discuss the remaining challenges and outline future directions to enable the transition of these technologies into real-world applications.

Light-emitting materials for intrinsically stretchable LEDs

The luminous performance of intrinsically stretchable LEDs has significantly advanced over the past decade, driven by progress in material engineering strategies for stretchable emissive layers (EMLs)[20]. Most conventional EMLs used in state-of-the-art LED applications—including thin

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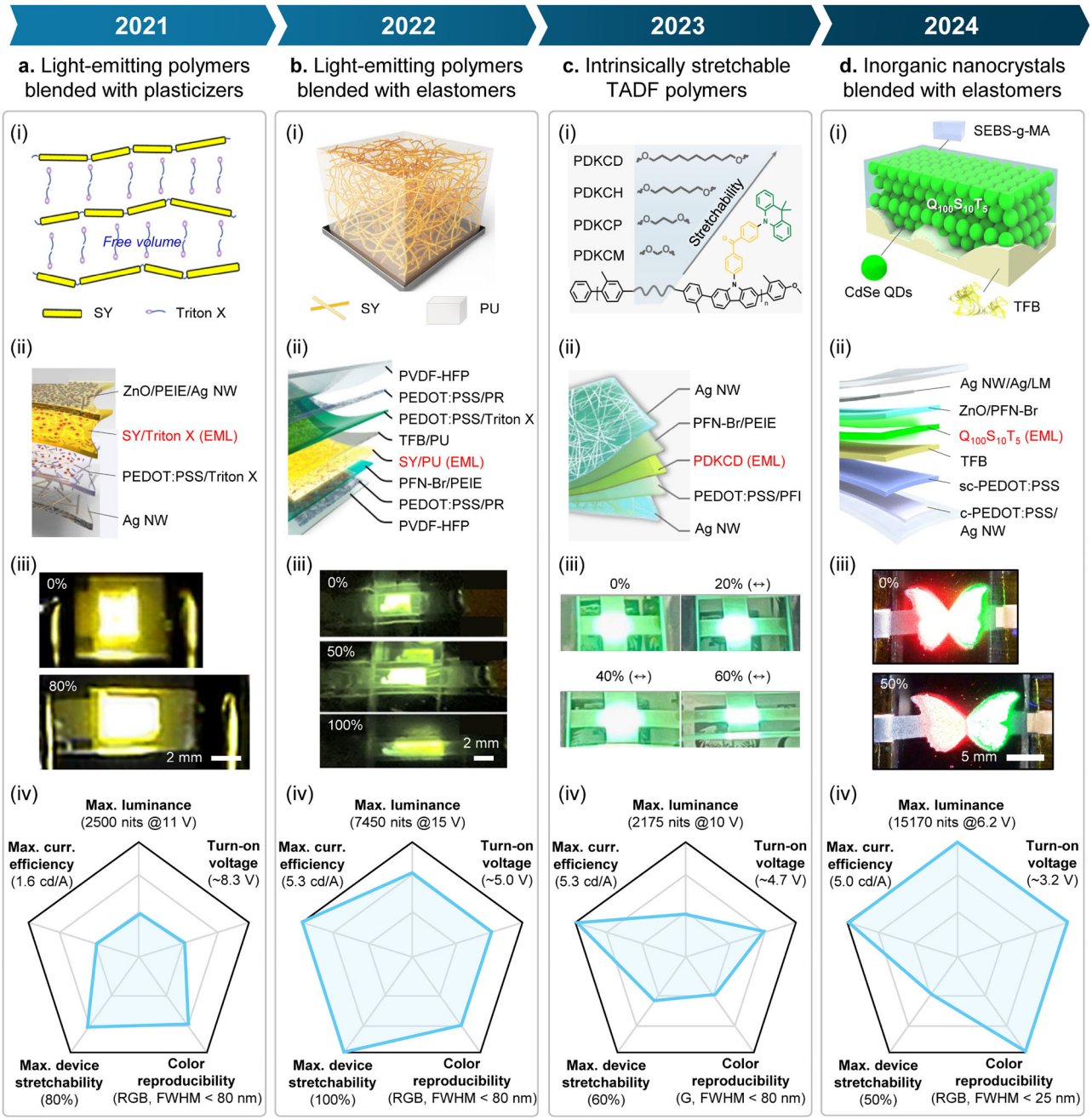

Fig. 1 | Recent advancement on intrinsically stretchable EL materials and their device applications. a–d Key approaches for intrinsically stretchable LEDs. For each approach, material strategies for stretchable EMLs (i), device structures of intrinsically stretchable LEDs (ii), photographs of device operation under the applied strain (iii), and comparative evaluation of device performance (iv) are provided. Reprinted with permission from ref. 37. Copyright 2021 AAAS. Reprinted with permission from ref. 38. Copyright 2022 Nature Publishing Group. Reprinted with permission from ref. 40. Copyright 2023 Nature Publishing Group. Reprinted with permission from ref. 43. Copyright 2024 Nature Publishing Group.

films of inorganic semiconductors (such as epitaxial III-V compounds, colloidal QDs, and perovskites) as well as organic semiconductors, including both small molecules and polymeric emitters—are inherently rigid and non-stretchable. This intrinsic rigidity poses a significant challenge to their integration into intrinsically stretchable LED devices. When a stiff thin film is stretched beyond its elastic limit, mechanical mismatch between the film and soft substrate leads to stress localization, particularly around defects or surface irregularities. This localized stress initiates micro-cracks that rapidly propagate perpendicular to the direction of strain. Prolonged deformation can further result in interfacial failure, causing delamination of the film and severely degrading its mechanical integrity and optoelectronic performance of devices.

Therefore, a key objective in the development of stretchable LEDs is to achieve mechanical stretchability without compromising the electrical and optical properties of EL materials. Table 1 summarizes previously reported stretchable EML systems used in intrinsically stretchable LED fabrication. Based on these studies, we review four major material engineering strategies, highlighting their distinctive approaches and the resulting device performance.

Organic emitters have been the most widely investigated luminescent materials for intrinsically stretchable LEDs due to their high EL efficiency and inherently soft mechanical properties[21–25]. Light-emitting polymers, such as poly(1,4-phenylenevinylene) (commonly known as Super Yellow, SY), stand out as promising candidates because of their flexibility, decent

Table 1 | Materials and device performance of previously-reported intrinsically stretchable LEDs

Emitter types	Year	Stretchable EML		Device structure (from anode to cathode)	Max. efficiency	Max. luminance	Max. stretch-ability	Device lifetime	Ref.
		Emitters	Additives						
Organic emitters	2011	PF-B	· PEO-DMA · LiTf	SWNT-PtBA/ **Stretchable EML**/ SWNT-PtBA	1.24 cd A^{-1}	300 nits (@12 V)	45%	LT_{55}: 7 h (L_0:170 nits)	26
	2013	SY	· ETPTA · PEO · LiTf	Ag NW-PUA/ PEDOT:PSS/ **Stretchable EML**/ Ag NW-PUA	5.7 cd A^{-1}	2,200 nits (@21 V)	120%	LT_{50}: 10 h (L_0:211 nits)	27
	2014	White-emitting polymer	· OXD-7	Ag NW-GO-PUA/ **Stretchable EML**/ PEI/ Ag NW-GO-PUA	2.0 cd A^{-1}	1,100 nits (@21 V)	130%	N/A	28
	2020	SY	· IC-polymer · ETT-15 · LiTf	Ag NW-PUA/ PEDOT:PSS/ **Stretchable EML**/ Ag NW-PUA	N/A	N/A	30%	N/A	29
	2021	SY	· Triton-X	Ag NW-PDMS/ PEDOT:PSS-Triton X/ **Stretchable EML**/ ZnO-PEIE/ Ag NW-PDMS	1.6 cd A^{-1}	2,500 nits (@11 V)	80%	LT_{50}: 27 s (L_0: 100 nits)	37
	2022	SY	· Triton-X	Graphene-Ag NW-PDMS/ PEDOT:PSS-Triton X/ **Stretchable EML**/ Crown-CPE/ Ag NW-PDMS	20.3 cd A^{-1}	2,185 nits (@15 V)	73%	LT_{50}: 7 h (L_0: 100 nits)	31
	2022	L-SY-PPV	· PAN	Au (serpentine)/ PEDOT:PSS-Triton X/ **Stretchable EML**/ PMMA/ Zn-PEIE-pBphen-TR/ Ag-Ag NW-PDMS	2.35 cd A^{-1}	3,780 nits (@13 V)	30%	N/A	30
	2022	SY	· PU	PEDOT:PSS-PR/ PEDOT:PSS-Triton X/ TFB-PU **Stretchable EML**/ PFN-Br- PEIE/ PEDOT:PSS-PR/	5.3 cd A^{-1}	7,450 nits (@15 V)	100%	N/A	38
	2023	SY	· PEO · KCF_3SO_3	Graphene-Ag NW-SEBS/ PEDOT:PSS-Triton X/ **Stretchable EML**/ Graphene-Ag NW-SEBS/	3.14 cd A^{-1}	1,754 nits (@11 V)	30%	LT_{50}: 150 s (L_0: ~1,000 nits)	32
	2023	PDKCD	None	Ag NW-TPU-PDMS/ PEDOT:PSS-PFI/ **Stretchable EML**/ PFN-Br-PEIE/ Ag NW-TPU-PDMS/	5.3 cd A^{-1}	2,175 nits (@10 V)	60%	N/A	40
	2024	SY	· Triton-X	Ag NW-PDMS/ PEDOT:PSS-Triton X/ **Stretchable EML**/ PFN-Br-PEIE-Triton X/ Ag-PEIE-Cs_2CO_3	4.2 cd A^{-1}	2,340 nits (@9 V)	70%	LT_{50}: 55 s (L_0: 100 nits)	50
Inorganic emitters	2017	$MAPbBr_3$ perovskites	· PEO	PEDOT:PSS-PEO/ **Stretchable EML**/ EGaIn or Ag NW	2.7 cd A^{-1}	15,960 nits (@8.5 V)	40%	N/A	88
	2024	CdSe QDs	· SEBS-g-MA · TFB	Ag NW-PUA/ *c*-PEDOT:PSS-FS31/ *sc*-PEDOT:PSS-FS31/ TFB/ **Stretchable EML**/ ZnO-PFN-Br/ AgNW-Ag- EGaIn -PUA	5.0 cd A^{-1}	15,170 nits (@6.2 V)	50%	LT_{50}: 20 min (L_0: 100 nits)	43

luminous performance, and cost-effectiveness[26–30]. However, the conjugated polymer backbones limit their stretchability, with pristine SY films typically exhibiting a crack-onset strain (COS) of less than 40%. Consequently, additional material engineering strategies are necessary to achieve sufficient stretchability of polymeric emitters[31–36].

Kim et al. (2021) enhanced stretchability by blending SY with molecular non-ionic surfactants (Triton X) as plasticizers (Fig. 1a)[37]. Plasticizers reduce interchain interactions, increasing the free volume of conjugated polymers. This led to significant improvements in mechanical properties: the Young's modulus decreased from 412 MPa to 15 MPa, and crack onset

strain (COS) increased from 40% to 110% as the Triton X content increased from 0 to 67 wt%. However, excessive addition of surfactants adversely affected the electrical properties due to the insulating nature of Triton X, leading to reduced hole and electron mobilities. Through optimization, a Triton X content of 33 wt% was identified as the optimal composition to achieve a balanced trade-off between mechanical stretchability and electrical performance.

The optimized stretchable EML was integrated into intrinsically stretchable LEDs with a structure comprising a silver nanowire (Ag NW) anode, PEDOT:PSS blended with Triton X as the hole transport layer (HTL), the stretchable EML, a composite of ZnO/polyethyleneimine ethoxylated (PEIE) electron transport layer (ETL), and an Ag NW cathode. The device demonstrated a maximum luminance of 2500 cd m^{-2} at 11 V, and maintained its EL performance under strains of up to 80%. The authors extended this strategy to other light-emitting polymers, achieving red, green, and blue stretchable LEDs.

Zheng et al. (2022) reported another approach for improving stretchability by adding polyurethane (PU) elastomers to SY (Fig. 1b)[38]. The uniform distribution of SY nanofibers in the PU matrix, facilitated by polar interactions, prevented phase separation and delayed crack formation. As PU content increased from 0 to 70 wt%, the Young's modulus decreased from 4.9 GPa to 205 MPa, while COS increased to 100%. Compared to the SY/Triton X blend, which only demonstrated enhanced film stretchability, the SY/PU composite exhibited significant improvements in optoelectronic performance. For instance, rigid EL devices fabricated with blended SY/PU EMLs demonstrated higher charge carrier transport density, increased PLQY, and longer PL lifetimes compared to devices using pristine SY EMLs, resulting in both enhanced current density and brightness. These improvements were attributed to the well-engineered morphology of the blended films, where SY nanofibers were uniformly embedded within the PU matrix, effectively reducing the charge-trap density in the SY phase. This dilution in trap density facilitated improved trap-limited carrier transport and effectively suppressed trap-assisted non-radiative recombination.

The resulting stretchable LEDs utilized SY/PU composites in a layered structure incorporating PEDOT:PSS blended with Triton X as the hole injection layer (HIL), PU-blended poly[(9,9-dioctylfluorenyl-2,7-diyl)-co-(4,4'-(N-(4-sec-butylphenyl)diphenylamine)] (TFB) as the HTL, the stretchable EML, and a poly(9,9-bis(3′-(N,N-dimethyl)-N-ethylammonium-propyl-2,7-fluorene)-alt-2,7-(9,9-dioctylfluorene)) dibromide (PFN-Br)/PEIE ETL. These devices achieved a maximum brightness of 7450 cd m^{-2} at 15 V and withstood strains of up to 100%. The approach was further extended to create skin-attachable LEDs integrated with sensors, enabling the real-time visualization of cardiovascular signals.

On the other hand, organic emitters can achieve stretchability without the need for blending additives[39]. Liu et al. developed an innovative method to synthesize intrinsically stretchable TADF polymers by adjusting the alkyl chain lengths in the polymer backbone (Fig. 1c)[40]. These TADF polymers utilize both singlet and triplet excitons to achieve a theoretical internal quantum efficiency (IQE) of 100%. By increasing the alkyl chain length, the polymer chain dynamics were enhanced, resulting in improved stretchability. Importantly, alkyl chains below a certain length were found to have minimal impact on EL performance. Since charge transport primarily occurs through hopping between adjacent TADF units, the percolation network that facilitates long-range charge transport is expected to remain intact, even with the incorporation of short alkyl chains into the molecular structure. Notably, a TADF polymer with a 10-carbon alkyl chain (named as PDKCD) exhibited stretchability of up to 125% and an external quantum efficiency (EQE) of 10% in rigid LEDs fabricated on ITO glass.

When integrated into intrinsically stretchable LEDs featuring a structure with Ag NW electrodes and semiconducting PEDOT:PSS as the HTL, along with PFN-Br/PEIE as the ETL, the stretchable device achieved a maximum brightness of 2,175 cd m^{-2} at 10 V and a low turn-on voltage of 4.75 V. Remarkably, the device sustained its EL under 60% strain without significant performance degradation, highlighting the potential of TADF polymers for combining exceptional luminous efficiency with robust mechanical flexibility.

Inorganic emitters, such as II-VI and III-V semiconducting compounds, have garnered significant attention for their exceptional EL properties, including high luminous efficiency, narrow emission spectra, and outstanding stability. However, compared to organic emitters, their rigid and brittle mechanical properties make them susceptible to crack generation under mechanical stress. While various structural engineering strategies—such as reducing device thickness or employing serpentine and kirigami designs—have facilitated their integration into flexible EL devices[41,42], achieving intrinsic stretchability requires advanced material engineering approaches. One promising strategy involves embedding nanoscale inorganic emitters within an elastomer matrix to impart stretchability while preserving their excellent optical properties.

Kim et al. (2024) developed a ternary nanocomposite-based stretchable EML using green-emitting CdSe QDs, elastomers (polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene grafted with maleic anhydride, SEBS-g-MA), and a charge transport polymer (TFB) (Fig. 1d)[43]. The incorporation of the elastomer matrix enhanced stretchability but also introduced an insulating effect, which could hinder efficient charge injection into the QDs. To address this and achieve charge balance, a p-type semiconducting polymer, TFB, was incorporated into the blend to improve hole injection. During film formation, TFB underwent phase separation, forming TFB-rich islands localized near the bottom of the film. These domains facilitated enhanced hole injection into the QD layer, enabling the simultaneous achievement of high stretchability and outstanding optoelectronic performance. As a result, a rigid QLED incorporating the stretchable QD-EML exhibited an impressive brightness of 173,171 cd m^{-2} at 8 V and a current efficiency of 28.4 cd A^{-1}. Furthermore, grazing-incidence small-angle X-ray scattering (GISAXS) confirmed that the optimized composite maintained stable interparticle distances even under mechanical deformation.

The optimized EML was incorporated into intrinsically stretchable QLEDs with a device structure consisting of AgNW and conducting PEDOT:PSS as the anode, semiconducting PEDOT:PSS as the HIL, TFB as the HTL, ZnO/PFN-Br as the ETL, and AgNW/Ag/liquid metal as the cathode. The stretchable device exhibited an impressive brightness of 15,170 cd m^{-2} at 6.2 V and maintained stable EL performance under 50% strain without noticeable degradation. Additionally, stretchable EMLs incorporating red, green, and blue-emitting QDs were successfully patterned using intaglio transfer printing techniques, facilitating the fabrication of high-resolution, full-color QLED arrays.

Challenges and outlooks

The development of intrinsically stretchable LEDs has been driven by advancements in stretchable EL materials, including blending strategies, polymer chain modifications, and nanocomposite engineering. These advances have enabled devices promising for skin-attachable displays and wearable electronics. Despite these recent advancements, several critical challenges remain, and overcoming these obstacles is essential for their widespread adoption and practical applications. Below, we present the challenges across four areas: materials, devices, fabrication, and system integration (Fig. 2a). Additionally, we summarize the current status and target goals for eight key performance parameters: (A) maximum luminance, (B) device efficiency, (C) driving voltage, (D) reliability, (E) color reproducibility, (F) environmental sustainability, (G) maximum stretchability, and (H) array fabrication (Fig. 2b). Through this analysis, we aim to outline the future research direction of this technology.

(i) Material engineering: Improving the stretchability of EL materials often compromises their electrical and optical properties[44], such as photoluminescence quantum yield (PLQY) and color reproducibility. This trade-off highlights the need for balanced material designs. Achieving both mechanical flexibility and optimal optical performance requires nanocomposite systems with finely tuned interactions between light-emitting materials and elastomeric components.

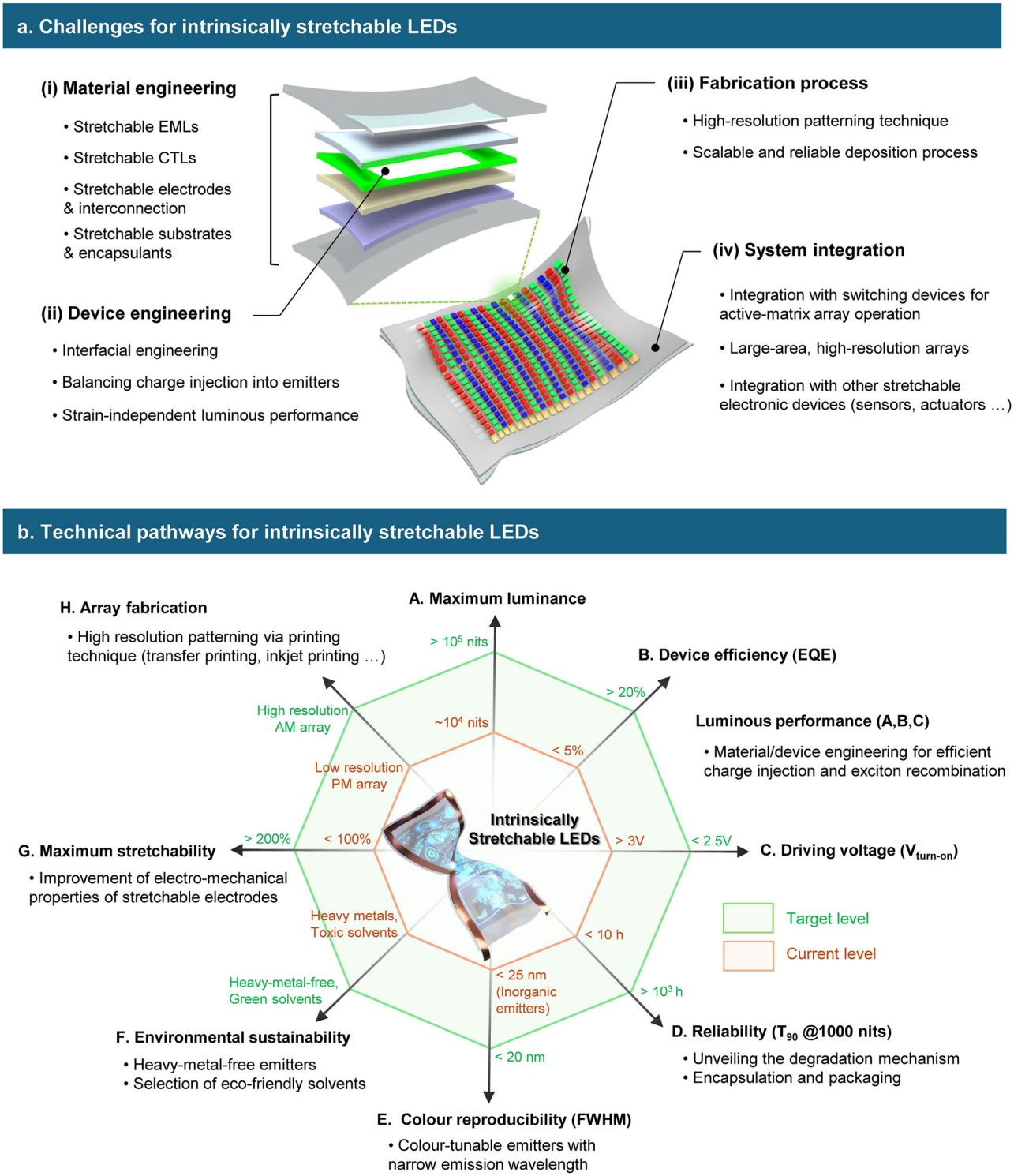

Fig. 2 | Future directions for intrinsically stretchable LEDs. a Challenges for intrinsically stretchable LEDs. **b** Technical pathways for intrinsically stretchable LEDs. $V_{turn\text{-}on}$, device turn-on voltage; T_{90}, device lifetime for the brightness to decrease to 90% of its initial value. FWHM, full-width half-maximum.

Additionally, advanced material engineering strategies, such as molecular tuning and interfacial optimization, can further enhance these properties. Ideally, stretchable EL materials should exhibit high PLQY (>90%), narrow emission spectra (full-width half-maximum, FWHM ≈ 20 nm), and a wide color gamut to meet the requirements of REC 2020.

Moreover, they must be biocompatible and comply with the Restriction of Hazardous Substances Directive, which limits the use of heavy metals such as lead and cadmium to ensure minimal environmental impact and reduce potential health risks associated with exposure to toxic materials[45–48]. In this regard, the toxicity associated with cadmium-based quantum dots and Pb-based perovskite materials remains a significant concern. Therefore, environmentally friendlier alternatives, such as indium phosphide (InP)-based quantum dots and lead-free perovskites, should be actively explored. Beyond emissive materials, elastomeric matrices

also require consideration from an environmental sustainability perspective; thus, developing bio-derived or recyclable elastomers will become increasingly important for realizing fully sustainable intrinsically stretchable LEDs.

In addition, the development of intrinsically stretchable LEDs requires all constituent layers—beyond the EMLs—to be inherently stretchable[49–51]. This includes electrodes[52–54], charge transport layers[55], and encapsulation layers[56]. Ensuring compatibility among these components is crucial for constructing fully stretchable devices. Research must focus on designing intrinsically stretchable electrodes and interconnections with high conductivity, stretchability, and transmittance (for transparent electrodes), to further enhance the mechanical performance beyond the current maximum strain range of 50–100%. Stretchable charge transport layers with an excellent carrier mobility, and stretchable encapsulation layers that provide effective protection against humidity and oxygen while maintaining mechanical resilience and stable operation under repeated deformation are also crucial.

(ii) Device engineering: While the luminous performance of intrinsically stretchable LEDs—evaluated through parameters such as luminance, external quantum efficiency (EQE), operating voltage, and color reproducibility—has steadily advanced over the past decades, it still falls short of conventional LED technologies. For instance, numerous studies on high-performance OLEDs and QLEDs have demonstrated maximum EQEs exceeding 20% and low turn-on voltages below 3V[13,46,57–59], both of which surpass the performance of most intrinsically stretchable LEDs. Therefore, it is crucial to properly align the energy bands of adjacent electronic materials to establish efficient charge transport pathways from the electrodes to the EMLs. Unlike conventional LEDs, intrinsically stretchable LEDs utilize novel electronic materials, necessitating a deeper insight of charge and energy transport at their interfaces to achieve balanced charge injection while minimizing leakage currents.

Additionally, operational stability remains a major hurdle to the commercialization of intrinsically stretchable LEDs. Despite their importance, device lifetimes are often overlooked in current studies due to the inherent instability of existing materials. Enhancing long-term stability requires a deeper understanding of the degradation mechanisms affecting EMLs[60–64], as well as the development of highly stretchable substrates and encapsulation materials with low oxygen and water permeability. Moreover, repeated mechanical deformation can induce material fatigue, causing microcracks within composite emitters, especially at stress-concentration points, and severely disrupting electrical pathways. Interfacial delamination between emissive layers, charge transport layers, and electrodes also commonly arises from mismatches in mechanical properties (e.g., stiffness or elasticity), impairing effective charge transport and device performance. To mitigate these challenges, future studies should focus on enhancing interlayer adhesion and optimizing composite microstructures—for example, by ensuring uniform dispersion—to improve mechanical durability.

(iii) Fabrication process: High-resolution patterning and deposition of red, green, and blue pixel arrays is critical for the realization of next-generation free-form displays using intrinsically stretchable LEDs. While conventional EL materials have been successfully patterned by well-established fabrication methods such as photolithography[65–68], inkjet printing[69–71], and transfer printing[72–75], these techniques are not yet effectively adapted to intrinsically stretchable EL materials. In particular, stretchable EL materials face compatibility issues with crosslinking processes used in photolithography, difficulties in achieving uniform pixel resolution and thickness control in inkjet printing, and mechanical challenges in maintaining pattern fidelity during transfer printing. Thus, developing scalable, high-resolution (>1000 ppi) patterning methods specifically suited for intrinsically stretchable EL materials remains a critical technological challenge. Furthermore, the encapsulation and packaging processes for intrinsically stretchable LEDs using soft, elastomeric passivation materials need further advancement to ensure the long-term stability of these devices.

(iv) System integration: Many previously reported studies on intrinsically stretchable LEDs have demonstrated passive-matrix (PM) arrays with a limited number of pixels, typically 5 × 5 or less[38,40,43]. However, achieving commercial-grade displays requires the development of large-area active-matrix (AM) arrays with high pixel densities. Compared to PM arrays, AM arrays offer significant advantages, including faster response times, lower power consumption, and reduced crosstalk between adjacent pixels. To develop fully stretchable AM-LED arrays, intrinsically stretchable LEDs should be integrated with switching devices, specifically intrinsically stretchable thin-film transistors (TFTs)[29]. This integration necessitates replacing all TFT components—including source, drain, and gate electrodes, channels, and dielectrics—with inherently stretchable materials, demanding substantial advancements in material science and device engineering[76–78].

By overcoming these challenges, intrinsically stretchable displays have the potential to transition from experimental prototypes to commercially viable products, thereby opening up exciting opportunities for their diverse practical applications (Fig. 3). A notable potential application of intrinsically stretchable LEDs is their versatile use in smart interactive displays, where display technologies are seamlessly embedded into various environments to enhance their functionality and interactivity. Beyond the currently available flexible portable electronics, future devices incorporating stretchable LEDs are expected to offer a broader range of design form factors, catering to needs of users for a new device experience. Moreover, augmented reality (AR) and virtual reality (VR) systems could greatly benefit from high-resolution, stretchable LED arrays integrated into head-mounted devices or even smart contact lenses. Similarly, incorporating stretchable LEDs into textiles could enable interactive smart clothing with dynamic visual effects, real-time bio-signal visualization, and intuitive communication interfaces. Beyond wearable applications, the automotive industry may utilize these free-form displays for shape-morphing dashboards and adaptive interior lighting[79], enhancing both esthetics and usability.

In the field of smart healthcare, intrinsically stretchable LEDs have the potential to function as efficient light sources or output signals for wearable biosensors and phototherapy platforms, facilitating wound healing and enabling optogenetic stimulation while maintaining user comfort through skin-conformal adhesion[19,80,81]. For successful implementation in healthcare applications, including phototherapy and wearable biosensors, it is essential to precisely control the emission wavelength to align with specific therapeutic windows. For instance, blue light with wavelengths ranging from ~450 to 480 nm is commonly utilized for antibacterial and anti-inflammatory purposes[82], whereas red light, ranging from ~630 to 660 nm, is widely employed in photobiomodulation therapies to accelerate wound healing, reduce inflammation, and stimulate tissue regeneration[83]. Additionally, robust biocompatibility and skin compatibility must be carefully considered to ensure safe and prolonged patient use. Additionally, these stretchable EL devices could serve as integrated optical sensors or visual indicators in robotic E-skins, allowing caregiver robots to assist in patient monitoring and daily care[11,84]. Physiological data collected by wearable or implantable sensors and robotic E-skins could be displayed in real-time on robotic interfaces or transmitted to remote caregivers and doctors. These robot-assisted smart healthcare systems[85–87], built on point-of-care testing, have the potential to revolutionize healthcare by allowing patients to continuously monitor their health status without the need for frequent hospital visits. We envision that intrinsically stretchable EL materials hold remarkable potential to re-define how we interact with light-based technologies across a wide array of fields.

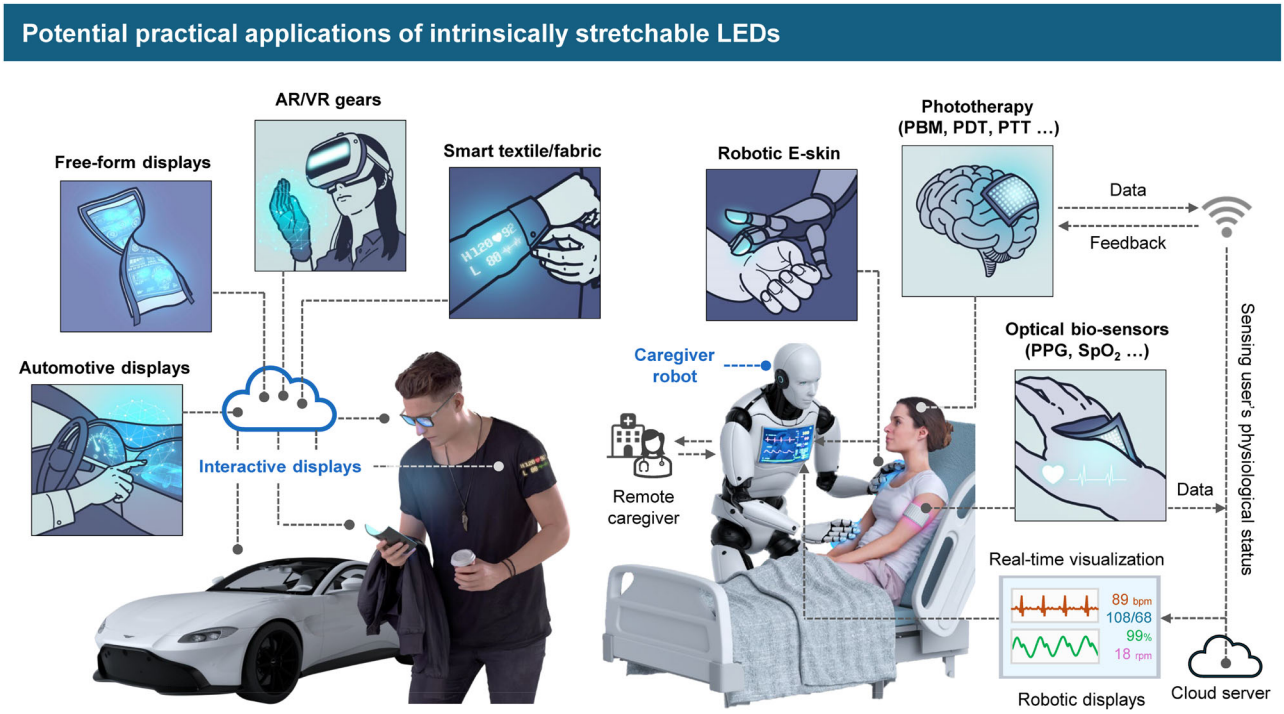

Fig. 3 | Potential applications of intrinsically stretchable LEDs. PBM photobiomodulation, PDT photodynamic therapy, PTT photothermal therapy, PPG photoplethysmogram, SpO_2 oxygen saturation.

Data availability

No datasets were generated or analyzed during the current study.

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Competing interests

The authors declare no competing interests.

Additional information

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