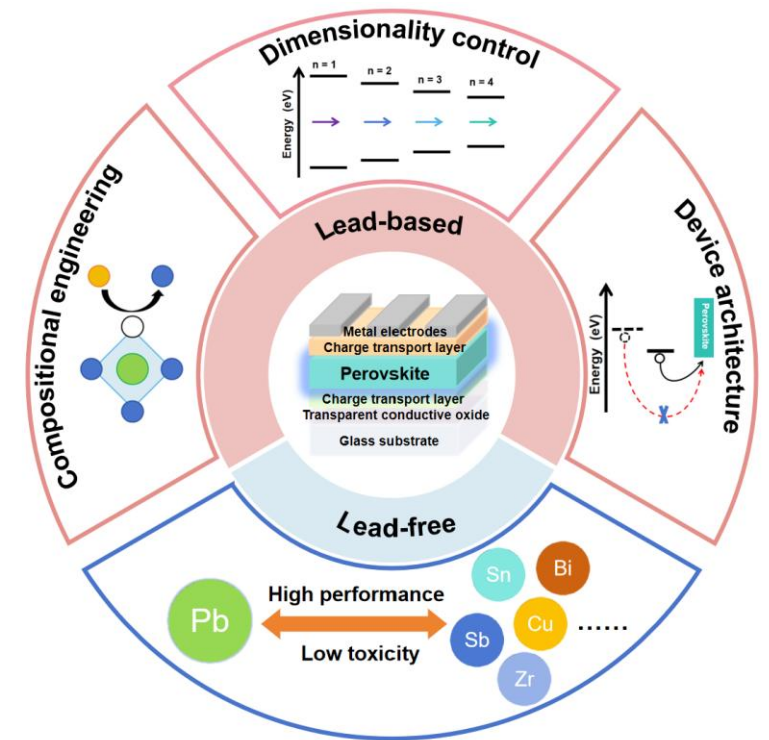


Deep-blue perovskite light-emitting diodes: towards high-performance and lead-free devices

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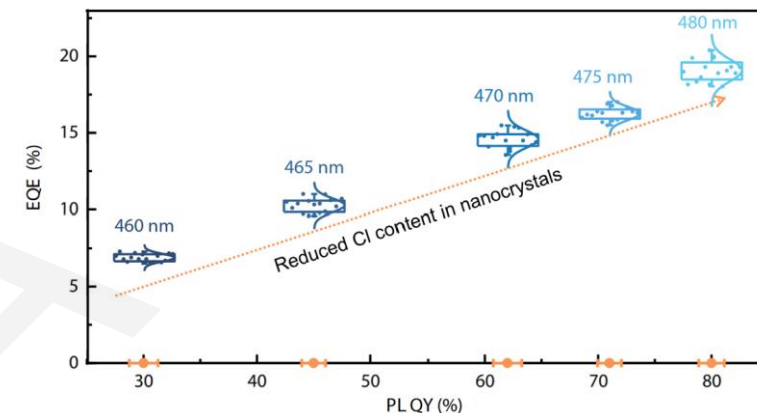
<https://doi.org/10.1631/jzus.A2600283>



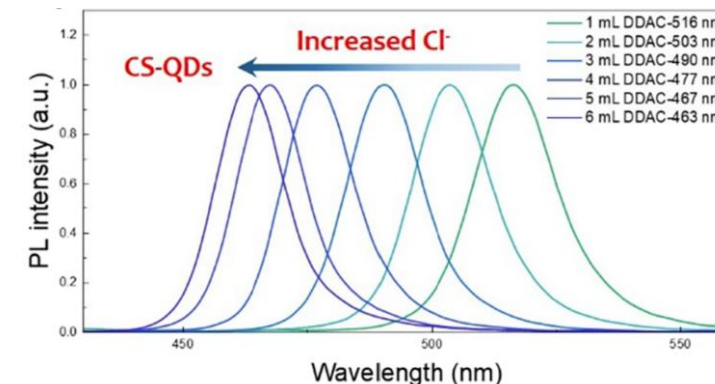
Deep-blue lead-based PeLEDs

Compositional engineering

- Halide composition engineering
- In-situ halide exchange
- Metal ion doping



Sci. Adv. **10**, eado5645 (2024)



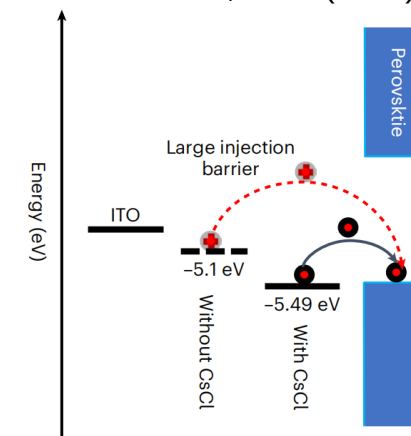
ACS. Nano. **19**, 3694 (2023)

Size and dimensionality control

- Quantum dots size regulation
- Dimensionality engineering

Device architecture

- Optimizing energy level alignment
- transport layer modification
- Interfacial passivation



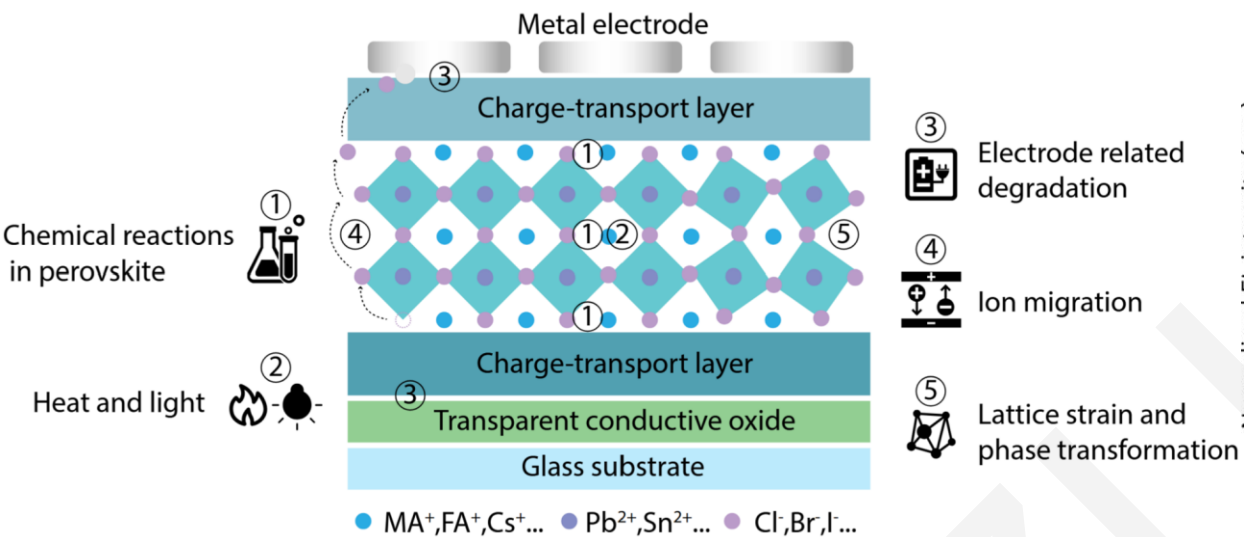
Nat. Electron. **6**, 360 (2023)

Device optimization strategies

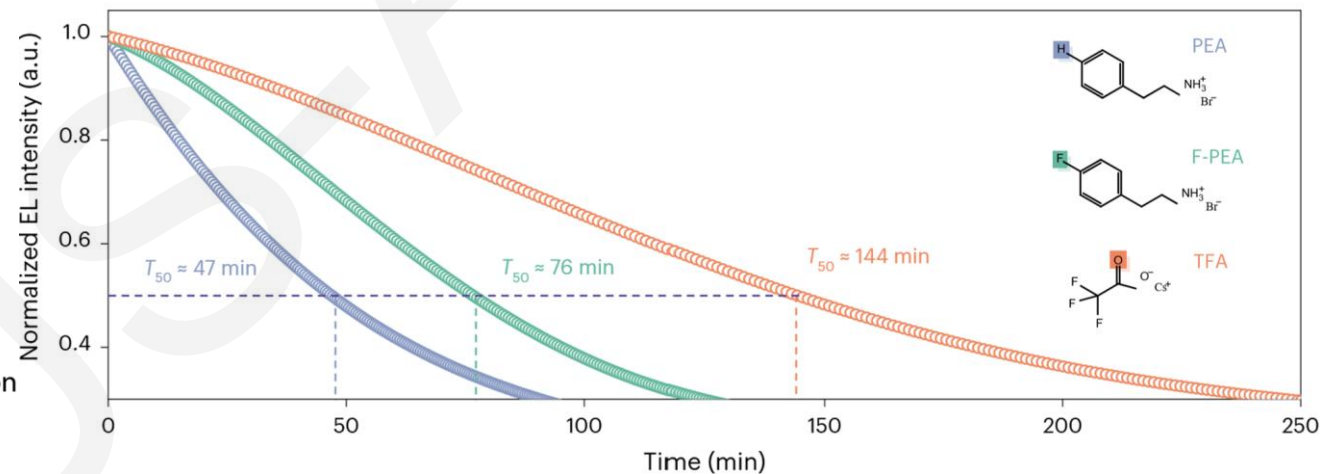
Deep-blue lead-based PeLEDs

Key challenges

1. Operational stability



Matter. 7, 772 (2024)



Nat. Nanotechnol. 20, 507 (2025)

2. Wavelength tunability

- Halide composition engineering
- Cation doping without halide mixing
- Reduced-dimensional perovskites

3. Brightness

- Injection barrier reduction
- Defect passivation
- Light outcoupling strategies

Deep-blue lead-free PeLEDs

Candidate elements for lead substitution in perovskites

Periodic Table of Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H																	He
Li	Be				A ₂	B(I)	B(III)	X ₆				B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	*	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
*			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
**			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

	Lanthanide and actinide halide perovskite		Group-14 metal halide perovskite
	Heterovalent metal halide perovskite		Metals chalcogenide perovskite
	Transition metal halide perovskite		Alkaline-earth metal halide perovskite

Lead-free perovskite candidates

- Sn/Zr (II/IV)-based perovskites
- Sb/Bi (III)-based perovskites
- Cu (I)-based perovskites
- Other lead-free materials

Summary & Outlook

Remarkable progress has been made in deep-blue PeLEDs through strategies including halide composition engineering, cation doping, dimensionality control, and device architecture optimization. Nevertheless, the overall performance still lags far behind that of red and green counterparts, and several critical issues remain on the path toward practical applications.

- Challenges ahead:**
- Efficient deep-blue emission
 - High-brightness operation
 - Long-term operational stability
 - Lead-free alternatives