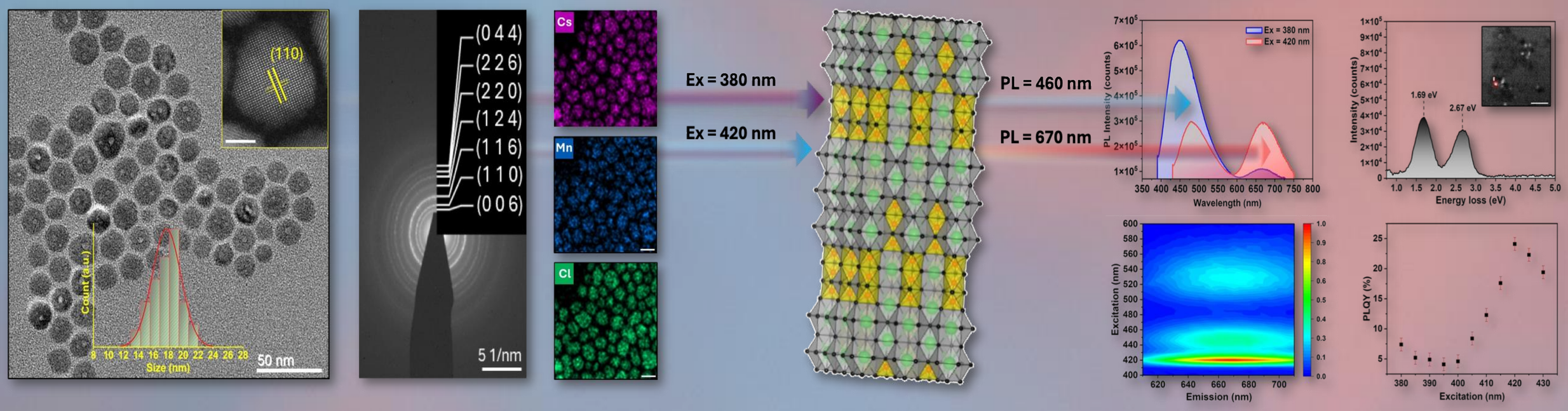
Tunable Dual Fluorescence in Lead-Free $CsMnCl_3$ Perovskite Nanoparticles Towards Light-Emitting Diode Application

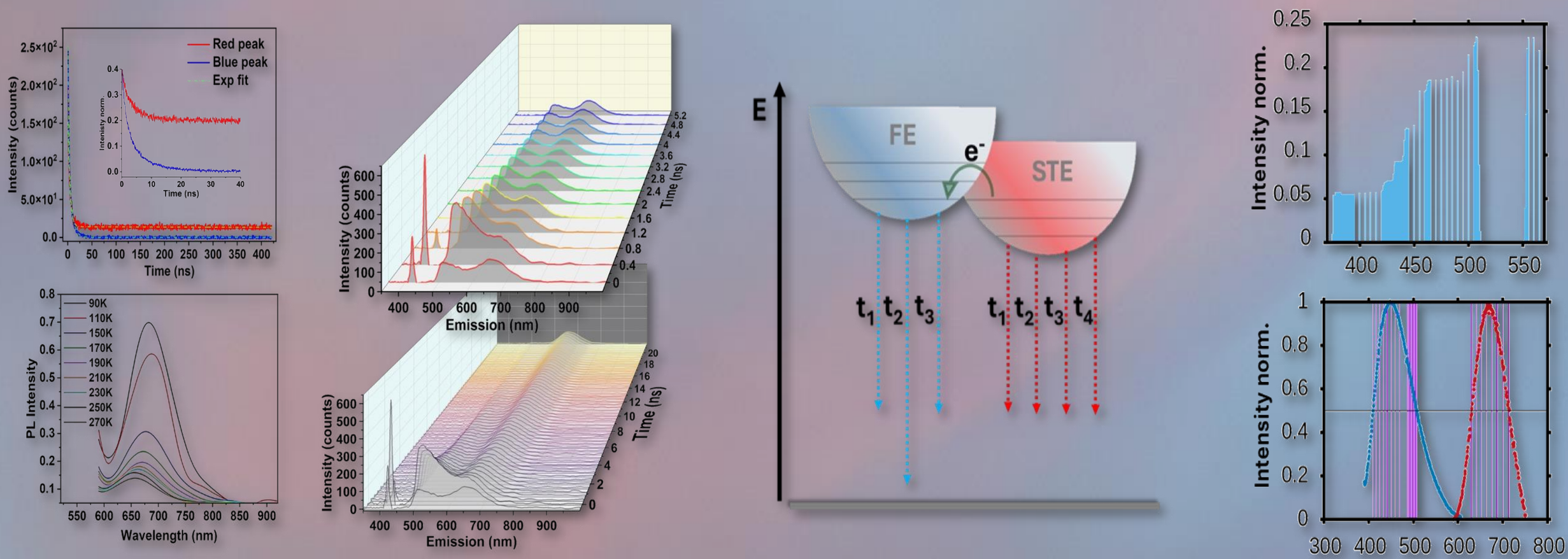
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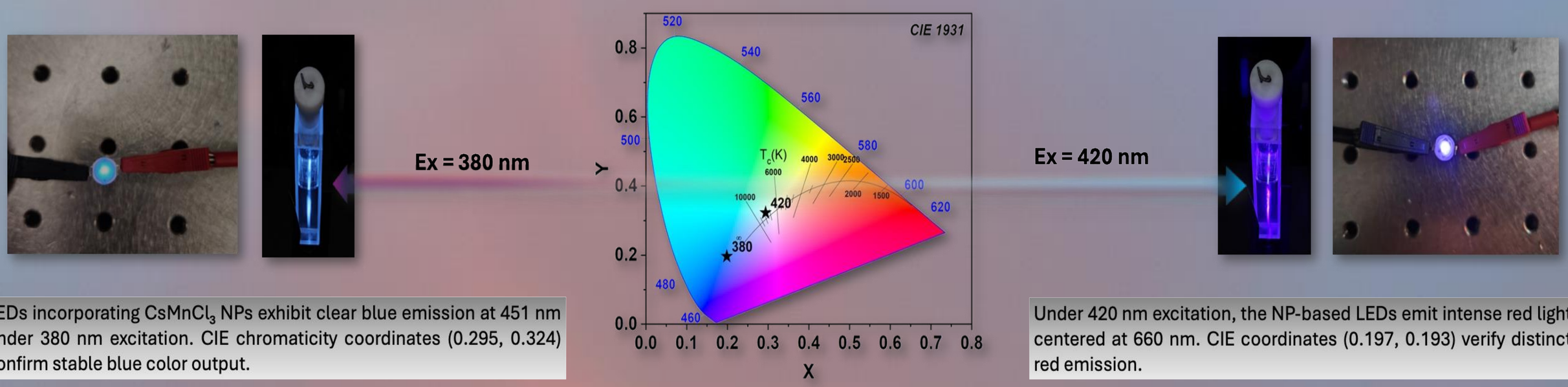
Lead halide perovskite (LHP) nanoparticles (NPs) are attractive for optoelectronic applications due to their excellent optical properties however, lead toxicity drives the search for safer alternatives. Here, we present a lead-free cesium manganese chloride ($CsMnCl_3$) NP system exhibiting excitation-dependent dual-color emission. By optimizing synthesis conditions, we achieved high phase purity in the hexagonal R-3m structure, enabling distinct blue (451 nm) and red (669 nm) emissions. Optical studies show tunable emission color and intensity via exciton energy control. Time-resolved photoluminescence reveals that the red emission originates from self-trapped excitons (STEs), with dynamic blue-to-red evolution within 0–3 ns. A four-band energy model explains the dual-emission mechanism. $CsMnCl_3$ NPs were integrated into LEDs, achieving a 24.1% PLQY, highlighting their potential for low-toxicity multi-color optoelectronic devices.



Phase-pure hexagonal $CsMnCl_3$ nanoparticles (17.7 ± 1 nm) were confirmed by TEM, ring diffraction, EDS, and EELS. The NPs exhibit excitation-dependent dual emission: blue (451 nm) under 380 nm excitation and intense red (669 nm) under 420–450 nm excitation. EELS verifies both emissions originate from single nanoparticles. The red intensity is a PLQY of 24.1% at 421 nm.



Time-resolved and teperature PL confirms the self-trapped exciton (STE) origin of the red emission. The blue band exhibits a fast nanosecond decay, whereas the red emission shows a much slower microsecond lifetime. Early-time dynamics (0–3 ns) reveal coupled blue–red evolution, indicating carrier relaxation and transfer from free excitons to localized self-trapped states via electron–phonon coupling and lattice distortion. A four-band energy model, including CB, VB, STE, and a sub-CB level, reproduces the dual-emission and PLE behavior.



LEDs incorporating $CsMnCl_3$ NPs exhibit clear blue emission at 451 nm under 380 nm excitation. CIE chromaticity coordinates (0.295, 0.324) confirm stable blue color output.

Under 420 nm excitation, the NP-based LEDs emit intense red light centered at 660 nm. CIE coordinates (0.197, 0.193) verify distinct red emission.

Aizenshtein et al. Tunable dual fluorescence in lead free $CsMnCl_3$ perovskite nanoparticles towards light emitting diode applications. Chem. Mater. 2025, 37, 8178-8186