Hybrid Tandem Perovskite-Organic Light-Emitting Diodes

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Abstract

This study demonstrates a high-efficiency, high-color-purity hybrid tandem (h-tandem) perovskite light-emitting diode (PeLED) that combines PeLED and organic light-emitting diode (OLED) units. Through microcavity optimization (h-Tandem Valley) and near-perfect charge balance, the device achieves an EQE of 37.0% and an FWHM of 27.3 nm, showcasing its potential for next-generation displays with superior performance and color purity.

Keywords

Perovskite light-emitting diodes; hybrid tandem perovskite light-emitting diodes; Microcavity structure; h-Tandem Valley.

Introduction

Perovskite light-emitting diodes (PeLEDs) have shown remarkable progress, achieving high external quantum efficiencies (EQEs) due to advances in stronger exciton confinement and defect suppression.(1–3) However, despite these developments, their device efficiency remains below the performance of cutting-edge organic light-emitting diodes (OLEDs).(4,5). Tandem structures, which incorporate multiple light-emitting units connected by charge generation layers (CGLs), have emerged as a promising approach to address the efficiency constraints of single-unit LEDs.(6–9) These structures not only improve overall efficiency by combining the performance of individual units but also mitigate electrical stress, thereby improving device stability.

In the field of PeLEDs, however, the application of tandem structures has remained largely unexplored. Challenges such as material integration and maintaining charge balance while achieving narrowband emission have hindered progress.

Recently, our group introduced a hybrid tandem (h-tandem) PeLED, combining PeLED and OLED units to achieve both high efficiency and color purity, reported in Nature Nanotechnology (2024)(10). At SID's Display Week 2025 talk, we will present the strategy and insights that enabled this breakthrough.

Results and Discussion

Key Factors for h-tandem PeLED Fabrication: Microcavity and Charge Balance(10)

The fabrication of an h-tandem PeLED, consisting of a solution-processed perovskite nanocrystal (PNC)-based PeLED unit and a vacuum-deposited OLED unit, depends critically on two critical factors: microcavity optimization and charge balance (**Fig. 1**).(10)

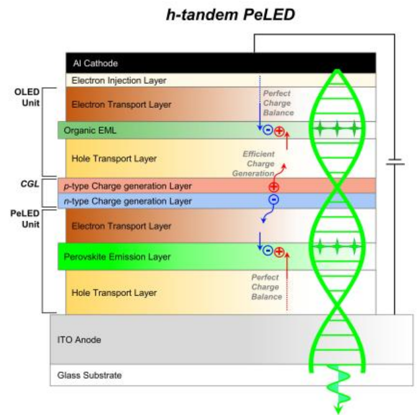

Figure 1. Device structure of h-tandem PeLED. The figure is modified from ref. (10), Copyright © 2024, Springer Nature.

One major challenge in h-tandem PeLED is addressing the disparity in emission spectra between narrowband PeLEDs and broadband OLEDs, which often leads to spectral broadening when combined.(10) Through optical simulations, we optimized the thicknesses of the hole transport layer (HTL) and electron transport layer (ETL) in the top OLED unit to control the microcavity effect.(10) This effort led to the discovery of the h-Tandem Valley, a specific structural configuration that minimizes the full width at half maximum (FWHM) to below 28 nm.(10) Devices fabricated within the h-Tandem Valley (Valley Centre Tandem) achieved an FWHM of 27.3 nm, closely matching the simulation prediction of 27.5 nm.(10) In contrast, devices outside this configuration exhibited significantly broader FWHMs.(10) These findings underscore the importance of precise microcavity control for achieving narrowband emission in h-tandem PeLEDs.(10)

Achieving high efficiency in tandem LEDs also requires balanced charge injection and transport across all emitting units.(10) In h-tandem PeLEDs, the differing current density-voltage-luminance (J-V-L) characteristics of the PeLED and OLED units pose challenges in maintaining charge balance, often resulting in spectral broadening, shifts in emission peaks, and reduced efficiency.(10) To address these issues, we fabricated devices with modified ETLs for both the bottom (PeLED) and top (OLED) units.(10) Notably, in the Valley Centre Tandem configuration, the J-V curves of the bottom and top units aligned perfectly within the 2.6–3.2 V range, corresponding to the maximum EQEs of the single-unit PeLED and OLED devices.(10) This alignment enabled the hybrid tandem device to achieve an EQE of 37.0%, significantly outperforming unbalanced configurations, which recorded EQEs of 26.8% despite similar device structures.(10)

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With these optimizations, the Valley Centre Tandem device demonstrated superior efficiency and stability.(10) It achieved a device lifetime (L_{50}) of 5,596 hours at 100 cd/m², far exceeding the performance of single-unit PeLEDs.(10) Additionally, the structure was successfully implemented in flexible large-area displays (4 cm × 4 cm) and a 10 × 10 passive matrix display, demonstrating its practical viability for next-generation displays.(10)

Impact

The h-tandem PeLED represents a significant milestone in optoelectronic device design by offering solutions to the efficiency and stability challenges of single-unit PeLEDs. This study provides the first successful demonstration of a high-efficiency, high-color-purity h-tandem PeLED and establishes comprehensive design guidelines for achieving narrowband emission, near-perfect charge balance, and enhanced device stability.

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