Supplemental Information

1.1. Recombination Parameter Fitting

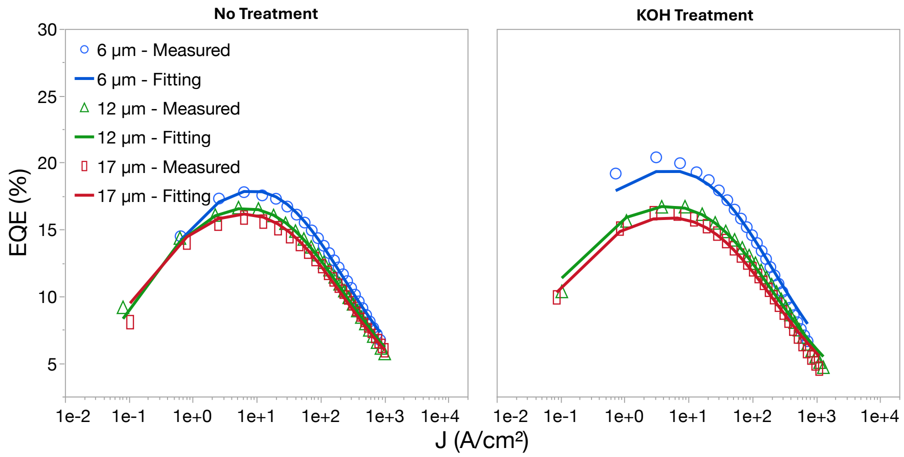
To fit the measured η_{EQE} vs J data to the η_{EQE} model, a standard MATLAB built-in nonlinear optimization loop was run to minimize the sum of squared errors (SSE) between measured and modeled η_{EQE}. The model first takes an initial estimate at the coefficients and then solves the following total recombination equation for the carrier density (n) by numerically finding the zeros of the polynomial at each J value for a specific device.

$$R\,(n,d) = \left(A_0 + v_s \frac{4}{d}\right)n + Bn^2 + C_{dl}n^3 + D_{dl}n^4 \quad (0-1)$$

R is the total recombination and is related to the J through,

$$R = \frac{J \cdot A_{\mu LED}}{e \cdot V_{active}} \quad (0-2)$$

J is the measured current density, $A_{\mu LED}$ is the cross-sectional area, and V_{active} is the volume of the active region.[19] Once the carrier density is numerically solved for each J, η_{EQE} is calculated using the current parameter estimates, and the SSE is then evaluated. Additionally, global boundary conditions were enforced so that all dies from the same epitaxial wafer share the same epi-dependent coefficients (A_0, B, C_{dl}, D_{dl}), since these values do not change with μLED size or sidewall quality. In parallel, μLED with identical passivation and sidewall quality (ex. Treatment) were bounded to have the same v_s, reflecting that v_s is not dependent on the μLED size. The MATLAB built in nonlinear optimization loop will vary the values of the parameters (bounded by physical limits) in a optimization loop until the SSE is minimized, thereby providing best-fit values that reflect both recombination behavior (A_0, v_s, B, C, D terms) and size-dependent light extraction ($\eta_{LEE}(d)$). Supplemental Figure 1 presents the measured EQE curves for SU-8 passivated µLEDs—with and without KOH treatment—across three device sizes (6, 12, and 17 µm). Data points represent experimental measurements, while the solid lines correspond to EQE curves generated by the fitting model used to extract recombination and light extraction parameters.



Supplemental Figure 1: Measured and modeled EQE as a function of current density:

Left—SU-8 passivated µLEDs without KOH treatment; Right—SU-8 passivated µLEDs with KOH treatment. Points indicate measured data, and solid lines represent the fitted EQE curves. Circle, triangle, and rectangle markers correspond to 6 µm, 12 µm, and 17 µm devices, respectively

The fitting procedure employed a physical model that enforces a single set of global parameters (A_0, B, C_{dl}, D_{dl}) shared across all devices, regardless of size, passivation, or treatment. To capture overall behavior, the optimizer simultaneously fit all EQE curves—covering three passivation/treatment configurations (SiO_2 untreated, SU-8 untreated, and SU-8 treated), each with three device sizes. In total, nine EQE curves were fitted concurrently using the global and local parameter constraints described above.