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High Quantum Efficiency and Low Droop of 400-nm InGaN Near-Ultraviolet Light-Emitting Diodes Through Suppressed Leakage Current

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Introduction

- In a NUV LED, the carrier localization within active region is weaker than those of visible LEDs, leading to a decrease of quantum efficiency.

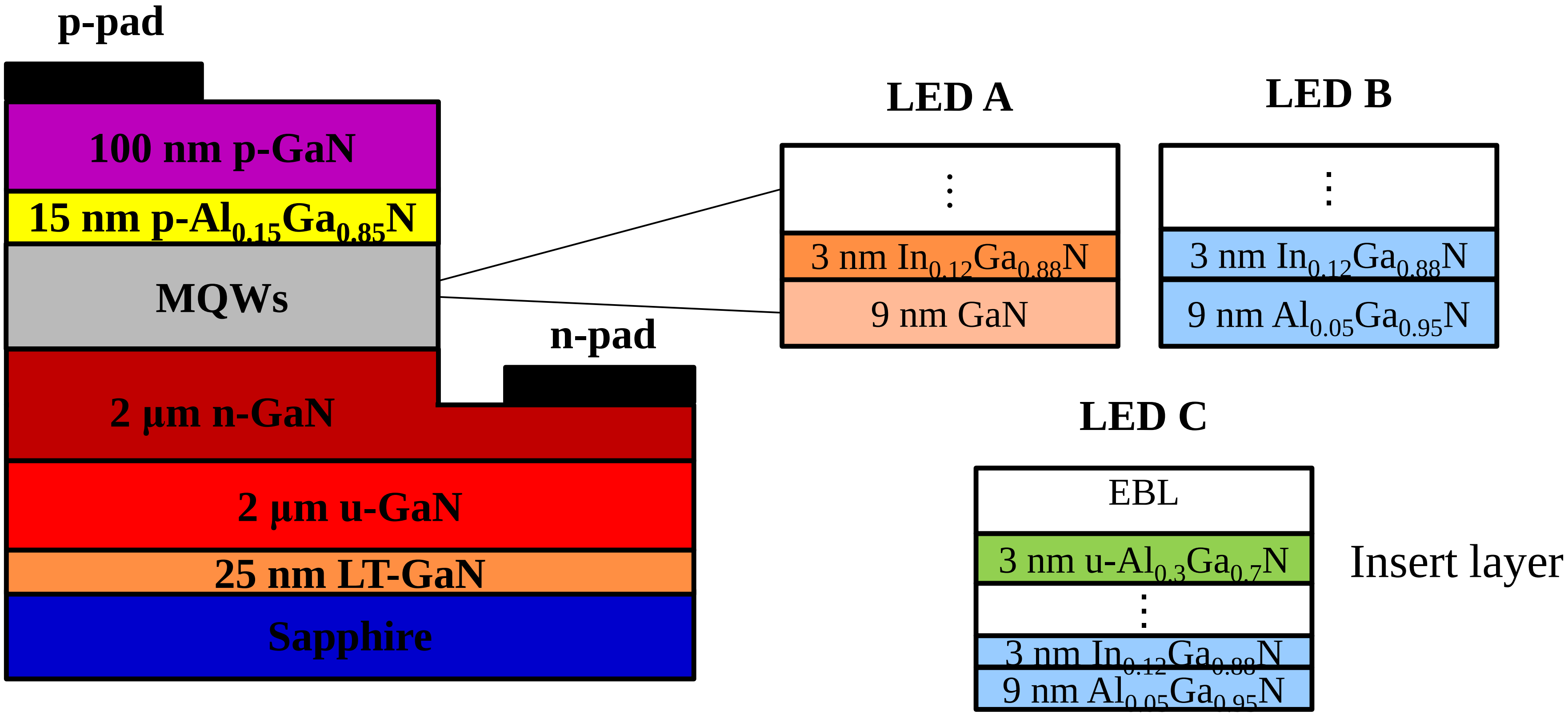
- Since the band offset between InGaN well and GaN quantum barrier (QB) becomes smaller due to a lower Indium content, the carrier confinement capability decreases.

- The week carrier confinement in NUV LED results in a significant carrier overflow.

- This ultimately leads to low quantum efficiency as well as severe droop effect at high driven current density

Experiments

Chip size ：$307 \times 332\ \mu m^2$



p-pad

100 nm p-GaN

15 nm p-$Al_{0.15}Ga_{0.85}N$

MQWs

n-pad

2 μm n-GaN

2 μm u-GaN

25 nm LT-GaN

Sapphire

LED A

⋮

3 nm $In_{0.12}Ga_{0.88}N$

9 nm GaN

LED B

⋮

3 nm $In_{0.12}Ga_{0.88}N$

9 nm $Al_{0.05}Ga_{0.95}N$

LED C

EBL

3 nm u-$Al_{0.3}Ga_{0.7}N$

⋮

3 nm $In_{0.12}Ga_{0.88}N$

9 nm $Al_{0.05}Ga_{0.95}N$

Insert layer

Fig. 1. Schematic diagrams of LED A, B and C

Results and discussions

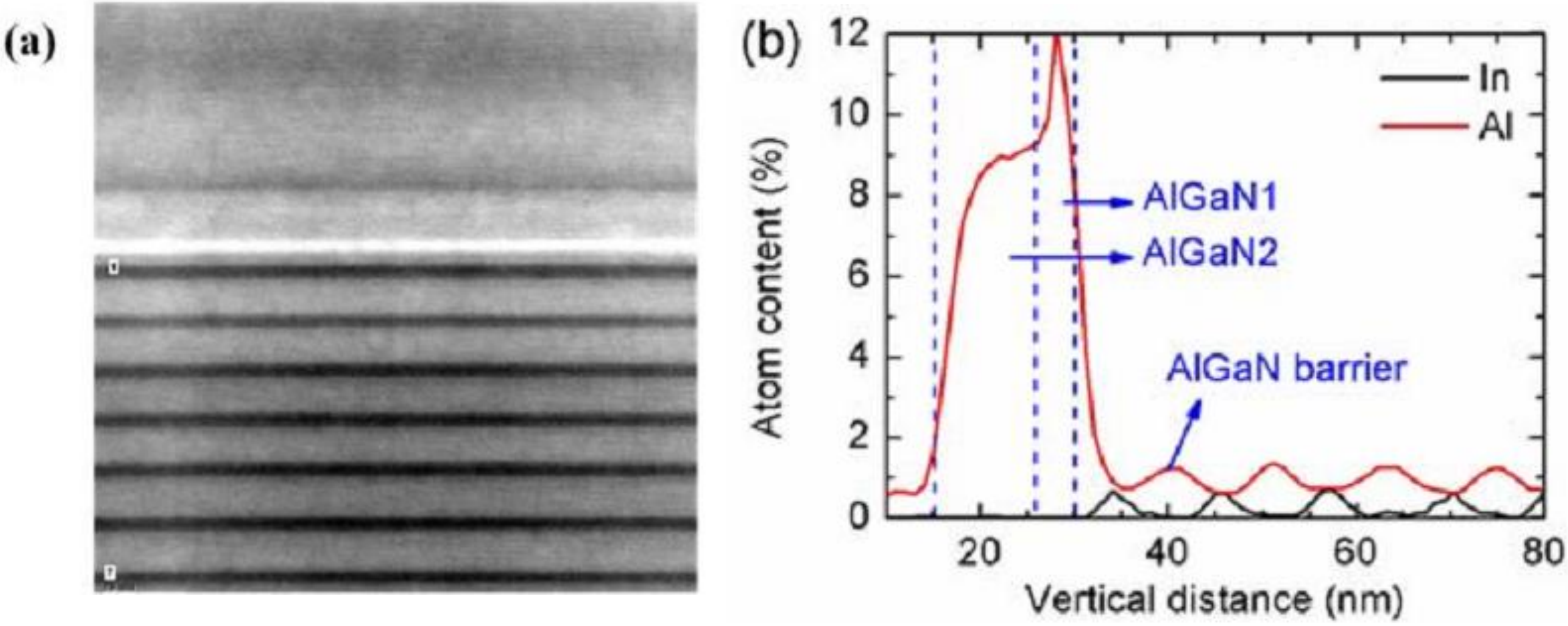
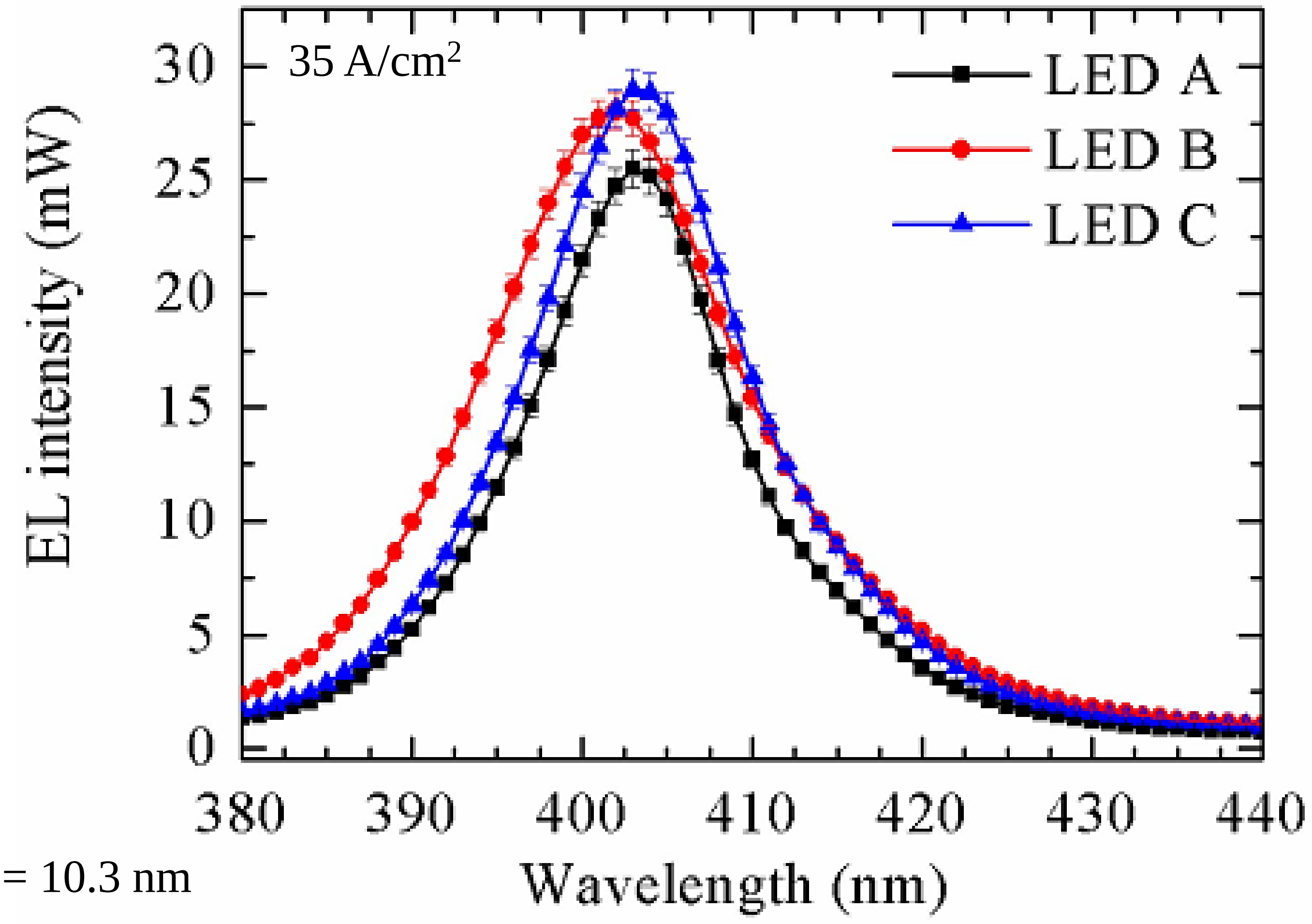


Fig. 2. (a) TEM and (b) SIMS results of LED C with $Al_{0.05}Ga_{0.95}N$ barriers and 3-nm $Al_{0.3}Ga_{0.7}N$ inserted on last barrier before p-type $Al_{0.15}Ga_{0.85}N$ EBL.



FWHM = 10.3 nm

Fig. 3. EL spectra of the three LEDs.

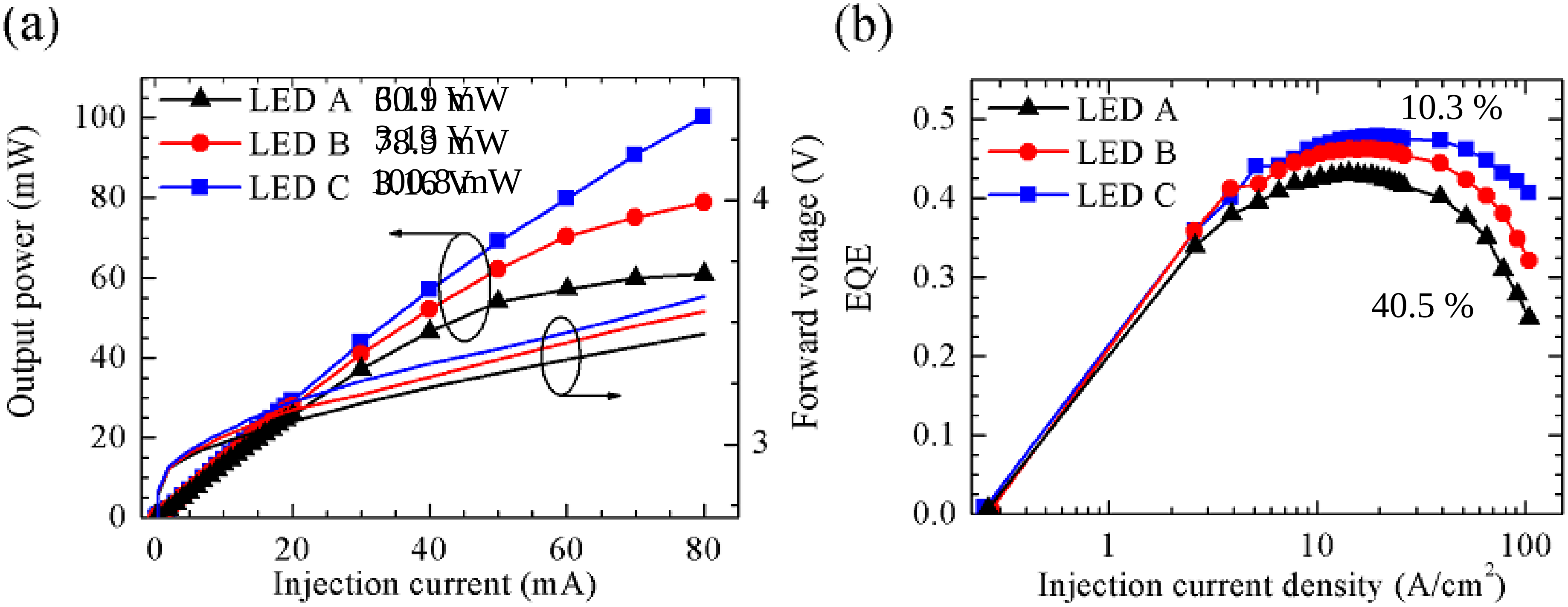


Fig. 4. (a) Forward voltage and output power as a function of current for the three LEDs; (b) EQE-versus-current density at log scale for the three LEDs.

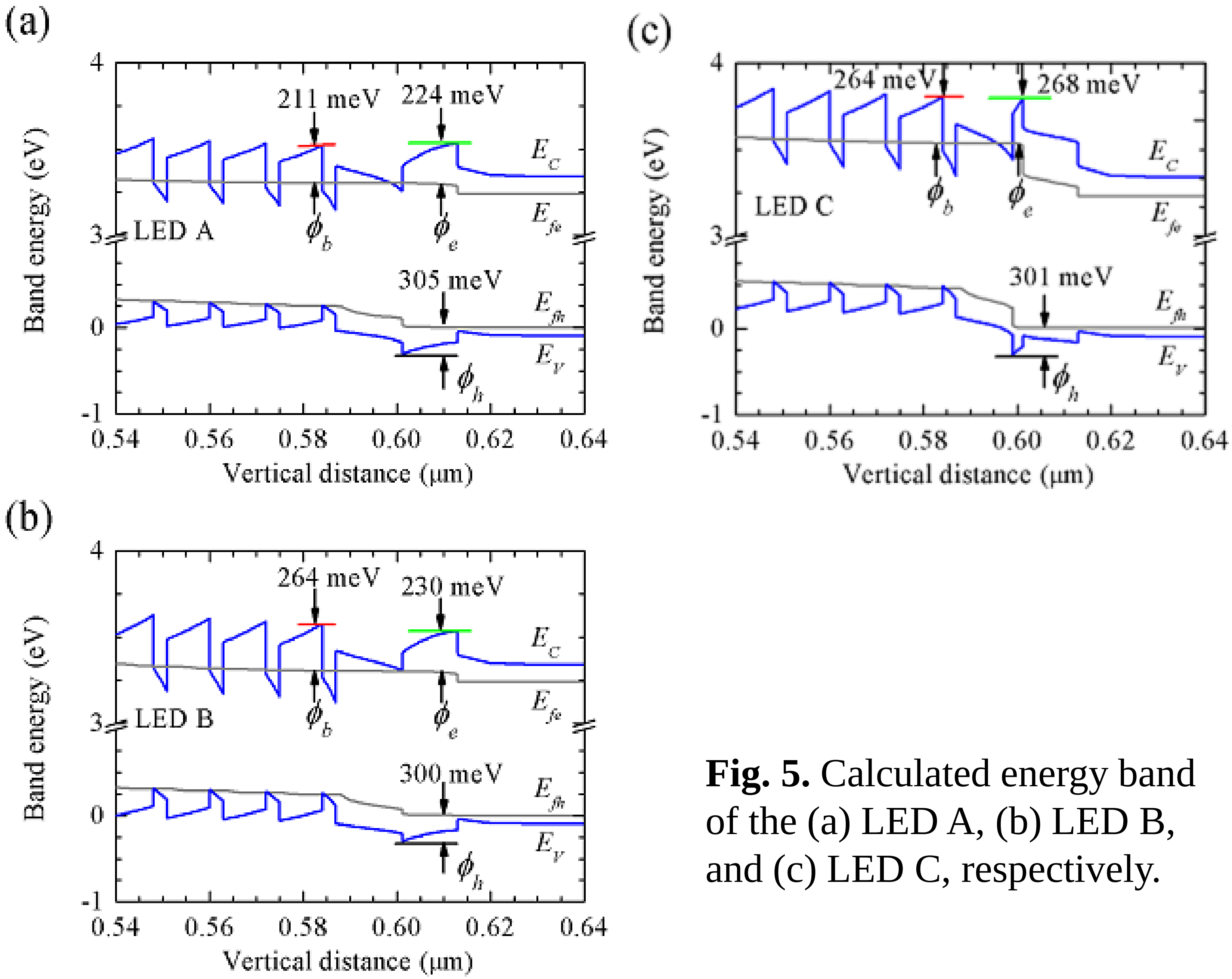


Fig. 5. Calculated energy band of the (a) LED A, (b) LED B, and (c) LED C, respectively.

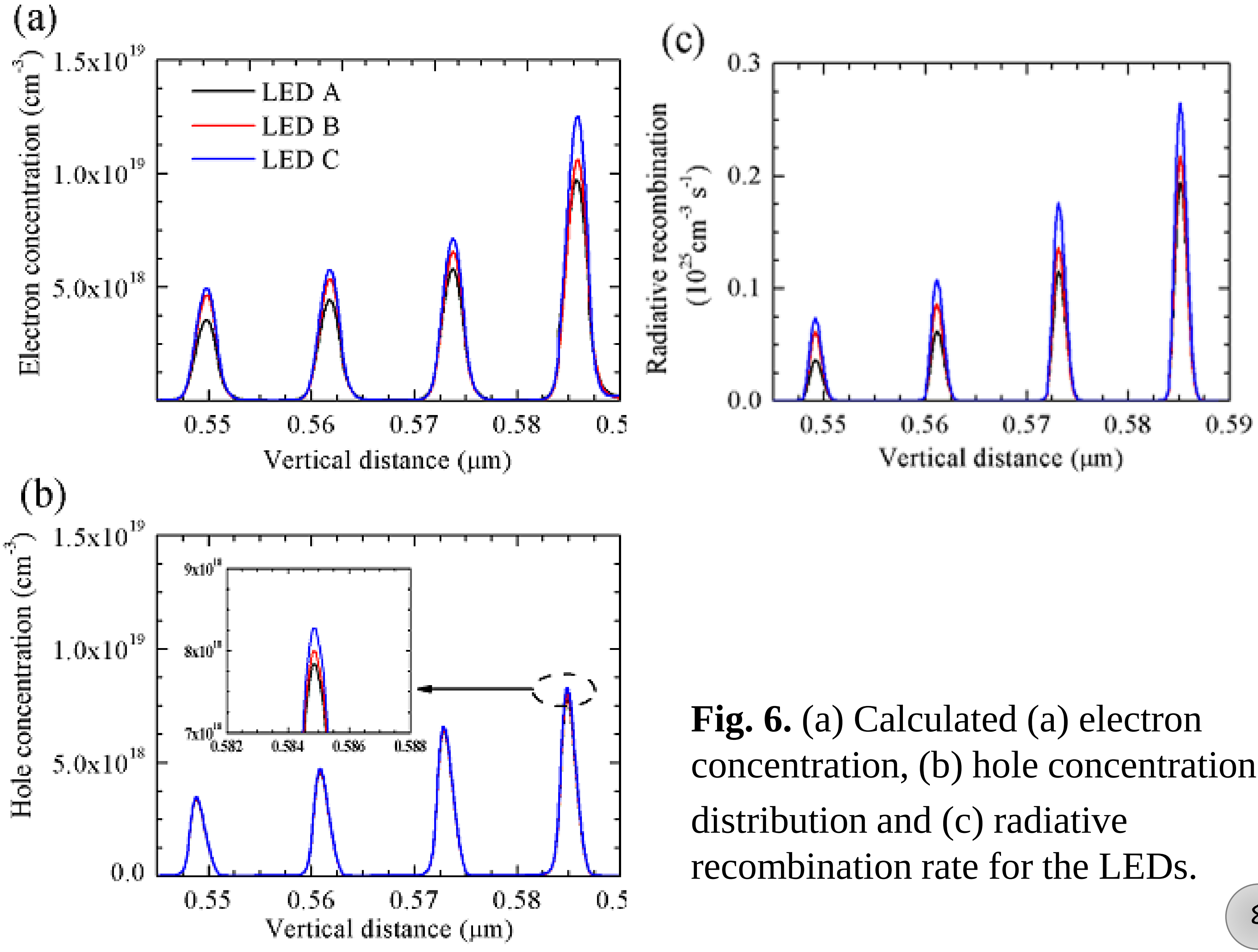


Fig. 6. (a) Calculated (a) electron concentration, (b) hole concentration distribution and (c) radiative recombination rate for the LEDs.

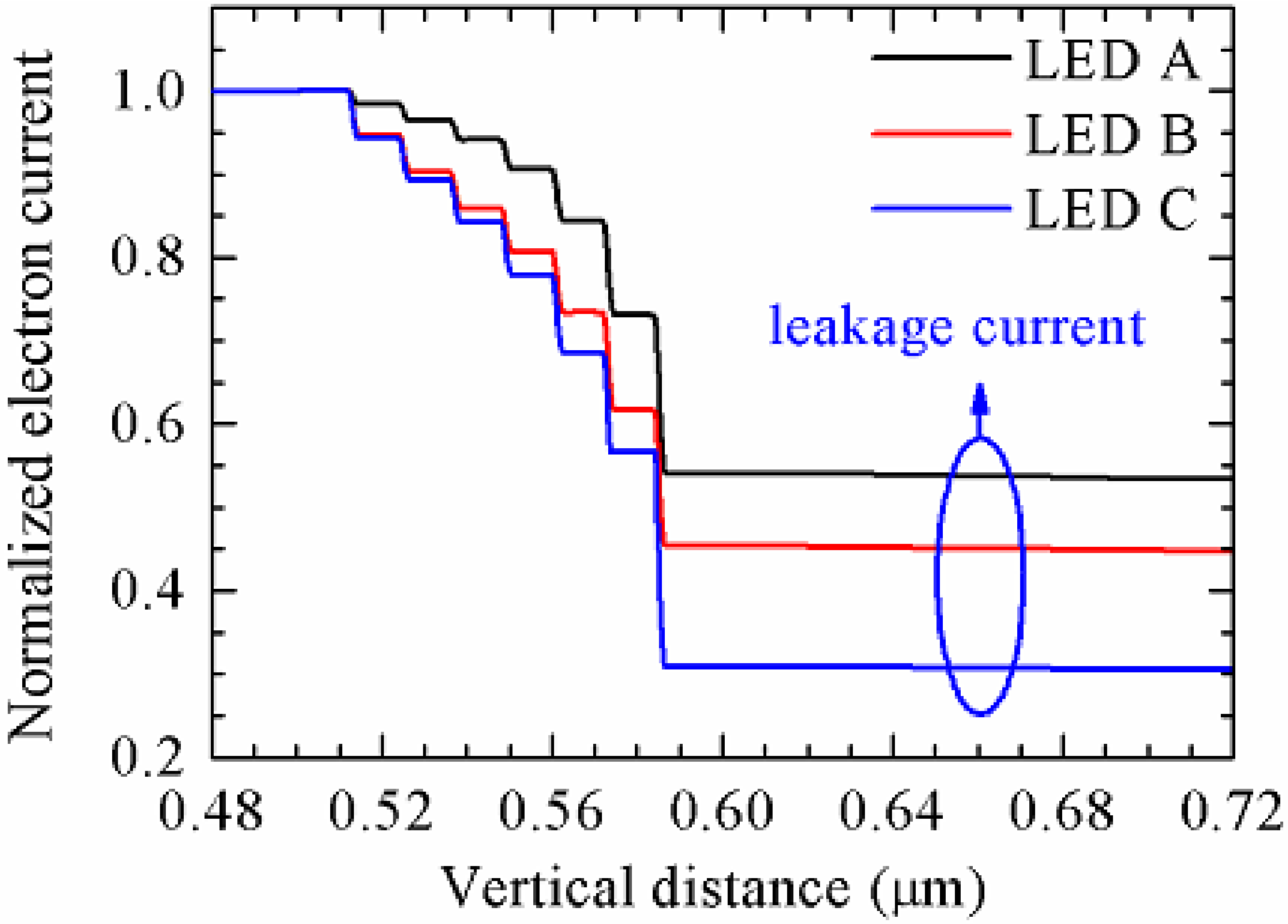


Fig. 6. Electron current distribution of the three LEDs.

Conclusion

- In conclusion, we have demonstrated performance enhancement of InGaN 400 nm NUV LED (~0.1 mm^2) with $Al_{0.05}Ga_{0.95}N$ QB and $Al_{0.3}Ga_{0.7}N$ inserted on the last barrier before EBL.

- At 100 A/cm^2, the 400 nm NUV LEDs with special designed barriers presents a high EQE of 40.7% and very low efficiency droop ratio of 10.3%.

- Simulation results reveal that the reduction of electron leakage is the main reason for the improvement of quantum efficiency as well as the suppression of efficiency droop.

Reference

- Y.-K. Kuo, Y.-H. Shih, M.-C. Tsai, and J.-Y. Chang, “Improvement in electron overflow of near-ultraviolet ingan leds by specific design on last barrier,” IEEE Photon. Technol. Lett., vol. 23, no. 21, pp. 1630–1632, Nov. 1, 2011.

- A. Knauer et al., “Effect of the barrier composition on the polarization fields in near UV InGaN light emitting diodes,” Appl. Phys. Lett., vol. 92, no. 19, p. 191912, 2008.

- P.-M. Tu et al., “Investigation of efficiency droop for InGaN-based UV light-emitting diodes with InAlGaN barrier,” Appl. Phys. Lett., vol. 98, no. 21, p. 211107, 2011.

Thanks for your attention.