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Current crowding effect on light extraction efficiency of thin-film LEDs

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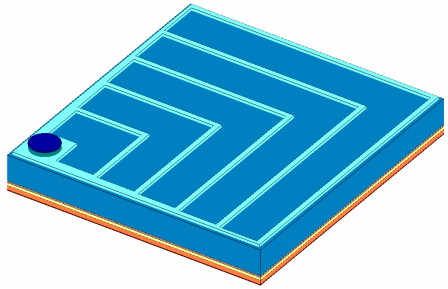
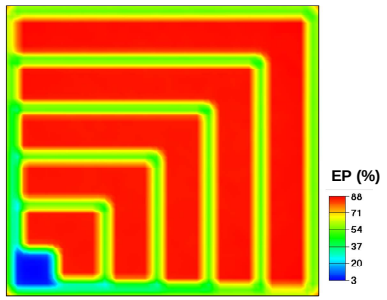
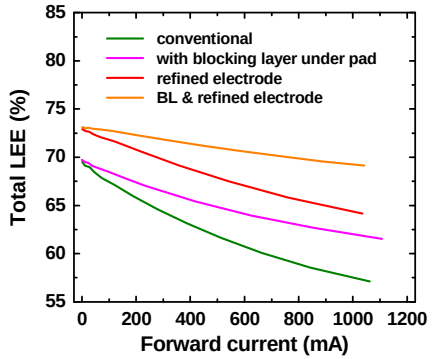
Content

- current crowding and operation of thin-film high-power blue LED
- effect of the current crowding on light extraction efficiency – a new mechanism contributing to LED efficiency droop
- possible ways to improve the light extraction efficiency

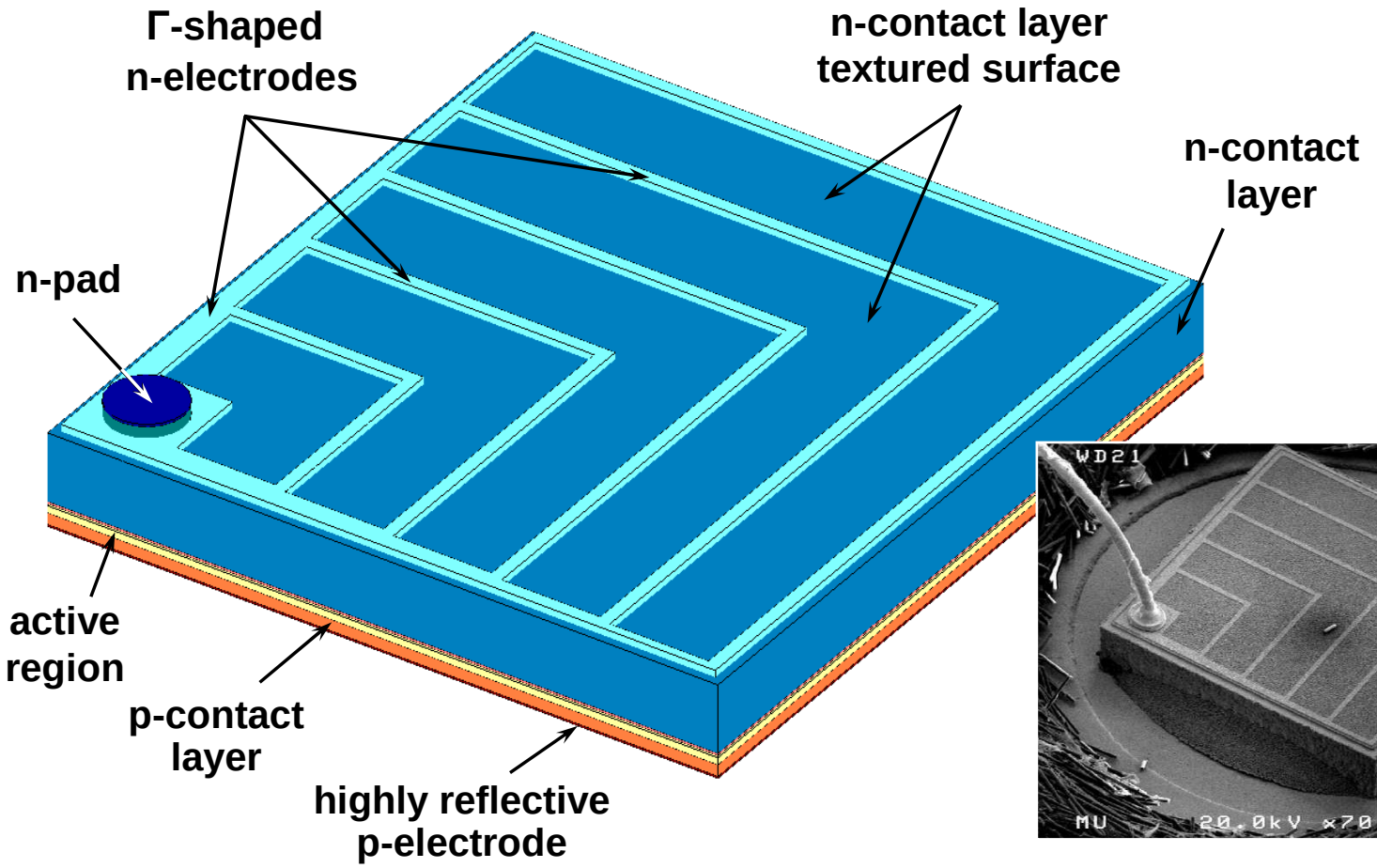






Basic design of 815×875 μm² blue LED die

V. Härle et al., Proc. SPIE 4996 (2003) 133 / phys. stat. solidi (a) 201 (2004) 2736



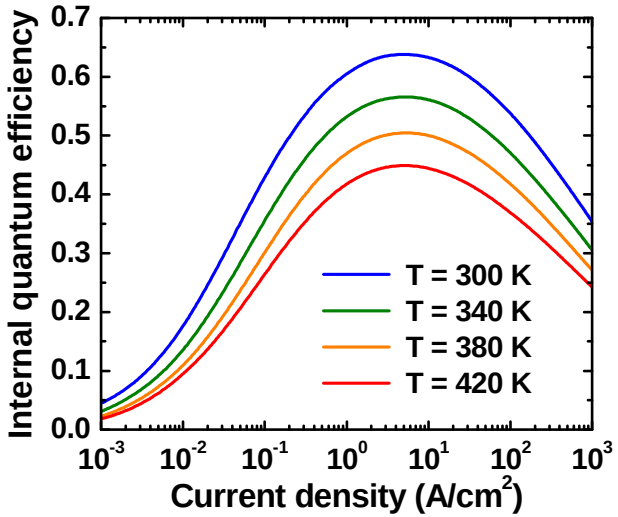
Micrograph of the die by MuAnalysis, Inc., 2008

Key elements of simulation model

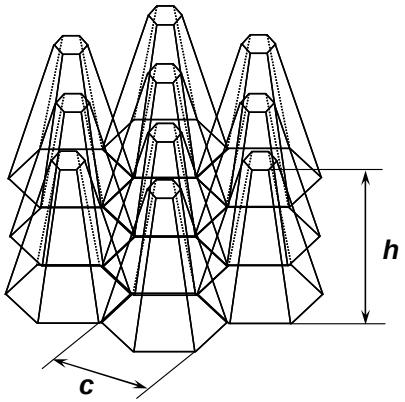
SimuLED™ package is used for modeling:

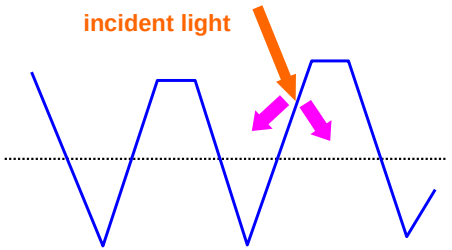
http://www.str-soft.com/products/SimuLED

- 3D coupled simulation of electrical, thermal, and optical processes in the LED die
- Auger recombination is considered is the main non-thermal mechanism of the IQE droop at high current densities
- textured surface is modeled by closely packed hexagonal pyramids with the aspect ratio *h*/*c* ~ 4
- optical properties of Au and Ag are used for n- and high-reflective p-electrodes, respectively

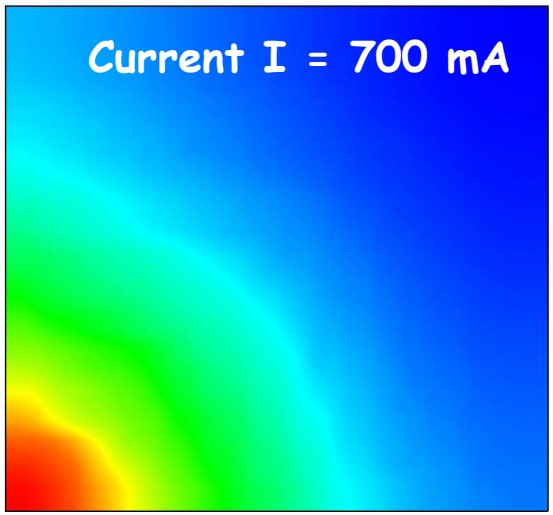


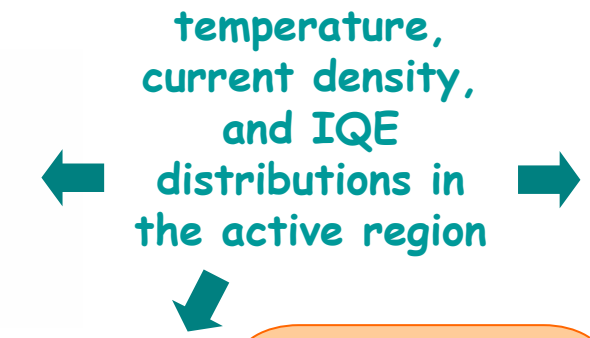
no electron leakage is predicted for InGaN MQW LED structure

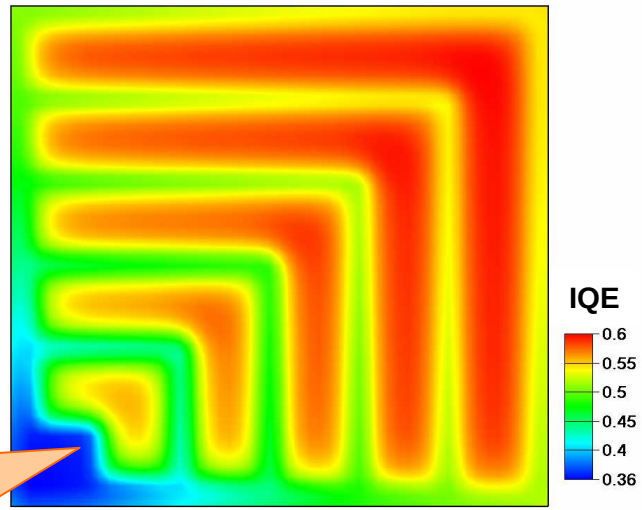




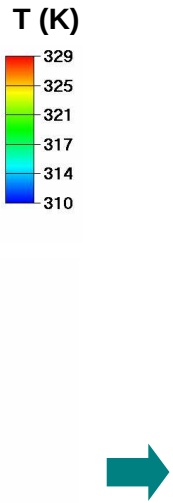
Current crowding near/under n-electrodes

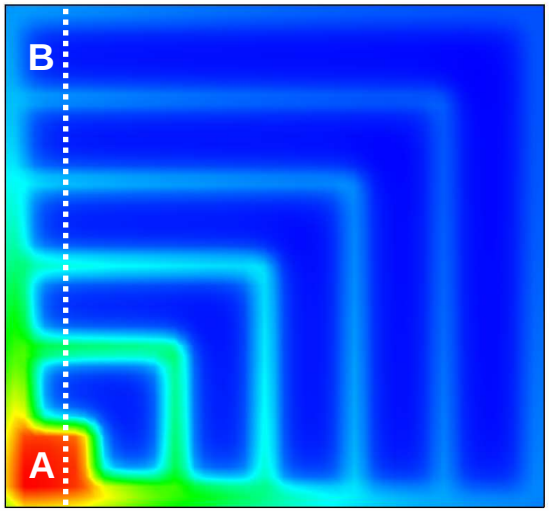


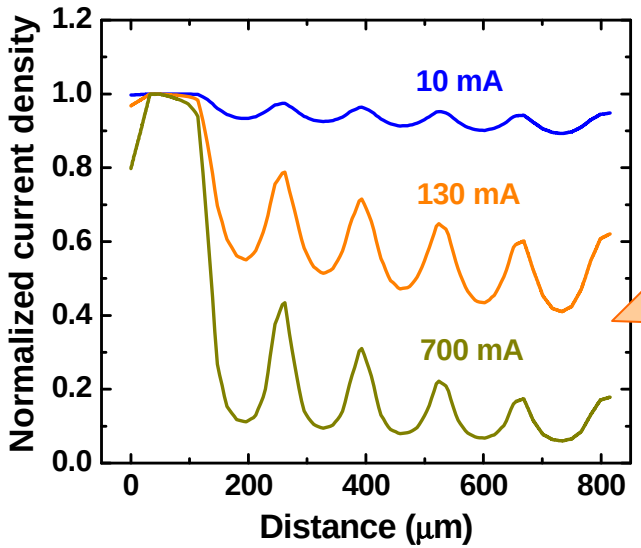




local IQE reduction in high-current density area



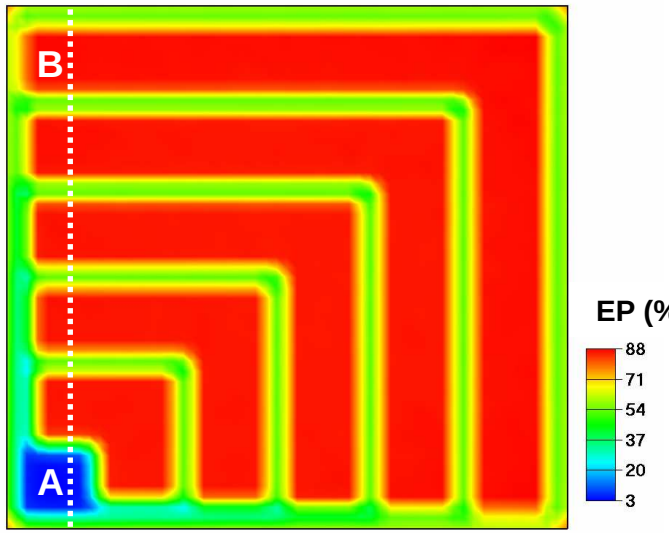


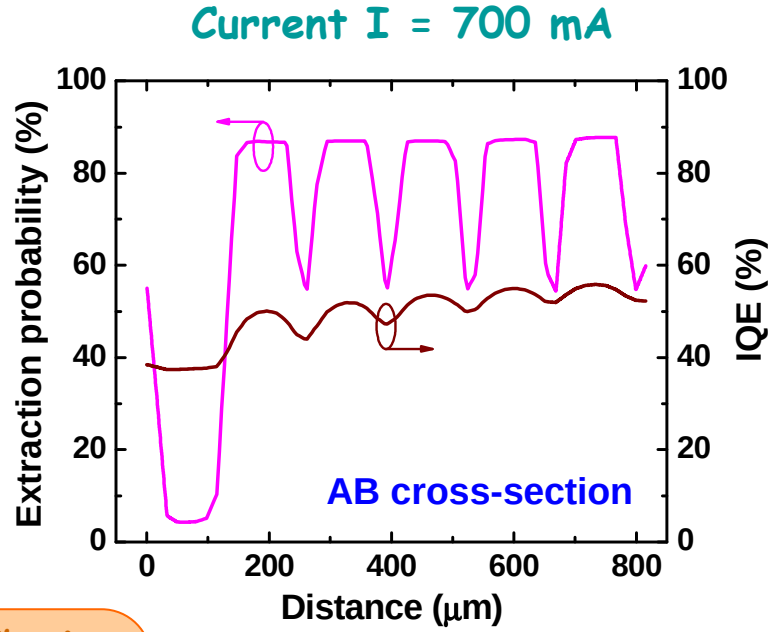


AB cross-section

current density non-uniformity depends on the total operating current

Light extraction from the LED

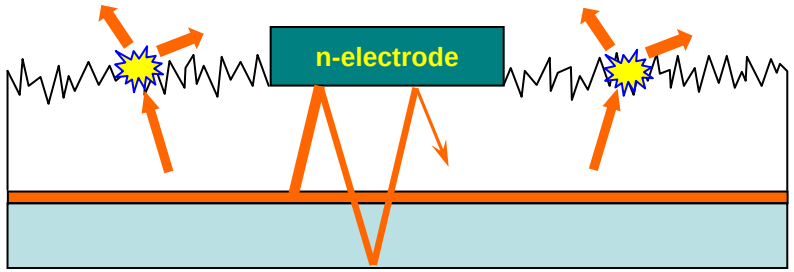




probability of light extraction falls down under and next to n-electrode

distribution of extraction probability is nearly independent of current

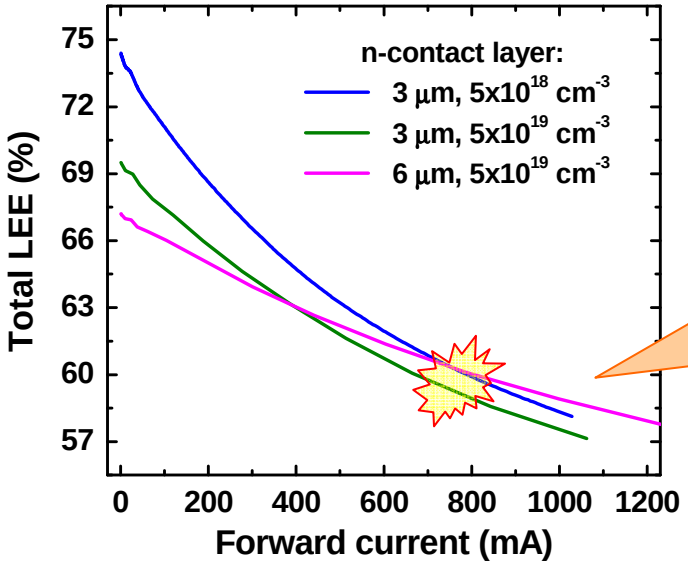
light generated under n-pad is not practically extracted from the die because of incomplete multiple reflection from metallic electrode



Dependence of light extraction efficiency on current

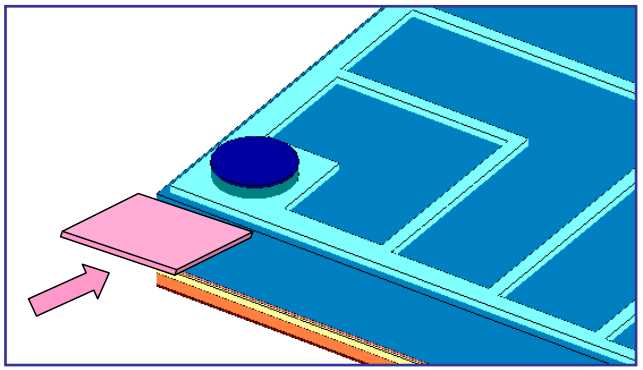
variation of n-contact layer parameters affects weakly the current crowding and, hence, the LEE at ~700-800 mA

alternative approaches are required

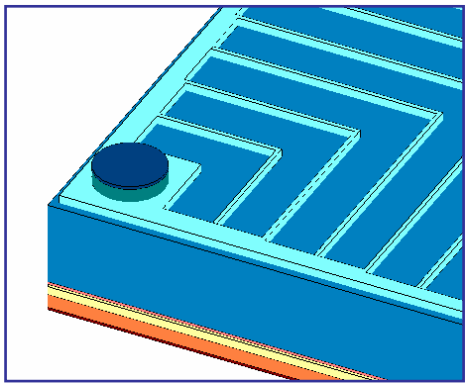


strong dependence of LEE on forward current

Approach 1: insertion of an insulating layer under the n-pad to avoid parasitic current flow in this region

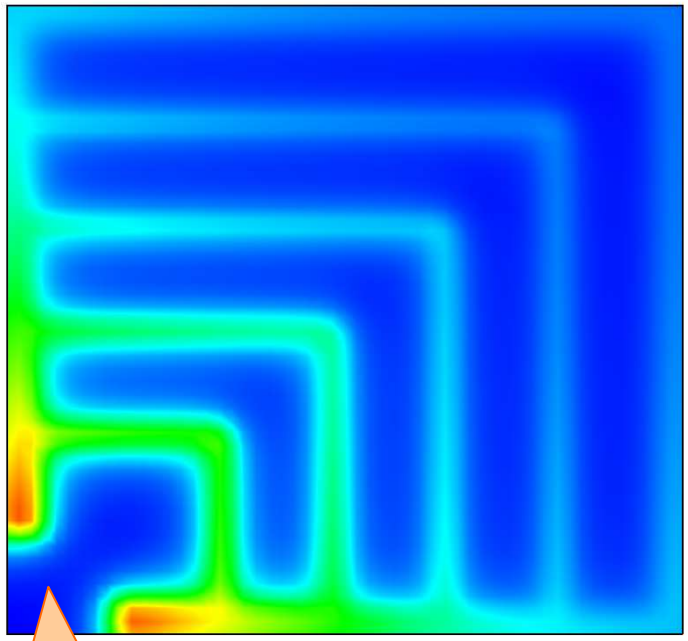


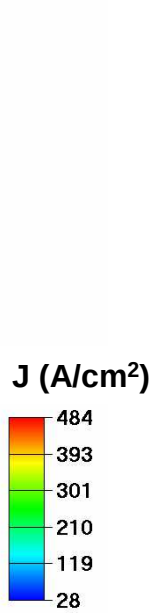
Approach 2: use of narrower Γ-shaped electrodes with reduced spacing between them

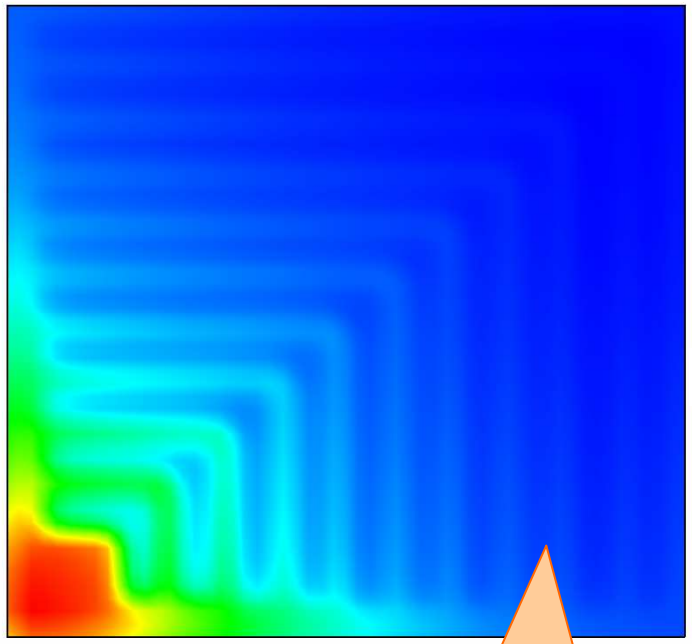


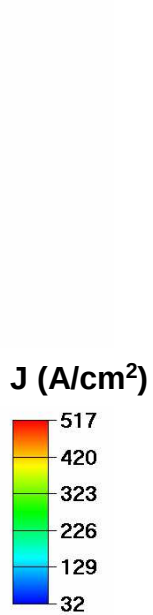
Current spreading in LED dice of modified designs

Total current through the diode I = 700 mA









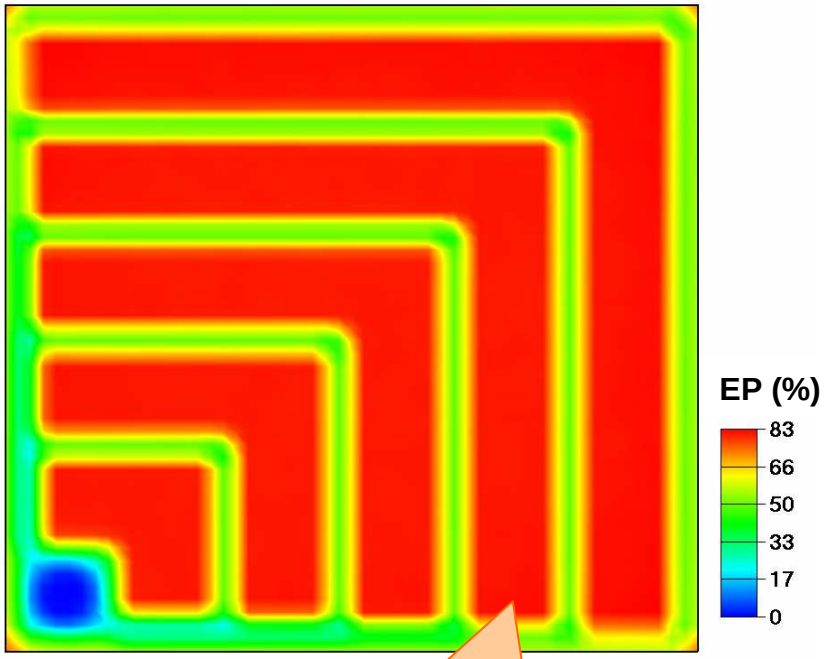
parasitic current flow under the n-pad is partly suppressed

both approaches are found to work well

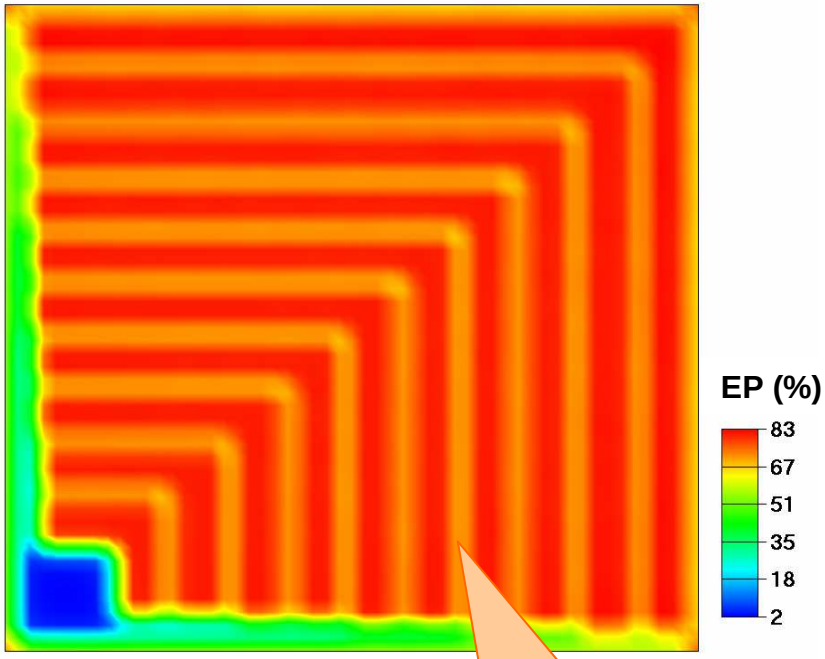
reduction of the current density contrast in the active region

Probability of light extraction from the dice of modified designs

Total current through the diode I = 700 mA



probability of light extraction is comparable with that of the basic die design

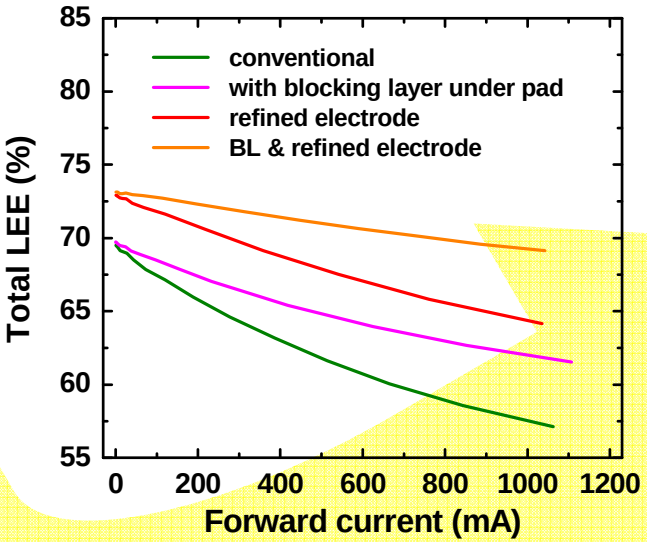


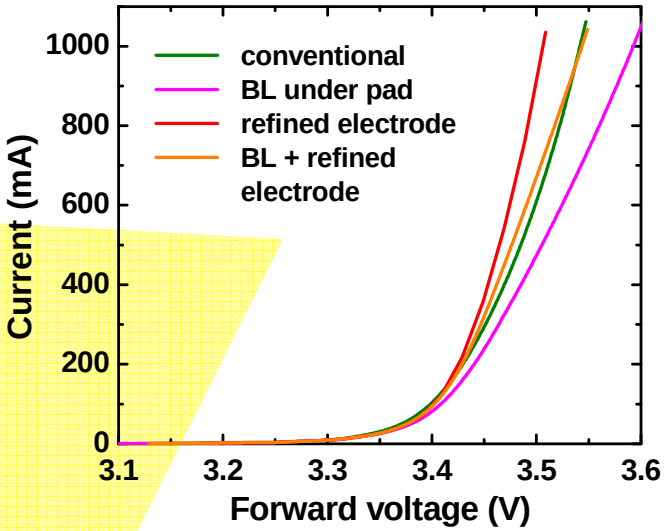
considerable enlarging of the area with high probability of light extraction

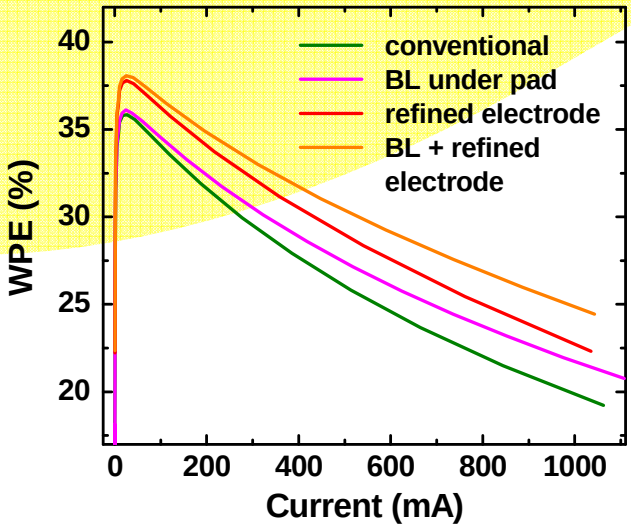
Assessment of performance improvement due to variation of LED die design

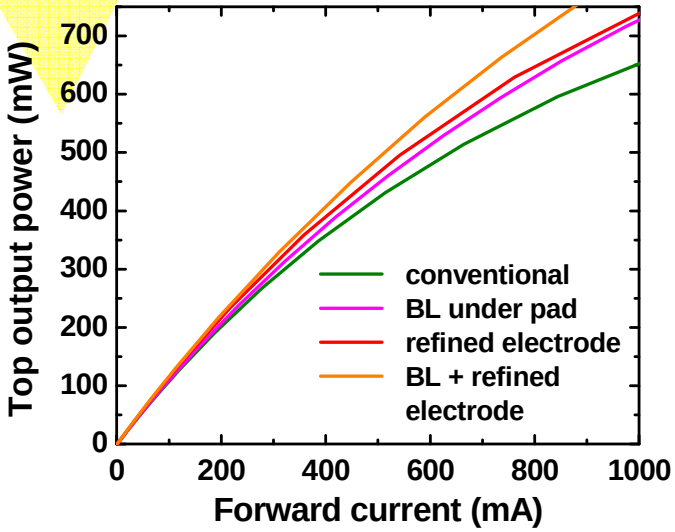
Performance improvements at the current of 700 mA:

- LEE ⬆ from 60 to 70%
- V_f remains the same
- optical power ⬆ from 530 to 635 mW (by ~20%)
- WPE ⬆ from 23 to 28% (by ~22%)









Conclusions

- ✓ current crowding may result in a strong dependence of light extraction efficiency (LEE) on operating current in vertical thin-film LEDs because of incomplete emitted light reflection from metallic n-electrodes
- ✓ predicted decay of LEE with current enhances the droop of total LED efficiency; this actually represent one more non-thermal mechanism limiting the LED performance
- ✓ the undesirable LEE dependence on current may be remarkably suppressed by appropriate modifications of the chip design; in particular, inserting of insulating film under the n-pad and the use of narrow electrodes with reduced spacing are found to be promising for improvement of LED performance