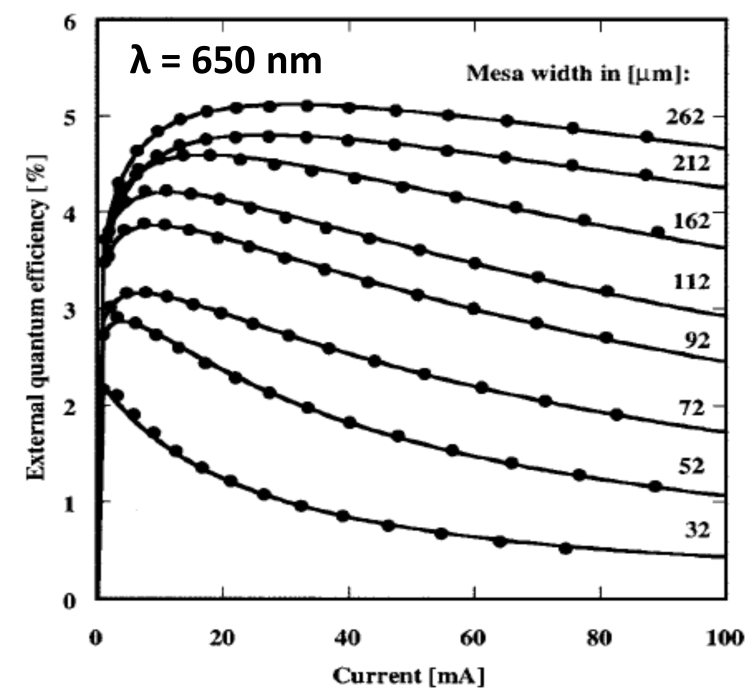
Surface recombination impact on performance of high-power LEDs

K. A. Bulashevich and S. Yu. Karpov

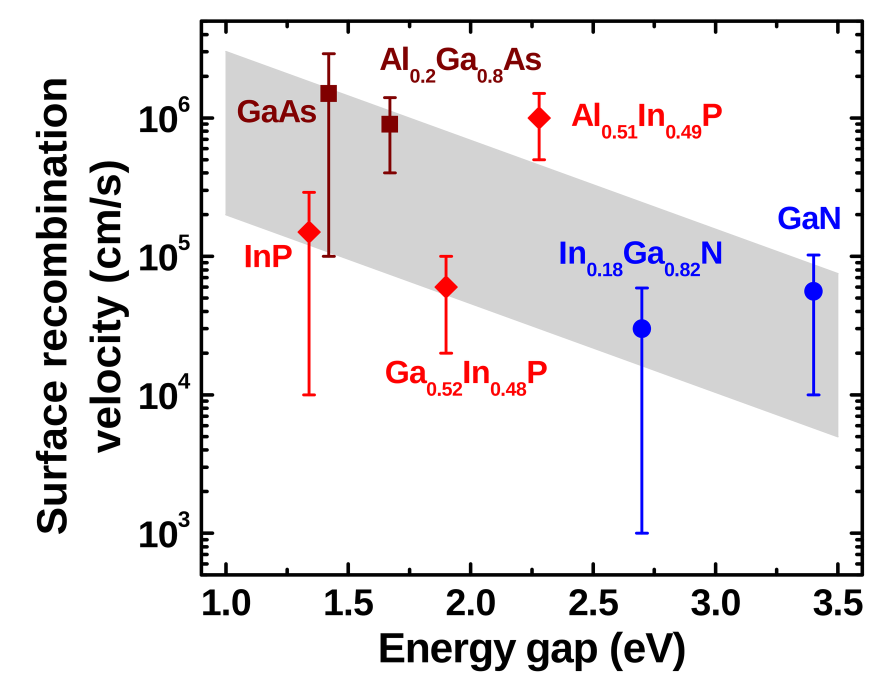
STR Group – Soft-Impact, Ltd. P. O. Box 83, St.Petersburg, 194156 Russia

Motivation:

- ✓ surface recombination is important channel of carrier losses in red AlGaInP LEDs, reducing remarkably their efficiency in small-size dice [1]
- ✓ impact of surface recombination in InGaN LEDs is not yet widely discussed probably because of low recombination velocity reported so far



[1] P. Royo et al, J. Appl. Phys. 91, 2563 (2002)



experimental surface recombination velocities from various sources

What happens in blue LEDs ?

Simulation approach:

- ✓ using the SimuLED™ package [2] modified as to account for the ambipolar lateral electron and hole transport in the LED active region and their surface recombination at the mesa edges
- ✓ using experimental data for the ambipolar carrier diffusivity D_a ~ 2 cm²/s [3] and surface recombination velocity S ~10^3-10^5 cm/s [4] in InGaN
- ✓ selecting the flip-chip design typical for high-power blue (450nm) LEDs, providing high light extraction efficiency due to one-side current access to contact layers [5,6]

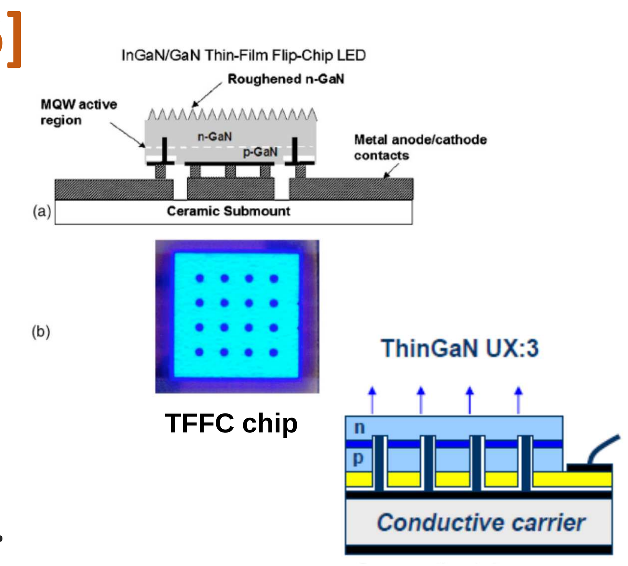
[2] www.str-soft.com/products/SimuLED

[3] K. Jarasiunas et al., Acta Phys. Polonica A, 110, 201 (2006)

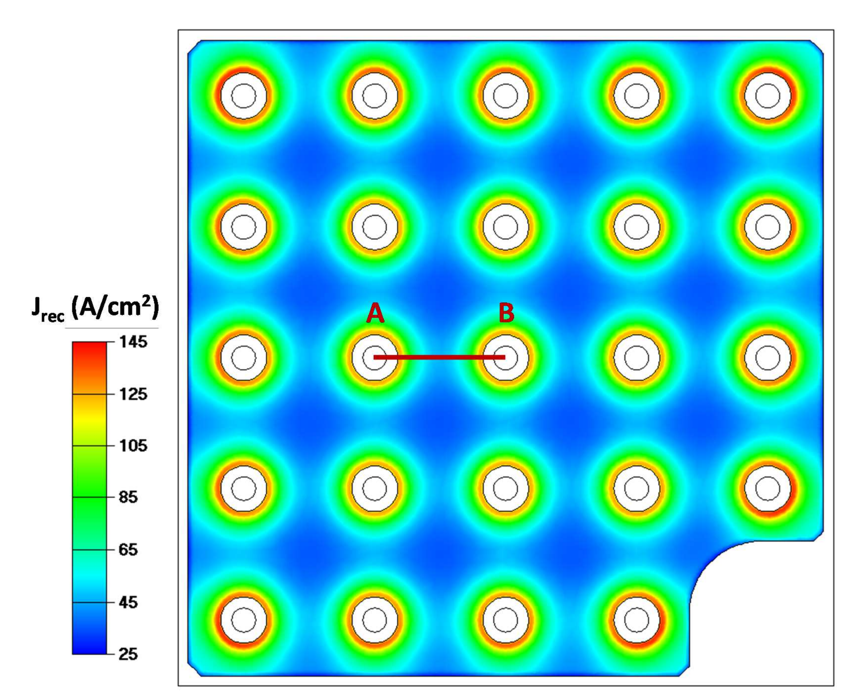
[4] M. Boroditsky et al., J. Appl. Phys. 87, 3497 (2000)

[5] O. Shchekin et al., Appl. Phys. Lett. 89, 071109 (2006)

[6] A. Laubsch et al., IEEE Trans. Electron. Dev. 57, 79 (2010)

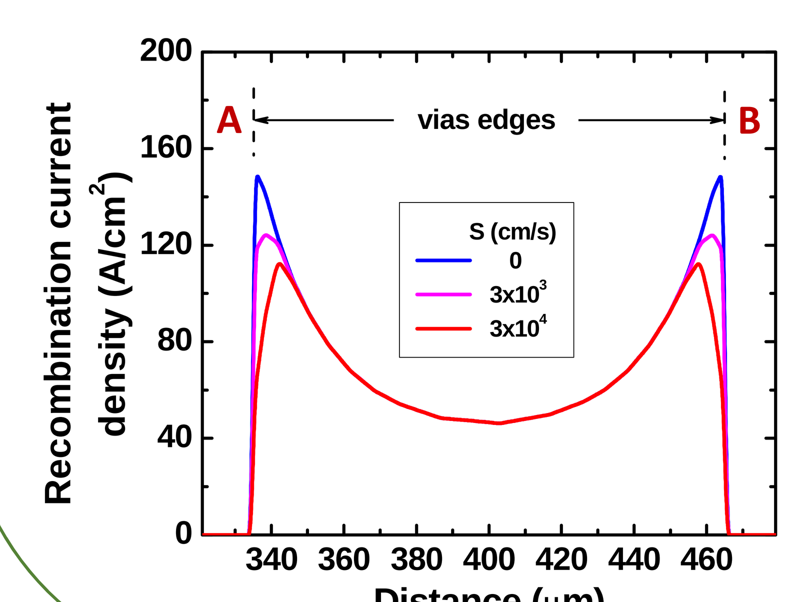


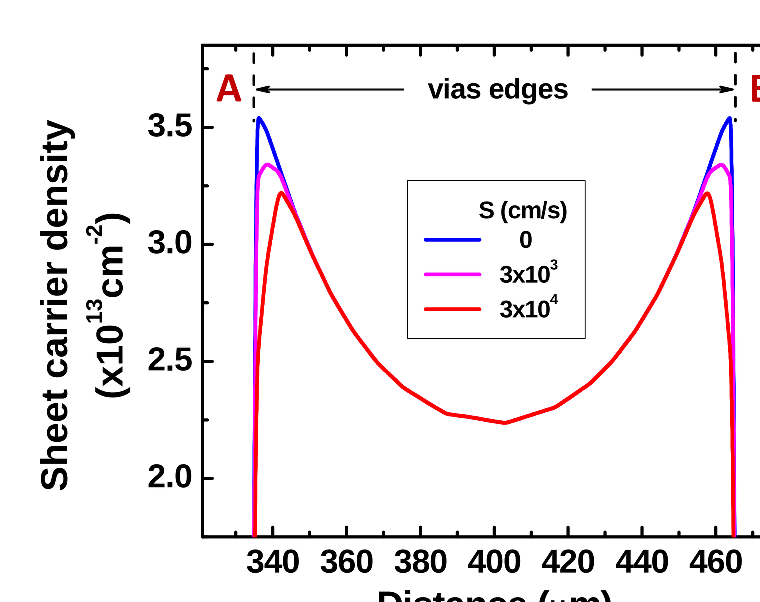
Effect of surface recombination on current spreading in the LED die



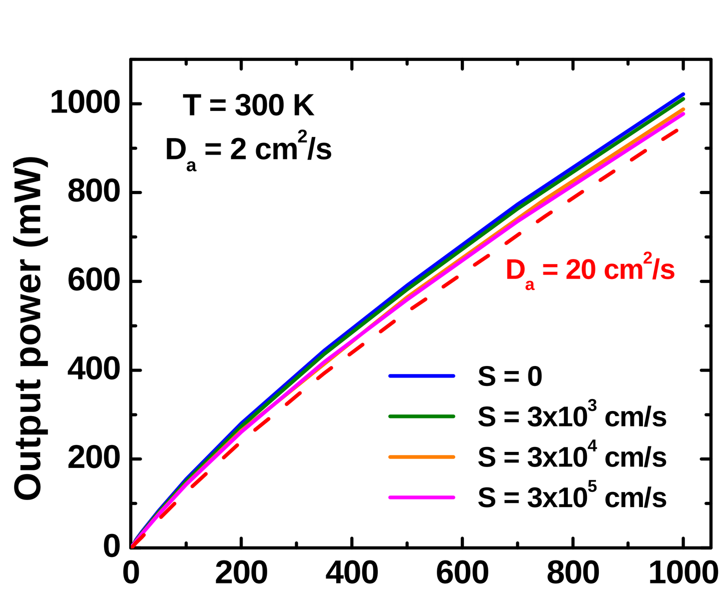
2D distribution of recombination current density in the active region corresponding to the surface recombination velocity S = 10^3 cm/s and the ambipolar diffusion coefficient D_a = 2 cm²/s ; the LED operating current is here of 500 mA

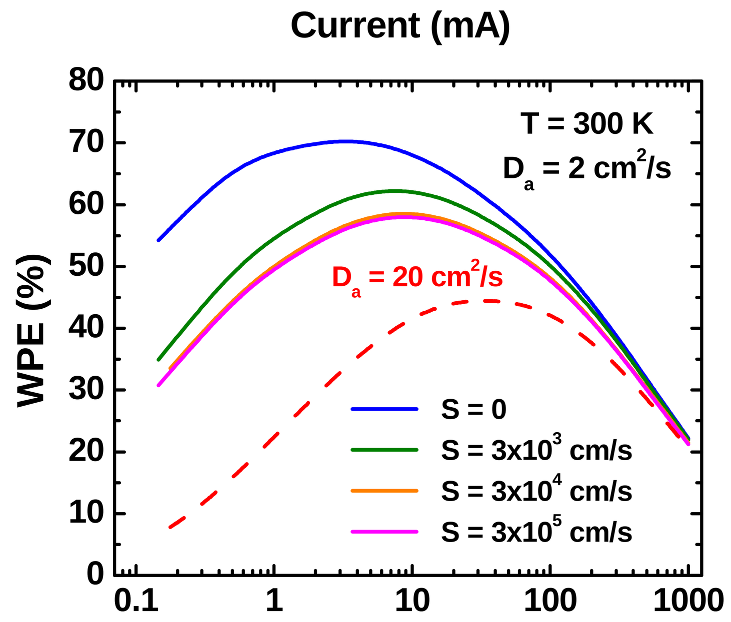
- ❖ current density rises dramatically at the vias edges because of current crowding, the effect enhanced with the LED operating current
- ❖ recombination current density (left plot) and electron/hole concentration in the active region (right plot) at the vias edges are largely affected by the value of surface recombination velocity
- ❖ the effect is observed only in the vicinity of the vias expanded to the carrier diffusion length which is rather small due to a low carrier diffusivity and short carrier lifetime





Effect of surface recombination on LED efficiency





- ❖ in the studied high-power blue LEDs, the surface recombination is predicted to be capable of reducing the output optical power by ~5% and wall-plug efficiency (WPE) by more than ~15% at its maximum value achieved at rather low currents
- ❖ the effect of surface recombination on LED efficiency is found to be remarkable already at the surface recombination velocities S as low, as ~10^3 cm/s
- ❖ starting from the value S~10^4 cm/s, the surface recombination velocity produces surprisingly weak impact on the LED efficiency
- ❖ ambipolar carrier diffusivity D_a is found to be the most critical factor controlling the strength of the surface recombination effect on the LED efficiency (see curves corresponding to hypothetically high D_a = 20 cm²/s); in combination with a short carrier life time, the low diffusivity "prevents" III-nitride LEDs from considerable carrier losses caused by surface recombination
- ❖ surface recombination is expected to become especially pronounced in the small-size LEDs when the device dimensions become comparable with the carrier diffusion length in the active regions

Conclusions:

- ✓ even at the recombination velocity as low, as ~10^3 cm/s, surface recombination may affect the efficiency of state-of-the-art blue LEDs, especially at low operating currents
- ✓ the major factor controlling the strength of the surface recombination impact is the ambipolar carrier diffusion length in the LED active region
- ✓ the impact of surface recombination is expected to be especially pronounced in the small-size LEDs, micro-pixel LEDs, and, probably, UV-LEDs that tend to stronger current crowding, may have a larger carrier diffusivity, and use Al in the active region normally enhancing the surface recombination velocity