Light emission from nano- and microLED arrays

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In this work we study the light emission properties of nanometer- and micrometer-scale light emitting diode (LED) arrays, with special focus on illumination spot size, near field and optical crosstalk. While microLED arrays are of great interest for display applications related especially to virtual and augmented reality, both nano- and microLEDs are highly useful also for specialized applications like for example lens-less microscopy, mask-less lithography or optogenetics [1-4]. In such applications, the spatial resolution of the optical field and precise control over the illumination pattern at the object plane is of special importance. We therefore studied by means of finite-difference time domain (FDTD) and ray tracing simulations, using CST and COMSOL Multiphysics, respectively, the emission from single LEDs in array configuration, for different LED sizes and pitches, and for different array designs, concentrating on the electromagnetic field near the LED structure and on quantification of optical crosstalk.

GaN together with its related alloys is particularly suited for micro- and nanoLEDs since it exhibits a low surface recombination velocity and limited lateral diffusion of injected carriers. In fact, InGaN/GaN nanowire LEDs have been successfully demonstrated down to 100 nm diameter. From a technological point of view, submicron LED arrays with individual pixel control are much more complex. Matrix addressing approaches have been implemented down to the micron scale, while direct individual addressing with emission through the p-side has been used for LEDs as small as 200x200 nm^2 with 400 nm array pitch, as shown schematically in Fig. 1. We therefore studied both approaches. We find that for LED sizes down to ~ 1 μm 3D-structuring of the active LED layers can be readily used to control the light extraction. However, for smaller LEDs, optical crosstalk is becoming a severe issue. In a direct addressing scheme, where no 3D-patterning is employed and LED size is defined by the contact-pad size, light extraction, spot shape and crosstalk is largely influenced by the metallization, as shown in Fig. 2. 3D-patterning can be used to partly suppress in-plane light propagation, using photonic crystal properties of the periodically etched structure (or bottom-up grown nanowires). This works down to array pitches ~ 300 – 400 nm, where crosstalk can be reduced compared to an un-patterned LED structure. However, a careful design is necessary in order to effectively eliminate light coupling e.g. through dielectric isolation layers or conductive transparent oxides (see Fig. 3).

References

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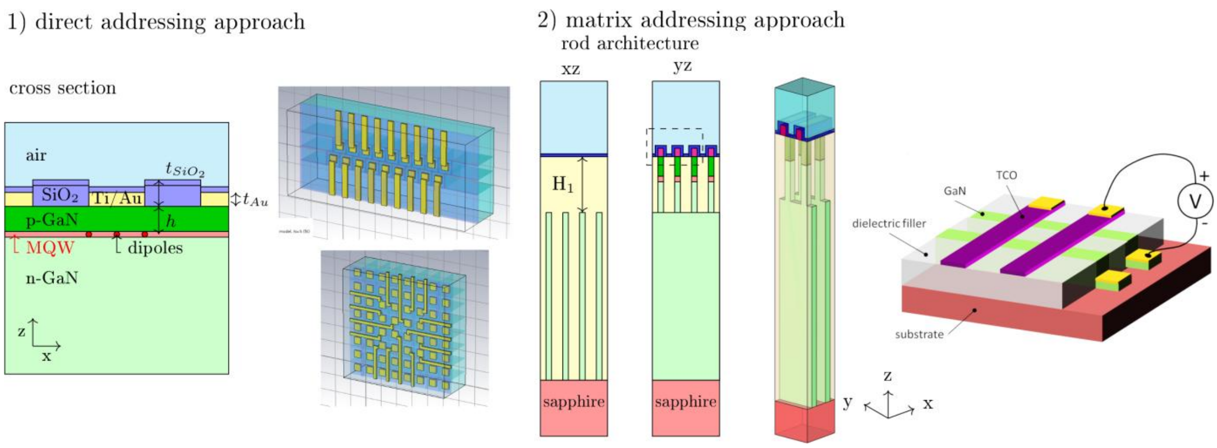

Figure 1: Schematic structure of InGaN/GaN nano- and microLEDs. 1) direct addressing approach, each pixel is addressed individually, no 3D-patterning by etching. 2) matrix addressing, columns and lines are isolated by etching the GaN, and 3D-patterning at top is used to control optical behavior.

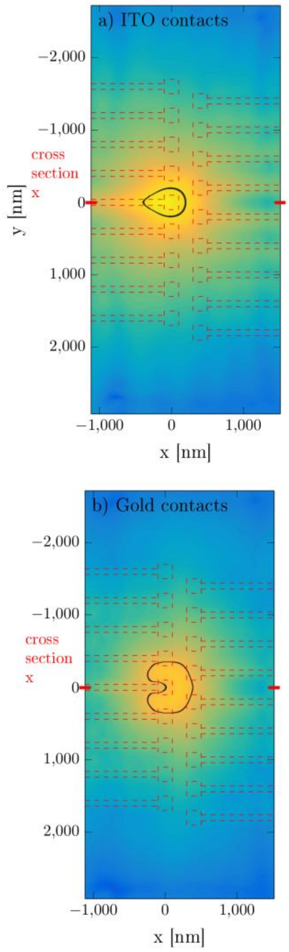

Figure 2: Intensity distribution above a double-line direct-addressing LED with 200 nm pixel size. Contacts (red dashed lines) are made of ITO (top) or gold (bottom), which critically influences both spot shape and intensity.

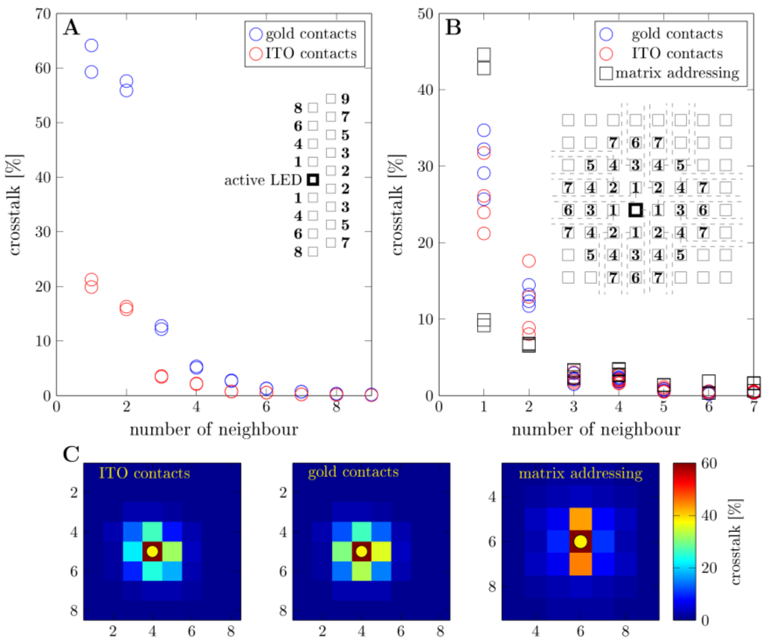

Figure 3: Comparison of optical crosstalk in three different arrays with 200 nm size LEDs and 400 nm pitch. Crosstalk is calculated as ratio between power transmitted through the area of the i-th neighboring pixel and the power emitted through the area of the activated pixel (thick black rectangle). A: results for the direct-addressed double line device. B: results for the direct-addressed matrix design and the matrix-addressed (3D-patterned) array. C: 2D visualization of the crosstalk, showing the anisotropy for the 3D-patterned array.

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