

# Quantitative Simulation of Pixel-Level Crosstalk in MicroLED Arrays with Outcoupling Structures for AR Applications

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## Abstract

*MicroLED displays for AR applications require high light extraction efficiency (LEE) while minimizing crosstalk to achieve optimal image quality. This study presents a simulation approach that demonstrates how light propagates in outcoupling structures from pixel to pixel. The results show that the practical impact of crosstalk is minimal due to the large incident angle when light enters adjacent pixels. This work establishes a simulation framework for studying crosstalk in microLED arrays.*

## Author Keywords

MicroLED, lens array, crosstalk, FDTD simulation.

## 1. Objective and Background

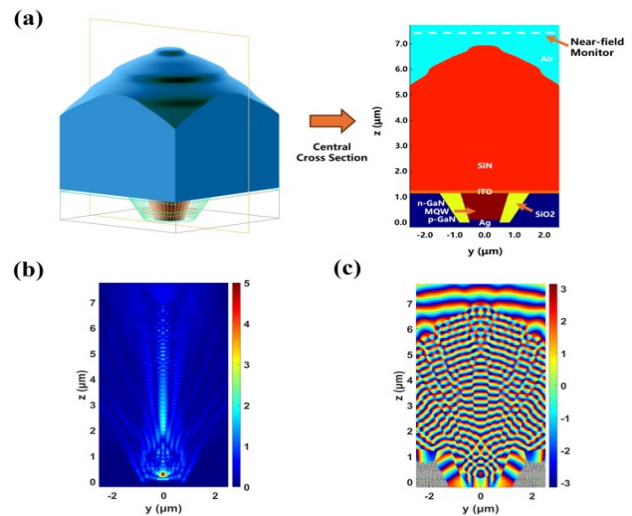
MicroLED ( $\mu$ LED) displays have emerged as a highly promising option for augmented reality (AR) applications, owing to their exceptional brightness, enhanced durability, and high pixel density [1][2]. However, light extraction and collimation continue to be major obstacles in utilizing  $\mu$ LED panels for AR applications. As the size of the  $\mu$ LED chip shrinks to micron-meter level, the ratio of light emitted from the sidewalls increases, resulting in wider angular distribution and possible crosstalk between neighboring sub-pixels [3][4]. Considering chromatic  $\mu$ LED pixel arrays, crosstalk can greatly impact the performance of full-color displays, as light leakage can interfere with the black levels of adjacent pixels and diminish the overall contrast of the display [5][6].

This paper studies an outcoupling structure that incorporates a reflecting cup and a freeform lens. The lateral emissions from the micro-LED are captured by the cup and redirected upward [7]. Subsequently, the lens collimates both the redirected and top-emitted light, thereby achieving optimal collimation. Although lens arrays have been widely used for pixel-level light collimation, most existing lens simulations rely on the Monte Carlo ray-tracing method [8][9], hindering the isolation and analysis of crosstalk components. This paper utilizes the three-dimensional finite-difference time-domain (FDTD) method to simulate light emission from dipoles in the main pixel's multiple quantum well (MQW) layer and subsequent crosstalk into adjacent pixels. We quantitatively analyze the energy contribution to practical crosstalk and elucidate its underlying mechanisms.

## 2. Results

**Figure 1(a)** illustrates the configurations for the film layers, the reflecting cup, and the freeform lens in simulation. The structure of the  $\mu$ LED was simplified to optimize the simulation efficiency without compromising the reliability of the results. This included omitting film layers that exert minimal influence on the simulation outcomes and reducing the MQW layer to a single layer. The

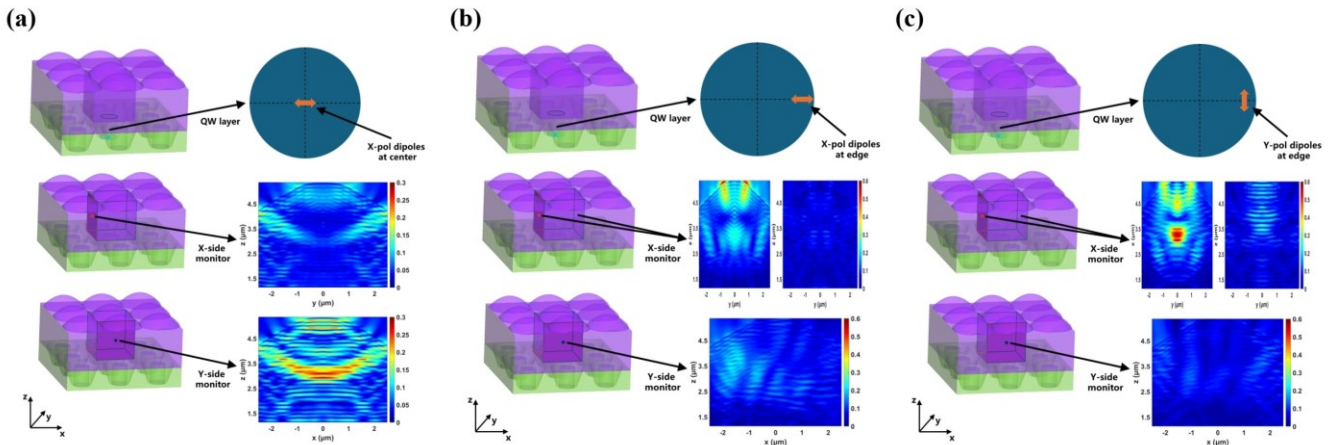
freeform surface of the lens was engineered to correct the unsynchronized phases of the field emitted from the microLED. In our simulations, a dipole source was positioned within the MQW layer of the main pixel. The spatial distribution of the field amplitude and phase, as it propagates from the central dipole, is visualized in **Figure 1(b)** and **(c)**. The freeform lens effectively collimates the field into a quasi-plane wave.



**Figure 1:** (a) Diagram illustrating the simulation model layout. (b)-(c) The evolution of the field amplitude and phase from the central dipole.

To isolate crosstalk, monitors were strategically placed at boundaries representing adjacent pixel interfaces. The laterally emitted field data was captured and then employed as an excitation source in subsequent simulations of neighboring pixels. This approach allowed for a detailed analysis of pure crosstalk propagation and behavior. To investigate the impact of emission position on crosstalk, simulations of the main pixel were conducted for dipole sources located at the center and edge of the active layer. For the centrally located dipole, as shown in **Figure 2(a)**, rotational symmetry allowed for consideration of only one polarization state. The dominant Y-side lateral emission was used as the crosstalk excitation source. For edge-located dipoles, both X and Y polarizations were analyzed, as shown in **Figure 2(b)** and **(c)**. The reflecting cup surrounding the microLED resulted in stronger lateral emission on the far side of the dipole offset, which was used to model crosstalk for edge-emission scenarios.

**Figure 3(a)**, **(b)**, and **(c)** show the simulation results of crosstalk corresponding to the main pixel's dipole source located at the



**Figure 2:** Different laterally emitted field data of the main pixel, with (a) the x-polarized dipole located at the center, (b) the x-polarized dipole located at the edge, (c) the y-polarized dipole located at the edge.

center, at the edge with X polarization, and the edge with Y polarization, respectively. Central cross-sectional electric field distribution reveals that crosstalk light enters adjacent pixels at oblique angles, regardless of the dipole’s location. Subsequent refraction at the lens interface further diverts the light. Far-field projections of the near-field data from the top surface monitor corroborate these findings. Moreover, the significant refractive index contrast between the lens and air induces reflection and total internal reflection of crosstalk light, leading to waveguide-like propagation to the next pixel.

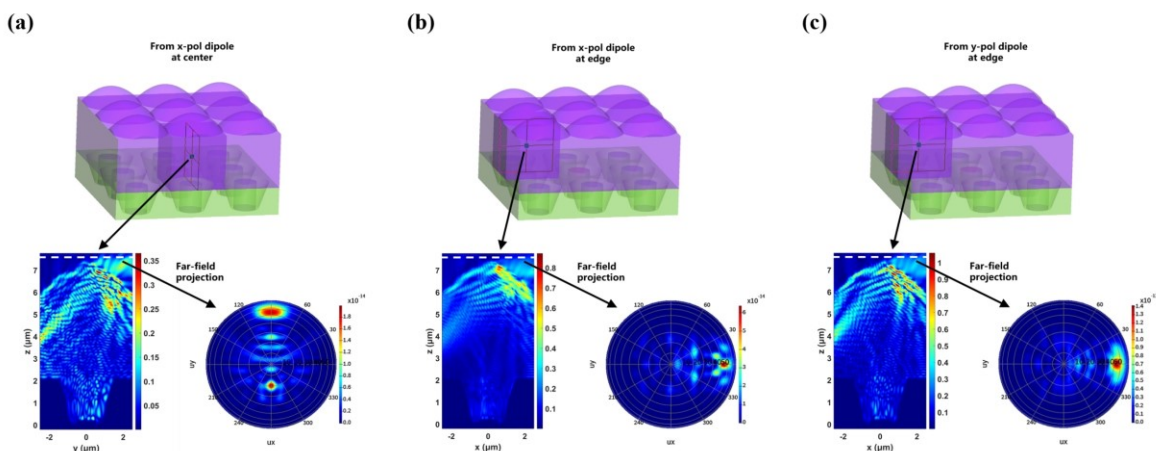
**Table 1** presents the energy transmission for various boundaries in the simulations of the main pixel and adjacent pixel. The results for both polarization states of the edge dipole are averaged. Only the power within a  $10^\circ$  solid angle was counted in the far field because the projector lenses used in a compact AR system have limitations in the acceptance angle of incident light [8]. From the results, we can find that compared to the central dipole, though edge-located dipoles exhibit higher energy transfer to adjacent pixels, most of

this light is either trapped within the lens array or escapes at large angles, rendering it unlikely to contribute to significant crosstalk in subsequent optical components.

Additionally, due to factors such as current crowding and surface recombination, for small microLED devices, the distribution of radiative carriers tends to be more concentrated in the central region [10][11]. Therefore, referring to the data for the central dipole in the table, the crosstalk output of adjacent pixels within  $10^\circ$  may be only in order of one-thousandth of the effective output of the main pixel. Considering the modulation transfer function (MTF) limitations of the waveguide in AR applications and the presence of ambient light in most usage scenarios, it is inferred that the crosstalk observed within the lens layer in this study is insufficient to cause practical problems.

### 3. Impact

The significance of our work lies in its contribution to the



**Figure 3:** Cross-sectional field intensity and far-field projection of the adjacent pixel corresponding to the main pixel's dipole located (a) at the center, (b) at the edge with X polarization, and (c) at the edge with Y polarization.

**Table 1 Transmission in different boundary planes**

	X side (left)	X side (right)	Y side	Top side	Far-field $\leq 10^\circ$
Main pixel (central dipole)	5.2%	5.2%	14.9%	45.7%	33.2%
Main pixel (edge dipole)	35.7%	6.4%	9.9%	16.2%	1.2%
Adjacent pixel (central dipole)	—	—	5.8%	0.7%	0.03%
Adjacent pixel (edge dipole)	17.0%	—	—	2.0%	0.06%

advancement of microLED arrays for AR applications, specifically addressing the critical challenge of crosstalk between neighboring pixels. By employing rigorous FDTD simulations, we have gained valuable insights into the propagation and behavior of crosstalk light within the pixel array. We demonstrate that while crosstalk does occur, its impact on practical device performance is limited due to factors such as the large emission angles and the trapping of light within the lens array.

Our results diverge from some previous studies that have highlighted the potential for significant crosstalk in microLED displays. These discrepancies can be attributed to differences in device structures, simulation methodologies, and the specific assumptions made for AR applications in analyzing crosstalk. From the insights gained from this study, we can conclude that the existence of the lens and the cup can significantly impact the optical properties of the device. Thus, it is feasible to further minimize crosstalk and enhance light extraction efficiency through the careful selection of materials and the strategic design of outcoupling structures.

#### 4. Acknowledgment

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