Conclusion

We have demonstrated that OLEDs are the first light sources that enable beam-shaping without any further optical elements and real-time continuous adjustment of the spatial brightness distribution. Several challenges were pointed out like the spectral drift of the emission colour especially in sideward emission, due to the curvature of the cavity mode. The use of emitters with spectrally narrower PL spectra would be an adequate response to that point. Furthermore, the emitted colour should be similar in both emission modes. This effect was addressed by utilizing two different emitters of similar spectral distribution but offset PL maxima.

Future work on this topic should focus on the development of green and blue beam-shaping OLEDs to cover the three primary colours. First tests have already been carried out and showed promising results. Nevertheless, the influence of the V(λ) curve for human perception of colours[33] works contrary to the curvature of the cavity mode, especially in the blue colour regime. On the one hand this requires a far more elaborate sample design, but on the other hand the emission wavelength scales with the layer thickness, which means that process-based deviations in the thickness compared to the simulation have much more impact on the outcoupled spectra. These two facts make it more complex to realize the conceived optical design – the optical minimum in particular. But having in mind that these are experimental and not theoretical limitations, we are optimistic that further evaluation of this promising concept will be presented in future work, heading towards full colour active beam-shaping light sources.

Clearly, the ultra-thin, area light source character of OLEDs paired with the ability to control their angular emission properties solely through the modulation of the driving signal opens a new opportunity to design and use complex, customized, and adjustable light sources and systems. The interplay between light sources and secondary optics begs further investigation to make use of the full potential of this concept.

Methods

Simulation All simulations were carried out with in-house developed simulation software. Theoretical details can be found in literature.[10,21] This simulation solves the Maxwell equation for stratified media, assuming the emission layer is infinitesimally thin and thus solving the equation system using Green functions.[30] Parameters that have to be set, are the thickness, the refractive index $n(\lambda)$, and the absorption coefficient $k(\lambda)$ of each layer. Furthermore, both the PL-spectrum and the molecular orientation of the emitter has to be known. The software itself has proven functionality with various types of planar devices[10,37] and even works for corrugated samples.[38]

Sample preparation and materials. All samples are produced on glass substrates pre-coated with ITO anodes. Organic layers and metals are deposited by thermal evaporation in a UHV chamber at a base pressure of 10^{-6}-10^{-7} mbar and rates of 0.2-2 Å/s. The samples are encapsulated to prevent oxygen, water, and dust exposure.

The OLEDs follow the pin-architecture. Two stacked OLEDs are evaporated directly on top of each other, separated by a Au/Ag wetting layer.[25] The hole transport layers (HTL) consist of 4 weight percent (wt%) 2,2'-(perfluoronaphthalene-2,6-diylidene)dimalononitrile (F_6-TCNNQ) doped into 2,2',7,7'-Tetrakis-(N,N-dimethylphenylamino)-9,9'-spirobifluoren (Spiro-TTB). Electron transport layers (ETL) are of caesium doped 4,7-diphenyl-1,10-phenanthroline (BPhen). Regarding energy barriers[31] and chemical interactions[32] the blocking layer materials are chosen from the following pool: BPhen or