Fundamental limits to metalens critical dimensions

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Arrays of microlenses have been integrated to imaging system to increase their spatial resolution of by tackling both electronic and optical crosstalk between pixels [1]. For practical applications, microlenses requires to have the size of the pixels, thus few microns, reaching the diffraction limits. It becomes increasingly difficult to fabricate with refractive lenses [2], therefore metasurfaces have been investigated as a promising solution compatible with traditional semiconductor processes.

Here, we studied the fundamental limits to micro-metalens design by considering a diffraction theory framework based on Stratton-Chu integral [3]. We identified two limits for which the metasurface is operating. The first limit is defined by the aperture of the metasurface itself while the second limit is defined by the period of the metasurface. Inside these limits, we identified two domains of operations: (i) high numerical aperture with full control of the wavefront and narrow bandwidth operation, (ii) low numerical aperture with partial control of the wavefront with "focal shift" [4] and broadband behavior. We verified our theory with 10µm diameter metalenses fabricated in GaN and operating at 617nm. Each metalens has a different focal length, thus probing the different regime of operations.

Our study presents guidelines in the design of small metalenses and explicit fundamental limits to their applications.

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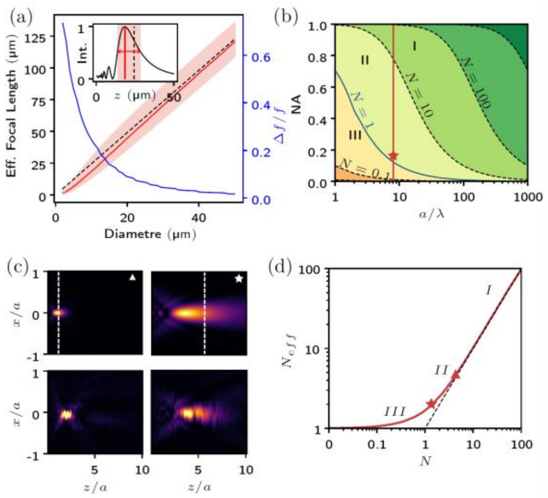

Figure 1: (a) In red, variation of the effective distance focal (maximum of amplitude) in function of the diameter of the metalenses with fix numerical aperture NA = 0.2. In blue (right y-axis), variation of the focal shift with regards to the designed focal length. (b) Mapping of the Fresnel number $N = a^2/\lambda f$, in function of the numerical aperture and the size of the aperture (in wavelength). The green color shows N > 1 and the yellow colors N<1. (c) Comparison between numerical simulations and measurements for GaN metalenses of $2a = 10\mu m$ at $\lambda = 617nm$, with focal length $f = 10\mu m$ and $f = 30\mu m$, represented by the with dashed line. (d) Evolution of the effective Fresnel number in function of the Fresnel number. Red line corresponds to the simulations and the symbols refer to (c).

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