Design of RGB-Polychromatic Metalens Optical System

Margarita Sharipova, Dmitrii Piskunov, Elena Malinovskaya, Stepan Ivanov, Viktoriia Kaidarakova,

Stanislav Shtykov, Byungkwon Kang, Dongil Seo, Kwanyong Lee, and Jeongyeol Lee

Samsung Electronics, Seoul, Korea

Motivation

Metalenses are flat optical elements consisting of nanosized structures that provide unprecedented control over the phase of electromagnetic light. Due to their resonant nature, metalenses are inherently dispersive, so additional efforts are required to achieve an achromatic response from a metalens optical system. However, current numerical methods allow one to tackle such challenges and use meta-atom optimization to achieve a polychromatic response.

We propose a complete pipeline for the design of an optical metalens system for RGB applications.

Results

The metalens optical system design was divided into several consecutive steps:

- Setting target RGB phase profiles
- Choosing optimal meta-atom parameters
- Metalibrary generation
- Calculating optical performance

1 Setting target RGB phase profiles

To determine the target phase profiles in the metalens system, first the initial system is defined as a set of lenses, each one defined by an analytical radially symmetric polynomial phase profile set by an optimizable phase function:

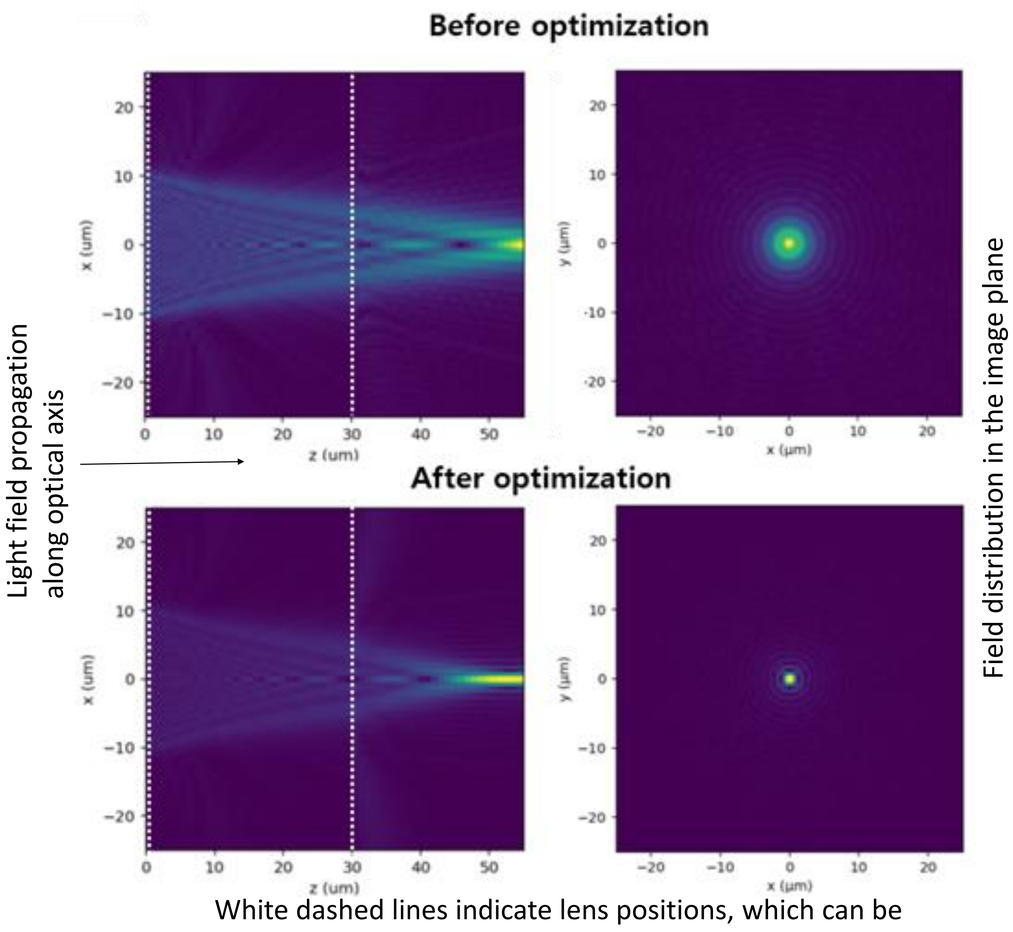
$$\phi(r) = \sum_{i=0}^{n} a_i r^{2i}$$

a_i – optimizable coefficients,
r – distance from the optical axis

The metalens system, including distances between lenses and their phase profiles, can be optimized by a fitness function, typically set to achieve maximum intensity in the focal point.

To achieve an achromatic response, the phase profiles are first defined for one wavelength λ_0 (green) and then recalculated for other wavelengths (blue and red light).

Optimization example for 2-lens system



White dashed lines indicate lens positions, which can be fixed or varied during target phase optimization process

Next, to determine if the required range of phase dispersion is achievable with the chosen meta-atom geometry we implemented a quick parameter sweep with a simple meta-atom shape (cylinder nanopillars). The goal of this sweep is to choose the best meta-atom parameters, usually remaining unchanged during fabrication, for further steps of meta-atom shape optimization. One can define a set of parameters to sweep through, such as the number of layers in the meta-atom geometry, materials, layer heights, and period.

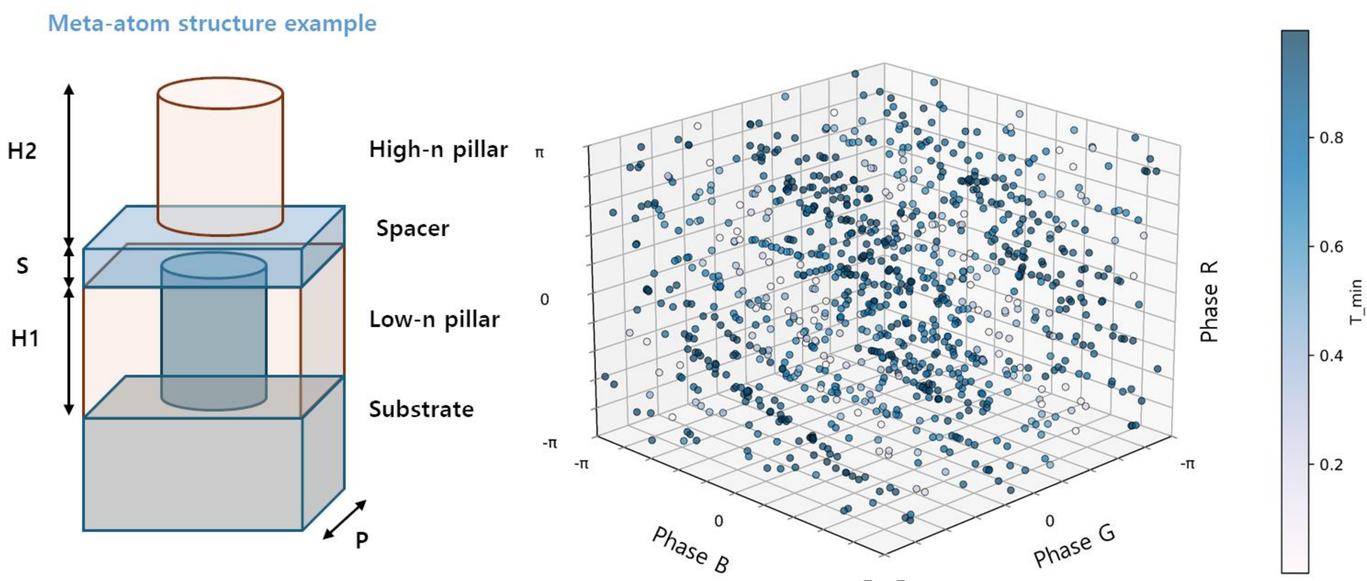
2 Building metalibrary

Fixing structure parameters: The sweep uses RCWA to calculate the optical response of meta-atoms in a 2D periodic square array with variable nanopillar diameter and compare RGB phase coverage with the required target values. After the sweep, the following parameters were chosen: TiO2 and SiO2 as high-index and low-index materials, respectively, with p = 350 nm, S = 750 nm, and H1 = H2 = 2 μm.

Shape optimization: After determining the meta-atom geometry, we need to optimize the meta-atom shape to provide the required RGB phase response. First, we set an acceptable phase mismatch when mapping target phase profiles:

$$|\phi - \phi_{target}|_{RGB} \leq \pi/10$$

After that, the whole RGB phase space was split into 10 segments along each axis, and a set of equidistant RGB phase targets were defined for further optimization, 1000 targets in total. The meta-atom shape for each layer of a bilayer meta- atom was chosen to be a freeform randomly generated level-shape with 4-fold geometry . The meta-atom shape optimization process included random generation, gradient search, and coordinate search. During optimization, the meta-atom transmittance and phase were calculated for 3 RGB wavelengths using a FDTD solver. Based on that data, the meta-atom was placed in a corresponding RGB phase cell. If several meta-atoms are placed in one cell, the one with the highest transmittance is picked for the final metalibrary. For an empty cell without a corresponding meta-atom shape, the meta-atoms from neighboring cells were tweaked to achieve the target RGB phase.



3 Calculating optical performance

In the final step, the metalens system was constructed with the generated metalibrary and its optical performance was evaluated. To achieve this, we separated the space into regions between the lenses and regions containing the metalenses. Free-space wave propagation was simulated using a FFT-based numerical integration method for Rayleigh-Sommerfeld diffraction formula (similar to first step of setting target phases). Light propagation through metalenses was calculated by either:

- FDTD solver in the case of small-scale metalens systems, when computational complexity is tolerable
- Block decomposition method in the case of large-scale metalens systems, when metalens response was mapped using precalculated metalibrary data on RGB phase and transmittance of each individual meta-atom in the metalens

Table below demonstrates calculated optical performance values for a 5-lens optical system with an aperture diameter of 5 mm.

Calculated optical performance of a metalens system

Wavelength	R λ_R=618 nm	G λ_G=518 nm	B λ_B=454 nm
RFE	91.1%	88.9%	87.2%
Transmittance	87.5%	86.7%	88.1%

The relative focusing efficiency (RFE) is defined as the ratio of the power focused within 3 FWHMs to the transmitted power. The transmittance is defined as the average transmittance per single metalens.

Conclusion

We have implemented an approach to RGB metalens system design, including setting target RGB phase profiles, choosing optimal meta-atom parameters, metalibrary generation, and calculating optical performance. The results may be useful for the design of polychromatic metalens systems, such as AR/VR systems, compact medical devices, and other applications.

Contacts: m.sharipova@samsung.com