Multiobjective optimization for highly efficient and robust metasurface designs

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Université Côte d'Azur, Inria, CNRS, LJAD, 06902 Sophia Antipolis Cedex, France

CNRS, CRHEA, Université Côte d'Azur, Sophia Antipolis, Valbonne, France
mahmoud.elsawy@inria.fr

ABSTRACT

We present an innovative computational methodology based on statistical learning multiobjective optimization to optimize highly efficient and robust metasurface designs. We optimize a large-scale 3D metalenses in the visible regime. Besides, we extended our multiobjective optimization to consider the fabrication imperfections for a robust beam steering design.

KEYWORDS: *Metasurface, Multiobjective optimization, Robust design*

Metasurfaces are attracting widespread interest notably due to their distinctiveness in controlling light properties in very short propagation distances with very high resolution [1-4]. Yet, the precise engineering of subwavelength patterning is compulsory in enhancing the performance of metasurfaces. Several innovative inverse design methodologies have recently been exploited to address this issue, but only considering single objective functionality [5]. Today, we are witnessing a noteworthy demand in designing flat optics devices with a wide variety of responses to realize multifunctional metasurfaces. This makes the exploitation of rigorous inverse design strategies for multiple functionalities mandatory for the next metasurface generation. However, this is not an easily manageable task, since the optimization of multifunctional metasurfaces requires a solution to an optimization problem with different conflicting objectives and potentially entails a large parameter space. In these circumstances, the development of Multiobjective Evolutionary Algorithms (MEAs) is a widespread methodology. MEAs are usually exploring the parameter space using stochastic search to converge to the global solution. They have been inspired by biological evolutionary mechanisms, like mutation, selection, and crossover to broaden the search scheme during the optimization, improving the possibilities to converge. Yet, they are computationally demanding and subject to high overheads iterations.

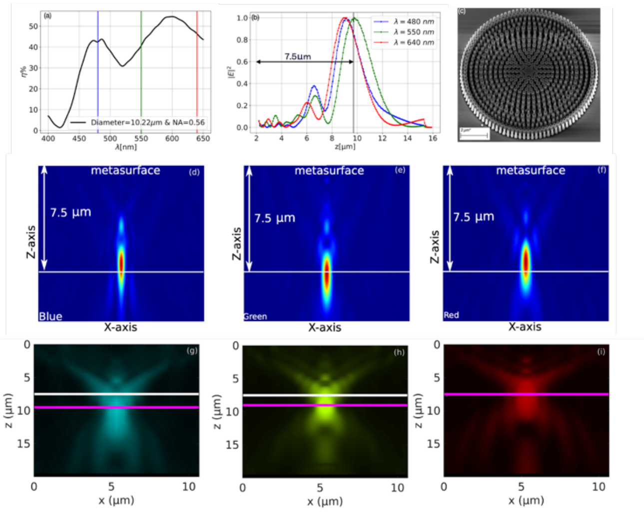

Fig. 1 Optimized RGB metalens

In this work, we present for the first time to the metasurface community a multiobjective optimization that relies on a statistical learning machine learning method. We demonstrate that this method converges rapidly to the global set of optimal solutions, using a moderate number of solver calls. This method is based on surrogate modeling, which replaces the high-fidelity electromagnetic evaluation process with a simpler and cheaper model for the prediction of the new designs during the optimization process. Even though it converges to the global set of solutions, it requires fewer iterations compared to the classical global evolutionary strategies [7]. We combine this approach with our in-house developed 3D electromagnetic solver based on the Discontinuous Galerkin Time-Domain (DGTD) method [8]. First, we optimize 3D achromatic metalens with numerical aperture NA>0.5. Fig. 1(a) provides the focusing efficiency of the optimized lens. The three vertical lines refer to the three wavelengths considered during the optimization. The cut along z at the center of the lens for the RGB colors is given in Fig. 1(b). The vertical line refers to the target focusing position along z. The fabricated lens is depicted in (c), besides, the corresponding intensity profiles at the x-z plane is given in (g-i), where the intensity is measured for the blue, green, and red colors respectively. The numerical focusing intensity for each color are drawn in (d-f). The fabricated and the numerical focusing efficiencies are almost 50% for three colors. To the best of our knowledge, this is the highest focusing efficiency obtained for RGB colors for a 3D metalens with NA=0.56 especially designed using classical nanopillars that are considerably easier to fabricate with respect to complex freeform geometries.

We further extend our numerical methodology to account for the manufacturing errors related to metasurface designs [10]. We present a novel optimization framework to account for the manufacturing errors of simple metasurface with classical cylindrical nanopillar geometry (see Fig. 2). Our procedure relies on a global statistical learning-based optimization method that substitutes the resource intensive simulations with a surrogate model. Our numerical results reveal that incorporating the Uncertain Quantification (UQ) analysis in the optimization scheme is crucial in achieving robust design. Our approach necessitates resolving a multiobjective optimization problem that accounts for the mean and the variance change of the efficiency under the given noise. With the UQ analysis, we obtained designs that are twice more robust than the analogous one in the deterministic case. Our discovery enriches the field of metasurface inverse design with a solution to rigorously consider the manufacturing issues.

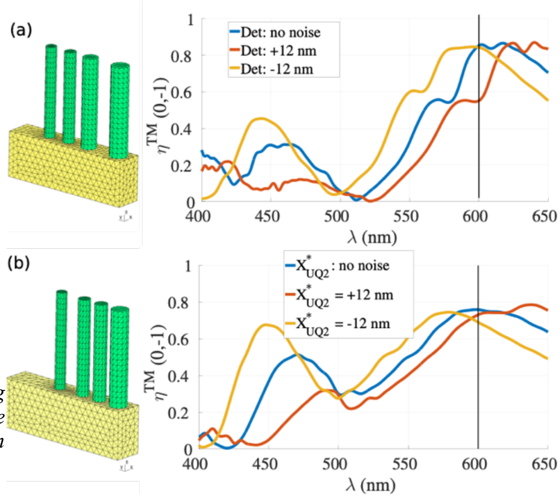

Fig. 2 Comparison between two optimized beam steering metasurface. (a) deterministic case without considering the fabrication imperfections and (b) with the fabrication imperfections. For more details we refer to Ref. [10].

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