Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Evolutionary and genetic algorithms for design of metadevices working on electric dipole resonance

To cite this article: Roman Melnikov *et al* 2020 *J. Phys.: Conf. Ser.* **1461** 012011

Evolutionary and genetic algorithms for design of metadevices working on electric dipole resonance

Roman Melnikov, Kseniia V. Baryshnikova, Mihail Petrov, Vladimir Ulyantsev, Andrey B. Evlyukhin, Boris N. Chichkov

ITMO University, 49 Kronverksky Pr., St. Petersburg, 197101, Russia

Institute of Quantum Optics, Leibniz Universität Hannover, 30167 Hannover, Germany

k.baryshnikova@metalab.ifmo.ru

Abstract. All-dielectric nanophotonics is a rapidly growing field of modern science. Metasurfaces and other planar devices based on all-dielectric nanoparticles lead to manage the light propagation at the nanoscale. Impressive effects such as perfect absorption, invisibility, chirality effects, negative refraction, light focusing in the area with size smaller than wavelength, nano-lasing etc - can be achieved with all-dielectric technologies. While it is needed to use more and more complicated designs for solution of modern nanophotonics' currents tasks, non-classical methods of optimization become relevant. For example, to design reconfigurable metalenses with an additional degree of freedom such as polarizability or temperature dependence, evolutionary or genetic algorithms show their high applicability. In this work, we show a new approach to design metalenses with evolutionary and genetic algorithms.

1. Introduction

Designs of devices based on metamaterials (meta-devices) become more and more complicated with the increasing of functionality of these devices. One of examples of metadevices which need complicated optimization is a metalens. The idea of designing lenses based on meta-surfaces comes from the original work by Veselago [1], where materials with both dielectric constant and magnetic susceptibility being negative ("left" materials) can be used for ideal lenses. This idea was developed in the works of Pendry [2]. It was shown that meta-surfaces can be such "special" materials [3, 4]. This means that ideal lenses are not a beautiful abstraction, but also a realizable thing. A number of works offer various realizations of metalenses: on the basis of plasmon and dielectric particles, tunable, operating in a wide range of wavelengths [5, 6, 7]. Previously, the approaches to design of metalenses were stochastic or based on previously considered designs and were not suitable for universal optimization. In this work we used optimization based on evolutionary (genetic) algorithms and electric dipole approximation to optimize metalens design from the very origin.

2. Optimization

Here we perform results of optimization using two different algorithms. All designs were optimized to give a main focus in 6 um. All metalenses considered here have a 10-circles structure with meta-atoms evenly distributed on the circle. Bigger radius of metalens was limited by 15 um. Number of particles was not limited. Each meta-atom was a spherical nanoparticle made of crystalline silicon.

IOP Conf. Series: Journal of Physics: Conf. Series **1461** (2020) 012011 doi:10.1088/1742-6596/1461/1/012011

Information about refractive index of silicon was got from [8]. Coordinates of metaatoms were parameters of optimization. The working wavelength is 620 nm where each meta-atom has an electric dipole resonance and could be approximated by the electric dipole only. Simulation of field distribution close to metalens were performed in case of normal incidence of a linearly polarized plane wave. Interaction between particles was omitted in calculations.

2.1. Evolutionary algorithms

Evolutionary algorithm (EA), in general, is a subset of evolutionary computation [1], a generic population-based metaheuristic optimization algorithm. In our case, implemented evolutionary algorithm represents the following sequence of actions:

1) generate random individual;

2) randomly mutate it;

3) if mutated individual has a lower score, we substitute our initial individual with it

In our problem individiual is represented as list of rings, each ring is characterized by its radius, number of metaparticles on it and initial angle (meta-atoms evenly distributed on the circle). Mutation is the following process: firstly, we peek random ring, and then randomly change one of its characteristic. Score is Euclidian distance between calculated and desired focus length.

For considered problem evolutionary algorithms seem to be rather inefficient. Thus, with 10 times changing of randomizer in algorithms only the one case went to the convergent solution. Other cases did not correspond to the solution during one thousand steps.

2.2. Genetic algorithms

Genetic algorithm in our optimization performs the following actions:
1) Generate random population;
2) get new generation from three parts:
- Pick some amount of individuals based on elitism (those from the previous who has the lowest score)
- Randomly pick some amount of pairs and breed them
- Randomly pick some amount and mutate them (mutation is taken from the evolutionary algorithm)
3) calculate scores for the new generation;
4) if new generation doesn't improve score for a long time, we generate new random generation and start once again.

Genetic algorithms turned out to be much more efficient in comparison with evolutionary for this task. Result of optimization with these algorithms depends strongly on randomization during the evoluation process. They can be compare by the effectiveness of field enhancement in the focus. We perform 10 optimization cycles and compare results with each other. It turned out that designs' efficiency depends on the number of particles: thus, design with 306 nanoparticles corresponds to enhancement of electric field intensity in the focus up to 6 times only, herewith design with 681 nanoparticles corresponds to enhancement of electric field intensity in the focus up to 29 times. Also it is reasonable to compare results from the following point of view: in the vicinity of main focus there should not be other focuses which efficiency is comparable with the main one.

3. Results and Discussion

Figure 1 shows most efficient designs corresponding to both evolutionary and genetic algorithms and intensity of electric field close to the metalens. As one can notice, genetic algorithm's design corresponds to the big enhancement of light intensity in the focus up to 22 times, however, area of focal spot (about 1 um) is much bigger than for case corresponding to evolutionary algorithms where electric field intensity in focus is enhanced only up to 5 times.

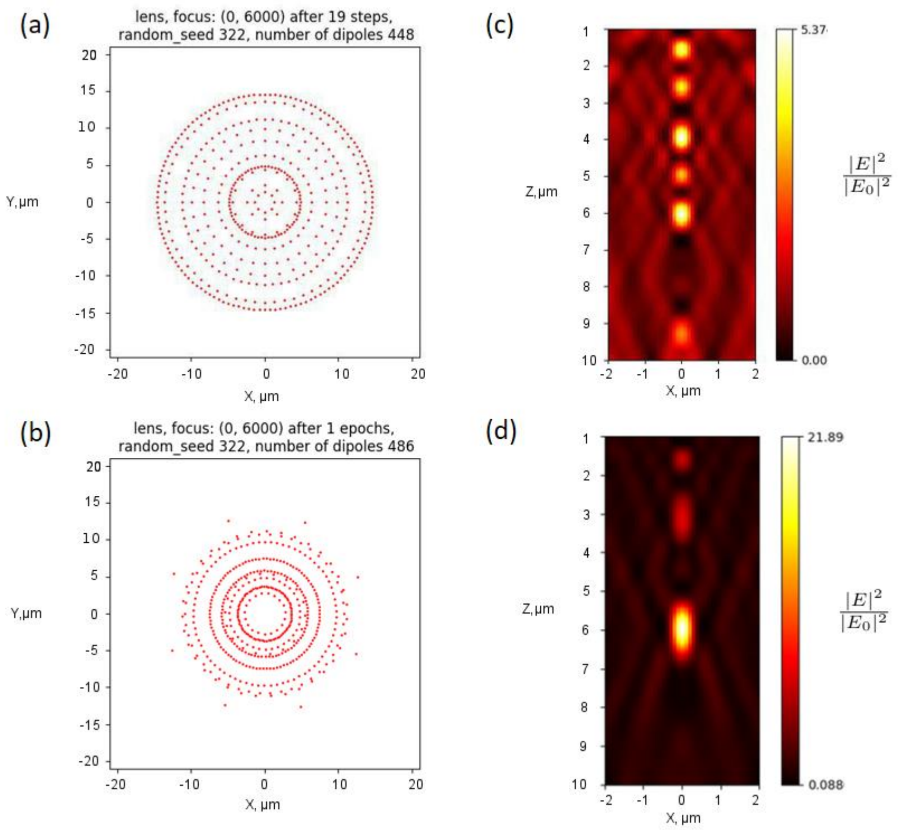

Figure 1 (a, b) Optimized metalens' designs with focus length equals 6 um. (c, d) Maps of normalized electric field intensity in the region close to metalens position. Z coordinate corresponds to the distance to metalens plane. (a, c) Results are obtained with evolutionary algorithm; (b, d) Results are obtained with genetic algorithm.

In further work we will consider more complicated structure taken into account higher order multipoles of meta-atom and consider efficiency of both type of algorithms in details. Also we consider more optimization functions such as half-width of focal spot, parasitic scattering and so on. This leads to construct effective metalens in visible range to focus the light at the subwavelength area.

Acknowledgements
The work was supported by the Ministry of Science and Higher Education of the Russian Federation (project No. 16.12780.2018/12.2). The authors would like to thank Maxim Buzdalov for his feedback.

References
[1] Veselago V G 1968 *Sov. Phys. USPEKHI* **10** 4 pp. 509–514
[2] Pendry J B 2000 *Phys. Rev. Lett.* **85** 18 pp. 3966-3969
[3] Soukoulis C M 2000 *NATO-ASI, Photonic Cryst. Light Localization*
[4] Smith D R and Kroll N 2000 *Phys. Rev. Lett.* **85** 14 pp. 2933-2936
[5] Ni X, Ishii S, Kildishev A V and Shalaev V M 2013 *Light Sci. Appl.* **2** e72
[6] Khorasaninejad M and Capasso F 2017 *Science*, ***358*** 6367 eaam8100
[7] Chen B H, Wu P C, Su V C, Lai Y C, Chu C H, Lee I C, Chen J-W, Chen Y H, Lan Y-C, Kuan C-H and Tsai D P (2017). GaN metalens for pixel-level full-color routing at visible light. *Nano letters*, *17*(10), 6345-6352.
[8] Vikhar P A 2016 *Proceedings of the 2016 International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC)* pp. 261-265