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# طراحی و شبیه سازی لنز دو کانونه بر اساس فراسطوح دی‌الکتریک

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**چکیده- در این پژوهش به طراحی و شبیه‌سازی یک لنز تک و دوکانونه با استفاده از فراسطوح در طول موج ۷۰۰ نانومتر پرداخته‌ایم. فراسطوح شکل دو بعدی فراواد حجیم می‌باشند که از مجموعه‌ای از تشدیدگرها تشکیل شده‌اند. برای کاهش تلفات تابشی در فراسطح و همچنین افزایش بازده لنز طراحی شده از تشدیدگر دی‌الکتریک سیلیکون در طول موج ۷۰۰ نانومتر استفاده گردید. در این نوع فراسطوح تحریک تشدیدها بر اساس جریان‌های جابجایی انجام می‌گردد. در پایان برای دستیابی به دو ناحیه کانونی یک مدولاسیون فاز روی چیدمان تشدیدگرها اعمال گردید.**

**کلید واژه**- تشدیدگر دی الکتریک، فراسطوح، فرالنز دوکانونه، مدولاسیون فاز

# Design and Simulation of a Bifocal lens based on Dielectric Metasurface

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**Abstract-** In this paper, we design and simulate a single and a bifocal lens at the wavelength of 700 nm. Metasurfaces are 2-D form of bulky metamaterials which consist of an array of resonators. To reduce the radiative loss and enhancement of efficiency, we take advantage of dielectric resonators such as Silicon. In these constitutions, the resonance modes excited by means of displacement currents. Finally, to focus the incident light at two different areas, a phase modulation has been applied on the arrangement of resonators.

Keywords: Dielectric resonator, Metasurface, Bifocal lens, Phase Modulation

## 1. Introduction

Optical metasurfaces are two-dimensional form of metamaterials composed of metal or dielectric subwavelength resonators. These ultra-thin flat surfaces manipulate the wave front by local controlling of the phase, amplitude and polarization with subwavelength spatial resolution [1]. Nowadays, unlike the metallic metasurfaces, the dielectric counterparts have been gained remarkable attention due to their low loss nature at the visible and infrared frequencies. The flat nature of high efficient metasurfaces open up new possibilities for integration of optical chips [2].

It has been demonstrated that Silicon metaatoms as a constitutional element enhance the efficiency of metasurfaces at infrared wavelengths and can be fabricated in one lithographic step. In addition, it is appreciably compatible with the complementary metal oxide semiconductor (CMOS) [3, 4]. The main challenge of designing a high-performance metasurface for any application is providing 2π phase shifts by means of metaatoms. Silicon with high refractive index support different order of electric and magnetic Mie-type resonances in the optical spectral range. The spectral position of these localized resonances can be tuned by adjustment of resonator geometrical dimensions. More importantly, an overlapping between the first order of electric and magnetic resonances, Kerker condition, could be achieved by fine-tuning of metaatom dimensions. The overlapping of resonance modes results to a 2π phase shift together with near unit amplitude of transmitted wave through metaatoms [5–8].

In current study, we design and simulate a bifocal dielectric metalens by means of C-shaped Silicon metaatoms at the wavelength of 700 nm.

## 2. Structure

Schematic diagram of the unit cell is depicted in Fig1. The designed silicon metaatoms are placed on a silica layer. The metasurface are illuminated by the y-polarized incident light from the substrate side and the transmitted light will be investigated at free space. In this study, all simulations are performed by full wave analysis considering finite difference time domain method and the dielectric constant of silica and silicon are extracted from [9]. The periodicity of unit cell is set to be P=360 nm and the thickness of C-shaped resonator is considered t=200 nm. The opening angle, inner and outer radius of the C-shaped metaatoms are denoted by α, $R_i$ and $R_o$ in Figs. 1(a), 1(b) and 1(c). The distribution of phase and amplitude of y-component of transmitted electric field, through the C-shape mataatoms with a sweep over the geometrical parameters of $R_i$ and α and with fixed values of $R_0$=140nm, t=200nm and P=360 nm at λ = 700 nm are plotted in Fig. 1(d). The applied sweeps over $R_i$ and α are considered between the values of 0 to 135 nm and 0 to 160◦, respectively.

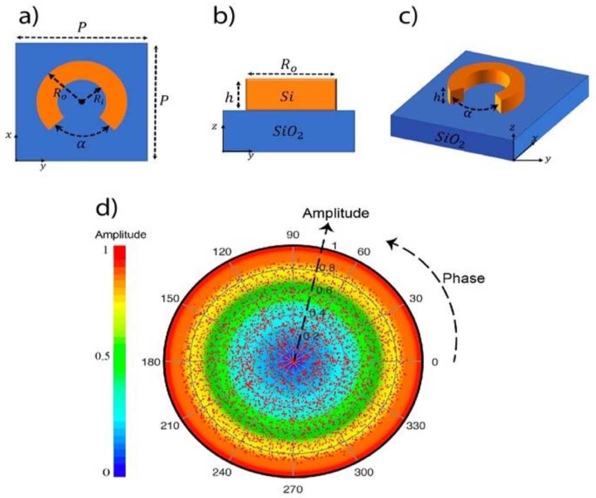


Fig. 1: (a) Top, (b) cross-sectional and (c) 3D view of unit cell. (d) The distribution of the phase and amplitude of transmitted light through C-shaped metaatoms as function of $R_i$ and α.

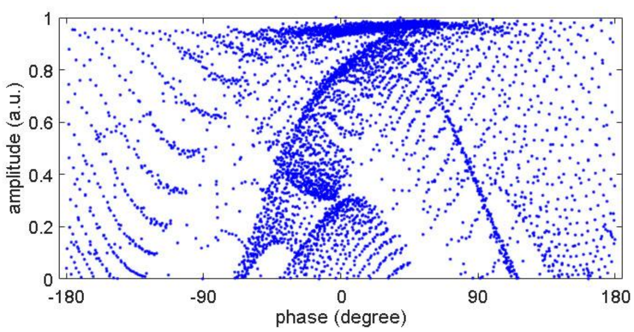


Fig. 2: The distribution of the phase and amplitude of transmitted light through C-shaped metaatoms as function of $R_i$ and α.

To clarify the amplitude and phase coverage of the different geometries of metaatoms we added Fig. 2. Fig. 3 shows the transmittance spectra of a unit cell with the fixed values of R0=140 nm, t=200 nm, P=360 nm, R0=85 nm and α=25 at λ = 700 nm. Two resonance dips are observed at transmittance spectra at $\lambda_1$=815 nm and $\lambda_2$=880 nm. To clarify the source of these resonance modes, the enhancement of electric and magnetic field has been studied. The insets in Fig. 3 reveal the excitation of magnetic dipole at $\lambda_1$ and electric dipole at $\lambda_2$.

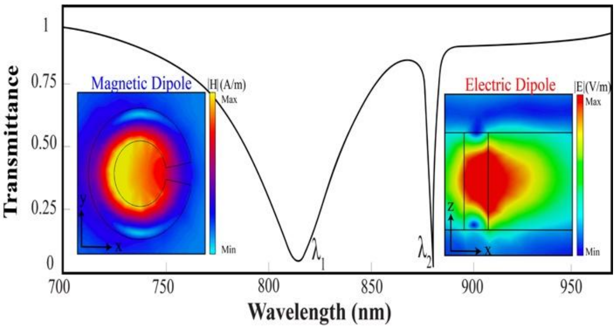


Fig. 3: Transmittance spectra of unit cell considering $R_0$=140 nm, t=200 nm, P=360 nm, $R_0$=85 nm and α=25 at λ = 700 nm. The insets show the excitation of magnetic dipole in x-y plane and electric dipole in x-z plane at $\lambda_1$ and $\lambda_2$, respectively.

## 3. Lens Design

To focus the incident plane wave, a phase profile similar to that of the conventional spherical lenses should be applied to the wave. To achieve such phase distribution, the relation between the rotational angle φ and the center of each CSRR should be governed by

$$\varphi(r) = \frac{2\pi}{\lambda}\left(\sqrt{r^2+f^2}-f\right), \qquad (1)$$

where f is the focal length, λ is the wavelength in the medium which light focuses (here, the silicon substrate with $\lambda = \lambda_0/n_{Si}$) and $\sqrt{r^2+f^2}$ denotes the distance between the C-shaped metaatoms and the focal point. A schematic of the meta-atoms arrangement along the x axis with the applied boundary conditions that surround the structure is plotted in Fig. 4. The structure is terminated by perfectly matched layers (PMLs) in the x direction and repeats itself along the y axis. Incident light illuminates the structure normally, in the z direction, with E $_y$-polarized electric field.

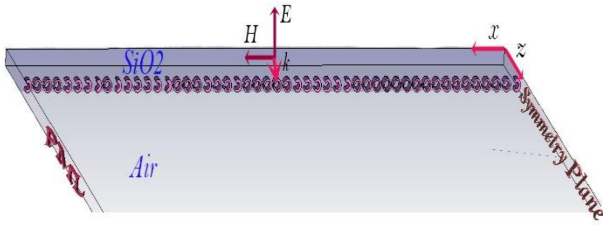


Fig. 4 Schematic design for AFA beam generation and the applied boundary conditions. Incident y-polarized light is propagating along the z axis.

To design a bifocal lens with two focal points at $f_1$ and $f_2$, with the correspond amplitudes of $a_1$ and $a_2$ have been considered. According to the Eq. (2) the proper metaatom, which has the nearest amplitude and phase to the a(x) and $\varphi(x)$, should be set at position x.

$$a(x)e^{i\varphi(x)} = a_1 e^{-i\frac{2\pi}{\lambda}\left(\sqrt{x^2+f_1^2}-f_1\right)} + a_2 e^{-i\frac{2\pi}{\lambda}\left(\sqrt{x^2+f_2^2}-f_2\right)}. \qquad (2)$$

Fig. 5 shows the FEM-based simulation of the lens performance. The field distribution of metalens with focal point of 15λ is shown in Fig. 5(a). Fig. 5(b) illustrates the electric field distribution of a bifocal lens. The focal points are set to be at $f_1$=10λ and $f_2$=15λ.

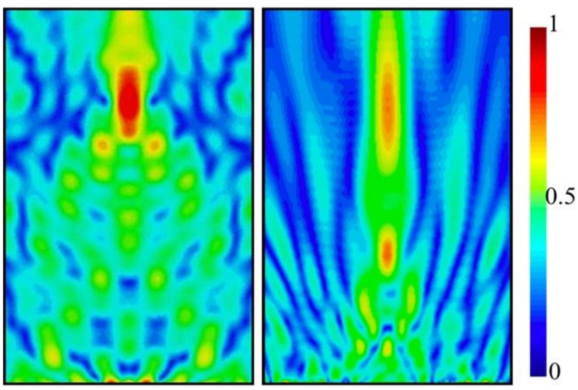


Fig. 5 The field distribution of y-component of electric field for a metalens with (a) the focal point at f=10λ and (b) two focal area at $f_1$=10λ and $f_2$=15λ.

## 4. Conclusion

Considering the phase discontinuity in the transmitted light through c-shape ring resonators, we designed a bifocal metalens. Our proposed metalens consists of a one-dimensional arrangement of metaatoms. We showed that our designed bifocal metalens works properly at the wavelength of 700 nm. Following this approach constitutes an effective step toward designing photonic devices in the visible frequency range. In addition, designing efficient multi focal lens provides a new possibility for bio applications and different type of spectroscopies.

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