Metalens for polarization conversion and focusing of laser light

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Abstract. We investigated 16-sector metalens that converts linearly polarized laser light to azimuthally polarized optical vortex and focuses the beam. It was shown that the metalens produces a focal spot with subwavelength diameters: FWHMₓ = 0.32λ and FWHMᵧ = 0.51λ (experiment) and FWHMₓ=0.37λ и FWHMᵧ=0.49λ (FDTD-simulation).

1. Introduction
A significant number of scientific papers is currently devoted to the investigation of metasurfaces – thin optical elements that simultaneously control amplitude, phase and polarization of propagated light [1-6]. Previously, we have investigated metalens, based on the subwavelength gratings and developed for generation cylindrical vector beams – beams with the direction of polarization having a radial symmetry [7]. Recently, the authors obtained theoretically an interesting optical effect – a backward flow of light energy in a tight focus [8-13]. This effect could be experimentally verified using metalenses.

This paper continues our investigations from [14,15]. In this work we have investigated a 16-sector metalens consisting of subwavelength gratings. The metalens converts linearly polarized light to an azimuthally polarized optical vortex and focuses it. Experimentally using scanning near-field optical microscope it was shown that the metalens forms a focal spot with diameters smaller than the diffraction limit: FWHMₓ = 0.32λ and FWHMᵧ = 0.51λ. The experimentally obtained values are close to the results of the numerical simulation (FDTD-method) of the manufactured metalens: FWHMₓ = 0.37λ and FWHMᵧ = 0.49λ.

2. Design of the metalens
The investigated metalens (Fig. 1) is a combination of a spiral Fresnel zone plate with a topological charge m = 1 and a sectorial subwavelength grating acting as a halfwaveplate. The lens consists from 16 radial sectors. Each sector rotates the polarization of incident light to produce the azimuthal polarization. Each sector is divided into sub-areas in the shape of a circular arc. The angle of the relief in neighboring areas within one sector is chosen so that the polarization of the light passing through them differs by π. Incident linearly polarized light transforms to focused azimuthally polarized optical vortex.
Period of the grating is equal to 220 nm, the depth of the relief is equal to 120 nm. The grating was designed to focus length with wavelength $\lambda=633\text{nm}$.

An electron microscope image of the manufactured metalens is shown in Fig. 2.

![Template of the metalens](image1.png)

![An electron microscope image of a spiral metalens in an a-Si film.](image2.png)

3. Experiment

The focusing by the fabricated metalens was investigated experimentally using scanning near-field optical microscope. In the experiment, a light beam from a He-Ne laser (wavelength 633 nm) illuminates the metalens. The intensity in the focal spot was measured using a hollow metallized pyramid-shaped probe having a 100-nm hole in the vertex. Fig 3 shows the experimentally measured intensity in the focal spot. Focal spot diameters were equal to $\text{FWHM}_x = 0.32\lambda$ and $\text{FWHM}_y = 0.51\lambda$.

![Experimentally measured intensity in the focal spot (a) and its sections along x-axis (b) and y-axis (c).](image3.png)

4. Numerical simulation

Numerical simulation was carried out using FDTD method implemented in the FullWave software. The simulations parameters were the follows: the wavelength was $\lambda=633\text{nm}$, the size of the simulated area was $8\times8\times2\ \mu\text{m}$, the simulation mesh step was $\lambda/30$. The index of refraction of metalens is $n=4.352+0.486\text{i}$ (amorphous silicon). Propagation of light through the manufactured relief shown on Fig. 2 was investigated. Focal length measured in the experiment was equal to 633 nm. Fig. 4 shows an intensity distribution in focal spot.

![An intensity distribution in focal spot.](image4.png)
The manufactured metalens forms elliptical focal spot with diameters of the focal spot smaller than the diffraction limit: \( \text{FWHM}_x = 0.37\lambda \) and \( \text{FWHM}_y = 0.49\lambda \).

**Figure 4.** Calculated intensity in the focal spot (a) and its sections along \( x \)-axis (b) and \( y \)-axis (c).

5. Conclusions

We have investigated 16-sector metalens that converts linearly polarized laser light to azimuthally polarized optical vortex and focuses the beam. It was shown that the metalens produces a focal spot with subwavelength diameters: \( \text{FWHM}_x = 0.32\lambda \) and \( \text{FWHM}_y = 0.51\lambda \) (experiment by SNOM) and \( \text{FWHM}_x = 0.37\lambda \) and \( \text{FWHM}_y = 0.49\lambda \) (FDTD-simulation).

6. References

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