Amplitude spiral zone plates for generation of optical vortices

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Introduction

Optical vortex beams [1] enabling a wide variety of applications such as measuring the localization and orientation of individual molecules, optical communication, materials processing, and magnetic field sensing [2]. Special optical elements have been used to produce vortex laser beams [3]. In this paper, by using the FDTD-method we study the formation of optical vortices by amplitude spiral zone plates (SZP).

Design of SZP and simulation parameters

The transmittance function:

$$T(r,\theta)=\exp\left[im\theta+ik\left(\sqrt{f^2+r^2}-f\right)\right]$$

where r and θ are polar coordinates, k is wave number, f is focal length.

The Sellmeiers permittivity model [4]:

$$\varepsilon_2(\lambda)=\varepsilon_\infty+\sum_m\frac{\Delta\varepsilon_m\lambda^2}{\lambda^2-\lambda_m^2-i\lambda\eta_m}$$

where λ is a wavelength; ε_∞ is the permittivity in the limit of infinite frequency; $\Delta\varepsilon_m$ is the resonance strength; λ_m is the resonant wavelength; η_m is the Sellmeier damping factor.

The Drude-Lorentz permittivity model [5]:

$$\varepsilon(\omega)=\varepsilon_\infty+\frac{\omega_p^2}{-2i\omega\nu-\omega^2}+\sum_m\frac{A_m\omega_m^2}{-\omega^2-2i\omega\delta_m+\omega_m^2}$$

where ω is a frequency; ν is the plasma frequency; ω_m is the collision frequency; A_m is the resonance strength; δ_m is the damping factor; ω_m is the resonant frequency.

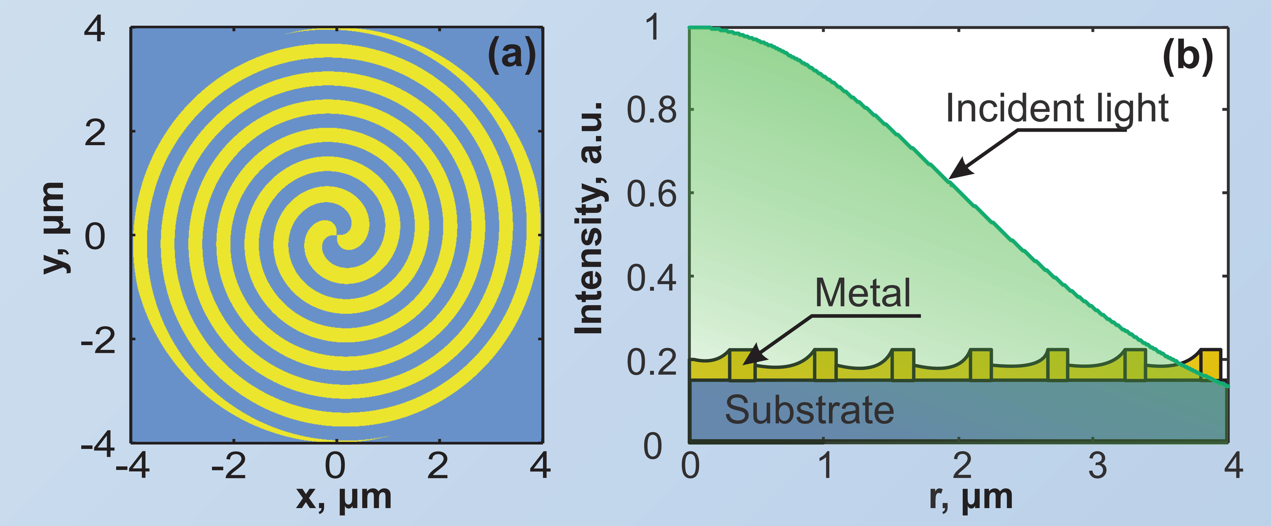

Fig 1. The template of SZP in a transverse (a) and a longitudinal (b) plane

The computation was conducted using FDTD-method at a 15 nm and 10 nm step along transverse and longitudinal coordinates. Temporal step cΔt was chosen equal to 7 nm.

Formation of optical vortex

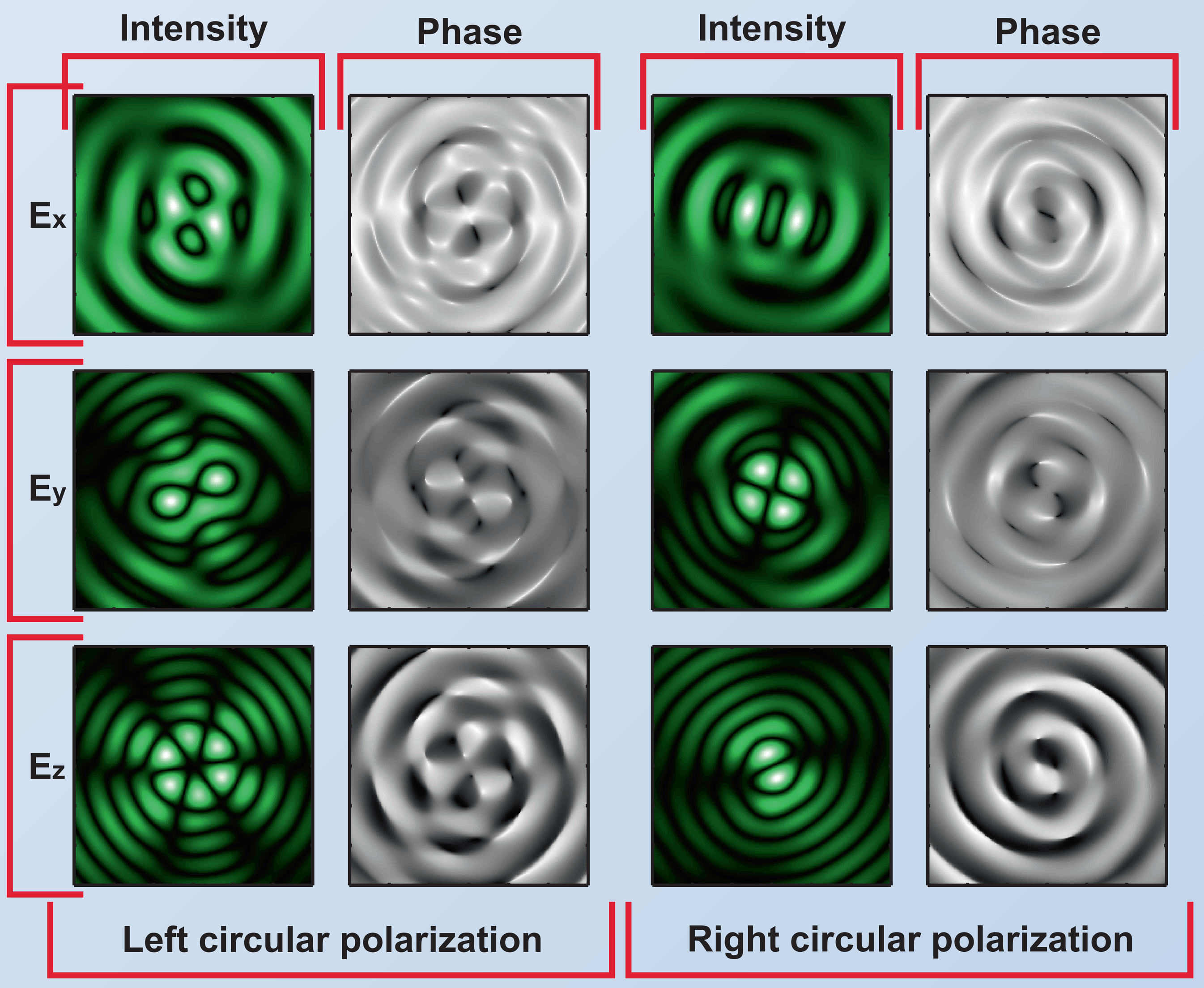

Fig 2. Amplitude and phase distribution of electric field vector components for optical vortex

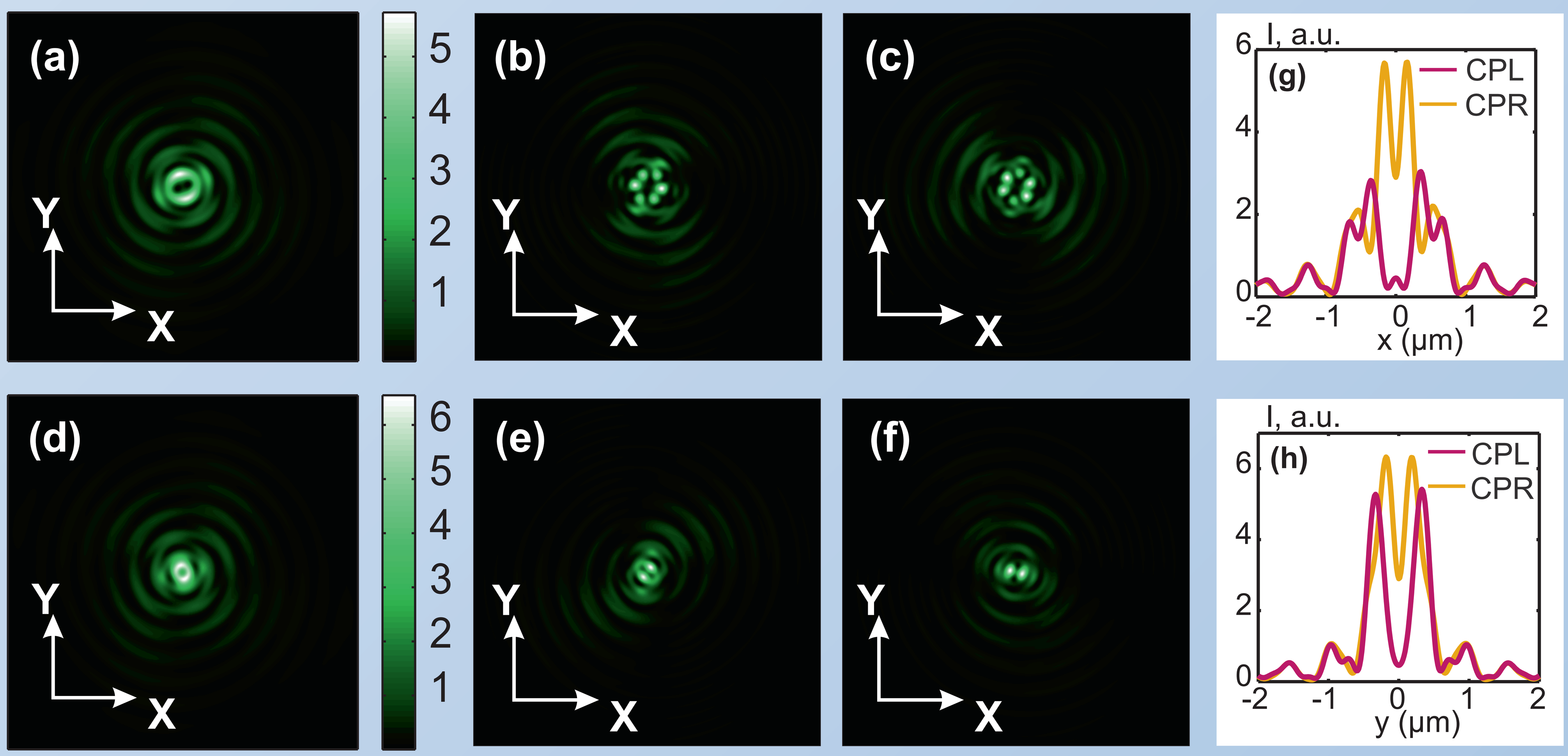

Fig 3. Simulation results: 2D average (a,d) and simultaneous (b,c,e,f) intensity for incident light with LCP (a-c) and RCP (d-f); 1D intensity distribution at the focus of the amplitude SZP aolg the transverse coordinates at y = 0 (g) and x = 0 (h)

Formation of backflow

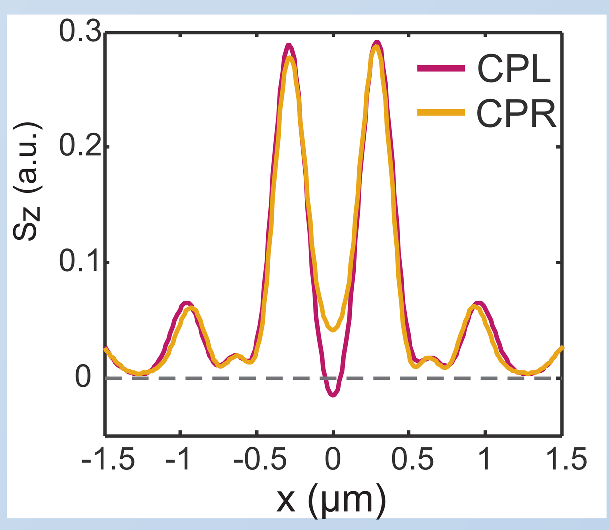

Fig 4. Distribution of the longitudinal component of Umov-Poiting vector Sz in the focal plane

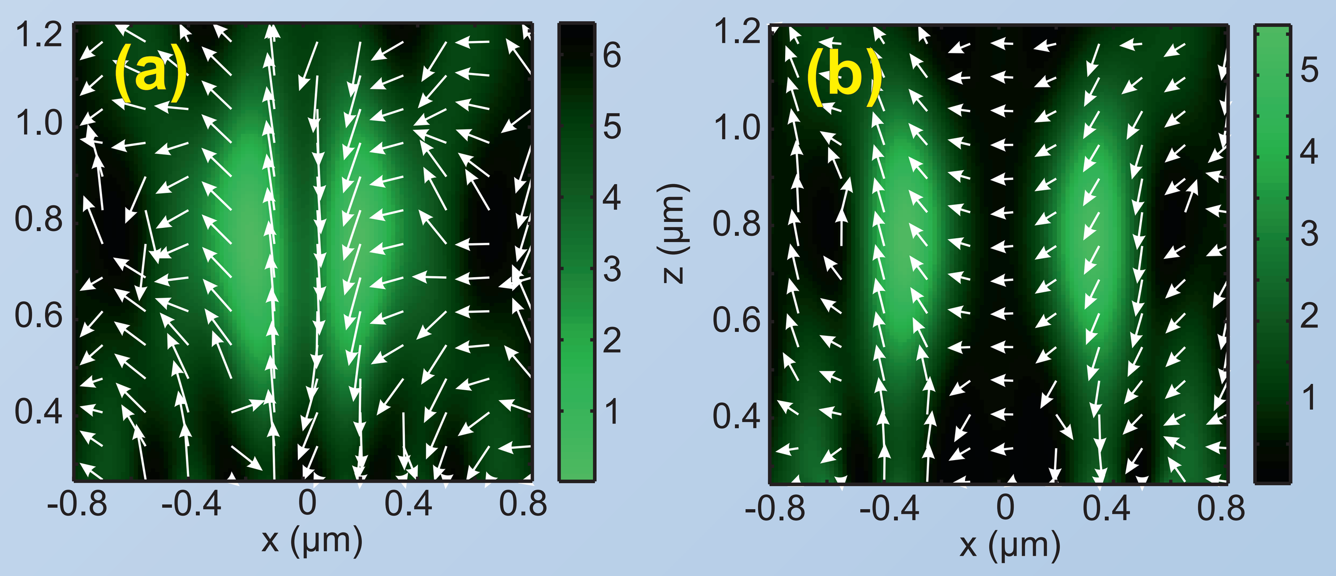

Fig 5. Directions of the Umov-Poynting vector in the XZ plane while focusing incident Gaussian baem with RCP (a) and LCP (b)

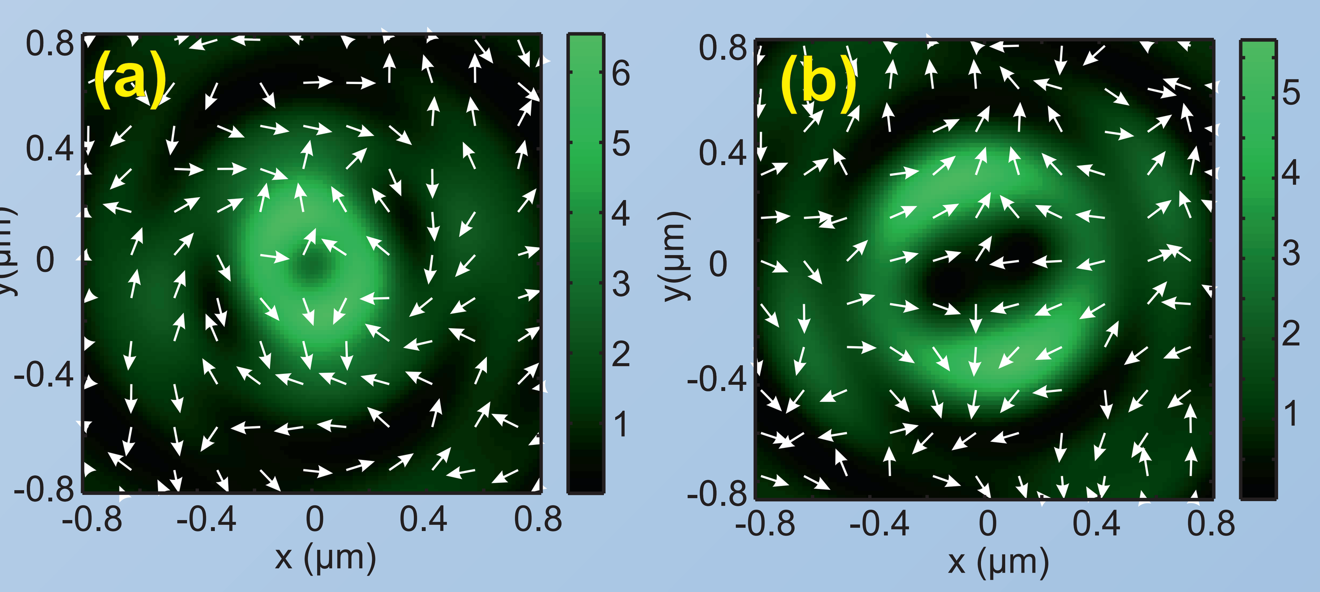

Fig 6. Directions of the Umov-Poynting vector in the focal XY plane while focusing incident Gaussian baem with RCP (a) and LCP (b)

Conclusion

In this paper generation of optical vortices by silver SZP is investigated by using (FD)2TD-method implemented in FullWAVE. Gausian laser beams with left and right circular polarization and wavelength of 532 nm is used as incident light. Phase and amplitude of each electric field vector component was calculated for analysis of simulation results. It is shown that silver SZP allows to generate optical vortices with maximal intensity 6 times higher than intensity of incident light. Ananlysis of Umov-Pointing vector shows presence of reverse energy flow in the focus.

Acknowledgement

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References

[1] K. Kitamura, M. Kitazawa, and S. Noda, Opt. Express 27(2), 1045 (2019)
[2] M.P.J. Lavery, C. Peuntinger, K. Gunthner, P. Banzer, D. Elser, R.W. Boyd, M.J. Padgett, C. Marquardt, G. Leuchs, Sci. Adv. 3(10), e1700552 (2017)
[3]K. Ou,G. Li,T. Li, H. Yang, F. Yu, J. Chen, Z. Zhao, G. Cao, X. Chen, W. Lua, Nanoscale 10, 19154 (2018).
[4] A. Couairon, L. Sudrie, M. Franco, B. Prade, and A. Mysyrowicz, Phys. Rev. B., V. 71(12), 125435 (2005)
[5] A. Vial, T. Laroche, M. Dridi, and L. Le Cunff, Appl. Phys. A., V. 103(3), 849 (2011)

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