Generation of Light Transverse Spin with a Vectorial Field Controlling Metasurface

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Abstract: We demonstrate the direct generation of focused transverse spin of light with a metasurface fully controlling the vectorial properties of the transmitted light field through sub-wavelength pixelized manipulation of phase, polarization, and amplitude independently.

1. Introduction

Light's spin and optical angular momentum properties have been extensively investigated recently due to their various applications in photonics, plasmonics, optomechanics, and quantum optics. Transverse spin is an angular momentum orthogonal to the propagation direction of light, having very different physical properties. [1] Naturally, transverse spin does not appear within paraxial approximation, but it can be observed in focused light beams and evanescent waves; however, strong transverse spin in focused beams only appears aside from a focal point. [2, 3] Hence, special optics capable of fully controlling the vectorial light field would be required to freely generate transverse spin at any desired position.

In order to manipulate the transverse spin of light, we need to create an asymmetric field distribution in a device plane, which is not possible using simple conventional optics. However, a metasurface can be designed to cover this gap. Metasurfaces are well-known for tailoring light properties, such as phase, polarization, and amplitude, with subwavelength pixel resolution. To date, such properties have been widely used to create metalenses, holograms, polarization converters, beam splitters, imaging optics, and multifunctional devices. [4–8] Here we developed a metasurface that can control phase, polarization, and amplitude independently, allowing us to fully manipulate the vectorial light field. Through proper phase distributions provided by the metasurface, we are able to focus light at a designated spot like a metalens; simultaneously, by controlling spatial variant polarization and amplitude distributions, we can generate the transverse spin right at its focal spot.

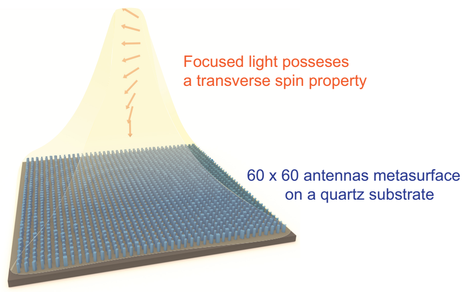

Fig. 1. An artistic illustration showing a metasurface that simultaneously focuses light and generates transverse light spin (shown by red arrows) in the middle of its focus spot.

2. Results and Discussion

We exploited Dyadic Green's function to analytically calculate and map the complex electric fields needed to create a pronounced transverse spin in a point corresponding to the maximum intensity of a focused beam. The electric field phase can be controlled in the entire 2π range by changing the geometrical cross-section of nanoantennas, while polarization can be assessed by changing a rotation angle. We optimize the amplitude and phase of both x- and y- electric field components for each spatial point. Each spatial point was correlated with a meta-atom from a library, which we established using full-wave simulations beforehand. We used amorphous nano-cuboid antennas for our meta-atom library. We vary the length and width of the nano-cuboids in order to get various phase and amplitude responses from the meta-atoms. In addition, we also incorporate the rotation of each nano-cuboid to obtain different polarization responses. Jones matrix calculus was exploited to represent this complex optical response of each meta-atom. Figure 2 shows the map of electric field components and their phases leading to a strong spin along y-direction in a focal point.

As a demonstration, we chose a device size of 30 μm and a focal length of 10 μm, with a lattice constant of 500 nm. The metasurface consists of 3600 meta-atoms in a 60 $\times$ 60 grid. Figure 3 shows a close-up view of predicted transverse spins along x- and y- direction in the focal point and the ratio between the transverse spin in the y-direction and the longitudinal spin in the z-direction.

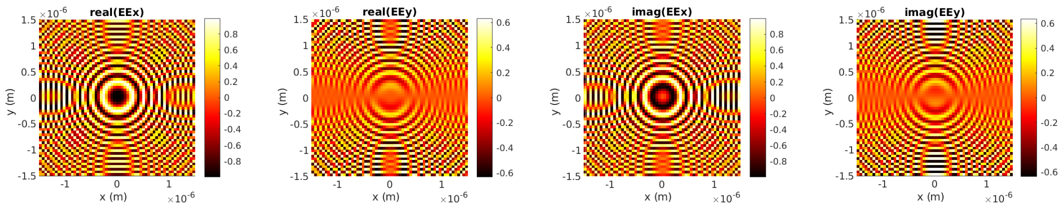

Fig. 2. Mapped real and imaginary parts of the electric field in the metasurface plane predicted to create a pronounced transverse spin in the y-direction in the focal point.

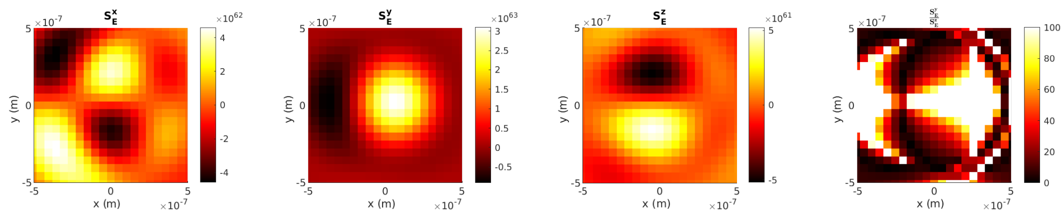

Fig. 3. Close-up views of spin distributions in the focal point of our metasurface and the ratio between absolute values of y- and z- spins.

After point-by-point optimization we designed a metasurface to mimic desired spatial distribution of an electric field. Full-wave simulations with the finite difference time domain method showed that transverse spin distribution is in good agreement with our theoretically predicted values. We can clearly see the pronounced transverse spin in the y-direction (S_E^y) in the middle of the designated focus spot. Moreover, the transverse spin is more than two orders of magnitude larger than the longitudinal spin in the z-direction (S_E^z) (Fig. 3). Experimental measurements of transverse spin will be conducted by measuring k-space scattering intensity of light with transverse spin properties. [2]

The opportunity to tailor a transverse spin on-demand can be further used in optomechanics and quantum optics.

References

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