Converting between circularly polarized waves and longitudinal fields with an individual plasmonic nanohelix

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Abstract:
A wide variety of optical applications and techniques require control of light polarization. So far, the manipulation of light polarization relies on components capable of interchanging two polarization states of the transverse field of a propagating wave (e.g., linear to circular polarizations, and vice versa). Here, we demonstrate that an individual helical nanoantenna is capable of locally converting longitudinally-polarized confined near-fields into a circularly polarized freely propagating wave, and vice versa, over a broad spectral range.

I. INTRODUCTION

Controlling the polarization vector of light provides a key approach to manipulating light-matter interaction on the nanoscale. In turn, tailoring the local optical response of subwavelength structures brings new prospects to light polarization control. Recent advances in plasmonics and metamaterials led to numerous novel polarization systems combining the merits of high compactness, broadband operation and new functionalities [1]. So far, polarization control mainly refers to the transverse vector components of a propagating light wave. At small scale however, the 3D nature of light cannot be avoided and a longitudinal optical component arises and can even become dominant for strongly confined fields [2]. Here, we demonstrate the polarization properties of a single plasmonic helix positioned in a nonradiative plasmonic focus showing dominant longitudinal electric field component (perpendicular to the focusing plane, parallel to the helix axis). So far, helical nanoantennas were excited with transversely polarized propagating waves. Here, we study the polarization properties of a single plasmonic helix positioned in a nonradiative plasmonic focus showing dominant longitudinal electric field component (perpendicular to the focusing plane, parallel to the helix axis)[4].

II. RESULTS

We positioned a helical nanoantenna at the center of a circular slit which perforates a thin gold film on a glass substrate (Fig. 1(a)). The nanoantenna consists of a left-handed four-turn gold-coated carbon helix (core-shell structure [3, 4]) lying on a 100-nm cylindrical pedestal. Two helix configurations, with a varying or constant pitch, are fabricated (see Figs. 1(b) and (c), respectively). The circular slit is 16-μm in diameter and 200-nm wide.

To demonstrate the generation of circular polarization from a longitudinal electric light field, we project a focused radially polarized beam onto the back of our sample. We then image the overall structure in the far-field with a microscope objective coupled to an infrared camera. The polarization state of the emerging light is analyzed with a rotating quarter-wave plate followed by a linear polarizer (i.e., a circular analyzer). Without circular analyzer, the image shows an individual spot at the center

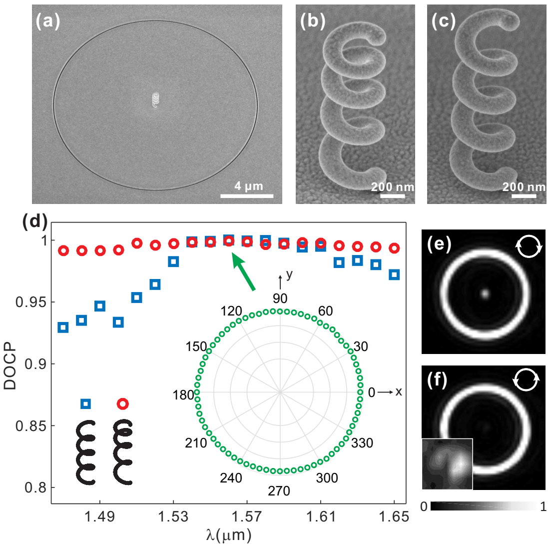

Fig. 1: (a) SEM image of a fabricated platform. (b) and (c) SEM images of two plasmonic helices of varying and constant pitch length, respectively. (d) On-axis DOCP spectra of the outcoming optical waves obtained with helical nanoantennas of homogeneous and varying pitches. (e) and (f) Optical images obtained at λ= 1.56 μm with the varying-pitch helical nanoantenna after inserting (e) a left-handed and (f) a right-handed circular analyzer in front of the camera. Image size: 25 × 25 μm^2.

of a 16-μm diameter narrow light ring. The ring pattern corresponds to the direct transmission of the impinging light through the circular slit. The spot located at the center of the bright ring corresponds to the light released by the helical nanoantenna. When the circular analyzer is inserted in front of the camera, the central spot is visible only when the analyzer selectively transmits left circular polarization (see Figs. 1(e) and (f)).

The spectral properties of the helix are investigated by measuring the on-axis degree of circular polarization (DOCP) of the leaving optical waves as a function of the wavelength. Being equal to the absolute value of the normalized stokes parameter S_3/S_0, the DOCP is defined as $|I_{RCP}-I_{LCP}|/(I_{RCP}+I_{LCP})$ where I_{RCP} and I_{LCP} are the intensities of the right and left-handed circularly polarized components of the outcoming light, respectively. For the helix of a constant pitch, the DOCP remains larger than 0.99 within a wavelength range of 80 nm. By breaking the helix periodicity, i.e., by using the varying-pitch helix, we extend the spectral invariance of the nanoantenna to a broader wavelength range exceeding the 180-nm bandwidth of our laser. We estimate that the efficiency with which the constant and varying-pitch helices convert incoming surface plasmons into freely propagating waves reaches 26% and 24%, respectively.

We also demonstrate the reciprocal configuration of incoming circularly polarized waves converted back into longitudinal fields [4].

III. CONCLUSION

We demonstrate an individual helical nanoantenna to convert between the circular polarization of a freely propagating wave and longitudinal electric fields in the near-field, thus providing a new degree of freedom in light polarization control. Being non-resonant, the helical nanoantenna operates over a broad spectral range.

References

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