Subwavelength Polarization Optics Using Helical Travelling-Wave Nanoantennas

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Abstract **– We present and demonstrate the concept of a helical travelling-wave nanoantenna (HTN) consisting of a tiny gold-coated helix end-fired with a rectangular aperture nanoantenna. The resulting non-resonant nano-antenna produces a background-free directional light beam of tunable polarization and intensity by swirling surface plasmons and taking advantage of optical spin-orbit interaction. Taken as individual or coupled nanostructures, HTNs lead to subwavelength polarization optics and provide new degrees of freedom in light polarization control.**

I. INTRODUCTION

A wide variety of optical applications and techniques demand control of light polarization. Manipulation of light polarization has recently experienced extraordinary advances with the emergence of plasmonics, leading to the concepts of polarization meta-optics [1]-[4]. However, all the structures developed so far rely on collective optical effects on arrays of nanostructures. They are therefore restricted to areas much larger than the wavelength of light, which limits design strategies in polarization control. Tailoring light with individual subwavelength devices would overcome limits but it remains a challenge [5], [6].

On the basis of spin-orbit interaction of light [7], we have generated a helical travelling-wave nanoantenna to produce directional light beam of tunable polarization through a swirling plasmonic effect. Our optical nanoantenna differs from existing helical plasmonic structures [1], [8] by its non-resonant nature, thus extending the concept of helical travelling-wave antenna to optics [9]. Four closely packed HTNs are shown to locally convert an incoming light beam into four beams of tunable polarizations and intensities. Moreover, by coupling HTNs of opposite handedness, we demonstrated a subwavelength waveplate-like structure providing a degree of freedom in polarization control that is forbidden with usual polarization optics and metamaterials.

II. RESULTS AND DISCUSSION

The HTN consists of a narrow gold-coated wire wound up in a screw-like shape forming a tiny helix (Fig. 1a). The gold-coated wire sustains a cutoff-free axially symmetric travelling SP, known as the TM0 mode. It is locally excited with the dipolar mode of a rectangular aperture nanoantenna that perforates a 100 nm thick gold layer right at the helix's pedestal. An incident wave on the back of the aperture is transmitted as a subdiffraction guided SP, which is non-radiatively converted into the wire mode of the helix. The nanoscale wire mode is non-resonantly converted into the helix-guided mode spreading over the overall structure cross-section and propagating along the helix axis. In the course of propagation, the helix-guided mode acquires OAM oriented along the helix axis (0z).

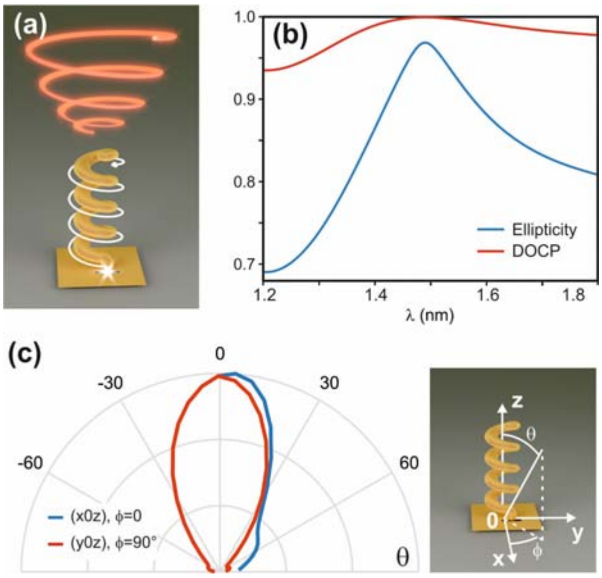

Fig. 1. (a) Schematics of the HTN and its operation principle. (b) Spectra of the ellipticity factor and DOCP of the HTN output beam. They reveal the tunable polarization properties of the nanoantenna. (c) Radiation pattern of the HTN in the polar angle θ measured in two orthogonal longitudinal planes (x0z) and (y0z) defined in the figure inset.

When circular polarization is generated by a HTN, this vortex mode (of charge ±1 depending on the helix handedness) is released as freely propagating waves carrying SAM of ±1 per photon (in ħ units). A HTN designed to operate as a circular polarizer at λ=1.5 µm has been predicted to radiate light with a polarization ellipticity and a degree of circular polarization peaking at 0.97 and 0.999, respectively (Fig. 1b). The polarization can be tuned either by tuning the operation wavelength or by modifying the geometrical parameters of the helix. The waveguiding properties of the plasmonic helix allows for producing directional beam: our nanoantenna of λ/3 lateral size produces an emission pattern whose full width at half-maximum approaches 55° (Fig. 1(c)).

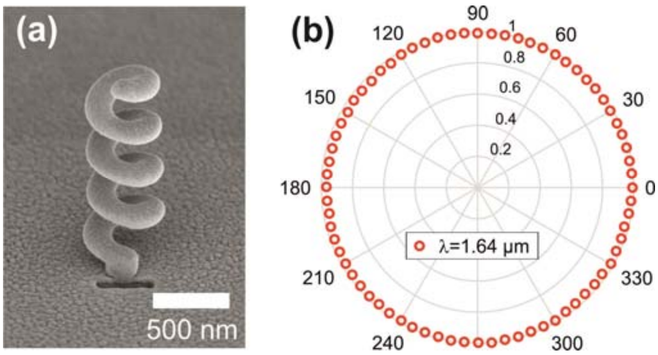

Fig. 2. (a) Scanning electron micrograph of a fabricated HTN. (b) Experimental polarization diagram of the HTN at λ = 1.64 µm.

The antennas were fabricated by combining focused-ion-beam-induced deposition, metal coating and focused ion beam milling. Fig. 2(a) shows a scanning electron micrograph of a resulting structure. The HTNs were back-illuminated with polarized light from a tunable laser at telecommunication wavelengths, the nanoantenna output beams were measured and their polarization states were analysed with a rotating linear polarizer. The observed polarization properties (Fig. 2b) agree well with the theoretical model, with an ellipticity factor peaking at 0.97.

First, we showed that HTNs arranged at will on a surface locally convert an incoming light beam into an arbitrary distribution of directional beams of tunable polarizations and intensities. Different polarization states are here imparted to the output beams in a controllable and tunable way. Second, by near-field coupling four HTNs of opposite handedness, we obtained a subwavelength waveplate-like structure providing a degree of freedom in polarization control that is forbidden with ordinary polarization optics and current metamaterials (i.e., devices utilizing or artificially reproducing birefringence and dichroism).

III. Conclusion

Relying on spin-orbit interaction of light, HTNs lead to ultracompact, versatile and robust individual components for manipulating light polarization on the subwavelength scale. They provide functionalities in light polarization control that have never previously been demonstrated. Taken as individual or coupled nanostructures, such nanoantennas may pave the way towards highly integrated polarization-encoded optics, particularly for the generation and control of spin-encoded photon qubits in quantum information and opto-spintronics. More generally, our results lay a solid basis for subwavelength polarization optics, thus opening new perspectives in photonic information processing, polarimetry, miniaturized displays, optomagnetic data storage, microscopy, sensing and communications, etc.

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