Resolving light spin via angular-to-linear moment conversion in a silicon microdisk nanoantenna

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Abstract (Arial 10)
It has been recently shown that the propagation direction of guided waves can be properly selected just by using as an excitation source a circularly-polarized dipole put in close proximity to a waveguide [1]. Although in Ref. [1] the concept was experimentally demonstrated for plasmonic waves (visible wavelengths), it can be extended to other kinds of waveguides and technological platform. In this work, we have used this concept to demonstrate experimentally at telecom wavelengths that a silicon microdisk nanoantenna can resolve the handedness (or spin) of an incoming light.

The idea is briefly sketched in Fig. 1. A circular microdisk resonator is known to support resonant whispering gallery modes displaying angular momenta given by $\pm l\hbar$, where *l* is the azimuthal number. Unlike higher-order modes that can display ultrahigh Q factors, the fundamental mode (*l*=1), which is essentially a dipolar resonance, is highly radiative. Under normal incidence with circularly polarized light (CPL), one of the two degenerate fundamental modes, with an angular momentum per photon equal to $+\hbar$ (for left-handed circular polarization, LCP) or $-\hbar$ (for right-handed circular polarization, RCP), is excited. This means that there is an angular momentum transfer and match between the incoming CPL light beam and the microdisk nanoantenna.

Now let us consider that the microdisk nanoantenna is implemented on a silicon photonics platform close to a waveguide. It is well known that the resonant modes of a microdisk can be excited on-chip by introducing light through an optical waveguide which at some point is in close proximity to the microdisk, and the direction of propagation of light along the waveguide (or the direction of the linear momentum of the guided photons) will define the direction of rotation of the fields inside the microdisk at the resonance frequencies, due to local phase matching in the interacting region, and as a consequence, will define the sign of the excited angular momentum. In accordance to reciprocity, the reverse approach is also true: if a given resonance in the microdisk is excited from free space using CPL, part of the angular momentum transferred to the microdisk will be finally converted into linear momentum, which will result in light propagation along one or another direction of the waveguide depending on the handedness of incident light. Such unidirectional excitation of waveguided modes depending on the handedness of the microdisk resonant mode can also be easily interpreted as near-field interference, which inspired us to pursue this result. Therefore, the device will be capable of discerning between LCP and RCP without employing chiral structures. Notice that the placement of the microdisk with respect to the waveguide will determine the sorting direction of each handedness. The x-asymmetry achieved in the amplitude of excitation of the two waveguide outputs is only possible thanks to the broken y-symmetry in the full (microdisk + waveguide) structure, which constitutes a fundamental requirement of this approach.

Experimental results are in close agreement to numerical results which predict an extinction ratio over 18 dB in a 20 nm bandwidth, which by far outperforms other approaches for resolving light spin. Importantly, the device is reciprocal, so in a transmitting configuration it can radiate right or left circular polarization depending on the chosen feeding waveguide chosen.

This work complements the results shown in Ref. [2] in which a rectangular nanoantenna was used to sort linearly polarized photons. As in Ref. [2], feeding by both input waveguides simultaneously our device can generate any polarization state on the Poincaré sphere [3], which could be a disruptive step in the field of optical nanoantennas.

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References

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Figures

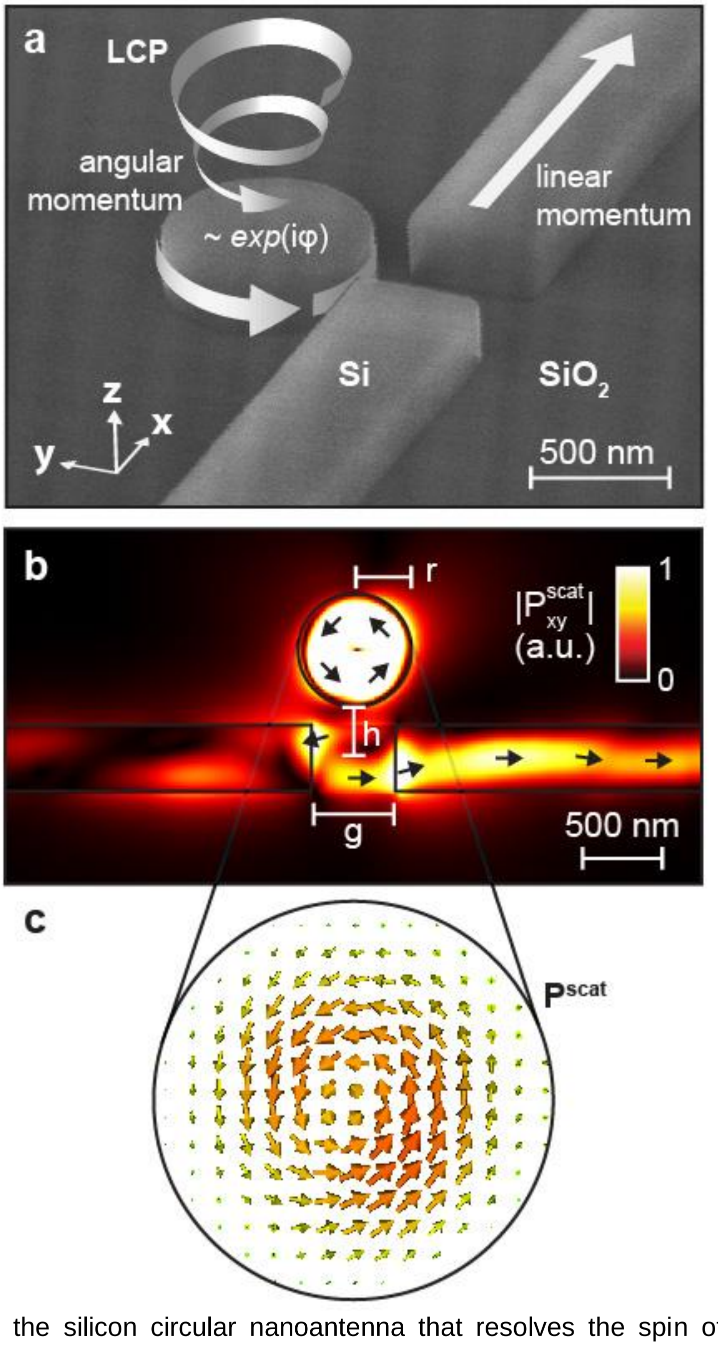

Figure 1. Scheme of the silicon circular nanoantenna that resolves the spin of a normally incident circularly polarized light beam. (a) Scanning electron microscope (SEM) image of the fabricated microdisk and silicon waveguide, annotated with arrows describing the fundamental idea of this approach. (b) Magnitude of the in-plane component of the Poynting vector of the scattered fields in the midplane of the silicon structure when a left-handed circularly polarized (LCP) plane wave is incident (scattering is obtained by subtraction of the background fields in a straight waveguide to the total fields obtained in numerical simulations), and (c) a vector plot of the Poynting vector of the scattered fields in the midplane inside the nanodisk. It is evident from symmetry that an incident right-handed circularly polarized (RCP) wave will excite the microdisk and waveguide with an x-mirror-symmetry, directing the light into the left output waveguide.