Plasmonic resonance scattering from silver nanowire illuminated by tightly focused singular beam

Alexander Normatov, * Boris Spektor, Yehuda Leviatan, and Joseph Shamir
Department of Electrical Engineering, Technion—Israel Institute of Technology, Technion City, Haifa 32000, Israel
*Corresponding author: alexn@tx.technion.ac.il

Received May 24, 2010; accepted July 2, 2010; posted July 20, 2010 (Doc. ID 128898); published August 10, 2010

We investigate scattering features of tightly focused singular beams by placing a cylindrical nanowire in the vicinity of a line phase singularity. Applying an illumination wavelength corresponding to silver cylinder plasmonic resonance, we compare the scattering response with that of a perfect conductor. The rigorous modeling employs a 2D version of the Richards–Wolf focusing method and the source model technique. It is found that a cylinder with a plasmonic resonance produces a strong scattering response by deflecting the power flow toward the optical singularity region, where otherwise the power approaches zero. © 2010 Optical Society of America

OCIS codes: 200.3850, 240.6680, 050.4865.

Objects that are significantly smaller than a wavelength are known to produce a strong scattering response when illuminated at wavelengths corresponding to their plasmonic resonance [1,2]. The scattering properties of silver nanowires, which are considered in this work, have been thoroughly investigated as a function of their cross-sectional shape under plane-wave illumination (see, for example, [3] and references therein). In this Letter, we are concerned with the scattering of tightly focused beams containing wavefront dislocations [4], referred to here as singular beams. Scattering of focused beams by cylinders can be analyzed with the help of the generalized Lorentz–Mie theory, as in [5,6], where the focused beam is represented using basis functions that lend themselves to an analytical scattering solution. Alternately, one may evaluate first the tightly focused incident field distribution and then employ a numerical method, such as in [7], where the optical force on elliptic nanowires is investigated in a tightly focused Gaussian beam to derive the scattered field. A common feature of the indicated approach and many other investigations is that the scattering object is exposed to a significant incident power density. In contrast, our investigation deals with a situation where a nanowire is placed in a region where the density of the incident power flow, the Poynting vector, approaches zero. This region corresponds to the location of an optical singularity. Our results suggest that for the case of plasmonic resonance, the power flow is significantly altered, thus producing a strong impact on the scattered far field.

The optical system is schematically illustrated in Fig. 1. A line phase singularity is formed in an incident plane wave, propagating along the z axis, by means of a π phase step. The phase step is located at the entrance pupil of a focusing optical system with NA = 0.87. The tightly focused beam is scattered by a nanowire placed along the geometrical focal line O, parallel to the y axis. The scattering angle φ is measured in the x–z plane, relative to the positive direction of the z axis. The illumination wavelength of \( \lambda = 338 \) nm is chosen for silver cylinder resonance with corresponding \( \varepsilon_{Ag} = -1.07 + 0.29i \) and diameter 30 nm. This diameter is adequately small when compared to the focused field distribution, but large enough to allow us to neglect the dependence of the imaginary part of \( \varepsilon_{Ag} \) on the cylinder size [8]. We evaluate the tightly focused field impinging on the cylinder employing a modification of the rigorous Richards–Wolf focusing method [9]. The scattered field is calculated using the source model technique [10]. It must be noted that the incident illumination should be \( x \) polarized to excite plasmonic resonance in an infinitely long cylinder whose axis is parallel to the y axis. The real part of the Poynting vector of the incident, tightly focused field looks similar to Fig. 2. Actually, Fig. 2 shows the real part of the Poynting vector for the case of scattering by a perfectly conducting nanowire, placed in the waist region of the tightly focused singular beam. The perfect conductor is modeled by a dielectric constant with a large imaginary part, \( \text{Im}(\varepsilon_{PC}) \gg 1 \). Figure 3 shows the same situation as Fig. 2, with a silver nanowire of the same size. Figure 4 presents a magnification at the vicinity of the silver nanowire of Fig. 3. It is apparent from Fig. 4 that the resonant silver nanowire deflects the power flow, which is in turn either dissipated or reradiated. It must be noted that our evaluation did not take into account nonlinear effects. We tried to compare our results with the Poynting vector field structure, investigated under plane-wave illumination in [11], but unfortunately, the nature of the incident field was too different to yield a

![Fig. 1. (Color online) Optical system schematic.](image-url)