

Research Article

Elongated Photonic Nanojet from Truncated Cylindrical Zone Plate

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Previously (Chen et al., 2004), it was shown that dielectric cylinder can form focal spots with small diameters and long depth. This type of focal spot was called photonic nanojet. In this paper, it was shown that dielectric cylinder of radius 595 nm (1.12 of wavelength) forms near the surface a photonic nanojet with diameter equal to 0.31 of wavelength and depth of focus equal to 0.57 of wavelength. Adding truncated concentric rings with radiuses equal to radiuses of zone plate to the cylinder increases the depth of focus to 1.18 of the wavelength. The diameter and intensity of focal spot near the cylinder surface remain unchanged.

1. Introduction

One of the promising areas of research in nanophotonics is tight focus that is formed using dielectric cylinders or spheres with diameters about wavelength. This type of focal spot was called “photonic nanojet” [1]. Unique features of photonic nanojets are small diameter and low divergence of the beam.

The name “photonic nanojet” was for the first time used in [1]. In [2], photonic nanojet was formed using dielectric spheres with different diameters illuminated by plane wave ($\lambda = 400$ nm). Also in [2], it was shown that the spheres with diameters of $1\ \mu\text{m}$ and $2\ \mu\text{m}$ formed photonic nanojets with diameters in the plane perpendicular to the direction of incident polarization equal to 0.325λ and 0.375λ . In [3], photonic nanojet with the maximum intensity 150 times larger than the intensity of the incident beam was obtained. In [4] photonic nanojet was obtained experimentally using scanning confocal microscope. It was shown that latex sphere with diameter equals to $3\ \mu\text{m}$ forms focal spot with a diameter FWHM = 270 nm (the wavelength equals to 520 nm). The influence of incident light polarization was investigated in [5]. It was shown that radially polarized light formed photonic nanojet with effective focal volume 10 times smaller than the circularly polarized light. Photonic nanojet could be formed not only by spheres but by finite

or infinite cylinders. For instance, in [6] photonic nanojet formed by discs from silica nitride with width 400 nm and diameters from 1 to $10\ \mu\text{m}$ was obtained experimentally. The diffraction of light by multilayers cylinders was considered in [7]. Dielectric sphere with properly graded refractive index was used in [8] to increase the length of photonic nanojet. The length of a photonic nanojet formed by the graded-index microsphere can be increased to approximately 20 wavelengths.

2. Numerical Modeling

The diffraction of the TE-polarized plane wave was simulated using FDTD method [9] implemented in FullWAVE [10]. The mesh grid size in space was equal to $0.01\ \mu\text{m}$ (0.02 of wavelength), in time— $0.007\ \mu\text{m}/c$, where c is the velocity of light. Perfectly matched layers with width of $0.5\ \mu\text{m}$ were located on the borders of calculated area. TE-polarized plane wave ($\lambda = 532$ nm) was used as the incident wave.

3. Cylinder

First, we numerically investigate propagation of TE-polarized light throw 2D dielectric cylinder with radius $0.595\ \mu\text{m}$ and refractive index $n = 1.5$. Figure 1 depicts intensity

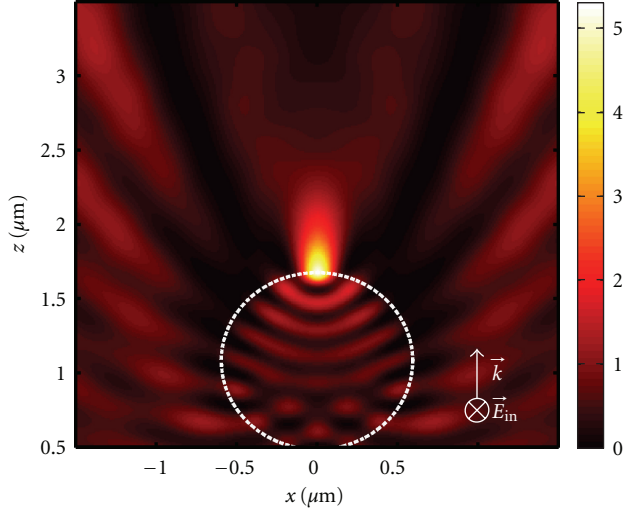


FIGURE 1: Intensity distribution in fragment of the calculated area for the dielectric cylinder with radius $0.595 \mu\text{m}$. White dashed line shows the cylinder border.

distribution in calculated area. Intensity distribution along z -axis is shown in Figure 2. From Figure 2 the depth of focus equals to $\text{DOF} = 0.57 \lambda$. Intensity distribution in focal plane is shown in Figure 3. Diameter of focal spot near the surface equals to $\text{FWHM} = 0.31 \lambda$. On the distance of $0.1 \mu\text{m}$ from cylinder surface, the diameter of focal spot equals to $\text{FWHM} = 0.38 \lambda$. Both diameters are smaller than the diffraction limit for 2D case ($\text{FWHM} = 0.44 \lambda$).

4. Truncated Cylindrical Zone Plate

To increase the depth of focus formed by dielectric cylinder, we used nonclosed concentric dielectric rings with refractive index $n = 1.5$. Radiuses of the rings were calculated using equation for Fresnel zone plate $r_m^2 = \lambda m f + \lambda^2 m^2 / 4$, where $f = 532 \text{ nm}$. 12 rings were added to the cylinder. Thus TE-polarized wave was focused by 2D truncated zone plate. Figure 4 depicts intensity distribution in calculated area. Intensity distribution along z -axis is shown in Figure 5. Figure 5 depicts that there are two peaks of intensity along z -axis. Diameter of focal spot near the surface is equal to $\text{FWHM} = 0.30 \lambda$ (Figure 6). But diameter of focal spot formed by truncated zone plate increases more rapidly than the focal spot formed by cylinder. On the distance of $0.1 \mu\text{m}$ from cylinder surface, the diameter of focal spot is equal to $\text{FWHM} = 0.40 \lambda$. The depth of focus is equal to $\text{DOF} = 1.18 \lambda$ and is two times larger than the depth of focus formed by cylinder. So adding of nonclosed concentric rings to the cylinder does not change the diameter of focal spot near the surface but increases the depth and divergence of the beam.

5. Conclusion

In this paper, it was shown that 2D dielectric cylinder ($n = 1.5$) with radius 1.12λ illuminated by TE-polarized plane wave ($\lambda = 532 \text{ nm}$) forms photonic nanojet with diameter

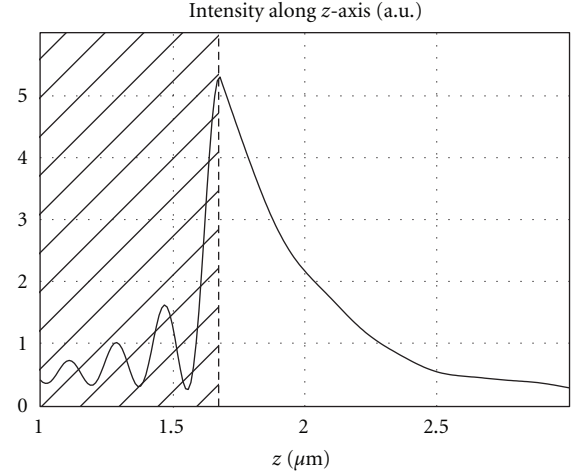


FIGURE 2: Intensity distribution along z -axis for the dielectric cylinder with radius $0.595 \mu\text{m}$.

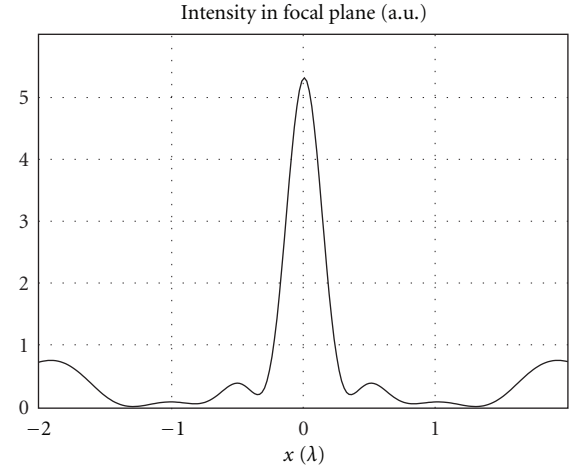


FIGURE 3: Intensity distribution in focal plane for the dielectric cylinder with radius $0.595 \mu\text{m}$.

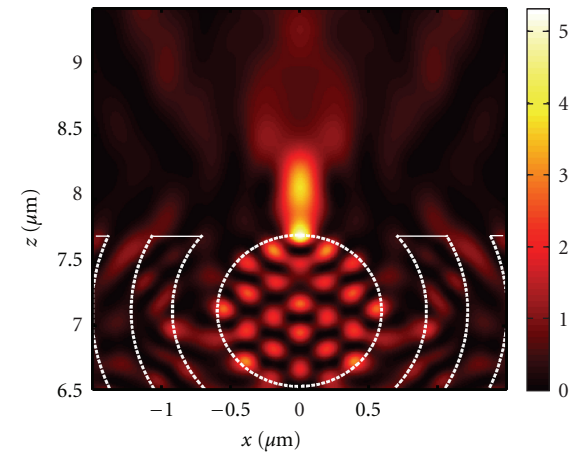


FIGURE 4: Intensity distribution in fragment of the calculated area for the truncated zone plate. White dashed line shows the cylinder border.

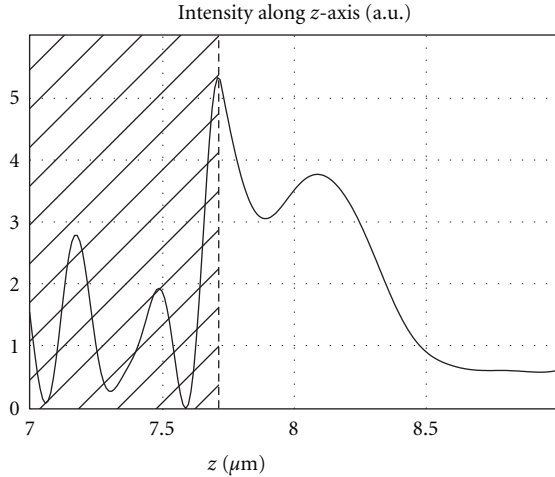


FIGURE 5: Intensity distribution along z -axis for the truncated zone plate.

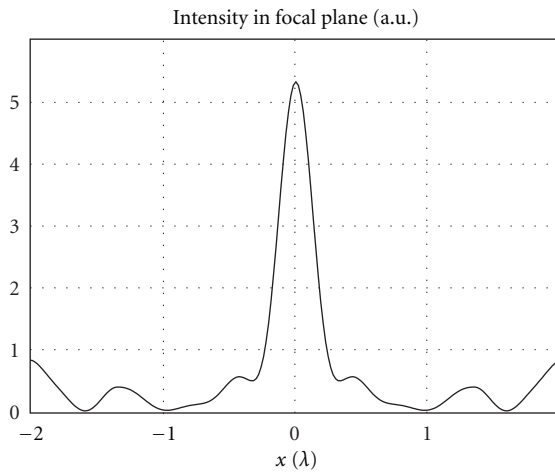


FIGURE 6: Intensity in focal plane for the truncated zone plate.

0.31λ and depth 0.57λ . Adding truncated concentric rings with radiuses equal to radiuses of zone plate to the cylinder increases the depth of focus to 1.18λ . The diameter and intensity of focal spot near the cylinder surface remain unchanged.

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