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Geometric effect on photonic nanojet generated by dielectric microcylinders with non-cylindrical cross-sections

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ABSTRACT

We experimentally report the geometric effect on photonic nanojet generated by dielectric microcylinders with non-cylindrical cross-sections. The non-cylindrical cross-sections include truncated microcylinders and elliptical microcylinders. The truncated microcylinder is formed with the cutting thickness. The elliptical microcylinder is defined by ratio of minor to major axes. The specific spatial electromagnetic fields for microcylinders with different non-cylindrical cross-sections are studied by using finite-difference time-domain calculation. The direct imaging of photonic nanojets for microcylinders with different non-cylindrical cross-sections are performed with a scanning optical microscope system. The field distribution and location of photonic nanojet depending on the various spatial shapes are experimentally demonstrated. The photonic nanojet with long focal length and low divergence could be used to scan over a target to obtain a large area image when the non-cylindrical micro-media are coupled with a conventional optical microscope.

1. Introduction

Photonic nanojet is a non-resonant localized spot with high intensity and low divergence that was first reported by Chen et al. in the numerical calculation of a circular microcylinder illuminated by a plane wave [1]. In general, a narrow and spatially highly confined optical field appears on the shadow side surface of the dielectric spherical micro-media with a diameter comparable or larger than incident wavelength. Many numerical calculations and experimental measurements are based on the physical mechanism of photonic nanojet generated by microcylinders, microdisks, or microspheres [2–12]. The direct imaging of photonic nanojet created by single dielectric microcylinder, microdisk, or microsphere has been observed with a scanning optical microscope. The practical applications of photonic nanojet are based on the point that photonic nanojet has a small waist and can provide the high intensity optical field in a localized space very close to the dielectric spherical micro-media. Optical microscopy with microspheres emerged as a simple, high-resolution, and broadband imaging technique [13,14]. However, the localization and field distribution of the photonic nanojet are dependent on the morphologies and dielectric properties of the spherical media. The utilization of photonic nanojet is limited by the short effective length of photonic nanojet because the short effective length only allows photonic nanojet to interact with near surface objects. Hence, photonic nanojets generated by a composite inhomogeneous microsphere or microcylinder consisting of several concentric shells with different materials are reported [15–20]. The longitudinal and latitudinal dimensions of a photonic nanojet depending on the optical contrast variation of shells have been investigated. The effective length of a photonic nanojet can be elongated to a several orders of magnitude. The photonic nanojet properties, such as the focal length, lateral full width at half-maximum (FWHM) and divergence, can be flexibly adjusted by the variation of the refractive index contrast between the core and shells. However, the manufacturing process of the layered inhomogeneous spherical micro-media is very difficult and expensive. Therefore, the photonic nanojet shaping by a simple and cheap way is an interesting research topic for the far-field projection system. The non-spherical micro-media of various spatial shapes, such as microellipses, microcones, micropyramids and microcuboids, have been intensely studied in recent years [21–32]. Such non-spherical micro-media are very attractive because they have unique ability to modify the spatial distribution of the lightwave in specific formations. It is possible that the non-spherical micro-media can be used to produce highly localized intensive optical flux with subwavelength waist and low divergence. The key parameters of a photonic nanojet are the focal length, FWHM and divergence. So far the mass of numerical and experimental data on the photonic nanojet properties has been obtained for spherical micro-media. The spatial distribution and intensity of a photonic nanojet are highly related to the diameter

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of the parent spherical micro-media. The focal length formed by a spherical micro-medium is small when the diameter of a spherical micro-medium is comparable with incident wavelength. For a homogeneous spherical micro-medium, the elongation of focal length for photonic nanojet is possible only through an increase of micro-medium diameter. However, the FWHM and divergence of photonic nanojet are also increased in proportion with the micro-medium diameter. The investigation for further improvement of photonic nanojet properties is proposed by the authors.

In this paper, we first experimentally study the geometric effect on photonic nanojet generated at the shadow side surface of the dielectric non-cylindrical micro-media illuminated by a plane wave. The non-cylindrical cross-sections include truncated microcylinders and elliptical microcylinders. The key parameters of focal length, lateral FWHM and divergence for photonic nanojets depending on the variation of spatial shapes are studied systematically. The simulation of non-cylindrical micro-media for photonic nanojet is presented in Section 2. The experimental results and shaping effect of photonic nanojet for non-cylindrical microcylinders and elliptical microcylinders are presented in Section 3. The theoretical simulations are compared with experimental results in a good agreement. The conclusion and future works are presented in Section 4.

2. Simulation of non-cylindrical micro-media

The purpose in this paper is to analyze the photonic nanojet formation in the different non-cylindrical micro-media. The theoretical simulations are based on the finite-difference time-domain (FDTD) method which executes direct numerical solution to the differential Maxwell equations [33]. All electromagnetic field vectors in the computational scheme are interleaved in space and the electromagnetic fields are calculated with discrete time and lattices. The computational domain is a non-uniform triangular mesh with perfectly matched layer boundary conditions [34]. The mesh size is selected to be 10 nm after the convergence verification. The time step is determined by the mesh size and chose to ensure numerical stability. The MATLAB code is used to execute the FDTD calculation. The computer program is implemented on the central processing unit of Intel Core i7 and random-access memory of 24 GB accelerated by graphics processing unit. A linearly polarized monochromatic plane wave propagating in the x direction is assumed to illuminate the non-cylindrical micro-media. The electromagnetic distributions depending on time can be obtained by using discrete time and lattices according to the second-order accurate centered difference. Fig. 1 depicts the

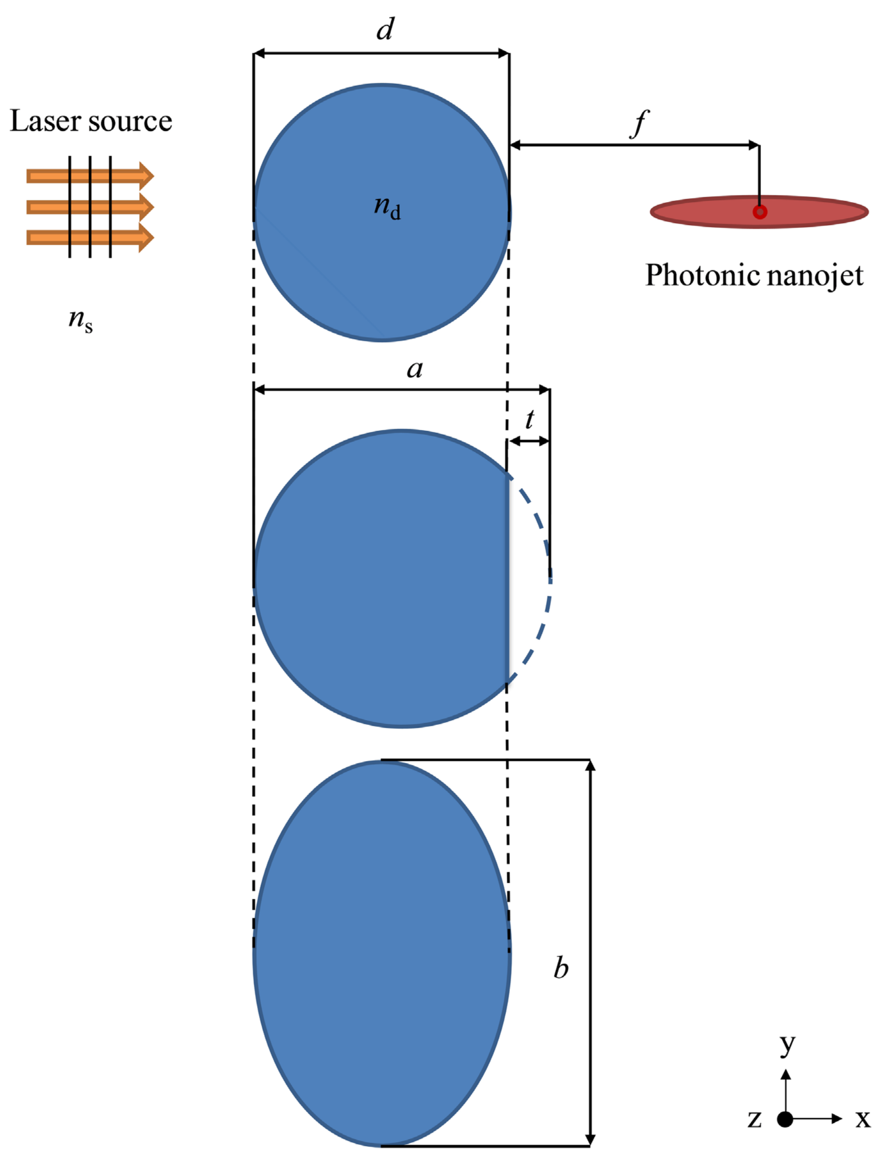

Fig. 1. Schematic diagram of the non-cylindrical micro-media for photonic nanojet.