Physica E 73 (2015) 226–234

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Characterization of photonic nanojets in dielectric microdisks

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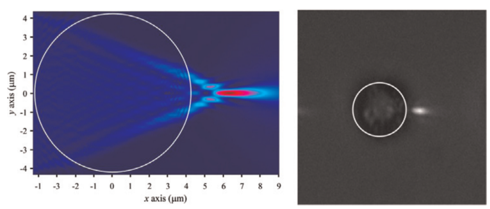
HIGHLIGHTS

- We report the direct imaging of photonic nanojets in dielectric microdisks.
- Photonic nanojets are studied by using finite-difference time-domain method.
- Photonic nanojets are measured by using a scanning optical microscope system.
- The results provide a microdisk based system in nano-photonic circuits.

GRAPHICAL ABSTRACT

We report the direct imaging of photonic nanojets in dielectric microdisks.



ARTICLE INFO

Article history:
Received 6 October 2014
Received in revised form
5 June 2015
Accepted 9 June 2015
Available online 17 June 2015

Keywords:
Photonic nanojet
Microdisk
Microscopy

ABSTRACT

The direct imaging of photonic nanojets in different dielectric microdisks illuminated by a laser source is reported. The SiO_2 and Si_3N_4 microdisks are of height 650 nm with diameters ranging from 3 μm to 8 μm. The finite-difference time-domain calculation is used to execute the numerical simulation for the photonic nanojets in the dielectric microdisks. The photonic nanojet measurements are performed with a scanning optical microscope system. The photonic nanojets with high intensity spots and low divergence are observed in the dielectric microdisks illuminated from the side with laser source of wavelengths 405 nm, 532 nm and 671 nm. The experimental results of key parameters are compared to the simulations and in agreement with theoretical results. Our studies show that photonic nanojets can be efficiently created by a dielectric microdisk and straightforwardly applied to nano-photonics circuit.

1. Introduction

Breaking through the diffraction limit become a popular issue in modern optics [1,2]. When light beam is focused by a conventional lens, the spot waist can not be infinitely sharpened due to the optical diffraction. In 2004, Chen et al. report that the transparent dielectric microsphere with micro-scale radius can generate a photonic nanojet by a plane wave illumination [3]. The critical properties of photonic nanojet are that it is a non-evanescent wave and propagating lightwave with low divergence and smallest waist smaller than diffraction limit. Then, many scientists investigate the generating mechanism of photonic nanojet and the effects of the physical parameters of microsphere or microcylinder on photonic nanojet [4–8]. Under theoretical demonstrations, the photonic nanojets appear as elongated and narrow spots with a high intensity of electromagnetic radiation, if dielectric spherical media are well illuminated [9–11]. A qualitative morphological analysis of photonic nanojet shaping for different structural composition of spherical particles is presented. The studied cases of the photonic nanojet shapes indicate a high variability of spatial forms [12]. The experimental studies of photonic nanojet are necessary for nano-optical applications. The direct experimental observation of photonic nanojets created by single dielectric microsphere illuminated by a plane wave at a wavelength of 520 nm has been performed with a fast scanning confocal microscope [13].

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http://dx.doi.org/10.1016/j.physe.2015.06.005
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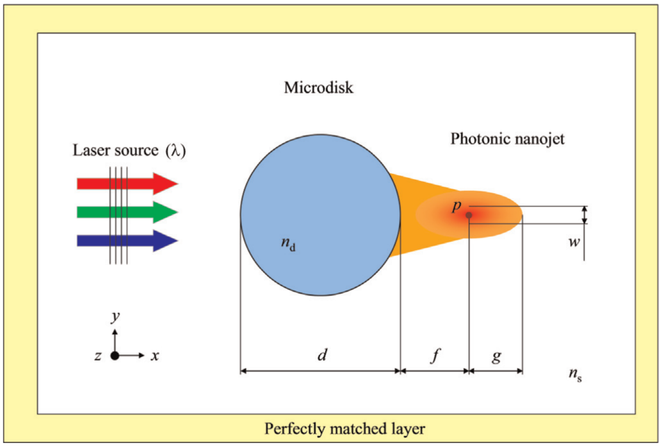

Fig. 1. Geometrical description of photonic nanojet for the microdisk.

The observations are conducted for 1 µm, 3 µm and 5 µm microspheres deposited on a glass substrate. The full three-dimensional photonic nanojet beam is reconstructed from the collected stack of images. Furthermore, Kim et al. have investigated on experimental grounds how different illumination conditions affect the properties of photonic nanojets [14]. The localization and the distribution of the photonic nanojets can be affected by the wavelength, the amplitude, and the polarization of the light source. The outstanding optical properties of photonic nanojets recommend this phenomenon as a useful tool for many nano-scale applications with high resolution such as fluorescence microscopy improvement [15], nano-patterning [16] and nano-target measurement [17]. The dielectric microspheres with high refractive index can be used for super-resolution imaging of liquid-immersed nanostructures [18,19]. The microspheres have been proved the facility to discern the shape of pattern with a minimum feature size of 25 nm. This super-resolution imaging technique can find many applications in micro-fluidic system, biomedical microscopy and nano-photonics circuit [20–22]. However, the detailed imaging mechanism of photonic nanojets in a dielectric microdisk should be studied further.

In this paper, we theoretically and experimentally demonstrate the direct observation of photonic nanojet in different dielectric microdisks illuminated by a laser source. The finite-difference time-domain (FDTD) calculation is used to execute the numerical simulation for the photonic nanojets in the dielectric microdisks. The experimental measurements are performed with a scanning optical microscope system. The photonic nanojets are observed from the collected stack of scanning images for microdisks of 3 µm, 5 µm, and 8 µm diameters on a silicon substrate. The numerical approaches of photonic nanojets in the microdisks are presented in Section 2. The measurement setup and experimental results are presented in Section 3. The conclusion and potential applications of this study are presented in Section 4.

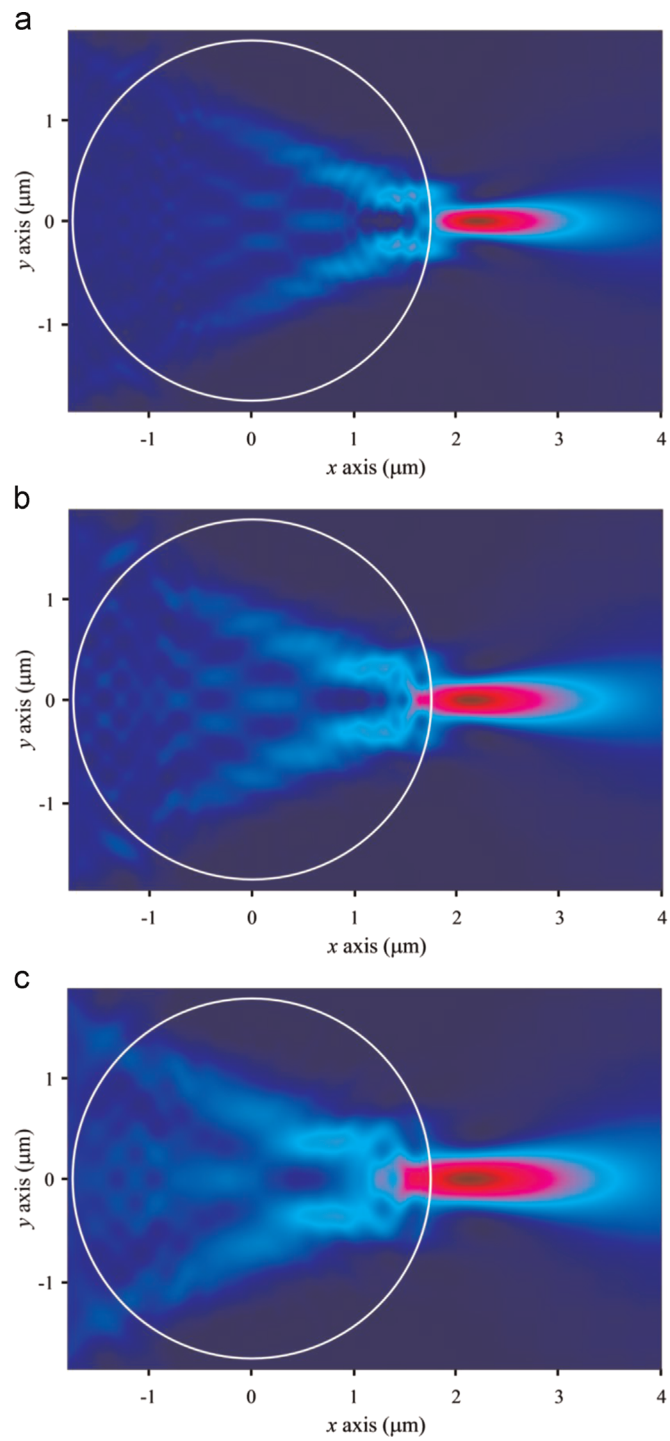

Fig. 2. Normalized power flow patterns of the photonic nanojets for the 3 µm SiO_2 microdisks at incident wavelengths (a) 405 nm, (b) 532 nm, and (c) 671 nm. The white circle shows the disk rim.

2. Numerical approach

Light scattering by spherical particles has been investigated by the analytical Mie solutions [1]. At that time, light scattering from water droplets in cloud become an interesting topic for high energy laser propagation. Lately, with increased computational ability, the properties of light scattering from small particles have been explored with high resolution numerical techniques such as FDTD and finite element methods [23]. This has lead to the prediction that the FDTD method has been selected to execute the numerical calculations for scattering distribution of photonic nanojets. Recently, we have conducted three-dimensional (3-D) FDTD simulation with high resolution on photonic nanojets for the dielectric microspheres [24–26]. The enhancements of elongated photonic nanojets generated at the shadow side surfaces of the