Research Of FWHM And Focal Length on Photonic Nanojet Generated by Microsphere

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Abstract. Photonic nanojet (PNJ) is generated on the shadow side of the microspheres, and various potential characteristics of PNJ are widely used in various fields such as medicine, nanomanufacturing, super-resolution imaging. Therefore, it is of great value to study the properties of PNJ. In this paper, the influence of internal and external factors on the distance between the maximum intensity point formed by PNJ and the surface of the microsphere (viewed as focal length) and the full width at half maxima (FWHM) with the method of finite difference time domain (FDTD) have been studied. The internal factors include the refractive index and radius of the microsphere. As the refractive index and radius increase, the focal length and FWHM will both be reduced with the increase of refractive index while opposite characteristics are featured with the change of radius of microspheres. The external factors include the wavelength and polarization direction of the incident plane wave. With the increase of the wavelength, the distance and FWHM have the opposite trend, and the distance decreases while the FWHM increases. By changing the polarization direction of the light, it is found that the focal length and FWHM also have significant changes. The research will build a good theoretical foundation for the application of PNJ in photoelectric field and other related fields.

Keywords: FWHM, Photonic Nanojet, Microsphere.

1. Introduction

Over the past two decades, diffraction optics, nanophotonics, and laser physics have actively studied micron-scale dielectric particles in various spatial forms (spheres, cylinders, ellipsoids, cones, pyramids, cuboids, etc.)[1]. The scientific interest of such mesoscale objects with an effective size comparable to the wavelength of illumination radiation depends on their unique properties of altering the spatial structure of the incident light wave and producing a concentrated luminous flux of sub-wavelength width and enhanced intensity in the near-field scattering region.

Photon nanojets (PNJS) are tightly focused beams of light that emerge from the shadowy surface of a particle. Due to its peak intensity and subwavelength beam waist, PNJ is receiving increasing attention[2].Under the irradiation of plane waves, photon nanojets (PNJs) are formed on the shadow surface of dielectric microcolumns or microspheres. Traditional optical focusing cannot be limited to the subwavelength region, e.g. the size of dielectric particles. With the specific interference of radiation transmission and scattering on the microspheres or microcylinder, optical light can be limited in all three dimensions - this effect is called PNJ [3]. By using the finite difference time domain (FDTD) numerical solution of Maxwell's equations, Chen et al. demonstrated that a locally intense photon jet is formed near the shadow side surface of a dielectric microcylinder. The results show that this PNJ can potentially reach the subdiffraction limit transverse size and propagate over multiple wavelengths without significant divergence[4], thus the main characteristics of PNJ can be summarized as follows: (1) it is a transmitted beam. By selecting the incident wavelength and changing the properties of the microsphere, its FWHM can be controlled in the subwavelength range. (2) It has a high electromagnetic density, and its electric field intensity is much greater than that of the incident light. (3) It has vertical components. It has been proved to have a wide range of applications in single molecule detection, optical capture, super-resolution imaging, fluorescence enhancement, etc. [5]. At present, PNJ has been applied and broken through in many aspects. (1) A system using microspheres to induce PNJ to write directly on the surface of the sample at sub-

diffraction limit resolution while observing the writing process in situ. Due to the limitation of diffraction limits, the resolution of sub-wavelength laser processing has been difficult to achieve. Microsphere-induced PNJ can be used to create optical spots that exceed the diffraction limit, that is, the diameter of the spot can be reduced to even smaller. This ability can allow lasers to map nanoscale structures on a variety of substrate materials by using microspheres [6]. (2) The reaction of dielectric particles mediated by photonic nanojets has no effect on thermally induced turbulence. The reaction forces act on dielectric particles, which have a wide range of sizes, while most biological particles are dielectric, with a refractive index greater than that of the surrounding medium, and thus can inspire applications of biophotonics (such as cell sorting and classification) [7]. At the same time, structural dielectric materials that manipulate light in novel ways have many potential applications in the electronics industry and telecommunications[8]. (3) Optical lenses made using polystyrene microspheres have been shown to efficiently focus relatively low-power incident light onto adjacent neurons via photonic jets. In vitro and in vitro experiments, the presence of microspheres significantly located and enhanced the power density of target neurons, resulting in an increase in inward current and evoked action potential. Microsphere photogenetic stimulation can induce more motor behavior and neuron activation at lower power densities [9].(4) The photonic nanojet phenomenon is often used to improve the resolution of optical microscopy and capture nanoparticles. The modulation of photonic nanojets can be controlled by standing waves, and the modulation of reflected photonic nanojets can be significantly reduced. The obtained results help to understand the formation process of photonic nanojets in reflection mode, and open up a new way for the design of functional optical devices[10].

PNJ is formed by irradiating dielectric particles in a medium (usually air or water). It depends on the refractive index, shape and size of the particle; refractive index of the outer medium; wavelength of incident light. Usually, the conditions for the formation of nanojets can be obtained by solving Maxwell's equations directly. Solutions are usually calculated using approximate theory or numerical methods such as the finite difference Time domain (FDTD) [5]. In this study, the focal length and FWHM formed were studied through the finite-difference time-domain (FDTD). In the fixed water environment, the light field distributions of different PNJ were calculated by changing the refractive index, radius of the microsphere, the wavelength of the incident light, and the relevant data. The variation of focal length and FWHM caused by different factors were visualized. In addition, by changing the polarization direction of the incident light, the calculated light field distributions were observed to determine whether it has a changing trend, and relevant conclusions were obtained.

2. Microsphere Model

This paper mainly studies that a single uniform microsphere which is placed in a uniform medium, either in air or in water. The PNJ effect is generated on the back side of the microsphere by irradiation with parallel light. PNJ is a narrow beam with high electromagnetic density. The focal length and the FWHM of the generated PNJ are studied.

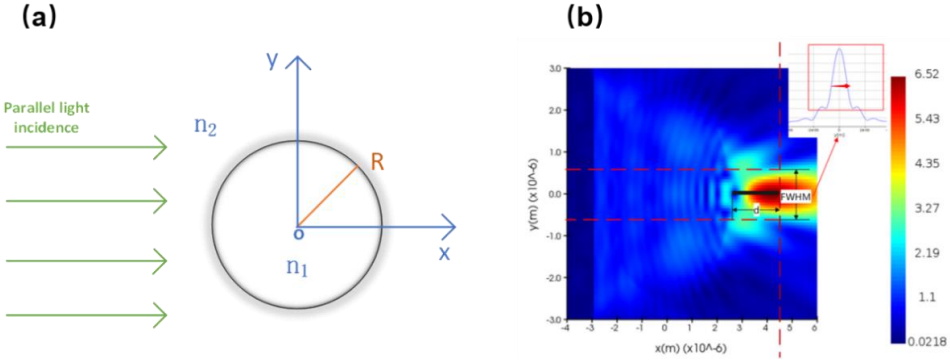


Figure 1. (a) the specific model of the study. (b) the mode distributions of PNJ and the scheme diagram of FWHM.

A uniform ball with radius R and refractive index n_1 is placed in a uniform medium with refractive index n_2. In order to make the effect of the study more obvious, it is placed in water. Focal length d is one of our research objects, that is, the distance between the light spot formed by PNJ and the surface of the microsphere. After determining the size of d, the strongest point is found. The curve of y and intensity is drawn at the position of the dotted line in the figure.

3. Results and Discussions

3.1. The influence of polarization directions

By using FDTD simulation software, the conditions of polarization directions were changed in the water environment, and the radius of the microsphere was determined to be 2.5 microns, the refractive index was 1.6, and the wavelength of the incident light was 1.064 microns. The light field diagrams with polarization of 30 degrees and 90 degrees along the x direction were drawn, respectively shown as fig. 2(a) and (b).

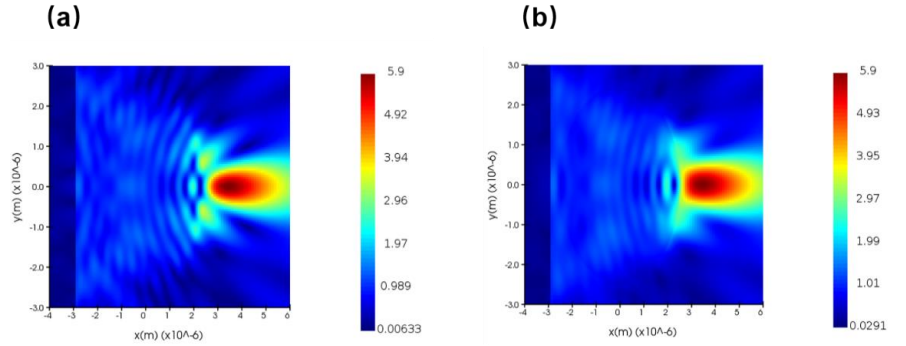


Figure 2. The electric field distributions with the polarization directions of (a) 90 and (b) 30 degrees.

From the figure, we can observe that the relative position of the light spot formed by PNJ and the microsphere is changed, and the distance between the light spot formed by PNJ and the surface of the microsphere is also different. FWHW is obviously different, so it can be seen that changing the polarization direction of light will obviously change d and FWHW.

3.2. The influence of refractive index of microspheres

In the FDTD simulation software, in the water environment, by changing the refractive index of a uniform microsphere with a wavelength of 1.064 microns irradiating parallel light with a radius of 2.5 microns, the light field diagram under different conditions is shown as Fig 3(a) and (b) with different values of d and FWHW calculated.

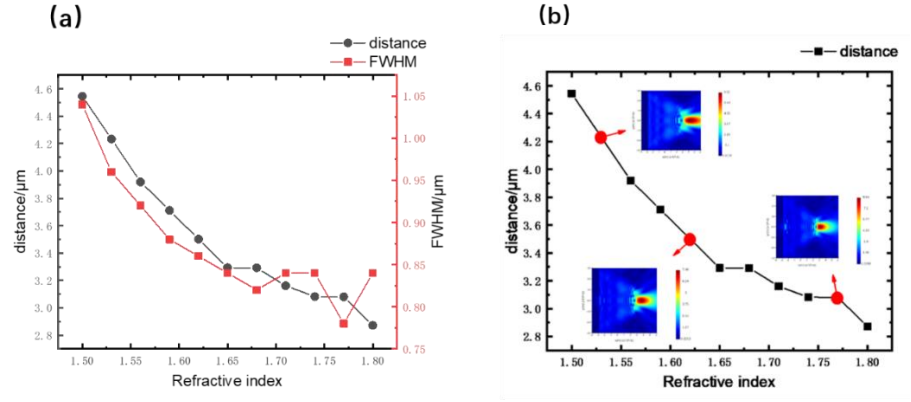


Figure 3. (a) The relationship of focal lengths and FWHM and different refractive indexes of microspheres. (b) some specific electric field distributions have been shown for clear comparison.

From the figure, it can be intuitively seen that with the increase of the refractive index of the microsphere, the values of d and FWHW both tend to decrease, and the changes of both have the same trend, the decrease of d value is very obvious, while the change trend of FWHW is not obvious. The change of beam width has been displayed in Fig. (3) for clear comparison.

3.3. The influence of microsphere radius

In the FDTD simulation software, parallel light with wavelength of 1.064microns irradiates a uniform ball with refractive index of 1.6 microns in the environment of water. By changing the radius of the ball, the light field diagram under different conditions is drawn and different values of d and FWHW are calculated. The results are shown as Fig. 4(a) and (b).

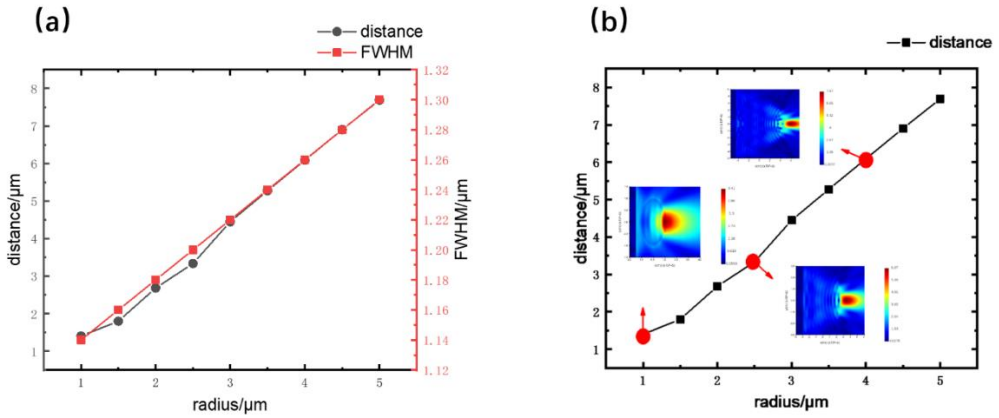


Figure 4. (a) The relationship of focal lengths and FWHM and different radius of microspheres. (b) some specific electric field distributions have been shown for clear comparison.

From the figure, the information can be obtained that with the increase of the radius of the microsphere, the values of d and FWHW both tend to increase, and the changes of both have the same trend, and the change trend of d and FWHW is also very obvious. Observing the light field diagram under different radius conditions, it can be clearly seen that the change of the beam width is very clear.

3.4. The influence of wavelength of incident beam

The quantitative changes discussed above are all characteristics of microspheres, and the influence of changing microsphere characteristics on d and FWHW values is studied. The following will take incident light as the entry point and explore the changes of d and FWHW values by changing the incident light wavelength, that is, in the FDTD simulation software, under the condition that water is kept as the environment. Using parallel light of different wavelengths to irradiate a uniform ball with a radius of 2.5 microns and a refractive index of 1.6, the light field diagram of different situations is drawn through the wavelength of light, and different values of d and FWHW are calculated and the results are shown in Fig. 5(a) and (b).

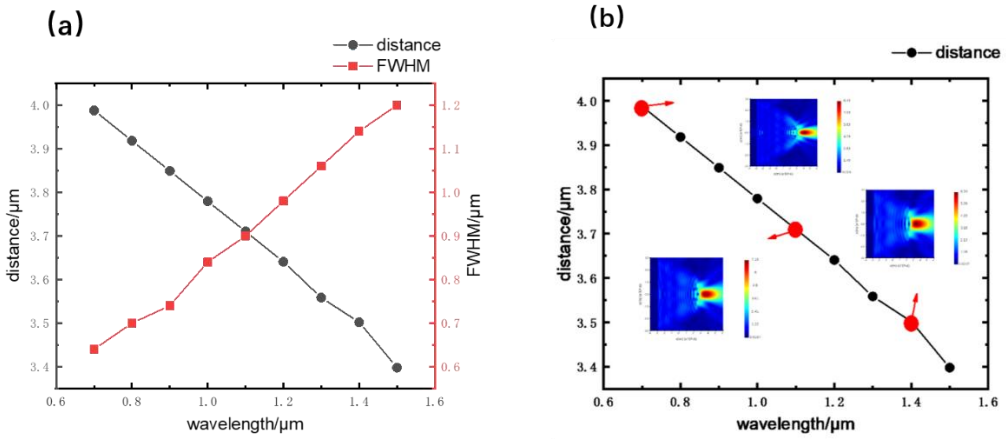


Figure 5. (a) The relationship of focal lengths and FWHM and different incident wavelengths. (b) some specific electric field distributions have been shown for clear comparison.

By observing the above figure, it can be found that with the increase of the incident light wavelength, the values of d and FWHW show as an opposite change trend. The value of d tends to decrease with the increase of wavelength, and the value of FWHW tends to increase with the increase of wavelength. The change trend of both parameters is obvious. The distance between the PNJ spot and the surface of the microsphere and the variation trend of the beam width can be observed both from the data and from the light field diagram.

4. Conclusions

According to the above research, the relevant theories of PNJ generated by microspheres are more clearly understood. The distance between the maximum intensity point formed by PNJ and the surface of the microsphere (termed as focal length) and the beam width (FWHM) formed are studied by using the finite difference Time domain (FDTD), and more explicit conclusions are obtained (mainly divided into two aspects).

a. The properties in the microsphere are mainly the refractive index and radius. When other conditions are kept constant, the refractive index and radius are changed respectively. The conclusion is as follows: (1) With the increase of the refractive index, the focal length and FWHM have the same change trend, and they decrease with the increase of the refractive index. (2) With the increase of radius, its focal length and FWHM have the same change trend and increase with the increase of radius.

b. Properties outside the microsphere: mainly the wavelength and polarization direction of light, under the same research method as above, the conclusion is as follows: (1) With the increase of wavelength, the change trend of distance and FWHM is opposite. With the increase of wavelength, the distance decreases and the FWHM increases. (2) when the polarization direction of light is changed, we can find that the focal length and FWHM have significant changes according to the electric field distributions.

According to the analysis of the light field diagram and the specific data of the calculation, the above conclusions can be preliminarily obtained. With the continuous development of PNJ, its application will continue to expand, and the research on its related parameters is particularly important.

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