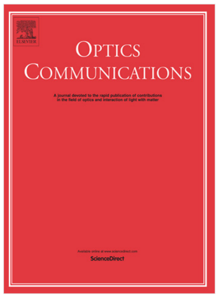
Accepted Manuscript



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PII: S0030-4018(18)30553-4
DOI: https://doi.org/10.1016/j.optcom.2018.06.062
Reference: OPTICS 23249

To appear in: *Optics Communications*

Received date : 14 April 2018
Revised date : 14 June 2018
Accepted date : 21 June 2018

Please cite this article as: H.Q. Quy, D.Q. Tuan, T.D. Thanh, N.M. Thang, Enhance of optical trapping efficiency by nonlinear optical tweezers, *Optics Communications* (2018), https://doi.org/10.1016/j.optcom.2018.06.062

Enhance of optical trapping efficiency by nonlinear optical tweezers

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Abstract
In this article, enhance of optical trapping efficiency by the nonlinear optical tweezers is investigated. The expressions described the longitudinal and transverse optical trapping efficiencies are theoretically derived. The influence of average laser power on the optical trapping efficiency is observed and discussed in comparison with that of linear optical tweezers. Remarkably, the optical trapping efficiency of nonlinear optical tweezers can be enhanced by using average laser power, and get several times higher than that of the linear optical ones having the same configuration.

Keywords**:** Optical devices; Nonlinear optical tweezers, Organic dye thin layer, Optical trapping efficiency; Biochemical.

1 Introduction

The optical tweezers are seen as efficient support tools for biomedical studies (Gu, 2014). Using an optical tweezer, the observed samples are manipulated and hold at trap position. The precise control and manipulation of micro- and nano-particles are potentially important, consequently, the stability of trapped samples in trap position depends on the optical trapping efficiency (OTE) (Kim, 2003). As well known, the trapped dielectric particles by the optical trap (tweezers) are embedded in a certain fluid having refractive index different to that of particles (Ashkin, 1970). So, beside the optical forces, the dielectric particles are always being under the Brownian force (Volpe, 2013), consequently, they oscillate randomly inside the temporal (A. Rohrbach. 2005, Ho, 2010) and spatial regions (Kim, 2003, Thai, 2016). It is clear that the oscillation amplitude of trapped particles depends on the magnitude and direction of forces acting on them, generally, on the configuration of the optical tweezers. For the convenient tweezers called "linear optical tweezers-LOT ", the OTE is enhanced by using the embedding fluid with lower refractive index (MacDonald, 2002), microscope objective with high NA to increase the intensity gradient and order of optical vortex of the Gaussian laser beam (Ashkin, 1990, O'Neil, 2001, Kim, 2003, Honglian, 2013) or coating particles (Kotsifaki,2016). Unfortunately, for every LOTs been previously designed, all of whose parameters are constantly established, so OTE- a quality used to evaluate conversion of laser power to optical force can be enhanced by using embedding fluid with lower refractive index, only. For the same purpose, up to now there is a lot of works having paid attention to the LOT, in whose configuration the Kerr particles (Couris, 2003, Wilkes, 2009, Ho, 2012) or Kerr embedding fluids are used to enhance the ratio of refractive indexes. Moreover, using the Kerr embedding fluid, the "called" nonlinear optical tweezers (NOT) has been proposed to control dielectric particles linking to DNA molecule in 3D space by tuning of the power of two lasers (Anita, 2016, Thai, 2016). As well as LOT, which needs two facts, at least (Hao, 2017), in NOT (Thai, 2016) we must use two laser sources to control trapped dielectric particles in 2D or 3D space, so called the all optical control method. By this method, the trapped particles will be finely controlled by tuning of average laser power. However, there is a complexity that the Kerr fluid must be changed suitable to other dielectric particles due to ratio of their refractive indexes. To avoid this obstacle and refer to the operation principle of the acousto-optical tweezers (Thanh, 2018), the novel model of NOT using thin layer of Acid Blue (TLoAB) with nonlinear coefficient of refractive index about $n_{nl} = 10^{-6} cm^2 / W$ at laser wavelength of $\lambda = 0.532 \mu m$ as the addition nonlinear lens has been proposed (Ho, 2018). To use the proposed NOT for longitudinal control of trapped particles by tuning of laser power, in that work, the dependence of the focal length and distribution of longitudinal force on the average laser power is numerically observed and discussed. However, up to now, the OTE of NOT has been not evaluated, yet. That is an important requirement for application of NOT, especially, in controlling process of trapped particles in fluid and stretching DNA molecules, image reconstruction (Duarte, 2008) and sub-Nyquist sampling image acquisition using compressive sensing (Shekaramiz, 2016).

In this paper, the NOT using TLoAB is presented. The theoretical expressions described the longitudinal, transverse OTE of NOT are derived. The influence of average laser power on the OTE is also investigated and discussed in comparison with that of LOT.