Thickness Dependant Effective Radius of an Optical Trapping Toward Water-Air Interface

Muhamad Safuan Mat Yeng, Mohd Farid Mohamad Yusof, Shahrul Kadri Ayop

Abstract: ***This study aimed to determine the effect of sample thickness on optical trapping towards water-air interface. 3 µm polystyrene bead was diluted in deionised water and transferred to special test cell design to form 18, 70 and 141 µm. Bead was trapped by 975 nm laser from 20 to 220 kW/cm^2 from the bottom glass-water interface towards water-air interface. The result showed that the bead is more confined with smaller effective radius in higher water thickness.***

Keywords: Effective radius, optical trapping, water-air interface

I. INTRODUCTION

Optical tweezers are a useful tool to manipulate microparticle without mechanical contact [1], [2]. One of the Nobel Prize in Physics 2018 was awarded to Ashkin and friends for their work on the optical tweezers and its applications in a biological system. This superior manipulation technique of optical tweezers provides a non-destructing and contactless method which minimises sample damage and flaw [3]. This is significantly important in manipulating biological microparticle that has a higher chance of damage [4].

Optical tweezer is established by using a tightly focused laser beam. A microparticle with higher refractive index than its environments such as cells, colloids and microbeads, is attracted to the laser focus. Two main forces are responsible for the tweezing action of the microparticlebased on the conservation of momentum; scattering force (F_s) and gradient force (F_g) [5]. The scattering force is a force imparted by the light on the microparticle. Depending on the microparticle properties, the light is being absorbed and scattered away from the microparticle.

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The transfer of light momentum to the microparticle leads to the effect of the net scattering force as shown in Figure 1. Meanwhile, light rays enter and leave the microparticle at different directions due to the interface refraction.

Higher intensity light diverts the microparticle stronger. Thus, for focused Gaussian laser beam, gradient forces attract the microparticle towards point O. The balance between scattering force and gradient forces are important for stable microparticle trapping near the laser spot.

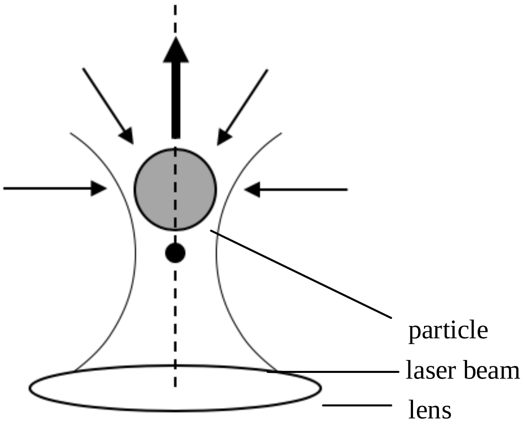

Fig. 1 Optical trapping near the focus of the laser beam.

The establishment of stable trapping occurs when various factors such as the type of objective lens, microparticle size and trapping medium are optimised. The confinement of the microparticle in an optical trap is characterised by its optical stiffness. For one dimension, the potential energy of the system equates the thermal energy of the system as expressed by $\frac{1}{2}k_BT = \frac{1}{2}kx^2$ where k_B, T, k, and x are Boltzmann constant, system temperature, optical stiffness and microparticle displacement, respectively.

Applications of optical tweezers commonly require the trapping procedure to be done in a liquid environment [3], [5]. However, some microparticle such as amphiphilic substance cannot be trapped in liquid and tend to be on the liquid surface. This requires special technique so that optical trapping at the interface of two media is possible. Among challenges in interface trapping are the refractive index mismatch and interface surface tension. In this study, the effective radius of optical trapped is investigated at varying laser focus height and laser power density in relation to the water thickness.

II. MATERIALS AND METHODS

Optical Setup

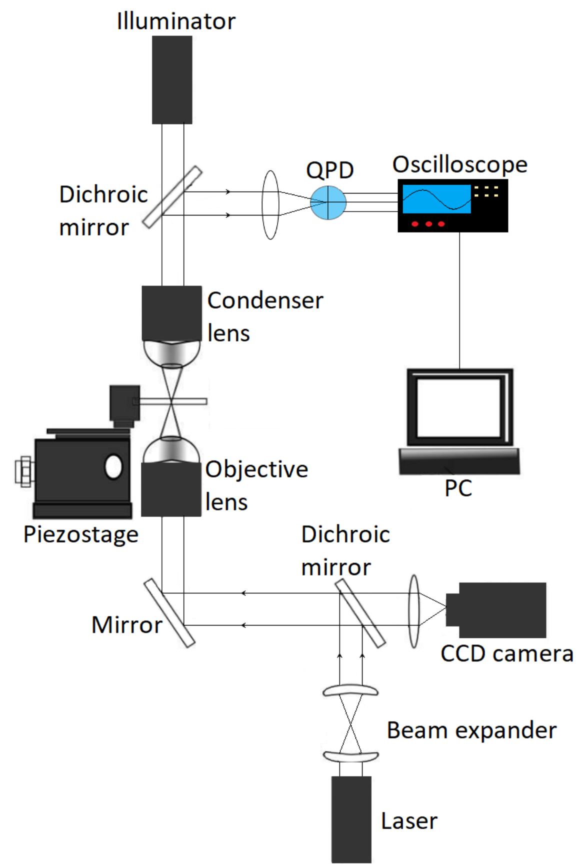

Fig. 2 Schematic diagram of optical tweezers setup

Figure 2 showed the schematic diagram of the optical tweezers setup. In this setup, an infrared laser beam with 975 nm wavelength was used as the main trapping laser source. The laser was focused by an objective lens (oil-immersion, 100×, and 1.25 NA) and set to vary between 20 to 220 kW/cm. 3 □m microbead (Polysciences) in water with free top surface was prepared in a special glass chamber. The scattered light from the trapped bead is collected by the condenser lens (10×) and directed to the quadrant photodiode (QPD). The illuminator was used for trapping observation using CCD. The piezostage was used to adjust focus position in the glass chamber.

In order to get the bead displacement, the temporal signal of the trapped particle was obtained by QPD and analysed by OSCal[6]. The displacement distribution around the trapping centre assembled a Gaussian distribution shape. The effective radius (r^*) of the trapping is defined as the standard deviation of the Gaussian distribution. The smaller r^* indicates strong optical stiffness and vice versa [7].

III. RESULTS AND DISCUSSION

The trapping starts at h_{focus}=0. Even though the laser was focused at the water bottom surface, the effective trapping is focus-offset which is at the position higher than h_{focus}. The scattering force is responsible for the offset. Thus, the bead was trapped at the position above h_{focus}. In order to trap at the water-air interface, the laser focus must be placed below the intended trapping spot since the scattering force is dominant, which might push away particle from the laser spot.

The bead trapping was harder to achieve at water thickness more than 20 µm. This is due to the difference in working distance (WD) of the objective lens used (230 µm) and the coverslip thickness (170 µm), resulting in an effective working distance range of ≈ 60 µm.Therefore, to trap toward water-air interface, one must take consideration on the limitation of WD and prepare appropriate trapping medium thickness.

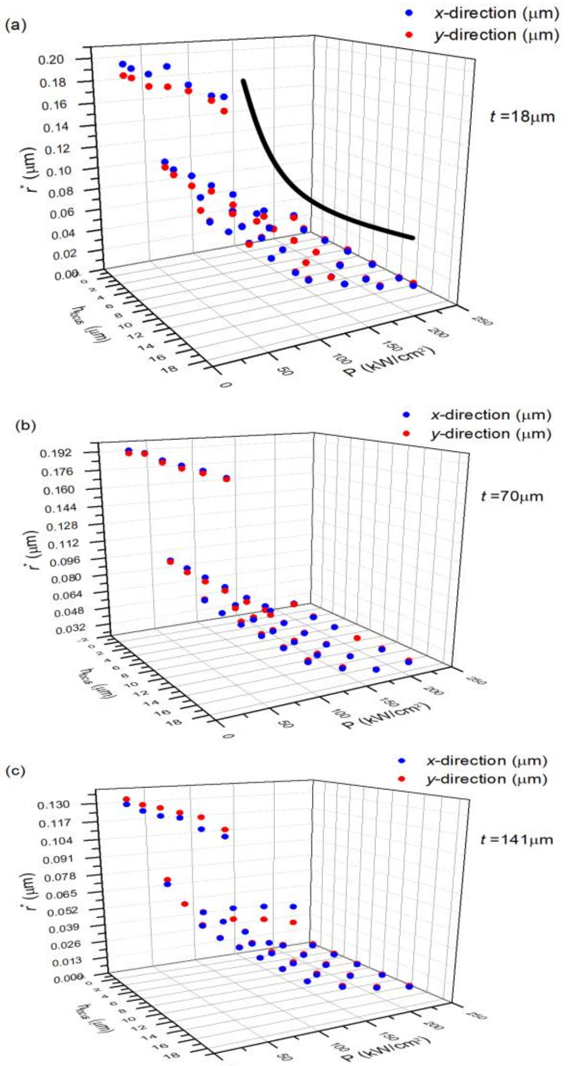

Fig. 3 3D graph of r^* versus $h_{focus}$and P at three selected thickness (a) t = 18 µm (b) t =70 µm and (c) t = 141 µm.

Figure 3 shows 3D graph of r^* versus h_{focus} and P at selected thickness (a) t = 18 µm (b) t =70 µm and (c) t = 141 µm. All graphs show curving planes with highly changing slope $\left|\frac{\partial r*}{\partial P}\right| > 0$ at fixed t and h_{focus}. Curved thick lines (Fig. 3(a)) serves as an eye guide to indicate the exponential-liked relation between r^* versus h_{focus} and P.

This can be well understood since the gradient force is proportional to the laser power density.

At higher *P*, the bead is more confined due to strong attraction to the laser focus.

At fixed *t* and *P*, $\frac{\partial r*}{\partial h_{focus}} \approx 0$. The bead lateral displacement was almost constant along the vertical change in focus height. However, it was reported that the axial displacement from the the laser focus was significantly large due to dominant scattering [8].

At fixed$h_{focus}$and *P*, *r** is smaller from higher water thickness. For comparison, ath_{focus}=0and$P$= 22 kW/cm^2 , effective radius is 0.19 µm and 0.13 µm for water thickness, *t* = 18 µm and 141 µm, respectively. The confinement of the bead in the thicker water is possibly due to the hydrostatic pressure that acts in all direction, depending on its position from the water surface. The lateral displacement of the bead is more restricted in thicker water due to greater hydrostatic pressure, in addition to the gradient force. Therefore, one must take into consideration the trapping medium thickness as well as WD requirement, especially for trapping applications near water-air interface.

IV. CONCLUSIONS

A 3 µm polystyrene bead was trapped at various focus height (0 to 18 µm from water bottom surface) and power density (20 to 220 kW/cm^2) in water with air exposed surface with different thicknesses (18, 70 and 141 µm). The effective radius of the bead displacement is relatively smallest in 141 µm thick water, possibly due to hydrostatic pressure. This study implies that medium thickness contributes to the optical stiffness.

V. ACKNOWLEDGEMENTS

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