A Novel Optoelectronic Tweezer Using Light Induced Dielectrophoresis

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ABSTRACT

We demonstrate a novel optoelectronic tweezer using light induced dielectrophoresis mechanism to optically trap and transport micro particles with optical power in the μW range. This device consists of two pattern-less surfaces: a bottom glass substrate coated with photoconductive material and a top transparent indium-tin-oxide (ITO) glass. To achieve optical trapping, we sandwich the liquid-immersed micro particles between these two surfaces and supply an ac electric bias. A 633-nm He-Ne laser focused by a 40x objective lens is used to transport the particles. Negative dielectrophoretic trapping is demonstrated in this paper. Our experiment results show that optical beam with power as low as 1 μW is sufficient to transport 25-μm-diameter latex particles at a speed of 4.5 μm/sec. The transport speed increases with higher optical power. A maximum speed of 397 μm/sec is observed at 100 μW.

INTRODUCTION

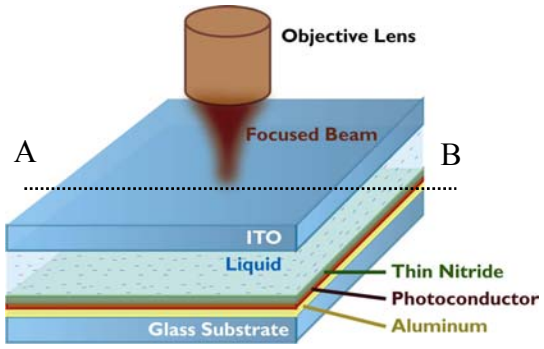
Optical tweezer is a very important tool in biological research area since it was first demonstrated by Ashkin [1]. However, the potential photodamage caused by the intense optical energy has restricted its use. For example, a 100 mW optical tweezer has a light intensity on the order of 10^{10} mW/cm^2 when focused to diffraction limit. Such an intense light energy may cause damages due to local heating or two-photon absorption [2]. To reduce the photodamage, lasers with wavelengths in the near infrared region are often chosen to avoid the absorption in water or biological objects. However, the recent research shows the cell metabolism may still be affected even using infrared lasers [3].

Recently, Ozkan *et al.,* proposed a light induced electrophoresis mechanism to optically address polymer beads by using dc electric bias [4]. The electrically charged particles are attracted to the electrode with opposite polarity. In this paper, we present a light induced dielectrophoresis mechanism that would allow the optical addressing of electrically neutral micro-particles with μW optical energy, which is much lower than the 1 ~ 100 mW optical energy used by optical tweezer. Dielectrophoresis (DEP) refers the motion of an electrically neutral particle resulting from the interaction between the applied electric field and the induced dipole. It has been used widely in the manipulation of micro- or sub-micro-particles and biological cells [5-6]. An analytical expression of DEP force is given by [7]

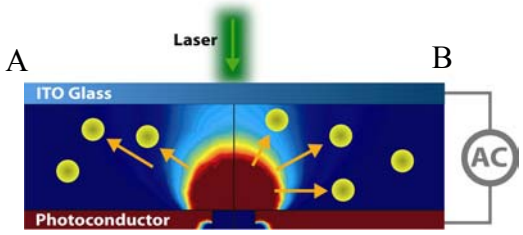
$$F_{dep} = 2\pi a^3 \varepsilon_m \,\mathrm{Re}[K^*(\omega)]\nabla(E^2)$$

$$K^*(\omega) = \frac{\varepsilon_p^* - \varepsilon_m^*}{\varepsilon_p^* - 2\varepsilon_m^*}, \varepsilon_p^* = \varepsilon_p - j\frac{\sigma_p}{\omega}, \varepsilon_m^* = \varepsilon_m - j\frac{\sigma_m}{\omega}$$

where E is field strength, a is particle radius, ε_m and ε_p are the permittivities of the surrounding medium and the particle, respectively, σ_m and σ_p are the conductivity of the medium and the particle, respectively, ω is the angular frequency of the applied electric field.



(a)



(b)

Fig.1(a) Schematic of the device structure. (b) Illustration of the light induced dielectrophoresis mechanism.

The term $\mathrm{Re}[K^*(\omega)]$ can have any value between 1 to –1/2, depending on the applied ac frequency and the polarizability of the particle and the medium. If $\mathrm{Re}[K^*(\omega)]<0$, it is called negative DEP (the direction of the DEP force is towards lower electric field). Since the DEP force is proportional to the gradient of the square of the applied electric field, a highly non-uniform electric field is desired to achieve a higher trapping force. In the following experiment, we demonstrate light induced negative DEP force.

PRINCIPLE AND DEVICE STRUCTURE

Figure 1(a) shows the schematic structure of the optoelectronic tweezer. The liquid solution containing the particles is sandwiched between two surfaces

separated by a gap spacing of 100 μm. The top surface is a commercial ITO glass. The bottom surface is a glass substrate coated with three pattern-less layers: a 2000-Å-thick aluminum layer, a 2-μm-thick photoconductive (amorphous silicon) layer, and a 200-Å-thick silicon nitride layer. An ac bias is applied between the top (ITO) and the bottom (aluminum) electrodes. In the dark state, most of the voltage drops across the photoconductor due to its high electrical impedance. This results in a very weak electric field in the liquid layer. When the laser beam is focused on the photoconductive layer, the local photoconductivity at the site under light illumination is greatly increased due to the photo generated electron-hole pairs. A light defined micro electrode is turned on locally and creates a highly non-uniform field in the liquid layer as shown in Fig. 1(b). The laser spot creates a light defined electrode and a highly non-uniform electric field in the liquid layer. The particles inside the liquid is polarized by the non-uniform field and pushed away from the illuminated site by the negative DEP force.

Since light is used to switch the ac voltage drop between the photoconductive layer and the liquid layer, rather than to directly trap the particles, the required optical power is orders of mangnitudes lower than that of conventional optical tweezers.

EXPERIMENT AND RESULT

In the experiment, a 800μW laser with a beam width 0.24mm and a wavelength of 632 nm is used as the light source. The laser beam is steered by a pair of orthogonally scanning galvanometer mirrors and then sent through a combination of a convex lens and a 40x objective lens. The optical spot size on the photoconductive layer is around 17μm. Neutral density filters are used to control the incident optical energy. A 100kHz ac bias is applied between the top and the bottom electrodes to drive 25μm latex particles. To measure the particle speed, the scanning mirror is programmed to scan at a constant speed to push the particle. The particle is pushed by the optical beam, until at sufficiently high scan rate, the particle can no longer keep up with the optical beam. The maximum speed at which the particle responds to scanning optical beam is measured for various optical powers and ac bias voltages. Figure 2 shows the experimental results. An optical beam with power as low as 1 μW light is sufficient to transport the particle at a speed of 4.5 μm/sec at 10V ac bias. The maximum speed observed here is 397 μm/sec, which corresponds to a force of 187pN estimated by Stokes' law. Figure 3 shows an example of multi-particle focusing. The laser beam is programmed to scan in circular patterns. The four particles are focused, or squeezed, to the center of the shrinking circular pattern.

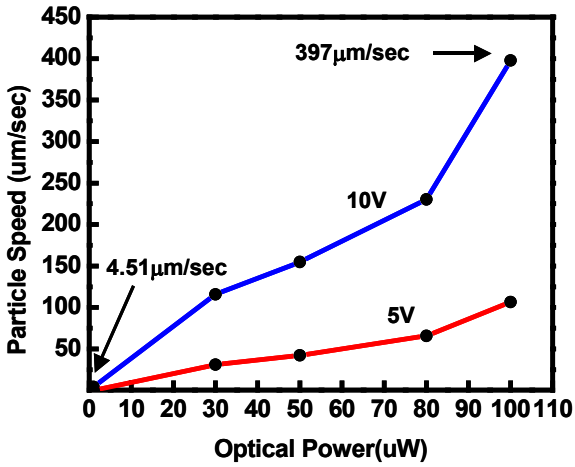


Fig.2 The relationship between the particle speed and the optical power

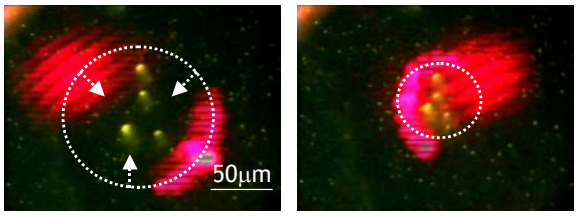


Fig.3 Example of multi-particle focusing.

CONCLUSION

A novel optoelectronic tweezer is demonstrated for the first time and successfully applied to transport neutral micro particles. The required optical power (1 ~ 100 μW) is one to two orders of magnitudes lower that that of optical tweezers. Particle transport speed of 397 μm/sec and trapping force of 187 pN are measured for 25-μm latex particles with 100 μW optical power and 10 V ac bias.

ACKNOLEDGEMENT

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