DYNAMIC PICO-LITER BUBBLE MANIPULATION VIA TIOPC-BASED LIGHT-INDUCED DIELECTROPHORESIS

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ABSTRACT
To manipulate a pico-bubble which volume is in pico-liter scale with a dynamic light pattern is first presented in this article. We give a new application to a organic photoconductive material, TiOPc, to fabricate a optoelectronic chip with a function of light-induced dielectrophoresis (DEP). We also establish a optical system to minify the dynamic light pattern onto the operation surface of this TiOPc-based chip. The dynamic virtual electrode is applied to manipulate the pico-bubble with positive DEP force until it vanish in the surrounding. This optical approach uncover a new approach to manipulate gas pico-bubble.

KEYWORDS: titanium oxide phthalocyanine, optoelectronic tweezers, dielectrophoresis, microbubble

INTRODUCTION
Recently utilizing optically-induced electric field to manipulate microparticles named as optoelectronic tweezers (OET) has been developed and studied [1-3]. However, the fabrication process requiring specific instrument such as plasma-enhanced chemical vapor deposition (PECVD) and multi-layer bulk-heterojunction polymers makes some constraints. In this research, we take advantage of spin-coat 200nm thin titanium oxide phthalocyanine (TiOPc) layer on indium tin oxide (ITO) electrode surface to develop our light-induced dielectrophoresis (DEP) chip, which needs only one fabrication process for the substrate chip. This TiOPc-based OET (Ti-OET) chip could be utilized to manipulate polymer beads and cells. In this paper, we focus on the manipulation of pico-liter bubbles (pico-bubble) within the silicone oil (5cSt). The experimental results reported in this paper demonstrate the expanding application of OET.

THEORY
Based on DEP principle, this research utilizes the time-averaged DEP formula to describe the driving force to manipulate pico-bubble. Force acting on a spherical particle of radius $r$ suspended in a medium with relative permittivity $\varepsilon_m$ is

$$F_{\text{DEP}} = 2\pi r \varepsilon_m \text{Re}[f_{\text{CM}}(\omega)] \nabla E_{\text{rms}}^2$$

(1)

where $E_{\text{rms}}$ is the root mean square of the AC electric field and $f_{\text{CM}}(\omega)$ is the Clausius-Mossotti (CM) factor which depends upon the applied angular frequency and the electrical conductivity of the particle or the medium.

However, to measure the electric field between top ITO glass and bottom TiOPc substrate as the scale is too small to put any probe tip. One indirectly approach to get the force acting on the bubble is to apply Stokes’ law. When a pico-bubble moves with a constant velocity, the two force, driving force and drag force, are equal and drag force is shown as the following.

$$F_{\text{D}} = 6\pi \eta \nu_{\text{OET}} a$$

(2)

where $\eta$ is the dynamic viscosity of the medium (kg m$^{-1}$ s$^{-1}$), $a$ is the radius of the particle (m) and $\nu_{\text{OET}}$ is the velocity of the particle (m s$^{-1}$). To measure the constant velocity, $\nu_{\text{OET}}$, of a moving pico-bubble and its diameter, $a$, we are able to calculate the force acting on the pico-bubble. Details of this measurement about the positive DEP force acting on the pico-bubble are still under investigation.

EXPERIMENTAL
Figure 1 illustrate the system of pico-bubble manipulation chip. A UHP Hg lamp illuminates on a digital micromirror display (DMD, with a spatial resolution of 1024 × 768 pixels) which is programmed via a computer. The light pattern reflected on the DMD surface is projected on the TiOPc surface. A function generator is to control the applied electric potential and frequency on the chip.

![Figure 1. Schematic diagram of the optical system setup for the light-driven pico-bubble chip.](image-url)
Figure 2 illustrates the Ti-OET device fabrication. (a)–(d) is the process of top cover which is made by PDMS micro-channel. The ITO glass is embedded at the channel top. We punch two holes, inlet and outlet, for pico-bubble injection. Because the PDMS is difficult to bond on the ITO surface, we use etching method to remove the outer area for PDMS bonding. (g) and (h) show that the TiOPc is coated on the bottom ITO glass and this is the key process because only this one step the photoconductive chip is already finished. The TiOPc is not solved in the water, but the alcohol can be utilized to dissolved it. Therefore, we use 75% alcohol to remove the TiOPc layer on the glass. After the oxygen plasma treatment on PDMS surface and button glass substrate part, these two parts are aligned and bonded together.

Figure 2. Fabrication of the Ti-OET chip. (e)–(h) illustrate the one process to spin-coat 200 nm TiOPc on the ITO surface. The Ti-OET chip (i) is bonded with the top PDMS microchannel cover (d) and button TiOPc-based substrate (h).

Figure 3 illustrate the simulation of electric field distribution. A commercial finite element software CFD-ACE+ (CFDRC, Huntsville, AL) is used to simulate the steady-state electric field, which dominates the field-induced positive DEP force used in this work. While the light pattern projected on the TiOPc surface, the conductivity of illuminated region decreases. This light-illuminated area transforms to a virtual electrode because of the characteristics of the photoconductive material. Then, the gas pico-bubble is attracted toward this illuminated area under the positive DEP (pDEP) force and dragged by following the movement of the light square, which generates the light-induced pDEP effect.

Figure 3. The electric-field simulation shows that illuminated pattern creates the virtual electrode to trap a pico-bubble via DEP force. The substrate is the photoconductive material, TiOPc, on the ITO glass

RESULTS AND DISCUSSION

This is the first report for the characterization of the DEP force acting on a gas picobubble. The relationship between picobubble volume and time is measured and shown in Figure 4. The pDEP force acting on the 300 pl volume bubble surrounded by silicone oil is about 160 pico-Newton (pN). When the bubble volume decreases, the pDEP force decreases correspondingly. Right before the pico-bubble dissolves entirely, there is still 30 pN force acting on a 4pl bubble observable.
Figure 4. The gas molecule in pico-bubble dissolves into surrounding silicone oil slowly. The relationship between picobubble volume and manipulation time is measured. It is utilized to estimate the picobubble volume when the bubble is manipulated in experiment.

The process of picobubble manipulation is shown in Figure 5. It is noted that the picobubble volume decreases when we compare the bubble size in Figure 5 (a) and (d). The bubble dissolving process shows that the gas molecule diffuses into silicone oil continuously. The size decreases from 79µm to 57µm and the volume diminishes from 180 pl to 97 pl. Before the picobubble disappears, it is still affected by the DEP force and its position is still manipulated with the moving light pattern.

Figure 5. A moving illuminating square image controlled by a moving cursor manipulates a 180 pl volume picobubble. The hand-shape cursor controlled with a multi-touch panel is utilized to drag the white square. We integrate touch panel technology into our control interface for convenient and intuitive manipulation. Applied voltage is 10Vpp and 10 kHz in frequency. The scale bar is 100µm.

CONCLUSION

In conclusion, we utilize the photoconductive material, TiOPc, to fabricate optoelectronic tweezers chip. This device is applied to manipulate gas bubble via light-induced DEP force. We also measure the dissolve rate of the pico-bubble in the silicone oil surrounding and the results seen like that the gas molecule dissolve into the liquid with a constant rate. The positive DEP force acting on the pico-liter volume bubble is estimated with Stokes’ law and the results are still investigated. Furthermore, this is the first article to present the dynamic light capability for manipulating gas bubble in micro scale.

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REFERENCES


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