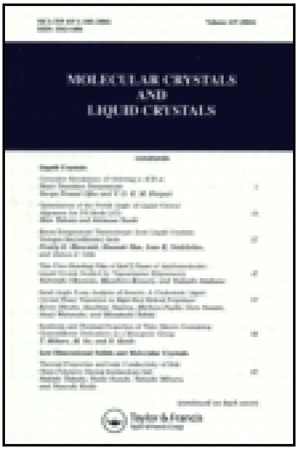

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Optical Trap for Manipulating Plural Particles by Using a Liquid Crystal Device

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Optical Trap for Manipulating Plural Particles by Using a Liquid Crystal Device

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We propose an optical manipulation system for simultaneously trapping and controlling the positions of microscopic multiple particles by using a liquid crystal (LC) optical device and a condenser lens. The positions of the multiple particles trapped at the bright region of the linear interference fringe patterns can easily be shifted along the fringe patterns by controlling the applied voltage to the LC optical device.

Keywords: interference fringe pattern; liquid crystal devices; multiple particles; optical manipulation; optical trap

I. INTRODUCTION

Manipulation of micro-sized objects without mechanical contacts has been studies and achieved by using optical tweezers [1–4]. The optical tweezers exploits an optical gradient force of a very intense focused laser beam. The gradient force from a few tens of femto-Newton up to hundreds of pico-Newton produces potential wells where microscopic particles are trapped. The optical tweezers method for manipulating dielectric spheres, biological particles such as viruses, bacteria and living cells is established as a powerful

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method for many applications of various physical and biological fields. We have already reported an optical manipulation system for controlling the three-dimensional (3D) positions of microscopic particle by using a composite lens of an objective lens and an LC lens with variable focusing and beam deflection properties. Only single polymer ball particles (~11 μm) can be trapped and controlled in the longitudinal direction as well as the transverse direction without mechanical parts [5]. In this paper, the positions of the trapped multiple particles immersed in distilled water are controlled by activating the interference fringe patterns in the LC optical device without any parts of mechanical movement.

II. EXPERIMENTAL

Figure 1 shows a schematic diagram of an optical manipulation system for controlling the positions of multiple objects by using an LC optical device and a condenser lens. The laser beam from a TEM_{00} doubled-Nd:YVO_4 laser source at a wavelength (λ) of 532 nm passes through collimator lens, polarizing prism (Glan-Thompson polarizing prism), the LC optical device, condenser lens with a high numerical aperture (20x, NA = 0.45) and sample holder. The strongly-condensed-laser-beam is focused on the sample holder which the microscopic particles such as the polymer ball particles at the diameter of 11 μm suspended in water. The image of the trapped particles is projected through the different objective lens (20x). The images are observed

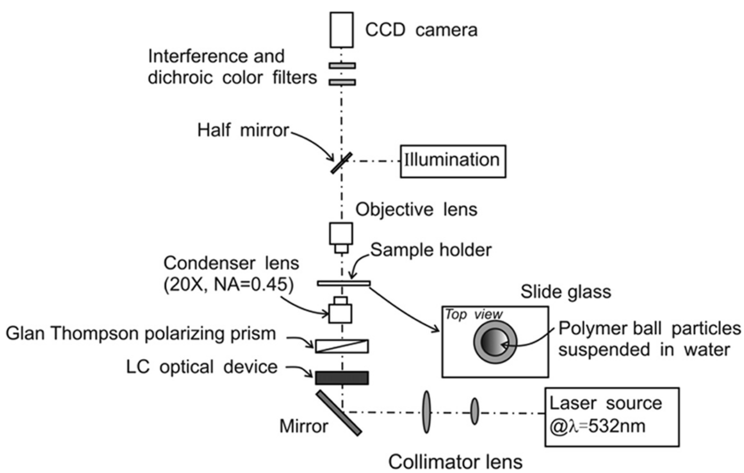

FIGURE 1 Schematic diagram of an optical manipulation system.

with a charge coupled device (CCD) array camera and recorded with a personal computer for further analysis. Interference and dichroic color filters are used to remove the highly focused laser beam before the CCD camera. The infrared cut filter is inserted between the illumination light source and the sample holder in order to reduce the heat from the light source.

Figures 2(a) and 2(b) show schematic diagrams of the LC optical devices as a wedge LC cell and a circularly hole-patterned LC cell. In the wedge LC cell shown in Figure 2(a), the LC layer is sandwiched between two glass substrates with indium tin oxide (ITO) films at two different diameters (11 μm and 110 μm) of polymer ball spacers. The surfaces of the ITO films are coated with polyimide film and its film on the upper and bottom substrates is unidirectionally and homogeneously rubbed. An LC material (E44, Merck) with a positive dielectric anisotropy is injected into the empty cell. The voltage across

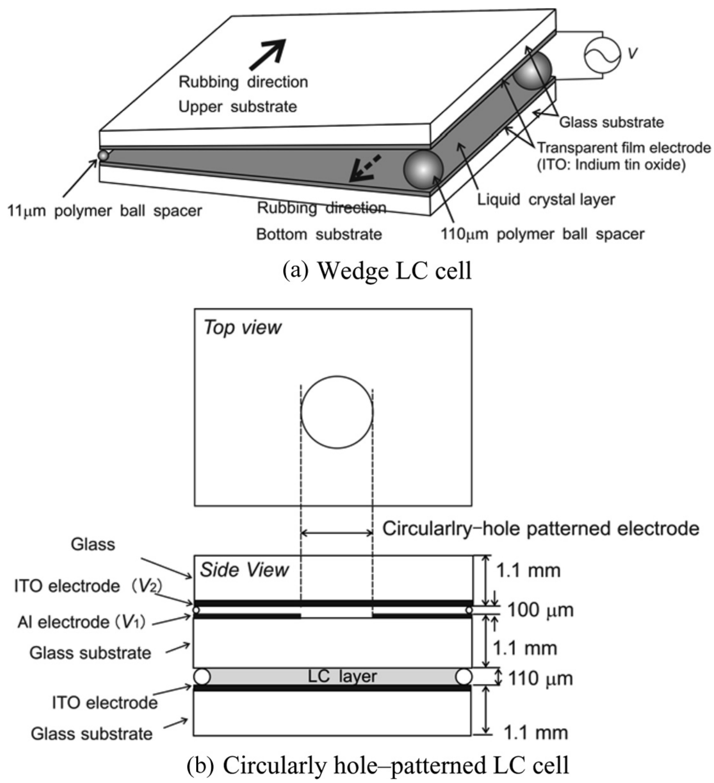

FIGURE 2 Structures of LC devices.

two ITO electrodes which face the LC layer is applied. In Figure 2(b), the structure of the circularly hole-patterned LC cell in this study is similar to that of the conventional LC lens [6]. The diameter of the aperture is 4.5 mm and structure parameters are shown in Figure 2(b). The LC material (MLC6080, Merck) is injected into the LC layer. Two alternating voltages at a frequency of 1 kHz and same phase voltages V_1 and V_2 are applied to the circularly hole-patterned electrode and external ITO electrode. Since the insulating layer of the thick glass substrate (thickness = 1.1 mm) is inserted between LC layer and circularly hole-patterned electrode, the applied voltages to both the circularly hole-patterned and external ITO electrodes are higher than that to the wedge LC cell.

III. RESULTS AND DISCUSSION

The linear fringe patterns at the defocusing laser spot (~70 μm) on the microscopic particles through the wedge LC cell and condenser lens are shown in Figures 3(a)–3(c). The LC director of the LC device is set to 45 degree to the polarization direction of the incident laser beam. The polarization direction of Glan-Thompson polarizing prism is set to 90 degree to that of the laser beam. There is a phase difference of 2π between the neighboring fringes. When the voltage is applied from 0.99 V to 1.10 V to the upper and bottom electrodes on two ITO glass substrates, the bright region of the interference fringes seems to be shifted from left side to right side. The LC director distributions; that is the profiles of the phase difference can easily be arranged by the applied voltages. Figures 4(a)–4(c) show the circular interference fringe images at the defocusing laser spot of ~70 μm when the circularly hole-patterned LC cell is used in the optical manipulation system. Where the applied voltage to circularly hole-patterned electrode is constant ($V_1 = 60$ V) and the applied voltage to the external control

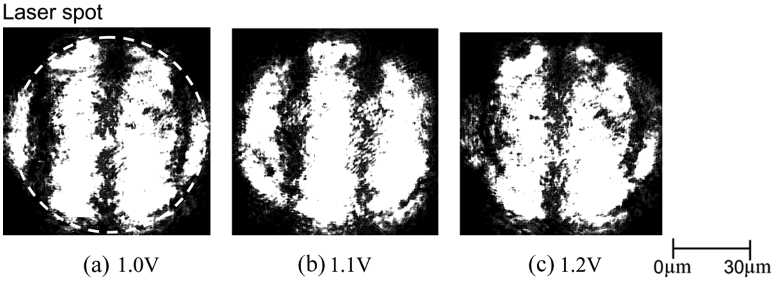

FIGURE 3 Linear interference fringe pattern images.

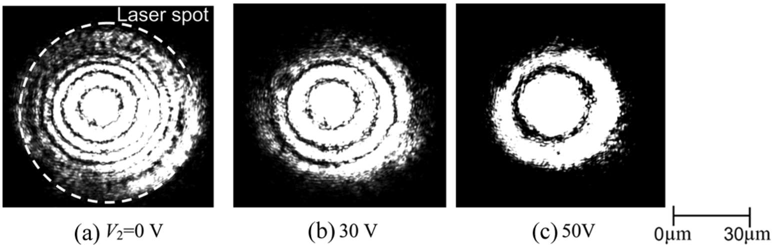

FIGURE 4 Circular interference fringe pattern images in the hole-pattern region ($V_1 = 60$ V).

electrode (V_2) is gradually increased from 0 V to 50 V. The applied voltages of the electrodes in the circularly hole-patterned LC cell are relatively higher than that of the wedge LC cell since the insulating layer as the thick glass layer 1.1 mm is inserted between the LC layer and circularly hole-patterned electrode shown in Figure 2(b).

Figures 5(a)–5(c) show demonstrations of the position control of the trapped microscopic particles when the wedge LC cell is used in the optical manipulation system. The laser power is about 0.8 W. Since the interference and dichroic color filters are inserted before the CCD camera, the interference fringes are disappeared and only the particles illuminated and dispersed in water can be observed. The positions of the four polymer ball microscopic particles (A∼D) at a diameter of 11 μm can be simultaneously trapped and controlled by generating the interference fringe pattern of the wedge LC cell shown in Figure 3. The trapped particles can be shifted about 40∼50 μm from left side to right side when the applied voltages are tuned as shown in Figures 3. Since the optical force at the bright region of the interference fringe pattern is strong, the bottom of the potential wells for the trapping the objects is deep then the particles

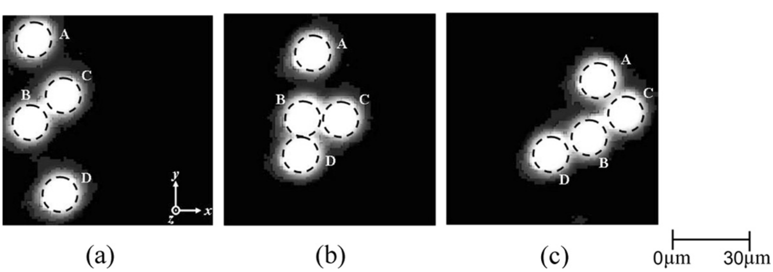

FIGURE 5 Microscope images of the trapped multiple particles by changing the linear interference fringes.

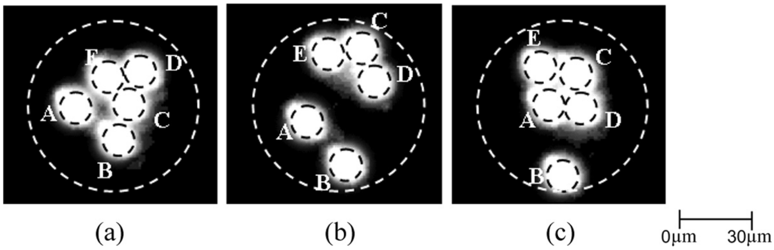

FIGURE 6 Distributed and collected particle images by shifting the circular interference fringes.

can be captured in the bright region. Since the relationship between the intensity of the laser beam and the material properties such as sizes and refractive indices of the polymer ball particles are difficult, we will discuss about the detail analysis of the optical forces for the trapped particles in somewhere. When the LC optical device as the circularly hole-patterned LC cell as shown in Figure 2(b) is used in the optical manipulation system, the microscope images of the five trapped polymer ball particles (A$\sim$E) are shown in Figures 6(a)–6(c). The multiple particles are simultaneously trapped and distributed from the center shown in Figure 6(a) to the outside (b) at around laser defocusing laser spot ($\sim$60 μm) along the circular interference fringes. In addition, the trapped particles can be collected from the outside (b) to the center (c) by adjusting the applied voltages (V_2) to the external ITO electrode.

IV. CONCLUSION

The optical manipulation system for controlling and trapping the multiple micron-size ball particles was proposed by using an LC optical device with a function of moving the interference fringe distributions. The multiple microscopic particles can be shifted along the bright region of the linear or circular fringe patterns with the application of the voltage to the LC optical devices.

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