Design and Fabrication of Microlens Array by Solvent-type Polymer of Inkjet Printing

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Abstract

We present for the first time here that the micro-lens array is designed and fabricated with water-type polymer by inkjet printing technology. The micro-lens is, but not limited to be, simply designed with convex shape and small size less than 300 micrometers; the column and row of array cab be up to 100 × 100 and more. Meanwhile, by hydrophobic surface treatment of the substrate, micro-lens array is able be formed onto without coffee-ring. The specific fluid material of lens is formulated with low viscous solution of water-born Polyurethane (PU). Its optical refractive-index n is about 1.5. We also develop a new inkjet printing system that can generate droplets of such PU solution and deposit them onto the desired positions. Consequently, the dried solid micro-lens array is successfully fabricated after solvents completely drying. Many industrial applications for those micro-lens arrays can be found in LED package, LCD components, optical fiber component, and so on.

Introduction

It is well-known that the micro-lens and lens array, particularly has played a key role for products in many current industrial applications, such as the digital camera, 3D display, light-emitting diode and so forth.[1,2] Several manufacturing methods were reported in the recent years, which included curable UV, ink-jet method and photo-resist melting.[3-5] These lenses fabricated by those methods are generally characterized with the convex curvature of the surface. In 2004, Chen et al, one of authors this paper, proposed a new microfluidic deposition method that employed water-born solution of Polyvinyl Alcohol (PVA) to fabricate the concave micro-lens.[6,7] It is noticed that those PVA lenses were made with negative curvature (concave) due to the well-known coffee-ring effect in evaporation process.[8] In the present paper, we further explored a new method to obtain positive (convex) microlens and lens array that were fabricated by waterborne polyurethane (PU) on the specifically treated substrate. Once again, we are of much interest in using micro droplets to produce such a microlens and array, which the fluid material solution contains at least two components of solute and solvent contents. The microlens could be immediately self-formed by the solid content after the solvent part of droplet has naturally evaporated in the end.

Design and Equipment

Materials of Microlens

The transparent material waterborne polyurethane (PU, optical index n ≅ 1.5) was used to fabricate the lenses on glass substrate (Soda lime). Waterborne PU is offered from the GPI-tech (Taiwan-based company), with 18% solid content. We diluted waterborne PU to 6% by D.I. water with simple processing. For the purpose of forming high contact angle lens, we modified substrate surface from hydrophilic to hydrophobic with 1% Teflon solution. 6% Teflon® solution (DuPont®, USA) was diluted to 1% by diluent FC-40 (Acros), then coated the 1% Teflon solution onto glass by spin coating and baked under 150°C, 15 minutes, then 260°C 15 minutes by the hot plate to form a uniform hydrophobic surface.

Fabrication Equipment

The fabrication of the microlens needs droplet dispenser and its driven controller. Whenever the inkjet signal was send out from the driven controller, the droplet would be jetted by drop-on-demand (DOD) mode. However, it could only fabricate single lens, for the lack of the motion of the dispenser or the substrate. Furthermore, to obtain the microlens array, the motion print system is necessary. The system assembled by 3D-jet Laboratory is called PrintFab system. The PrintFab consists of digital (CCD) cameras, inkjet control board, system control program, motion stages, motion control module and control computer. It is already a fully computer-controlled system as shown in the Figure 1. There are two CCD cameras; one is equipped for top-view capture, yet the other is equipped for side-view capture. The top-view CCD camera is used to observe the patterns of microlens. It can measure the size of single lens and lens array through the control program. The side-view camera is used to observe the droplet behavior jetted by the drop dispenser. The optimal controlling parameters of the dispenser could be obtained by the droplet observation using side-view CCD camera.

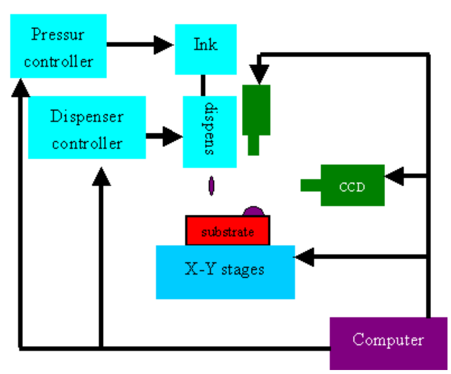

Figure 1. The Schematic configuration of the inkjet equipment system for the lens array fabrication

The function of the inkjet control board provides the jet signal of the dispenser. It accepts the firing signal from the control program and then sends the jetting signals to the dispenser. The inkjet control board could be MicroFab JetDrive 3 controller or functional generator made by OES own laboratory. There are two motion stages; one is X-direction stage and the other is Y-direction stage. Two stages can carry the substrate to move in two-dimensional motions. The micro-stepping motor driven is used to drive the stage. The accuracy of the stage could be less than 5 micrometers (1um = 10^{-6}m).

The inkjet control board and the motion stages are both connected to the control computer. The computer installed with a control program (in LabView®), to connect the motion stages, control board and CCD cameras. Integrating with the LabView program, all controlling jobs can be simply run in a computer by any user. In this program, the control of the dispenser, motion stages and image capture would be operated in the same window. Whenever the single microlens would be fabricated by jetting, the control of the dispenser should be only used on a static stage position. Instead, it would need two controllers mentioned above whenever the microlens array would be fabricated. At this time, the dispenser and the motion stages would be directed by the control program. The program, which provides the jetting parameters of the dispenser and the interval parameters of the motion stages, could be operated as an automatic printing system.

Inkjet Control System

In the inkjet technology, the printing controller always plays the important role to drive a print head. In general, a printing-controller is used for a specific print head. If it is necessary to use multi-types print head in the printing system (named PF in 3Djet Lab), the printing controller has to be changed. It is inconvenient for the user to change the controller. Besides, it needs two or more controllers and driving programs in the same printing system. For the multiple-head purpose, the present control system is designed to be able to drive all kinds of print head, including thermal and piezoelectric print head. It can provide square pulses for thermal print head and ladder-shape pulses for piezoelectric print head. Besides, it also provides high current and voltage, because thermal print head generally needs large current to heat resistance yet piezoelectric print head needs large voltage to drive actuator. The present controller consists of a waveform generator and an amplifier to provide pulses for operating print head and a switch to exchange print-head. The flowchart is design in the following Figure 2. At first, the controller must receive all parameters of waveform from the computer terminal. Then the parameters are recorded on the memory of the controller. If the trigger signal is exported from the computer, the counter of the controller starts counting the address of the memory and the digital signals are exported from the memory. Depending on digital-to-analog converter (DAC), the digital signals are converted to the analog pulse. But the analog pulse is still too small to drive print head. So it is necessary to amplify the small pulse by the amplifier. Finally, the channel expected to drive the print head is selected by the switch.

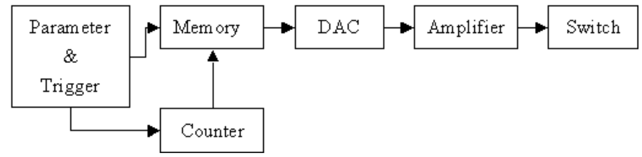

Figure 2. The design flowchart of inkjet controlling hardware for the present fabrication system

Graphic Measurement

The dimension of a microlens is one of the most important parameters that we are concerned in the fabrication. Generally speaking, the most popular way to measure such tiny things (smaller than 1 mm) is to employ the microscopic devices that can easily measure dimensions from a calibrated camera. Therefore, in 3Djet Lab, we capture images from the CCD camera with the zoom lens to measure the dimension of microlens. For single microlens whose diameter is between 60 um and 1000 um, it is hard to measure its diameter directly, but we can estimate it from the area if we can extract the rim of microlens from its background by the image processing. The formula of estimating diameter from area is as below:

$$waddel\ disk\ diameter = \sqrt{\left(\frac{4\times area}{\pi}\right)} \tag{1}$$

By image processing, we also can estimate the center of a microlens by gravity method and find out its contour. Usually, we always put the contour on its raw image and show on the screen to make sure that the data is credible. But how to measure a microlens array distributed in a 5 cm × 5 cm region which is out of ranges of the CCD camera and each of them is about 250 um in diameter? In 3Djet Lab, we can do it well with stability by building image that looks like a jigsaw. With a calibrated CCD camera, we can calculate the dimension of a picture at one position through the CCD resolution, so we can move the microlens array by motorized stages to next position and take another picture. Following the procedure, each single picture is attached to a big picture and we can find out all microlens in this big picture by image processing, as showed in Figure 3. In addition, each lens in the big picture is assigned a number and saved with its measurement data. Any user can check out the data of each lens from the number on the big picture and see the full view of microlens array. For example, Figure 3 is made up with multiple pictures to measure the dimensions and center for every microlens in the array.

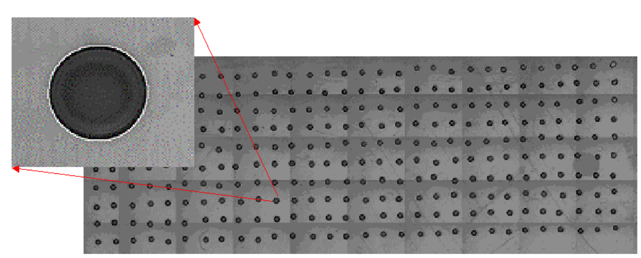

Figure 3. Graphic measurement of microlens array

Experiment and Results

The equipment used for micro lens array production was our PF machine mentioned above. A 60μm orifice diameter piezoelectricity inkjet head (Microfab, USA) was set up to jet waterborne PU solution on Teflon coated glass. Each micro lens in array was jetted with 75 droplets, and the pitch between lens and lens was set 700 um. The water evaporation rate during lens liquid drying was controlled in a slow and uniform way. Contact angle of micro lens was measured by the FTÅ125® (First Ten Ångstroms®).

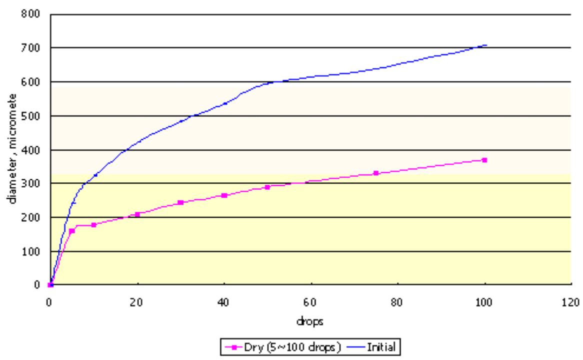

Figure 4. The relationship of droplets vs. microlens initial diameter and dry diameter

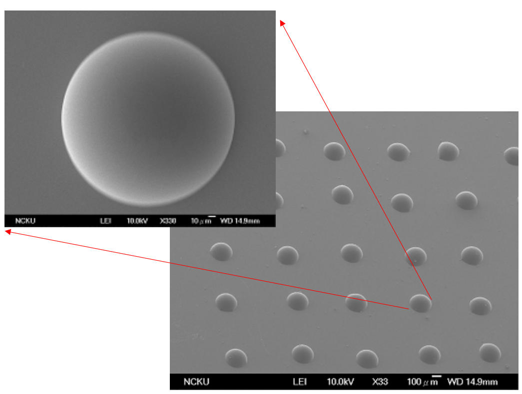

Figure 5. SEM pictures for the microlens array with about 292.9±8.35um in diameter and the contact angle of micro lenses are around 65°.

The relationship of droplets versus lens initial diameter and dry diameter as showed in figure 4 was confirmed before lens array production, so that we can find the data of pitch setting. The shape of micro lens made of waterborne PU by inkjet technique is semi-spherical. Our PF machine can automatically measure the diameters and relative coordinate of micro lenses in array. The lenses are about 292.9 ± 8.4 um in diameter and the contact angle of micro lenses are around 65°. Figure 5 showed a region of micro lens array by scanning electron microscope (SEM). There is no coffee-ring phenomenon found in the microlens array. But the alignment of micro lenses is somewhat not so straight; the vibration of the stage during the moving may cause it. The coverage of micro lenses array was about 27.2%. Shorter pitch also has been tested to increase the density of micro lens array, but the adjacent lenses were easily merged to one lens if token carelessly. Printing pattern or solid content of waterborne PU solution could be changed to get higher coverage.

Conclusion

We proposed in the study that the micro-lens array is designed and fabricated by inkjet printing water-born polymer solution. The microlens was demonstrated with convex shape and size of 292.9 ± 8.4 um diameter without coffee-ring; the relationship of droplets versus lens initial diameter and dry diameter was quantitatively found as well. Meanwhile, the surface of the substrate was coated with Teflon before micro-lens array is formed onto. The specific fluid material of lens was formulated with low viscous solution of water-born Polyurethane (PU). In addition, we developed a new inkjet printing system that can generate droplets of such PU solution and deposit them onto the desired positions. The system consists of digital (CCD) cameras, inkjet control board, system control program, motion stages, motion control module and control computer. In terms of array size, the column and the row can be up to 100 × 100 and more. Many industrial applications for those micro-lens arrays can be found in LED package, LCD components, optical fiber component, and so on.

Acknowledgment

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