PRODUCTION OF POLYMER MICROLENSES BY DROP DEPOSITION

J.Pertuiset[1], C.Chanut[2] , J.Hosek[3]

[1] CTU Faculty of Mechanical Engineering, julien.pertuiset@insa-lyon.fr
[2] CTU Faculty of Mechanical Engineering, cecile.chanut@insa-lyon.fr
[2] CTU Faculty of Mechanical Engineering, jan.hosek@fs.cvut.cz

Abstract:

A microlens is a small lens, generally with a diameter less than a millimetre and which may be as small as 10 micrometres. Microlenses are key components for optical devices. Thus they are widely applied in several application fields such as communications (optical fibers), 3D displays, optical data storage and photodetectors. Numerous classes of microlenses exist, depending on the technology and the specific applications. Today, polymer microlenses have been developed because of their low cost and good properties. Also, a large variety of fabrication processes have been developed for plastic/polymer-based microlenses, such as embossing, soft lithography, micromolding , photolithography, electron beam lithography, reactive ion etching, the laser assisted technique, and printing techniques. In this article, we will introduce drop deposition of polymer, a way we used to develop microlenses in laboratory.

Keywords: microlenses, polymer, drop deposition, curing, optical properties.

1 Introduction

Through our study, our goal was to produce very small polymer lenses by drop deposition on a substrate. To perform that, we have chosen a polymer with convenient optical properties. Then, we have used a precision dispenser for the deposition. The drops were then cured to make solid polymer lenses. The curing can be made either by heating or with UV, depending on the polymer type. The shape of the drop is affected by different parameters: the volume deposited (controlled with the dispenser), the surface tension, the contact angle between the polymer and the substrate and the curing if a shrinkage occurs. The deposition parameters, the polymer and the substrate used, or even the curing are then the parameters that we can play on to obtain microlenses in a reproducible way, with given dimensions and a given geometry (and thus a given focal distance) [1].

2 Experimental Setup

2.1 Setup

Our setup is divided in three different parts: the Ultimus II [2] is the dispensing system (from Nordson EFD), the syringe with the chosen tip and finally the air compressor.

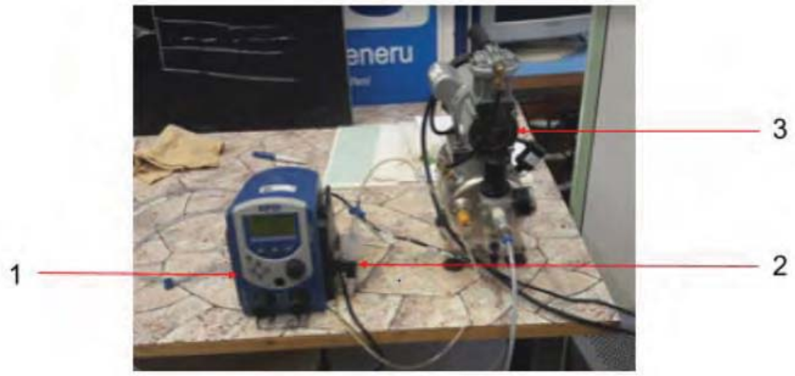


Fig.1. Experiment setup for the drop deposition

On the picture just above we can distinguish:

- Ultimus II features 0-15 psi (0-1 bar) constant-bleed air pressure regulation and provides greater control when dispensing any type of fluid. We can play on three different parameters to change the diameter of the drop: the time of deposition (controlled by a foot pedal), the air pressure regulation and the vacuum.

- The syringe barrel, capacity of the syringe 3cc. It means it can contain 3 cubic centimeters (cc) of a liquid. The brand is also Nordson EFD. The syringe is molded from a polymer that gives chemical compatibility. A piston is used to provide consistent fluid deposit by prevending air entrapment. We put precision tips at the extremity of the syringe. There are 2 different diameters (0,20 mm and 0,15 mm) for the tips (same brand).

- The Air Compressor: The air compressor permits to deliver air at higher pressure from the compression of air at atmospheric pressure. Model MB0102S, brand: PUMA.

To measure the dimensions of the deposited drops, we use a microscope associated with a camera. The camera offers a view from the top, and we use a mirror prism to have also a view from the side. Then it is possible to make measurements on the drop.

2.2 Choice of the polymer

Before beginning our experiments, we had to find some polymers which respected different criteria for our study and which could be used with our devices. The criteria are:

- Transparency;
- Not expensive;
- A viscosity not too high in order to make the deposition easier;
- A low shrinkage after curing;
- A contact angle greater than 0°.

This why we have studied different articles found on the internet in order to find some interesting polymers and their properties. We have finally selected the NOA81 [3] of the brand Norland Product © with the following properties:

Tab. 1. Properties of the NOA81.

Name	Curing Method	Refractive Index	Viscosity	Contact angle
NOA81	UV ($E=2J/cm^2$)	1,56	300 cps at 25°C	40° on glass

The NOA81 is easy to obtain and have a reasonable cost. For the curing, the polymer is sensitive to UV with wavelengths between 320 and 380 nm (peak at 365 nm) so it will be possible for us to cure it. The viscosity before the curing is not very high (300 centipoise corresponds to motor oil).

2.3 EDM

To perform a good reproducibility of our experiments, we have decided to fix the syringe on a device used for the Electrical Discharge Machining (EDM). The machine is a Sodick LP1 model. The motorized arm allow us to choose the motion of the syringe in every direction.

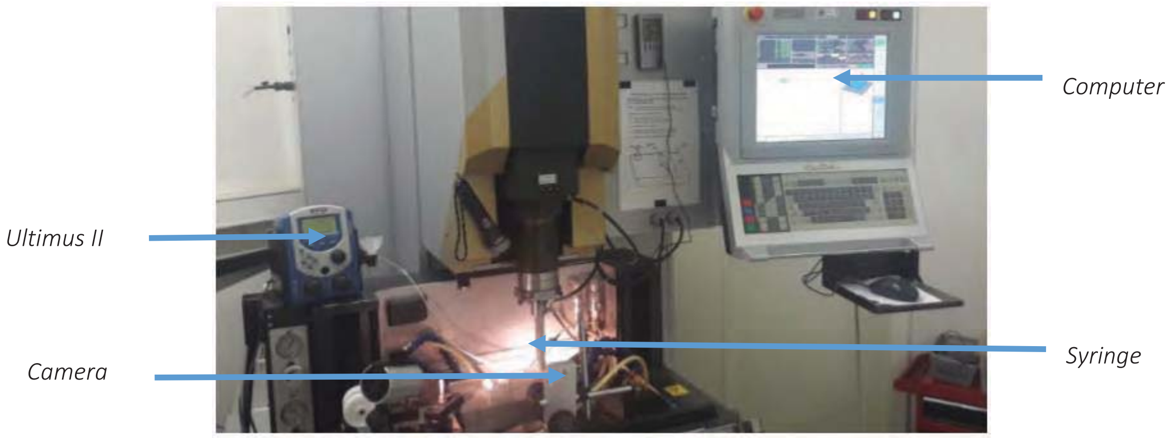


Fig.2. Experiment setup with the EDM

We can control the motion both thanks to a controller module (which does not appear on the picture above) or thanks to the computer. The computer has two different modes: manual or program (execute). In the manual mode we can change the values of the position (X,Y and Z axis) by modifying the absolute value or by incrementing the values on the three axis. With the device, it is then possible to control the position of the deposited drops, but also to set the inclination of the syringe. This parameter influences the amount of liquid that comes out of the syringe, and it is now possible to control it.

2.4 Image Analysis Software

We use different software to analyze our images during the laboratories sessions:

- IC Capture 2.4;
- IC Measure 2.4.

These two software allow us to take snapshots and videos thanks to the camera and make some measurements.

For the analysis of the snapshots and videos, we have used the software GIMP 2. This software allows to calculate distances in pixel. Thanks to that, it is possible to find the real distance by knowing the length of a pixel (calibration). The calibration is performed with a known distance such as the diameter of the syringe or the thickness of the substrate.

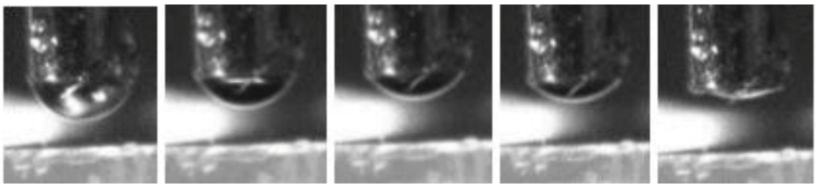
With the diameter (d, in µm) and the thickness (e, in µm), it is possible to find the contact angle of the drop. First we can compute the curvature radius (R, in µm) with the following formula $R = \frac{1}{2e} * (\frac{d^2}{4} + e^2)$ (1).

Then, the contact angle $\boldsymbol{\theta}$ is: $\theta = \sin^{-1}(\frac{d}{2R})$ (2). It is also possible to compute the apparent surface of the drop which can be a useful parameter to compare the drops: $S = R^2 * \cos^{-1}\left(\frac{R-e}{R}\right) - (R-e) * \sqrt{R^2 - (R-e)^2}$ (3).

3 Experiments

3.1 Drop deposition with the EDM

We choose an angle of 90 ° and create a program to have repeatable conditions. The initial position (z0) of the syringe is 0,4mm above the substrate. The pressure P2 is then set to create a meniscus:



P (inH2O)= 0,7 1 1,5 2 2,5

Fig.3. Meniscus created at the end of the tip when at the syringe is at 90°

A second position (z1) very close to the substrate is then set to bring the meniscus in contact with it. We then go back quickly to z0 and the deposition is made. The distance z1 will also influence the final shape of the drops. On the following picture, we can observe an array of lenses. The 3 first drops from the left are made with z1 = 0,05 mm, the 3 next are made with z1 = 0.04 mm and the 3 last are made with z1 = 0.03 mm :

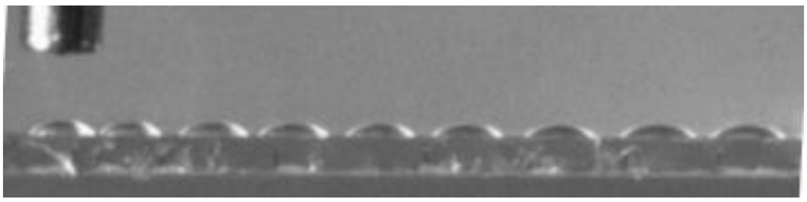


Fig.4. Array of lenses obtained with the previous deposition technique

We can see that the liquid is not spreading in the same way for each value of z1, so it is a parameter that has to be taken into account to determine the final shape of the lens. The problem is that glass substrate is not perfectly planar There can exist variations up to 0,02 mm along the surface. This is why it is hard to control perfectly z1. That is why we decide to fix z1, and only change the pressure of deposition with the Ultimus II. Finally, only one parameter will be modified to achieve the different sizes of drops that we want.

Fig.5. Top view of the array of lenses

By setting different pressures, we can create various height of meniscus. This height will modify the size of the deposited drop. From the experiments, it is possible to draw some graphs to represent the evolution of the dimensions of the deposited drops with the height of the meniscus:

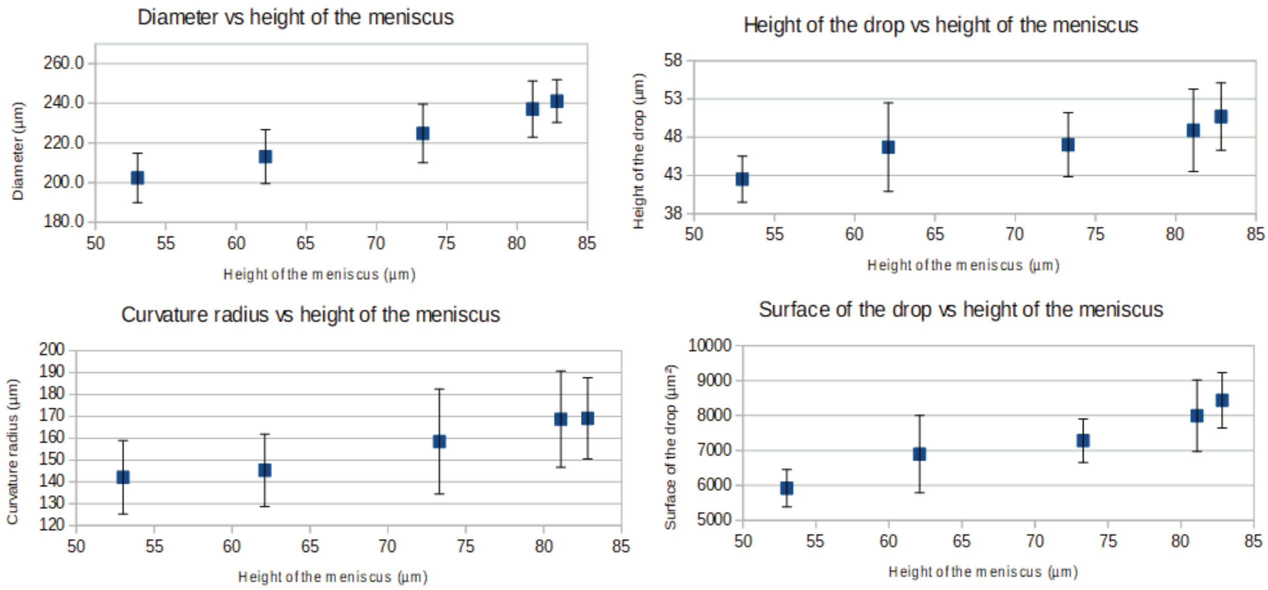


Fig.6. Dimensions of the drops vs height of the meniscus

We observe that the diameter, the height, the curvature radius and the surface of the drops are decreasing when the size of the meniscus is decreasing, which was predictable. We can also notice that for the curvature radius and the height of the drop, the standard deviation is approximately equal to 5%. Thus, these values are less reliable than the ones obtained for the diameter and the surface of the drops.

Tab. 2. Study of the contact angle of the drop and the height of the meniscus according to parameter P2

P2 (inH2O)	0,9	0,8	0,6	0,4	0,2
Height of the meniscus (µm)	53	62	73	81	83
Contact angle (°)	45,5	47,4	45,4	44,9	45,6
Standard deviation	2,0	2,6	2,8	2,6	2,2

It seems that the contact angle doesn't really depend on the meniscus, and is always worth between 45 and 47,5° approximately.

3.2 Curing

Before observing some images through our lenses, we need to cure our drops so as to form microlenses. For the UV curing of the drops of NOA81, we use a nail dryer. Its power is 6 mW/cm² (measured with the UV light meter "digital instrument YK – 35UV"). We know from the manufacturer of the NOA81 that 2 J/cm² are needed to fully cure the polymer. Then, we will have to put the drops 333s under the UV source to create our lenses.

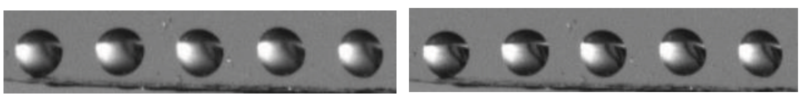


Fig.7. The same drops before (on the left) an after curing (on the right)

By eye, there is nearly no differences, but the drops are now cured and are then hardened. It is now a micro-lens. For 11 consecutive drops, the diameter has been measured (from the top view) before and after curing. The mean difference computed is 0,3%, so it is looking that the shrinkage after curing is very low, and don't have a big influence on the final shape of the lenses.

3.3 Images obtained through the lenses

It is possible to observe objects through the microlenses. For example, we observed the cover of a book, placed at 50 mm behind an array of lenses that we created. The following pictures show the image obtained by focusing the camera on the surface of the glass and the image obtained on the image of the book through the lens.

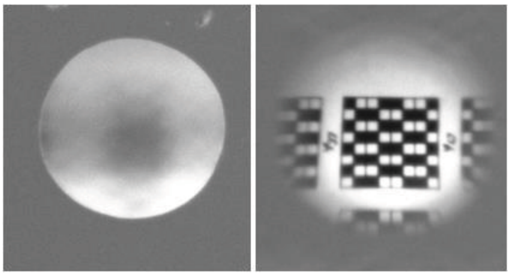


Fig.8. Focus on the surface of the glass (left) and on the image of the book through the lens (right)

From the distance between the surface of the glass and the image through the lens and the distance between the substrate and the book, we can compute the focal distance thanks to the following formula:

$$\frac{1}{f} = \frac{1}{D_{glass/object}} - \frac{1}{D_{glass/image}} \quad (4)$$

The focal distance (f) can also be computed with the curvature radius (R) and the refractive index (η):

$$\frac{1}{f} = \frac{n-1}{R} \quad (5)$$

We obtain results between 500µm and 800µm.

4 Conclusion

To conclude, we can say that we have reached our goal as we found a technique to deposit micro drops on glass. We have reached values ranging between 200 and 240 µm for the diameter, between 40 and 50 µm for the height leading to a contact angle of approximately 45° on the glass. We have also implemented one protocol with the EDM which allowed us to create arrays of lenses with a good reproducibility. Finally, we were able to cure our drops in order to study the optical properties and observe images through them.

If we have had more time, we could have tried to deposit other polymers than NOA81 and use more different substrates for the deposition so as to create lenses with different shapes and sizes. It could have been also interesting to create a template on our substrate to make perfectly reproducible arrays of lenses.

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