Complete Digital Fabrication of Polymeric Microsieves

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Abstract

We report on the substitution of a fabrication step for the manufacture of polymeric microsieves, carried out manually so far, by an inkjet printing technology. As published previously [1] the microsieves are manufactured by using a solution of Poly(methyl methacrylate) (PMMA) in chloroform. However, this solution is not printable with an inkjet printer due to its high vapor pressure. Hence, the PMMA solution was replaced by a commercially available UV curable ink to enable inkjet printing. This variation of the ink leads to a UV exposure driven fabrication method enabling the prospective production of microsieves with an automated high throughput manufacturing. Additionally, the digital fabrication character of inkjet printing allows the manufacture of customized microsieves for given filtration application requirements like size selectivity and mechanical stability.

Introduction

Showing a high size selectivity and a minimum flow resistance microsieves are applicable for a wide range of filtration processes [2-5]. Already introduced about 10 years [2] ago meanwhile different approaches were found for their manufacture:

(1) Etching of silicon nitride (standard mask lithography or laser interference lithography) [2]
(2) Interference Holography [3]
(3) Phase Separation Microfabrication [4]
(4) Via Particle Assisted Wetting [5] and Breath Figure Patterns [6]

Additionally, in a previous work we already introduced inkjet printing as a cost effective alternative to manufacture customized microsieves [1] by a digital fabrication method. The principle is based on the use of liquid sessile drops as templates for the creation of holes in a polymeric film: initially an aqueous ink is inkjet printed to form sessile drops on a solid subcarrier. Subsequently a solution of PMMA in chloroform is deposited manually. Afterwards chloroform evaporates faster than the sessile drops which then created holes in the solidified polymer film.

The aim of this work is the substitution of the manual deposition of the polymer solution by inkjet printing to achieve a complete digital fabrication of microsieves. Therefore, the polymer solution not being printable due to the high vapor pressure of chloroform was replaced by a UV curable ink.

Materials and Methods

Procedure

The extended procedure for the complete manufacture of microsieves via inkjet printing is based on a slow evaporation of the first printed ink creating the pores and a fast curing of the film forming UV-curable ink. The principle can thus be termed shortly as *Template Inkjet Printing via UV Curing*. The overall procedure is given in fig. 1.

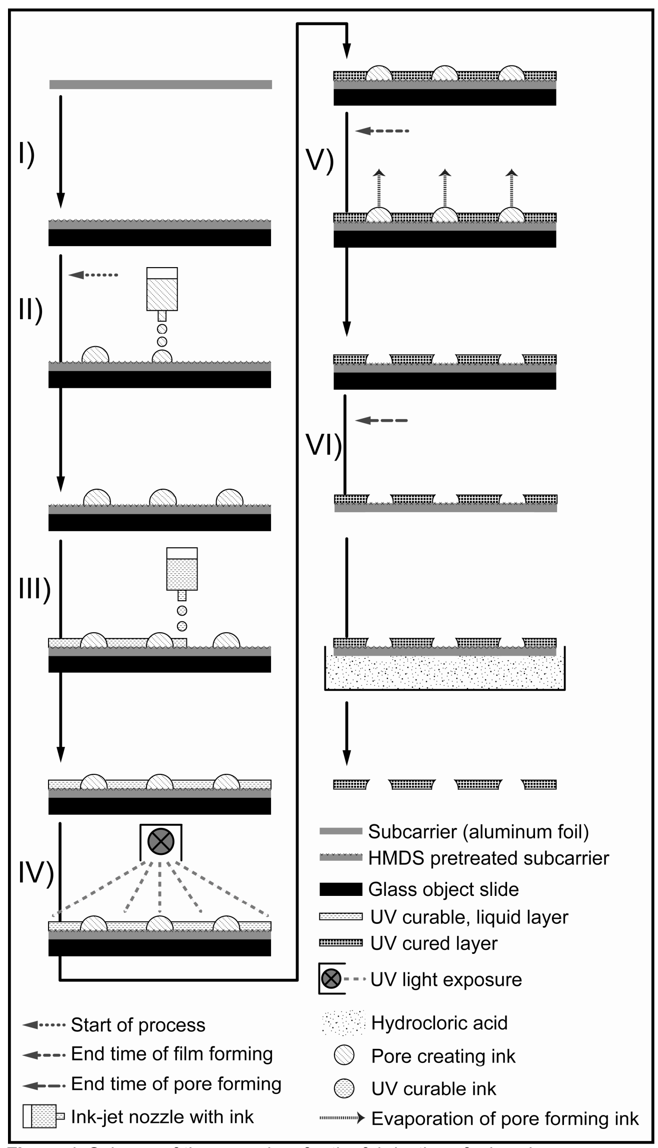

***Figure 1.** Scheme of the procedure for the fabrication of microsieves.*

Both printing steps II and III were conducted by using the Dimatix Materials Printer DMP 2831 with 10 pL printheads. The process steps I, II and VI rely on [1] and are described there in detail. Steps III, IV and V represent our new approach:

I) Commercially available aluminum foil is used as subcarrier. To ensure the formation of sessile drops with a high contact angle by the aqueous ink the foil is functionalized with 1,1,1,3,3,3-hexamethyldisilazane (HMDS, Merck). Additionally the foil is mounted on a glass object slide.

II) The aqueous ink is printed such that a number of individual droplets merge on the subcarrier to form separated sessile drops later acting as templates. As ink a mixture of 30 wt% water and 70 wt% ethylene glycol is used.

III) A commercially available black UV-curable ink (Crystal UFX7683, Sunjet) is printed around the sessile drops. In this state both inks are liquid on the subcarrier, get in contact and should not merge with each other.

IV) The UV curable ink is cured for one minute via UV exposure by using the BlueWave-50 (Dymax Light Curing Systems). To ensure the creation of holes in the film this curing step has to be faster than the evaporation of the sessile drops.

V) The polymer is cured and thus solid. The complete evaporation of the sessile drops takes places. Furthermore, before the next step a frame can be printed around the microsieve with the UV-curable ink and be cured. This gives a mechanical stable part to handle the microsieve after the last manufacturing step (for example to lift it up or transfer it).

VI) The aluminum foil is removed from the glass object slide and dissolved in an aqueous solution of 17 wt% hydrochloric acid. After dissolution of the subcarrier the completed microsieve is floating on the aqueous phase.

Print Patterns

For printing both layers two print patterns were generated like exemplarily shown in fig. 2. The grid has a resolution of 5080 dpi. Every black pixel gives an individual droplet of the aqueous ink, each grey pixel gives an individual droplet of the UV-curable ink.

First the aqueous ink is deposited to create a template layer with separated sessile drops. Each sessile drop consists of a number of individual droplets (in this example 13) deposited at a drop spacing of 5 µm and merging on the substrate. By changing the number of the individual droplets the volume of the sessile drops and therewith the resulting pore size can be adjusted.

Secondly the UV-curable ink is printed around the sessile drops with a drop spacing of 20 µm (in this example).

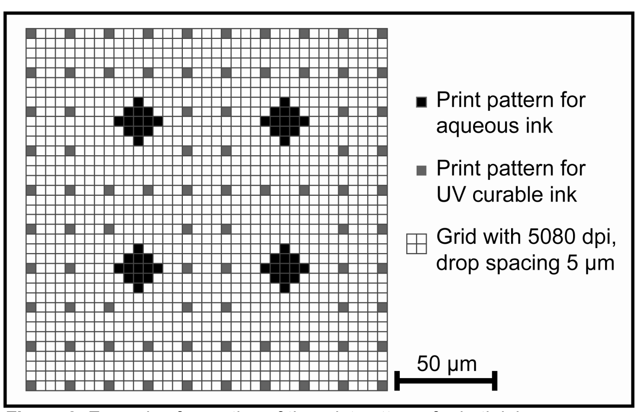

Figure 2. *Example of a section of the print patterns for both inks.*

Evaluation

The evaluation of the printed patterns was done with the light microscope Leica DM4000M. The layer profile of the microsieves was examined with the Dektak 150 Surface Profiler (Veeco) and laser scanning microscope VK-9700 (Keyence).

Results and Discussion

Complete Inkjet Printed Microsieves

In the first experiments the number of the pore-forming aqueous droplets was kept constantly at 24 droplets. The UV-curable ink was printed around the sessile drops with a drop spacing of 10 µm. It could be confirmed that the new procedure leads to the formation of a film with well ordered circular holes (fig. 3a). The thickness of the polymer layer lies in the range of 5 µm to 8 µm with some peaks at 12 µm around the pores (fig. 3b). This already gives a qualitatively good mechanical stability and the microsieves were not harmed by the mechanical stress caused by the dissolution of the aluminum foil with hydrochloric acid. But for a manual treatment, for example for a transport process, an additional support was needed. For this purpose a frame of the UV ink was printed around the sieve and cured. With this microsieves with an area of 1 cm² could be produced and be handled manually (fig. 4).

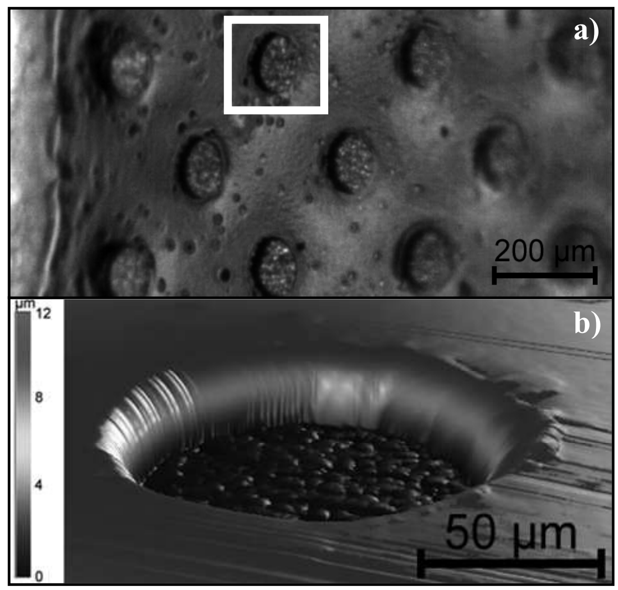

Figure 3. *Microsieve, completely fabricated via inkjet printing: a) camera image; b) 3D profile of the pore marked with a frame in 3a (taken with a Dektak 150 Surface Profiler)*

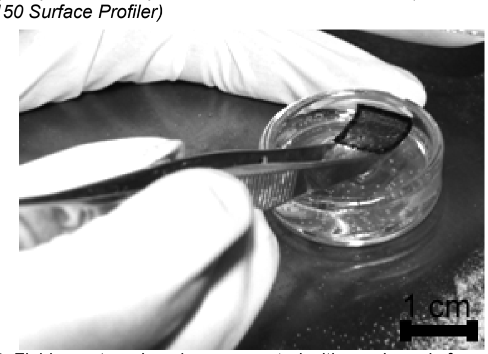

Figure 4. *Fishing out a microsieve supported with a polymeric frame*

By varying the number of pore forming droplets between 3 and 24 microsieves with pore diameters between 38 ± 4 µm and 114 ± 10 µm could be realized. All results are given in table 1. For each result 5 microsieves were investigated whereby for each sieve 26 pore diameters were measured by using images of the light microscope.

Table 1. Realized pore diameters of inkjet printed microsieves

Nr. of aqueous droplets [n]	Average diameter of the pores [µm]	Stand. deviation of the pore diameters [µm]
3	38	4
5	51	6
9	62	6
13	73	7
17	89	9
24	114	10

Skin Formation in pores

With the investigation of the pores with the light microscope a skin of residues of the UV ink at the ground of each pore was observed. Measurements with the laser scanning microscope showed that these skins mostly cover the whole area of the pores. The skins exhibit a thickness of 1.4 ± 0.2 µm in the centre and become thinner outwards towards the contact line of the microsieve. After dissolution of the aluminum foil some skins break off from the polymer film of the microsieve (fig. 5) but are still connected to the microsieve.

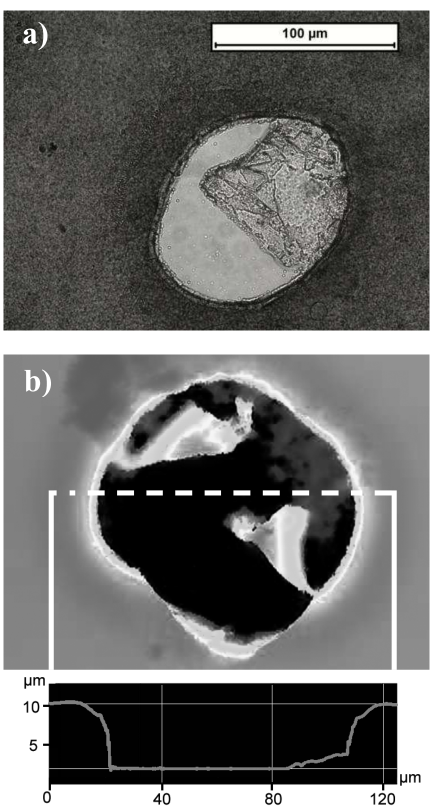

Figure 5. *Thin polymeric skin in the pores: a) Image of one pore (light microscope); b) Image of another pore (laser scanning microscope)*

Conclusion

Inkjet printing as a digital fabrication technique was used for the complete manufacture of polymer microsieves. After the deposition of an aqueous ink forming separated sessile drops on a solid substrate a UV-curable ink is printed around them and cured.

By changing parameters of the print patterns microsieves with pore sizes between 38 µm and 114 µm and a homogeneous pore size distribution could be realized. Microsieves with an area up to 1 cm² were produced and exhibited enough mechanical stability to be handled manually after printing a polymeric frame around the whole microsieves.

Actually, the major challenge in this process is a thin skin of the UV ink within the pores which will be overcome in further research.

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Jens Hammerschmidt has received his Master of Arts in German and Media Production in 2008 at Chemnitz University of Technology. Since then he is Ph. D. Student at the Institute for Print and Media Technology in Chemnitz in the department of Digital Printing and his scientific interests are focused on digital fabrication based on inkjet printing technology.