Microfluidic Liquid Jet

Khurram Ali Chohan, University of Freiburg, Germany

September 9, 2014

Abstract

A new and simple way of making microfluidic chip that can produce liquid jets with micrometer diameters while operating at very low flow rates. The chip production is based on established soft-lithographical techniques employing three-layer design protocol. The chips are designed to generate liquid jets exiting at right angle. The device should be able to work under vacuum conditions making them highly relevant for a wide range of applications, for example, for free-electron lasers.

Contents

1 Introduction

The generation of liquid jets with diameters in the micron-or sub-micron range is of high relevance in many technologies such as microfiber spinning,inkjet printing and the microanalytical dosing of liquids, mostly applied for pharmaceutical formulations and in microbioanalytics. A very challenging example of the latter is its use for free electron lasers (FEL) to provide sub-micron diameter liquid jets for femtosecond X-ray nanocrystallography[2, 3]. The enormous intensity of the X-ray pulses from FELs demands a continuous stream of fresh samples, in some cases also under high vacuum conditions, which can be realized by the generation of very small liquid jets that consume only very small amounts of samples over time.

2 Theory

Thin liquid jets can be generated based on the principles of hydrodynamic focusing using gas sheaths developed by Gan-Calvo et al. Microjets can also be realized by other techniques such as high-pressure liquid flows or electric fields(electro-spinning). The success of pressurized gas systems is based on the gas dynamic virtual nozzle (GDVN)-principle where the liquid enters a volume which is completely filled with pressurized gas that is moving towards the nozzle's exit. This gas flow controls the liquid's shape and flow, forming a continuous liquid jet that is smaller than the liquid inlet geometry and that exits the nozzle without wall contact. Hence, nozzle clogging is essentially eliminated as an experimental concern and sub-10m jets and droplets will only be feasible using the GDVN-principle[4, 5, 6]. Further, the underlying physics of the GDVN-principle are well understood which helps to create devices that allow resilient jetting of a wide range of liquid samples with only very little consumption of samples overtime.As an example, recent publications show that sub-micrometer liquid jets at flow rates around 75 lh1 are possible using this principle[8]. This high efficiency of sample consumption for the generation of continuous liquid jets is a key element for micro-analytic applications.[7] Figure 1 shows a Light microscopic image of a microfluidic jet device that focuses water jet with pressurized air.

Figure 1: Microfluidic jet device

3 Device Fabrication

3.1 Microfluidic Soft Lithography

The microfluidic liquid jet devices are fabricated using established soft lithography techniques. This process can be seen as a two-part sequence.
The first part is about creating a microstructured master which will then be used as a molding template in the second part of the device fabrication routine. This master can be created relatively fast which enables rapid prototyping due to the use of established SU-8-based photolithographic procedures. Further, this master can be re-used multiple times in the subsequent fabrication process.
The second part of the fabrication process can be performed easily and a large number of nozzle geometries can be replicated with each single mold. The molding and device sealing steps only require minimal equipment, which should help to migrate the microfluidic liquid jet technology to a wide range of users. An overview of this process is illustrated in Figure 2.

3.2 Microfluidic liquid jet device fabrication

The integration of the GDVN-principle into the microfluidic chips is realized by fabricating 3D-microchannels that are replicated from multilayered SU-8-microstructures on a polished silicon wafer. The underlying photolithographic sequence for the creation of these multilayered templates involves repeating cycles of spin coating the photoresist, photo mask alignment and UV exposure. Next, the master structure is replicated with

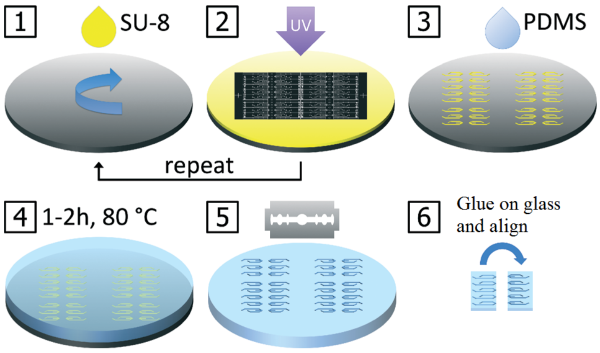

Figure 2: Soft lithographic fabrication sequence for microfluidic liquid jet devices. The photolithographic master fabrication involves repeating steps to build up a multilayered microstructure: spin-coating (1) and UV-exposure (2). After development, the uncured photoresist is removed and the resulting microchannel template is replicated using polydimethylsiloxane (PDMS). The replica is peeled off the master device and inlet ports for fluids are added. The polymer is cut using a razor blade (5)and the device is fabricated by transferring the structure on glass via glue and then stick together (6)[1].

polydimethylsiloxane (PDMS) which, in a single molding step, yields the upper and lower halves of the three-dimensional microchannels. Scanning electron micrographs of these PDMS-nozzle geometries. Next, the epoxy glue is made separately and applied on the PDMS. The glass/plastic material is then attached with PDMS. After several minutes (10-15min), when the glue is partially hard, the features are transferred on the glass/plastic material. The last step involves the exact alignment and sealing of this pair of glass/plastic-microchannel halves. The precise alignment is achieved by additional multilayered orientation structures next to the main nozzle geometries. These guiding pairs of 3D-microstructures have already been included in the mentioned photolithographic steps and, now, facilitate the necessary alignment almost automatically by snapping into each other. This results in well-centered microchannels and liquid jets that exit the microfluidic nozzle in a straight line at perfect right angles.

3.3 Nozzle Design

The benefit of using softlithography-based microfluidics for the generation of liquid jets lies in the high reproducibility of microstructures and the precise control over very small features in the micrometer-range. As a result, the liquid inlet is perfectly centered and the jet exits the nozzle's outlet in a straight line. The microfluidic liquid jet devices are designed using the software AutoCAD that allows control of the design parameters of the nozzle geometry that directly determine the conditions for liquid jetting. This microfluidic nozzle design and the design parameters definitions are presented in Figure. 3 and Table 1.

Table 1: List of microchannel design parameters and their definitions along with relevant parameter combinations and ratios

Design Parameter	Definition
ro	Width at the outlet (30 m)
ri	Width of the main channel (15 m)
d	Distance from main channel inlet to nozzle outlet (95 m)
dG	Distance of the gap between main channel inlet (55 m)
dA	Distance of the aperture (40 m)
lA	Length of the air inlet (20.4 m)
a	Angle of the air stream (15)
c	Curvature of the tapering (144.3 m arc radius)
Not shown in the illustration:	
hn	Height of layer n (30 m)
Extra aperture	Presence of an aperture at the top and bottom layer of the nozzl
Relevant design parameter ratios:	
rO : d	dG : dA
ri : rO	lA : ri : lA
(ri +2 lA): rO	(ri +2 lA): d
a : d	c : d

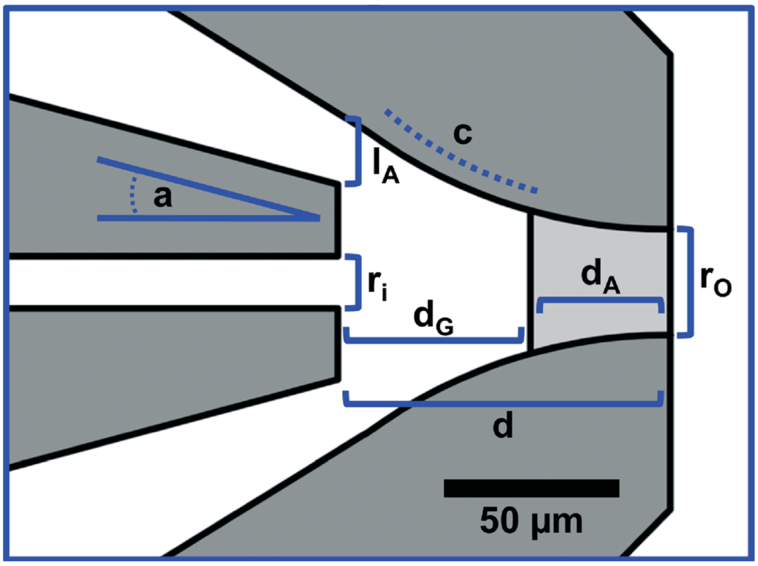

Figure 3: Nozzle design parameters. An illustration of the controllable design parameters is depicted. These features can be adjusted with high precision and reproducibility to fine-tune the jetting behavior of the desired liquid.

4 Results and Discussion

Since the project is totally new idea and 7 weeks time was not enough to complete it. Most of the time was spent in experimental setup and making the fluidic chips. In the end we were successful to make good aligned fluidicchips using plastic and glass material. Some of the test were run and got some good results. The project is still under process.

References

[1] Microfluidic liquid jet system with compatibility for atmospheric and high-vacuum conditions by *Martin Trebbin, Kilian Krger,Daniel DePonte,Stephan V. Roth, Henry N. Chapmanc and Stephan Frster*

[2] N. Mongkoldhumrongkul, S.Best, E.AaronsandS.N.Jayasinghe, J. Tissue Eng. Regener. Med.,2009, 3, 562566

[3] S. N. Jayasinghe, Analyst, 2011, 136, 878890.

[4] A. M. Gan-Calvo and A. Barrero, J. Aerosol Sci., 1999, 30,117125.

[5] D. P. DePonte, U. Weierstall, K. Schmidt, J. Warner,D. Starodub, J. C. H. Spence and R. B. Doak, J.Phys. D: Appl.Phys., 2008, 41, 195505.

[6] R. B. Doak, D. P. DePonte, G. Nelson, F. Camacho-Alanis,A. Ros, J. C. H. Spence and U. Weierstall, AIP, 2012, vol. 1501,pp. 13141323.

[7] H.N.Chapman, P. Fromme, A.Barty, T.A.White, R.A.Kirian, A.Aquila, M.S.Hunter, J.Schulz, D.P.DePonte, U.Weierstall,R. B. Doak, F. R. N. C. Maia, A. V. Martin, I. Schlichting, L. Lomb, N. Coppola, R. L. Shoeman, S. W. Epp,R. Hartmann, D. Rolles, A. Rudenko, L. Foucar, N. Kimmel, G. Weidenspointner, P. Holl, M. Liang, M. Barthelmess, C. Caleman, S. Boutet, M. J. Bogan, J. Krzywinski, C. Bostedt, S. Bajt, L. Gumprecht, B. Rudek, B. Erk, C. Schmidt, A. Hmke, C. Reich, D. Pietschner, L. Strder, G. Hauser, H. Gorke, J. Ullrich, S. Herrmann, G. Schaller, F. Schopper, H. Soltau, K.-U. Khnel, M. Messerschmidt, J. D. Bozek, S. P. Hau-Riege, M. Frank, C. Y. Hampton, R. G. Sierra, D. Starodub, G. J. Williams, J. Hajdu, N. Timneanu, M. M. Seibert, J. Andreasson, A. Rocker, O. Jnsson, M. Svenda, S. Stern, K. Nass, R. Andritschke, C.-D. Schrter, F. Krasniqi, M. Bott, K. E. Schmidt, X. Wang, I. Grotjohann, Lab on a Chip Paper Published on 17 February 2014. Downloaded by Deutsche Elektronen-Synchrotron (DESY) on 22/07/2014 15:08:24. View Article OnlineLab Chip,2014, 14,17331745 — 1743 This journal is The Royal Society of Chemistry 2014 J. M. Holton, T. R. M. Barends, R. Neutze, S. Marchesini, R. Fromme, S. Schorb, D. Rupp, M. Adolph, T. Gorkhover, I. Andersson, H. Hirsemann, G. Potdevin, H. Graafsma, B. Nilsson and J. C. H. Spence, Nature, 2011, 470,7377.

[8] A. M. Gan-Calvo, D. P. DePonte, M. A. Herrada, J. C. H. Spence, U. Weierstall and R. B. Doak, Small, 2010, 6, 822824.