COMPUTER AIDED MICROFLUIDICS (CAMF) – HIGH-RESOLUTION PROJECTION LITHOGRAPHY FOR THE RAPID CREATION OF LARGE-SCALE MICROFLUIDIC STRUCTURES

Ansgar Waldbaur, Bernardo Carneiro, Paul Hettich, Bastian E. Rapp
Institute of Microstructure Technology (IMT), Karlsruhe Institute of Technology (KIT), Germany

ABSTRACT
In this work we introduce CAMF, a process that allows the creation of a physical microfluidic structure from a conceptual block drawing (similar to an electronic circuit diagram) within a few hours. This paper describes the physical creation of a microfluidic chip via maskless lithography based on a digital mirror device (DMD) from digital 3D models created automatically with custom-written software.

KEYWORDS
Microfluidics, lithography, rapid prototyping,

INTRODUCTION
As of today the most commonly used technique for the prototyping of microfluidic structures is their creation in thick layer resists such as SU-8. Such structures are then either used directly in microfluidics or they are replicated by casting (e.g. using polydimethylsiloxane, PDMS). Therefore casting and direct lithography can be considered the most important techniques in microfluidic prototyping. This classical approach has two major disadvantages. First, the creation of the layout is often burdensome busywork. Second, a change in the microfluidic layout usually requires the creation of a new mask which increases both costs and concept-to-chip times. As a solution to this, we implemented a 3D computer aided design (CAD) capable framework that allows the rapid generation of digital three-dimensional microfluidic structures from a conceptual block drawing (similar to an electronic circuit diagram) within a few hours. These models are directly parsed by software and processed by a custom-designed DMD based projection lithography system for maskless lithography. Changes in the microfluidic design can therefore be implemented within a very short timeframe with minimal costs as only changes in digital layouts are required and no intermediate masks need to be created.

EXPERIMENT
The process described in this work is termed Computer Aided Microfluidics (CAMF). It is suitable for enhanced microfluidic system prototyping reducing the design process to the mere creation of a functional block diagram from which the physical structure can be created within a few hours by means of a custom-designed maskless projection lithography system. The software used in this process (the so called CAMF builder) is custom-written and allows the user to compose a microfluidic system as a combination of different microfluidic components (such as different types of mixers, reaction chambers, valves, etc.) selectable from an expandable library of parameterized digital microfluidic models and arranged in drag-and-drop style. Each model is described by means of parameterized extensible markup language (XML) based template. Figure 1 shows an example in form of a Tesla-mixer model together with the parameters (red lines). Setting the parameters allows the CAMF builder to resolve the individual points of the structure (displayed in light blue) and therefore to create the 3D model.

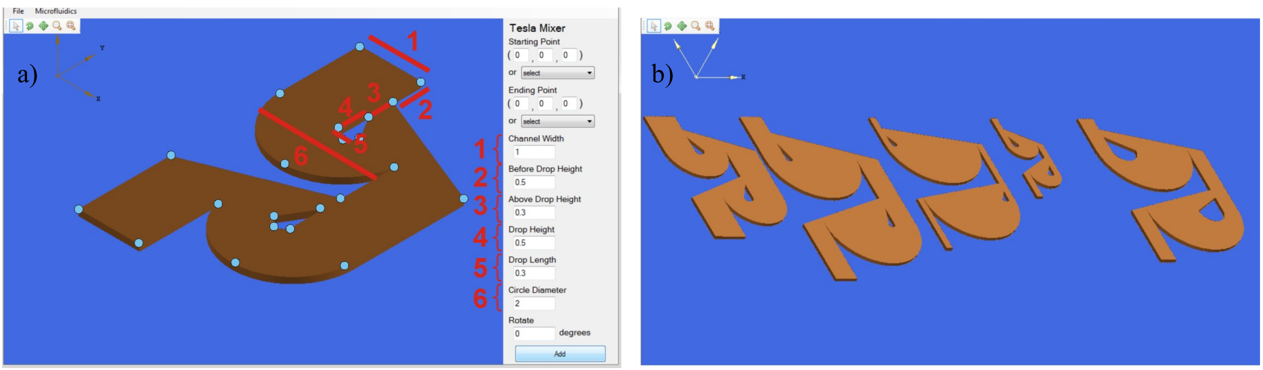

Figure 1: View of the CAMF builder software and of an exemplary microfluidic model (in this case a Tesla-mixer structure). a) The 3D-preview window of the CAMF builder allows viewing and rotating of the structure. The CAMF builder allows various parameters to be set on the model (in this view, the parameters have been highlighted by red bars and the input fields on the sidebar have been labeled accordingly). The user can assign physical distances to the parameters which allows the CAMF software to calculate the structure accordingly. The model itself is described in form of an XML file which relies on points (in this view highlighted by light blue points) that are interconnected by lines or curves. The points can be described by means of formulas using the parameters as variables. b) View of several versions of the Tesla-mixer model created with different parameters

The data created by the software is directly translated to a custom-designed maskless lithography system (as opposed to classical mask based lithography) based on a DMD (figure 2) [1]. These devices consist of thousands of individually addressable micro mirrors which can be tilted to an on- or off-state. To have maximum flexibility, we use a broadband high-pressure mercury lamp as light source, filtered to the wavelength required for each individual application. Thus the wavelength can be chosen according to the application and the system is not strictly limited to UV-sensitive resists only, but ranging from protein patterning [1] to the polymerization of custom-made resists [2].

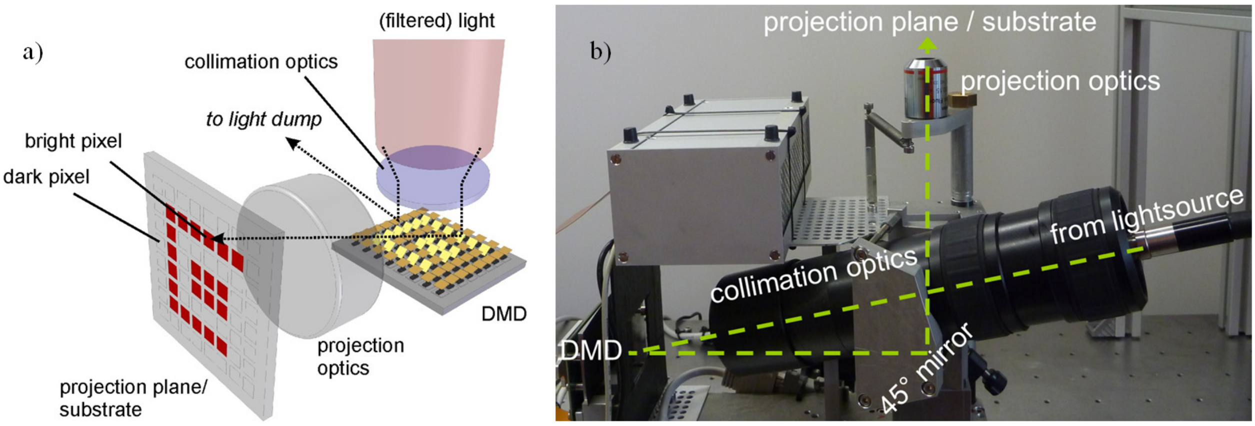

Figure 2: Schematic view of a maskless lithography system (a) and its actual setup (b). Collimated filtered light is translated to a projected image by the digital mirror device (DMD) by setting the mirrors accordingly. Depending on whether the respective pixel is in the on- or off-state, light is either deflected to a light dump or projected onto the substrate through the projection optics creating either a dark or a bright pixel. The system is controlled by the custom-written software that directly parses digital monochrome bitmaps preferably created by the CAMF builder from digital 3D models or in any digital image format (e.g. by Photoshop or Windows Paint).

Because this technique illuminates an area of ~2.0 × 2.5 mm² as opposed to illuminating one pixel per time, it is also much faster than laser writing and other direct structuring techniques. Stitching images together by means of an x-y-stage allows a chip of 40 × 30 mm² lateral size to be created. The individual images projected are demagnified by means of an inverted microscope optics resulting in pixel size of 2.5 µm with a total of 200 megapixels structured. Figure 3 shows a cascading Tesla-mixer structure created by the CAMF within a few hours. Figure 4 shows the chip in use as a gradient mixer. Besides models created by the CAMF builder, the software can read any digital image format (even simple bitmap files) which allows a wide range of applications [1].

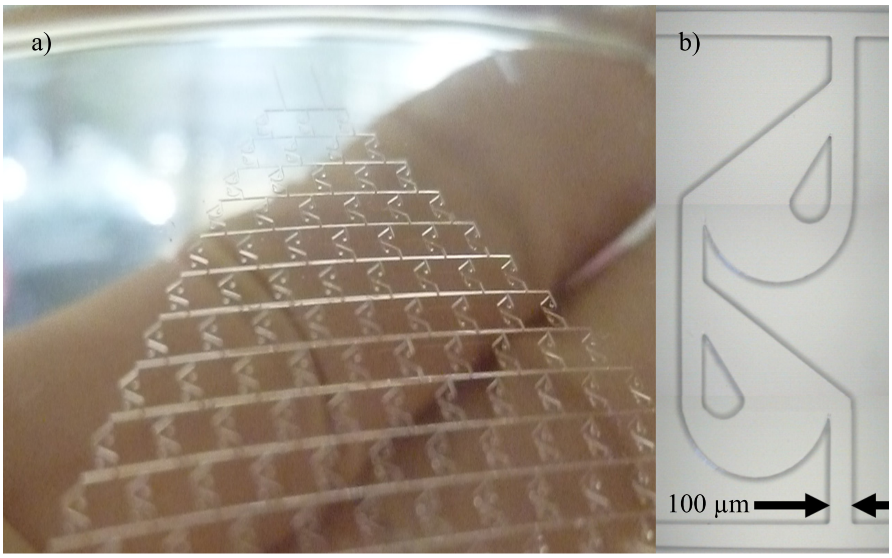

Figure 3: a) A cascading Tesla-mixer structure (created in digital 3D CAD by the CAMF builder, see figure 1) replicated from a lithographically structured SU-8 master. The master was created within one hour using the DMD based lithographic system. b) Microscope image of one Tesla-mixer.

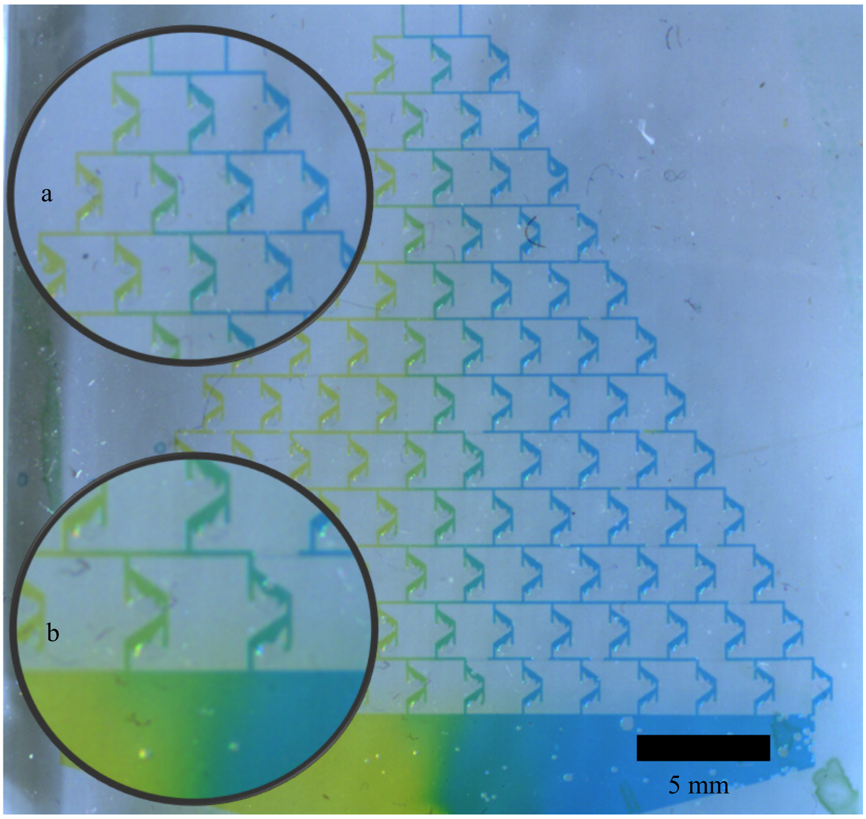

Figure 4: Cascading Tesla-mixer structure created by CAMF (3D model created by the CAMF builder), physical structure created by replication from an SU-8 master. The mixing is illustrated by using water with blue and yellow dye. The total process (from concept of the chip to running the actual experiment) took less than seven hours. In this early stage of the setup, one can see trapped air inside the channels.
Inlay (a) shows the principle of a gradient mixer: two different samples are injected, split and mixed. The outer channels guide unmixed liquids, while in between each step of the gradient mixer adds another level of mixture. Inlay (b) shows the gradient of mixed liquids inside the microfluidic chamber.

We will show that CAMF is the preferred method to create microfluidic structures of several cm² lateral size with micrometer resolution within a day resulting in extremely short concept-to-chip times. This will significantly speed up microfluidic device prototyping allowing an experimental turnover unmatched.

REFERENCES

[1] A. Waldbaur, B. Waterkotte, K. Schmitz and B. E. Rapp, *Maskless projection lithography for the fast and flexible generation of grayscale protein patterns,* Small, Volume 8, Issue 10, pages 1570–1578, May 21, 2012
[2] A. Waldbaur, M. Dirschka, K. Länge, B. E. Rapp, *Rapid prototyping of microfluidic structures from UV curable PTFE-like polymers: creating structures in maskless direct lithography and casting*, Proc. The 15th International Conference on Miniaturized Systems for Chemistry and Life Sciences (µTAS) 2011 Conference, 2011

CONTACT

Ansgar Waldbaur, ansgar.waldbaur@kit.edu