Hochschule Reutlingen
Reutlingen University

AC Angewandte Chemie

Build-up and validation of a low-cost benchtop photolithography tool

Benjamin Naggay[a], Kiriaki Athanasopulu[a], Ralf Kemkemer[ab]

[a] *Department of Applied Chemistry*, *Reutlingen University, Alteburgstrasse 150, 72762 Reutlingen, Germany*
[b] *Dept. New Materials and Biosystems, Max Planck Institute for Intelligent Systems, Max Planck Society, Heisenbergstr. 3, 70569 Stuttgart, Germany*

Abstract

The central equipment piece for the lithography fabrication is an ultraviolet (UV) light source. Conventional UV-light sources are based on high-pressure mercury lamps. These lamps are requiring considerable maintenance but therefore provide a broad-band illumination with intensities that often changes in their lifetime. In this article we present a benchtop photolithography tool based on ninety-eight 375 nm light emitting diodes (LEDs). In our model we choose a parallel series connection of three LEDs in series, together with a 47 Ω protective resistor. One series connection consists only of 2 LEDs and a 220 Ω protective resistor. Because of the arrangement of the LEDs on the circuit board a diffusor glass was used to homogenize the light intensity. For the production of the structures two different SU-8 photoresists were used. The self-build light source was used to fabricate micro patterns with a thickness from ~10 µm to ~60 µm and a width of ~20 µm to ~200 µm. An exposure time of 20 s for a working distance of 1.5 cm between LED-head and wafer, produced patterns of good quality. In the experiments the effect that stripes can be better developed with an increasing distance between the stripes and a higher ratio of the width of stripes and the interspace between the stripes was observed. The proposed light source is built with a total cost below 900€, requires a minimal amount of power (below 1% of the power a mercury lamp needs), is expected to last for more than 90 000 exposures (which is 50-100 times longer than a conventional mercury lamp), and is nearly maintenance-free. Therefore, this device is appealing for educational institutions which want to provide the possibility to students to work with photolithography, microfluidic teaching laboratories and microfluidic research and development laboratories but can´t afford the expensive industrial solutions.

Keywords: photolithography, low-cost

Introduction

The technology of photolithography is a crucial technique of producing different patterns for several application fields. For instance, in the field of bio-analytical sciences, where the fabrication of polymeric disposable microfluidic devices is of great importance [1]. The master molds for these microfluidic devices can be fast and easily fabricated by using the photolithography technology to form various patterns of photoresist on silicon wafers. This type of rapid prototyping is used, because the photolithography devices (mask aligner and a UV-light source) are small and don´t require much additional equipment. Another example for the use of photolithography is the structuring of polymeric surfaces to obtain an orientation of cells on this produced surfaces [2]. One of the most widely used photoresist family for rapid prototyping is the ultraviolet-curable epoxied family SU-8. The SU-8 epoxies provide the possibility to fabricate microchannels with a broad range of thickness, from <1 to >500 µm with nearly rectangular profiles, and large ratios of their depths to widths (aspect ratios). When using narrow UV-light spectrum fitting to the characteristic SU-8 adsorption length of ~370 nm, it leads to a relatively weak dependence of the optimal exposure time on the thickness of the SU-8 layer [3].
The most expensive equipment part for the rapid prototyping of microfluidic devices using UV-light lithography is a source of collimated UV-light. Such a standard light source is built around a powerful high-pressure mercury lamp and requires a feedback loop for steady illumination. Even though the light source is only used unfrequently, mercury lamps are often kept on continuously because of their long warm-up times and adverse effect that restarting has on their life span. In result the power costs alone can be as much as 900€ a year. Mercury lamps have the ability to produce a broad spectrum, including deep UV-light, which makes them versatile light sources of illumination for fluorescence microscopy and UV lithography. However, deep UV-light is a problem for the fabrication of tall patterns with SU-8 photoresists. The UV-absorbance of SU-8 increases sharply at a wavelength below 350 nm, that's why manufacturer recommend to filter those wavelengths out if someone wants to obtain straight walls for patters taller than ~25 µm.
In this work, a low-cost self-build photolithography tool will be build and validated with different photomasks. The aim is test the approaches which were made in the publications of “Teri Odom and Mark Huntington” [4] and “M. Erickstad, E, Gutierrez and A. Groisman” [3]. In these approaches a solution to the problem of the high price of the industrial manufactured photolithography stations should be provided. The price of such a mask aligner with a UV-light source is around 50,000€, so the purchase is not possible for small companies which have only a low budget or for educational institutions where such devices are oversized.

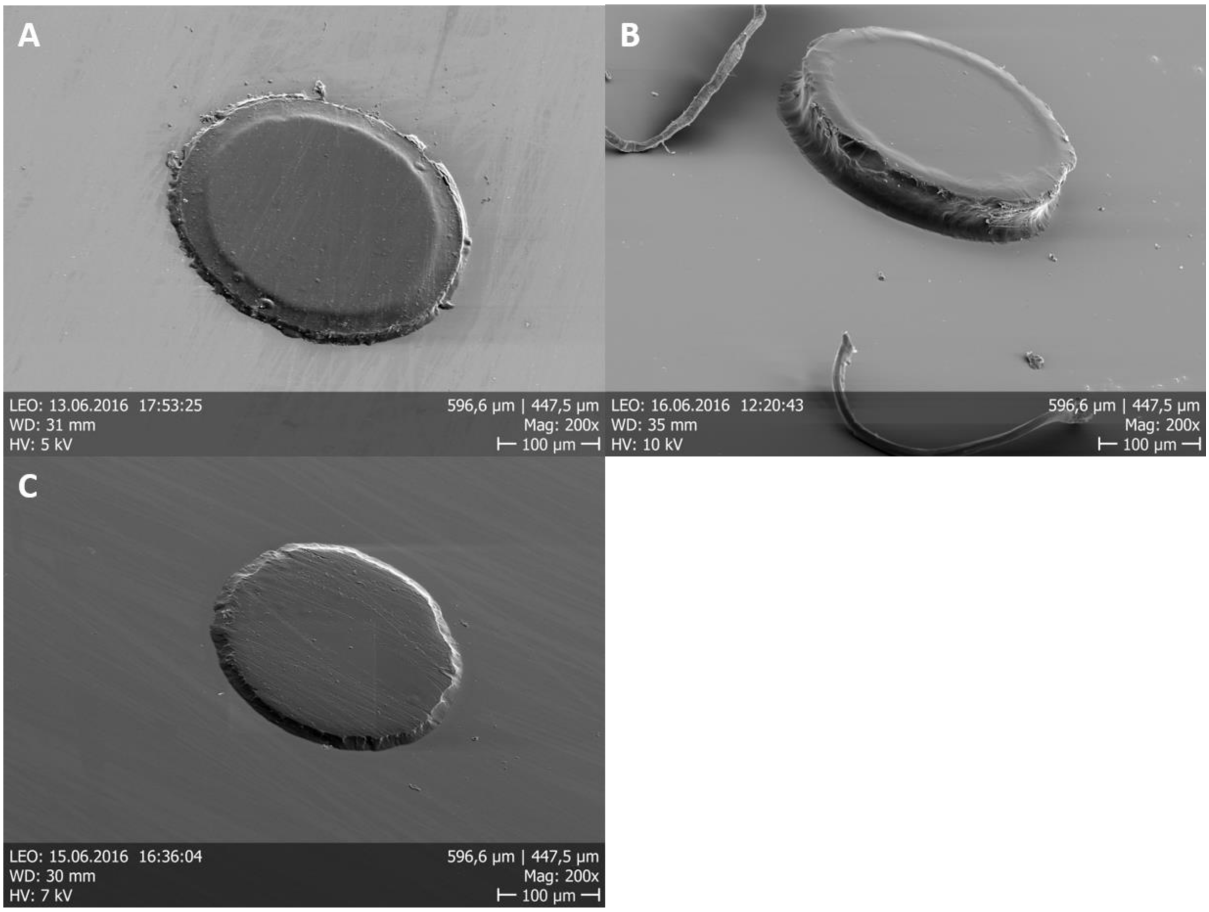

Figure 1:REM-images of the produced patterns on a silica wafer. (A) Dot produced with the SU-8 10, a working distance of 1.5 cm and an exposure time of 40 s. (viewing angle 45°) (B) Dot produced with the SU-8 2075, a working distance of 1.5 cm and an exposure time of 40 s. (viewing angle 60°) (C) Dot produced with the SU-8 10, a working distance of 1.5 cm and an exposure time of 20 s. (viewing angle 45°)

Materials and Methods

The LEDs (Nitride UV LED 5 mm 365 nm by PUR-LED GmbH & Co. KG) are placed and soldered to the circuit board like seen in Figure 2 B. To control the later exposure time of the photoresist a Panasonic digital multifunction-time-relay (LT4H LT4H24SJ 12 - 24 V/DC) was added in the electric circle. As a power supply for the time-relay a 12 V power plug (VOLTCRAFT SNG-2250-OW) was used. For the case of the photolithography station several parts were bought from the company “item Industrietechnik GmbH” and later assembled (Figure 2 C).

To later get a sufficient and homogeneous UV-light exposure, a diffusor glass (150 x 150mm 120 Grit Ground Glass Diffuser) was purchased from the company “Edmund Optics GmbH”. As seen in Figure 2 C the LED-head is directly placed on top of the diffusor.

In the experiments for this paper only two photoresists were used. Both photoresits were bought from the company Micro-Chem. The SU-8 10 was used for thinner layers and due to the lower need of energy for the polymerization also for the most validation testing’s. The SU-8 2075 was used to produce thicker layers and to analyze how good the edges of the produced patterns are. The working procedure was conducted like described in the data sheets of the respective photoresist [5] [6].

In this paper two types of photomasks were used. The first one is a printed photomask on a plastic wrap. These kind of masks provide a cheap alternative to the expensive quartz glass photomasks. As a second type a conventionally used quartz glass photomask was used.

For the analysis of the produced patterns on the silicon wafers images were made by a reflected light microscope and a scanning electron microscope.

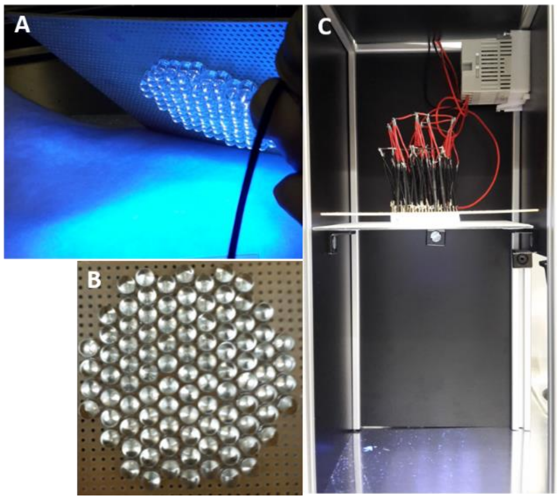

Figure 2: Images of the solid-state photolithography tool. (A) Image of the operating LED-head. (B) Image of the arrangement of the LEDs. (C) Image of the photolithography station based on a solid-state light source.

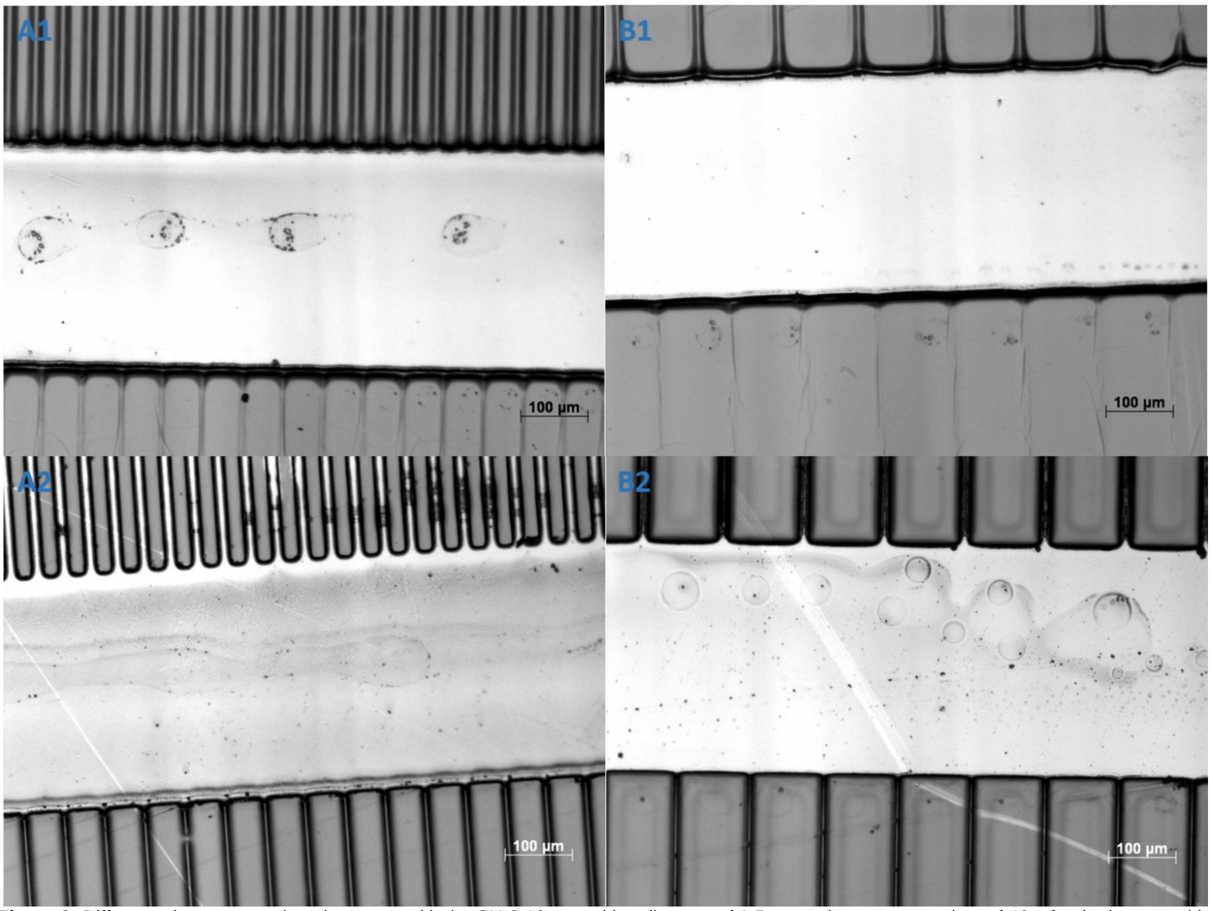

Figure 3: Difference between produced patterns with the SU-8 10, a working distance of 1.5 cm and an exposure time of 40 s for the images with the "suffix _1" or 20 s for the images with the "suffix _2" viewed under a reflected light microscope.

Results

For the testing of the process parameters and the working principle only the printed photomasks were used. They have been chosen because the produced patterns have a bigger scale, although it is assumed that quartz glass photomasks are better in terms of handling and processing than the printed photomasks.

With the first experiments have been considered to show if the built light source provides a sufficient exposure energy for the polymerization of the used photoresists. It could be shown, that the self-build photolithography station based on a solid-state light source provides a sufficient energy exposure to the used photoresists SU-8 10 and SU-8 2075.

The next number of experiments were performed to analyze how the working distance between the LED-head and the wafer is influencing the appearance and shape of the produced patterns. A working distance of 6 cm combined with an exposure time of 40 s was not sufficient for an establishment of a good developed surface pattern. After the post exposure bake (PEB) the image of the photomask was only slightly visible, what indicates a poor polymerization of the photoresist. This was confirmed by the complete removal of the photoresist during the development step. But the slightly visible image indicates a starting of the polymerization of the photoresist. Which leads to the assumption that a longer exposure time at that working distance will provide a sufficient polymerization.

A working distance of 3,5 cm combined with an exposure time of 40 s was sufficient to form a good developed surface pattern. Meaning, it was possible to form pillars but they didn´t form an exact round shape. The produced image of the photomask was well visible without a microscope after the PEB step. This indicates a successful polymerization of the photoresist.

An exposure time of 40 s. and a working distance of 1,5 cm was sufficient for an establishment of a better but still only good developed surface pattern. When looking on the produced dots with a lightmicroscope it is likely to get the impression that the borders of the patterns are well developed. But imaged with REM it is visible that the dots have no vertical edges (Figure **1** A). It is suggested that the slope edges come from a too long exposure-time for this working distance. Because the light source used in this paper isn´t a collimated light source the incident photons polymerized the slope area although it is desired.

In Figure 1 B for the SU-8 2075 the slope edges are much less developed but as well as for the SU-8 10 it was not possible to produce straight and vertical edges. Instead of the slope edges a bulge was formed on the top of the produced dots. This is

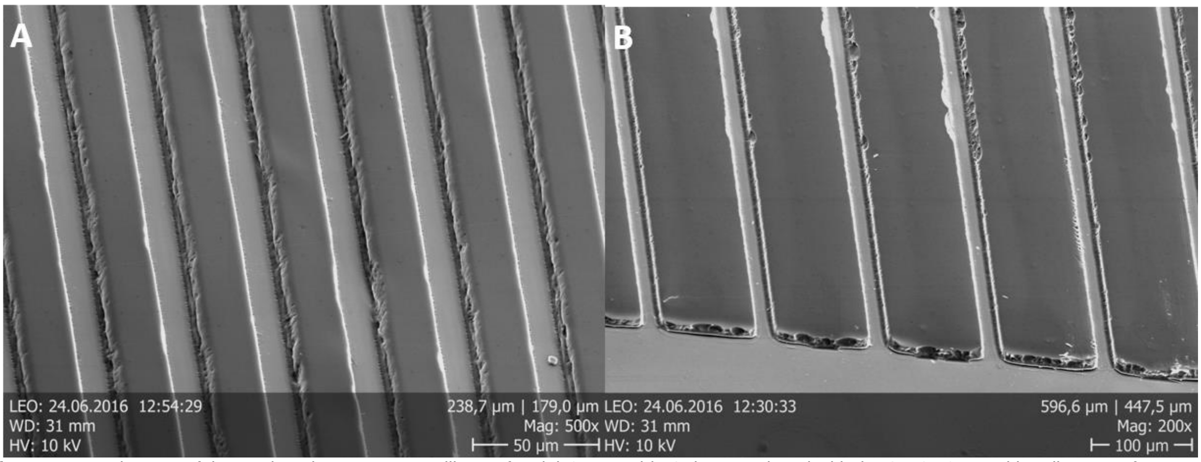

Figure 4: REM-images of the produced patterns on a silica wafer. (A) 25 µm wide Stripes produced with the SU-8 10 a working distance of 1.5 cm and an exposure time of 20 s. (viewing angle 45°) (B) 85 µm wide Stripes produced with the SU-8 10 a working distance of 1.5 cm and an exposure time of 20 s. (viewing angle 45°)

suggested to be produced by the oblique incident photons that as well produce the slope edges on the SU-8 10.

As the next parameter only the exposure time was varied. The working distance was fix set to 1.5 cm. In the first of the experiments the exposure time was reduced to 20 s. This had a great effect on the produced edges. The slope edges could be drastically reduced as it can be seen in Figure 1 C. But it also had the effect of reducing the round shape of the pillars. In the second step the exposure time was reduced to 15 s. With the exposure time of 15 s it was not possible to produce patterns which were stable on the surface of the wafers. The image of the photomask was only slightly visible after the post exposure bake, that as well indicates a poor polymerization of the photoresist like in the previous experiments where the negative images of the photomasks have been removed during the development step.

With the quartz glass photomask only the effect of the exposure time was tested. Therefore, one lithography process was executed with 20 s and the second one with 40 s. Both processes had working distance between LED head and waver of 1.5 cm.

With the exposure time of 40 s it was not possible to create a good developed negative of the photomask. As it can be seen in all images of the produced stripes with the suffix _1 in Figure 3, they are still connected to each other. It is assumed that it is related to the same effect that produced the slope edges in Figure **1** A. But it is observed as the distance between the stripes is increasing and the ratio between the width of stripes and the interspace between the stripes rises the stripes become clearer visible. With the exposure time of 20 s it is possible to create small stipes which are not connected (Figure 3 A2). Still the effect that stripes can be better developed with an increasing distance between the stripes and a higher ratio between the width of stripes and the interspace between the stripes shows the same behavior. The attachment of the stripes with a width of ~20 µm to the wafer was not sufficient and were mostly washed away during the development procedure.

In Figure 4 the produced stripes are viewed with an angle of 45° to investigate the development of the edges. As it can be seen in Figure 4 A, the stripes have a bulge on the top as in prior experiments the produced dots in Figure 1 B, despite the stripes are made with the Su-8 10 with an expected height of 10 µm and the dots are produced with the SU-8 2075 with an expected height of 60 µm. In Figure 4 B it can be seen that the edges are much better developed, they have a more uniform shape and they have no bulges on top of them.

Discussion and conclusions

The proposed LED based UV-light source, is an effective tool for SU-8 photolithography. Also it is possible to use other positive photoresists sensitive to 375 nm UV-light (i-line). Unlike the conventional used mercury lamp UV-light source, neither the spatial patterns nor the light intensity of the LED light source changes with time, eliminating the need to periodically calibrate the illumination and modify the fabrication protocols [3]. The narrow spectrum of the LEDs, with a maximum at 375 nm, fitting to the characteristic SU-8 adsorption length of ~370 nm, leads to a relatively weak dependence of the optimal exposure time on the thickness of the SU-8 layer. In further experiments it is suggested to test bigger working distances combined with higher exposure times to achieve better developed edges. In this paper we used only short exposure times between 20 s and 40 s where in the paper of M. Erickstad [3] an exposure time of 4 min was used.

The costs for the proposed light source is below 900€ for materials, parts and machining to build. Because the LED is expected to last for more than 90 000 exposure cycles and is only powered during the exposure procedure it is nearly maintenance-free. The low costs of producing and maintenance of the light source make it especially attractive for small academic and industrial fabrication facilities, microfluidic teaching laboratories and microfluidic research and development laboratories in general.

Acknowledgements

This work was done in cooperation with the Max Planck Institute for Intelligent Systems at the University of Reutlingen as part of a research internship.

Notes and references

[1] E. Verpoorte and N. F. D. Rooij, "Microfluidics meets MEMS," *Proceedings of the IEEE,* pp. 930-953, June 2003.

[2] L. Altomare, N. Gadegaard, L. Visai, M. Tanzi and S. Farè, "Biodegradable microgrooved polymeric surfaces obtained by photolithography for skeletal muscle cell orientation and myotube development," *Acta Biomaterialia,* pp. 1948-1957, June 2010.

[3] M. Erickstad, E. Gutierrez and A. Groisman, "A low-cost low-maintenance ultraviolet lithography light source based on light-emitting diodes," *Lab on a Chip,* pp. 57-61, 04 October 2014.

[4] T. Odom and M. Huntington, "A Portable, Benchtop Photolithography System Based on a Solid-State Light Source," *Small,* pp. 3144-3147, 18 November 2011.

[5] microchem, *PROCESSING GUIDELINES FOR: SU-8 2025, SU-8 2035, SU-8 2050 and SU-8 2075,* 2015.

[6] microchem, *Negative Tone Photoresist Formulations 2-25,* 2014.