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Low-cost photolithography system for cell biology labs

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Abstract: Soft lithography, a tool widely applied in biology and life sciences with numerous applications, uses the soft molding of photolithography-generated master structures by polymers. The central part of a photolithography set-up is a mask-aligner mostly based on a high-pressure mercury lamp as an ultraviolet (UV) light source. This type of light source requires a high level of maintenance and shows a decreasing intensity over its lifetime, influencing the lithography outcome. In this paper, we present a low-cost, bench-top photolithography tool based on ninety-eight 375 nm light-emitting diodes (LEDs). With approx. 10 W, our presented lithography set-up requires only a fraction of the energy of a conventional lamp, the LEDs have a guaranteed lifetime of 1000 h, which becomes noticeable by at least 2.5 to 15 times more exposure cycles compared to a standard light source and with costs less than 850 € it is very affordable. Such a set-up is not only attractive to small academic and industrial fabrication facilities who want to enable work with the technology of photolithography and cannot afford a conventional set-up, but also microfluidic teaching laboratories and microfluidic research and development laboratories, in general, could benefit from this cost-effective alternative. With our self-built photolithography system, we were able to produce structures from 6 µm to 50 µm in height and 10 µm to 200 µm in width. As an optional feature, we present a scaled-down laminar flow hood to enable a dust-free working environment for the photolithography process.

Keywords: low-cost, photolithography, laminar flow hood

1 Introduction

Photolithography is a versatile method for the production of three-dimensional patterns on surfaces and is the key method used in semiconductor technology. In general, it is a simple and fast method suitable for surface patterning in the micrometer or even nanometer scale [1]. A substrate, for example, a silicon wafer or glass, is coated with a thin layer of a photoactive polymer (photoresist). After thermal curing and UV exposure through a photomask, a transparent plate with defined opaque regions, the photoresist gets modified, and the two-dimensional structures of the mask are transferred to the resist. Depending on the type of photoresist, the exposed areas are either cross-linked (negative resist) or their solubility is increased (positive resist). In both cases, the more soluble regions of the photoresist are removed subsequently during the development step, using a suitable chemical. The process of coating, curing, and UV light exposure of the wafer is usually done under the premise of a very clean surrounding, requiring

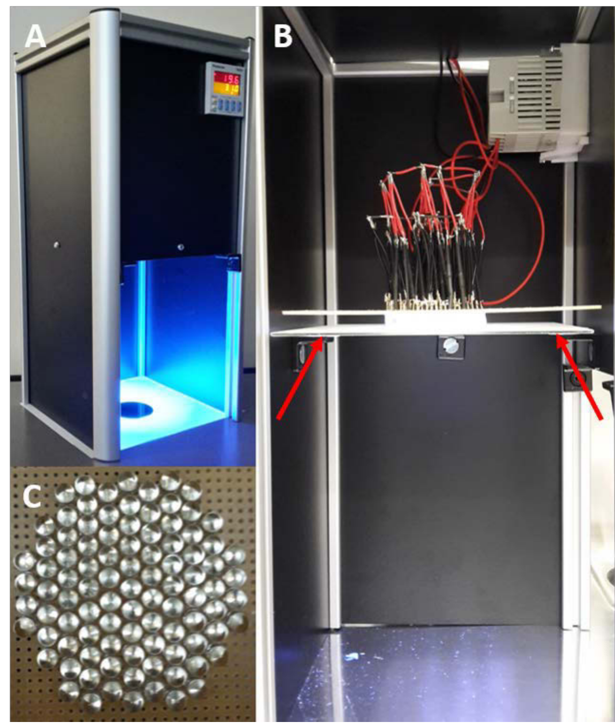

Fig. 1: Images of the self build low-cost bench-top photolithography set-up. A) Completely assembled set-up shown in operation. B) Interior of the lithography-system with diffusor glass (red arrows), LED head and time relay. C) Image of the LED array on the circuit board.

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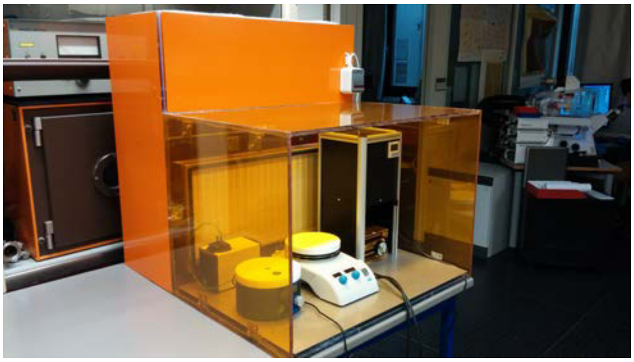

Fig. 2: Image of the self-built laminar flow hood with complete set-up for the photolithography process.

Tab. 1: Listing of the components used for the UV exposure unit as well as the sterile bench.

Parts	Amount	Cost
Photolithography set-up		
LED 375 nm	95	474.05 €
Diffusor glass	1	44.10 €
Time relay	1	95.32 €
12-V power supply	1	31.99 €
Small electrical parts	1	35.15 €
Resistors	32	4.13 €
Housing		132.06 €
Cost photolithography set-up		**816.80 €**
Laminar flow hood		
AC centrifugal blower	1	321.56 €
Filter parts	2	70.30 €
Housing		304.59 €
Cost laminar flow hood		**696.45 €**
Cost complete set-up		**1,513.25 €**

a clean room, as dust can not only contaminate the photoresist but also influences the illumination by shading.

Photolithography is the main step in soft-lithography, a method widely used in numerous life science applications. There, the three-dimensional structures produced by photolithography get transferred to soft polymers by replica molding. Commonly, elastomers such as Poly(dimethylsiloxane) (PDMS) are used. The structured polymer substrates are then used for investigating cell adhesion, proliferation, and migration or even for measuring cell-generated forces or producing microfluidic devices [2–5]. However, the access to photolithography technology for biologists often is limited by the need for specialized equipment and facilities.

We report a simple low-cost and self-built lithography system that can be easily reproduced, allowing the use of soft-lithography methods in biology labs. The central part of the photolithography set-up is a mask-aligner, with typical costs between 150,000 € and 300,000 €. Most commonly it is equipped with a high-pressure mercury or xenon lamp. Their advantage is emitting a broad spectrum of wavelengths at a relatively high intensity. However, these lamps also have several disadvantages, such as high purchase and maintenance costs and the loss of radiation intensity over time. Additionally, the lifetime of high-pressure mercury lamps in mask-aligners is about 600 h [6]. With the need for a warm-up period of 5 min to 30 min and its short lifetime, only 1,200 to 7,200 exposure cycles can be performed without the need to renew the light source. The use of UV-LEDs addresses these disadvantages, and in recent years more and more conventionally available UV-LED-based mask-aligners were introduced to the market, reducing the investment costs to about 50,000 €, which still is cost-intensive.

T. Odom and M. Huntington [7] as well as Erickstad et al. [8] already demonstrated the feasibility of low-cost photolithography set-ups based on UV-LED exposure units. We, however, present a different kind of UV-LED-based, low-cost photolithography exposure unit that consists of ninety-eight 375 nm UV-LEDs and costs less than 850 € in parts, materials, and machining. With a guaranteed lifetime of 1000 h and no need for a prewarming period, our set-up allows 2.5 to 15 times more exposure circles compared to a standard high-pressure mercury lamp [6]. Additionally, our system has a low energy consumption of about 10 W, corresponding to a power consumption of only 2.9 % to 0.2 % of a high-pressure mercury lamp. To work in a clean-room-like environment, we also developed a self-built laminar flow hood based on a consumer HEPA filter avoiding dust particles on the samples. In combination with a simple spin-coater and heating plate, our system offers a cost-effective and simple alternative to standard photolithography equipment and allows the reliable production of surface features in commonly used photoresists in a size range down to several micrometers.

2 Materials and Methods

Construction of the UV-LED exposure unit: For the LED exposure unit, 98 UV-LEDs (Nitride UV LED, 5 mm, 375 nm; PUR-LED GmbH & Co. KG) were placed and soldered on a circuit board, as shown in Fig. 1C. To obtain a uniform intensity of the LEDs, sets of three LEDs were connected in series and provided with a 47 Ω series resistor. The two remaining LEDs were connected in series with a 220 Ω series resistor and the resulting LED blocks were subsequently connected in parallel. To control the exposure time, a multifunctional time relay (LT4H24SJ; Panasonic) was built into the circuit and a 12 V power plug (SNG-2250-OW; VOLTCRAFT)

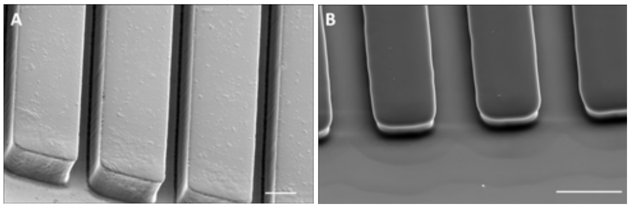

Fig. 3: Scanning electron micrographs of fabricated structures in photoresist. A) SU-8 2075 structure with a thickness of 25 µm, a width of 50 µm, and a distance of 10 µm between lines. B) SU-8 10 structure with a thickness of approx. 10 µm, a width of 25 µm, and a distance of 10 µm between lines. Scale bars 25 µm.

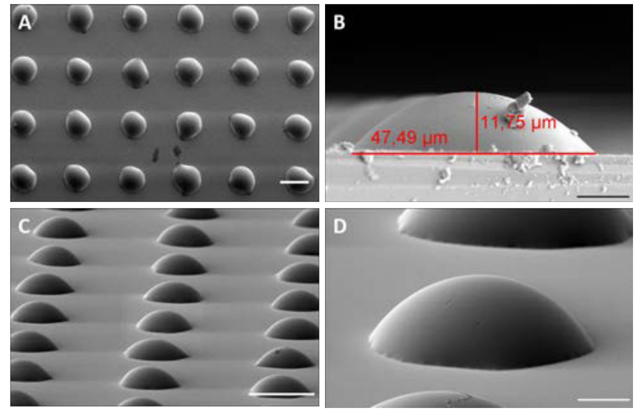

Fig. 4: Scanning electron micrographs of the partial spheres created with the photoresist ma-P 1275 HV, with a dot diameter of approx. 50 µm, a dot height of approx. 12 µm and a distance between the dots of 50 µm. A) Image of the top view. B) Side view of wafer with break edge. C) & D) Side view with a tilt angle of 15°. Scale bars 50 µm (A & C) and 10 µm (B & D).

serves as the voltage source for the time relay and the LEDs. For the housing of the photolithography system, modular aluminum profiles and black plastic plates (item Industiretechnik GmbH) were assembled, as shown in Fig. 1A & B. To achieve a sufficiently homogeneous illumination, a diffusor glass (150 x 150 mm 120 Grit Ground Glass Diffuser; Edmund Optics GmbH) was placed directly below the UV-LED head, as shown in Fig. 1B (red arrows).

Construction of the laminar flow hood: For constructing the laminar flow hood, Makrolon® plates with a thickness of 5 mm were used and assembled with angles to form the housing. A filter mat (HS-Filtermatte E/360; Luftfilterbau) and a HEPA filter (HS-Mikro SF, Gr.:305x305x78 mm, EN 1822 Kl. H14; Luftfilterbau) served as filter material. The air circulation was realized with an AC centrifugal blower (G2E140; ebm-papst) and a voltage regulator to regulate the performance of the oversized blower. To protect the working area, and especially the photoresist, from ambient UV radiation, all relevant surfaces were covered with transparent, orange-colored, self-adhesive foil (Velken-Folientechnik). The assembled laminar flow hood is shown in Fig. 2. A list of the individual components and their possible costs is given in Tab. 1.

Photolithography masks: The most commonly used photomasks in photolithography are chromium masks based on quartz or soda-lime glass. However, these masks have the disadvantage that they are expensive and complex to manufacture, making them rather unsuitable for advanced prototype production. Additionally, they have a limited lifetime when used for contact exposure photolithography due to the detachment of the chromium layer. An inexpensive alternative, especially suitable for prototyping, is provided by masks printed on plastic films. Depending on the type of printing, masks with resolutions down to approx. 50 µm can be printed. A printer resolution of 2400 dpi, for example, corresponds to a screen dot size of 11 µm, which means that edges are represented cleanly at approx. 50 µm. However, it should be noted that conventional inkjet or laser printers are not capable of highly pigmented color printing, a requirement for printing films with sufficient UV absorption.

Materials for validation process: Two different negative photoresists and one positive photoresist were used to fabricate structures on silicon wafers. The two negative photoresists SU-8 10 and SU-8 2075 (MicroChem) were used for validation and edge evaluation of the structures. Both photoresists were used to produce structures with thicknesses ranging from 10 µm to 50 µm. The photoresists were used according to the manufacturer's instructions. The positive photoresist ma-P 1275 HV (microresist technology), processed as described in the datasheet, was used for the generation of curved structures using post-development thermal reflow of the resist [5]. Spin coating was performed with a spin coater (KLM SCC-200; Schaefer-Tec). Both conventional quartz glass photomasks and printed film masks were used to perform the structuring of the photoresists. For exposure, the mask was placed on the substrate with the photoresist. Exposure and illumination can be adjusted either by time or working distance to the LED unit using the time relay or a conventional laboratory lifting platform, respectively.

3 Results

Validation of the exposure unit with negative and positive photoresists: In the first step of the validation process, the working distance between the LED head and the wafer was set to 1.5 cm and the exposure time was varied. For this working distance, an exposure time of 20 s was sufficient to crosslink the SU-8 photoresist. However, it was not possible to form vertical edges and therefore to separate the structures from each other. This is a consequence of the fact that the presented exposure unit does not use collimated light, which is adversely affecting the projection of the mask pattern to the resist by transversely incoming UV-rays. In the next step, the working distance was increased to 15 cm between the LED exposure unit and the wafer, reducing the amount of scattered UV-rays reaching the photoresist. With the increased working distance and an adjusted exposure time of 200 s, it was then possible to produce well-defined structures with vertical edges regardless of the investigated photoresist thickness (10 µm to 50 µm) (Fig. 3A & B). During the validation using photomasks with linear structures, it was observed that by decreasing the ratio between line width and line gap, the quality of the sidewall development increased. With the positive photoresist ma-P 1275 HV, we could create pillars with diameters down to 50 µm and an approx. heights of 12 µm, and ridges of approx. 10 µm width and 6 µm height. Since this photoresist is a non-crosslinking novolak, a post-developmental thermal reflow is possible, where the resist can be softened when heated, forming smooth-edged structures (partial cylinders or spheres) based on the mask layout and surface tension of the molten resist, seen in Fig. 4 and described in detail by Frey et al. [5]. The use of the reflow method has two advantages. Firstly, small impreciseness can be compensated by melting the resist, and therefore smaller topographical features are achievable. Secondly, it enables the fabrication of cell study platforms with curved surface topographies, which are much closer to the surrounding cells encounter *in vivo*, compared to conventional sharp-edged topographies [5].

Validation of the printed photomasks: Fig. 4A shows that, for the dot size of 50 µm, the generated structures are deviating from the circular outline. Closer examining the printed masks used, we could confirm that the outcome is not based on the working process but because the minimum printable resolution was reached, resulting in not ideal circular structures on the film. For other dot sizes, we were able to obtain circular structures.

4 Conclusion

We could show that the proposed LED-based UV-light source is an effective tool for processing 375 nm UV-light (i-line) sensitive photoresists. The costs for the proposed photolithography set-up are below 850 € in parts, materials, and machining. Because the LEDs are expected to last for more than 18,000 exposure cycles and are only powered during the exposure procedure, the illumination part is nearly maintenance-free. Additionally, we could also show by light-microscopy and SEM imaging of the samples, that using a self-built bench-top laminar flow hood provides sufficient cleanliness for the soft-lithography application in a bio-lab. This, together with the low costs of production and maintenance of the light source, makes it especially attractive for small academic or fabrication facilities in small enterprises, microfluidic teaching laboratories, and microfluidic research and development laboratories in general. Furthermore, we could show that it is possible to produce reliable structures with low-cost printed film masks down to the minimum printable resolution of 50 µm, further facilitating prototyping in these areas.

Author Statement

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