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ScienceDirect

Procedia Engineering 5 (2010) 331–334

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXIV, September 5-8, 2010, Linz, Austria

A maskless exposure device for rapid photolithographic prototyping of sensor and microstructure layouts

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Abstract

A very cost effective maskless exposure device (MED) for the fast lithographic prototyping of various layouts is presented. The device is assembled using a digital light processing projector (DLP), an optical microscope, alignment stages and a web camera. Layouts created on a computer screen can be easily transferred to substrate surfaces without using expensive photomasks and the process can be repeated by introducing new drawings on the screen. Components are tuned for a constant area of exposure and a resolution of around 20μm is possible at the moment without using any reduction lenses. The MED has been used in patterning the surfaces of silicon, glass, metal etc. successfully. The device can be assembled using commercially available components at a very minimum cost and can be effectively used in fast prototyping applications like in MEMS, microfluidics, patterning of sensor and electrode structures.

Keywords: Lithography, maskless lithography, microfabrication, rapid prototyping

1. Introduction

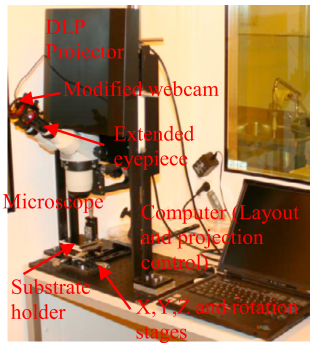
Photolithography is an optical process of transferring geometric shapes on photomasks to the surface of a wafer, silicon for instance. It is a binary pattern transfer technique and involves stages as wafer cleaning, barrier layer formations, photoresist coating, soft baking, mask alignment, UV exposure, development, hard baking, etching etc. [1][2] The photomasks consist of high precision patterns usually defined by chrome metal on glass or high purity quartz plates. During exposure, UV light from a typical exposure system shines through the mask, which blocks light in chrome patterned areas and lets it transmit to other transparent blanks. The transmitted light falls onto photoresist where the exposed areas are modified distinctly than that of the unexposed areas by photochemical reactions. The selective removal of exposed or unexposed photoresist is made possible by resist developers. Consequently desired patterns are formed in photoresist after the resist development. The photomasks are hence an integral component in the entire procedure and manufactured by industrial companies using highly precise techniques like electron beam lithography. Quality masks are generally very expensive and depending on the complexities of intended structure, several lithographic steps with several masks are needed for fabricating one structure resulting in escalating mask costs per design to thousands of euro. The delay associated with the manufacturing and shipping of new photomasks also detains entire fabrication processes and therefore prototyping of new ideas becomes an expensive and time-consuming procedure. Of course, there are maskless lithographic techniques based either on a charged particle maskless or optical maskless methods like zone plate array lithography (ZPAL), dip-pen lithography (DPL), multiaxis electron beam lithography (MAEBL), scanning electron beam lithography (SEBL), focused ion beam lithography (FIBL), interference lithography (IL), maskless optical

1877-7058 © 2010 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2010.09.115

projection lithography (MOPL) etc.[3][4]. But these endeavours require expensive instrumentation and/or controlled experimental environments [3][4] and moreover none of them can be considered as a fast cost effective prototyping tool for micro fabrication. Because of these complexities attempts for inexpensive photomasks, mask alternatives and maskless lithography have been intensified and especially maskless lithographic techniques are more attractive as it could lead to cost-effective small-scale manufacturing with various flexibilities.[5] Certain optical cost effective maskless techniques based either on direct UV/laser writing or on spatial light modulators (SLM) such as liquid crystal display (LCD), digital micromirror device (DMD) have also been reported in recent years.[6][7][8][9][10][11][12][13][14] Compared to slow direct writing methods, SLM based approaches are faster and have a major advantage of utilizing computer images as soft masks instead of hard photomasks. The projected beam with image information from an SLM can be suitably modified and focused on to the surface of a wafer coated with photoresist for defining patterns on photoresist[6]. In certain cases, to maximize simplicity and speed, and minimize costs, certain commercially available low cost devices can be modified and rearranged to function as soft masks in lithographic exposures.[9][14]This concept has been used for devising our maskless exposure device as shown in Fig. 1for rapid photolithographic prototyping applications. Bitmap layouts created on a computer screen can be effortlessly transferred to photoresists on various substrates by a series of time set slides and a specific pattern transfer can be completed in 15 to 20 minutes. Pattern transfer is repeated by introducing new layout slides and the quality of images is dynamically monitored by a modified web camera. The device is tuned for an area of exposure of 1.6cm x 1.2cm. Therefore, the size of a single pixel is around 16 µm and a lithographic resolution of around 20µm is possible at the moment without using any reduction lenses.

2. Designing and functioning of maskless exposure device (MED)

The MED is shown in Fig. 1(a) and the schematic of assembly of different components is shown in Fig. 1(b) [15][16] The components include a modified DLP projector, a stereo-microscope, axes and rotation controllers, a modified webcam and a computer. The DLP projector used is PJ458D from Viewsonic with XGA (1024 x 768 pixels) display standards. The SLM of the projector is a DMD chip which has a surface matrix array of 1024 x 768 micormirrors in a rectangular area of 11 mm x 8 mm.



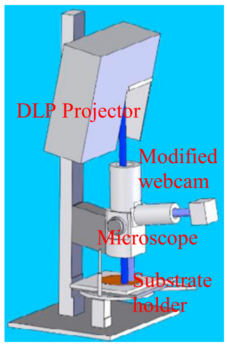


Fig. 1 (a) Maskless Exposure Device (MED; (b) Assembly of the components in MED.

All the micromirrors act like individual light switches and can be distinctly addressed and tilted by SLM digital signals. [17][18] Inside the projector, the DMD chip reflects white light from a 200W mercury lamp of brightness 2000ANSI lumens. The reflected light consists of image information as each of the micromirror is addressed and tilted differently by the digital signals corresponding to the image to be displayed. The optics in front of the chip accepts the reflected light and delivers a magnified image on a screen situated at a suitable throw distance. Thus in principle, the projector optics is intended for projecting larger images at distant screens, but in MED the projector optics has been totally replaced by an inverted stereomicroscope with the aim of creating smaller images at shorter distances with respect to the DMD chip. Though it is possible to assemble a totally new optical system for providing smaller images at shorter throw distances, an inverted stereomicroscope is particularly optimal because of its aberration free optics and possibility of inspecting the quality of the projected image using its in-built eyepieces. [14] The microscope used is SMZ-168 stereomicroscope from Motic with a 3.5 cm wide camera port and a 10x

eyepiece lens. The inverted microscope is arranged in front of the DMD chip, letting its camera port to accept the rays reflected from the micromirrors. The rays propagate through the microscope optics as shown in Fig. 1 (b) and finally come out through one of the two microscope objective ports. The substrate holder which is attached to x, y,z and rotation stages, is placed in front of the objective ports. When the rays fall on the substrate holder a really erect image is formed on the surface. The second objective port collects light from the formed image for the eyepieces of the microscope. Out of two available eyepieces, the image is available only in one eyepiece. Besides, the image plane is axially and laterally not inside the eyepiece coordinates of the available eyepiece either. Therefore the eyepiece is axially extended for 10 mm outwards and laterally shifted 8 mm away from the eyepiece coordinates. The focus and quality of the image formed can be monitored and tuned by looking through the extended eyepiece. Image blurring, unfocused edges etc. result in non-uniform exposures and hence the image quality must be precisely double checked using the extended eyepiece. A dynamic image monitoring is made possible by attaching a digital camera to the eyepiece and we have used a modified Night vision 305WC Intex web-camera for this purpose. The microscope focusing knob can be utilized for adjusting the size of the image formed on the substrate holder. In the present setup, the image size is optimized to 16mm x 12mm at a distance of 13cm from microscope objective. Resultantly, the size of each pixel in the image will be around 16um. When a substrate coated with photoresist is placed on the holder, the thickness of the substrate with photoresist can be compensated by raising and lowering the holder using the z stage. Ideally, the z stage is, therefore nothing but a fine focusing stage. All the x, y, z and rotational movements of the substrate can be viewed through the eyepiece. For the results presented in this paper we have used a positive photoresist Futurrex PR1-2000A for different substrate materials. From a number of experiments the suitable time of exposure for PR1-2000A is around 100s when the spin coated resist thickness is around 2µm. The time of exposure is very critical and during exposure, image depended photochemical reactions take place in the photoresist. Following the exposure, the substrates were developed in Futurrex RD6 developer for around 40s. The quality of patterns formed was examined using Zeiss Axio imager.A1m inspection microscope followed by other lithographic process like chemical etching etc. High resolution 3D surface profile measurements of a few fabricated microstructures were carried out using Wyko NT1100 optical profilometer. The computer used for image projection is IBM Thinkpad laptop at a screen resolution of 1024 x768 pixels. The layouts can be drawn in layout designing software like CleWin from WieWeb or generally in any CAD program that supports saving output files in bitmap format, otherwise a bitmap converter is needed.

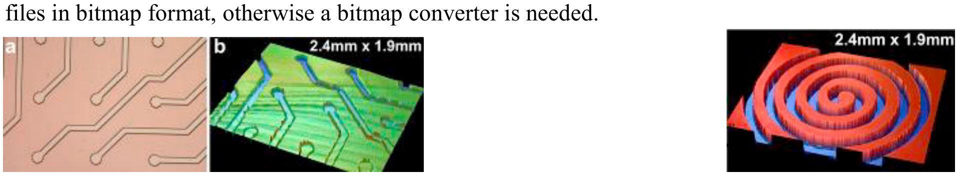


Fig. 2 (a) Patterned photoresist on silicon for an electrode structure and its profilometer image; (b) Profilometer image of patterned photoresist on silicon for a planar coil.

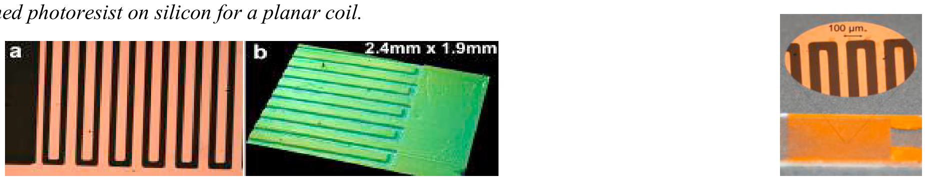


Fig. 3 (a) Gold interdigital electrodes fabricated on glass substrate and its profilometer image; (b) Gold interdigital electrodes of 50µm fabricated on glass substrate.

For the results presented in this paper only black features on a white background or vice versa were used in layouts and output files were saved in 1024 x768 pixel dimensions. In order to manage exposure time and multiple image projections we use a time set MS Powerpoint presentation as a set of three slides. The first slide consists of an image for focusing (a longer time was set), the second slide consists of the layout to be transferred (100s – the set resist exposure time) and the third slide is a plane black slide (a longer time was set). Red lines or features on a black background do not create any exposure in the photoresist so such an image was used for focusing. To facilitate patterning in more substrate areas, instead of three slide projection more slides can be added as multiples of the three slides. An electrode configuration as in Fig. 2(a), a coil structure as in Fig. 2(b) were patterned on photoresist on silicon. Interdigital gold electrodes as in Fig. 3(a) and Fig. 3(b) were fabricated on glass plate.

3. Results and discussion

The MED is the simplest version compared with other SLM based devices with an extremely tunable assembly of component devices and has been used in patterning the surfaces of silicon, glass, metal etc. successfully. Layouts drawn using commercial drawing/CAD software can be easily transferred to various substrates without using expensive photomasks. Components are tuned for a constant area of exposure and a resolution of around 20µm is possible at the moment without using any reduction lenses. We have utilized 99% of projected area successfully for imaging. The flexible assembly without using any computer controlled mechanical stages facilitate the test replacement of components by similar parts, resultantly more studies can be conducted when other comparable parts like a UV source, microscope, reduction lenses etc. are available. No color filters are used, instead white light is used for exposures and a dynamic image quality monitoring is made possible by a modified web camera. These factors reduce the entire cost of the device as low as a few thousand euro, opening the possibility to assemble the device in any labs where a fast maskless prototyping of low resolution layouts is needed.

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