Microelectronic Engineering 141 (2015) 37–43

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Simple maskless lithography tool with a desk-top size using a liquid-crystal-display projector

Toshiyuki Horiuchi *, Soichiro Koyama, Hiroshi Kobayashi

Tokyo Denki University, Tokyo 120-8551, Japan

ARTICLE INFO

Article history:
Received 23 October 2014
Received in revised form 26 December 2014
Accepted 5 January 2015
Available online 23 January 2015

Keywords:
Exposure tool
Projection exposure
Liquid crystal display
Desk top
Maskless lithography
Projector

ABSTRACT

A very simple and low-cost maskless exposure tool with a desk-top size was developed for applying to fabrications of various micro electro mechanical systems (MEMS) and bio-devices. A commercial projector with three liquid crystal display (LCD) panels of red, green, and blue colors was utilized as it was, except attaching a macro-lens for a camera after removing the magnification optics of the original projector. Therefore, the sizes were as small as 300 wide × 400 deep × 500 high mm^3, and the system was fabricated at a very small expense (¥500,000 ≈ €3500). Pixel pitches on the LCD panel were 8.5 μm, and the 7.4-μm square pixels were projected onto a wafer in a magnification ratio of 1.65. Efficient pixel numbers were 1024 × 768, and the exposure field sizes were 14.3 × 10.7 mm^2. Using the system, isolated line patterns with a width corresponding to one pixel size of approximately 14 μm, and 1:1 lines-and-spaces (L&S) patterns with a width of two pixel sizes of 28 μm were stably printed. Not only line patterns in orthogonal directions, but also radial oblique patterns were clearly and smoothly printed, and complicated arbitrary patterns were also printed. These projection ratio and pattern widths were decided considering the present applications to fabrications of micro-fluidic devices and lens arrays. If smaller patterns are required, the minimum pattern size and the projection ratio are conformably changed in principle. Because arbitrary patterns designed on a personal computer are directly printed on a wafer, preparations of expensive reticles are not necessary. Accordingly, besides the system cost and footprint are drastically saved, working expenses are much saved.

1. Introduction

Lithography is often used for printing large patterns with widths of 5–200 μm in various fabrications of micro electro mechanical systems (MEMS), bio-devices, and sensors. For example, patterns with widths of 50–100 μm are required for fabricating micro-fluidic devices and 30–100 μm are required for fabricating lens arrays at hand in the author's group. In the cases of above mentioned devices or articles, production volumes are generally very small comparing with the fabrications of semiconductor devices. On the other hand, various diversities of patterning are required, especially in sizes, shapes, thicknesses, and materials of substrates. In addition, no alignment or only very rough positioning is required in most cases. Therefore, simple, easy, and low-cost lithography tools are strongly required for these usages. However, commercially available lithography systems are too expensive for small companies to possess. In addition, they also need a moderate footprint in a clean room and everyday maintenances. For this reason, it is difficult to apply lithography for small volume productions in small companies. It is required that lithography tools are easy to handle as if they are personal computers, cameras, and televisions in order that lithography is used by engineers in small companies without constraint. In addition, they should be inexpensive even they were generously wasted after being used for the primary purposes.

To reply to these requirements, the authors have been developing maskless matrix exposure systems using liquid crystal display (LCD) panels in place of reticles [1–7]. Similar exposure systems were also proposed by other research groups [8–13]. On the other hand, many researches on exposure systems using digital micromirror devices (DMDs) instead of LCD panels were also reported [14–19]. Besides, an exposure system using grating light valves (GLVs) or spatial light modulators (SLMs) was proposed [20].

Although black matrix parts are always opaque for exposure light rays in the case of LCD matrix exposure, smooth patterns without notches are obtained, because parts corresponding to narrow black matrix lines on a wafer are also exposed by light diffracted from the neighbored bright LCD pixels. If the resolvable pattern size for the projection lens is sufficiently larger than the

* Corresponding author.
E-mail address: horiuchi@cck.dendai.ac.jp (T. Horiuchi).

http://dx.doi.org/10.1016/j.mee.2015.01.003
0167-9317/

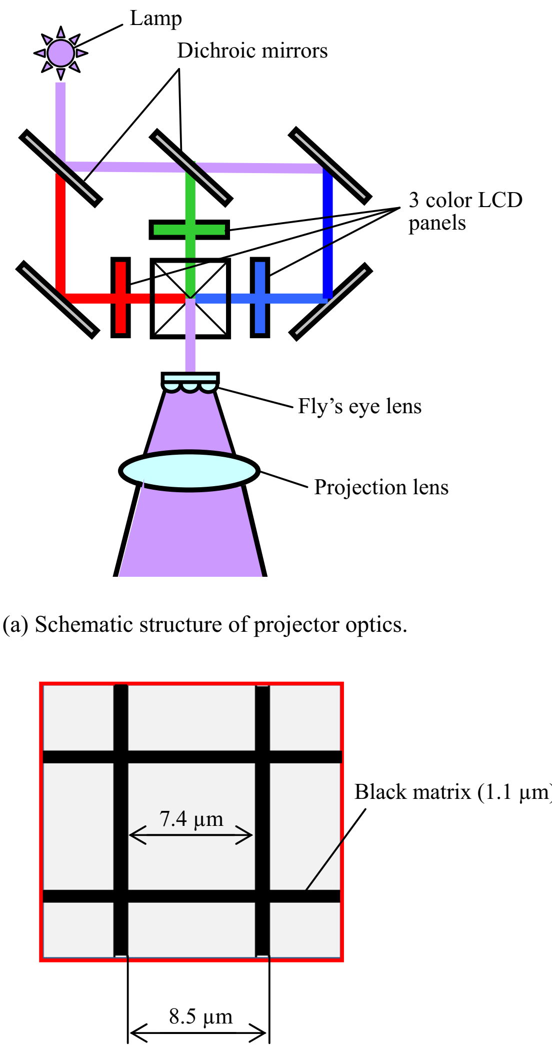
widths of black matrix lines, the black lines are not resolved, and they are not replicated.

In addition, because each transmittance of LCD cells is arbitrarily changed in 256 grades, oblique or curved patterns are also smoothly printed, and they are arbitrarily positioned, if the pattern widths are wider than the twice of pixel pitches [4]. If neighbored pixels of a two-pixel line patterns are assigned in different transmittances, for example, position of the printed line pattern shifts to the side of higher transmittance and brighter pixels depending on the transmittance difference between the neighbored pixels. In contrast, in the case of systems using DMDs or SLMs, laser beams are scanned on element mirrors or GLVs. For this reason, it is difficult to giving different exposure doses arbitrarily on each element mirror or GLV.

On the other hand, the LCD panel can control only visible light with wavelengths between 420 and 750 nm, and efficiency of utilizing light energy is low. These are the disadvantages of LCD matrix exposure. However, an novel multi-layer resist process has already been developed to transform top-layer resist patterns printed by the LCD lithography using visible light to bottom-layer resist patterns sensitive to ultra-violet (UV) light [5–7]. Accordingly, the LCD lithography has also been applicable to UV lithography using resists such as SU-8 (MicroChem). Therefore, it is considered that large inconveniences are not found in effect.

On the basis of these considerations, extremely small and low-cost lithography tool was developed this time [21]. In the past research, an LCD panel with small pixel numbers of 320 × 240 was used. The black and white LCD was a view finder of video camera used approximately 15 years ago. Although it had the smallest pixel pitch of 15 μm in those days, the pixels had rectangular shapes, not square shapes. For these reasons, too small exposure-area size and directional differences of patterning performances prevented the technology from being applied to practical micro-fabrications. In addition, because the hand-made exposure systems developed in the past research were fabricated using a light source at hand and makeshift collective optics, downsizing and cost minimization of the exposure system were not earnestly considered.

In this research, a new advanced commercial LCD projector with pixel numbers of 1024 × 768 and pixel pitch of 8.5 μm was directly used for earnestly downsizing the system and reducing the fabrication cost at minimum. It was the first trial in the world. In addition to reducing the system cost at minimum, pixel numbers and the exposure field size were greatly improved to be applied to various practical applications. Although the target pattern size and exposure field size were different, an exposure system with similar structure was proposed by chance in the same conference [22]. Simple and low-cost exposure tools are impatient.



(a) Schematic structure of projector optics.

(b) Schematic structure of pixels.

Fig. 1. Schematic structure of LCD projector.

2. Concept design and lens selection

In this research, simplification and downsizing of the system, and reduction of the costs required for fabricating the exposure system were strongly considered. For this reason, commercially available video-projectors applicable to the projection exposure lithography were searched at first. To print patterns similarly in both lateral and longitudinal directions, LCD panels with square shapes and same pixel pitches in both directions are expected. In addition, it is preferable that the pixel pitches are as small as possible, and the black matrix lines are as narrow as possible. For this reason, LCD video-projectors with these performances were looked for. As a result, a projector with three-displays of red, green, and blue (RGB) was selected. The schematic projection optics of the selected projector (Mitsubishi Electric, LVP-HC5000) are shown in Fig. 1. LCD pixel pitches in vertical and horizontal directions were 8.5 μm, and the width of black matrix line was 1.1 μm. Therefore, the LCD pixel size was 7.4 μm square. Pixel numbers used for the research were 1024 × 768 depending on the specification of the personal computer used for designing patterns to be printed.

However, at the front of the projector, projection lens optics for making largely magnified images on a screen was attached. In the case of exposure system for lithography, images should be projected onto substrates in a small exposure field compared with large screen sizes, and the resolution appropriate for printing aimed patterns has to be secured. For this reason, it was considered that the initially attached projection lens optics should be removed, and new projection optics should be attached instead. Here, it was also considered that the distance between the projection system and the substrates should be appropriately short for developing a compact exposure system. As a result, a macro-lens of a camera (Sigma, EX DG MACRO) was selected. There was another reason that the lens had been actually used for developing simple exposure system in other researches.

Besides the video-projector and the macro-lens, it was necessary to prepare stages for moving substrates. However, because no alignment or only very rough positioning was required for the live works, it was decided to use very simple manual *XYZ* stages.