Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

EXPOSURE OF PRINTED CIRCUITS BY SUB-PIXEL SCROLL METHOD

Piotr Domanowski, Ryszard Wocianiec

University of Technology and Life Sciences in Bydgoszcz
al. Prof. S. Kaliskiego 7, 85-789 Bydgoszcz, Poland
e-mail: piotr.domanowski@utp.edu.pl

Abstract

The article shows principle of operation of the direct transfer of the image, and the idea of sub-pixel image scroll used in digital platesetter. It consists of a UV radiation source, the micro mirror image forming, system of the projection of an image onto the photopolymer and placed in the optical path mirror deflecting UV rays at an angle of 45°, and associated with the piezoelectric actuator. Such shaped optical system allows the usage of sub-pixel scrolling image projected on the photopolymer. The second mirror with the actuator deflecting the image in a direction perpendicular to the primary scanning direction placed in the optical path allows to increase the accuracy of the transfer of the image.

Keywords: *photolithography, exposure, DMD*

1. Introduction

In the production of microelectronic devices are used photolithography methods of direct transfer of the image on the panel covered a photopolymer without printing plates. "Digital matrixes of mirrors" (DMD), e.g. Texas Instruments can be used for direct transfer of the image. DMD consists of a system of mini-mirrors covering 415 872 individual mirror elements (DLP3000) [1], each of which can be set in two positions (Fig. 1). The slope of the mirror elements of the mini-mirror system produced a surface consisting of the deflected and undeflected mirror element, whose image is projected by the optics projection on the photosensitive surface. Further, successive images are generated by using a computer and then transferred to the surface. At reproduction ratio of 1:1, the substrate surface about the size of 6571.8 x 3699 microns (DLP3000) [1] is exposed to light.

Most recent application of DMD for direct image transfer are using mainly two methods of irradiation of larger areas of the substrate:

1. Static method (step-and-repeat) [2, 3],
2. By scrolling (scrolling method) [2, 4].

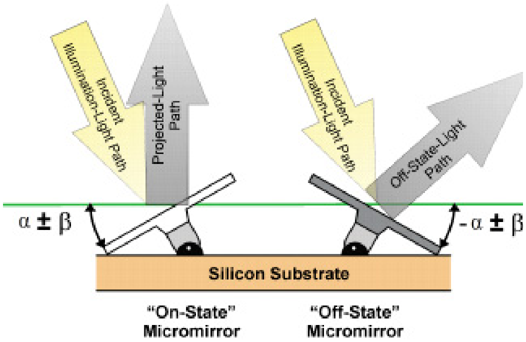

Fig. 1 The principle of operation of the system DMD (Digital Mirror Devices) Texas Instruments Inc. [1]

A continuous scrolling method (2) can be described as exposure the substrate surface element (pixel) by the mirror element. Mirror element and the substrate surface element are moving relative to each other with carefully controlled rate. In order to obtain an image of the same dimensions as the DMD mirror matrix, the relative movement takes place at a distance equivalent to the length of the matrix of mirrors. When matrix is moving to a new location, transferring the next image to the DMD takes place.

Both methods have some disadvantages. In the method of step-and-repeat you need to make thousands of precise positioning, leading to the complex mechanics and long periods of dead time. The scrolling method accomplishes the uniform feed motion at the cost of ''smeared'' edge transition and with a scan velocity limited by the mirror switching frequency, for example with a imaging ratio of 1:1 is approximately 135 mm / sec. The mentioned scrolling methods require a precisely controlled speed, thus inexpensive toothed belt drives are not usable.

2. Construction of a system for direct transfer of the image by sub-pixel scrolling method

"Sub-pixel method" (Sub-pixel Scroll Method), uses an additional element in the form of a mirror inclined at an angle of 45°, which is placed between the matrix and the DMD projection optics [2] for the optical shift position mirror elements relative to the axis of each projection the size of a single sub-pixel. In a preferred embodiment, the 45° mirror is shifted by 1/4 the width of a mirror element by a controllable actuator. The size of this change of position and the time point are synchronized by the position indicator signals of the scan sled in such a way that the mirror element (as with the standard scrolling method) seems to stand relative to the substrate surface element. Differently than with the standard scrolling method is the resetting, which however is not bound to the DMD switching speed of 10 kHz. Due to its higher resolution, the present invention reduces the blur at the edge transition and makes a higher scan velocity possible, whereby the scan velocity depends on the dynamics of the actuator, the effective UV-power of the UV source and the sensitivity of the photosensitive polymer. A further advantageous function of the present invention is the possibility of transferring a pattern with higher resolution than given by the mirror element size. For an increase of the resolution in X (scan direction) and Y perpendicular to the scan direction) two mirror actuators are necessary, which work in X and Y.

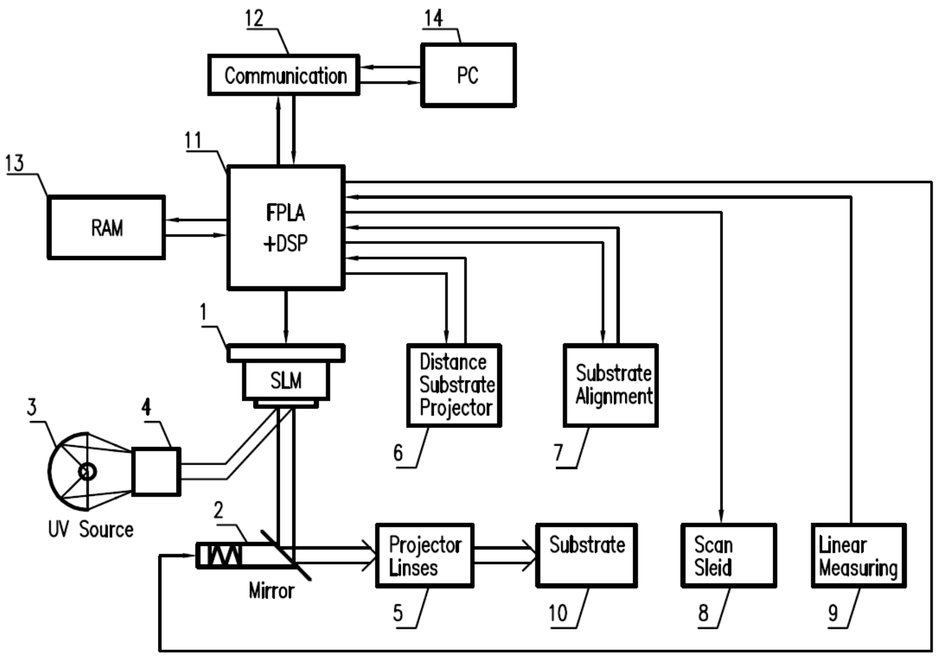

Fig.2 System for direct transfer of the image by sub-pixel scrolling method
(a description is in the contents of Chapter 2)

Designed lithographic system shown in Figure 2 contains a source of ultraviolet radiation - 3, condenser optics - 4, a spatial light modulator (SLM) - 1 (in this project modulator is equipped with a digital array of mirrors (DMD), such as the Discovery 1100 from Texas Instruments), the projection lens system - 5 and mirror's controllable actuator sloping at an angle of 45 ° - 2.

The beams reflected by the mirror matrix 1 are optically shifted along the projection axis 2 controlled mirror actuator. Additionally, Fig. 1 shows the control system of digital signal processor (DSP) and free programmable logic array (FPLA) 11, that controls all functions of the lithographic system. In a computer system (PC) 14 the layout data of a pixel pattern are prepared.

For a preferred substrate format 600x500 mm and a preferred resolution of 12.7: per pixel, the size of the prepared data set is about 275 megabyte. This amount of data is transferred via a fast communication means 12 to the RAM 13. The exact distance of the projector optics 5 to the substrate 10 is measured and adjusted constantly by the distance substrate projector feature 6 of the DSP/FPLA 11. Before beginning the exposure, each new substrate 10 is measured: exactly and aligned to the scan direction of the scan sled 8 by the substrate alignment feature 7 of the DSP/FPLA 11. The linear measuring system 9 supplies the trigger signals for the exact synchronization of all switching processes of the SLM 1, and the optical displacement of the reflected UV beams by the mirror actuator 2. The synchronization of all switching processes with only the position indicator signals makes the-exact lithographic transfer of the patterns independent of the speed of the projection optics relative to the substrate. At low speed about the point of reversal of the scan direction, the UV energy is controlled by variation of the on-off relationship of the mirror elements 1.

3. The direct transfer of the image

Referring to the drawings, the preferred details of the present invention are graphically and schematically shown. Like elements in the drawings are indicated by numbers, and any similar elements are indicated by the corresponding numbers with the addition of letters.

Figures 3a-3f show the process of the present sub-pixel scroll method with the exposure of a substrate surface element by three mirror elements. In this example, each step of correction by the 45° mirror actuator amounts to 0.5 pixels. In the embodiment illustrated in the figures, the 45° mirror actuator has a total correction potential of 2 pixels, i.e., after four steps of correction of 0.5 pixels each, the 45° mirror actuator must be pulled back to the zero value (reset). However, any number of correction steps may be practiced in the present invention under appropriate process control and scale of the actuator mirror 2. The sub-pixel scroll method is described with the drawings. 3a-3f [3, 4].

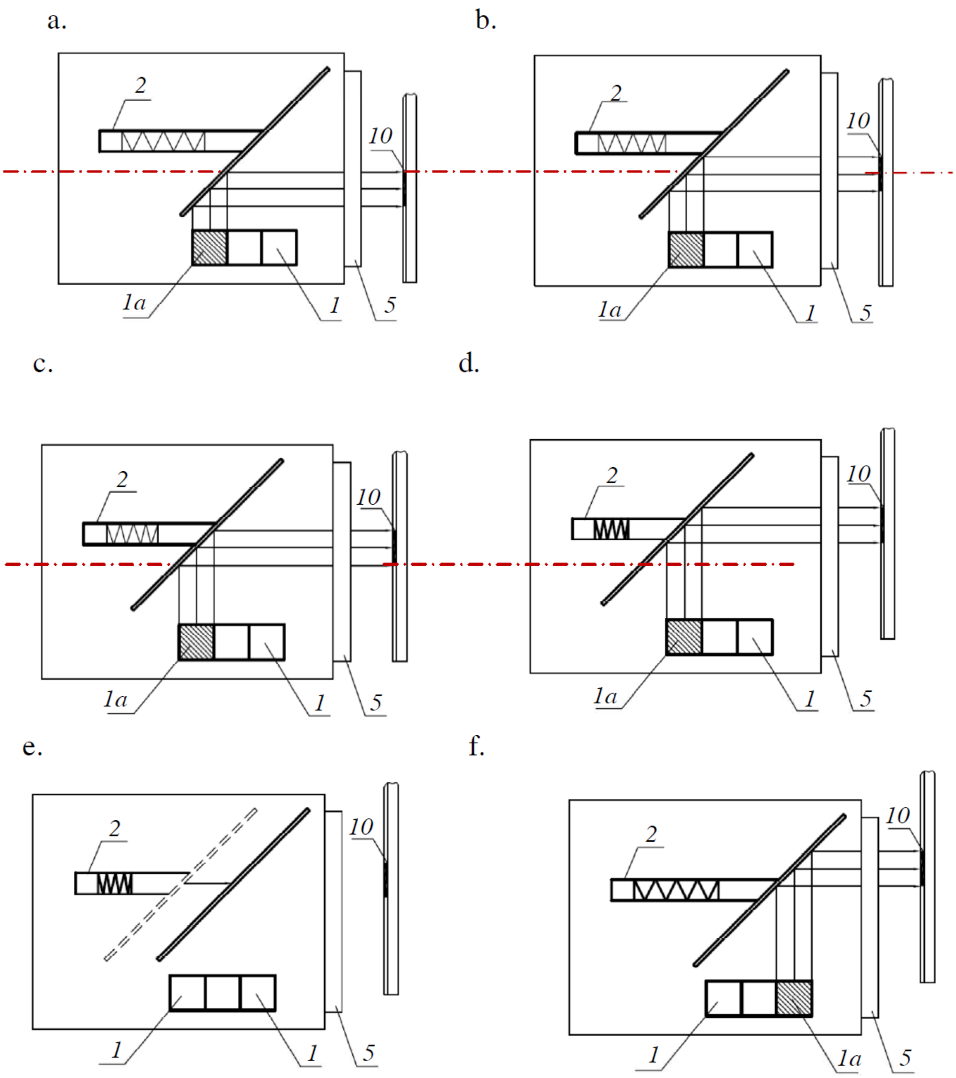

Fig. 3 The next phases exposure by sub-pixel scrolling method

The Sub-pixel Scroll method exposes a substrate surface element of the substrate 10 while exposure optics and substrate move relative to each other. The blur of the substrate surface element edge depends on the number of correction steps per substrate surface element, can thus amount to 1/10 the width of the substrate surface element. The speed of the exposure system is not limited to switching frequency x substrate surface element width, as with known scrolling methods. The maximum scan velocity and thus the exposure time for the entire substrate depends on the correction potential of the mirror actuator, the switching time for loading of a new pattern in the DMD, the resist sensitivity and the effective UV power on the substrate.

Figs. 4a-4d show the method for the improvement of the resolution, a more advantageous function of the Sub-pixel scroll method, the increase of the resolution of the pixel pattern by using of a mirror actuator with deflection possibility in X/Y. The Sub-pixel Scroll method is advantageous because it increases the resolution of the pixel pattern by usage of a mirror actuator with deflection possibility in X/Y. A substrate surface 301 is to be exposed, which is larger than two substrate surface elements and has edges, winch lie in the raster 0.5 x width of the substrate surface element. For known maskless lithographic procedures the resolution is fixed by the size of the mirror elements, the smallest raster thus is 1 x width of the substrate surface element.

- Fig. 4a shows a substrate surface 1 and a mirror element 2, which exposes substrate surface element 3 with the deflection mirror in zero position and substrate surface element 4 with a deflection mirror deflected in X/Y.
- In Fig. 4b, a program for processing of pixels generates a mirror pattern that exposes the surface substrate 1 as far as possible with substrate surface elements 3.
- In Fig. 4c, for the non-exposed partial surface of the substrate surface, then a mirror pattern is generated by the program, which exposes these surfaces as far as possible with substrate surface elements 304. In the corners partial surface squares with an edge length of 0.5 x width of a substrate surface element can remain unexposed.
- Fig. 4d shows the distribution of the exposure energy in the substrate surface after the exposure illustrated in Figs. 4b and 4c.

In order to avoid unnecessary scanning paths, the process steps shown in Figs 4b and 4c should be mutually changed after the cycle of Figure 3 during exposure of the substrate surface.

Conclusions

- The higher resolution of this method is accomplished by doubling of the exposure time. By introduction of further partitioning steps and exposure passages the resolution potentially can be increased at will.
- The described method reduces the blur at the edge transition and makes a higher scan velocity possible, whereby the scan velocity depends on the dynamics of the actuator, the effective UV-power of the UV source and the sensitivity of the photosensitive polymer.

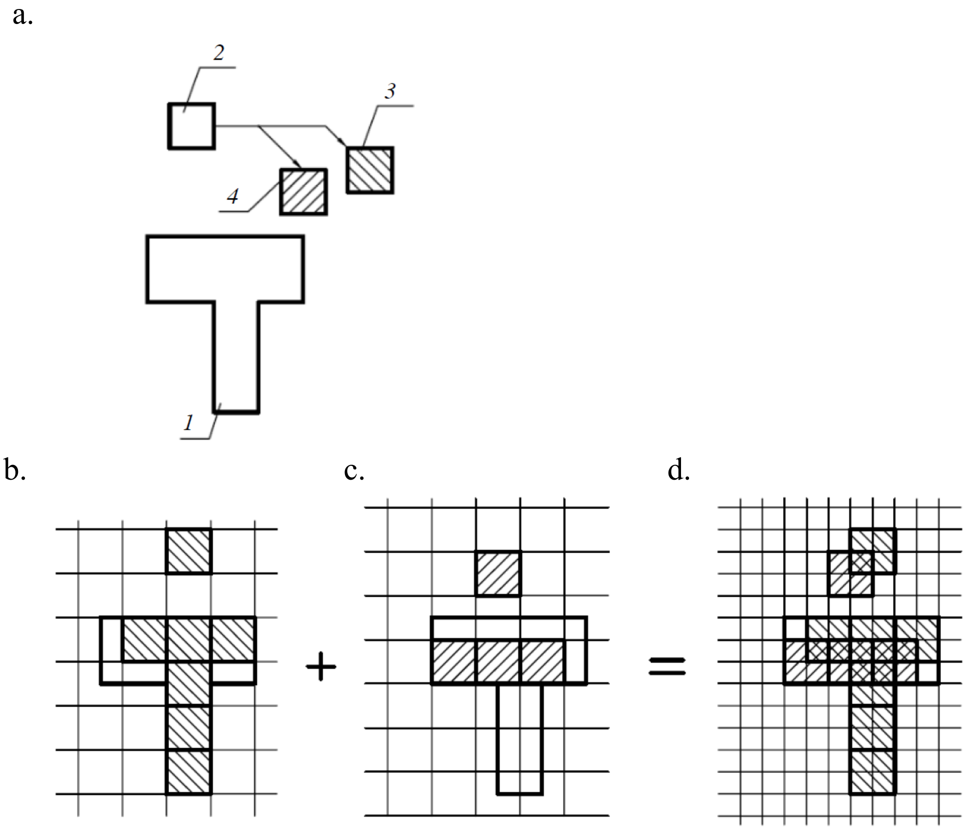

Fig. 4 Function of increase in resolution by the method of sub-pixel scrolling

- Sub-pixel scrolling method allows the transfer of a pattern with a higher resolution than that which is determined by the size of the matrix element DMD mirror.
- Multiple variations and modifications are possible in the embodiments of the invention described here. Although certain illustrative embodiments of the invention have been shown and described here, a wide range of modifications, changes, and substitutions is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the foregoing description be construed broadly and understood as being given by way of illustration and example only, the spirit and scope of the invention being limited only by the appended claims.

References

[1] *DLP3000 Technical Documents*, http://www.ti.com/product/DLP3000, 24 Oct 2012

[2] Domanowski P., Wocianiec R.: *Wpływ jakości montażu układu optycznego cyfrowej naświetlarki obwodów drukowanych na dokładność odwzorowania obrazu*, Projektowanie Mechatroniczne – Zagadnienia wybrane, praca zbiorowa pod redakcją Tadeusza Uhla, Kraków, 2011

[3] Skibicki D., Paczkowski T., Domanowski P.: *Lithographic method for mask less pattern transfer onto a photosensitive substrate*, United States Patent, US 7,982,853, B2, 2011

[4] Domanowski P., Wocianiec R.: *Konstrukcja cyfrowej naświetlarki obwodów drukowanych*, Projektowanie Mechatroniczne – Zagadnienia wybrane, praca zbiorowa pod redakcją Tadeusza Uhla, Kraków, 2013