Region-based Pattern Generating System for Maskless Photolithography

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Abstract: In the maskless photolithography based on the Digital Micromirror Device (DMD) by Texas Instruments Inc. (TI), the micromirror array works as a virtual photomask to write patterns directly onto Flat Panel Display (FPD) at high speed with low cost. However, it is neither simple to generate region-based patterns for the micromirror array nor easy to deliver sequences of patterns for the micromirror controller. Moreover, the quality of lithography yields the precise synchronization between generating sequence of patterns and irradiation rate off micromirrors. In this study, the region-based pattern generating system for maskless photolithography is devised. To verify salient features of devised functionalities, the prototype system is implemented and the system is evaluated with actual DMD based photolithography. The results show that proposed pattern generating method is proper and reliable. Moreover, the devised region-based pattern generating system is robust and precise enough to handle any possible user specified mandate and to achieve the quality of photolithography required by FPD manufacturer.

Keywords: Photolithography, Maskless, Digital Micromirror Device (DMD), Flat Panel Display (FPD)

1. INTRODUCTION

Recently, the Digital Micromirror Device (DMD) by Texas Instruments Inc. (TI) has brought the innovation on the digital light processing technology [1]. Especially in the field of microdisplays, the DMD which is an array of micromirrors appears to be the most successful Micro Electronic Mechanical System (MEMS) solution [2, 3].

Nowadays, many new DMD application fields are emerged. One of them is the photolithography for Flat Panel Display (FPD) fabrication [4]. The conventional lithography has been carried using pattern masks in order to have patterns on photo resistant coated substrates be exposed to ultraviolet light. Besides the cost and time for manufacturing disposable photomasks or reticles, the contamination of the final products caused by pattern masks has become significant in FPD industry. Moreover, the lithographic accuracy yields the alignment of the mask with the substrate or stage, which is hard to be ensured because of the vibration caused by fabrication environment.

In DMD based maskless photolithography system, the micromirror array works as a virtual photomask to write patterns directly onto FPD glass substrates at high speed with low cost. In comparison with other maskless photolithography technologies, DMD based maskless photolithography technology possesses superior features all together such as sufficient throughput for highly customized patterns, higher but precise resolution, fine lithographic quality, efficiency in cost and time, and so on. Moreover, DMD even comes out with its own motion controller.

However, the task providing command for DMD controller against millions of individually addressable and adjustable micromirrors in DMD frame for the photolithographic pattern generation is left behind on each system developer unsolved. The development of the entire pattern generating system from loading of photolithographic pattern data till delivering it to DMD controller is essential and crucial for photolithography, even though it is not simple to generate region-based patterns for the micromirror array and is not easy to deliver sequences of patterns for the micromirror controller. On the other hand, the synchronization between generating sequence of patterns and irradiation rate off micromirrors significantly affects the quality of lithography.

In this study, we aim to develop an effective pattern generating system that creates photolithographic region for the micromirror array. The region-based pattern generating system for maskless photolithography is proposed.

The devised pattern sequence data generating system consists of four major functionalities; 1) Reading CAD Data written in the Drawing eXchange Format (DXF), 2) Extracting the regional information and constructing the lithographic region, 3) Transforming constructed lithographic region into binary data, 4) Delivering binary data to DMD controller for lithography.

To evaluate proposed functionalities, the prototype system is implemented, and actual DMD based photolithography using the system is carried. The results show that proposed pattern generating method is proper and reliable. Moreover, the implemented region-based pattern generating system is precise enough to achieve the quality of photolithography required by FPD manufacturer.

2. DMD BASED MASKLESS PHOTOLITHOGRAPHY EQUIPMENT

The DMD based maskless photolithography equipment consists of three major devices. The first one is the radiation device. The second is the irradiation device including DMD controller, DMD, focusing optics, photo resistant coated glass substrate, and base stage assembly and its controller. The last is the dynamic pattern control device being composed with the photolithographic pattern generating system, the radiation control unit, and the stage control unit.

Figure 1 shows the schematic diagram of DMD based maskless photolithography equipment. The eXtended Graphic Array (XGA) 1024X768 Array DMD manufactured by TI has 13.68 μm of one Pixel Field Of View (FOV) and it is enlarged to 40 μm in present work. As shown in Fig. 1, micromirrors of DMD are exposed to incoming radiation released from the ultraviolet light source. The reflection off the micromirrors is determined upon the signal from the photolithographic pattern generating system to DMD controller. Then, the light reflected off the micromirrors is projected through focusing optics onto the photo resistant material coated on top of the glass substrate laid on x-y scrolling base stage. Throughout DMD based maskless photolithography in concern, all DMD controller does is only digital control of the light reflection for micromirrors *i.e.*, it gives the approval of reflection as on or off. Therefore, the operation of the maskless photolithography equipment might be thought so simple.

However, in reality, it is not. Sending the approval of on/off reflection for each of millions of micromirrors to DMD controller is more complicated than thought. Especially when reflection by the rotated DMD frame is unavoidable and/or in case when projection into the scrolling object is required, it is even troublesome to construct the proper lithographic region.

Unfortunately through the maskless photolithography in concern, both reflection by the rotated DMD frame and projection into the scrolling object are imposed. Therefore, devising a customized pattern generating system entirely from loading of photolithographic pattern data till delivering it to DMD controller is inevitable.

In this study, we focused our attention on the development of an effective pattern generating system that gives signals to DMD controller for the generation of photolithographic pattern, at prescribed radiation signal upon the irradiation intensity and stage control signal adjusted upon the pitch proper to the angle of DMD rotation and resolution. The region-based pattern generating system for DMD based maskless photolithography is proposed.

3. LITHOGRAPHIC PATTERN GENERATION

The region-based pattern generating system in present study consists of four major functionalities. Figure 2 shows the region-based pattern generating flow. The first is loading Computer Aided Design (CAD) data written in the Drawing eXchange Format (DXF) through the recognition of geometric entities as lines and arcs. The second is associated with three routines. The extraction of pattern boundary is performed through the reconstruction process of geometric entities with open loops into closed loops. The construction of region-based pattern is done upon polygonal set operation of computational geometry. The confirmation of photolithographic region is carried in accordance with geometric and technological constraints upon substrate and micromirror conditions. The third is the transformation of constructed photolithographic region into binary data upon DMD controller configuration. The last is the delivery of binary data to DMD controller for lithography in accordance with the DMD performance and glass substrate scrolling speed.

3.1 DXF formatted CAD data Loading

To ensure the capabilities of devised pattern generating method, the testing of pattern generation is performed before it is applied to the actual DMD based maskless photolithography process. The test CAD data in DXF format loaded into memory. Through the recognition, the geometric entities are considered as lines, arcs, circles. Each of the recognized geometric entity is reconstructed as the entity defined in this study, which is abstract entity for polygonal region.

3.2 Extraction of pattern boundary

The boundary of the pattern is extracted with the conversion of geometric entities with open loops into polygonal entities forming closed loops. Figure 3 shows the extracted boundary of the pattern from the test CAD data. The diameter of circle is in between 50μm and 700μm, and the space between them is given in between 50μm and 200μm. The width of polygons representing lines lies in between 30μm and 50μm, and the space between them is given in between 30μm and 50μm.

3.3 Construction of region-based pattern

The construction of region-based pattern proceeds as follows. Each enclosed area extracted from the pattern boundary corresponds to each of polygonal entity. In case if there are overlapping polygons, the intersected area needs to be excluded from region-based pattern. In order to discard the intersected region, polygonal set operation in computational geometry is performed. Finally, to construct the region-based pattern, the interior area is considered as the area stands for photolithographic pattern.

3.4 Confirmation of photolithographic region

In general, the maskless photolithography system uses the resolution improvement mechanism by virtue of the rotated DMD frame (*i.e.*, micromirror array) and the scrolling substrate. To satisfy the specification required by the FPD manufacturer, the system in concern uses the same mechanism. Figure 4 shows the configuration of DMD rotation and substrate scrolling. In present study based on XGA 1024 x 768 Array DMD, one DMD frame is made up with total of 786432 (longitudinally 1024 / horizontally 768) micromirrors with 40

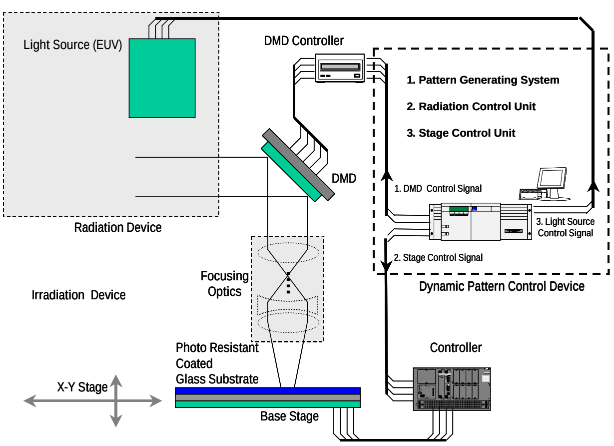

Fig. 1 DMD based maskless photolithographic equipment

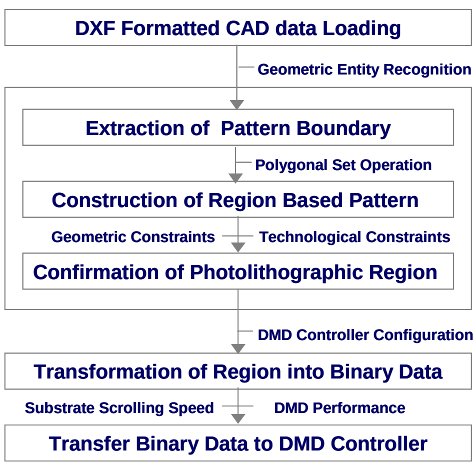

Fig. 2 Region-based pattern generating flow

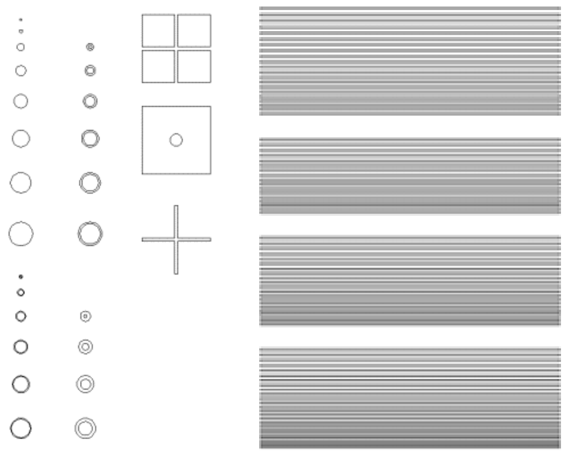

Fig. 3 Extracted boundary of the test pattern

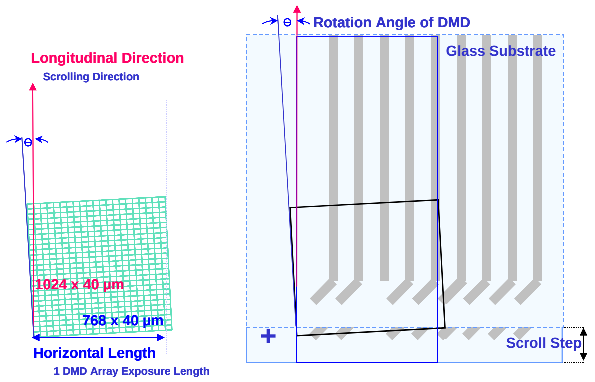

Fig. 4 Configuration of DMD rotation and substrate scrolling

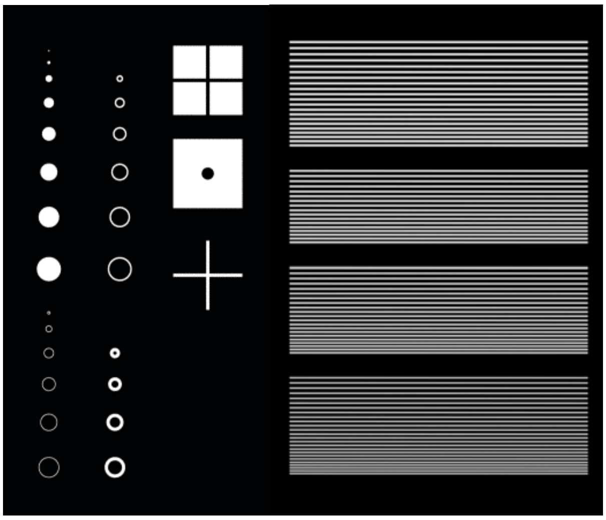

Fig. 5 Confirmed photolithographic region

μm of enlarged FOV. The DMD frame is rotated clockwise from the longitudinal axis assigned as substrate scrolling direction. The pattern region is considered as being rotated counterclockwise from the longitudinal axis due to the clockwise rotation of DMD frame. The region projected onto DMD frame is extracted from pattern region. As a result, the extracted part of the region is mapped to lithographic region at each scrolling step.

3.5 Transformation of region into binary data

The transformation of photolithographic region into binary data is performed upon DMD controller configuration. In present study, to match the lithographic region with DMD resolution, one DMD pixel is subdivided into 100 sub-pixels. The approval of on/off reflection for the mirror pixel on DMD is carried upon the number of sub-pixels occupied by the confirmed photolithographic pattern.

Figure 5 shows the confirmed photolithographic region generated by devised method. To generate testing patterns, the pitch is assigned to be 5 with 40μm of enlarged FOV to have irradiation every 8μm scrolling. The area threshold value for binary data creation is hold at 80% and the bit depth is held at 768 and up with 5 degrees rotation of DMD frame. The total number of 9250 frames is used to irradiate the total area of the testing pattern. The results show that proposed method is capable of generating proper photolithographic pattern for DMD.

3.6 Transfer binary data to DMD controller

The binary pattern data is transferred to DMD controller in accordance with substrate scrolling step and DMD performance. The PCI board with the data transit speed 1200 frame per second (fps) is selected to play a role for delivery.

4. IMPLEMENTATION

In order to attain our aims to make region-based pattern generation feasible for actual DMD based maskless photolithography, the prototype photolithographic pattern generating system is implemented. The implemented system is mainly composed of the lithographic pattern generation module discussed in section 3, the signal interchange module that handles the real time communication with hardware components of the radiation control unit and the stage control unit, and the Graphical User Interface (GUI) that enables the photolithography equipment operator to view and control various operations of the system.

Figure 6 shows the main window of GUI for the photolithographic pattern generating system. The management toolbar, the irradiation control sub-window, the pattern display sub-window, and the processing message sub-window are shown on the top, on the left, on the right middle, and on the right bottom, respectively. As shown in fig.6, the user specified input to the implemented system is the origin of the coordinate system, angle of DMD rotation, angle of substrate misalignment, two-directional DMD resolution, irradiation accuracy or pitch upon scrolling step, threshold value for binary data creation, and selection for normal/flip/mirror conversion of CAD data. Therefore, the system is robust enough to handle any possible user specified mandate and even substrate misalignment.

To ensure the capabilities in devised system, the system is then applied to the generation of photolithographic pattern for FPD glass fabrication. Figure 7 shows the FPD glass photolithography process upon our system. Throughout the

Fig. 6 Photolithographic pattern generating system

FPD pattern generation, the lithographical conditions are kept to be identical to those of the test pattern generation discussed in section 3, except the total number of frames needed to have the total area of FPD pattern be exposed to irradiation is shifted to 9250 frames. The CAD data of the pattern for FPD glass, with the minimum of 140μm line space (L/S), is shown in fig.7-(a). The illustrative example showing the accumulation of 16000 frames is appeared in fig.7-(b). The confirmed photolithographic region for FPD pattern is in fig.7-(c), and marked four sections are enlarged in fig.7-(d) to show the predicted photolithographic pattern in detail. The obtained FPD pattern shows that the implemented system based on region-based pattern generating method is capable to produce the actual pattern for DMD based maskless photolithography.

5. RESULTS AND DISCUSSION

For the validation of devised photolithographic pattern generating system, the DMD based maskless photolithography is carried to fabricate actual FPD glass using the system. Figure 8 shows the enlarged portions of electron microscope images from the actual FPD photolithography results obtained by the system discussed in section 4. The boundary of the final pattern appears to be clear enough insisting the accuracy of the devised system. Moreover, no manifestation of discrepancies between input from CAD data and output resulted from the actual photolithography is found.

Overall, the result of actual FPD pattern photolithography verifies that the implemented system is capable of generating photolithographic pattern precise enough to acquire the high qualification from FPD manufacturer.

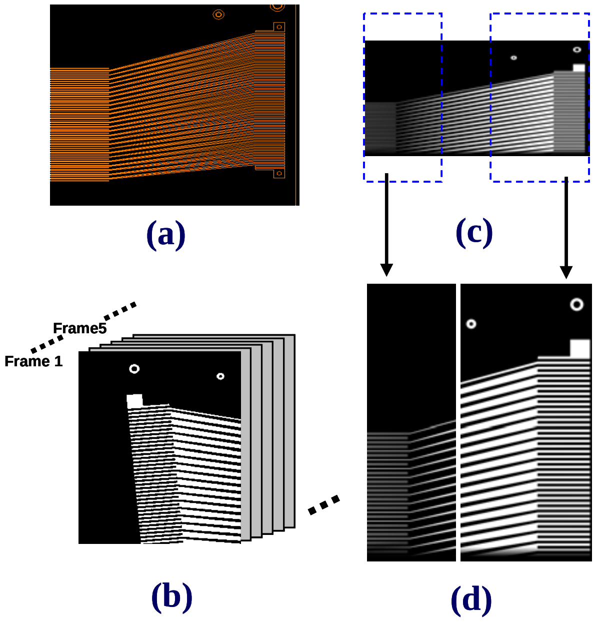

Fig. 7 Actual FPD glass photolithography process

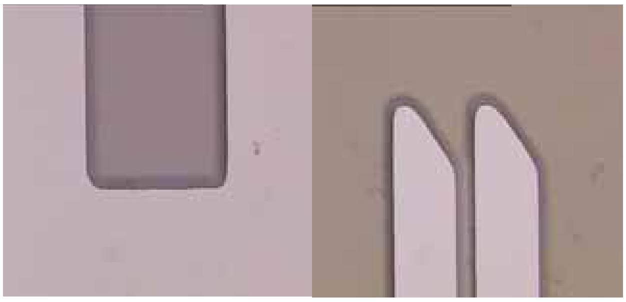

Fig. 8 Enlarged portions of electron microscope images resulted from actual FPD photolithography

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