Digital micro-mirror device based modulator for microscope illumination

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Abstract

A flexible illumination scheme for microscope based on a spatial light modulator named Digital Micro-mirror Device (DMD) is presented in this paper. Through the combination of DMD and conventional illumination system, the incident light can be modulated to certain preset patterns as new illumination for microscope. Some features, including intensity, shape, distribution, area and exposure time, were all precisely controllable via computer. The improvement has a promising potential in some fields such as bio-technology and optical lithography.

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1. Introduction

With the development of industrial production and scientific technologies, the application of microscope has been involved in every field of scientific research. In observing different objects for disparate purpose, people demand diverse methods of illumination, for example, light field illumination, dark field illumination, tilted illumination, and phase contrast illumination. Nevertheless, these traditional illumination systems can’t satisfy nowadays needs any more, because the new applications raise more and more critical requirements, which restrict the application of microscopy in the other aspect. For instances, the utility of Fluorescence Recovery after Photo-bleaching (FRAP[1]), where microscope is used to observe the proliferation of protein in the bio-tech researches. Another example is Maskless Photolithography, where objective lens needs to project certain pattern onto the substrate of wafer [2]. Both techniques above require outstanding capability of illuminator to expose a very small region instantaneously and to change spatial distribution of light source. Such rigorous request has been out of the reach of traditional microscope illumination system.

It is hoped to design a light source which is flexible and lattice-formed, by changing the arrangement of lattice to obtain different illumination effects, that is, to achieve spatial light modulation. However, so far a considerable
portion of spatial light modulators still rely on special devices, such as pinhole array and micro-lens array. The disadvantage of these modulators is that the size and the performance of these arrays are unchangeable once after manufacturing. To change effect of lighting modulation means to replace modulator, which does not facilitate the actual use. So these modulators can't be called 'being flexible'.

In recent years, several new types of spatial light modulator devices, such as Liquid Crystal Display (LCD [3]), have realized the requirement of being flexible and have been applied in the scanning microscope [4]. Like LCD, Digital Micro-mirror Device (DMD) is another flexible spatial light modulator, which has been widely used in digital light processing (DLP) at present. As a good spatial light modulator, DMD is introduced briefly as below.

2. Digital Micro-Mirror Device (DMD)

As Micro Electro Mechanical System (MEMS), Digital Micro-Mirror device (DMD) is developed by TI (Texas Instruments, TI Inc, U.S.) in 1987. Its manufacturing processes are similar with traditional CMOS products and its large-scale production [5] has been achieved so far.

Why DMD is called a ‘real’ flexible spatial illumination modulator is because of its structure. Each piece of DMD chip is integrated with nearly one million micro-mirrors. For example, the current DMD chip of XGA format can be integrated with 1024 × 768 pieces of micro-mirrors, of which the material is aluminum alloy with high reflectivity. The size of single micro-mirror is 16μm × 16μm with 1μm gap between every two micro-mirrors. Such layout of DMD chip ensures an extremely high filling factor, up to 89%, so that light energy efficiency is much higher than other illuminators. As shown in Figure 1, single micro-mirror of DMD consists of mirror, hinges, support posts and address circuit so on, which are all integrated on Complementary Metal Oxide Semiconductor (CMOS). Micro-mirror has been fixed in the hidden yoke; the torsion hinge connects yoke and support post while the structure of hinge allows the mirror a rotation of ±10 degrees. During working, the bias/reset bus, under the support post, charges mirror, while address circuit, formed by a pair of address electrodes, is applied with voltage. Between the mirror and one side of address electrodes, electrostatic attraction is produced and the mirror tilts until it touches the landing electrode with the same voltage as mirror. Micro-mirrors tilt +10 degrees, if a binary digit 1 is written in units of SRAM array, while -10 degrees needs digit 0 in SRAM. The two states are known as 'ON' and 'OFF'.

Currently the main application of DMD is Digital Light Processing (DLP). Showed in Figure 2 is the working principle of DLP based projectors.

Compared with LCD, DMD makes better use of reflective illumination. Additionally, it couples with a high filling factor, so its optical efficiency is better than LCD. Meanwhile, the life-span of mirrors on DMD is as long as 4700 hour and its performance is extremely stable. Finally, the characteristics of digitalization make DMD convenient for computer control, which can modulate uniform incident illumination not only into gray value image but also to digital image. Therefore DMD is a pretty fine spatial light modulator.
3. System Design

DMD-based microscope illumination modulation system consists of illumination modulation system of optical path and control system.

3.1. illumination modulation system of optical path

Figure 3 shows the structure of the illumination modulation, which consists of illumination modulator and Kohler Illumination layout.

The illumination modulator includes the parts of light source, lens condenser and DMD while the rest components build a typical Kohler illumination. The beam comes from the light source, that could be traditional sources like halogen as well as laser, travels through a group of condenser lens and is reflected by the reflector on the surface of DMD. DMD can be pre-programmed so that the micro-mirrors on the surface are either in the status of 'ON' or in the status of 'OFF'. If micro-mirror is ON, incident light will enter Kohler optical path after the reflection of DMD. If micro-mirror is OFF, incident light will be reflected to an absorption board. In this way, spatial illumination modulation is realized. It should be noted that the reflected light by DMD, with command of micro-mirror 'ON', can go into Kohler path, provided the incident angle to DMD is strictly 20 degrees.

As in a typical Kohler illumination, the image of DMD, situated on the aperture, is conjugate with the sample. Such structure ensures that the pattern modulated by DMD can be projected precisely on the surface of sample, and the illumination of sample is also as uniform as possible.

3.2. Control system

Modulation Control System is made of three parts: graphic generator, DMD controller and an interface connecting generator and controller.

Graphic generator includes a graphic editor, an Alpha mixer, an I/O port, a calibrator and a ratio convertor. The graphic editor responds to input devices such as mouse and keyboard and generates pattern, while the Alpha mixer displays DMD modulation graph, generated by editor, on computer monitor in a semi-transparent mode. The I/O port output modulation pattern to DMD controller in the form of numerical data. As the pattern generated by the editor may have a different resolution from the resolution of DMD, the calibrator and the ratio convertor are responsible to zoom pattern into appropriate size before transferring it into DMD. The implementation of all
operations in graphic generator is under the control of central controller, which is connected to CCD and monitor. Therefore, the real-time acquisition and presentation of modulation effect can be realized.

In DMD controller [6], there is an independent memory, which functions as buffer and storage for the data from graphic generator. DMD is connected to DMD controller. And all operations of each micro-mirror on DMD, such as spinning, status maintaining and resetting, are mastered by DMD controller.

Interface between DMD controller and graphic generator is formed by logic device, like FPGA, and clock generator. Logic device converts the data from graphic generator into a sequence and determines the mapping relationship between graphic data and DMD pixels, which actually addresses drive electrodes of every micro-mirror on DMD. And, according to clock signal, pattern data is updated.

The entire modulation control system and its data flow are presented in Figure 4.

![Modulation control system and its data stream](image)

**Fig. 4 Modulation control system and its data stream**

### 4. Experimental Results

In order to verify spatial light modulation system discussed in this article, a series of graphics are designed and are transferred into DMD via digital interface. The modulation system is connected with a metallographic microscope. To ensure brightness, high-pressure mercury lamp is used as light source. And CCD is used to capture the image of modulated pattern. In fig 5 a series of illumination patterns are shown.

![Modulation result of illumination](image)

**Fig. 5 Modulation result of illumination**

In pattern 5(a) and pattern 5(b), line width of graphics is 16μm, which is the same as the width of a micro-mirror. In pattern 5(d), each grid is formed with 10×10 pixels of DMD, which is 160μm×160μm. The experimental results testify that this set-up is able to spatially modulate illumination in accordance with pre-set pattern so that the scope of illumination and the spatial distribution become flexible and adjustable.
5. Conclusions

In this paper, a flexible microscope illumination system based on Digital Micro-Mirrors Device (DMD) as spatial light modulator is raised and it has the following advantages.

1. Precise control over spatial distribution of illuminating light. The scope of illumination can be adjusted from several microns to hundreds of microns arbitrarily so that it can be used both for general micro-testing and special field research such as FRAP.

2. Flexibility to change illumination settings, for example the scope and shade of illumination, regarding actual demand, which is a great advantage particularly in the field of biotechnology.

3. The features of DMD, such as high brightness (reflective illumination), fast response, digitalization and high pixel density (filling factor), are fully utilized. With the help of above features, exposure time interval of illumination for certain area is controllable. It is extremely important for FRAP and mask-less lithography studies.

4. DMD has been commercialized. Compared with other spatial light modulators, the cost of DMD has been greatly reduced, which may bring up fine prospects for actual application.

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