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Development of Blue Laser Direct-Write Lithography System

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Abstract

The optical lithography system researched in this study adopted the laser direct-write lithography technology with nano-positioning stage by using retailing blue ray optical pickup head contained 405nm wavelength and 0.85 numerical aperture of focus lens as the system lighting source. The system employed a photodiode received the focusing error signal reflected by the glass substrate to identify specimen position and automatic focused control with voice coil motor. The pattern substrate was loaded on a nano-positioning stage; input pattern path automatically and collocate with inner program at the same time. This research has successfully developed a blue laser lithography process system. The single spot size can be narrowed down to 3.07 μm and the linewidth is 3.3μm, time of laser control can reach to 450 ns and the exposure pattern can be controlled by program as well.

Keywords: lithography, laser direct-write, blue ray, optical pickup head, voice coil motor

1. Introduction

With the rapid development of the semiconductor industry, every semiconductor factory pursues the goals included high density, small linewidth and low cost. The key to reach these goals is the lithography during process. Generally speaking, lithography covers optical lithography[1] such as ultra violet (UV), deep ultra violet (Deep UV), electron beam (E-Beam) lithography[2-3], and X-ray (X) lithography[4] is the current major technology. Nanoimprint lithography technology was first proposed by Prof. Stephen Y. Chou team in Princeton University in 1995[5]. The paper presented by Prof. Stephen Y. Chou team proposed the research of Nanoimprint lithography technology and the development of direct imprinting technology is more mature than other new technology[6-9]. Differ from traditional lithography, Nanoimprint lithography technology doesn't adopt any energy beam, it will not be limited by diffraction, scattering and interference effect in agent. Roller nanoimprint is derived from continuous nanoimprint and nanoimprint lithography technology has been developed into mass production in recent years. In 2003, M. Kuwahara et al. [11] proposed a new type lithography called thermal lithography. With 635 nm wavelength of red light laser, thermal lithography generates the heating area by focusing light on the resist. Both point and line of 100 nm in diameter were successfully made, which can be used as low cost read-only memory (ROM). In 2009, C.P. Lin et al. [12] used blue laser of 405 nm wavelength and Ge-Sb-Cr-O (GSCO) materials to proceed thermal nano-lithography process. The minimum line width is 140 nm which exceeds the diffraction limitation of the blue laser. The result showed that the greater laser power used, the bigger the line width increased. Meanwhile, C.P. Lin et al. [13] also used their own experiences to increase the oxygen dissolution rate in the process and issued new inorganic resist film called as Ge-Sb-Sn-O (GSSO). With

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GSSO thickness of 80 nm, nano-pattern obtained from thermal lithography can reach up to 140 nm. In the same year, Y. Usami et al. [14] developed one inorganic resist available for thermal lithography with high resolution. By the premise that improving the vaporization temperature, the resist achieved the significant temperature curve to form the laser at the center spot. The result of half pitch of thermal lithography can reach up to 40 nm. This study proposed the laser direct-write technology with a low cost optical pickup head of Blu-ray DVD and a nano positioning stage. By integrated the autofocus mechanism in the optical pickup and the nano positioning stage, this paper successfully developed a laser direct-write technology system using the photoresist of the blue ray.

2. System configuration and experimental process

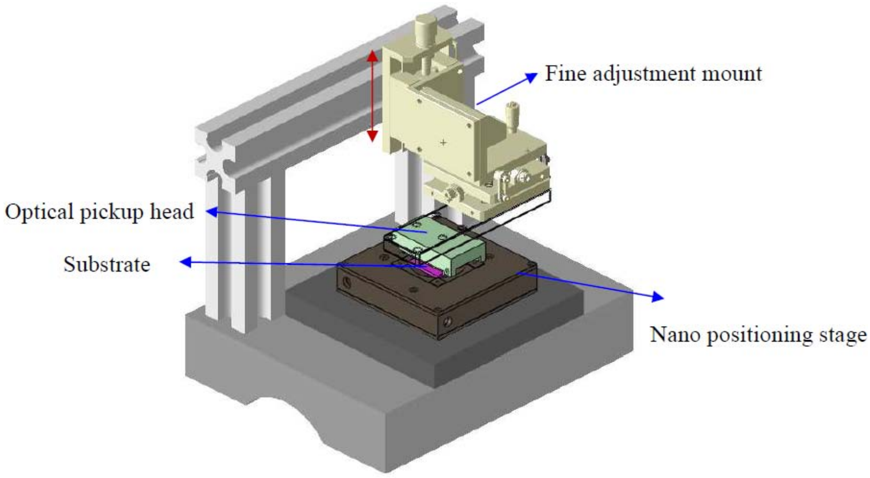

Fig. 1 The lithography system configuration

The overall system configuration was shown in Fig. 1. It was composed of an aluminum frame and a steel base and a DVD optical pickup and a nano-positioning stage. The position and angel of the optical pickup head is very important; therefore, the optical pickup head should be set up precisely on a three axes stage and a single axis stage. It is helpful to adjust the optical pickup head with using a three axes mechanism. The substrate was placed on a nano-positioning stage. The type of the optical pickup head in the Blu-ray DVD player is GBW-H10N from LG co.ltd shown in Fig. 2. The function information of the pin positions used in this paper is shown in the Table 1.

The overall optical system of the DVD pickup was shown in Fig. 3, the emission beam of the laser diode (LD) was reflected to a λ/4 plate (P) and a collimator lens (C) by mirrors (M1)(M2) through polarization beam splitter (PBS). The condense lens (L) placed on a voice coil motor (VCM) focused the laser beam on the lithography substrate and substrate reflects the beam back to its original path. The reflected beam was transferred into a transmitted light after through a condense lens (L), a collimator lens (C), a λ/4 plate (P), mirrors (M1)(M2) and a polarization beam splitter (PBS), and the transmitted light produces astigmatic beam through polarization beam splitter and an astigmatism lens. This astigmatic beam imaged on photodiode integrated circuit (PDIC) and the PDIC converted the current signal into voltage signal, then focusing error signal can be obtained by software calculation.

If the focusing error signal detected by PDIC is not equals zero, the voice coil motor moves up and down to focus the position due to analog voltage signal produced by DAQ card. During this process, the program automatically records the voltage value while sensing the focusing error signal from PDIC. The condense lens is displaced to the prime focus position by voice coil motor after scanning, thus focus process is totally completed.

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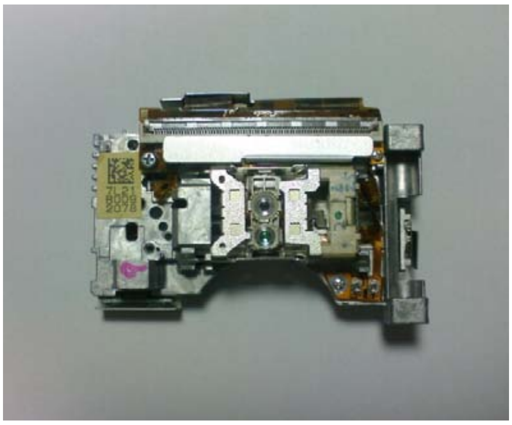
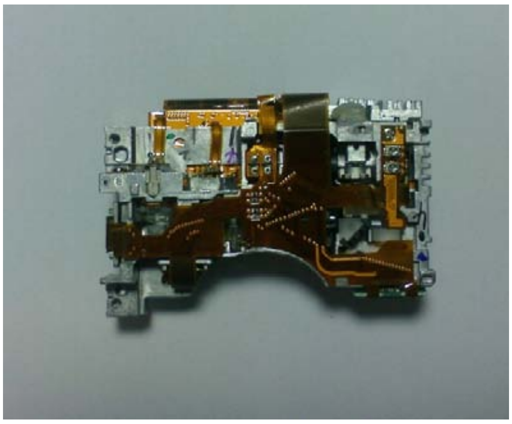
Table 1 PDIC table of GBW-H10N

Function	V_{cc}	V_{ref}	GND	A	B	C	D
Pin No.	1	22	9	8	10	17	19



(a) Front



(b) Back

Fig. 2 GBW-H10N optical pickup head

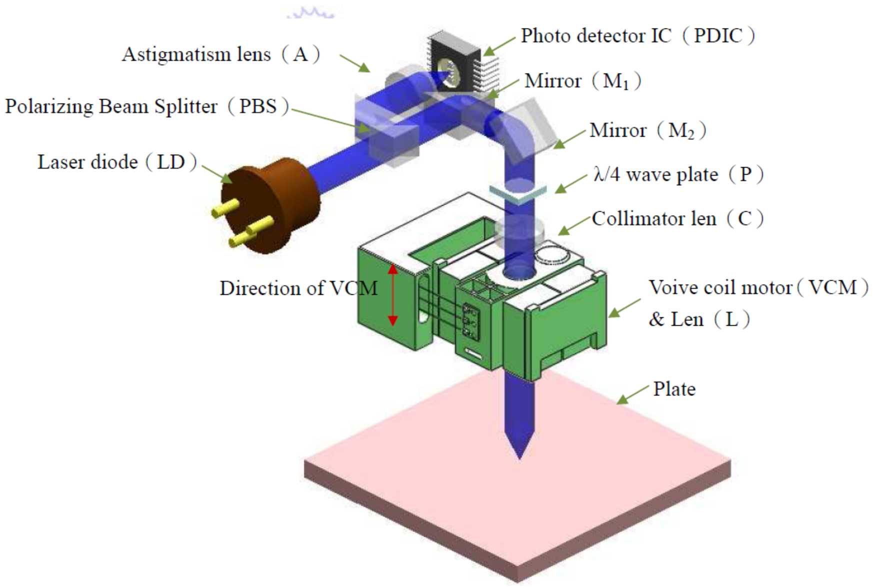


Fig. 3 The lithography optical system

Lithography can be proceeded after autofocus. The signal generator is adjusted to the frequency of 2.2MHz after completing focus. This system requires rapidly ON/OFF actions for laser light source; therefore, digital output was used to control laser light source. The nano-positioning moving range can be extended to 120 μm and the lithography can be completed by controlling spot constant on-time and matching with nano-positioning after arranging the path. The photoresist S1813 compatible with wavelength of 405μm produced by Shipley company was used in this study.

3. S-curve calibration and process

This section analyzed the unstable light exposure size due to the noise level of the system and stated the acceptable range. In order to obtain the noise level of the system, our study used the characteristic curve (S-curve) of optical pickup head to analyze and get linear region equation with numerical curve fitting. The fitting equation could be the assessment for focus spot size as well. The focus method is based on the astigmatic principle shown in Fig. 4. For the astigmatic method, a light passes

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through a cylindrical lens and difference aberrations are produced around the focus and the laser spot intensity pattern, as shown in Fig. 4. A laser spot intensity pattern on the four-element photodiode IC is used to obtain focusing error signal (FES), which can be derived as:

$$FES=(VA+VC)-(VB+VD) \tag{1}$$

where V_A, V_B, V_C , and V_D are voltages on a four elements of the photodiode detector in PD2, respectively. The analysis of FES is as follows:

(1) Position 1: FES>0：$(V_A+V_C)>(V_B+V_D)$, an ellipse on PDIC.

(2) Position 2: FES=0：$V_A+V_C=V_B+V_D$, a circle beam on PDIC.

(3) Position 3: FES<0：$(V_A+V_C)<(V_B+V_D)$, an ellipse is produced on PDIC.

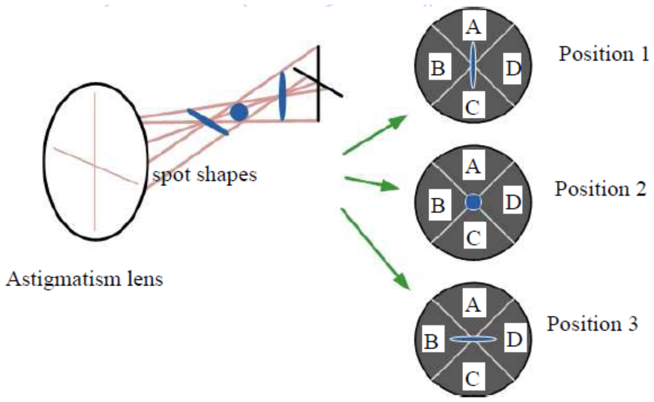

Fig. 4 The autofocus method based on the astigmatic principle

Fig. 5 shows the S-curve calibration in this system. The laser signal received by PDIC and this light spot location corresponds to the focusing error signal. We should adjust the three-axes until the reflected light back to the optical pickup head in the same direction. A single-axis stage should be displaced back and forth to adjust the reflected position exactly on the light focal plane. As shown in the Fig. 5, the calibration range is 5μm and taking the middle part between -0.6 μm to 0.6μm as the linear section of the S-curve to calculate the data fitting equation. The noise level at the focused point is about 20 nm. Therefore, we can give the proportional constant and fitting equations. The range of residual error lies between -0.01 μm to 0.04 μm and the standard deviation is smaller than 0.01 μm, as shown in Fig. 6 (a), (b) and (c).

4. The experimental result

This study uses glass as an experimental substrate. In order to reflect laser to optical pickup head, the glass was sputtering by chromium film which is a high reflectivity metal to help the calibration and focusing of the system. During the glass substrate making process, the substrate should be immersed in acetone first and remove the impurities and oil gas with ultrasonic vibrator. Then, take the substrate out of the acetone and cleanse in deionized water. After cleansing, the substrate should be placed in the oven to get rid of water vapor. The chromium of high reflectivity was chosen as reflecting layer because the substrate must possess the function of reflecting laser back to optical pickup head. Sputtering machine sputters metal film on the substrate and uses photo resist spinner to spin coat with positive photoresist the substrate after sputtering. The substrate is then sent to the oven in order to stabilize the resist. Through above mentioned process, the lithography substrate is completely made.

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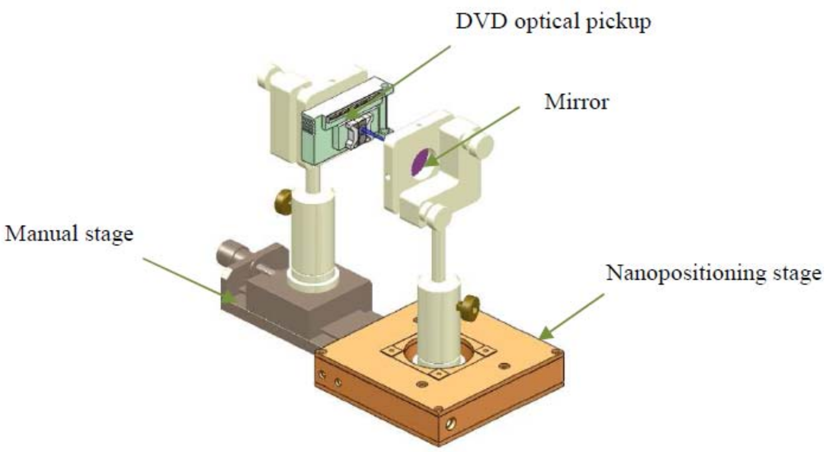
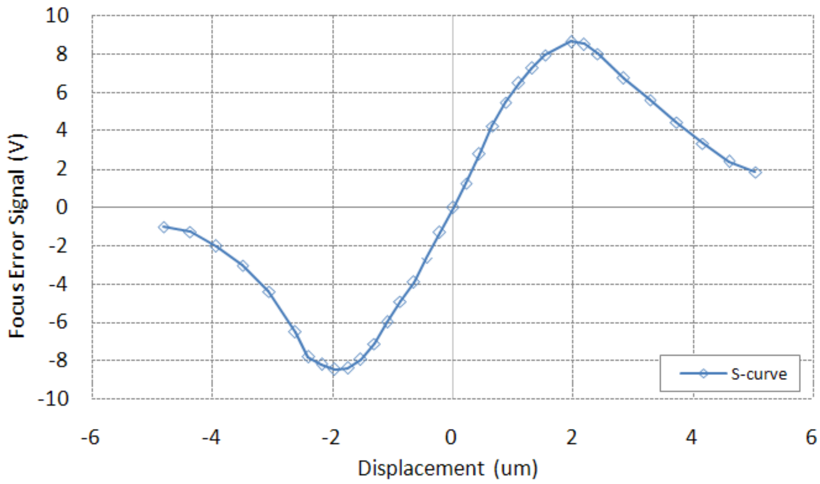
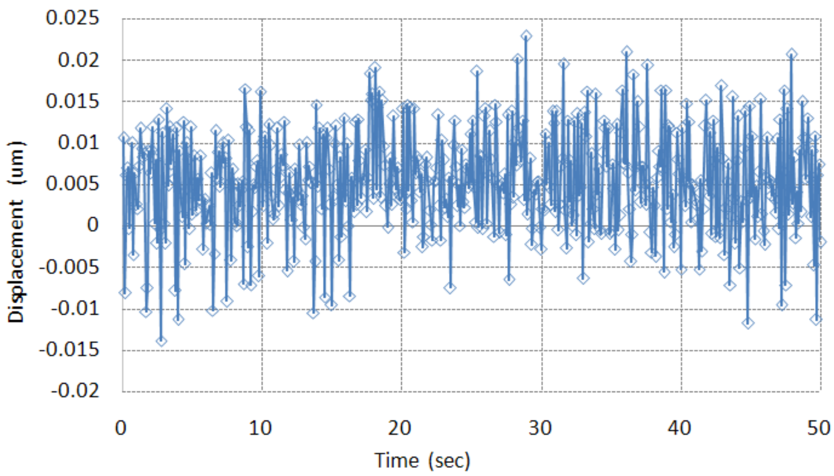


(a) The calibration system



(b) Calibration result of S-curve



(c) The noise level at the focused point

Fig. 5 The calibration system and result of S-curve

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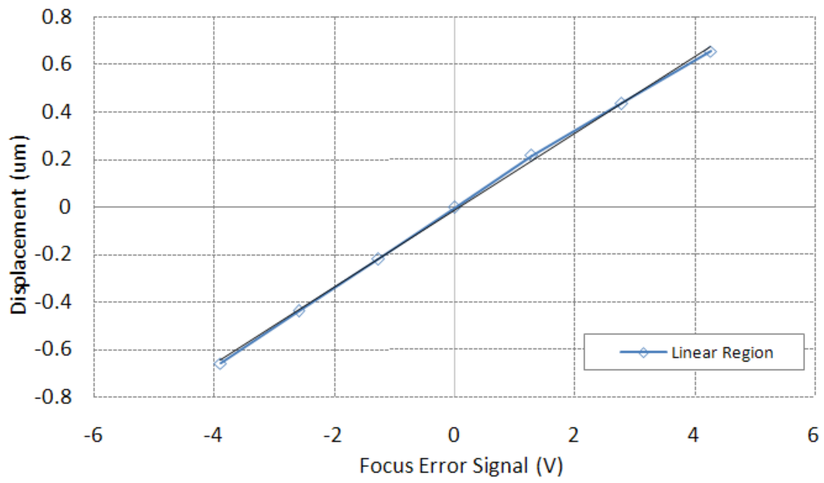
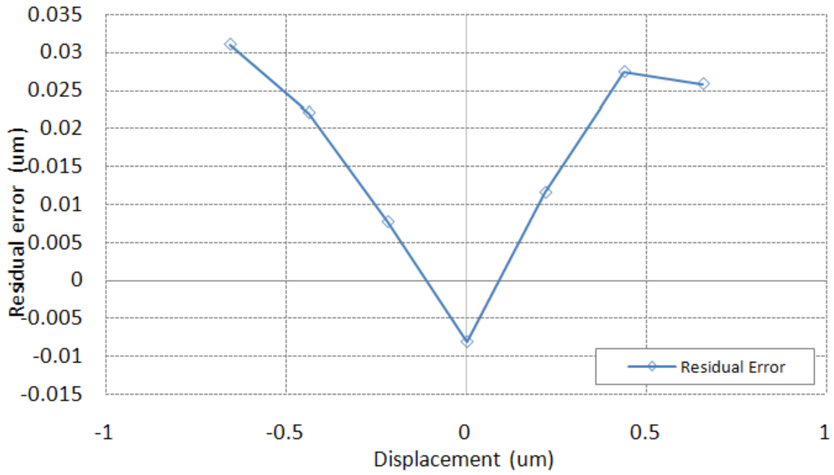
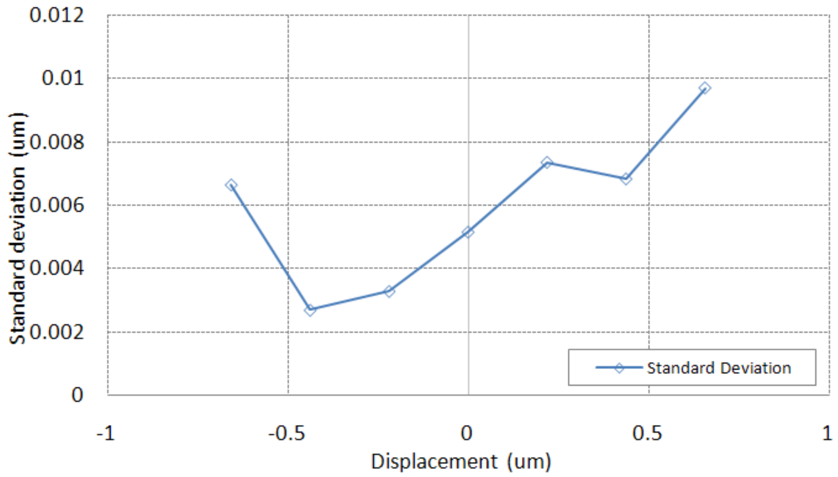


(a) The linearity of the linear zone



(b) Residual error



(c) Standard deviation

Fig. 6 The data of calibration curve in the linear region

We use alpha-step to measure the coating thickness of the resist after the substrate is made. The alpha-step uses probe to sweep the surface of the specimen mechanically. The transformer core is displaced when the probe across the rough surface,

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resulting the exchange of voltage to measure the film thickness. This study selects the central part of the flat specimen to measure and the coating thickness is about 130 nm, and the surface flatness is within 5 nm. The experiment was performed the exposure of one-dimensional spot array and two-dimensional spot array and the result of the automatic exposure for this system. The power of laser is 15.4 μW, the control frequency is 2.2MHz, single step distance is 5 μm, and total stroke is 120μm, consecutively carrying out the 24-spots exposure as shown in Fig. 7. The bigger circular starting spot is the secondary exposure because the inadequate usage between the nano-positioning stage running and switch IC. The result of the automatic exposure and programmable pattern control of this study can be arranged by two-dimensional spot array to present the recording result which as shown in Fig. 8. The exposure line of the laser lithography showed in Fig. 9. The line width is about 3.3μm. Fig. 10 showed the 2D cross-section measured by atomic force microscope with scanning range of 30 μm to present (a) the different depth of level by colored (b) the exposed spot is 3 μm by observing the exposure result of 3D side view, and (c) the distance between two spots of the cross-section analyzed by instrument is 20 μm.

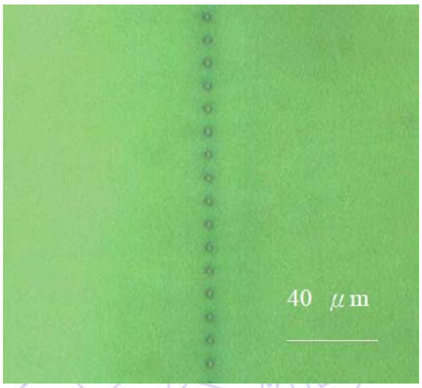

Fig. 7 The experimental result of one-dimensional spot array

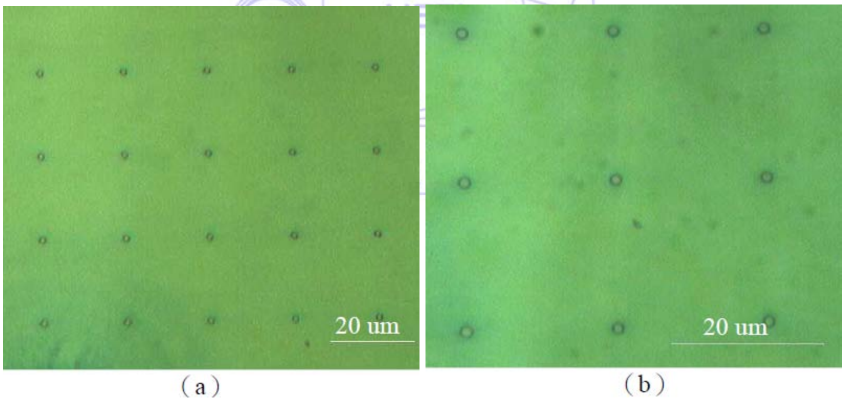

Fig. 8 The experimental result of two-dimensional spot array.（a）The result of microscope magnification: 50x（b）The result of microscope magnification: 100x

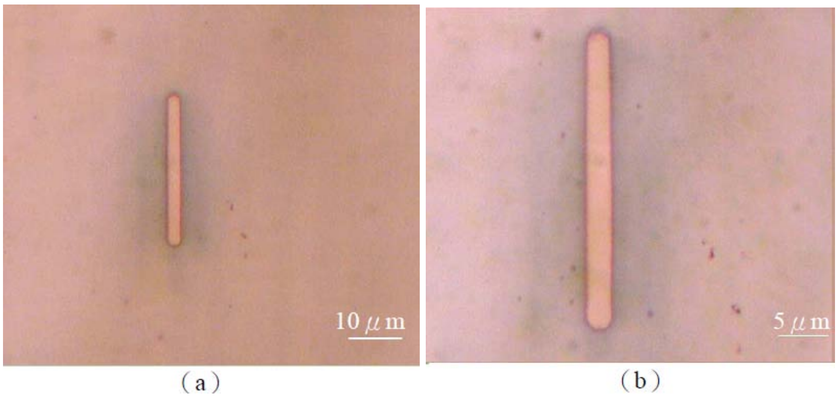

Fig. 9 Experimental result of the line.（a）The result of microscope magnification: 50x （b）The result of microscope magnification: 100x

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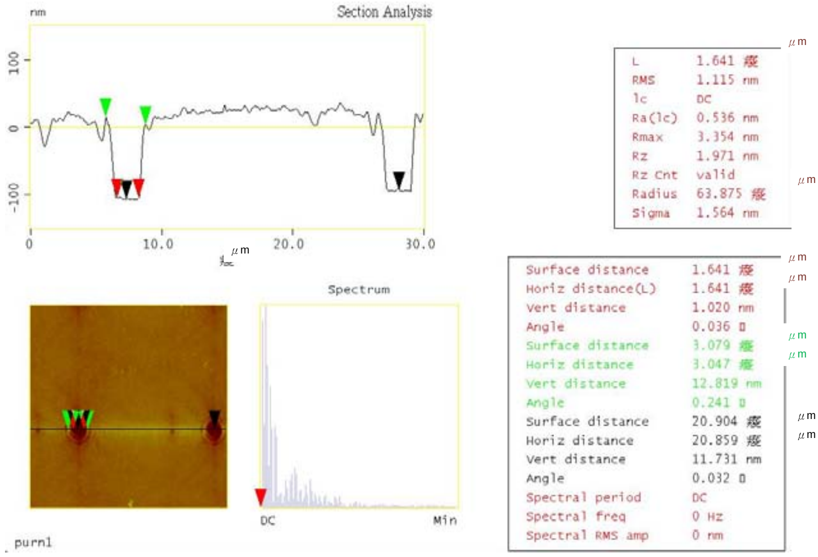

Fig. 10 The measurement result for atomic force microscope

5. Conclusions

This study has successfully developed the Blue-ray optical lithography system and used a commercial blue ray optical pickup head to significantly decrease the cost and miniaturize the whole system. This system with the automatic focus ability of software scanning can fix the condenser lens on the focal plane. It was found that the resist thickness of coating is bigger than depth of focus by this optical system during the experiment, hence this study changes the energy of laser and controls the exposed time to reduce the spot size. Currently, the size of spot is 3 μm, the shape is the perfect circle and this study built the linear micro structure with 3.3 μm line width. In the meanwhile, the exposed time is reduced to 450 ns.

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