Article ID: 1004-924X(2001)05-0451-04

Binary Laser Direct Writing System and Its Applications

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Abstract: A new laser direct writing system is introduced and the potential application of the diffractive optical elements (DOE's) fabricated by applying laser direct writing system are presented. The fabrication techniques by applying the laser direct writing are developed. Experimental results have been obtained by applying laser direct writing machine with line width of 5μm and 10μm.

Key words: laser direct writing systems; diffractive optical elements (DOE); photolithography
CLC number: TN305.7 **Document code:** A

1 Introduction

DOE's are important components for optical communication, optical computing, optical signal processing, optical interconnection, optical data storage, and aspherical testing applications. The laser direct writing in linear photoresist is an advanced fabrication technique of DOE's at the present time. As in other optical-resist-based methods, an appropriate resist is coated onto a substrate and then selectively exposed to light. By varying the laser intensity, one can control the exposure of the photoresist and thus the profile of the elements. A single subsequent etching step completes the process. The continuous range of the laser intensity eliminates the multilevel limitation imposed by binary mask lithography. So far the laser direct writing system used to fabricate DOE's is either Cartesian coordinate system[1-3] or polar coordinate system[4-11].

The binary laser direct writing system developed by Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences (CIOMP) has a key feature. Its writing system consists of a Cartesian coordinate system and a polar coordinate system, in which a binary pattern or continuous micro-relief is written by focused laser spot on the planar or curved substrate with thin photoresist film.

2 Binary laser direct writing components

A schematic diagram of our laser direct writing system is shown in figure. 1. A translation stage defined X-direction in Cartesian coordinate system or radial axis in polar coordinate system, which carries a vertical Z translation stage with an optical system of the focusing objective, is mounted on a bridge over the Y-stage and W-spindle on a granite base. The substrate with thin photoresist film is fixed on the top of Y-stage or W-spindle. Three air-bearing X, Y, and Z translation stages are driven by linear motors and positioned precisely by piezoelectric systems. The stages are controlled in a closed loop by attaching glass scale sensors to the stages for instantaneous detection of the stage position. The translation stages of X and Y have a positioning accuracy of ±0.2μm over the range of 200mm, and Z-stage has a positioning accuracy of

Received date: 2001-08-29; **revised date:** 2001-09-16

±0.1μm over the range of 40mm. The air-bearing spindle shaft is driven by a servo-controlled motor and its angular position and velocity are measured by an optical encoder. The available stable angular velocity is within 60-600 rpm. Both radial and axial runout of the spindle are measured to be less than 0.03μm.

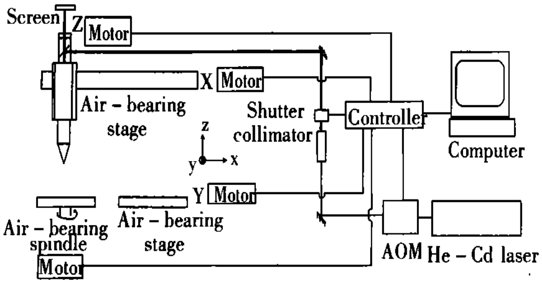


Fig. 1 Schematic diagram of the main components of the four axis laser direct writing system

Linearly polarized light from the 150mW He-Cd laser source ($\lambda = 0.442\mu m$) is diffracted by two acousto-optic(A-O) modulators and passes through the pinhole of a collimator. The first modulator accounts for only the overall change in power required as the radius changes, and the second modulator controls the variation of laser power within each individual zone. This configuration results in 40 dB of analog intensity modulation where the beam alignment after the pinhole is maintained despite laser pointing instabilities and thermal effects in the modulator crystal. A beam steering shutter is located after the collimator to shut off the modulated light beam whenever photoresist exposure is not desired. Following the collimation, the conditioned beam propagates parallel to the slide translation axis (X axis) and is directed through a microscope objective by a reflecting mirror, focusing on the substrate surface. The spot size is controlled by the choice of focusing objective, and is chosen as large as possible for a given microstructure relief. There are four replaceable focusing objectives with different numerical apertures for writing process, and its spot size ($1/e^2$ intensity points) is 1, 2, 5 and 10μm, respectively. An optical system with video-screen attaching to X-stage is used to precisely focus and align optical and mechanical axes.

A computer is used to direct the controller that controls the motion of four stages and A-O modulator by calling the data files and the DMC (motion control software) files in Visual C++ language programs under the Microsoft windows. These files define the structures of DOE and then command the motion and the intensity of writing spot directly. In addition, the work on two-dimensional CAD package for fabricating DOE's and auto-focused system is under way in our teams.

3 Methods and techniques

Because the binary laser direct writing system (BLDWS) includes a couple of writing systems, the multiple writing methods make it have advanced function and wide application range than one in a single system. In polar coordinate system that consists of X (called radial axis), W, and Z stage, DOE's are written by two methods: continuous spiral scanning and raster scanning. In the first case the scanning of substrate surface is fulfilled by two motions (substrate rotation and radial displacement of writing spot). Typically the later (radial sliding of X-stage is noncontinuous while substrate rotation all along) is used to fabricate rotationally symmetrical DOE's such as Fresnel microlens, zone plate, and wave-front correction etc. Alternatively, Cartesian coordinate system is composed of X, Y, and Z stages when X-stage slides over the Y-stage. Similarly, there are two writing methods: the vector scanning and the ruling scanning in Cartesian coordinate system, which are suitable for fabricating DOE's such as mask, grid, optical grating lens and lenslet array etc.

When writing circularly symmetrical DOE's and computer-generated holograms (CGH's) in polar coordinate system, it is important that we require precise centering of a focused optical system over the mechanical axis of a rotating optical substrate. The technique for aligning optical and mechanical axes based on a rotating linear grating has been described by Tom D. Milster et al[12]. Decentration errors of less than 0.2μm can be readily achieved by this technique with a rotational grating. The accuracy of this technique is approximately one-tenth the spatial period of the grating that is used. In general, there are two modes for writing single line with larger width than spot size in the fabrication of DOE's by applying laser direct writing. For example, if one considers the fabrication of a zone plate with a fixed spot size, the spot size must be smaller than or equal to the width of the smallest outer zone. The objective is appropriately chosen account to the minimum feature size of the zone plate. All larger zones are machined by the overlapping of the spot until the zone is milled. The other mode is the intentional defocus writing for filling the zone with larger width. It is very difficult to control precisely the spot size by varying the amounts of defocus that are fulfilled through the fine updown Z-stage.

4 Experimental results

Considering the range of the focal depth, a 0.15 (four orders) numerical aperture objective is used and then an approximate 4.5μm focused spot is produced. The photoresist used is Shipley Microposit 1805, spinning-coated onto glass substrates. A spinning speed of 5000 rpm gives a film thickness of about 0.5μm. Thicker resist films can be obtained using lower spinning speed for shorter times. After coating, the films are baked in an oven at 90℃ for 30 minutes, and the evelopment is carried out using Shipley Microposit AZ303 developer at a dilution of typically 1:10 with deionized water.

Examples presented here were fabricated by our laser writing system in the preliminary experiment. Firstly, the isolated lines written in photoresist with thickness 1.0μm by the laser direct writing is shown in figure 2. In order to verify the method of defocus writing, we have gotten an experimental plot of the spot width vs the amount of defocus[see fig. 3] and then wrote a reticle with nominal line width 10μm and the circular rings with line space 50μm in the photoresist in terms of this plot [see fig. 4].

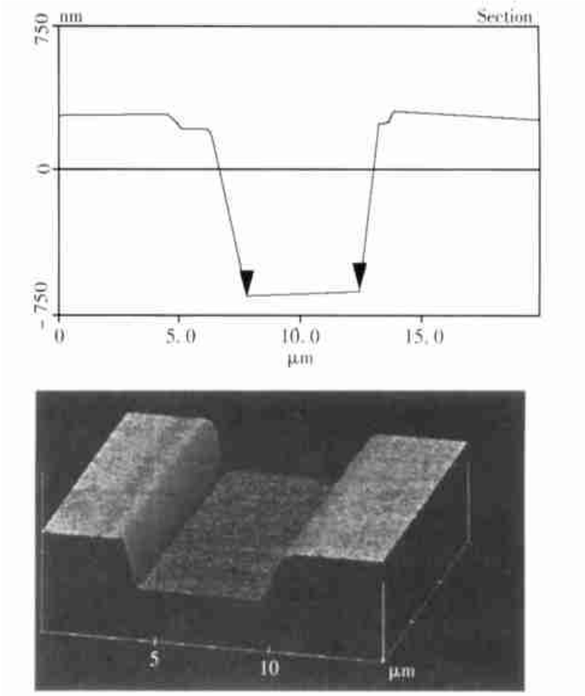


Fig. 2　Isolated line with width 4.67μm obtained in photoresist by laser direct writing in Cartesian coordinate system (AFM)

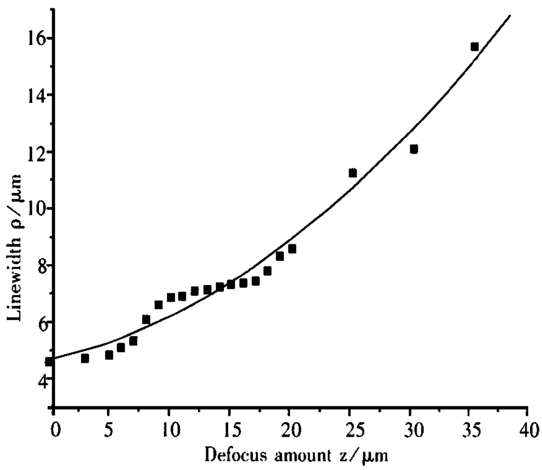
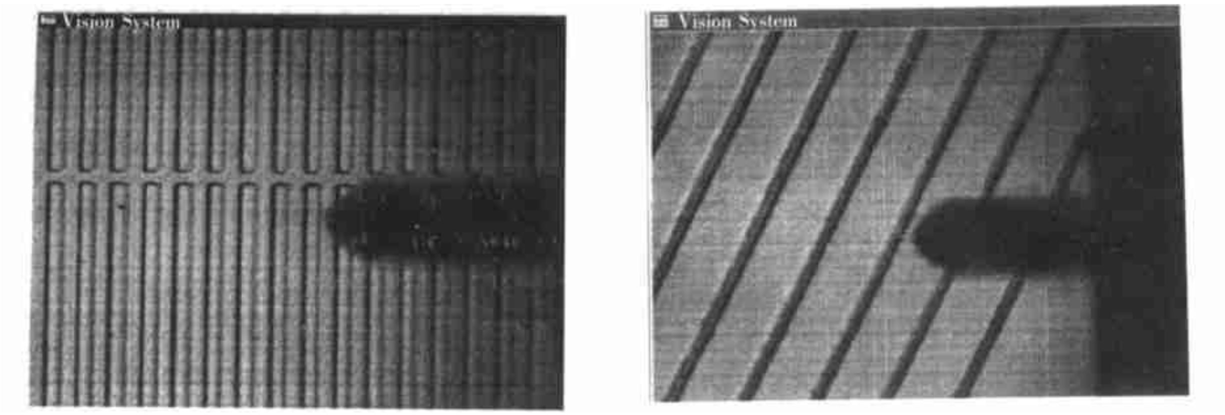


Fig. 3　Experimental plot of linewidth ρ vs defocus amount z, in which scanning velocity is 5.0mm/s and beam power is 1.5mW.



(a) (b)

Fig. 4 Photograph of the elements fabricated by laser direct writing in photoresist under the intentional defocus case. (a) the reticle with linewidth is 9.36μm and space period is 20.117μm in Cartesian coordinate system, (b) a set of circular rings with linewidth 10μm and line space 50μm in the polar coordinate system.

5 Conclusion

Experimental results on writing pattern in photoresist have shown that BLDWS is capable of fabricating a wide range of binary, multilevel, and blaze DOE's. Rotationally symmetrical computer-generated holograms (CGH's) for testing convex aspheric surface on the substrate which may be planar, spherical surface will be primarily developed by our teams in the next step.

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