Continuous micro-optics fabrication using half tone masks and proximity printing

Chuankai Qiu, Changtao Wang, Chunlei Du, Xiaochun Dong
(State Key Lab of Optical Technologies for Microfabrication, Institute of Optics & Electronics, Chinese Academy of Science, Chengdu 610209
Tel: 028-85100889, Fax: 028-85100210, E-mail: ckqiu@ioe.ac.cn)

Abstract

It is reported in this paper a method to fabricate three dimensional continuous micro-optical structures using half tone masks and proximity printing. The frequency modulation coded half tone masks are employed to obtain the predetermined exposure distribution. Several components like Cylinder microlens arrays, phase correctors are realized in photoresists.

**Keywords:** half-tone mask, random distributed coding, proximity printing

1. Introduction

With the development of micro-optics, many technologies have been proposed to fabricate micro optic elements with continuous profiles. From the view point of cost and complexity, the half tone mask lithography has been regarded as a wonderful way for its compatibility to the standard equipments and methodology for IC production [1-5]. There are mainly two features governing the principle of half tone mask lithography: 1) the desired height profiles are represented into the chromium mask with a great amount of pitches with tunable sizes and/or spaces for pulse-width modulation, pulse-frequency modulation or their combination. 2) a projection lithography system with finite resolution is employed to filter the high spatial frequency and obtain the desired exposure distribution on the wafer coated with photo resist.

Proximity printing is another commonly used method to fabricate micro optics. Compared with projection steppers, it is much more appealing for its simple process, competitive price and the facility of printing finely structured graphs with considerably high fidelity. As so far, this technology is usually restricted to manufacturing only binary micro structures to our knowledge. So the extension to three dimensional arbitrarily shaped structures would surly help to promote the application of micro optics. Both the proximity printing and projection systems have limited resolution, which implies that the light passed through patches beyond the resolution will be spread. This similarity makes it possible to apply the half tone mask technology to proximity printing.

Some initial works were carried out recently in our laboratory to investigate the feasibility of combining half tone masks technology with proximity printing. Frequency modulated half tone masks with constant chromium pixel of 2.0um is fabricated with the calculated mask data considering the nonlinear characteristics of the following lithography process. A phase corrector and Cylinder microlens array are obtained in resist.
2. Principles

Fig. 1 gives the schematic of proximity printing system, in which the light, for instance i-line mercury lamp, is shaped with specific illustrating optics and pass through the mask and so the graph on the mask is printed to the resist on the wafer below. It is worth to note that there is a distance (typically several microns) between the mask and the resist. Structures with too small features can not be distinguished due to diffraction, as shown in Fig. 2. The theoretical resolution for a pattern of equal lines and spaces in proximity lithography is given by:

\[ 2b_{\text{min}} = 3\left[\frac{\lambda}{s + 0.5d}\right]^{1/2} \]

where symbols \(2b_{\text{min}}, s, d\), and \(\lambda\) stand for grating period, width of gap between mask and resist surface, resist thickness and exposure wavelength respectively. The light passed through the transparent line or squares on the mask will be spread to a wide range of resist. So the density of transparent lines or squares represents the gray levels in some sense.

3. Frequency Modulation half tone mask

The three common ways to code a 3-D profile are pulse width modulation using chromium pixels with different size but constant pitch, pulse density modulation with constant size but different pitch size and a combination of them. Here, a random distributed density modulation coding method is proposed to represent variant values of gray levels. As shown in Fig. 3, each coding pitch is divided into multiple squares with constant size and random distribution. Two advantages are associated with this coding method: a) more gray levels can be realized, compared with the conventional pulse width modulation or frequency modulation; b) the interference fringes occurred in the overlapped exposure areas can be smoothed to some extent.
4. Mask making and lithography process

Fig. 3. Frequency modulation half tone masks

Fig. 4. Procedures of the fabrication of continuous micro optics using half tone masks
As shown in Fig.4, the process of fabricating continuous micro optics includes mainly three procedures, design and making of half tone masks, exposure and development of photo resist, transferring the shaped structure in the resist to specific substrate material by dry etching like RIE or DRE. The key process of this performed technology is preparing the data for making half tone masks. Several factors, such as the nonlinear characteristics of photo resist, have to be considered and pre-corrected in this step.

5. Experiment

The experimental test of this technology is performed. A laser direct writer with a resolution of 1.0um is used to generate random distributed frequency modulation half tone masks. The size of the transparent squares of masks is 2.0um. Several optical components like phase plate and microlens array are fabricated in the resist by a proximity printing system (with the resolution of about 3.0um) and the proposed technology. As shown in Fig.5, a phase corrector is fabricated in the experiment to compensate human eye aberrations. The height of the corrector is up to 2.5um. Fig.6 gives the micrograph of a fabricated cylinder microlens array in photoresist and half tone mask.

![Fig.5 Phase corrector for human eye aberration a) half tone mask b) measured 3-D profile](image_url)
6. Conclusion

The method of fabricating continuous micro optics with half tone masks and proximity printing technology is proposed and experimentally investigated in this paper. The realization of microlens arrays and phase correctors for human eyes aberrations proved the validity of this technology. Admittedly, it is much more complex for this method to control precisely the profiles of micro structures than the projection and filtering of half tone masks. Some works are still in process to improve the quality of fabricated micro elements.

References


