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SU-8 紫外深度光刻的误差及修正

郑津津¹, 陈有梅¹, 周洪军², 田杨超², 刘刚², 李晓光¹, 沈连娟¹

(1. 中国科学技术大学 精密机械与精密仪器系, 安徽合肥 230027;

2. 国家同步辐射实验室, 安徽合肥 230029)

摘要:在深紫外 LIGA 加工中, 制作高精度大高宽比的微器件是很困难的。难点在于 SU-8 光刻胶对紫外光的吸收系数随着波长变短而很快变大, 而且其穿透深度也相应迅速变小; 同时由于紫外光的衍射效应, 获得高精度的大高宽比结构并不容易。本文深入研究了影响紫外深度光刻图形转移精度的如下因素: 衍射效应、曝光剂量、紫外光波长和蝇眼透镜的分布等等。建立了基于模型区域的校正系统, 该校正系统采用了分类分区域的思想将掩模图形按其畸变的特点进行了分类, 在校正过程中对不同的类别分别建立校正区域, 在每一校正区域内进行校正优化处理和校正评价, 这种基于模型的分区域评价思想, 使得校正过程有效且实时, 该校正方法不仅降低了校正的复杂性, 同时提高了校正的效率。

关键词: SU-8 光刻胶; 紫外深度光刻; 掩模; 图形转移; 误差修正

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Correction of pattern transfer errors for SU-8 UV deep lithography

ZHENG Jin-jin¹, CHEN You-mei¹, ZHOU Hong-jun², TIAN Yang-chao²,
LIU Gang², LI Xiao-guang¹, SHEN Lian-guan¹

(1. *Department of Precision Machinery and Precision Instrumentation, University of Science and Technology of China, Hefei 230027, China*; 2. *National Synchrotron Radiation Laboratory, University of Science and Technology of China, Hefei 230029, China*)

Abstract: The diffraction and absorption of UV light in SU-8 resist makes it very difficult to fabricate high precision microstructures with high aspect ratio in the process of UV LIGA, because the absorption coefficient gets bigger and the penetration depth gets shorter rapidly as the wavelength gets shorter. Therefore, such factors having effect on the precision of deep UV lithography as diffraction effect, exposure dosage, wavelength and distribution of fly's eyes lens etc., are investigated in this paper. A method of correcting pattern transfer errors is developed through investigation of pattern transfer errors. Proposed method adopts the feature classification and area evaluation to modify the mask contour, thereby making the lithography contour as close as possible to the desired contour. In addition, it can be used to reduce the complexity and enhance the correction efficiency.

Key words: SU-8 photoresist; UV deep lithography; mask; pattern transfer; error correction

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1 Introduction

UV lithography has been widely used for fabrication on microstructures with high aspect-ratio in Micro-electro-mechanical System (MEMS). SU-8 resist has also been widely used in MEMS. Its high photosensitivity and small absorption coefficient, enable requisite exposure dose to be calculated in short time and exposure dose to be uniformly distributed in a layer of thick resist. So microstructures with high aspect ratio can be fabricated using UV lithography. However, the absorption coefficient of SU-8 resist gets bigger and the penetration depth gets smaller as the wavelength gets shorter. The coefficients at the wavelengths of 380 nm, 365 nm and 330 nm are 0.001, 0.003 985 and $0.1 \mu\text{m}^{-1}$, respectively^[1-2]. Generally, UV light with a longer wavelength is selected for a very thick resist. Fly's eyes lens are usually used in the illumination system to form a multi-point source to keep the light intensity uniform^[3]. In this paper, such factors having effect on the precision of deep UV lithography as diffraction effect, exposure dosage, wavelength and distribution of fly's eyes lens etc., are investigated, and an error correction method is developed for the errors incurred in the process of deep UV lithography.

2 Diffraction effect

The source of UV lithography machine is a partial coherent source. And the fly's eyes lens are used to form multi-point source to keep the intensity uniform. The diffraction effect of UV light is prominent among the factors having effect on the precision of deep UV lithography, because the wavelength is longer in contrast with the size of a microstructure. A model based on Kirchhoff's diffraction theory and incoherent super-impose of multi-point source diffraction intensity is used to simulate deep UV lithogra-

phy^[4]. Hexagon fly's eyes lens^[5] is used in this paper as an illumination source for lithography simulation. The diffraction complex amplitude of one light beam from a multi-point source at point Q can be expressed as

$$U_n(Q) = \frac{n_1 + jn_2}{j\omega_0} \iint_{\Sigma} U_n(P) K(\theta) \frac{e^{jk_0 n_1 r}}{r} e^{-\frac{ar}{2}} ds, \quad (1)$$

where $U_n(P)$ is the complex amplitude of one light beam at point P on the mask, $K(\theta)$ is the obliquity factor, n_1 is the real part of refractive index of resist, n_2 is the complex part of refractive index of resist, a is the absorption coefficient of resist, r is the distance between point P and point Q , k_0 is wave number, and ω_0 is the light wavelength in vacuum. The intensity at point Q can be expressed by incoherent super-impose of multi-point source diffraction intensity as shown below

$$I(Q) = \sum_{n=1}^N U_n(Q) \times U_n^*(Q). \quad (2)$$

The real part of the complex refractive index of SU-8 resist is 1.67, and the absorption coefficient at the wavelength of 365 nm is $0.003\ 985 \mu\text{m}^{-1}$. Fig. 1 is the exposure dose isoline of a square of $5 \mu\text{m}$ by $5 \mu\text{m}$ in a layer of $10 \mu\text{m}$ deep from resist surface at exposure dosage of $400 \text{ mJ}/\text{cm}^2$. Fig. 2 is exposure dose isoline of rectangle of $3 \mu\text{m}$ by $8 \mu\text{m}$ in a layer of $10 \mu\text{m}$ deep from resist surface at exposure dosage of $300 \text{ mJ}/\text{cm}^2$. SU-8 resist with an exposure dose above $150 \text{ mJ}/\text{cm}^2$ will stay and the resist with

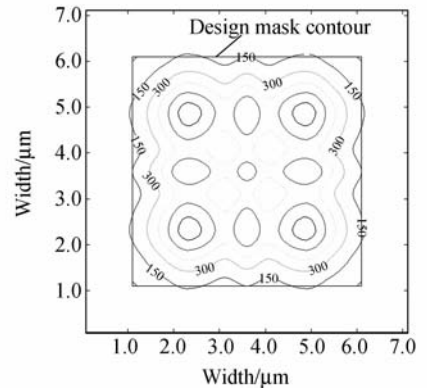


Fig. 1 Exposure dose isoline of square of $5 \mu\text{m}$ by $5 \mu\text{m}$

an exposure dose below 150 mJ/cm^2 , will be removed^[6]. So the line of exposure dose 150 mJ/cm^2 is the contour of a microstructure. The line width variation, line end shortening and corner rounding can be seen from Fig. 1 and Fig. 2. It is therefore necessary to compensate for the pattern transfer non-idealities at certain layer to satisfy the requirement for performance and precision of microstructures.

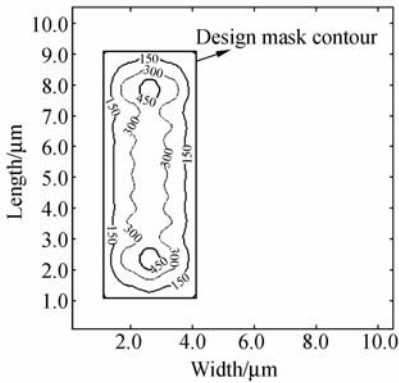


Fig. 2 Exposure dose isoline of rectangle of $3 \mu\text{m}$ by $8 \mu\text{m}$

3 Exposure dose

Even if the contour of mask is the same, different exposure dosages have their effects on the precision of deep lithography. Different precisions can be clearly seen at different exposure dosages as shown in Fig. 3, Fig. 4 and Fig. 5. The precision in $50 \mu\text{m}$ thick resist at exposure dosages of $400, 500, 600 \text{ mJ/cm}^2$ is $0.5, 0.2, 0.2 \mu\text{m}$ as shown in Fig. 3, Fig. 4 and Fig. 5. As the resist gets thicker, the precision changes too. The precision in $100 \mu\text{m}$ thick resist is $1.0, 0.6, 0.2 \mu\text{m}$ at exposure dosage of $400, 500, 600 \text{ mJ/cm}^2$ respectively, as shown in Fig. 6, Fig. 7 and Fig. 8. The lithography depth varies with exposure dosage at the same precision. For example, the lithography depth is $50 \mu\text{m}$ for lithography precision of $0.2 \mu\text{m}$ at exposure dosage of 400 mJ/cm^2 , but for the same precision the lithography depth is $80 \mu\text{m}$ at exposure dos-

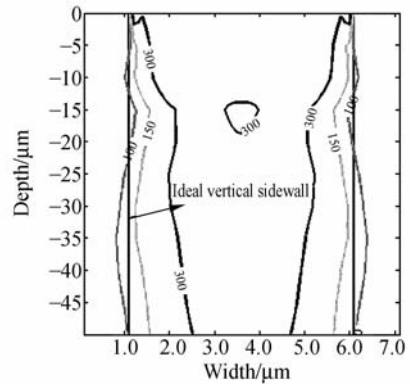


Fig. 3 Exposure dose isoline at exposure dosage of 400 mJ/cm^2 in $50 \mu\text{m}$ resist

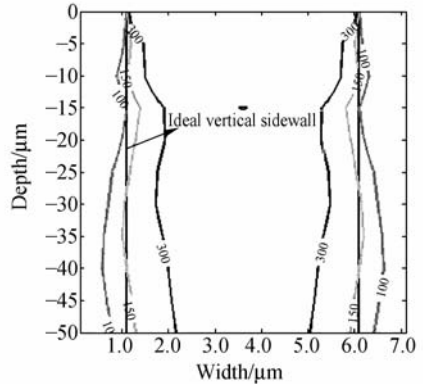


Fig. 4 Exposure dose isoline at exposure dosage of 500 mJ/cm^2 in $50 \mu\text{m}$ resist

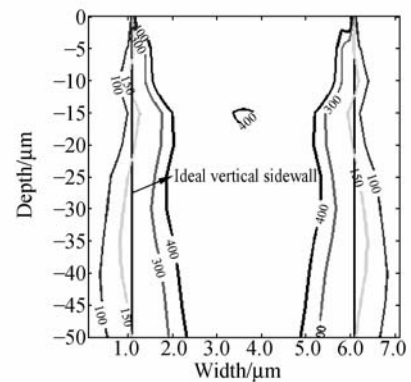


Fig. 5 Exposure dose isoline at exposure dosage of 600 mJ/cm^2 in $50 \mu\text{m}$ resist

age of 600 mJ/cm^2 . If we want to get higher precision, we should choose an appropriate exposure dosage according to the thickness of resist and simulation results, which is the key to better microstructures.

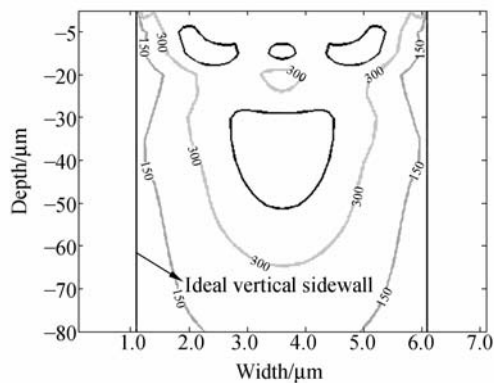


Fig. 6 Exposure dose isoline at exposure dosage of 400 mJ/cm² in 80 μm resist

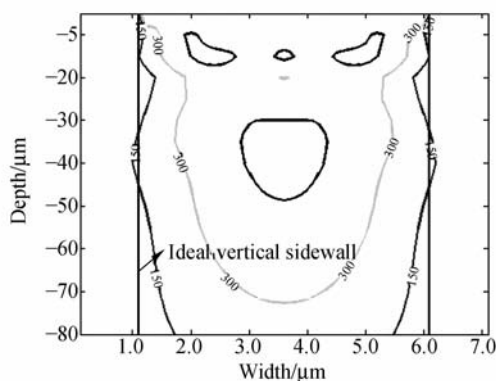


Fig. 7 Exposure dose isoline at exposure dosage of 500 mJ/cm² in 80 μm resist

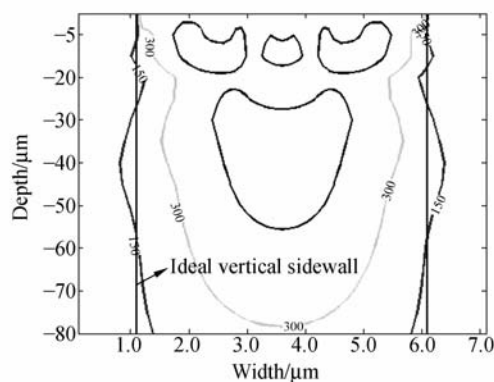


Fig. 8 Exposure dose isoline at exposure dosage of 600 mJ/cm² in 80 μm resist

4 Light wavelength

The absorption coefficient of SU-8 resist varies with wavelength. In deep lithography differ-

ent absorption coefficients result in different penetration depths. At the same exposure dosage, different lithography depths of square of 5 μm by 5 μm can be got at different light wavelengths as shown in Fig. 9, Fig. 10, Fig. 11. We can not get a lithography depth of more than 20 μm at 330 nm wavelength, but we can get a microstructure of 75 μm thick at 365 nm wavelength and can get a microstructure of more than 100 μm thick with good precision and steep sidewall.

It can be seen from analysis above that the wavelength has its effects on the lithography depth and sidewall gradient, and a longer wavelength should be selected for a thick resist film.

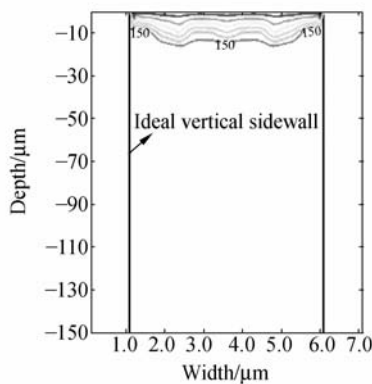


Fig. 9 Exposure dose isoline at exposure wavelength of 330 nm (exposure dosage of 500 mJ/cm²)

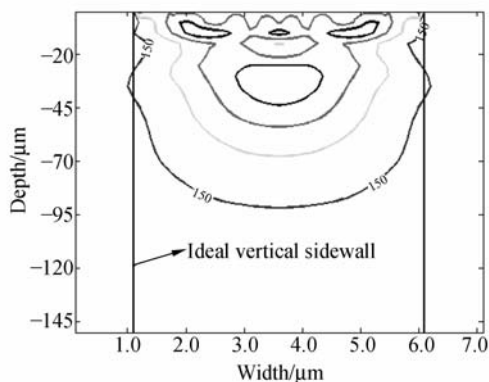


Fig. 10 Exposure dose isoline at exposure wavelength of 365 nm (exposure dosage of 500 mJ/cm²)

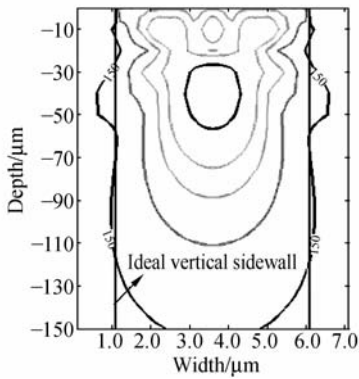


Fig. 11 Exposure dose isoline at exposure wavelength of 380 nm (exposure dosage of 500 mJ/cm²)

5 Multi-point source array

All vertexes of the hexagons in the hexagon point source array are point sources. Lithography has been simulated at different max solid angles of light beam. Fig. 12 is the exposure dosage isoline of square of 4 μm by 4 μm in 100 μm

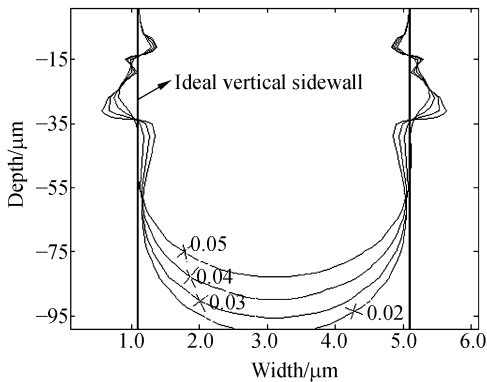


Fig. 12 Lithography contour of 4 μm by 4 μm in 100 μm thick resist at different solid angles at exposure dosage of 500 mJ/cm²

thick resist film at different solid angles of 0.05, 0.04, 0.03, and 0.02. Fig. 13 is the exposure dose isoline of square of 5 μm by 5 μm in 150 μm thick resist film at different solid angles of 0.05, 0.04, 0.03, and 0.02. It can be seen from Fig. 12 and Fig. 13 that a smaller solid angle has its good effect on the enhancement of sidewall gra-

dent and lithography depth. But at the same time, a smaller solid angle also has its effect on the precision of a certain deep resist film, such as the layers of from 50 μm to 60 μm thick resist film as shown in Fig. 13.

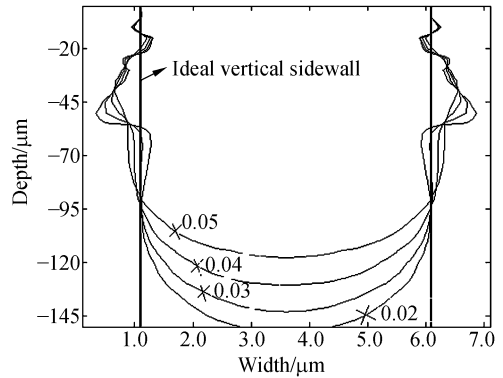


Fig. 13 Lithography contour of 5 μm by 5 μm in 150 μm thick resist at different solid angles (exposure dosage of 600 mJ/cm²)

An appropriate multi-point source array should be selected to enhance lithography depth and sidewall gradient without adverse effect on deep layer precision.

6 Conclusions

A model based on Kirchhoff's diffraction theory and incoherent super-impose of multi-point source diffraction intensity has been used in this paper to simulate deep UV lithography to investigate the factors having effect on the precision of deep UV lithography, such as diffraction effect, exposure dose, wavelength and the distribution of fly's eyes lens, etc. and a method has been developed to correct pattern transfer errors. In order to satisfy the requirement for performance and precision of microstructures, it is necessary to compensate for pattern transfer non-idealities in certain layer. In order to get the steep sidewall it is essential to choose an appropriate exposure dosage according to the simula-

tion results before the experiment. And the fly's eyes lens of the lithography machine is an important factor having effect on the precision and the sidewall gradient.

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Authors' biography: **ZHENG Jin-jin**, professor with the Department of Precision Machinery and Instrumentation of the University of Science and Technology of China, obtained a "Hundred Talented" Project funding in 2004. He received his BSc from Fudan University, Shanghai, China, MSc from University of Science and Technology of China, PhD from the University of Birmingham, UK in 1998. He worked at the National Centre for Computer Animation, Bournemouth University, UK. His research interests include CAD, CAM, micro-fabrication, computer simulation etc. E-mail: jjzheng@ustc.edu.cn