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Abstract

When using Heidelberg DWL66+ laser writer to fabricate the photomask, the pattern feature dimensions may have deviations. These deviations can be caused by the lithography process and the undercut in the metal etch process. The same deviation value of 0.8μm was found to appear in all the patterns independent of the pattern original size and local pattern density. To overcome this universal deviation, a universal bias is suggested to be applied to the original patterns during the data preparation for the lithography process. In order to ensure this pre-exposure bias method can work, both the laser direct-write exposure conditions (laser power, filters, focus parameters) and the metal etch time should be kept consistent.

Keywords

Heidelberg, Laser Direct-Write (LDW), Photomask

Disciplines

Biomedical Engineering and Bioengineering | Electrical and Computer Engineering | Electronic Devices and Semiconductor Manufacturing | Engineering Mechanics | Materials Science and Engineering | Mechanics of Materials | Nanotechnology Fabrication | Other Electrical and Computer Engineering | VLSI and Circuits, Embedded and Hardware Systems

Correction of pattern size deviations in the fabrication of photomasks made with a laser direct-writer

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When using Heidelberg DWL66+ laser writer to fabricate the photomask, the pattern feature dimensions may have deviations. These deviations can be caused by the lithography process and the undercut in the metal etch process. The same deviation value of $0.8\mu m$ was found to appear in all the patterns independent of the pattern original size and local pattern density. To overcome this universal deviation, a universal bias is suggested to be applied to the original patterns during the data preparation for the lithography process. In order to ensure this pre-exposure bias method can work, both the laser direct-write exposure conditions (laser power, filters, focus parameters) and the metal etch time should be kept consistent.

Key Words: Heidelberg, Laser Direct-Write (LDW), Photomask

I. Introduction

To fabricate a photomask of a user-designed pattern, laser direct-write (LDW) lithography is widely used to pattern the positive tone photoresist on a blank mask (a transparent substrate fully covered by a layer of chromium on one side), followed by wet chemical etch to transfer the patterns on the resist to the chromium layer. This conventional method of photomask fabrication, however, can cause pattern feature size, or critical dimension (CD), deviations. The goal of this paper is to characterize the pattern CD deviations that occur in the photomask fabrication process, and provide a solution to overcome these deviations.

Patterns on a photomask can be classified into two types: bright field and dark field. As shown in Fig 1, in the bright field case, most of the resist is exposed, therefore the metal below the resist in these areas is removed, leaving behind a small metal pattern protected by the resist; in the dark field case, most of the metal are intact, surrounding a small 'void' pattern where the resist gets exposed and the metal is removed. Bright field patterns are actually unexposed areas while dark field ones are exposed area. As a result, bright field patterns and the dark field ones always have opposite-sign CD deviations. Therefore, in order to compare the CD deviations in these two cases, dark field patterns are defined to have positive CDs, while bright field ones have negative CDs.

The photomask pattern CD deviations have two possible sources. One of them is the lithographic deviation. As indicated in Fig 2(a), firstly, a dose-to-clear is required to completely remove the resist (the resist threshold in red line). In addition, the actual dose distribution

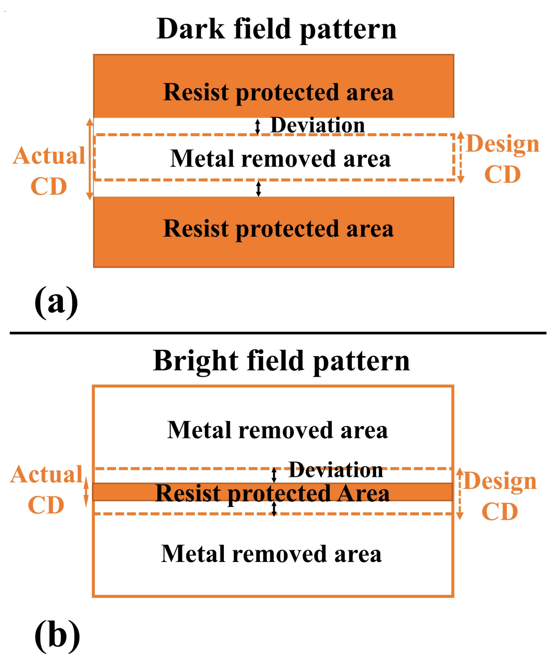

FIG. 1. Illustration of two types of patterns. (a) The dark field pattern defined to have a positive size. (b) The dark field pattern defined to have a negative size.

is not a step function represented by the dash line, but a Gaussian-like function represented by the solid line[1]. Therefore, two intersections of the dose-to-clear and the dose distribution represent the edge of the actual pattern. The CD of the pattern is the length between these intersections, which may have a deviation from the original size depending on the dose.

The other deviation source is the metal etch undercut. As can be seen in Fig 2(b), when the patterns on the

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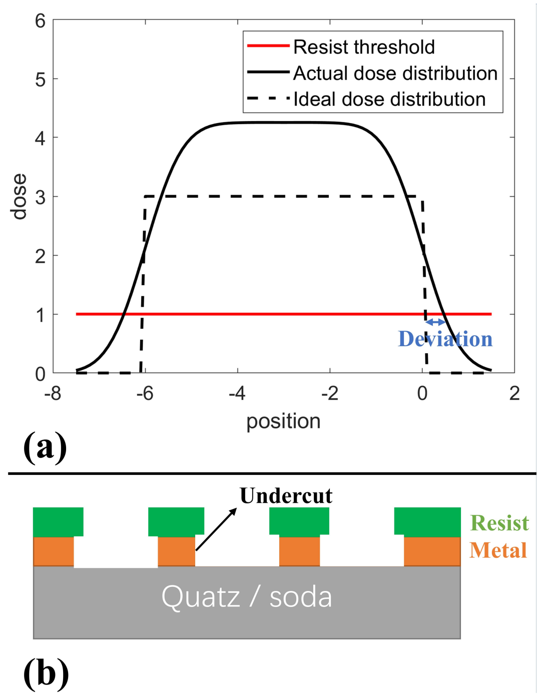

FIG. 2. Illustration of two sources of pattern CD deviations. (a) The lithographic deviation that depends on the dose. (b) The wet chemical etch deviation that depends on the etch time.

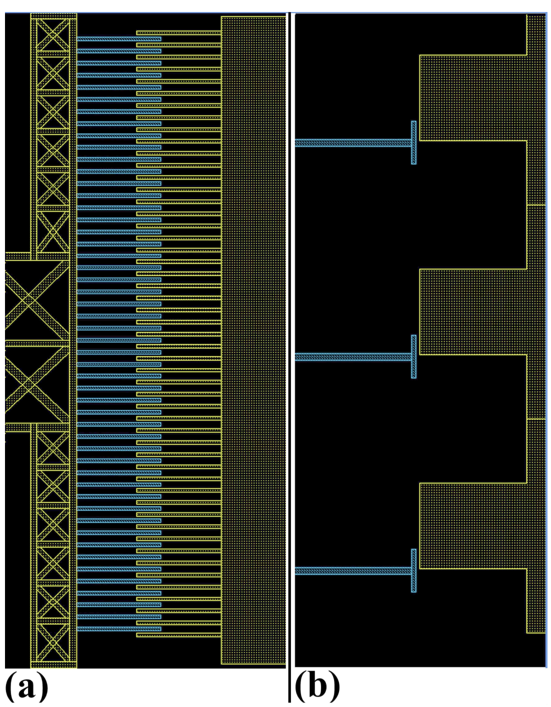

FIG. 3. The design of the pattern of a MEMS device. (a) The electrical actuator patterns. (b) The electrical oscillator patterns.

resist are transferred to the metal layer by wet chemical etch, an undercut can occur, causing an additional deviation. In this paper, experiments and optical microscopy measurements were done to characterize the CD deviations dependence on various pattern types, original sizes, and local pattern density.

TABLE I. Pattern CDs comparison

Pattern Type	Gap	Vertical beam	Horizontal beam
Original size (μm)	+1.4	-2.6	-3.4
After development (μm)	+1.6	-2.3	-3.2
Lithographic deviation (μm)	+0.2	+0.3	+0.2
After metal etch (μm)	+2.2	-1.7	-2.7
Etch undercut deviation (μm)	+0.7	+0.6	+0.7

II. Experiment

A. LDW lithography

A blank 5-inches photomask (quartz substrate covered by a low reflective chrome layer and 5300$\mathring{A}$ thick IP3500 photoresist) was written using Heidelberg DWL66+ laser writer with 2mm write head. The pattern written is a design of a MEMS device, as shown in 3. After the LDW exposure, the photomask was fully immersed into the MF-319 developer for 90s with agitation to develop the pattern, followed by the rinsing with DI water and air drying with nitrogen[2].

B. Wet chemical etch

The developed photomask was fully immersed into the Chromium etchant 1020 for 4 min without agitation to etch away the chrome unprotected by the photoresist, followed by the rinsing with DI water[2]. After that, the photomask was immersed into the Remover PG for 90 sec with the facilitation of ultrasonic wave to remove the remaining photoresist, followed by two rinsing with acetone and then isopropyl alcohol and air dry with nitrogen.

C. Optical microscope observation and measurement

Before and after the wet chemical etch step, the photomask was inspected using Zeiss Axio Imager M2m microscope. Images of different patterns were taken with a 100x objective with a Numerical Aperture of 0.85.

III. Results and Discussion

A. Patterns CD before and after metal etch

Fig 4(a) and (b) show the optical microscopy images of patterns before and after metal etch. The original and measured CDs of the patterns are summarized in Table I. As shown, the dark field pattern (gap) is defined to have a positive size while the bright field patterns (beam) have negative sizes. The CD deviation caused by the lithography process and the metal etch process for all patterns are listed. As can be seen, both lithographic deviations and etch deviations were non-zero and were generally the same for three different types of patterns. These results demonstrate that both lithography and metal etch contribute to the pattern CD deviations.

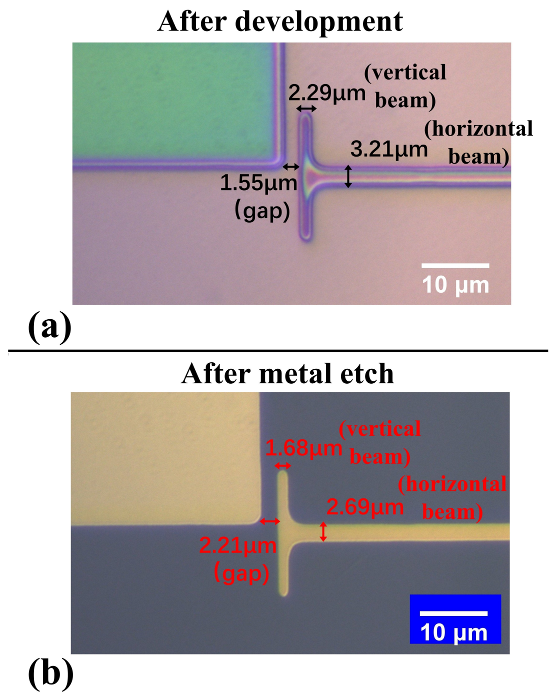

FIG. 4. Pattern comparison before and after metal etch. (a) The optical image of patterns on the photomask after LDW exposure and resist development but before metal etch. (b) The optical image of the same patterns on the photomask after metal etch.

B. Pattern CD deviations dependence on pattern sizes

As indicated in Fig 5(a) and (b), the CDs of different types of patterns including dense horizontal gap arrays, scarce vertical beams, vertical gaps, and horizontal beams with different original sizes were measured. The measured CDs vs original sizes data were plotted in Fig 5(c). As can be seen, the pattern CD deviations is a constant around $0.8\mu m$, independent of the pattern local density, pattern types, and pattern original sizes. Therefore, to cancel out this constant deviation, an opposite bias is suggested to be applied to the original patterns during data preparation for LDW. The bias can be applied in the BEAMER software[3] using the bias function, as shown in Fig 6(a). Fig 6(b) shows the patterns before and after applying the bias function. As can be seen, the bias is applied to all sides of the pattern. As a result, the bias value should be half of the opposite of the constant deviation indicated in Fig 5(c), which is $-0.4\mu m$. The bias value shown in 6(a) and (b) is larger than this value to make the effect of bias more visible in the figure illustration.

The CD deviation value may change with the LDW exposure condition and the Cr etch time, but the fact that this deviation value be independent of pattern sizes and local pattern density holds. Therefore, the method of applying opposite bias to the patterns can always be used to address the CD deviation problem. Using this method, the process-induced deviation should be kept

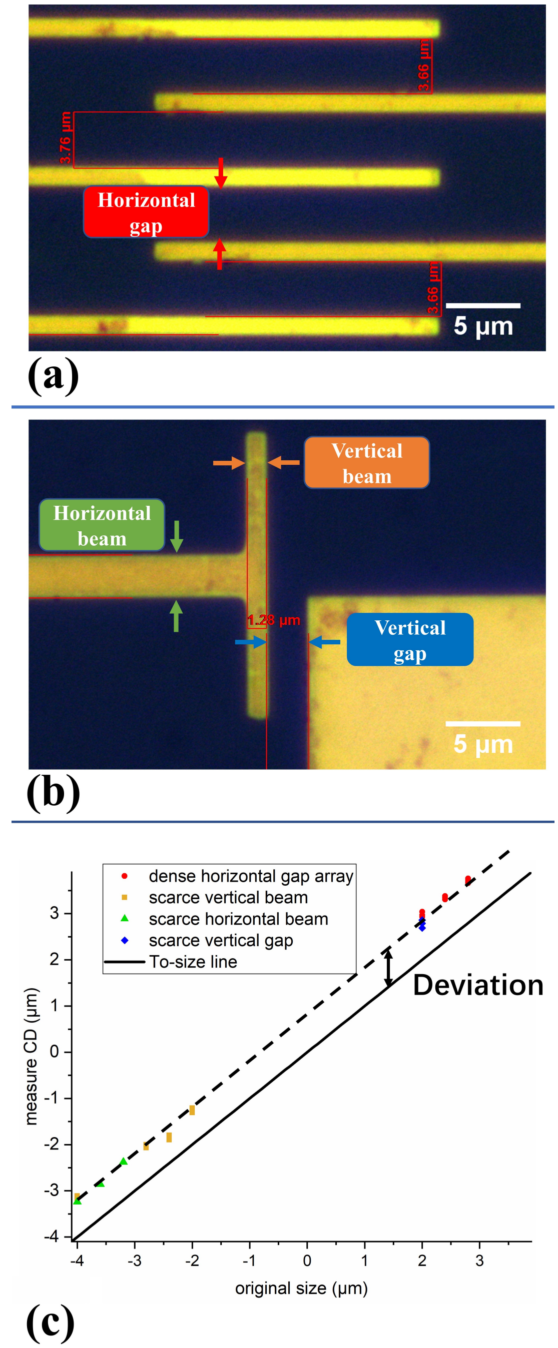

FIG. 5. Measured CDs vs original sizes for different patterns. (a) One typical image of the patterns of an electrical actuator that contain dense horizontal gap array. (b) One typical image of the patterns of an electrical oscillator that contain scarce vertical beam, vertical gap, and horizontal beam. (c) Measured CDs vs original sizes of different types of patterns.

consistent among different runs. The deviation comes from lithography and metal etch, which depend on the exposure dose and the etch time, separately, as discussed in the introduction section and in section IV A. Therefore, both the DWL exposure conditions (laser power, filter, focus parameters) and the metal etch time should be consistent among different runs.

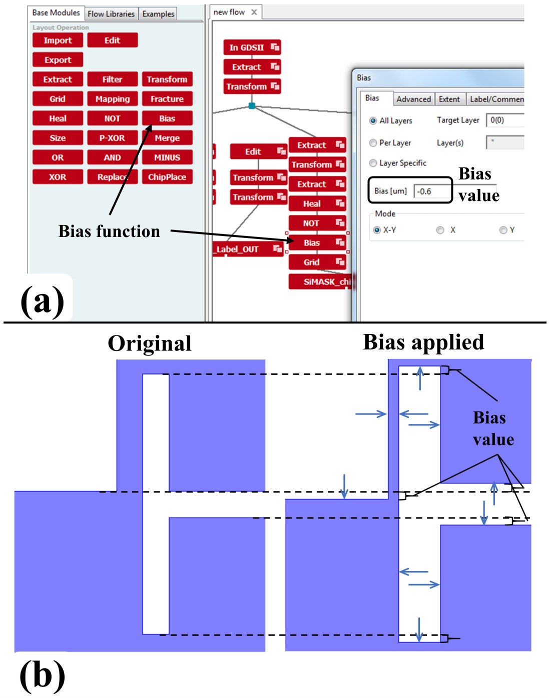

FIG. 6. Pre-exposure bias of the patterns in BEAMER. (a) Bias function applied to the patterns in BEAMER software. (b) Pattern before and after the bias function applied with a bias value of $-0.6\mu m$.

IV. Summary

CD deviations from the coded dimensions of patterns made on a photomask were found to be caused both by the lithography process, using a Heidelberg DWL66+ laser writer, and by the undercut from the Cr etch process. The value of the deviation was found to be independent of the pattern original size and local pattern density. To overcome this universal deviation, a universal bias of $0.8\mu m$ should be applied to the original patterns during data preparation for.

V. Acknowledgements

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