Microelectronic Engineering 9 (1989) 235–238
North-Holland

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FABRICATION OF GRATING PATTERNS BY E-BEAM LITHOGRAPHY

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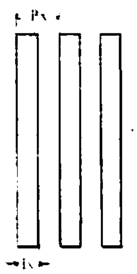
Along with the development of optical communication, optical integrated devices are now making rapid progress, and especially the grating, which is of a periodic structure, is now playing an important role in a wide variety of fields. In recent years, there is an increasing need for smaller grating pitches, and not only semiconductors but also a variety of materials are used for substrates. Recently, we have established a technique to finely control the grating pitch to 1 nm, less than the pattern data unit (5 nm), by E-beam (E-B) lithography. Also, the fabrication of gratings with phase shift has been simplified by changing the stage shift distance.

1. INTRODUCTION

As is widely known, the grating is used for the DFB laser [1] [2], multiplexer [3] [4], demultiplexer, etc.

The important factors in grating fabrication are precise grating pitch and width setting. Fig. 1 illustrates these factors.



lx : Grating pattern width
Px: Grating pitch

Fig. 1. Definition of grating factors

Conventionally, the holographic interference method [5] has been generally used for grating fabrication. The pitch of a grating fabricated by the holographic method is determined by the wavelength of laser light and its incidence angle on the substrate material as shown by equation (1).

$$\Lambda = \lambda/2 \cdot \sin\theta \quad \text{.......................} \quad (1)$$

Λ : Grating pitch
λ : Wavelength
θ : Incidence angle

In recent years, as sharp resist patterns are required to obtain narrow exposure width, E-B lithography has been attracting attention.

Namely, as compared with the optical method, the E-B lithography easily makes it possible to change not only the grating pitch but also phase, thus allowing easy fabrication of a DFB laser with a $\pi/4$ phase shift.

E-B writing data has a minimum unit for data generation and the grating pitch cannot be controlled to units smaller than this unit. Therefore, we have established a new method to write gratings having a pitch matched to the wavelength of light to be used.

The new method is to adjust the stage shift distance and the electron beam deflection width at the same rate. Below is given its concept in detail.

2. WRITING TECHNIQUE

In E-B lithography of gratings, stitching of E-B scan fields is required. Therefore, in order to finely control the grating pitch, it is necessary to make constant not only the beam deflection width, but the pitch at the field stitching portions. The control method employed in the present study is as follows:

The beam deflection width is calibrated to the stage shift distance measured using a laser interferometer. Namely, one mark for deflector calibration is moved between A and B positions, which are apart at a reference value L, and exact distance L is detected, as shown in Fig. 2, and then the beam deflection width is calibrated so that the distance between the two detected positions becomes equal to the shift value measured by the laser interferometer.

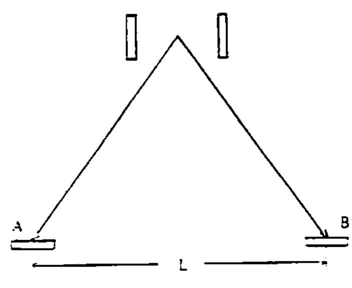


Fig. 2. Correction of beam deflection width

A, B: Mark detection positions
L: Stage shift distance

By giving a length correction ΔL to the reference value L, the stage shift distance is adjusted to the new reference value, and the beam deflection width can also be adjusted to L + ΔL. By this method, both the deflection width and the stage shift distance are changed by the same amount, (1 + ΔL/L) times. As a result, the writing pattern is changed both in the pattern size and pattern pitch, allowing (1 + ΔL/L) times finer pitch control.

The most importance of this method is to increase the stitching accuracy. The stitching accuracy is obtained by the correction method to feed the stop position error of the stage back to the deflector. Also, the same correction is applied to stage vibrations caused by floor vibration. This correction accuracy is dependent on the accuracy (λ/120) of the laser interferometer that measures the stage position. The accuracy is 5 nm with the JBX-5DII Electron Beam Lithography System that we used for the present study.

RESULTS

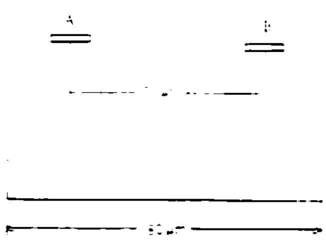
Table 1 shows measurement result of the stitching accuracy of this system.

The standard deviation of the stitching accuracy is 5 nm.

Table 1 Stitching accuracy of 50 μm × 50 μm field (Vernier with 5 nm resolution used)

Number of measurement points	30
Standard deviation (σ)	5 nm

As shown in Fig. 3, vernier patterns with 5 nm resolution are written at left and right portions in the 80 μm × 80 μm field with 50 μm distance. The exposure result, using the 50 μm pitch for the stage shift, was used for measurement.



A: Upper side vernier (0.995 μm pitch)

B: Lower side vernier (1.0 μm pitch)

Fig. 3. Vernier pattern for field stitching accuracy measurement

Fig. 4 shows one of verniers used for this measurement.

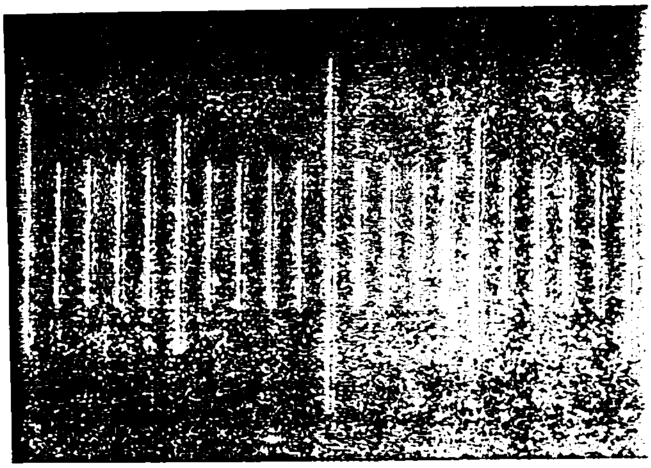
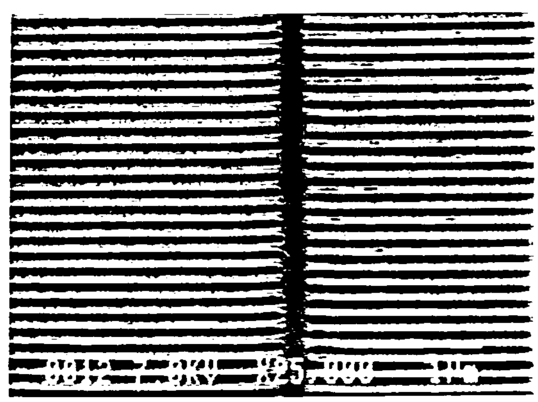


Fig. 4. Vernier pattern used for measurement of field stitching accuracy

Figs. 5 and 6 show examples of E-B written gratings using fine pitch modulation.

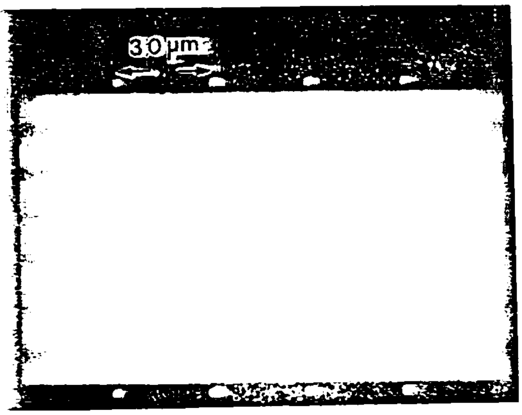
The right grating in Fig. 5 was written at a 0.115 μm pitch, and the left grating was written using the data of the right grating, by increasing the beam deflection width by 0.87% , that is, at a 0.116 μm pitch.

Fig. 6 shows the result of overlay exposure of the 0.115 μm and 0.116 μm pitch grating patterns. Since the pitch difference between the two gratings is 1 nm, both gratings are superposed on each other at the 115th line (0.116 μm pitch) and 116th line (0.115 μm pitch). Since the total number of the grating lines written is 782, the two gratings are superposed seven times including the first superposition. This is the reason why seven stripes are seen on Fig. 6.



Left: 0.116 μm pitch
Right: 0.115 μm pitch

Fig. 5. Fine pitch modulation



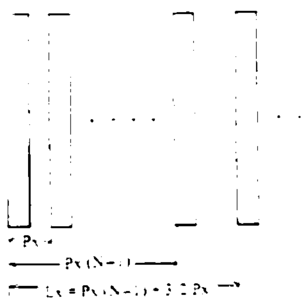
Overlay exposure of
0.116 μm pitch and
0.115 μm pitch grating patterns

Fig. 6. Fine pitch modulation

Si substrate were used for both gratings. The resist used was PMMA 100 nm, and the sensitivity was 2.25 nC/cm² for the former and 0.8 nC/cm² for the latter.

Fig. 8 shows the writing result of a 0.23 μm pitch grating with π/4 phase shift. This phase shift pattern was written by giving an offset in 5 nm increment to the stage shift distance. As shown in Fig. 7, when the grating is formed providing unexposed portions, an offset amount is 1/2 Px, and stage shift distances are expressed as follows:

Lx = Px (N−1) + 3/2 Px (Unexposed portions form grating)
Lx = Px (N−1) + 1/2 Px (Exposed portions form grating)



Lx: Stage shift distance
Px: Grating pitch
N : Number of grating lines (within one chip)

Fig. 7. An example of unexposed portions forming a grating

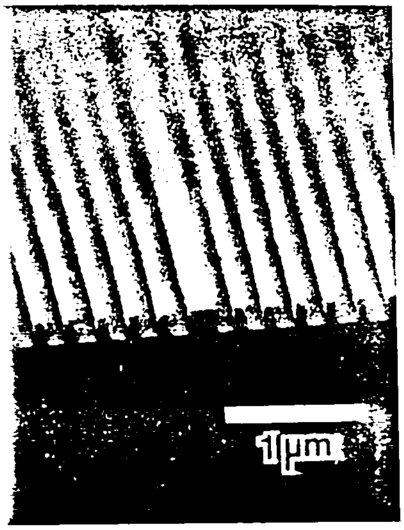
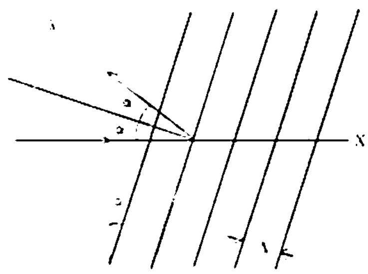


Fig. 8. 0.23 μm pitch grating pattern with π/4 phase shift

The substrate used was Si, the resist was PMMA 200 nm, and the sensitivity was 410 $\mu C/cm^2$.

Fig. 10 shows an example of a written grating for a multiplexer. Fig. 9 shows the grating for multiplexing of light with wavelength λ from X direction to 2α direction.



$\Lambda = \lambda / 2n \cdot \cos\alpha$

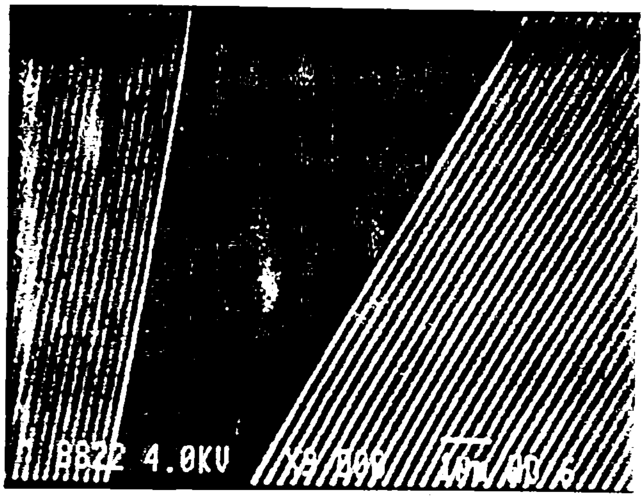
Λ : Grating pitch
λ : Wavelength of incident wave
n : Refractive index of medium
α : Inclination angle of grating

Fig. 9. Light multiplexing by grating

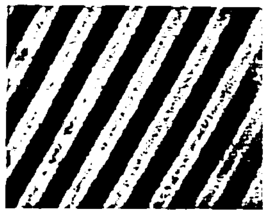
The grating shown in Fig. 10 is one with n = 1.5. The values of α and Λ are as follows:

α	10°	30°	50°
Λ	0.21 μm	0.24 μm	0.32 μm

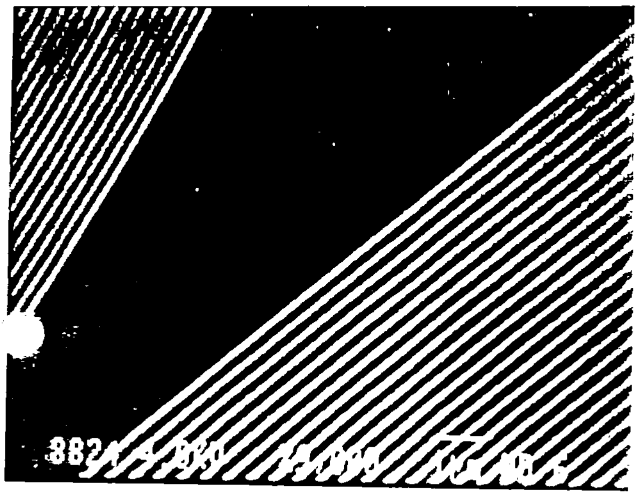
The substrate used was Si, the resist was PMMA with the thickness 200 nm, and the sensitivity was 300 $\mu C/cm^2$.



$\alpha = 10^\circ$ $\Lambda = 0.21\,\mu m$



$\alpha = 30^\circ$ $\Lambda = 0.24\,\mu m$



$\alpha = 50^\circ$ $\Lambda = 0.32\,\mu m$

Fig. 10. Oblique grating patterns

Fig. 11 shows an example of a grating of 0.52 μm pitch written on an insulating substrate. In this case, after coating the resist (PMMA with the thickness of 350 nm). Al was evaporated to approximately 12 nm to prevent charge-up. For pealing off Al, a mixture solution of $NaOH/H_2O$ was used.

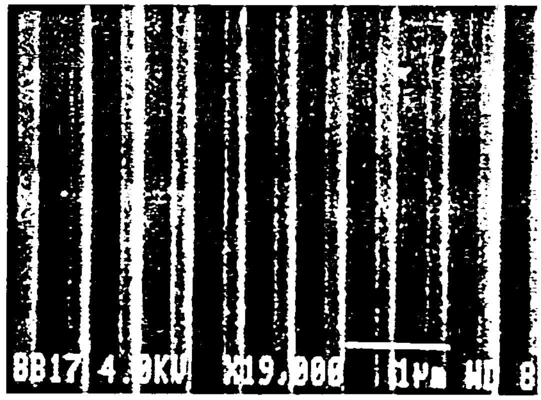


Fig. 11. 0.52 μm pitch grating pattern on insulating substrate

4. CONCLUSIONS

By changing the stage shift distance from the reference value to a 0.87% wider one, and matching the beam deflection width to the new stage shift distance, a standard 0.115 μm pitch grating and a 0.116 μm pitch grating were successfully fabricated. From this result, it was ascertained that the pitch difference was improved from the 5 nm designation unit to 1 nm. In addition, the fabrication of gratings with a phase shift has been simplified by changing the stage shift distance.

ACKNOWLEDGEMENTS

We are indebted to Messrs. Ogura and Aoyage for the cooperation in taking the SEM photos contained herein.

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At first, the outer and inner arcs are divided to 1 degree and they are approximated with short straight lines. Then each sectioned part is further divided into trapezoids by the lines drawn from vertexes in parallel to the X axis as shown in Fig. 2.

When outer and inner arc radius are same, the arc will be expressed by a series of short oblique lines as shown in Fig. 3.

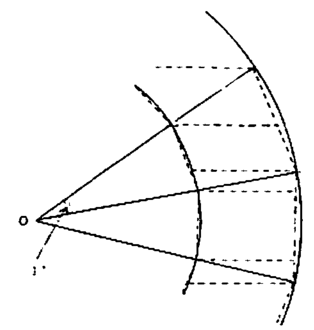


Fig. 2 Approximation of curved pattern
Solid lines: original feature
Dotted lines: partitioned feature

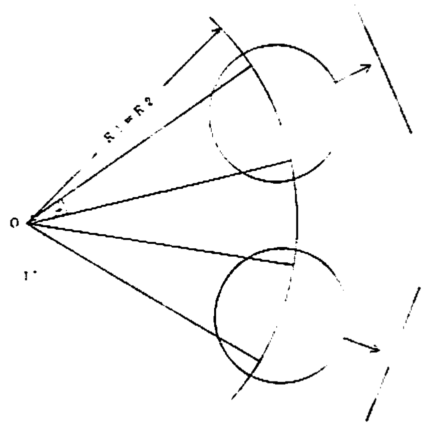


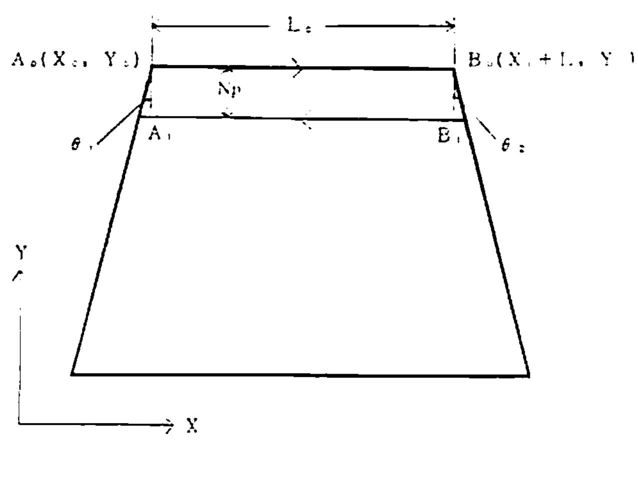
Fig. 3 Approximation of curved line

2.3. Delineation Technique for Curved Features

In trapezoid writing, during the writing of the first line, the positions of the start and end points for the next line are pre-calculated.

This method is carried out as shown in Fig. 4.

While the electron beam scans from Point A_0 to Point B_0, the next start and end points B_1 and A_1 are calculated using the following formula:



$$X_{A1} = X_0 - Np \cdot \tan\theta_1 \qquad Y_{A1} = Y_0 - Np$$
$$X_{B1} = X_0 + L_0 + Np \cdot \tan\theta_2 \qquad Y_{B1} = Y_0 - Np$$

(Np denotes the scanning increment)

Fig. 4 Trapezoid writing method

These calculated values are saved in the PRE-DATA register in the E-B lithography system. It therefore helps write patterns at high speed. The calculation time exerts no influence on the delineation time for one line, because the former is shorter than the latter.

As mentioned already, a curved single line is approximated with short oblique lines. In writing them, exposure time or the scanning speed may be modulated, depending on the angle of oblique lines as describing below.