CALIBRATION OF THE DEFLECTION FIELD OF THE LITHOGRAPH USING SEM MODE

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ABSTRACT

The following text describes a new method for the calibration of geometric distortion of deflection field. This method uses a regime of scanning electron microscope (SEM), which was added to electron beam lithographs BS600 and BS601 in project ELITO. The main advantage of this method was the reduction of the time required to calibrate the lithograph.

1 INTRODUCTION

A beam of electrons in electron lithography is used for exposing the PMMA layer sensitive to electrons. The electron beam is deflected by the magnetic field. The electron beam within lithographs of the BS600 series can be deflected in 0.1 µm steps up to 30,000 steps. The silicon wafer with the PMMA layer is fixed in a frame, which lies on a stage. The stage has to be moved to expose structures larger than 3 mm. The position of the stage is controlled using a laser interferometer, which measures an accuracy of 0.1 nm. The offset position of the stage is diminished by the deflection of an electron beam. Deflection of electron beam is carried out by set of inductors.

Deflection is a complex problem. The geometry of the deflection of the magnetic field has to be calibrated. Calibration is carried out by changing the magnetic field of a set of inductors. The change is dependent upon the selected position of the electron beam. Solving this problem started with the development of the lithograph. There were many methods and mathematical models used. Models and methods of the calibration changed with improving ability of computers. The method described here uses the latest technical features of the SEM regime and is built on a practically verified mathematical model.

The work of the Electron Beam Lithography laboratory within the Institute of Scientific Instruments at the Academy of Sciences, Brno, Czech Republic is oriented to development of diffractive structures. The calibration of the geometry of the deflection field is a considerable problem, because of the size of the diffractive structures, which usually exceeds 3mm. The exact link-up of the individual exposed fields does not have to be as high as the exactness required for masks which are used in microchip production. This allows the use of a simplified two dimensional mathematical model.

2 MATHEMATICAL MODEL

The mathematical model used in the calibration is a two dimensional polynomial in the first order.

$$\begin{aligned} \Delta X &= A_x + B_x \cdot X + C_x \cdot Y + D_x \cdot X \cdot Y \\ \Delta Y &= A_y + B_y \cdot Y + C_x \cdot X + D_y \cdot X \cdot Y \end{aligned} \tag{1}$$

If the offsets of the four points of the exposed field are known it is then possible to calculate the calibration constants using this equation.

$$\begin{bmatrix} A_x & B_x & C_x & D_x \\ A_y & C_y & B_y & D_y \end{bmatrix} = \begin{bmatrix} \Delta X_1 & \Delta X_2 & \Delta X_3 & \Delta X_4 \\ \Delta Y_1 & \Delta Y_2 & \Delta Y_3 & \Delta Y_4 \end{bmatrix} \cdot \begin{bmatrix} 1 & 1 & 1 & 1 \\ X_1 & X_2 & X_3 & X_4 \\ Y_1 & Y_2 & Y_3 & Y_4 \\ X_1 \cdot Y_1 & X_2 \cdot Y_2 & X_3 \cdot Y_3 & X_4 \cdot Y_4 \end{bmatrix}^{-1} \tag{2}$$

The symbols in equations (1) and (2): ΔX, ΔY are the offsets for each of the points X_n, Y_n. A_x,...D_y are calibration constants. The range of the calibration constants significantly differs, therefore the calculated calibration constants are multiplied by the constants, which differs for specific algorithms.

3 SCANNING OF MARKINGS

The set of pictures for consequential analysis is carried out by scanning metallic markings in the SEM regime of lithographs. The objective of the scanning is to obtain a set of images with markings to determine the offsets of deflection by comparing their midpoints. All the algorithms used for exposition these days use four quadrants. There are nine offsets required for calculating the whole set of calibration constants.

There are two possible ways to obtain a beam at a certain point. The first one is to deflect the beam. The second is to move the stage. The inaccuracy of the movement of the stage is eliminated by deflating the beam, which is to be calibrated. The offset of the deflection is lower when the beam is not deflated too much. This corresponds with the mathematical model, which has been previously described. Therefore the slow, inaccurate mechanical movement of the stage has to be taken as a more accurate procedure than the deflection of the beam. There is always some probability of an inaccuracy, because all the system trembles in a range of tens of nanometres and the offset of movement of the table differs.

One marking or a set of nine markings can be used for getting the set of offsets. The set of markings with an accuracy of tens of nanometres are required. A set of markings was created lithographically, with stage movement only. This set of markings has an inaccuracy in tens of nanometres, but even this inaccuracy affects the results of the calibration. The measurement of the offsets in the accuracy of nanometres on distance in a range of millimetres was required. The offsets of the position of the markings were read directly without deflating the beam to diminish the offset of the movement of the stage. Even this result had to be modified empirically in many steps. Positions of the markings used for getting offsets have to correspond to the edge of particularly exposed fields to obtain the best exactness, because the simplified mathematical model and only four quadrants are used. Therefore the method of calibration, which uses only one marking, is required. The stage has to be moved for getting a set of offsets using one marking. A strip of silicon wafer with markings is fixed to a frame holding the substrate. The vertical position of the substrate and markings differs; therefore the recalculation of the offsets is required.

Scanning of both described methods is driven automatically by a Visual Basic Script. The highest zoom useful for scanning depends on the maximum offset expected and also on the size of the markings used. The size of a pixel on an image taken with the usual zoom corresponds to 0.1 μm. The size of the image is 512×512 pixels. Offsets exceeding 20 μm can be measured.

4 MARKINGS AND DISTORTION FILTERING

The coordinates of the centres of the markings are determined by the position of the first order of the fast Fourier transform analysis applied to a sum of each point of an analysed image. A filtering of the distortion of an analysed image is necessary before analysis can be carried out.

There are several different types of markings used for scanning. There are also different types of distortions of the image, because of the different setting of the lithograph. A new setting of the filters is required for each scanning. The shape of the beam can be dependent on the deflection. The shape of the beam affects the brightness of the image.

There are four different possibilities of filters. The filters will be described in the order they are ran during analysis. The first one is the 2DFT filter. This filter is the only filter, whose selection of points is dependent upon the surrounding points. The second filter is a logical function for separating background and marking. The result of this filter is a black and white image. The third filter changes the colour of selected white points back to their original colour from grey scale. This filter is obviously used in combination with the 2DFT filter. The fourth filter reduces the amount of analysed data. The sum of each point per axis is taken then the fourth filter is applied.

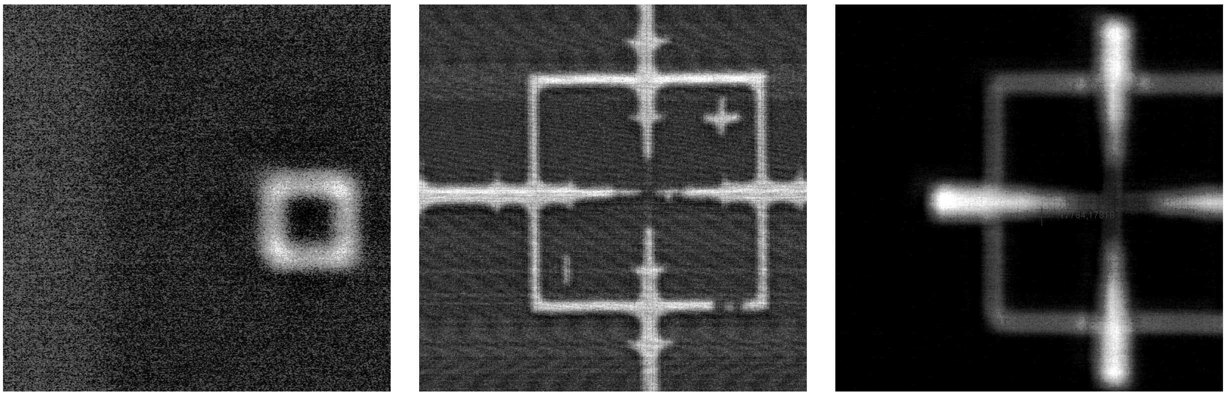


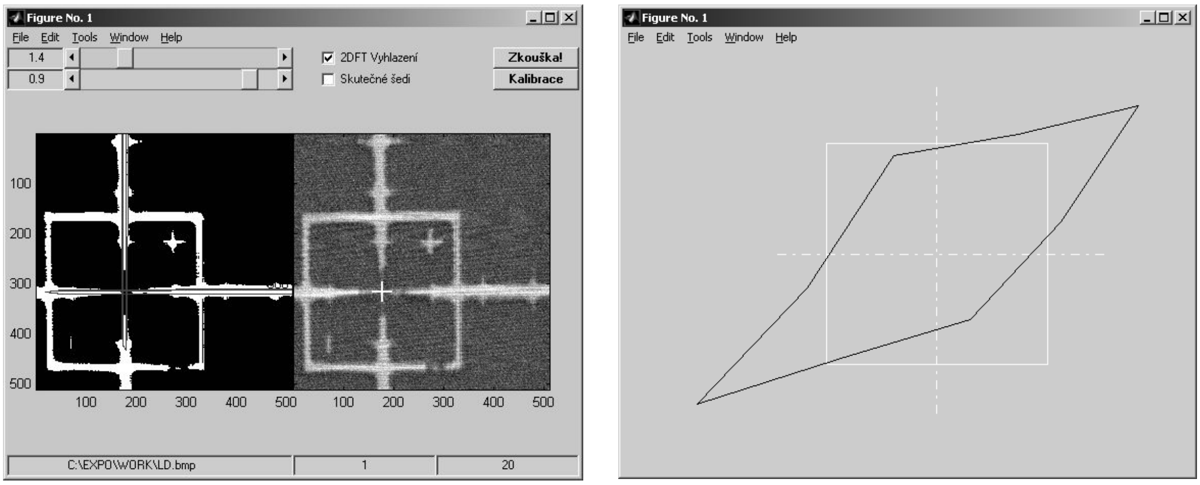
Fig. 1: *Types of used markings and distortion of images*

Every described filter is used for a different purpose. The first filter removes the noise light points from the background. This filter is the slowest one and is only used in rare occasions. The first filter in combination with the third one is useful for reducing the noise, which is visible on the middle picture. The "shadow" shown in the left part of the left most picture would be highlighted by the 2DFT filter. The second filter is used to remove the 3D effect. The third filter cancels the effect of removing the 3D effect. The quantity of information obtained using the fourth filter differs for each type of marking. For analysis of the marking at the left most picture the highest possible amount of information is required.

The quantity of information used for analysis of the data taken from the middle picture has to be lower to remove the anti-symmetry. The fourth filter is also required to reduce the influence of the lines surrounding the main cross shown in the right most picture of fig.1.

5 ANALYSIS AND CALIBRATION CONSTANTS

Analysis of the images is carried out by a function, which can be run in three different user modes. The simplest one only returns resulting coordinates, dependent on the setting which is passed through the command line. The second one in addition to the first user mode shows the result and waits for confirmation or correction, which is carried out by clicking the right mouse button on the picture. The third user mode lets the user set the value of each filter in a user interface (fig.2 left). The described user interface also allows the user to choose the name of the file used for setting the analysis and the dimensions of the cross indicating the centre of the marking. Changes in the setting are to be evaluated by pressing the button labelled “Zkouška”. After accepting a setting, a set of scripts used to create a file with calibration constants is executed by pressing the button labelled “Kalibrace”. A window showing the offsets (fig.2 right), is viewed to an operator to avoid gross errors in the analysis.



1.4
0.9
☑ 2DFT Vyhlazení
☐ Skutečné šedi
C:\EXPO\WORK\LD.bmp 1 20

Fig. 2: *Interface for setting analysis of images and view of offsets*

A set of functions for processing offsets and calibration constants was required. The set of functions includes scripts for:

- conversion of the set of coordinates of the centres of the markings to the offsets,
- conversion of the offsets to a different plan of the axis z,
- function for viewing the shape character of the set of offsets,
- function for calculating the calibration coefficients,
- function for creating a file of the calibration constants,
- function for reading the file of the calibration constants,
- function for reading a set of offsets from a file.

6 EVALUATION OF THE QUALITY OF A CALIBRATION

Quality of calibration is evaluated after exposition and development of the wafer.

The goal of the calibration is the link-up of fields exposed separately. The quality of calibration is not absolute, because the link-up changes during exposition and depends on the offset of the position of the stage. The diffractive structures also do not often link-up which, makes evaluation of the quality of the calibration hard to carry out. There were many special structures developed, for the purpose of calibration, because it was the only way to obtain the offsets for the calculation of the calibration constants. These structures were also used for evaluating the quality of calibration. The structure used these days is shown in fig.3, which shows the difference between the exposition with (at the right) and without calibration. The description of the structure can be found in [1]. The colour of the images differs dependently on the stage of technological process. The darker image was obtained after development and the lighter image had already been plated before it was acquired. Both images were obtained through an optical microscope.

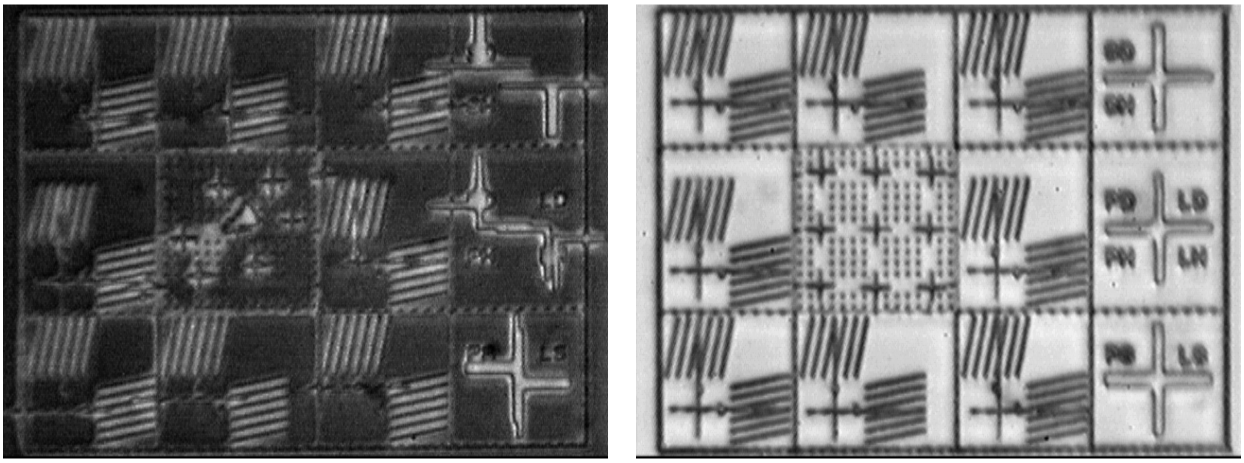


Fig. 3: *Linkup of exposition fields with [right side]and without calibration [left side]*

It is possible to check the quality of calibration by scanning the markings using a checked set of calibration constants. The operator can thus find an error. However, this method can not improve the quality of calibration.

7 CONCLUSION

The time required to create a calibration constants file approached the time required for the scanning of markings, which is in the range of minutes.

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