100kV Electron Beam Lithography System: JBX-9300FS

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Spot electron-beam(e-beam) lithography systems are promising equipment for fabrication and research of sub-100nm size devices. And, adding to the conventional applications such as fabrication of high speed transistors or optical devices, new demands for higher voltage lithography for X-ray or e-beam projection lithograph have been increasing. Now, sub-50nm size fabrication is aimed at and the required writing accuracy will increase as feature sizes decrease. To play an important role in next generation device fabrication, we have developed the JBX-9300FS, a 100kV spot e-beam lithography system.

In this paper we introduce the JBX-9300FS in terms of system implementation, performance, and writing results.

1. Introduction

The JBX-9300FS is a 100kV spot e-beam lithography system for fabricating sub-100 nm size devices and masks of X-ray or e-beam projection lithography[1].

We describe its system specifications and key technologies to achieve high accuracy writing.

2. System Specifications of the JBX-9300FS

We show the system specifications in Table 1. The JBX-9300FS employs a ZrO/W emitter for forming a spot beam, a vector-scanning system, and step & repeat stage-movement system.

Adapting to the increase of writing material sizes, we have made it possible to load wafers up to 300 mm and mask blanks up to 230 mm.

Accelerating voltage can be switched from 50 (100) kV to 100 (50) kV.

Field size is 1000 ㎛m at 50kV and 500 ㎛m at 100 kV.

We have employed a two-stage electrostatic deflector system, to increase the writing speed adapting to the high sensitivity e-beam resists.

Critical dimension (CD) uniformity within a writing field has been improved by dynamic focus and astigmatism correction. And writing accuracy has been increased by employing some new technologies for height correction, signal processing, and mark alignment in direct writing.

3. System Implementation of the JBX-9300FS

Figures 1 shows the external view of JBX-9300FS. Figures 2 the electron optics system, and Figures 3 the block diagram of the control system.

3.1. Electron Optics System

As shown in Fig.2, an electron source image at a ZrO/W emitter is optically demagnified.
and projected to the writing plane.

Generated electron beam is accelerated to 50 kV or 100 kV through the four-stage accelerating electrodes. This accelerating field plays the role of an electrostatic lens, and the first crossover is formed at the center position of the split blanking electrodes.

Two condenser lenses work as zoom lens, which means that the 3rd condenser lens value is set up linked to the 2nd lens value, in order to project a demagnified image onto the fixed point as the third crossover.

Finally, the objective lens projects the third crossover onto the writing plane as a spot beam.

3.2. Deflection System

We have employed a two-stage electrostatic deflector system adapting to a high resolution and high sensitivity e-beam resists.

One is the deflector that designates writing positions (positioning deflector), and the other is the deflector that writes patterns rapidly (writing deflector).

The positioning deflector consists of octopole cylindrical electrodes and is located in the objective lens. It uses 20-bit DACs. The writing deflector, on the other hand, consists of quadrupole cylindrical electrodes and is located above the objective lens. It uses 12-bit DACs.

Furthermore, we have implemented two electrodes to improve the writing uniformity within a writing field correcting deflection aberration and astigmatism.

The former works for dynamic focus correction and the latter works for dynamic astigmatism correction.

These correction values are revolved in a writing field using third-degree polynomial and they are supplied as a correction voltage in pattern writing.

3.3. Signal Detection Systems

The signal detection systems we have newly developed are the height correction, backscattered electron (BE) signal processing, and absorbed electron (AE) signal processing.

The purposes of height measurement are corrections of objective lens focusing, deflection amplitude and rotation of main- and sub-deflectors.

Two pairs of height measurement systems detect height difference between the height standard plane on the stage and writing plane. And acquired height fluctuation is fed back to the focusing and deflection control unit.

BE signal is used for mark position determination and correction of deflection amplitude and rotation of main- and sub-deflectors. Detected signals from alignment marks in direct writing are also processed as BE signals.

The BE signal processing unit consists of BE signal detectors and the signal processing system. Detected digital BE signal is processed by correlation operation and a mark position is determined from the top peak signal position.

\[ g(i) = \sum_{j} f(i - j) \cdot f(i + j) \]

where \( f(i) \) is detected signal, \( j \) is calculation range of correlation operation, and \( g(i) \) is correlation operation processed signal.

Practical mark detection signals in direct writing (from top: raw signal, differential signal, correlation operation processed signal) are shown in Figures 4.

AE signal is mainly used for focus adjustment at the focus standard plane.

The AE signal processing unit consists of mesh marks with the role of edge, e-beam detectors below the meshes, and the signal processing system.

Detected digital AE signal when e-beam passes across a mesh mark is fitted to an error function, and a beam size is defined from coefficients of the error function.

Adding to the beam size measurement function, an automatic focus adjustment function to minimize a beam size is attached.

3.4. Chip Mark Alignment Method

Some wafers used in direct writing have some distortions such as warping, expanding, and shrinking through several thermal pre-processes.

To compensate these distortion influences on writing accuracies, four chip marks provided around a writing chip are detected for measuring how the chip region is distorted.

Assuming the designed mark coordinates as \((x_i, y_i) (i=1\sim4)\) and the actual mark coordinates including wafer distortion as \((X_i, Y_i) (i=1\sim4)\), we have the equations shown below.

\[
X_i = A_0 + A_1 \cdot x_i + A_2 \cdot y_i + A_3 \cdot x_i \cdot y_i
\]

\[
Y_i = B_0 + B_1 \cdot x_i + B_1 \cdot y_i + B_3 \cdot x_i \cdot y_i
\]

Solving these equations, we can obtain the distortion coefficients \(A_0 (i=0\sim3), B_0 (i=0\sim3)\). By using these coefficients, the designed coordinates of field corners \(f_i (i=1\sim4)\) shown in Figures 5 can be converted to \(g_i (i=1\sim4)\). Here the equations showing the conversion of \(f_i \cup g_i\) are obtained in the same manner as for the distortion mentioned above. Actual writing positions are then determined using the conversion coefficients for \(f_i \cup g_i\).

The pattern writing program send these coefficients to the hardware arithmetic unit.
Then this hardware calculates compensated writing positions using coefficients and pattern writing goes on.

When one field writing is completed, the next coefficients are sent and the next field writing starts.

Repeating this procedure over the entire writing chip, direct writing is achieved with high accuracy.

4. Writing Results

Figures 6 and 7 show results of line and space pattern writing on ZEP520 (40 nm thick) on Si. Accelerating voltage is 100 kV and beam current is 100 pA. Line width of 15 nm in the X direction and 17 nm in Y direction have been attained.

5. Conclusion

It has been ascertained that high-accuracy writing results were obtained by employment of some technologies such as improvement of address unit resolution, newly developed signal processing systems, and dynamic correction within a writing field.

6. Acknowledgments

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References


Fig.3. Block diagram of the JBX-9300FS’s control system.

Fig.4. Mark detection signals.

Fig.5. 4-chip marks alignment.

Fig.6. X-direction line and space pattern writing (15nm)

Fig.7. Y-direction line and space pattern writing (17nm)