Technology of EB Lithography System for 65-nm Node Mask Writing

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OVERVIEW: Semiconductor manufacturing equipment requires both high accuracy and high productivity at the same time. The same can be said for mask writing technology used in KrF or ArF UV (ultraviolet) lithography. A new series of the EB (electron beam) mask lithography system developed by Hitachi Group has high-accuracy CD (critical dimension) controllability obtained with a new electron optical system, new compensation technology, higher precision stage and temperature control technology, as well as high positioning controllability, thus achieving a higher degree of accuracy. In addition, to cope with the huge, terabyte-order data volume that comes with miniaturization, a SAN (storage area network) system was adopted to unify management of previously localized data and to expedite data management and conversion processing to reduce the burden on the system user. Furthermore, higher current density and faster deflection calculation technology can be applied to realize high system throughput for the current generation of mask production lines which are the bulk of existing products, as well as to production systems in the 65-nm node generation.

INTRODUCTION

ADVANCES in LSI integration scale and function continue without pause, and device miniaturization has accelerated in recent years. ITRS 2003 (International Technology Roadmap for Semiconductors 2003) predicts production for the 90-nm node in 2004 and production for the 65-nm node in 2007. Device manufacturers are proceeding with development based on these targets. Although device development that employs KrF or ArF UV (ultraviolet) lithography is

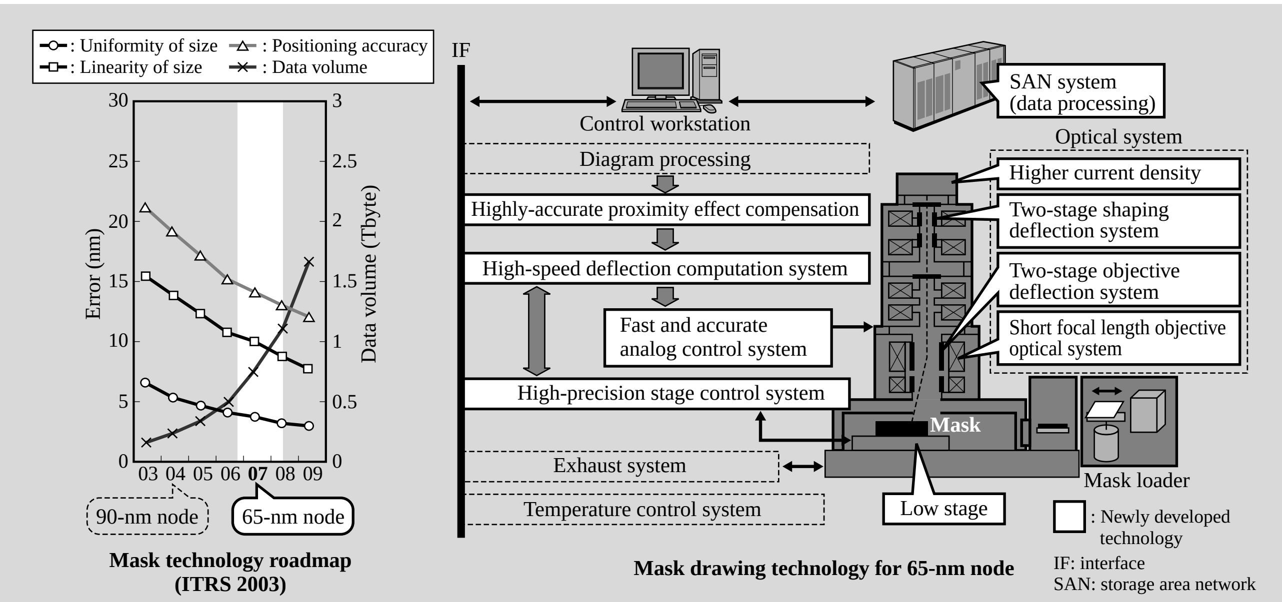


Fig. 1—Specifications Required for 65-nm Node and Description of EB Mask Writer that Implements Them.
The roadmap (ITRS 2003) is shown on the left. The required specifications for a 65-nm node mask writer require about 30% higher accuracy and twice the data volume relative to the specifications for a 90-nm node. The newly developed technology is shown on the right.

said to be mainstream for this generation, further development of mask writing technology is desired and higher system accuracy is mandatory in either case. Current production lines, however, have mainly adopted masks for 90-nm or earlier nodes, and production is expected to continue over the next few years. For this reason, maintenance of conventional mask productivity and development of the next-generation mask will proceed in parallel, and mask writers that combine high accuracy and high productivity (high throughput and high reliability) will be required. In this report, we describe the basic performance and functions of the new series of EB (electron beam) mask lithography system[1], which was developed to meet those requirements for 65-nm masks (see Fig. 1).

PROBLEMS AND NEW TECHNOLOGY FOR ACHIEVING HIGHER ACCURACY

Improved Deflection Control with New Electron Optical System

Concerning dimensional accuracy, OPC (optical proximity effect correction) pattern size control for correcting the optical proximity effect has become an issue in recent years, in addition to the improvement of CD linearity. The OPC patterns include small figures down to the order of several nanometers in size, so an electron optical system design that takes into account beam resolution is required.

(1) Two-stage shaping deflection for improved CD control

In the beam-shaping optics, fabrication error in the deflectors that effects CD control causes axial displacement of the trajectory. That is to say, for a given deflection voltage, a high-order distortion phenomenon arises and degrades the CD accuracy. The new optical system employs a two-stage (upper and lower) shaping deflection system. The lower stage of the deflection system bends the beam back to correct the axial displacement and achieve linear control to improve the CD linearity and OPC pattern precision. The principle of the two-stage shaping deflection system and the dimensional accuracy improvement effect with a divided OPC pattern are illustrated in Fig. 2. The two-stage shaping deflection system can reduce the beam distortion that accompanies axial displacement, achieving a CD error of 3.6 nm or less even in a divided OPC model pattern.

(2) Higher resolution with a short focal length objective lens

Furthermore, beam blur at a high current density can be reduced by making the lens smaller and the focal length shorter in the objective optical system, thus achieving higher resolution. Examples of CD linearity and resolution evaluation are shown in Fig. 3. CD linearity is 3.3 nm or better, and the good resolution of 70-nm L&S (line and space) has been obtained.

(3) Improvement of deflection control with an electrostatic two-stage objective deflection system

Deflection control technology for reducing CD variation within the mask has also been developed. The deflection system is configured with two stages, the main deflection stage and the sub deflection stage;

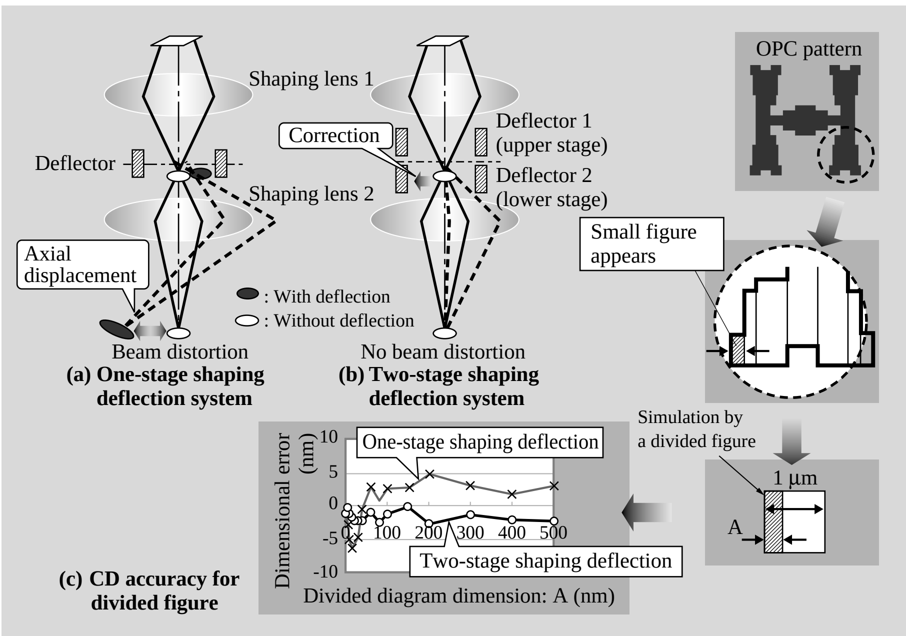


Fig. 2—Two-stage Shaping Deflection System for OPC Patterns.
Fig. (a) shows beam distortion due to the axial displacement that occurs in deflection because of manufacturing error in the deflector, etc. Fig. (b) shows correction of the axial displacement by adjustment of the deflection by the upper and lower deflection stages, thus eliminating beam distortion. Fig. (c) shows the dimension error in a divided figure that simulates an OPC pattern (1-µm isolated line). While CD variation occurs with one-stage shaping, two-stage shaping makes the beam distortion small and thus reduces the CD variation.

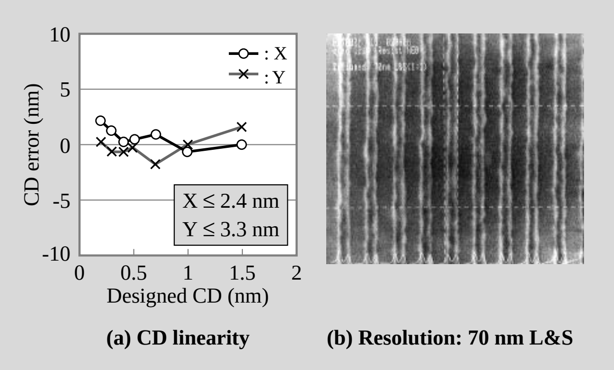


Fig. 3—Example of Dimension Linearity and Resolution Evaluation Results for New Series of EB Mask Lithography System.
(a) CD linearity of a 0.2 to 1.5-μm isolated line; (b) Resolution for an L&S pattern (resist: NEB22, 300-nm thick).

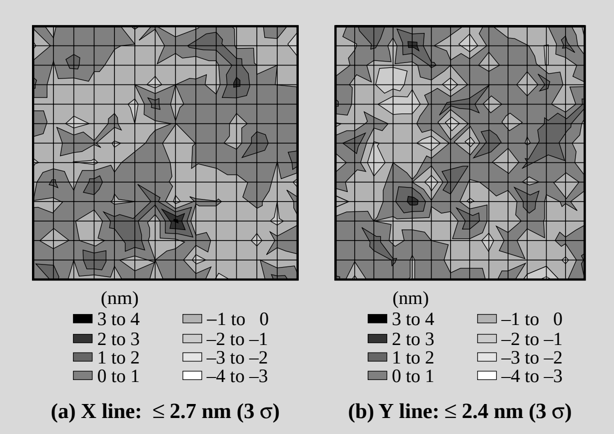


Fig. 4—CD Univormity within Mask.
Example of evaluation results for CD uniformity of a 1-μm isolated line within a mask (130 mm square), excluding process error.

a high speed and high accuracy amplifier is used to attain both controllability and high speed. Electrostatic deflection has the advantage of high-speed operation of about 100 ns for a small deflection (about 40 μm) and several microseconds even for large deflection (about 1 mm).

Using low-aberration octapole electrodes for both stages of the two-stage deflection system and correcting astigmatism reduces the beam distortion and improves the CD variation during deflection. This increases reliability in mask writing and achieves a CD uniformity of 2.7 nm or better within the mask (see Fig. 4).

Higher Accuracy in Proximity Effect Correction

Concerning the EB exposure, the deposited energy of the beam varies with pattern density, which causes fluctuation of CD. This is called the proximity effect; a PEC (proximity effect correction) is a means of reducing error due to this effect. A method, which appropriately corrects the exposure dosage by calculating the deposited energy from the pattern area density divided into a micrometer-order grid through filter processing simulated as electron scattering, has been used in the EB mask lithography system and is effective in terms of processing speed. This method, however, is prone to computation error for sudden changes in density, so a high-order correction term must be considered.

In a newly developed exposure correction method, the deposited energy for changes in density is calculated in advance(2), and CD error is reduced by adding a high-order correction to the conventional amount of exposure as required. Evaluation results for the new and conventional PEC methods applied to a pattern that contains a sudden change in density are shown in Fig. 5. In the vicinity of large areas, the exposure in insufficient and the dimensions tend to be reduced, but adding corrective exposure improves the CD accuracy.

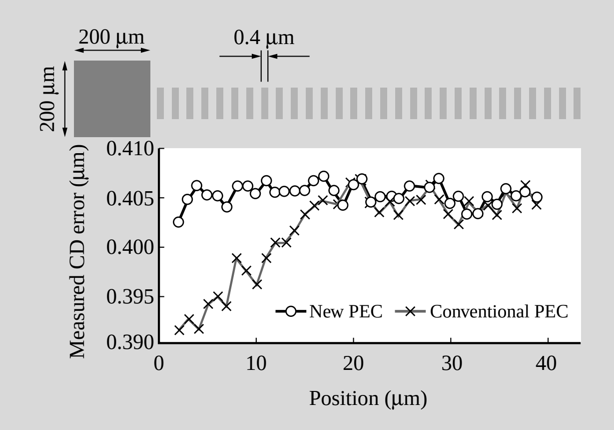
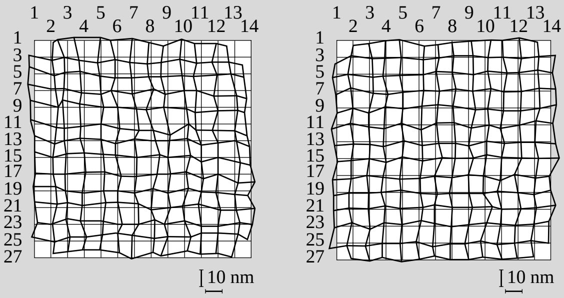


Fig. 5—Example of Proximity Effect Correction Results.
It shows example results for the conventional PEC and the new PEC regarding CD variation with respect to a sudden change in density in a large-area pattern (200 μm × 200 μm).

Higher Stage Control Accuracy and Low-expansion Stage Material

Positioning accuracy was increased by strengthening the system temperature control to make the system more robust against changes of the environment in addition to stabilizing the deflection control. In particular, the material of the stage was changed to more robust one against temperature



Summary	X line (nm)	Y line (nm)
Mean	0.16	–0.10
3 σ	12.10	13.73
Min.	–9.70	–13.09
Max.	10.95	9.58

(a) Conventional stage

Summary	X line (nm)	Y line (nm)
Mean	–0.07	0.25
3 σ	8.66	7.95
Min.	–7.06	–6.67
Max.	7.39	6.37

(b) Low-expansion stage

Fig. 6—Example of Positioning Accuracy.
Evaluation results for the positioning accuracy before and after changing the stage material (130 mm square, 10 nm/div): use of the low-expansion material improved the accuracy from the 13.7 nm to 8.7 nm (3 σ).

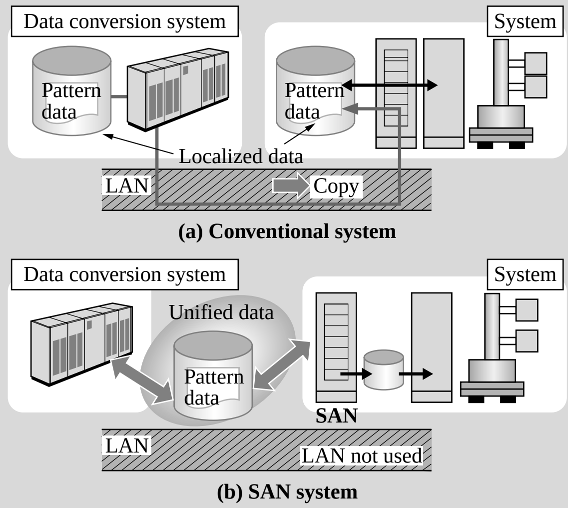


Fig. 7—SAN System Configuration.
The upper part is the configuration of the system that employs a LAN; the lower part is the configuration when SAN is used. The pattern data must be transferred to the system when a LAN is used, but when the SAN is used, the pattern data is shared and need not be transferred.

fluctuations and the stage control was made more accurate.

In the mask writer, the plate displacement is measured with a laser interferometer and the data is fed back into the control system. Thus, the accuracy of the position measurement and the expansion due to the heat from friction during the stage motion are factors in the degradation of the positioning accuracy.

The accuracy of the position measurement can be increased by raising the resolution of the laser interferometry to 0.3 nm or better; the effect of thermal expansion can be minimized by reducing the coefficient of thermal expansion of the stage material to 1/3 or less compared to conventional stage materials, thus further improving the positioning accuracy (see Fig. 6).

INCREASED DATA VOLUME AND ADAPTATION OF SAN SYSTEM

Because the data volume increases as miniaturization proceeds, means of managing and processing large volumes of data are required.

The conventional use of a LAN (local area network) to copy the patterns to be written to the hard disk is expected to pose the following problems:
(1) The transfer time is greatly affected by the speed of the LAN.
(2) Large volume data transfers monopolize the transmission line.

To deal with the above problems, data transfer management and exposure management are being required with respect to the writing data to be copied to the system by the user, while keeping in mind the local hard disk capacity of the system.

For that purpose, a SAN (storage area network) is employed, not simply for high-speed data access, but for virtual unification of data as well. The use of SAN achieves high reliability and can reduce the load on the LAN as well, because the LAN uses physically separate networks.

In this way, the two hard disks used previously can be unified and the copying of data eliminated. The complex schedule management that has previously been performed by the user is no longer necessary, and the desired pattern can be written at the desired time. In addition, the flexible expandability of SAN allows the addition of capacity without having to stop the entire system if the data volume increases. It is also possible to cluster multiple systems (see Fig. 7).

THROUGHPUT IMPROVEMENT

When this system is adopted for fabrication lines that are producing existing products, throughput must be maintained or improved so that productivity does not decline. As means of improving throughput, reduction of exposure time and faster deflection calculation should be effective.

The new series of EB mask lithography system can reduce exposure time by about 20% (product simulation pattern: 5 G shot/exposure dosage: 8 μC/cm^2) by changing the current density from 7.5 A/cm^2 to 15 A/cm^2. Furthermore, because the conventional three-stage deflection system was replaced with a two-stage system, the calculation can be simplified, achieving a speed increase of about 10%. The result is that a 40 G shot pattern (pattern for evaluating throughput) can be written in eight hours or less.

Furthermore, triangular pattern cell projection technology(3) can be used for patterns that include many oblique lines. Use of triangular patterns (2 μm, maximum) allows a reduction in the number of rectangular shots for oblique figures, thus making higher throughput possible.

CONCLUSIONS

The evaluation results obtained in this work are summarized in Table 1, which compares the accuracy required for the 65-nm node published in ITRS (2003). The results show that the new series of EB mask lithography system is suitable for the 65-nm node and subsequent technology.

Actually, however, there are many difficult problems other than lithography to be overcome for the 65-nm node and beyond, including processes (resist, etching, etc.) and evaluation technology. To solve these problems and to realize the full potential of this system, the Hitachi Group will provide technological support that includes peripheral equipment and strive to improve system accuracy and productivity.

TABLE 1. Evaluation Results for New Series of EB Mask Lithography System

The examples of evaluation results from this research are compared with the ITRS (65-nm node) specifications.

	Results	ITRS (65 nm)
Smallest feature size	70 nm	130 nm
Dimensional uniformity (3 σ)	2.7 nm	≤ 3.6 nm
Dimensional linearity (range)	3.3 nm	≤ 9.9 nm
Positioning accuracy (3 σ)	8.7 nm	≤ 14.0 nm

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