Electron Beam Mask Writing System for High-precision Reticles

—The HL-900M Series—

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OVERVIEW: Along with the accelerated miniaturization of semiconductor devices, the specifications for reticles used in lithography processes are rapidly demanding higher levels of accuracy. Many semiconductor manufacturers are already developing 130-nm nodes, and the electron beam writing systems used in manufacturing reticles must also follow the trend toward higher accuracy that is seen in devices. In December 1999, Hitachi, Ltd. announced the HL-900M Series electron beam photomask writing system, which was developed in response to user demand for high-precision reticles 1). This system is based on the HL-800M Series and introduces new electron optics, a low-distortion stage, and parallel processing function for coping with large volumes of data to achieve higher accuracy and higher throughput. The writing system is not the only factor in achieving advanced masks; the fabrication processes are also important, and progress is being made in the use of chemically amplified resists in the mask fabrication processes.

INTRODUCTION

RAPID progress is being made in the further miniaturization of semiconductor devices. According to the ITRS (International Technology Roadmap for Semiconductors) published by the SIA (the Semiconductor Industry Association of the US) in 1999, the mass production of 130-nm devices is expected in 2002 (Fig. 2). Among semiconductor manufacturing processes, the lithography process is the one that must cope with increasing miniaturization

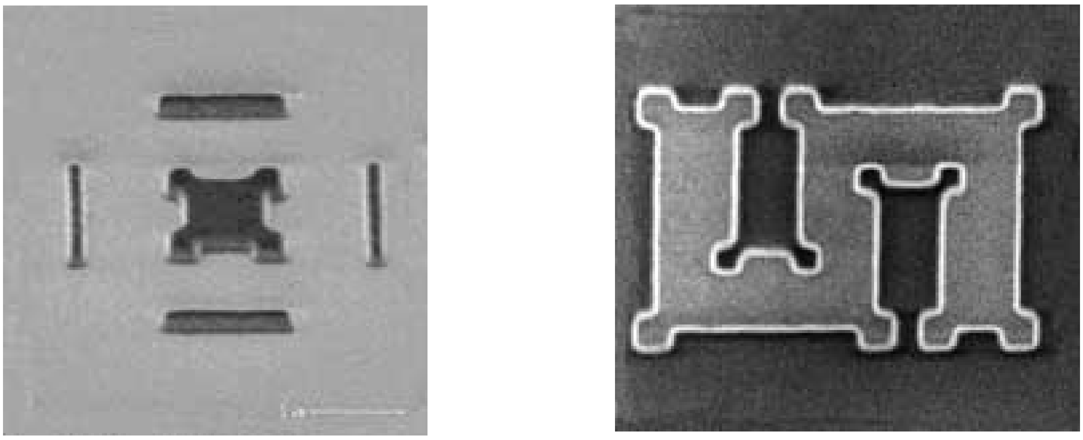
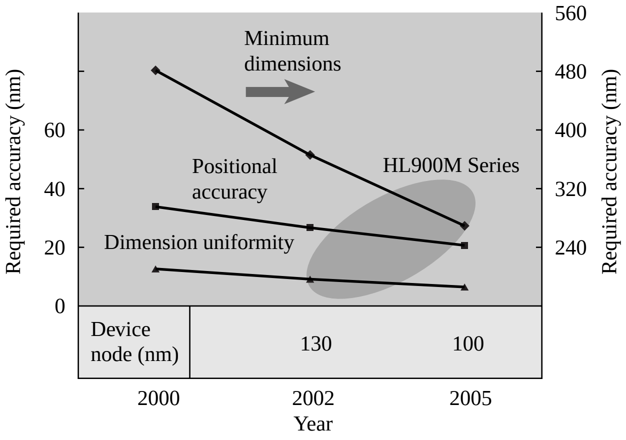

(a) 0.4-µm serif-pattern image
(b) 0.3-µm serif-pattern image

Fig. 1—Resist Images for a Fine OPC (Optical Proximity Correction) Pattern Obtained with a High-end Mask.
The OPC patterns for a 300-nm OPC dimension ZEP7000 resist dosed at 25 $\mu C/cm^2$ and observed with an S-7840 scanning electron microscope are shown. Using an electron beam makes it possible to draw OPC patterns, etc. at higher resolutions than can be achieved with laser light.



Reference data: International Technology Roadmap for Semiconductors 1999

Fig. 2—Accuracy Requirements for Reticles.
The changes in accuracy requirements for reticle over time are shown here. For 130-nm nodes, the required dimensional accuracy has become 10 nm or less.

the earliest, and the demands placed on the reticles used in that process are becoming severe. Currently, most advanced reticles are fabricated by using an electron beam writing system, so the accuracy demands of the specifications of that equipment are also increasing in pace.

On the other hand, the wavelength of light employed by the optical reduction exposure equipment (stepper) that is used in the lithography process is becoming increasingly shorter, and new trends in the field of reticle fabrication include the addition of OPC (optical proximity correction) patterns (see Fig. 1), the use of phase shifting masks, and so on to further extend the resolution limit.

In this report, we describe the HL-900M Series electron beam writing system that was developed by Hitachi, Ltd., the current situation regarding chemically amplified resists, and the future of the electron beam writing systems that are used in mask fabrication.

SYSTEM FEATURES

The HL-900M Series targets high-precision reticle fabrication at resolutions of 150 nm or better. This system is based on the HL-800M[2, 3], and, in order to increase accuracy, introduces (1) high-precision electron optics, (2) a low-distortion stage, (3) a highly accurate temperature control system, and (4) a parallel processing function for dealing with large-volume pattern data.

The main features of the HL-900M Series and their effects are listed in Table 1. This system employs a variable beam shape, vector scanning, and a continuous-stage-movement writing method. The acceleration voltage is 50 kV, the maximum beam current density is 10 A/cm^2, and the maximum beam size is 2×2 μm^2. Beam deflection is accomplished by using three types of deflectors, with a main deflection area of 2×2 mm^2, a secondary deflection area of 480×480 μm^2, and a sub-secondary deflection area of 60×60 μm^2. The approximate corresponding mask sizes are 12.7 cm (5 inches), 15.2 cm (6 inches), and 17.8 cm (7 inches).

The system configuration of the HL-900M Series is shown in Fig. 3. The control workstation performs data preparation, equipment calibration, writing control, and other system control functions. The writing data that is transferred from the workstation to the buffer memory of the equipment is expanded from a compressed format into the basic pattern shape. The proximity effect correction unit calculates the amount of dose correction at writing time based on the electron beam energy accumulation due to differences in pattern density. The shot controller provides real time feedback of the position data for the continuously moving stage to the deflector and also executes correction of the electron beam shape, position, and dosage.

Furthermore, duplication of the control circuit makes it possible to do the processing for the writing operation and the proximity effect correction in parallel. That shortens the writing time and increases the accuracy of the proximity effect correction. At the same time, easing some of the limitations on the

TABLE 1. Main Features of the HL-900M Series and Their Effects
A system that meets the requirements for high-precision reticles of 150 nm or less.

Feature	Effects
High acceleration voltage (50 kV)	High resolution , high accuracy
Variable-shape beam and vector scanning	High throughput
Parallel processing capability	High accuracy, high throughput, and ability to handle large data volumes
Automatic mask transport function	Ease of operation
Graphical operation screen	Ease of operation

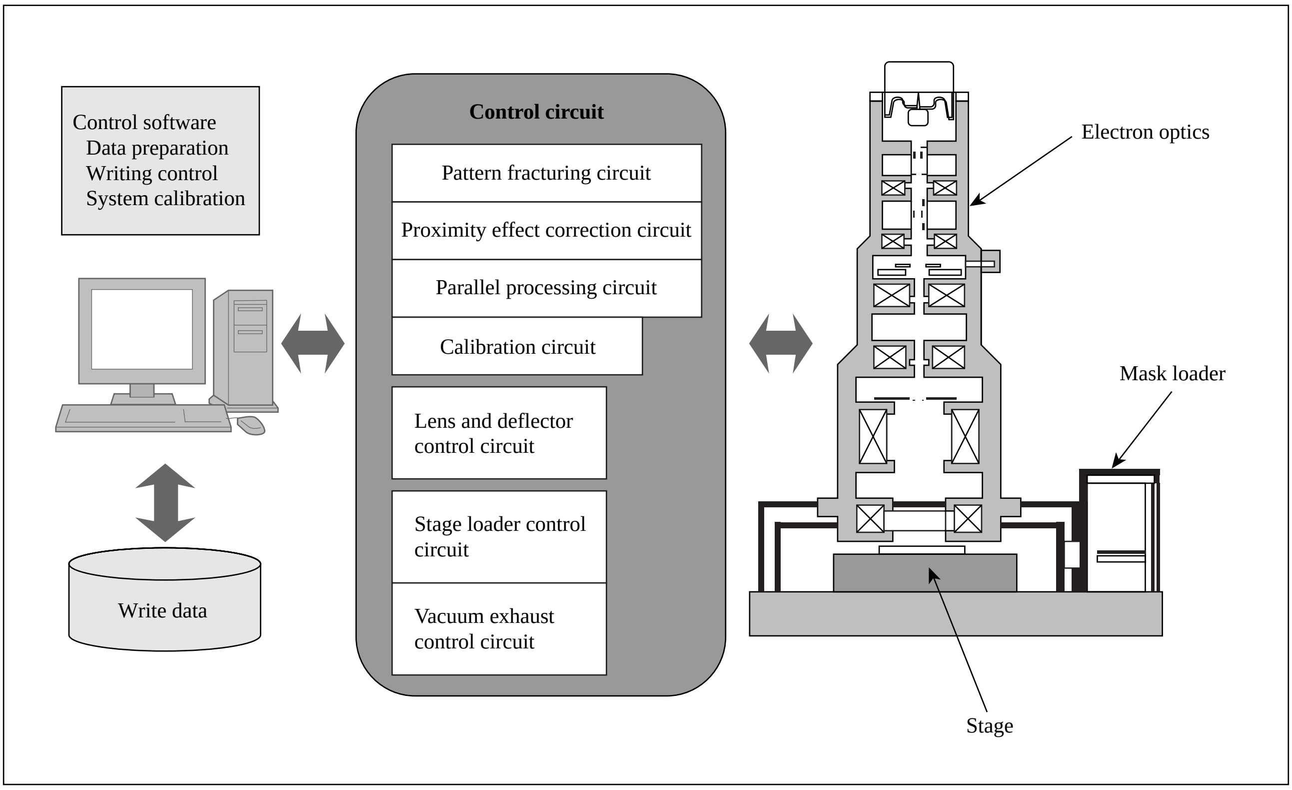


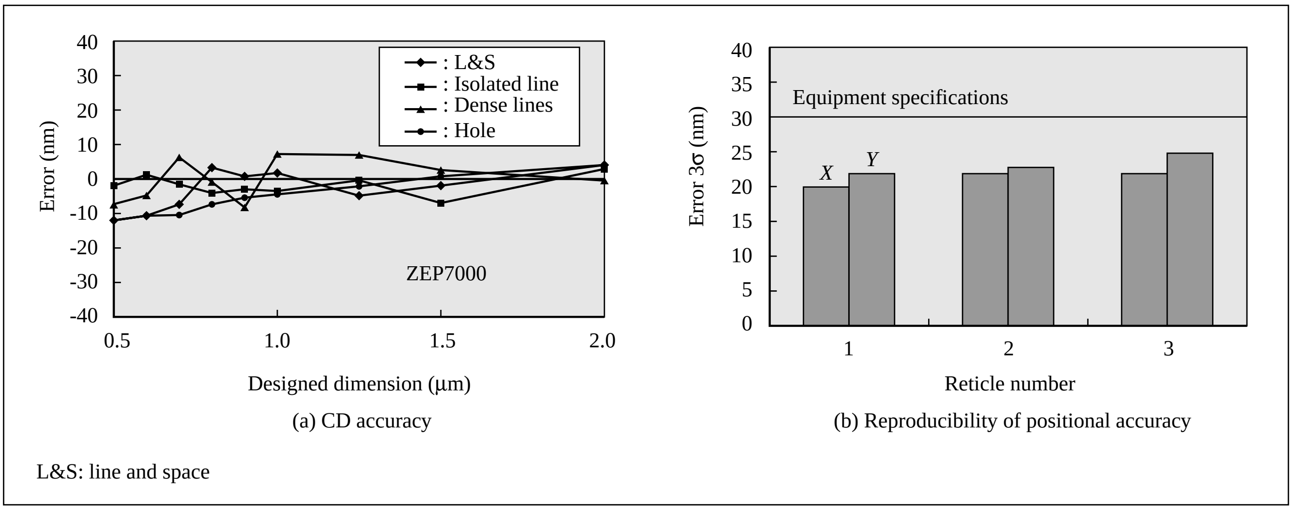
Fig. 3—HL-900M Series System Configuration.
The electron beam writing system comprises electronic circuits, software, and other such components. In order to attain the specified system performance, all parts of the system must perform at the required level.

amount of pattern data makes it possible to write more than 20 gigabytes of pattern data.

The mask transport mechanism employs an autoloader and an automatic batch system and is capable of continuous processing of up to six wafers with the C to C (carrier to carrier) scheme. Application to an automatic mask transport system is also possible. Furthermore, we revised the stage structure so as to prevent table deformation when the stage moves. The stage position is measured with high accuracy by laser interferometer, but the interference mirror must be attached to the stage. Mechanical deformation of the stage during movement causes displacement of the mirror, and thus reduces the accuracy of the position. The amount of stage deformation may be minute, but even slight deformation cannot be permitted in order to achieve nanometer-level writing accuracy. The structure of the new stage used in this system has a separate Y table, with the reflection mirror and plate mounted on the top table. The result is that deformation of the Y table does not affect the top table, so the distance between the reflection mirror and the mask is always constant and a high degree of positional accuracy is achieved.

In addition to the above, we revised the column structure and strengthened the magnetic shielding of the objective lens unit to achieve higher rigidity, reduced heat generation by the lens coils, and increased robustness to changes in the environment, such as magnetic fields, etc.

To verify the effects of these improvements, we used an external coil to intentionally generate a magnetic field disturbance around the new column and measured the effect on the electron beam. The results showed that the new column reduced beam wavering from 1/3 to 1/8 that of the conventional column at frequencies of 10 Hz and 1 kHz, confirming that robustness to external disturbance is greatly enhanced. As an example of equipment characteristics, measured results for CD (critical dimension) accuracy and reproducibility of positional accuracy are presented in Fig. 4. Both types of data were obtained by measurements made on a plate that had been processed up to the stage of etching after writing the test pattern on a mask of approximately 15.2 cm (6 inches). The positional accuracy data are the result of evaluating



(a) CD accuracy

(b) Reproducibility of positional accuracy

Fig. 4—Evaluation Results (Example).
Among the items evaluated for the electron beam writing system, critical dimension (CD) accuracy and reproducibility of positional accuracy are shown here.

three plates with an optical measurement instrument. The range of evaluation was a 115 × 115 mm area on a 6-inch plate.

APPLICATION TO ADVANCED RETICLES

In the fabrication of an advanced mask, the processing that is done to the plate up to the reticle after writing is important to accuracy no less than improving accuracy of the writing system. Of the post-writing processes, which include resist development processes such as baking, the etching process, the washing process and the like, we describe the use of chemically amplified resists in the resist processes below.

In the conventional resist processes, the cross-linking and unlinking of the molecules of the resist material is directly effected by the irradiation energy of the electron beam to produce image. In contrast, the use of chemically amplified resist (CAR) has been gaining ground recently.

With a chemically amplified resist, irradiation by the electron beam causes the formation of an acid inside the resist. The chemical reaction of that acid produces the photosensitizing process. Chemically amplified resists feature higher sensitivity than conventional resists and greater resistance to dry etching. For example, comparing with the ZEP7000 positive resist that is widely used at this time, the sensitivity is about three times as high (8 $\mu C/cm^2$ at an acceleration voltage of 50 kV) and the resistance to dry etching is about twice as high.

Although chemically amplified resists offer such advantages, their use presents problems that are difficult to deal with, such as that characteristics vary according to storage time, baking conditions, the processing environment, etc., because a chemical reaction is involved in the imaging process. Recently, however, with the cooperation of resist manufacturers, we have been investigating the use of these resists at the manufacturing site with the aim of solving these problems. Resolution photographs for a typical chemically amplified resist are shown in Fig. 5.

FUTURE FORM OF THE SYSTEM

Currently, the issue of whether high-precision reticles can be realized is the key to further increases in device miniaturization—discussions have been held on revising mask magnification and proposals of new reticle fabrication methods have been made. Even under these circumstances, the need for continuous improvement in the accuracy of electron beam mask system writing is expected to continue into the future, and that is something that must be dealt with.

Furthermore, the stable production of high-precision reticles requires quick optimization of the system and the process, measures to find solution quickly in case of not qualified reticles are produced, as well as the technological improvement of the system and the process. This requires a systemization of functions that includes mask inspection equipment to achieve quick and easy feedback of inspection results to equipment parameters and process conditions.

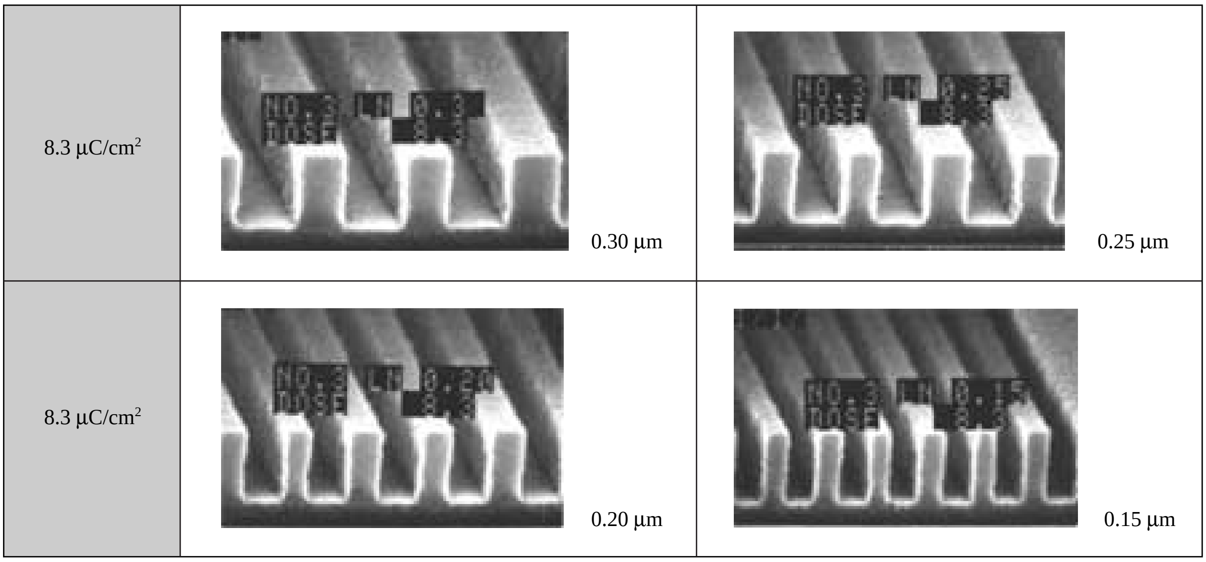


Fig. 5—Resolution of the Positive Chemically Amplified Resist.
The resolution of a positive chemically amplified resist (RE-5400 Series) is shown here.
Photo source: Hitachi Chemical Co., Ltd.

CONCLUSIONS

We have described the HL-900M Series electron beam mask writing system.

As we believe that the miniaturization of devices will progress even further, Hitachi, Ltd. will continue to develop technology and provide the equipment required to support that progress.

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