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Electron Beam Image Projection System with High Accelerating Voltage

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The system design and performance of a newly developed electron beam image projection system are presented. The system has a 5 inch wafer full exposure capability with automatic wafer handling. Focusing parameters were optimized concerning resolution capability, pattern distortion, proximity effect and mask-wafer discharge. High accelerating voltage provides substantial advantages for improving resolution capability, alignment accuracy and for reducing proximity effect. 0.5 μm design rule model memory patterns were successfully replicated with steep profiles by 30 second exposures. Alignment mark detection accuracy better than 0.05 μm was achieved.

1. Introduction

Electron beam (EB) image projection technology [1] is one of the most powerful candidates for submicron lithography in future VLSI fabrications. Performance data demonstrating its usefulness have been reported.[2) 3)] However, several problems should be solved in order to put this technology into practical use. For instance, the well-known proximity effect, which causes degradation in pattern size accuracy in submicron regions, is more serious in EB image projection than in EB writing. Recently, our preliminary results showed that the use of high accelerating voltage (Vacc) led to proximity effect reduction in EB image projection.[4)] Also, the high Vacc in EB projection is anticipated to provide many advantages such as higher resolution, deeper depth of focus and higher alignment mark detection accuracy. Thus, we have developed a fully automatic EB image projection system with high accelerating voltage for practical submicron lithography.

This paper reports the system design, the optimization of the focusing parameters and some pattern replication characteristics.

2. System design

2.1 Performance target

We designed a 5 inch full wafer exposure system in order to obtain useful data for a future step and repeat system. The system performance is listed in Table 1. The practical resolution of 0.5 μm was aimed at in consideration of the difficulty of mask-making and the proximity effect, although ultimate resolution higher than 0.1 μm was obtained substantially.

The overlay accuracy between successive exposures is determined by machine alignment accuracy, mask error, wafer bow and wafer nonlinear distortion. Machine alignment accuracy was set at ± 0.13 μm (3σ) from machine error budget analysis. This value corresponds to the overlay accuracy of ± 0.25 μm when we assume the mask error of ± 0.15 μm and the errors due to nonlinear wafer distortion and wafer bow of ± 0.15 μm.

At first , the throughput was set at 20 wafers/hr for PMMA resist. However, the maximum achievable throughput can be enhanced to be more than 50 wafers/hr by using a more sensitive resist and improving the alignment subsystem and wafer handling control subsystem.

Table 1. Performance Target.

Wafer Size	5 inches
Practical Resolution	0.5 μm
Alignment Accuracy (Machine)	± 0.13 μm (3σ)
Throughput	20 wafers/hr

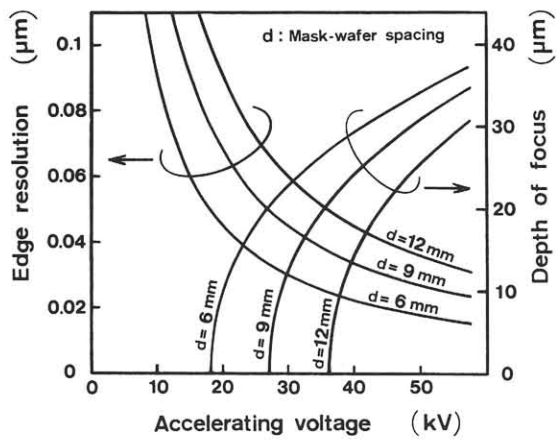

Fig.1. Edge resolution & depth of focus vs accelerating voltage.

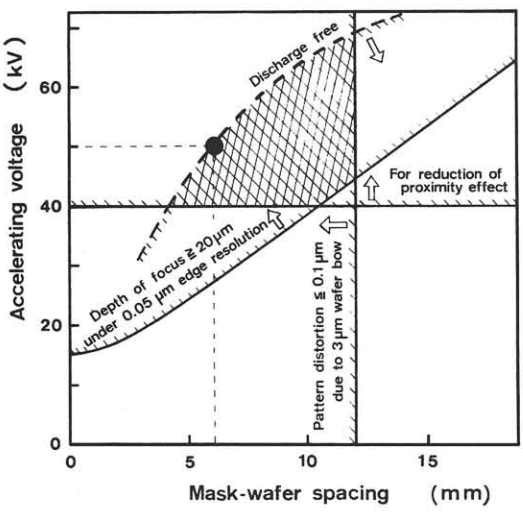

Fig.2. Optimization of accelerating voltage and mask-wafer spacing. The arrows indicate favourable regions for each system parameter.

2.2 Optimization of focusing parameters

Chromatic aberration caused by the initial kinetic energy distribution of emitted photoelectrons dominantly determines the ultimate resolution. Figure 1 shows the edge resolution and the depth of focus (DOF) under 0.05 μm edge resolution as a function of Vacc calculated from G.A.Wardly's exression[5] with mask-wafer spacing (d) as a parameter, where a CsI photoemitter and low pressure mercury discharge lamp are used. The higher Vacc and the narrower d offer the higher resolution and the deeper DOF. These characteristics allow to resolve finer patterns for the complicated topographic wafer surface. The higher Vacc also enables us to reduce the proximity effect.[4] Moreover, the narrower d provides the reduction of pattern distortions, which are caused by the inhomogeneity of the electric and magnetic fields.[5] However, the higher Vacc and the narrower d sometimes cause serious discharges between the mask and wafer. Accordingly, as shown in Fig. 2, the following four conditions should be satisfied for our system design goal: (1) DOF deeper than 20 μm under 0.05 μm edge resolution, (2) pattern distortion smaller than 0.1 μm due to 3 μm wafer bow, (3) Vacc higher than 40 kV for reducing proximity effect and (4) electric field intensity range in which stable image projection without any kind of discharge is performed. Thus, the most favourable operation region was optimized as shown in the crosshatched area in Fig. 2. The system can be operated up to 50 kV in the condition of the minimum d of 6 mm (see black dot in Fig. 3). Maximum magnetic field intensity is 4 kG.

3. System description

The block diagram of the system is shown in Fig. 3. The whole system is automatically controlled by a minicomputer. The focusing magnet is made of a newly designed superconducting magnet with several resistive-type field correcting coils. Superconducting magnet enables us not only to generate an intense and stable magnetic field because of its large exciting current and its persistent current mode operation, but also to control the temperature of the whole system stably because it does not generate Joule heat. Moreover, our new superconducting magnet is characterized by low heat dissipation.

Alignment mark detection is carried out by X-ray signals generated from heavy metal marks on the wafer.[2] The alignment of the mask and wafer is performed using a piezoelectric-driven XYΘ wafer table and deflection coils. In order to correct wafer expansion and shrinkage, the magnification correction coils are set inside the superconducting magnet.

The wafer handling subsystem mainly consists of two wafer prechambers, an orientation flat positioning station, two loading arms and a Z-axis wafer table. Each wafer is transferred from a load carrier to main chamber and then to an

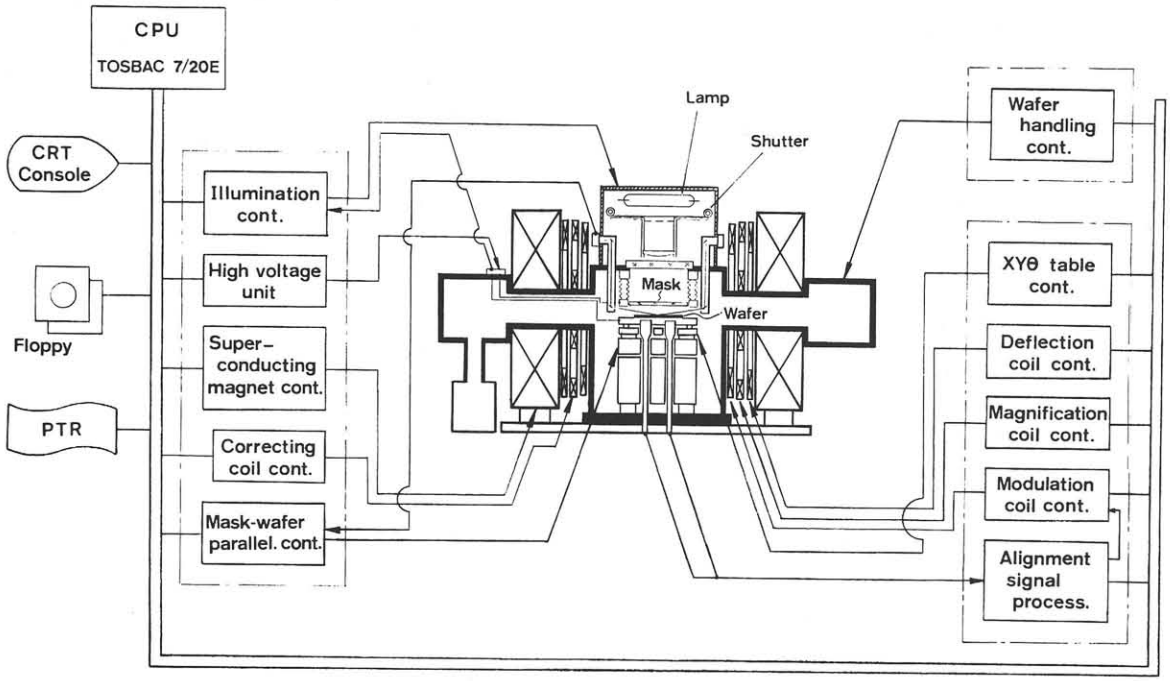

Fig.3. Block diagram of EB image projection system.

unload carrier. In order to clamp wafers in vacuum, electrostatic chucks are utilized.

The mask-wafer spacing and parallelism control subsystem, which consists of three optical wafer height sensors and a three-axes (Z, X_θ, Y_θ) wafer table, is equipped because mask-wafer spacing changes for each wafer.

4. Results and discussion

Figure 4 shows the overview of the system based on the above-mentioned design. The practical resolution capability was tested by using many kinds of test patterns and circuit model patterns. An SEM photograph of 0.5 μm design rule model memory cell patterns replicated in 1 μm thick PMMA at 40 kV acceleration is shown in Fig. 5. Exposure time for this sample was 30 seconds. Development was carried out in isoamyl-acetate (IAA) at 24 °C and its time was 3 minutes. A steep pattern profile was successfully obtained. The proximity effect was found to be reduced considerably at 40 kV as expected, but did not disappear completely. For more accurate submicron pattern replications, our newly developed proximity effect reduction method of the bias exposure method[6] is now investigated. The depth of focus was proved to be

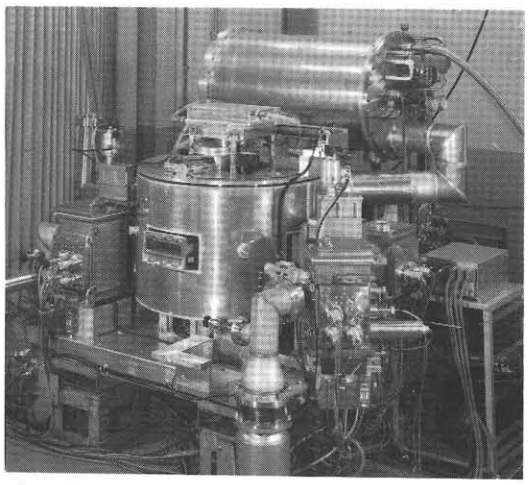

Fig.4. Overview of EB image projection system.

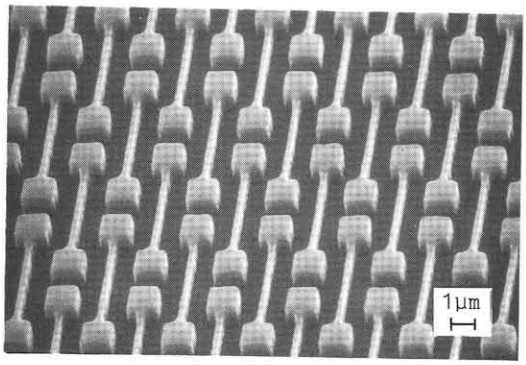

Fig. 5. 0.5 μm design rule model memory cell patterns. Vacc = 40 kV , exposure time = 30 seconds and resist : PMMA.

Table 2. Dependence of X-ray alignment signal on accelerating voltage (Vacc).

Vacc		20 kV	30 kV	40 kV
Ta	(S_1)	1	4	10
Ta covered with Al	(S_2)	0.4	3.2	10
S_2 / S_1		40 %	80 %	100 %

(Ta : 3000 Å , Al : 1 μm)

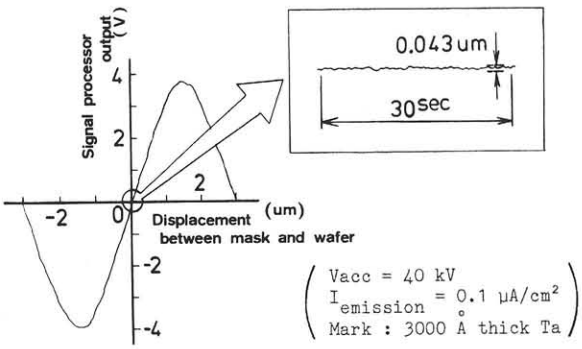

Fig.6. Alignment mark detection characteristic.

deeper than 20 μm under the condition that 0.5 μm patterns were replicated with a steep profile.

Dependence of alignment mark detection characteristic on Vacc was evaluated. The amounts of X-ray signals from 3000 Å thick Ta marks covered without any layers (S_1) and with 1 μm thick Al layer (S_2) at several accelerating voltages are shown in Table 2. The Vacc range from 20 kV to 40 kV demonstrated about 10 times larger X-ray signals in the case of the mark which was not covered with any films. Furthermore, the ratio of S_2/S_1 increased with increasing Vacc. This result was explained by considering the transmission rate of photoelectrons penetrating into the covered layer. The higher Vacc provides the larger transmission rate. Hence the amount of X-ray signal at 40 kV was not affected by Al layer. These characteristics enabled us to achieve high mark detection accuracy. Figure 6 shows variations of the alignment signal processor output as a function of displacement between the mask and wafer, which were obtained at 40 kV and 0.1 μA/cm² photoemission current using 3000 Å thick Ta marks. As inset in Figure 6, the noise fluctuation during 30 seconds around the zero point turned out to be limited to 0.043 μm. Consequently, an outstanding alignment mark detection accuracy was established.

5. Conclusions

A fully automatic EB image projection system which has a 5 inch wafer full exposure capability with a throughput of 20 wafers/hr has been designed and constructed. The use of high accelerating voltage provides substantial advantages for improving resolution capability, alignment accuracy and for reducing proximity effect. 0.5 μm patterns have been successfully replicated by 30 second exposures. Alignment mark detection accuracy better than 0.05 μm was obtained.

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