Extended Abstracts of the 19th Conference on Solid State Devices and Materials, Tokyo, 1987, pp. 287-290

0.25μm Pattern Formation by Variably Shaped EB Exposure System EX-7

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A patterning accuracy as well as throughput is an important factor for variably shaped electron beam exposure systems. A high accuracy variably shaped beam control technique has been developed on the EX-7 to make fine 0.25μm patterns. A resist heating effect has been found to be serious problem to form highly accurate resist pattern and to be overcome by lowering beam current density. As a result, 0.25μm pattern has been formed with a dimension accuracy of less than 0.03μm, with a beam stitching accuracy of less than 0.01μm and with a edge roughness of less than 0.01μm.

1. Introduction

Recently, a high speed and high accuracy 0.25μm patterning technique using an electron beam exposure system is demanded for VLSI device process development and X-ray mask making. For this purpose, the high speed EB exposure system EX-7[1], adopting a variably shaped beam, vector scanning, and continuosly moving stage schemes has been developed. Although the variably shaped beam system is expected to attain a high throughput, a high accuracy beam control technique has not been constructed to the practical use of the system, as yet. Moreover, it is reported that the resist heating effect becomes serious at high current density electron beam writing for achieving a high throughput. However, understanding of the resist heating effect[2)3)] has not been enough to make a 0.25μm pattern precisely.

This paper describes a new variably shaped beam control technique for the purpose of less than 0.25μm pattern formation. Furthermore, a relationship between a pattern accuracy and a resist heating effect is reported. A 0.25μm VLSI pattern has been formed with an accuracy of less than 0.01μm by overcoming a resist heating effect in addition to the precise beam size control method.

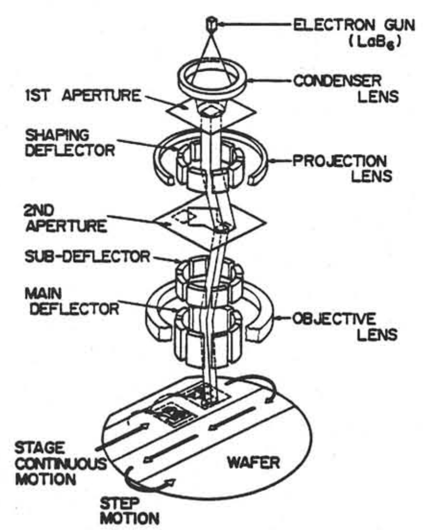

Fig.1 EX-7 writing method. Rectangular or triangular shaped beam exposes wafer on continuosly moving stage.

2. Beam calibration technique

A variably shaped beam is generated by overlapping a 1st shaping aperture image produced with the projection lens on the 2nd shaping aperture, as shown in Fig.1. The shaped beam size is dynamically changed by the shaping deflector located between the 1st and the 2nd shaping apertures. Then, the shaped beam is reduced by lens system and positioned by positioning deflection system on the target.

In order to form highly accurate resist

patterns, the variably shaped beam is calibrated precisely in the following three procedures.

(1) Shaping aperture direction adjustment

The directions of two shaping apertures have been mechanically adjusted so that the line profile corresponding to the side edge of the shaped beam, which is obtained by scanning a fine Au particle, is to be uniform, as shown in Fig.2. In this method, the directions of two shaping apertures can be adjusted to the deflection coordinate with high accuracy. In general, beam intensity profile is detected using a knife edge method[4]. In this method, the beam intensity profile is considered to be the line profile integrated along the detector edge direction and beam scanning direction. The line profile is obtained by differentiating the detected beam intensity profile, which includes some differentiation calculation errors. In contrast to this, a fine Au particle method[5] directly gives the line profile which has no calculation error. Therefore, the aperture direction can be adjusted with the error of less than 6.6mrad by this method.

(2) Deflection rotation and shift correction

The EX-7 has adopted an octapole electrostatic deflector in the beam shaping deflection system which makes it easy to correct deflection rotation, deflection magnification and deflection shift by shaped beam control circuit. The mechanical rotation error of shaping deflector electrodes and the deflection shift caused by the beam alignment error can be detected accurately by the relationship between the beam size data and the beam current measured by Faraday cup located on the work stage. As shown in Fig.3, the beam current I is given by

$$I=A*X^2+B*X+C ,$$

where X is beam size data, A is deflection rotation error, B is deflection magnification coefficient, and C is deflection shift error. The beam current shows nonlinearity due to the deflection rotation error of A. The octapole control circuit is corrected by analyzing a beam current data with a computer, so that the beam current nonlinearity error and the beam current shift error become less than values corresponding to beam size error of ±0.005μm. Because this method is not affected by error factors of lens and positioning deflection system located after the 2nd shaping aperture, these parameters are accurately calibrated with high speed.

(3) Deflection magnification correction

Finally, magnification parameter B is optimized by measuring beam size. This magnification parameter is adjusted so that the variation rate of designated beam size is equal to that of measured beam size. This is equivalent to measuring the sensitvity of shaping deflector. The fine Au particle (approximately 0.2μm in diameter) method allows the beam size to be measured with 0.013μm(3sigma) accuracy more than 0.4μm beam size. Resultant beam size nonlinearity error of ±0.008μm is achieved.

From the results of procedures (1),(2),(3), it is confirmed that the variably shaped beam is controlled with the accuracy of less than 0.01μm.

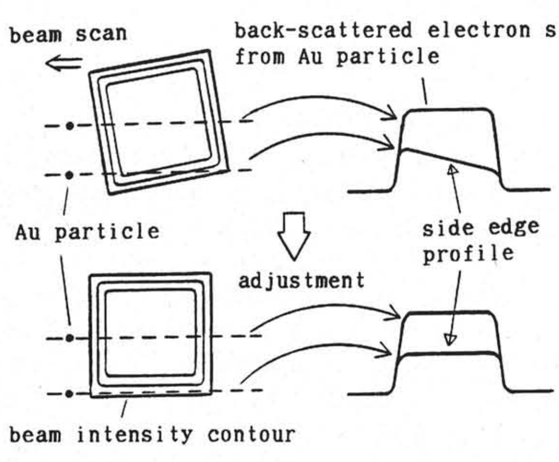

Fig.2 Shaping aperture direction adjustment using a fine Au particle method.

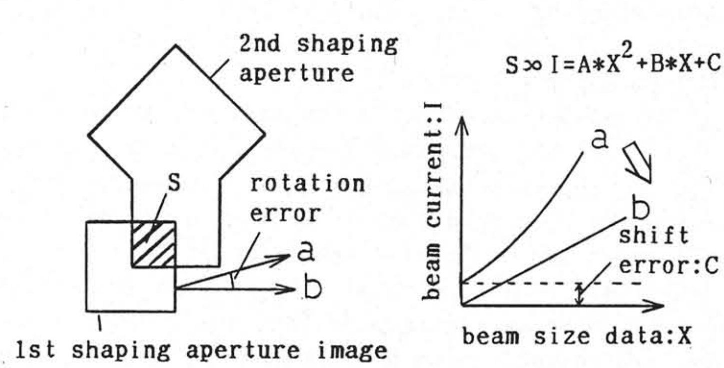

Fig.3 Beam current change arising from beam shaping deflection.

3.Resist heating problem

The high dosage is necessary to get the vertically walled profile of PMMA resist. Therefore, a beam current density (J) more than $100A/cm^2$ is required for realizing a high throughput. A resist heating effect is observed at a high dosage and high beam current density exposure. At delineation under this condition, the resist temperature rise more than 300 degree (this is the pyrolysis temperature of PMMA) was predicted by calculation on the base of the model that only the resist is heated by electron beam irradiation and the silicon substrate plays a role of heat sink. The temperature rise in resist depends on beam current, which is proportional to shaped beam size. Resist sensitivity has been found to be enhanced by resist temperature rise during exposure. Therefore, the development speed is faster , when the pattern has been written with larger beam size. As a result, the resist heating effect causes the degradation of patterning accuracy, as shown in Fig.4.

When a high dosage exposure is carried out with a shaped beam, the temperature of resist rises higher in the center of beam shot area than in the area of circumference. Therefore, a resist profile is developed in a circular fashion and a large edge roughness is generated in the beam stitching area, as shown in Fig.4. In order to avoid this effect, a low current density beam, a thin resist thickness, and a low dosage exposure or a high sensitivity resist are effective.

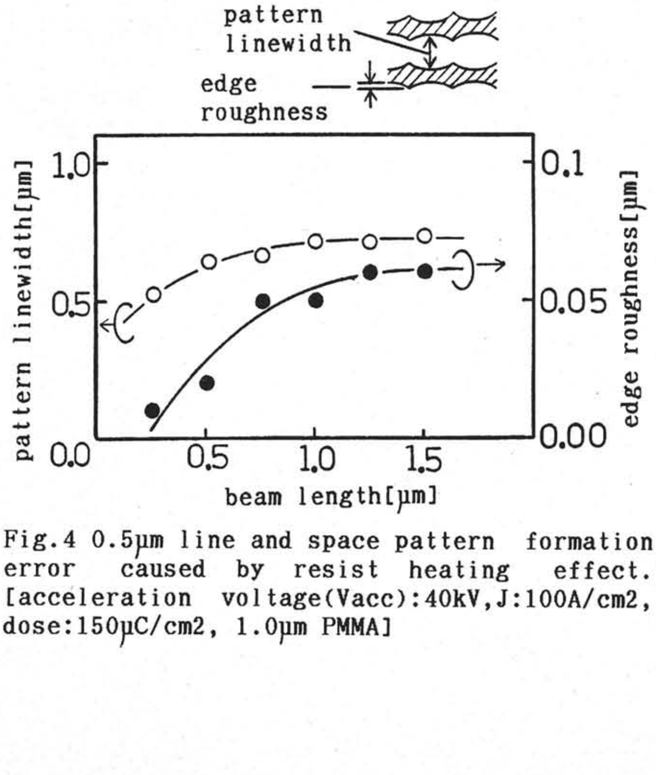

Fig.4 0.5μm line and space pattern formation error caused by resist heating effect. [acceleration voltage(Vacc):40kV,J:100A/cm2, dose:150μC/cm2, 1.0μm PMMA]

In order to form vertically walled PMMA resist pattern with a size of 0.25μm, it was necessary to expose at $150\mu C/cm^2$ dosage. For avoiding the resist heating effect, the test pattern was delineated on 0.5μm thickness PMMA resist with $50A/cm^2$ beam current density, by multiple exposure ($50\mu C/cm^2$ * 3) method. The vertically walled 0.25μm and 0.5μm resist profiles were obtained, as shown in Fig.5. The edge roughness, which is dependent on beam length, is not observed. The pattern linewidth accuracy of less than 0.03μm is achieved, as shown in Fig.6.

4.Beam stitching accuracy

The edge roughness of resist pattern is mainly generated by a beam size control error under the condition that the resist heating effect does not appear, because beam positioning error within ±0.005μm (1/2LSB of D/A converter) hardly affects the edge

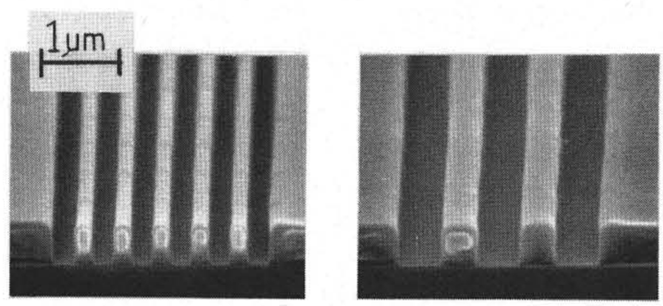

Fig.5 SEM micrographs of 0.25μm and 0.5μm line and space patterns. [Vacc:40kV, J:50A/cm2, dose:50μC/cm2 *3times, 0.5μm PMMA]

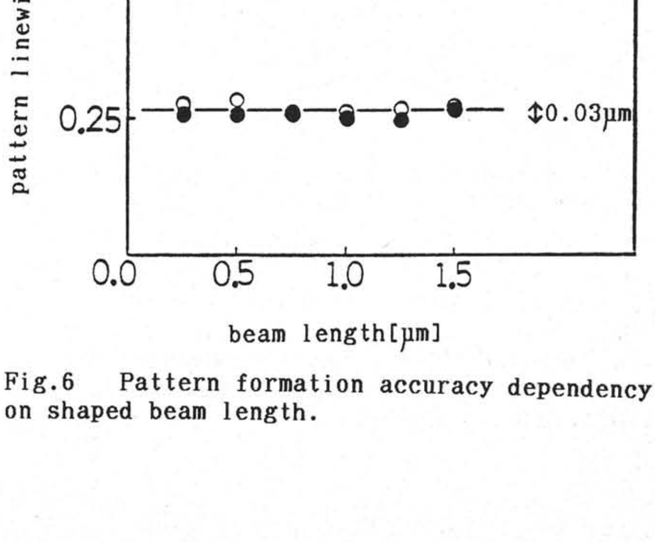

Fig.6 Pattern formation accuracy dependency on shaped beam length.

roughness. When a beam size control error is 0.02μm at 0.15μm beam resolution, the dosage irregularity amounts to 14%, which leads to some edge roughness.

A 0.25μm line and space pattern was exposed on the positive PMMA resist and on the negative SNR resist with changing offsets to the calibrated beam size. The writing conditions were $100\mu C/cm^2$ dosage and 0.5μm resist thickness for PMMA, $50\mu C/cm^2$ dosage and 0.2μm resist thickness for SNR. Beam current density was $50A/cm^2$ for both exposures.

It was not necessary to adopt a multiple exposure, because resist heating effect was not observed under these conditions. As a result, a edge roughness becomes large in proportion to beam size offset, as shown in Fig.7. From this result, beam stitching accuracy is estimated to be within 0.01μm. Therefore, 0.25μm lines can be formed with the edge roughness of less than ±0.01μm. A 0.25μm VLSI pattern formed on the SNR resist is shown in Fig.8.

5.Conclusion

The variably shaped beam control technique with high accuracy has been developed which is composed of a beam current analysis and a fine Au particle method. It is found that the resist heating effect affects the pattern accuracy seriously. By using this beam control technique under the condition that resist heating effect does not appear, a 0.25μm pattern has been formed with less than 0.01μm stitching error and with less than ±0.01μm edge roughness.

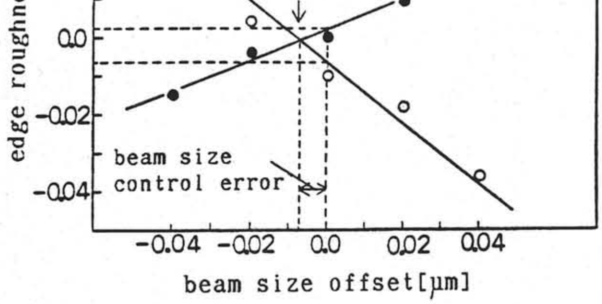

Fig.7 Evaluation of edge roughness caused by beam size offset from calibrated value. [Vacc:40kV, J:50A/cm2]

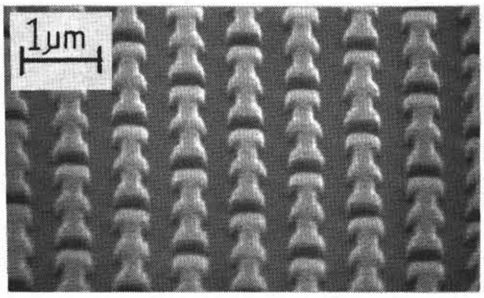

Fig.8 SEM micrograph of 0.25μm VLSI pattern. [Vacc:40kV, J:50A/cm2, dose:50μC/cm2, 0.2μm SNR on 1.5μm HPR]

Acknowledgement

The authors would like to thank Dr. Y.Horiike for his stimulating discussions and encouragement. They also thank Mr. T.Suzuki for his support in SNR resist process work, and Messrs. Y.Katoh and E.Nishimura for their helpful discussions.

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