Study of ADI (After Develop Inspection) On Photo Resist Wafers Using Electron Beam (Ⅲ)

Teruyuki Hayashi [a], Misako Saito[a], Kaoru Fujihara [a], Jack Jau [b]
[a] Tokyo Electron Ltd., 650 Mitsuzawa, Hosaka-cho, Nirasaki City, Yamanashi, Japan;
[b] Hermes Microvision Inc.,1762 Automation Parkway San Jose,CA 95131,USA

ABSTRACT

We proposed a model for highly sensitive detection of residue defects in electron beam defect inspection of photo resist patterns on a metal hard mask and verified the principle of that model. When there are photo resist residue defects on the bottom anti-reflective coating (BARC), the organic layer is thicker at the defect pattern than in areas where there is no residue. The model proposed here focuses on this increase in layer thickness. The landing energy of the primary electrons allows electron penetration to the under layer (TiN) in the patterns where there is no defect (thin layer), but does not allow such penetration in the defective patterns (thick layer). In that landing energy region, SEM image contrast differs according to the primary electron penetration or non-penetration in the non-defective patterns and in the defective patterns. This method detects defects according to the contrast change (penetration contrast method). The principle of this model (i.e., the penetration contrast method) is verified in this report. This method was also applied for quantitative detection of defects considered to be caused by exposure conditions. This method is shown to be clearly effective in ADI for metal hard masks.

Keywords: inspection, photo resist, electron beam, penetration contrast

1. INTRODUCTION

The thickness of the photo resist layer is becoming thinner with the shrinkage of semiconductor devices. Investigation has begun on using a metal hard mask, which has highly selectivity for the etching with insulation layer. In the hard mask etching process, photo resist residue on the BARC of the exposed area is transcribed in the etching process and may result in a defect. For that reason, after development inspection (ADI) to detect photo resist residue on metal hard masks is important for photo resist pattern wafers as well. Accurate detection of photo resist residue on the organic BARC at the bottom of trenches or holes with electron beam defect inspection equipment was difficult. Generally the BARC and the photo resist is an organic material, so the material properties of the BARC and photo resist residue are very similar and it is difficult to enhance gray level contrast of SEM image.In previous work, we confirmed that, in electron beam defect inspection of photo resist patterns formed on Poly-Si, the Poly-Si surface morphology appear as nuisance. We clarified the mechanism of the occurrence of those nuisance. as a contrast in the Poly-Si surface morphology that appears when primary electrons pass through the BARC. We showed that the defect of nuisance can be controlled by controlling the primary electron penetration depth.We propose inspection method for resist pattern defects on a metal hard mask that makes positive use of the contrast that arises from primary electrons penetrate the BARC. (penetration contrast method).The penetration depth of electron beam depends on the landing energy. And the secondary electron varies with the material. So, we were able to detect the photo resist residue by adjusting the landing energy of the electron beam to match the thickness of the BARC layer. Here, we propose a method for highly sensitive detection of photo resist pattern defects on a metal hard mask.

2. PROPOSAL FOR A NEW DEFECT DETECTION MODEL (PENETRATION CNTRAST METHOD)

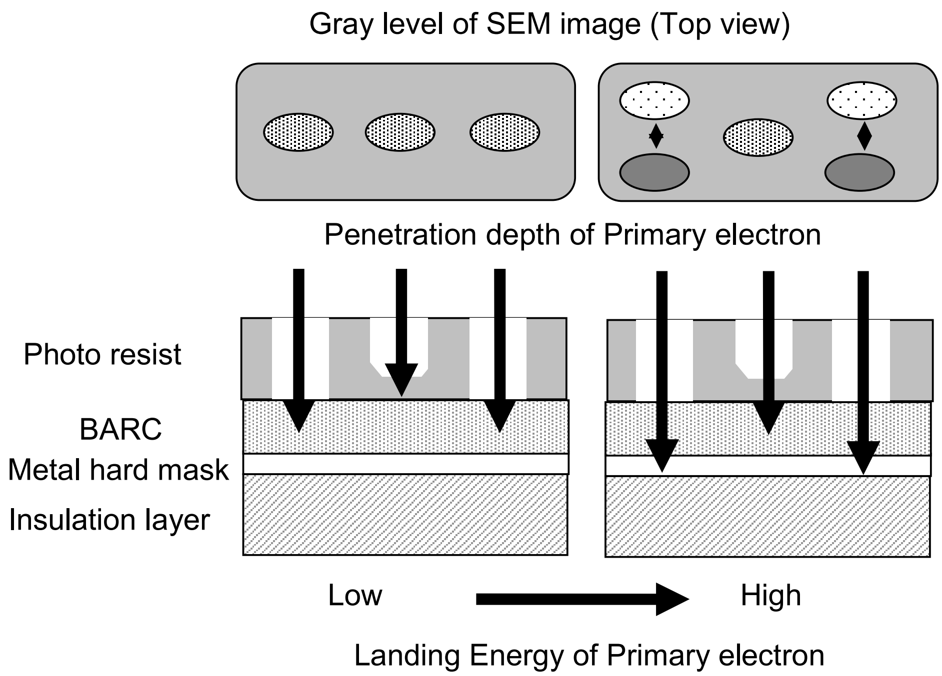
[Defect detection model]

One type of defect in a photo resist pattern is caused by photo resist residue on the BARC of an opening. When there is a photo resist residue defect on the BARC, the organic layer is thicker than in places where there is no

residue. This model focuses on this increase in layer thickness (Fig.1). There is a range of landing energies of the primary electrons in which the electrons do not penetrate the defective patterns (where the layer is thick) to the under layer (TiN), but they do penetrate the non-defective patterns (where the layer is thin). In that landing energy region, a contrast between the non-defective patterns and the defective patterns are created in the SEM image according to whether or not there is primary electron penetration. Our penetration contrast method uses that contrast to detect defects.

[Purposes of this report]

a. Verify the principle of the defect detection model of the penetration contrast method.
b. Show that the penetration contrast method is effective for ADI.



Fg.1. Proposal for a New Defect Detection Model (penetration contrast method)

3. VERIFICATION OF THE PENETRATION CONTRAST METHOD

This model uses the contrast that appears in the SEM image between the non-defective patterns and the defective patterns according to whether or not there is primary electron penetration. To verify the principle of this model, we confirmed whether or not there is a rapidly change in SEM image contrast due to the difference in BARC penetration by primary electrons. An actual defect is photo resist residue at the bottom of a 100 nm or smaller trench. That fact requires confirmation that this model can be applied to defects in a minute region as well. In this model, the penetration of the primary electrons creates a contrast. The penetration of the primary electrons varies with two parameters, the landing energy of the primary electrons and the layer thickness. In this report, we verify the applicability of this model to a minute defects by evaluating the variation in defect capture rate with respect to primary landing energy and layer thickness.

3.1. Verification of the principle of gray level variation according to the primary electrons penetrate the BARC

The proposed model predicts that if the primary electrons penetrate the BARC the gray level will change rapidly.

The gray level variation model is shown in Fig. 2. In the landing energy region where the primary electrons do not penetrate the BARC, there is a gradual change in the gray level according to the change in the rate of secondary electron emission from the surface. In the region where the primary electrons do penetrate the BARC, the gray level changes rapidly due to the effect of the TiN. To confirm the change in gray level, we obtained SEM images of the photo resist and BARC for various landing energies, and measured the gray levels. The evaluation sample is structured of a CVD oxidation layer and a TiN layer on a silicon wafer, above which the BARC and photo resist layers are applied and a development pattern is formed. The purpose of this experiment is to confirm the variation in gray level due to the penetration of the BARC by the primary electrons. For that purpose, it is necessary to use a sample that is little affected by the pattern edge and aspect ratio. In this experiment, a sample with photo resist openings of 10 square microns or more was used. The SEM image is shown in Table 1. As the landing energy increases, the BARC becomes darker than the photo resist. The dependence of the photo resist and BARC gray level on the landing energy is shown in Fig. 4. The gray levels of the photo resist and BARC are about the same in the region below 1000 eV. At 1200 eV, the BARC rapidly becomes darker than the photo resist. In the region above 1200 eV, the difference in gray levels increases even more. We compared the primary electron penetration depth (Fig. 5) and the gray level variation by Monte Carlo simulation. The energy at which the contrast between the photo resist and the BARC appears is about the same as the landing energy for which the electrons penetrate to the TiN. The above results verify the principle of gray level variation due to primary electron penetration (penetration contrast method).

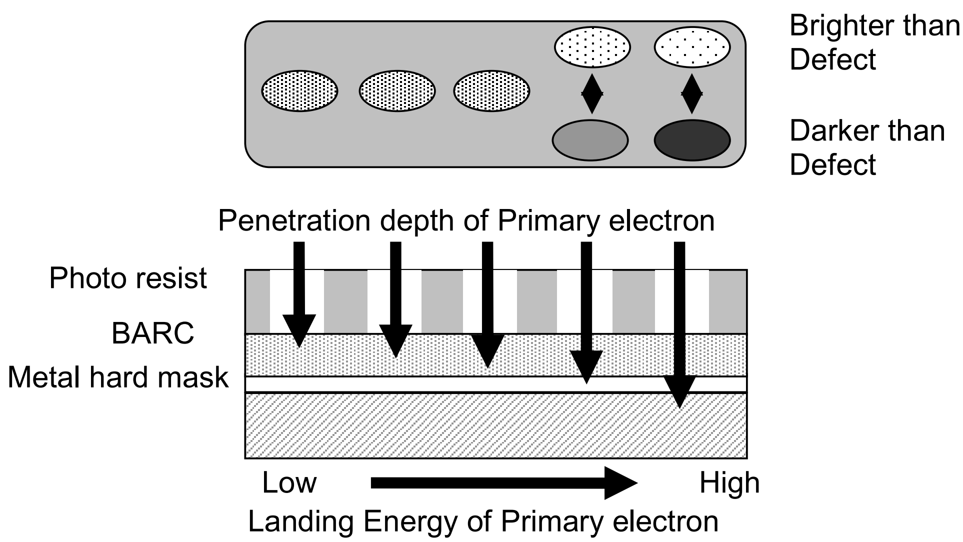


Fig.2. The model of gray level variation

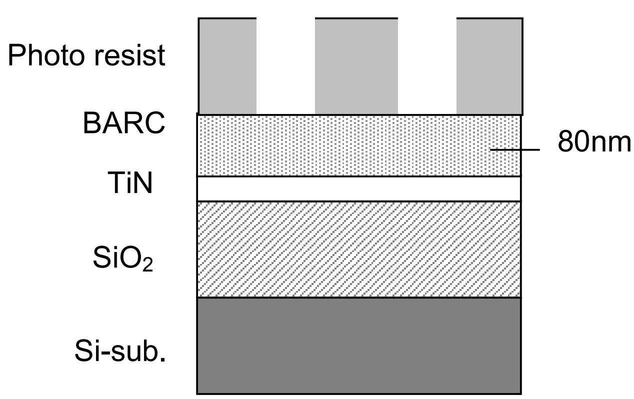
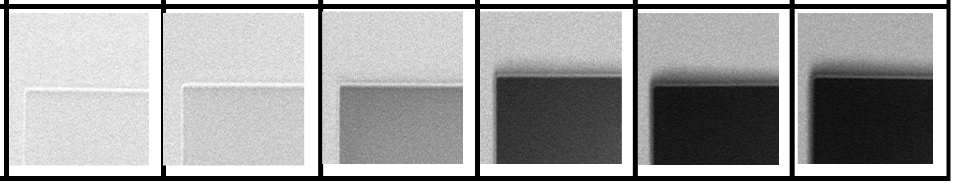
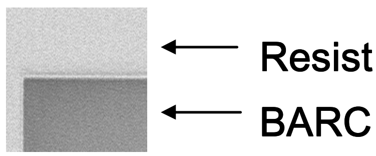


Fig.3. Sample structure

Table 1.   Landing energy dependency of primary electron of SEM image

LE[eV]	800	1000	1200	1400	1600	1800
SEM image						



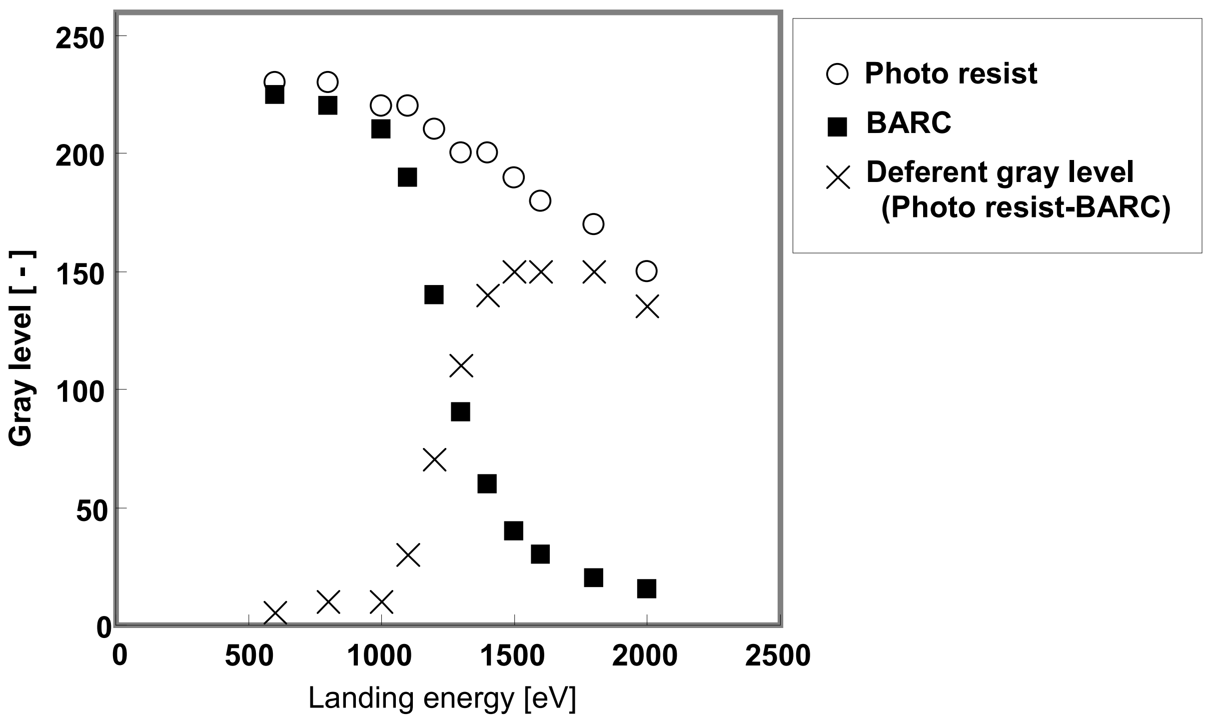


Fig.4. Landing energy dependency of primary electron of glay level

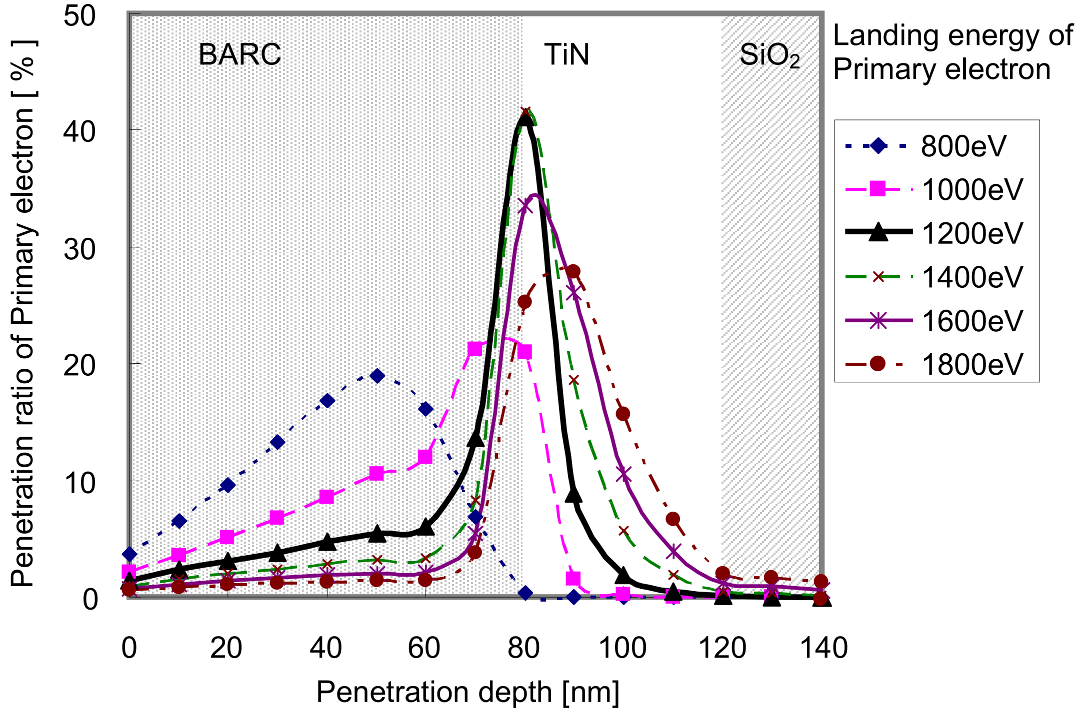


Fig.5. The relationship between landing energy and caluculated penetration depth of primary electron by Monte Carlo simulation.

3.2. Verification of the penetration contrast method with actual defects

3.2.1. Verification of the primary electron penetration due to change in the landing energy.

When the primary electrons penetrate the BARC, the gray level rapidly becomes lower than the patterns where the electrons do not penetrate. This is predicted by the defect detection model shown in Fig. 6. For landing energies at which the primary electrons either penetrates both the defective patterns and the non-defective patterns or do not penetrate either, the contrast does not appear. The contrast appears only in the landing energy region in which the electrons pass through the non-defective patterns but do not penetrate the defective patterns. In the landing energy region where the contrast appears, defect detection is possible. To compare the defect inspection performance to primary electron penetration due to change in the landing energy, we performed defect inspection on a photo resist pattern. We varied the landing energy of the electron beam defect inspection system over the range from 1,000 eV to 1800 eV. The evaluation sample was patterned with an array of trenches that were 90 nm width and 250 nm lengths (Fig. 7a). The under layer and photo resist structures are the same as shown in Fig. 3. The photo resist residue defects were roughly uniformly distributed within the scope of the inspection in this sample (Fig. 7b).The relation between the landing energy and the number of defects detected is shown in Fig. 8. Between 1,200 eV and 1,400 eV, the defect detection capability is high. The detection capability is low at 1000 eV and in the region above 1,600 eV. The above results show the same tendencies as the defect detection model assumed in Fig. 6. Furthermore, the landing energy region in which the penetration contrast appears that was obtained in section 3.1 and the energy range for which the detection performance is high are the same. We thus verified the penetration contrast method defect detection model in an actual defect inspection.

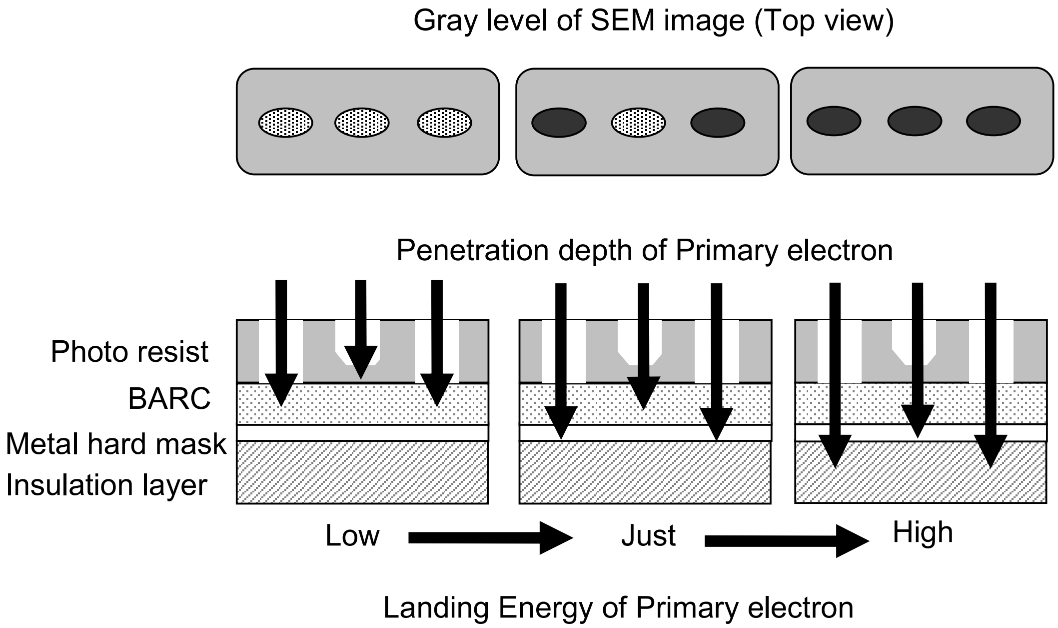


Fig.6 Defect detection model of the penetration contrast method

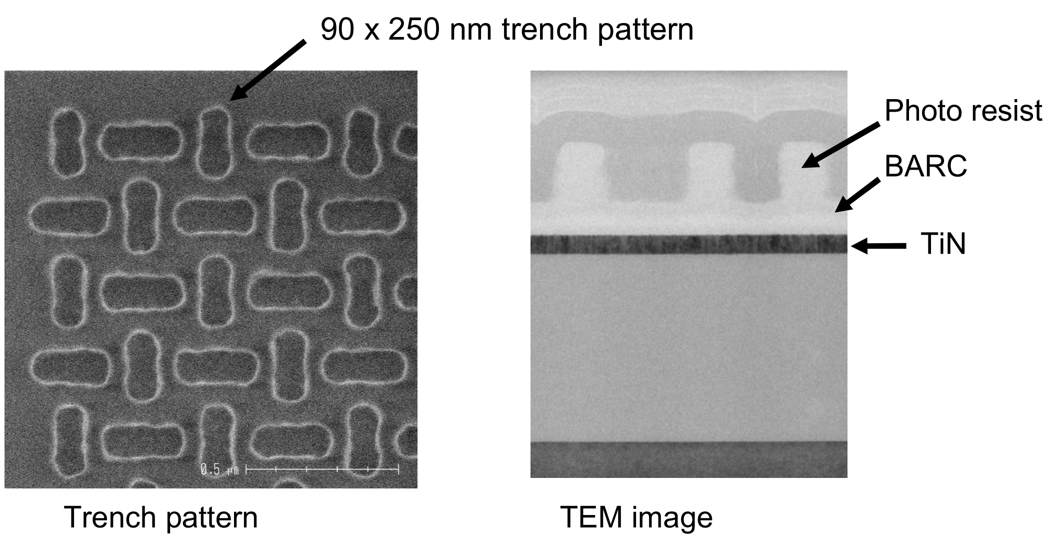


Fig.7 a) Sample of the inspection pattern   b) Cross section image of the sample

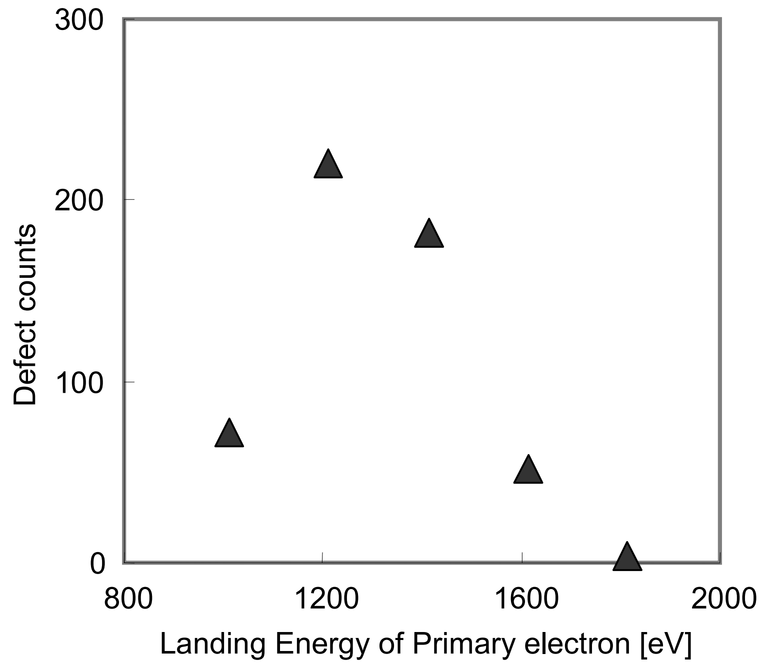


Fig.8. The relation between the landing energy and and the number of defect counts

3.2.2. Verification of the defect detection model due to the different layer thickness

Even when the layer thickness is changed, the principle of the penetration contrast method detection model does not change. As shown in Fig. 9, if the penetration layer becomes thicker, the landing energy required for the electrons to penetrate the non-defective patterns increases. Accordingly, the landing energy for detection is higher. To verify the principle of the penetration contrast method detection model, we performed the experiment of section 3.2.1 using a sample with a thick penetration layer (Fig. 10). This sample was fabricated with an adjustment for a thicker photo resist residue on the BARC. The results are the same as for the thicker penetration layer. The relation between the number of defects detected and the landing energy is shown in Fig. 11. To compare the different layer thicknesses, the results are plotted together with the results for the thin layer experiments of section 3.2.1. We can see that the landing energy range in which the defects were detected is higher than for the thin penetration layer. This is considered to result from the thicker primary electron penetration layer increasing the landing energy range for which the penetration contrast occurs, as shown in the model in Fig. 9. Here, a Monte Carlo simulation is used to calculate the primary electron penetration depth for various thicknesses of the penetration layer with respect to the landing energy (Fig. 12). Comparison was done for 80 nm and 120 nm penetration layers and landing energies of 1,200 eV and 1,600 eV. The calculation results show that the primary electrons penetrated the 80 nm layer to reach the TiN mostly at 1,200 eV. For the 120 nm layer, the electrons reached the TiN mostly at 1,600 eV. We confirmed the principle that when the penetration layer of the defective patterns and the normal patterns changes, the landing energy required for the primary electrons to penetrate changes, and the landing energy for which the defect detection capability is high also changes. The above experimental results verify the defect detection model that uses penetration contrast. Furthermore, we can see that the defect detection rate can be improved by controlling the primary electron penetration depth in correspondence with the penetration layer thicknesses of the defective patterns and the normal patterns.

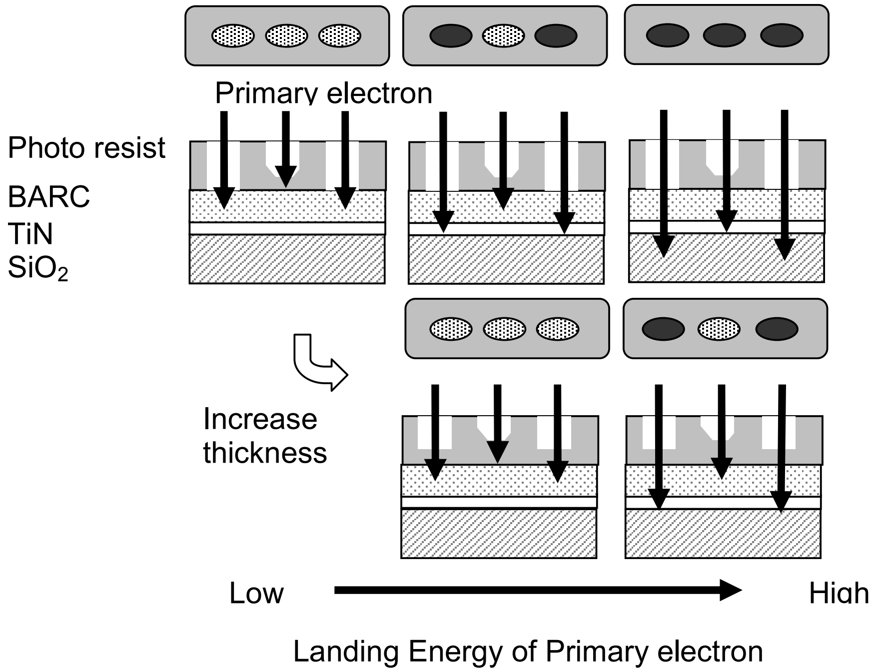


Fig.9. The principle of the penetration contrast method detection model.If the penetration layer becomes thicker, the landing energy required for the electrons to penetrate the non-defective pattern increases. Accordingly, the landing energy for detection is higher.

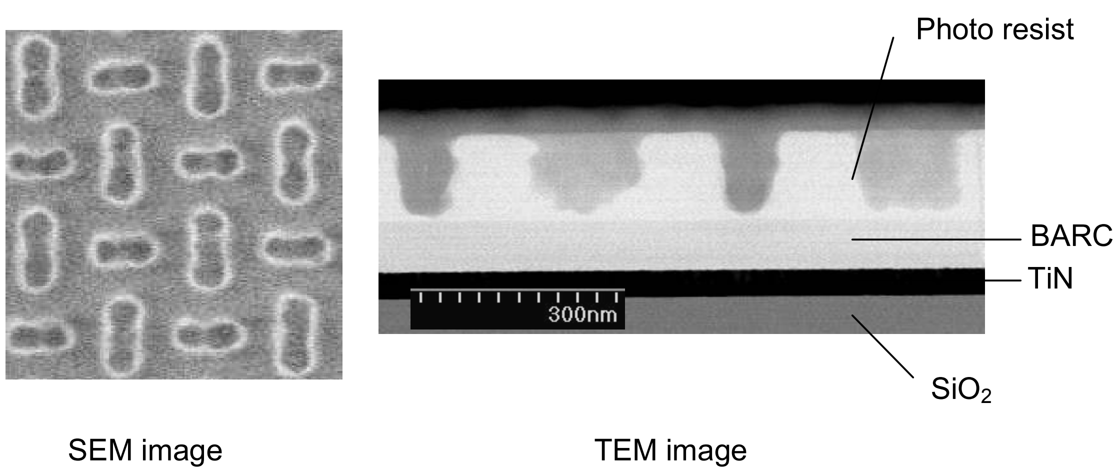


Fig..10. Sample of a thick penetration layer

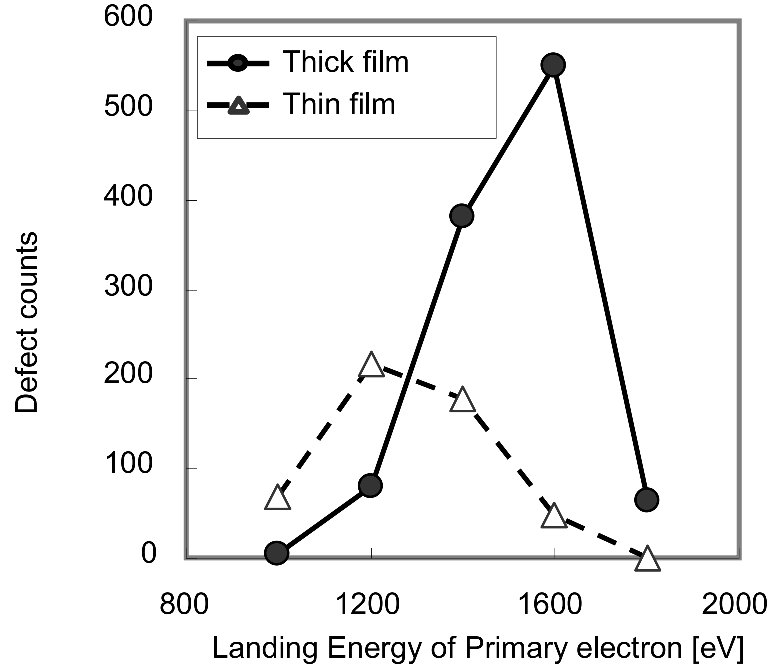


Fig.11. The relation between the number of defects detected and the landing energy of compare the different layer thicknesses.

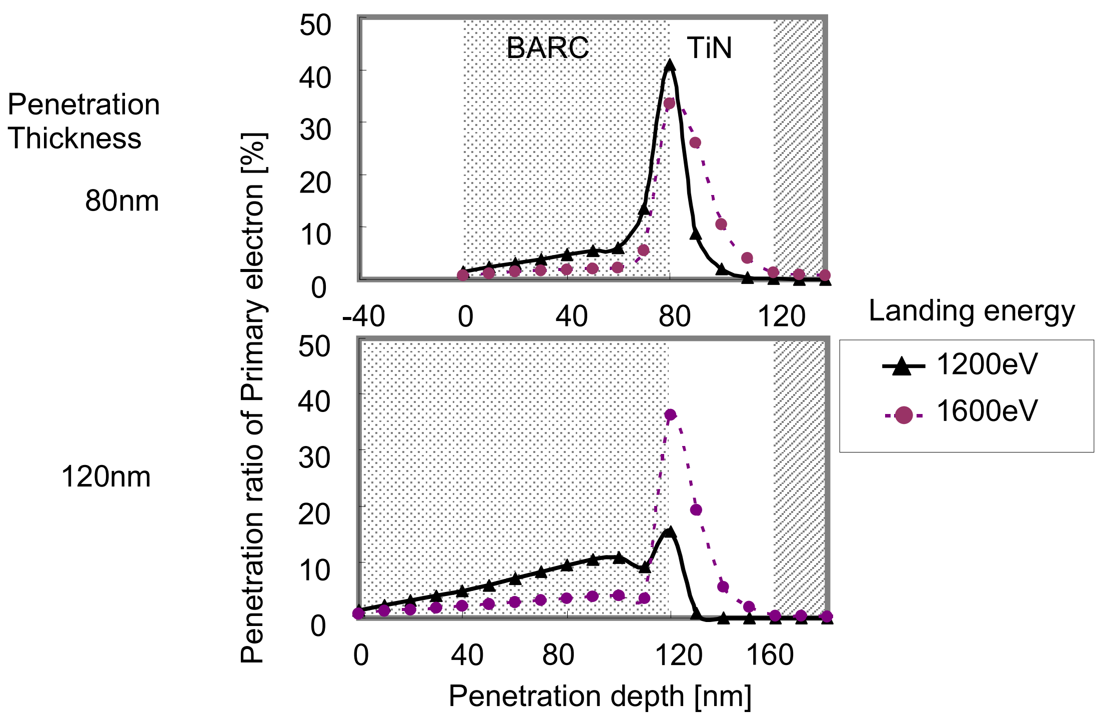


Fig.12. The primary electron penetration depth for various thicknesses of the penetration layer with respect to the landing energy calculated by Monte Carlo simulation.

4. VERIFICATION OF INSPECTION PERFORMANCE WITH AN ACTUAL PROCESS SAMPLE

The principle of defect detection by the penetration contrast method must be verified as effective for photo resist residue defect inspection in an actual process. We applied our method to an inspection for analyzing the behavior of defects that arise with fluctuation in the exposure conditions. The sample used in the experiment has the structure and pattern shown in Fig. 3 and Fig. 10. The sample was fabricated with a fluctuation in the dose at the time of exposure(Fig.13). The review image from the defect review SEM of the residue defects detected by this electron beam defect inspection system is shown in Fig. 14. We can see that this inspection method can detect photo resist residue defects. The relation of exposure dose and the number of defects is shown in Fig. 15. We can see that the number of defects increases as the dose decreases. This result show that the trenches are formed with smaller dimensions as the dose decreases, so the frequency of residue defect occurrence becomes higher. The above results make it clear that this method can be used in highly sensitive detection of defects caused by fluctuation in the exposure conditions. We also verified the effectiveness of this method in photo resist residue defect inspection.

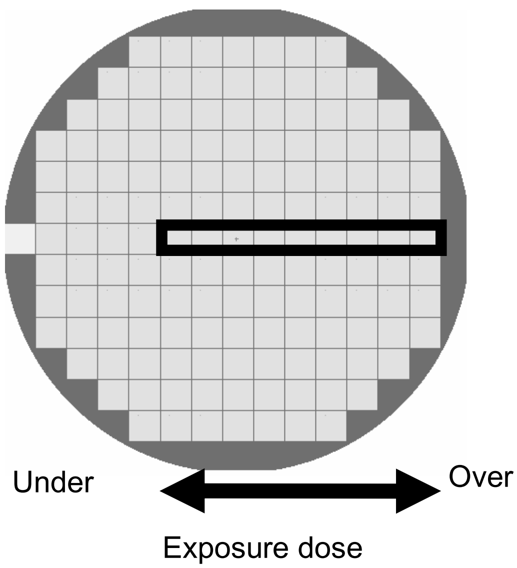


Fig. 13

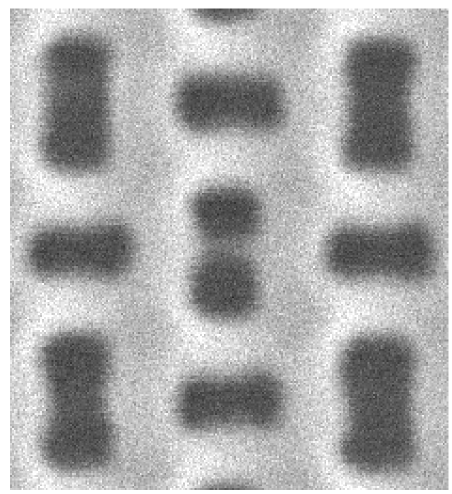


Fig.14

Fig.13 The sample of dose fluctuation at the time of exposure
Fig.14 The review image from the defect review SEM of the residue defects detected by the electron beam defect inspection system

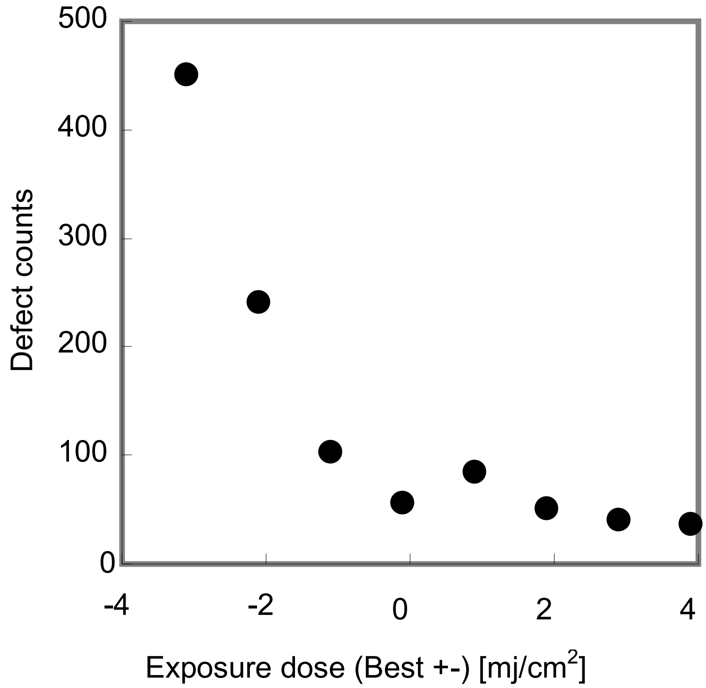


Fig.15. The relation of exposure dose and the number of defect counts

5.CONCLUSION

We proposed a model for highly sensitive detection of residue defects in electron beam defect inspection of photo resist patterns on a metal hard mask and verified the principle of that model. When primary electrons penetrate the BARC, to reach the under layer, a contrast in the SEM image is created. We proposed the penetration contrast method that uses that contrast to detect defects. That primary electron penetration to the BARC gives rise to a contrast has been verified by experiments performed with a contrast evaluation pattern. We verified the principle of the defect detection model of the penetration contrast method with an inspection of an actual trench pattern.
We also verified this principle for the case of variation in BARC layer thickness. We used this method to analyze the behavior of defects generated by fluctuation in actual exposure conditions. We have proved that the penetration contrast method is effective in defect inspection of photo resist patterns on a metal hard mask.

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