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Effect of the Silicidation Reaction Condition on the Gate Oxide Integrity in the Ti-Polycide Gate

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The effect of the silicidation reaction on the gate oxide integrity in the Ti-polycide gate was studied. The gate oxide breakdown failure increased with increasing silicidation temperature, which is related to increased amount of Ti diffusion from Ti-silicide to the gate oxide. However, reliability of the gate oxide for 750°C silicidation is better than for 650°C silicidation. This is because of the formation of the metastable C49 structure. Therefore, to obtain better reliablility of the Ti-polycide gate low temperature silicidation and the stable C54 phase are essential.

I. INTRODUCTION

As ULSI devices are scaled down, the fabrication technology with low resistivity silicided polysilicon (polycide) gates becomes necessary for faster devices. The titanium silicide ($TiSi_2$) is a promising candidate for this purpose. However, a Ti-polycide gate has a problem of the gate oxide breakdown at a low field. This is caused by the diffusion of Ti atoms through the polysilicon film into the gate oxide [1-4]. The gate oxide integrity may be affected by diffusion during the silicidation process.

In this paper, the effect of the silicidation reaction condition between sputtered Ti and underlying poly-Si on the gate oxide integrity in the Ti-polycide gate was investigated.

II. EXPERIMENTAL

Active region of 16Mb DRAM was defined with the 500nm-thick field oxide by LOCOS isolation . The area of active region was about 12 mm^2. The gate oxide was grown in dry O_2 to a thickness of 8 nm. Then the poly-Si was deposited, and phosphorus diffusion into the poly-Si film was carried out. Two different poly-Si thicknesses were employed: 150 and 200 nm. A 30nm thick Ti film was deposited by the DC magnetron sputtering. Formation of the silicide layer was carried out by either 1-step process or 2-step process in a temperature range between 650°C and 850°C. After wet etching in a solution of H_2SO_4 and H_2O_2 to remove unreacted Ti, a thin silicate glass film was deposited to prevent oxidation of the $TiSi_2$ during post-annealing. Post-annealing was performed in a furnace at 850°C for various times up to 150 minutes.

III. RESULTS AND DISCUSSION

Changes of the gate oxide breakdown failure with annealing time at 850°C for the 1-step silicidation condition are shown in Fig. 1. With increasing anneal time, failure in the gate oxide drastically increased. The breakdown failure at a given time decreased as the silicidation temperature was lowered from 850°C to 800°C and to 750°C. However, degradation in the gate

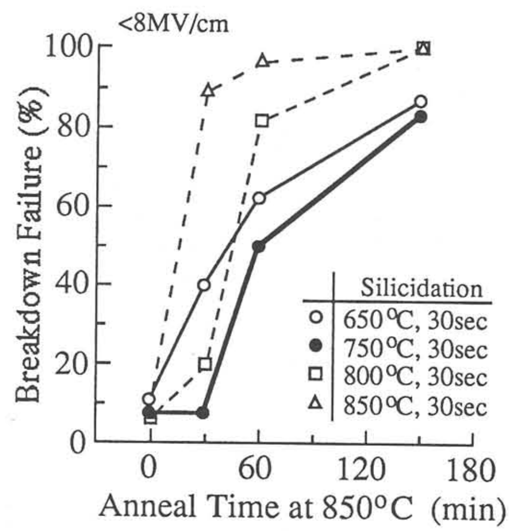

Fig. 1 Changes of the gate oxide breakdown failure with annealing time at 850°C for the 1-step silicidation condition.

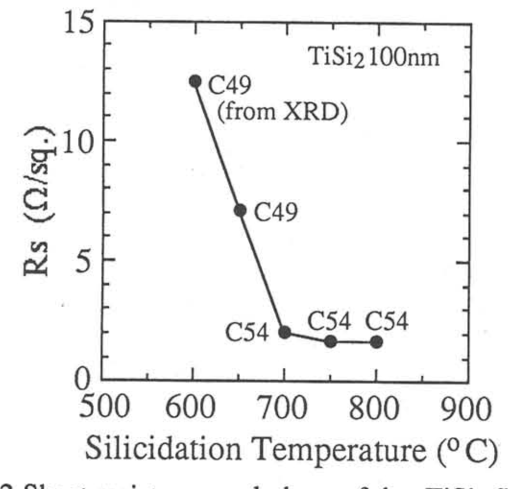

Fig. 2 Sheet resistance and phase of the $TiSi_2$ film with respect to the silicidation temperature. C49 and C54 represent the phase of $TiSi_2$ determined by XRD.

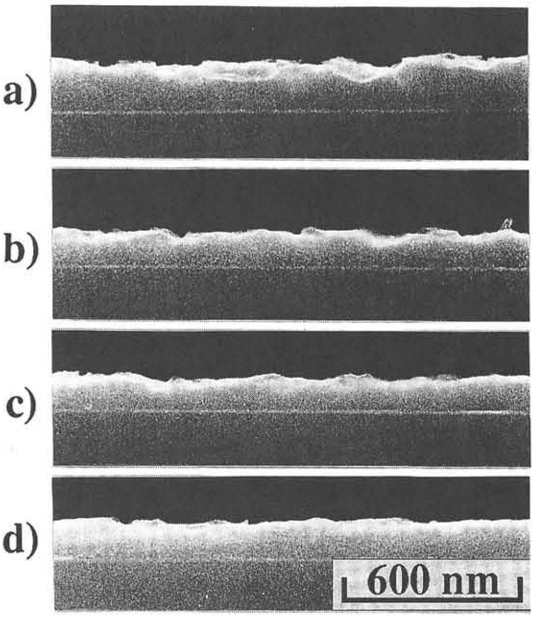

Fig. 3 Cross-sectional SEM photographs showing the morphology of the interface between $TiSi_2$ and poly-Si formed with the 1-step silicidation process after furnace anneal for 150 minutes at 850°C for various silicidation temperature; a) 650°C, b) 750°C, c) 800°C, and d) 850°C. The $TiSi_2$ film on poly-Si was removed by wet etching.

oxide reliability became more severe again in a sample silicidated at 650°C.

Figure 2 shows sheet resistance and phase of the $TiSi_2$ film with respect to the silicidation temperature. The silicide film formed at higher temperature than 700°C has the C54 phase with low resistivity while the C49 phase was observed at lower silicidation temperature.

Cross-sectional SEM photographs in Fig. 3 show the morphology of the interface between $TiSi_2$ and poly-Si formed with the 1-step silicidation process after furnace anneal for 150 minutes at 850°C for various silicidation temperature. For the silicidation process at lower temperature than 800°C, the interface is rough. This is probably because diffusion of Ti or Si occurs more easily in the $TiSi_2$ film of the metastable C49 structure and thus results in more severe morphological change.

Figure 4 shows the distribution of gate oxide breakdown failure with anneal time at 850°C for the 1-step silicidation at 650°C and the 2-step silicidation at 650°C and 850°C. Thicknesses of the titanium silicide film and the poly-Si film are 40 nm and 110 nm, respectively. For the Ti-polycide gate with silicide of the metastable C49 structure, breakdown failure may be reduced by additional silicidation at a high temperature. For the 2-step silicidation at 650°C and 850°C, interface between Ti-silicide and poly-Si formed after furnace anneal for 150 minutes at 850°C was smoother than for 1-step silicidation at 650°C, as shown in Fig. 5. These results suggest that the gate oxide degradation for the metastable C49 structure and higher silicidation temperature is more severe compared to the stable C54 structure and lower silicidation temperature.

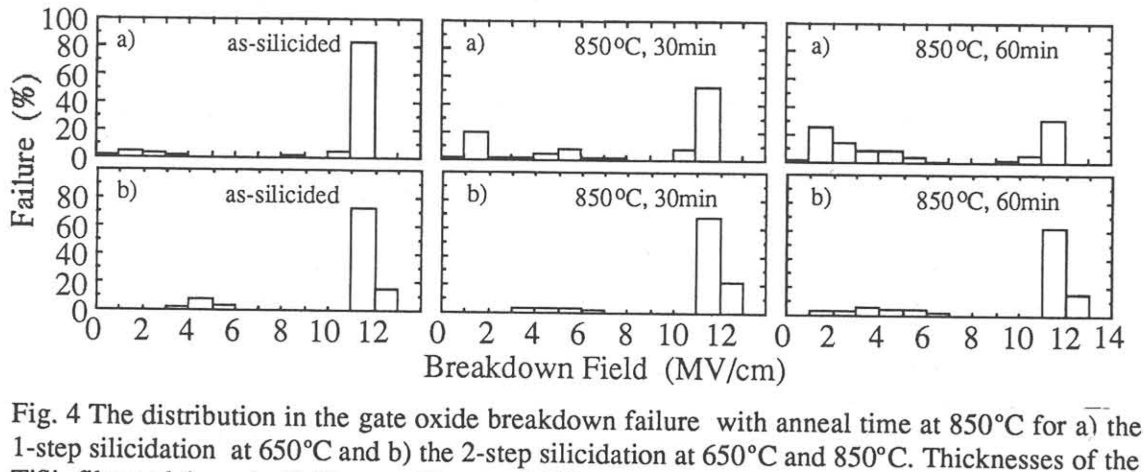

Fig. 4 The distribution in the gate oxide breakdown failure with anneal time at 850°C for a) the 1-step silicidation at 650°C and b) the 2-step silicidation at 650°C and 850°C. Thicknesses of the $TiSi_2$ film and the poly-Si film are 40 nm and 110 nm, respectively.

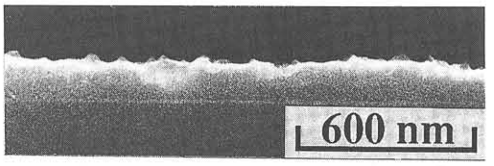

Fig. 5 Cross-sectional SEM photographs showing the morphology of the interface between $TiSi_2$ and poly-Si formed with the 2-step silicidation process at 650°C and 850°C after furnace anneal for 150 minutes at 850°C.

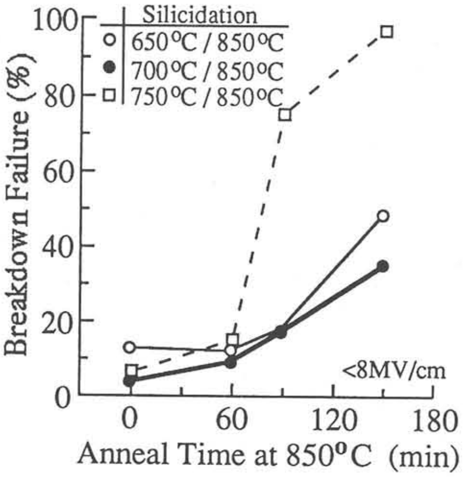

Fig. 6 Changes of the gate oxide breakdown failure with anneal time at 850°C for the 2-step silicidation.

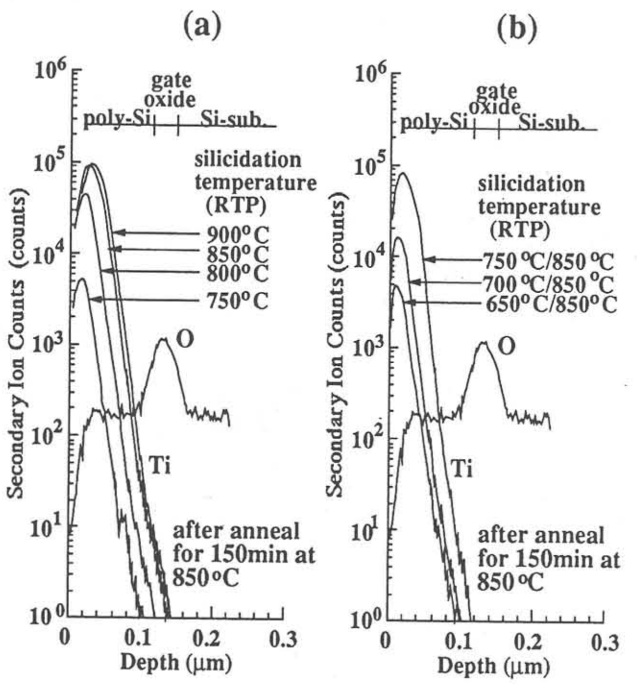

Fig. 7 SIMS depth profiles of Ti-atoms in the poly-Si/gate oxide/Si-substrate structure after removing the $TiSi_2$ film for Ti-polycide samples annealed for 150 minutes at 850°C ; a) the 1-step silicidation and b) the 2-step silicidation.

The changes of the gate oxide breakdown failure with anneal time at 850°C for the 2-step silicidation are shown in Fig. 6. Thicknesses of the $TiSi_2$ film and the poly-Si film are 40 nm and 110 nm, respectively. Results similar with the case of the 1-step silicidation is observed. For the 2-step silicidation, reliability of the gate oxide is improved by lowering the first silicidation temperature.

Figure 7 shows SIMS depth profiles of Ti atoms in the poly-Si/gate oxide/Si-substrate structure obtained after removing the Ti-silicide film for Ti-polycide samples annealed for 150 minutes at 850°C. The Ti atoms diffused more deeply with a higher peak concentration for higher silicidation temperature in both cases of 1-step and 2-step silicidations. This result indicates that the amount of diffusion of Ti atoms in poly-Si on the gate oxide may be affected by silicidation conditions. Increase of the breakdown failure at higher silicidation temperature is due to the increased amount of Ti diffusion from Ti-silicide to the gate oxide. Therefore, in order to obtain better reliablility of the Ti-polycide gate, the silicidation process at a low temperature is necessary as well as formation of stable C54 phase.

IV. CONCLUSIONS

With increasing anneal time at 850°C, failure in the gate oxide of the Ti-polycide gate increased. The breakdown failure increased with increasing silicidation temperature for both cases of 1-step and 2-step silicidation processes. Reliability of the gate oxide for 750°C silicidation is higher than for 650°C silicidation. This is due to the decrease of the interface roughness in the silicide-polysilicon interface which mainly results from the formation of the metastable C49 structure. The increased breakdown failure at high silicidation temperature is due to the increased amount of Ti diffusion from Ti-silicide to the gate oxide. The gate oxide degradation for the metastable C49 structure and higher silicidation process temperature is more severe than for the stable C54 structure and lower sillicidation process, respectively. Therefore, in order to obtain better reliablility of the Ti-polycide gate, the silicidation process at a low temperature is necessary as well as formation of the stable C54 phase.

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