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# A New Cracking Phenomena of Thin $Si_3N_4$ Film due to Stress from Poly-Si Grain Growth

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An influence of the poly-Si grain regrowth on oxidation resistance of thin nitride films, used as dielectric of Mega-bit DRAMs' capacitor, is discussed. Mechanical stresses generated from grain regrowth are laid on the nitride and crack the nitride. Because local oxidation of the poly-Si occurr under the cracking points, oxidation resistance on the poly-Si is inferior to that on the single silicon. It is found that stabilizing anneal of grains is a successful method to avoid decrease of oxidation resistance. Using the anneal, the oxidation resistance of the thin nitride on the poly-Si becomes similar to that on the single silicon.

## I.INTRODUCTION

Reducing the thickness of dielectric films for capacitors is one of the methods to obtain enough capacitances for 64M^bDRAM. The dielectric films usually consist of $SiO_2/Si_3N_4/SiO_2$ or $SiO_2/Si_3N_4$ (ONO or ON) composite to maintain low leakage current and high reliability[1]. As decreasing thickness of nitride films, the films lose the oxidation resistance during re-oxidation, which makes it difficult to form the uniform ONO or ON films.

The oxidation resistance of the thin nitride on the poly-Si is found to be inferior to that on single silicon. We find that thin nitride film is ruptured by a grain growth of underlying poly-Si films. Stabilizing anneal of poly-Si is very effective to improve the oxidation resistance of thin nitride films and hence to reduce thinner limit of nitride film thickness.

## II. EXPERIMENTS

First poly-Si films were deposited by LPCVD onto the thermally oxidized silicon wafers at 620°C with thickness of 100nm. Then arsenic ions were implanted into the poly-Si films with dose of $5X10^{15}cm^{-2}$. First anneal was carried out at 850°C in $N_2$ ambience for 30 min. Then poly-Si films were patterned for capacitor (100μmx200μm). Second anneal was performed with the same condition of the first anneal. After conventional RCA cleaning, the nitride films was deposited by LPCVD at 650°C with a $NH_3$:$SiH_2Cl_2$ gas ratio of 1:1. The film thickness varied between 3.0nm and 5.6nm. For formation of the top oxide, re-oxidation of the nitride films was carried out by wet $O_2$ ambience at 850°C for 30min. Various thermal treatments were performed for the underlying poly-Si before nitride deposition. Annealing conditions used in this work are listed in Table 1.

Table 1. Summary of annealing condition used in this work.

| Annealing condition | First Anneal as-implantation 850°C 30min in $N_2$ | Second Anneal as-patterning 850°C 30min in $N_2$ |
|---|---|---|
| A | ✕ | ✕ |
| B | O | ✕ |
| C | O | O |

## III. RESULTS AND DISCUSSION

In order to evaluate the oxidation resistance during re-oxidation, an increase of the nitride thicknesses between as-deposited and re-oxidized samples was measured by ellipsometry for on the single silicon and the poly-Si. The increase of the film thickness on the poly-Si sample is thirty times as large as that on the single silicon. Because the nitride layer on the poly-Si loses the oxidation resistance, thick oxide layer is formed at the poly-Si surface during re-oxidation.

The Annealing of underlying poly-Si is found to influence the oxidation resistance of the nitride films. Fig.1 shows measured capacitances as a function of nitride film thickness for the samples of various annealing conditions of A(without anneal), B(with first anneal), and C(with both first and second anneals). The samples with condition A exhibit constant capacitances for all nitride thickness. The capacitance for the sample with condition B increases as the nitride thickness increases. In the condition C, the capacitance increases with increasing the nitride thickness up to the thickness of 4.6nm. In the samples with 30nm-thick nitride, capacitances are found to be low values and independence of the annealing condition. In a thickness range from 3.8nm to 4.6nm, capacitance depends upon annealing conditions. Capacitances are found to increased with increasing annealing time.

In isothermal anneal at 850°C, the average grain sizes, observed by planer TEM, rapidly increased with increasing time up to 60min and slightly changed from 60min to 90min. Then regrowth rate of the poly-Si grains is saturated by the isothermal anneal at 850°C for more than 60min. Because the poly-Si samples with the condition A and B were annealed for less than 30min before the nitride deposition, the poly-Si grains regrew during re-oxidation.

The grain growth is considered to produce the stress in the thin nitride film[2], which results in a crack of the film. TEM studies sighted these cracking points and thick oxide region on the poly-Si surface. Fig.2 shows cross-sectional TEM for the sample surface of 4.3nm-thick nitride with the annealing condition B. Although multilayered structures of O/N/O are clearly observed at the parts of I and II in Fig.2, the multilayered structures are not observed at a part of III. Through the cracking points oxidizing species reach to the poly-Si surface and local oxidation initiates. The local oxidation parts were frequently observed in the sample surface. Therefore the effective oxidation resistance is degraded for the samples with conditions A and B. On the other hand the poly-Si grain size with the condition C is stable after nitride films deposition, since the annealing performed before nitride deposition is long enough to suppress the subsequent grain growth. Long time anneal before the nitride deposition is effective to improve the oxidation resistance.

Fig.3 (a), (b) and (c) show XTEM photographs at the first poly-Si edge for the samples deposited 4.3nm-thick nitride films with the condition A, B and C, respectively. In the sample with condition A(Fig.3(a)), the first poly-Si surface and side wall are covered with the oxide layers with the thickness of 60nm. The ruptured nitride layers are also observed on the top of the

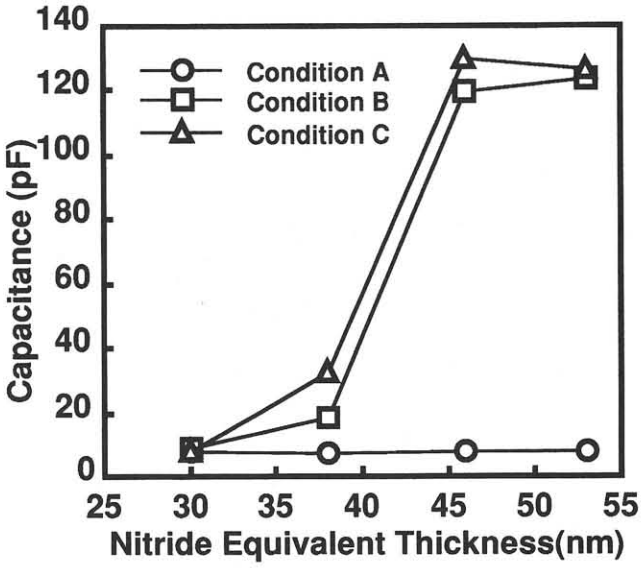


Fig.1 Nitride thickness dependence of capacitance as a function of annealing conditions.

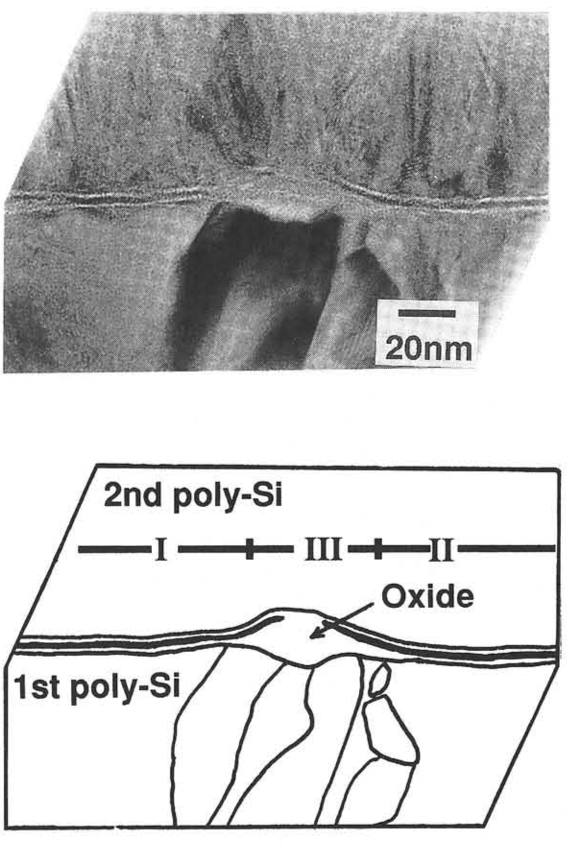


Fig.2 Cross-sectional TEM view at a cracking point in a sample surface with annealing condition B.

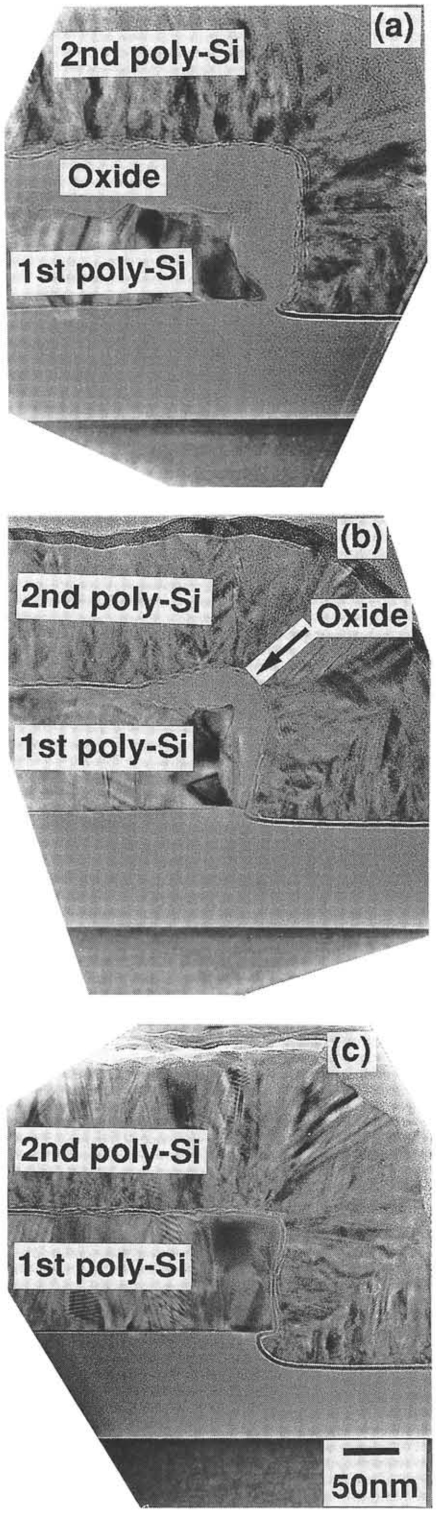


Fig.3 Cross-sectional TEM view at first poly-Si edge of annealing condition A:(a), B:(b) and C:(c).

oxide. In the sample with the condition B(Fig.3(b)), a oxide layer exists at the upper corner of first poly-Si. Since peripheral component of storage electrode plays an important role in capacitances of real DRAMs cell, the edge oxide layer is a serious problem. The oxide layer seems to be isotropically grown from the upper corner. Therefore, the cracking point, is considered to be present at the upper corner of first poly-Si. The nitride layer covered with the thin uniform top oxide is observed in the sample with the condition C(Fig.3(c)). Formation of the edge oxide layer strongly depends on the second anneal.

At the poly-Si edge, small grains are formed by patterning with dry etching and regrew during re-oxidation. Because the second anneal provides grain growth of the edge small grains and stabilizes them, the oxide layer do not appear in the sample with the annealing condition C as shown in fig.3(c).

## IV. CONCLUSION

The new cracking phenomena has been found in the thin nitride films on the poly-Si. Mechanical stress from underlying poly-Si grain regrowth is laid on the thin nitride and cracks the nitride. Oxidizing species diffuse through the cracking points to poly-Si surface. Therefore effective oxidation resistance of thin nitride on the poly-Si films are degraded from that on the single silicon. Accordingly, the capacitance did not increase with decreasing the nitride thickness in the ultra thin nitride. In order to avoid the phenomena, it is effective to stabilize poly-Si grain sizes using the anneal followed by the nitride deposition. In addition, the oxide layers at the corner of poly-Si can be prevented by the anneal after patterning. The oxidation resistance of thin nitride on the poly-Si is improved to that on the single silicon by these two annealing processes.

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