

Formation of Inter-Poly Si Dielectrics by Rapid Thermal Processing

Natsuo AJIKA, Masahiro SHIMIZU, Katsuhiko TSUKAMOTO, Makoto HIRAYAMA and Takayuki MATSUKAWA

Mitsubishi Electric Corp. LSI R and D Lab.

4-1 Mizuhara, Itami, Hyogo 664 Japan

Thin inter poly silicon dielectrics were formed by rapid thermal processing on arsenic implanted poly silicon. From the analysis of the depth profile of Auger electron spectroscopy and cross sectional TEM images, the obtained thin dielectric film was formed as three layered structure which both the top surface of the dielectric and bottom interface to substrate poly silicon were nitrogen rich nitroxide. Dielectric breakdown field was measured for various shaped capacitors and compared with that of simple single layered oxide film. The obtained three layered nitroxide film indicated better quality of dielectric breakdown characteristics and less dependence on the substrate poly silicon shape. From the measurements of TDDB characteristics, the MTF of the nitroxide film was estimated about ten years under stress condition of 3MV/cm.

1. Introduction

With the increase in the integration density of VLSIs, polycrystalline silicon (poly Si) substrate capacitor (stacked capacitor) is beginning to be used. But it is rather difficult to obtain high quality dielectrics on heavily impurity doped poly Si which has rough surface morphology. For this reason many experiments about the dielectrics on poly Si were carried out previously(1)-(4). This paper describes high quality three layered thin nitroxide film on poly Si formed by the rapid thermal processing.

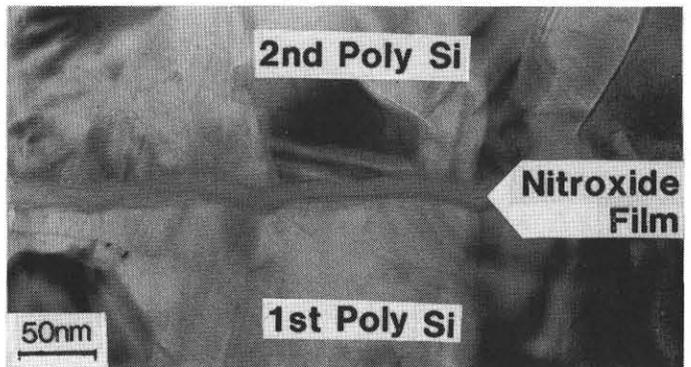
2. Experimental

30nm thick thermal oxide was formed on Si substrate, then non doped 250nm thick poly Si was deposited by LPCVD as 1st poly Si (lower electrode). Arsenic implantation was performed to an ion dose of $5E14-6E15/cm^2$ at 50keV. After patterning of this 1st poly silicon, two kinds of rapid thermal processing were made to form the thin inter-poly Si dielectrics. One was successive three step process of 1150C 60sec in dry O₂ (oxidation),

1150C 60sec in NH₃ (nitridation) and 1100C 60sec in N₂ (post annealing), to form a nitroxide film. The other was two step process of 1150C 60sec in dry O₂ and 1100C 60sec in N₂ to form a simple oxide film as a control. The thickness of these obtained films were measured about 15nm. After these rapid thermal processing 2nd poly Si was deposited 300nm thick as the upper electrode of the capacitor.

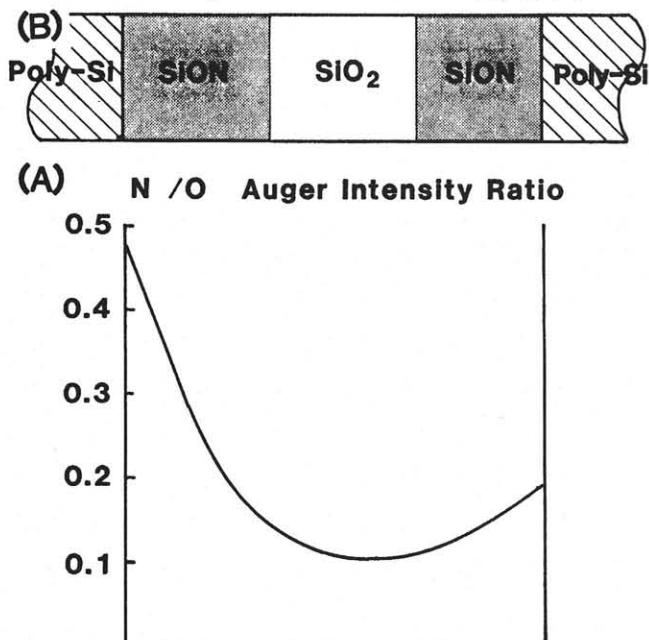
3. Structure of the nitroxide film

Figure 1 shows the cross sectional TEM image of the inter-poly Si nitroxide film formed by the rapid thermal processing as mentioned in section 2. It can be seen three



[Fig.1] Cross sectional TEM image of the nitroxide film.

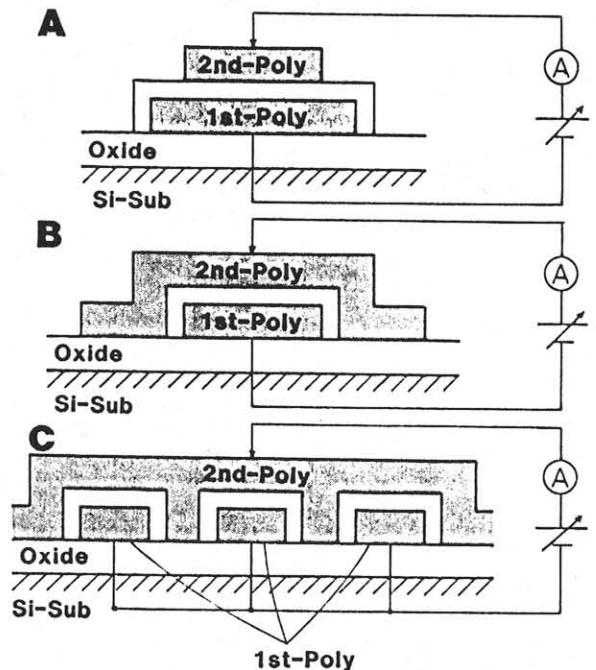
layered contrast, that is both the top and bottom interface region of the nitroxide film showing darker contrast (indicated by an arrow). Figure 2(A) shows the depth profile of Auger electron spectroscopy of the nitroxide film. Vertical axis is a ratio of Auger peak height of nitrogen to that of oxygen, and a horizontal axis indicates depth direction. From figs.1 and 2(A) the obtained nitroxide film was formed as three layered structure, both top and bottom surface of the dielectric film were nitrogen rich nitroxide as shown in fig.2(B) schematically(5),(6).



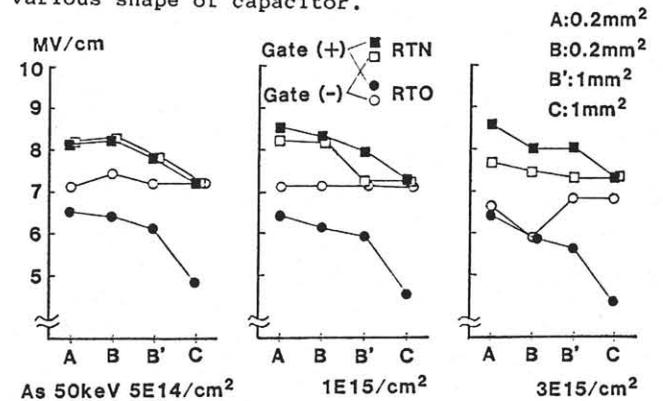
[Fig.2] (A) AES depth profile of the nitroxide film. Vertical axis is AES peak intensity ratio of N₂ and O₂. (B) Schematic diagram of the structure of the nitroxide film.

4. Dielectric Breakdown Field

Dielectric breakdown field was measured in three various shaped capacitors shown in fig.3 to investigate the influence of the edges of the 1st poly Si. The capacitor indicated by 'A' has no edge of the 1st poly Si. The capacitor indicated by 'B' has 1st poly Si edges and 'C' has longer ones. Results were shown in fig.4. Figure 4 shows that nitroxide film has better breakdown characteristics than that of the simple oxide film in all conditions about the arsenic dose



[Fig.3] Schematic cross sectional diagram of various shape of capacitor.

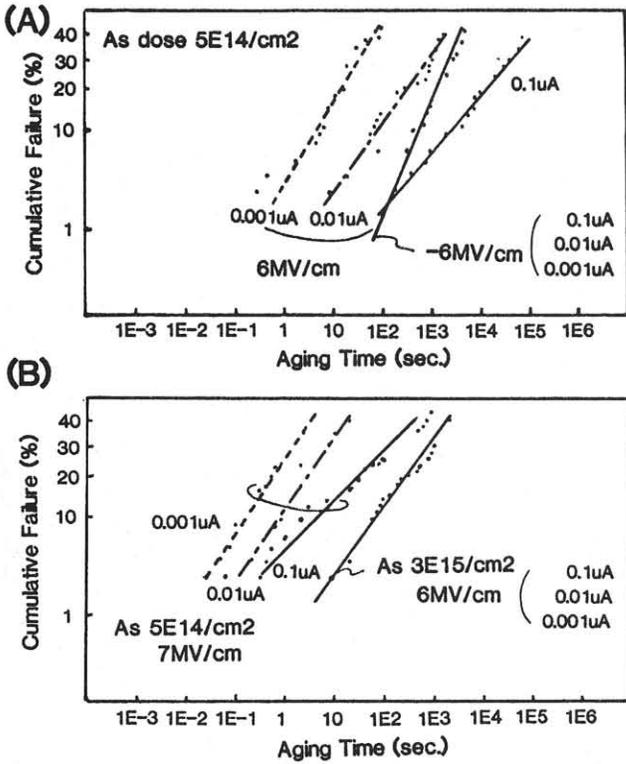


[Fig.4] Dielectric breakdown field of the nitroxide and oxide film. Square indicates the nitroxide and circle indicates the oxide film. Solid square and circle indicates the polarity of 2nd poly Si positive.

and shape of the capacitor. The dielectric breakdown field of the simple oxide film has strong dependence on the shape of the capacitor in the case of positive polarity for upper electrode. This dependence might be caused by the enhancement of electric field at the edges of the 1st poly Si. The dielectric breakdown field characteristics of the nitroxide film has less dependence on the shape of the 1st poly Si, and also on the polarity of electric field, than those of simple oxide film.

5. TDDB characteristics

Figure 5 shows the cumulative failure



[Fig.5] (A) Failure distribution of the nitroxide film formed onto $5E14/cm^2$ doped poly Si. (B) Failure distribution of the nitroxide film formed onto $3E15/cm^2$ doped poly Si under 6MV stress and $5E14/cm^2$ poly Si under 7MV/cm.

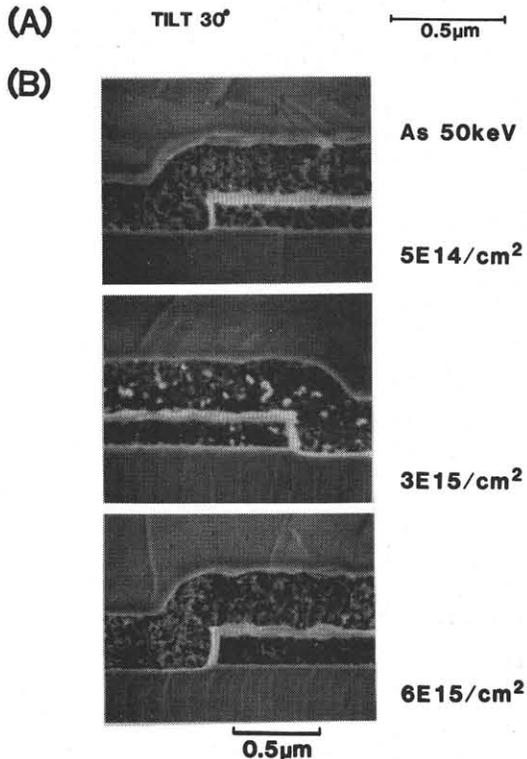
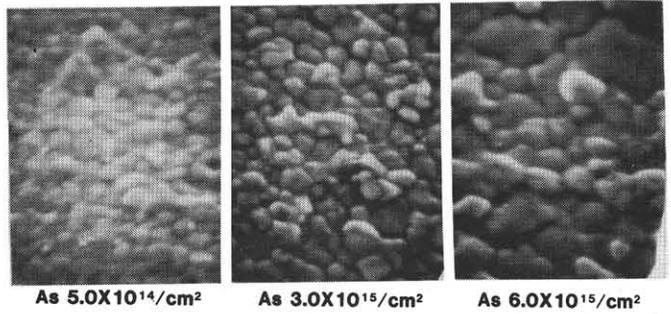
distribution of the nitroxide film. In this TDDDB measurement, failures were judged by three different amounts of leakage current (judgement current), such as 0.1uA, 0.01uA and 0.001uA. There are judgement current dependence in the MTF(mean time to failure) of TDDDB characteristics, in case of the nitroxide film formed onto $5E14/cm^2$ arsenic implanted poly Si under stress condition of +6MV/cm, as shown in fig.5(A). On the other hand no dependence is seen in the TDDDB characteristics at negative stress of -6MV/cm, and in that of nitroxide film formed onto $3E15/cm^2$ arsenic implanted poly Si under stress condition of +6MV/cm, as shown in figs.5(A). According to these results, those judgement current dependence were expected to be caused by the electric field enhancement due to surface asperity of the 1st poly Si.

From the measurements of TDDDB characteristics at electric field of 6MV/cm and 7MV/cm, shown in fig.5(A) and (B), it is

seen that 1MV/cm lower electric field raised the MTF of the nitroxide film in three orders of magnitude. From the result mentioned above, the MTF of this nitroxide film was estimated about 10 years under stress condition of 3MV/cm.

6. Surface morphology and edge shape of 1st poly silicon

To confirm the above expectations, SEM observation of the shape of 1st poly Si were carried out. Figures 6 shows that the surface morphology and the shape of the edges of the 1st poly Si are related to the total amount of arsenic dose in the poly Si. Figure 6(A) shows the tendency that heavier arsenic doped

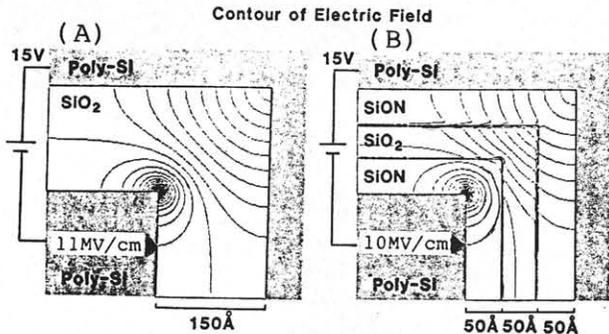


[Fig.6] (A) SEM observation of the 1st poly Si surface morphology. (B) Cross sectional SEM observation of the edge shape of the 1st poly Si.

poly Si has larger grain size, consequently that has rather smooth surface morphology. On the other hand, the edge shape of the 1st poly Si was almost independent of the total amount of arsenic dose in the 1st poly Si, as shown in fig. 6(B).

7. Discussion

Figure 7 shows the contour mappings of calculated electric field distribution at the 1st poly Si edge. Results show that three layered nitroxide film relieves about 10% the electric field enhancement at the 1st poly Si edge. According to the results shown in section 4, 6 and above calculation, the dependence of dielectric breakdown field on an electric field polarity and the capacitor shape in simple oxide film can be caused by the electric field enhancement at the 1st poly Si edge. On the other hand, the nitroxide film has higher breakdown field, showing less



[Fig.7] Contour mapping of calculated electric field at the edge of the 1st poly Si. (A) In case of oxide film. (B) In case of three layered nitroxide film. A dielectric constant of the SiON layer was assumed to be 5.2 in the calculation.

dependence on the 1st poly Si morphology and the edge shape, because the three layered structure relieves the electric field enhancement. In the same way, according to the results shown in section 5 and 6, the dependence of MTF of the nitroxide film on the TDDB judgement current and on an electric field polarity can be caused by the electric field enhancement due to the surface asperity of the 1st poly Si.

8. Conclusion

The obtained three layered nitroxide film formed by the rapid thermal processing showed better quality of dielectric breakdown characteristics and less dependence on the shape of the 1st poly Si, compared with the simple oxide film. This result might be caused by the effect of relieving the electric field enhancement at the edges of the 1st poly Si by the three layered structure. The MTF of the nitroxide film was estimated about 10 years under stress condition of 3MV/cm.

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