

A New Portrayal of Oxidation of Undoped Polycrystalline Silicon Film for Short Duration

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The oxidation mechanisms of undoped polysilicon films are examined in detail using the high resolution transmission electron microscopy. Both polysilicon films low-pressure-chemical-vapor-deposited (LPCVD) at 625 °C and amorphous films deposited at 550 °C with a subsequent annealing at 600 °C for 24 hr to form polysilicon films were used to grow the polyoxides at 850 °C in wet or dry oxygen. It is found that the oxidation phenomena of these two films are very different each other.

1. INTRODUCTION

Recently, polycrystalline silicon has been an important component of silicon technology. In most integrated circuits, thermal oxidation of polycrystalline silicon has been widely applied. For some special silicon devices, such as TFT's, the yield and reliability of thin polysilicon oxides, used as gate dielectrics, are important for mass production. Therefore, the comprehension of polysilicon oxidation for short duration is necessary.

For the polysilicon films low-pressure-chemical-vapor-deposited at 625 °C around, the oxidation mechanism is predominately surface-reaction-controlled for the lower oxidation temperatures. The oxidation rates are dependent on the orientations of silicon grains, causing the roughness of the interface between the polyoxide and the polysilicon layer. At higher oxidation temperatures, the oxidation mechanism is predominately diffusion-controlled, resulting in a smoother polyoxide/polysilicon interface¹⁾. On the other hand, the silicon films low-pressure-chemical-vapor-deposited at 560 °C as the amorphous phase and subsequently annealed at 600 °C as the polycrystalline structure were reported to have higher breakdown fields than those of the polysilicon films deposited at 620 °C^{2,3,4)}.

The high resolution transmission electron microscopy (HREM) analysis of these two types of polysilicon oxide was therefore utilized to understand the oxidation phenomena. The consequent electrical properties were also compared and discussed.

2. EXPERIMENTAL

Two different polysilicon films with 1000 Å in thickness were low-pressure-chemical-vapor-deposited onto thermally oxidized (100) silicon wafers. One is deposited at 625 °C, named as the polysilicon specimen. The other is firstly deposited at 550 °C as an amorphous phase and then annealed at 600 °C for 24 hr, named as the amorphous specimen. After a standard initial cleaning, polyoxides with the thicknesses ranging from 80 to 1200 Å were grown by wet and dry oxidations at 850 °C for both polysilicon films. Some samples were carried out by a two-mask procedure in order to fabricate the MOS capacitors. Al gate structure was adopted to avoid the subsequent thermal cycles.

The cross-sectional transmission electron microscopies of the thermal oxides and polysilicon films were obtained by the JOEL JEM 4000EX operated at 400 KV. An HP 4145B semiconductor analyzer was used to measure the current-voltage characteristics of the MOS capacitors with various polyoxides.

3. RESULTS AND DISCUSSION

Figure 1 is a cross-sectional TEM view of the wet polyoxide grown at 850 °C on the amorphous specimen which deposited at 550 °C and subsequently annealed at 600 °C for 24 hr. The variation of the polyoxide thickness is about 80 Å ± 5 %. The surface roughness of the wet polyoxide is almost the same as that of the

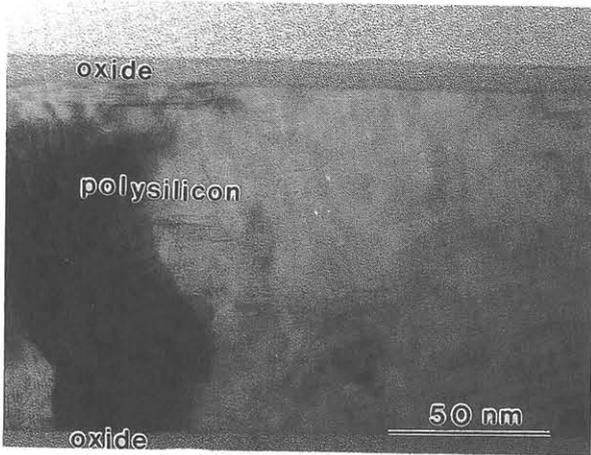


Fig. 1 The TEM for wet polyoxides on amorphous samples at 850 °C for 150 sec.

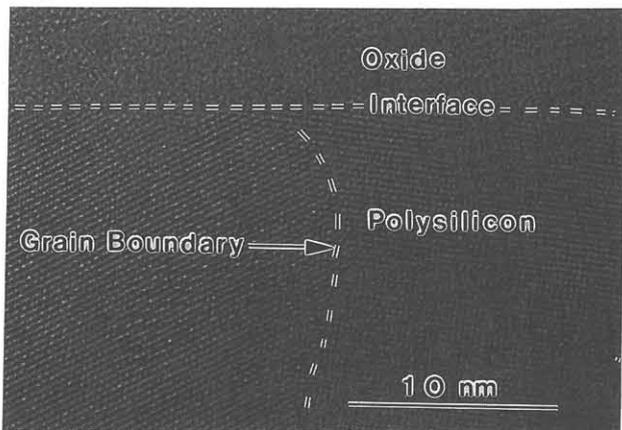


Fig. 2 The HREM for wet polyoxides grown on the amorphous specimen at 850 °C for 150 sec. It shows the smooth interface between polyoxide and grain boundary.

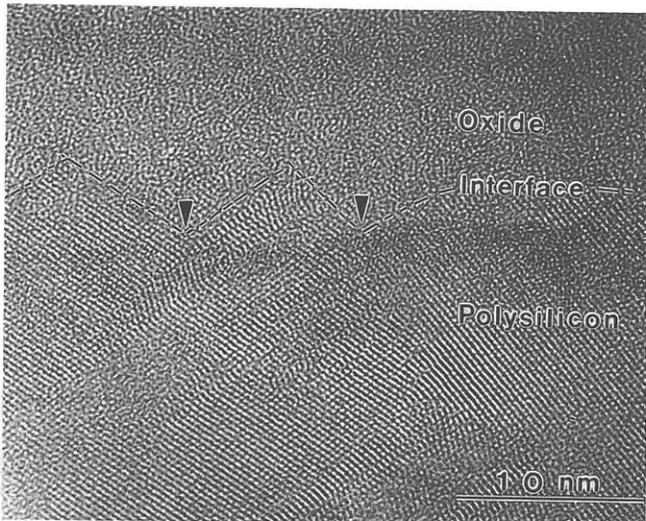


Fig. 3 The HREM for wet polyoxide grown on amorphous specimen at 850 °C for 150 sec. It shows the asperity existing at stacking faults of silicon grains.

dry polyoxide. As can be seen, the polyoxide/polysilicon interface is very flat for this amorphous specimens. No intergranular oxidation is found in the

amorphous sample for the polyoxide with 80 Å in thickness, as shown in Fig. 2. It means that the grooving effect of the grain-boundary oxidation does not occur for the amorphous specimen. However, the asperities are observed at the interface of the oxide and the weak-bond grain surface such as stacking faults, as shown in Fig. 3.

On the other hand, the oxidation phenomenon of the polysilicon films deposited at 625 °C is very different from that of the amorphous films. Figure 4(a) shows the cross-sectional TEM view of the dry polyoxide for the polysilicon sample. Fig. 4(b) shows that of the wet polyoxide. The surface of the as-deposited polysilicon film is rougher than that of the amorphous one. After oxidation, the polyoxide not only duplicate the roughness of underlayered polysilicon but also enhance the thickness variation due to the different oxidation rates for various grain orientations⁵. The wet polyoxide is even rougher than the dry polyoxide for the polysilicon sample since hydrogen atoms will enhance the diffusion rate, resulting in more orientation-related surface reaction. From the cross-sectional HREM observation, as shown

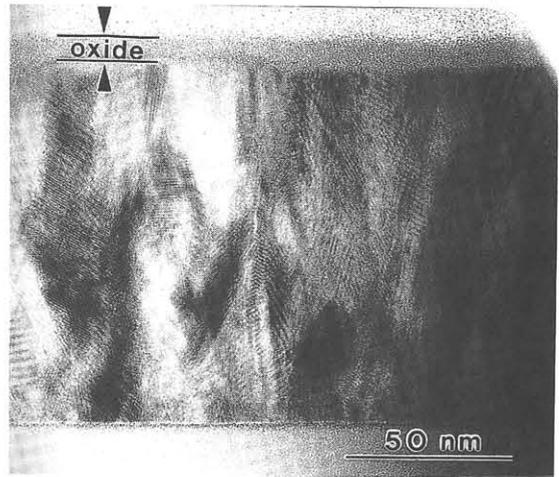


Fig. 4 (a) The TEM for dry polyoxide grown on the polysilicon specimen at 850 °C for 18 min.

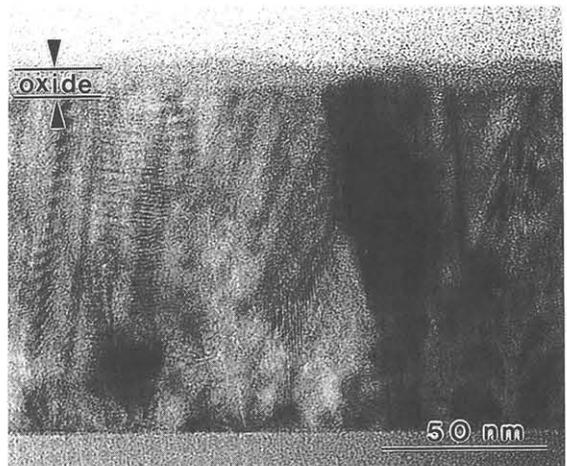


Fig. 4 (b) The TEM for wet polyoxide grown on the polysilicon specimen at 850 °C for 150 sec.

in Fig. 5, intergranular oxidation happens for the polycrystalline specimen after the wet oxidation at 850 °C for 60 min.

According to Fig.1 and Fig. 4(b), the polyoxide thickness for the amorphous specimen oxidized at 850 °C is varying from 75 to 85 Å, but the polyoxide thickness for the polycrystalline one is fluctuating from 40 to 120 Å. Hence, the polyoxide for the amorphous specimen is more uniform than that for the polycrystalline one. The electrical characteristics of the MOS capacitors with these polyoxides are also consistent with this result. Figure 6 shows the Weibull plots of TZDB characteristics for both polyoxides. A wider range of breakdown events occurs for the polyoxides grown from the polycrystalline sample due to the rougher polyoxide/polysilicon interface.

A simple model is proposed to explain the different oxidation results for these two kinds of polysilicon films. For the polycrystalline specimen, the oxidation rates are dependent on the grain orientations, leading to the surface-reaction-controlled mechanism. However, the oxidation mechanism for the amorphous sample

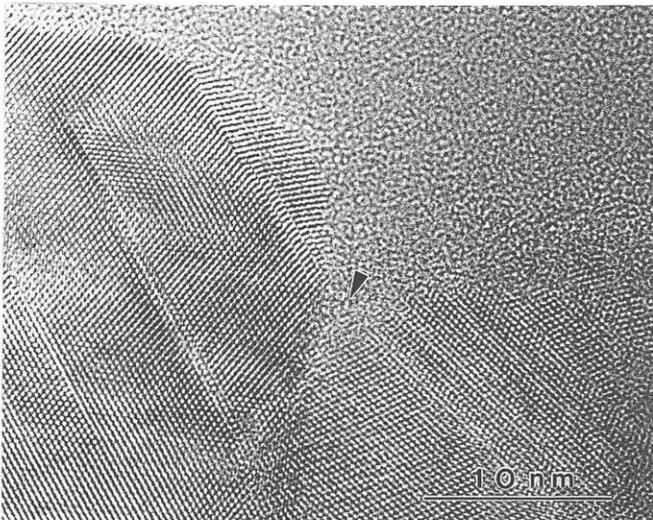


Fig. 5 The HREM shows the intergranular oxidation happens for wet oxidation of polysilicon specimen at 850 °C for 60 min.

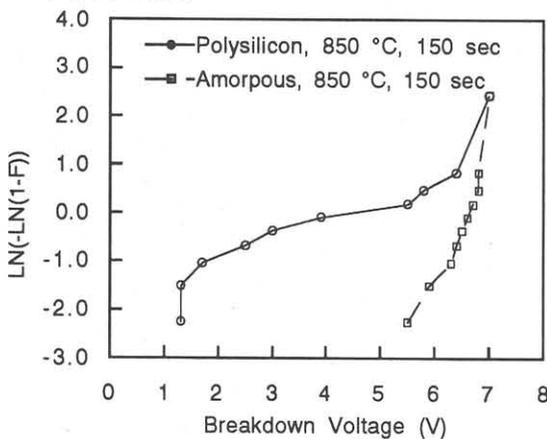


Fig. 6 Weibull plots of TZDB characteristics for polyoxides grown on both different polysilicon films.

become predominately diffusion-controlled since this specimen possesses a smoother polyoxide/polysilicon interface.

Furthermore, two kinds of polysilicon films were oxidized at 850 °C for 120 min in wet oxygen ambient. From the cross-sectional TEM photograph measurement, the polyoxide thickness for the amorphous one is about 1070 Å, and the thickness for the polysilicon one is about 900 Å. The oxidation rates of the recrystallized amorphous silicon films are remarkably higher than those of the polycrystalline ones. It is therefore suggested that the amorphous specimen has a higher surface-reaction rate during the oxidizing and leads to a diffusion-controlled oxidation mechanism.

4. CONCLUSION

For the silicon films low-pressure-chemical-vapor-deposited at 625 °C as the polycrystalline structure, the oxidation rates are dependent on the polysilicon grain orientations, leading to a surface-reaction-controlled mechanism. However, the silicon films deposited at 550 °C as the amorphous phase and subsequently annealed at 600 °C for 24 hr will possess the diffusion-controlled oxidation and higher oxidation rates.

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5. REFERENCES

- 1) E.A. Irene, E. Tierney, and D.W. Dong, *J. Electrochem. Soc.* 127 (1980) 705.
- 2) U. Mitra, J. Chen, B. Khan, and E. Stupp, *IEEE Electron Device Lett.*, 7 (1991) 390.
- 3) A. H. Carim and R. Sinclair, *Mat. Letters* 5 (1987) 94.
- 4) A. Yaron, J.C. Barry and G.R. Booker, *Philosophical Magazine A* 63 (1991) 423.
- 5) Y. Wang, J. Tao, S. Tong, and T. Sun, 138 (1991) 214.