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Leakage Current Conduction Mechanism of Liquid Phase Deposited (LPD)SiO_2 Film

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The leakage current conduction mechanism of liquid phase deposited (LPD) SiO_2 is verified. The ohmic conduction dominates the leakage current at low electric field. However, Fowler Nordheim tunneling and Poole Frenkel emission dominate the leakage current at medium high field and at much higher field, respectively. We also observe that the leakage conduction changes after thermal nitrogen annealing.

1. Introduction

There has been great interest in liquid-phase deposited (LPD) oxide recently because of their advantage of low-temperature processing. Until now, LPD oxide has been applied successfully as gate insulator in poly-Si TFTs[1] and dielectric of multilevel interconnection[2]. However, few studies have been reported on electrical properties of LPD oxide films, especially their leakage conduction mechanisms. In order to improve the oxide film properties , it is essential to clarify the leakage current conduction mechanisms of LPD oxide films. In this paper we will describe the various leakage current conduction mechanisms in LPD oxide films.

2. Experimental

P-type (100) silicon wafers with resistivity 1 ~ 5 Ω-cm were used in this study for LPD oxide deposition. The detailed processes of LPD oxide deposition were shown in our previous studies[3].. The metal oxide semiconductor (MOS) structures with aluminum gate electrode were used for electrical measurements to investigate the leakage current conduction mechanisms. The area of aluminum electrode is 1.77×10^{-4} cm^2 . All the current density vs. electric field (J-E) curves are measured by HP4145.

3. Results and Discussion

Typical J-E characteristics of as-deposited LPD oxide films are shown in Fig. 1. At lower electric field (E< 2 MV/cm), the leakage current is linearly proportional to electric field, that is $J\propto E$, (Fig. 2). According to the Arrehnius plot (Fig. 3), we find that at lower field (1.5 MV/cm) the leakage current is linearly dependent on the absolute temperature with a specific activation energy. This implies that the leakage current is traps-assisted. Because there are so many defects and traps in as-deposited film, the trapped electrons can hop from one trap site to another after thermal excitation. These traps are shallow ones in the energy level because of a lower activation energy. Thus, we may conclude that the leakage current at low field is dominated by the ohmic conduction[4]. We also found that the leakage current is reduced obviously and gradually identical to that of thermal oxide after some voltage stress ramps or a constant bias (-15V) stress for a period of time (Fig. 4). Because the electrons in shallow-level traps are swept out to nearby electrode by the low field[5], and thus result into a large initial current. Some isolated traps are detrapped, then the initial leakage current decreases. Finally the leakage characteristics is identical to that of thermal oxide.

The Fowler-Nordheim plot, $\log(J/E^2)$ vs. (1/E), was shown in Fig. 5. The figure exhibits clearly a linear relationship in the electric field range of 6 MV/cm ~10 MV/cm for the thin oxide (253Å). The leakage current in this region is transported by F-N tunneling. The barrier height ϕ_B is 2.8 eV from Al electrode, and 2.6 eV from Si substrate. The lower ϕ_B from the Si substrate results from the rougher interface between Si substrate and oxide film. For the thicker films (487Å and 574Å), there must to be different kinds of leakage current transports in 8 MV/cm ~10 MV/cm because there is a ledge hump over this region (Fig. 1). In addition, the F-N plot is not a straight line near the ledge hump.

At much higher electric field, the leakage current is transported by either the Schottky emission or the Poole Frenkel emission [4),5),6)].. However, there is only one dominant mechanism under a specific field and temperature condition. From the Schottky plot, we found the relationship between log(J) and ($\sqrt{E}$) is linear. However, from the Poole Frenkel plot the relationship between log(J/E) and ($\sqrt{E}$) is also linear. We calculated the dielectric constant of 1 from the Schottky plot and 2.8 from the Poole-Frenkel plot, respectively.

The Schottky emission mechanism is sensitive to the "band-edge discontinuity" between the electrode and the insulator, and should show a polarity dependence[4]. While in Poole Frenkel emission the trapped electrons must overcome a barrier height which is the depth of the traps potential well[7]; i.e. the Poole Frenkel mechanism should show a polarity independence. As shown in Fig. 6, the LPD film shows a polarity independence.

As shown in Arrehnius plot (Fig. 3), the plots for 7 and 8 MV/cm compose three different segments. Each segment corresponds to one conduction mechanism. We replot the Arrehnius plot for 8 MV/cm in Fig. 7. The three different segments are probably F-N tunneling (horizon segment), ohmic conduction (tilted segment), and Poole Frenkel emission (much tilted segment). The F-N tunneling dominates the leakage current at room temperature or even lower temperature at 8 MV/cm field because of temperature independence. When the temperature is below 125°C, the leakage current is dominated by F-N tunneling. While temperature is between 125°C ~ 200°C, the leakage is ohmic hopping enhanced conduction. However, when the temperature excesses 200°C the leakage current shows more severe temperature dependence, and has a larger activation energy than that of the ohmic conduction. The electrons trapped in the deep level traps are excited, and begin to jump. This conduction result into the third segment in the Arrehinus plot at 8 MV/cm. The combined mechanism is that the electrons tunneling from the first electrode (Al fermi level) to the deep level traps (traps-assited tunneling) [8]. These electrons carry so high energy at high temperature that they begin to jump to the oxide conduction band from the deep level traps. Finally, they are swept to the second electrode (Si conduction band).

The conduction mechanism will change after thermal nitrogen annealing. As indicated in Fig. 8, the J-E curves of annealed LPD oxide films are compared. It is worthy noting that there is still a ledge hump over much higher field. As previously mentioned, the conduction mechanism over this region is Poole-Frenkel emission. The hump decreases and gradually disappear when the annealing temperature excesses 400°C. Both the J-E curves of the annealed ones at 400°C and 500°C become linear in 6 ~ 8 MV/cm. Obviously, there is only F-N tunneling over this region, and the effective barrier height is 2.5 eV compared to that of 2.8 eV mentioned previously in the thinner film . The lower tunneling barrier height of the thicker film may be due to a rougher interface than that in the thinner film. However, the barrier height is still lower than that of thermal oxide because LPD film contains lots of charges and traps[4].

4. Conclusion

The leakage current of LPD oxide were found to be ohmic conduction at low field, F-N tunneling at the medium high field, and the Poole Frenkel emission at much higher field. In addition, the different annealing condition will result into different conduction mechanism. The Poole-Frenkel emission doesn't dominate the leakage current when the annealing temperature excess 400°C.

Acknowledgment

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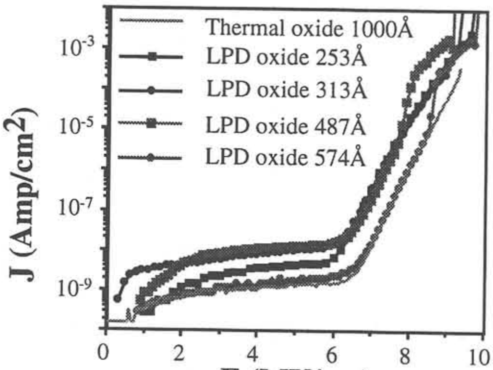

Fig. 1 Typical J-E characteristics of LPD oxide with different thickness. The thermal oxide was also shownfor comparison.

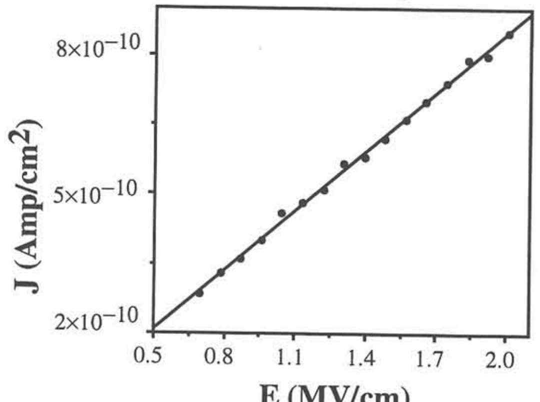

Fig. 2 Relationship between current density and electric field E at low field.

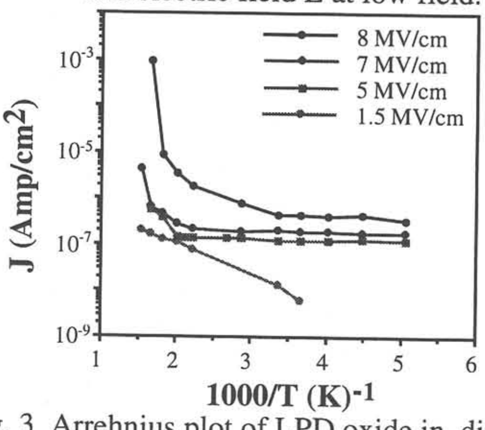

Fig. 3 Arrehnius plot of LPD oxide in different electric field. The oxide thickness is 547Å.

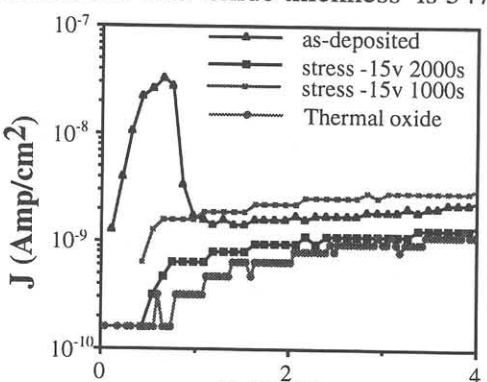

Fig. 4 J-E characteristics of LPD oxide before and after low constant bias stress.

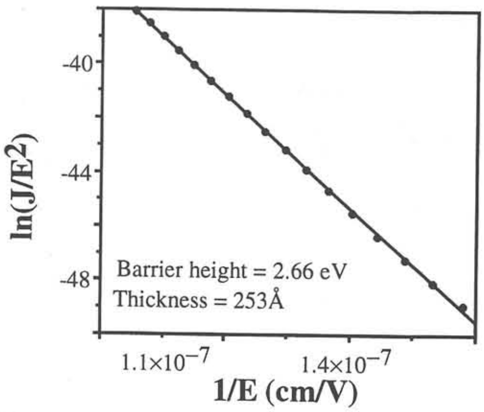

Fig. 5 F-N plot of LPD oxide, (m*/m) = 0.5

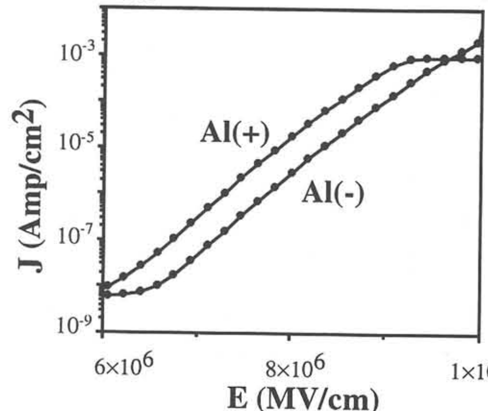

Fig. 6 J-E characteristics of Al-SiO_2-Si diode at room temperature.

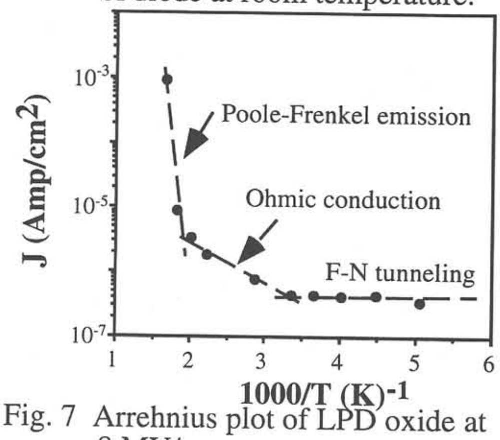

Fig. 7 Arrehnius plot of LPD oxide at 8 MV/cm.

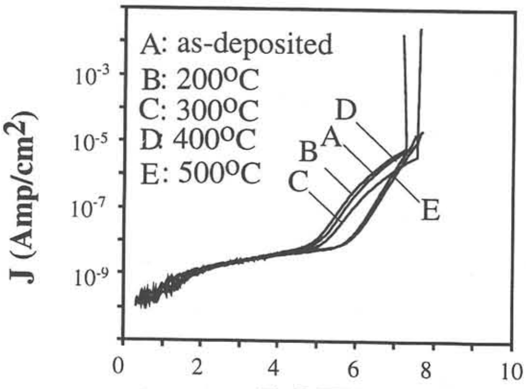

Fig. 8 The J-E characteristics of LPD oxide with different annealing temperature.