Prevention of degradation in poly $Si_{1-x}Ge_x$/high K structure by controlling Ge content in poly $Si_{1-x}Ge_x$ films

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1. Introduction

As the size of complementary metal oxide semiconductor (CMOS) technology device scales down, the studies on the replacing the currently employed SiO_2 with high K dielectrics have received considerable attention. Among the suggested materials, ZrO_2 films have many advantages, such as a high dielectric constant, a relatively large band, and so on. Besides above advantages, high K dielectric films must be thermally stable with gate electrode during the post process for the compatibility with the conventional process. Form the thermodynamic data, the ZrO_2 is expected to be stable with poly Si gate electrode during the post process. However, several electrical results of CMOS-FET with poly Si/ZrO_2 gate structure have showed some problems due to the silicidation between poly Si and ZrO_2. Therefore, the prevention of silicidation between poly Si gate electrode and ZrO_2 films was very important during the post process. In this paper, poly $Si_{1-x}Ge_x$ films were used as a gate electrode in order to prevent the silicidation during the post process. It is well known that Ge in epi $Si_{1-x}Ge_x$ films retarded the silicidation in Ti, Co, Zr/ $Si_{1-x}Ge_x$ system as compared to Co, Ti, Zr/poly Si system. From these previous results, compared with poly Si/ ZrO_2 system, the silicidation will be retarded in poly $Si_{1-x}Ge_x$ / ZrO_2 system and then, the retardation of silicidation is expected to bring about other reaction, silicate formation in poly $Si_{1-x}Ge_x$ / ZrO_2. Although the formation of thin silicate layer lower the capacitance of gate oxide, interfacial properties will be enhanced and leakage current will be decreased. In addition, the poly $Si_{1-x}Ge_x$ films have been suggested as a promising alternative to the currently employed poly Si gate electrode for CMOS-FET due to the suppression of B penetration and gate depletion.

2. Experiment

After standard cleaning of the p-type silicon wafer, 5.8 nm thick ZrO_2 films were deposited at room temperature (R.T.) by reactive DC magnetron sputtering from a Zr target with 99.9% purity in Ar+O2 gas ambient and 10nm thick poly $Si_{1-x}Ge_x$ films (x=0, 0.2, 0.4) were grown on ZrO_2 films at 600°C using low pressure chemical vapor deposition (LPCVD) system. After the formation of metal oxide semiconductor structure, the specimens were annealed at 800 °C and 900 °C in N2 ambient. And then, the interfacial reaction between poly $Si_{1-x}Ge_x$ and ZrO_2 films was investigated by using XPS and TEM and electrical properties with poly $Si_{1-x}Ge_x$ / ZrO_2 were measured.

3. Results and Discussion

Figure 1 shows the Si 2p spectra of poly $Si_{1-x}Ge_x$ / ZrO_2 system after annealing at 900 °C for 30min. In poly Si/ ZrO_2 films, the binding state of SiOx was weakly observed at the poly Si/ ZrO_2 interface and that of pure Si or Si in silicide was observed at the poly Si/ ZrO_2 interface. Since the peak position of Si 2p in silicide is similar to that of pure Si, it is difficult to identify the binding states of Si. From the spectra of Zr, the binding state of Si at the poly Si/ ZrO_2 interface is expected to be silicide. (see the Fig. 2) In contrast to the poly Si/ ZrO_2 system, notable features were shown in the poly $Si_{0.8}Ge_{0.2}$/ ZrO_2 and

poly $Si_{0.6}Ge_{0.4}$/ ZrO_2 films. The peak intensity of binding states of SiOx increased clearly at the binding energy of about 103eV and that of silicide diminished at that of about 99.3 eV. In addition, the peak intensity of binding states of SiOx increased with the increase of Ge content in poly $Si_{1-x}Ge_x$ films. From the spectra of Si 2p, the formation of the silicate layer is dominant at the poly $Si_{1-x}Ge_x$ (x=0.2, 0.4)/ ZrO_2 interface. The formation of silicide layer at the poly Si/ ZrO_2 interface and that of silicate layer at the poly $Si_{1-x}Ge_x$ / ZrO_2 interface were confirmed from the spectra of Zr 3d, as shown in the Fig. 2.

In poly Si/ ZrO_2 film, the peaks of binding energy of about 179eV and 183.3eV were observed at the poly Si/ ZrO_2 interface. The peak at a binding energy of about 183.3 eV is the spectra of ZrO_2 and that of about 179eV is expected to be the spectra of Zr in Zr-silicide or etched Zr, which peak positions are similar. Etched Zr could be observed due to the preferential etching rate, resulted from the difference of atomic mass. Compared with the peak intensity of pure Zr at the poly Si/ ZrO_2 interface, that of pure Zr in ZrO_2 films decreased at 179eV in spite of the increase of etching time. In addition, the spectra of pure Zr were not observed at the poly Si0.6Ge0.4/ ZrO_2 interface. From these results, the peak of pure Zr at poly Si/ ZrO_2 interface is expected to be Zr-silicide, resulted from the reaction between poly Si and ZrO_2 films. In contrast to the poly Si/ ZrO_2, the spectra of Zr-silicide were not observed at the poly Si0.6Ge0.4/ ZrO_2 interface, which results mean that silicide layer was not formed. In poly Si/ ZrO_2 and poly Si0.6Ge0.4/ ZrO_2, the peak intensity of etched pure Zr increased with increasing the etching time at a binding energy of 179eV due to the difference of sputtering yield. To investigate the effect of Ge on the silicate formation, the binding states of Ge in poly $Si_{1-x}Ge_x$ / ZrO_2 interface were observed in detail, as shown Fig. 3. However, notable features were not shown, indicating that Ge did not participated in the reaction at the poly $Si_{1-x}Ge_x$ / ZrO_2 interface and the effect of Ge on the formation of silicate layer could be nearly ignored. We will discuss the difference of reaction between poly Si/ ZrO_2 interface and poly $Si_{1-x}Ge_x$ / ZrO_2 interface in the thermodynamic considerations. In addition, the electrical characteristics of MOSCAP with poly $Si_{1-x}Ge_x$ / ZrO_2 and poly $Si_{1-x}Ge_x$ /Hf02 gate structure were investigated.

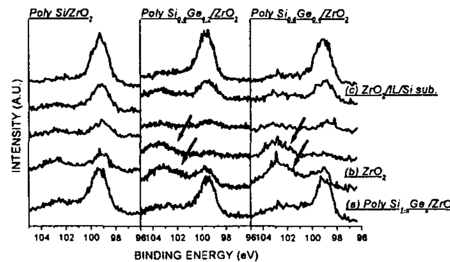

Fig. 1. The depth profile spectra of Si in poly $Si_{1-x}Ge_x$ / ZrO_2 (x=0, 0.2, 0.4) after annealing at 900 °C for 30min

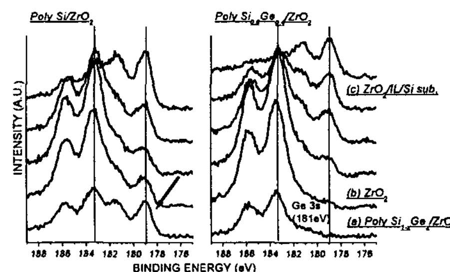

Fig. 2. The depth profile of Zr in poly Si/ ZrO_2 and poly $Si_{0.6}Ge_{0.4}$/ ZrO_2 after annealing at 900 °C for 30min

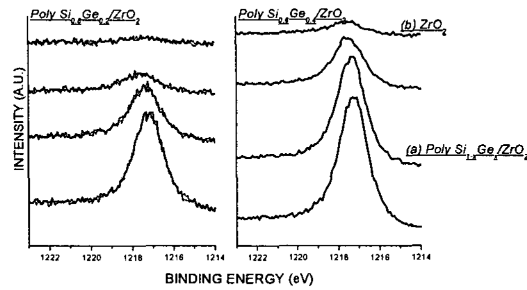

Fig. 3. The depth profile of Ge in poly $Si_{0.8}Ge_{0.2}/ ZrO_2$ and poly $Si_{0.6}Ge_{0.4}/ ZrO_2$ after annealing at 900 °C for 30min

4. Summary

In summary, we investigated the interfacial reaction between poly $Si_{1-x}Ge_x$ and ZrO_2 with the Ge content and electrical properties of MOSCAP with poly $Si_{1-x}Ge_x$ / ZrO_2. In the poly Si/ ZrO_2 structure, the silicidation is dominant due to the continuous formation of ZrSi and SiO during annealing. However, in the poly $Si_{1-x}Ge_x$ (x=0.2, 0.4)/ ZrO_2, the silicide layer was not observed and the silicate layer was observed after annealing at 900 °C for 30min. Before the Ge piles up, the silicidation is expected to be dominant at the poly $Si_{1-x}Ge_x$ / ZrO_2 interface due to the selective reaction with Si. However, the formation of silicide results in the depletion of Si and the accumulation of Ge at the poly $Si_{1-x}Ge_x$ / ZrO_2. After the Ge piles up, the silicate layer forms since the ZrSi and SiO does not form any more and the SiO reacts with ZrSi and ZrO_2. Therefore, the silicidation between poly $Si_{1-x}Ge_x$ and ZrO_2 will be prevented by controlling the Ge content and annealing condition since the formation of silicate layer depends on the Ge content and the annealing condition.

Acknowledgements

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