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Rapid thermal post-metallization annealing effect on thin gate oxides

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Abstract

Rapid thermal processing is used for post-metallization annealing (PMA) in this work. It was found that the rapid thermal PMA can do almost the same anneal work in the initial characteristics of MOS capacitors with an oxide thickness of 10 nm as the conventional furnace PMA. But the reliabilities in hot-carrier and radiation resistances of MOS capacitors depend on the PMA process significantly. It was found that rapid thermal PMA samples exhibit worse properties in hot-carrier resistance but better properties in radiation hardness than furnace PMA samples. For rapid thermal PMA process, the higher the annealing temperature, the stronger the initial annealing extent but the worse the hot-carrier and the radiation resistances.

1. Introduction

High quality thin oxide devices are necessary in VLSI technology. Many works had been done on how to grow high quality oxide layer, such as nitride oxides [1], reoxidized nitrated oxides [2,3], or N_2O oxides [4,5], etc. In addition, a few works [6,7] reported that the post-metallization annealing (PMA) process can also affect the performance of MOS devices. It is well known that the PMA is necessary for devices after metallization process. It can sinter the metal/silicon contact and lower the contact resistance. In addition, it can also anneal the defects at the interface, such as fixed oxide charges, oxide trapped charges and interface charges. Recently, rapid thermal processing is widely used in IC technology [1,2,6–8]. Mainly, it can reduce some drawbacks

caused by conventional furnace processing, such as long duration and out-diffusion, etc. It is believed that rapid thermal processing is also applicable to PMA. It is known that the samples with poly-gates may show quite different behavior from those with metal-gates [8]. For simplicity, only poly-gate MOS capacitors are investigated in this work. It is found that the rapid thermal PMA can achieve almost the same annealing effect as the furnace PMA. In addition, it was found that an annealing temperature of 500°C in rapid thermal PMA is high enough to effectively reduce the oxide defects. However, it is noted that the sample with a low annealing temperature is more resistant to hot carrier stress and radiation damage than the one with a high annealing temperature. The same phenomenon is also observed in furnace PMA samples. Possible mechanisms are given for these phenomena based on the bond-strain gradient model [9,10].

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2. Sample preparations

The sample substrates are p-type Si(100) 3" wafers with a resistivity of $\sim 20\text{--}50\ \Omega\cdot\text{cm}$. They were oxidized in dry O_2 at 980°C and then in situ annealed in N_2 for 10 min to obtain a thickness of about 10 nm. A LPCVD poly-Si film with a thickness of about 300 nm was deposited at 620°C . The deposition pressure and the deposition rate are $\sim 180\text{--}220$ mTorr and 10 nm/min, respectively. Doping of the poly-Si films was achieved by POCl_3 diffusion at 950°C for 20 min. After removing the phospho-oxide, Al-gate films with a thickness of 90 nm were thermally evaporated and then patterned by photolithography method. Finally, after removing the backside poly-Si film and oxide, Al films were also evaporated on the backside for electrical contacts. Various PMA processes were then carried out after sample preparation. The flatband voltage V_{FB} and midgap interface trap density D_{itm} are obtained from high–low frequency $C\text{--}V$ curves. Hot-carrier stress was performed with a constant current density of $J = 0.1\ \text{mA}/\text{cm}^2$ for 10 s. ^{60}Co irradiations with a total dose of 1 Mrad were performed to examine the radiation hardness. Time zero dielectric breakdown TZDB characteristics were obtained by applying a staircase voltage of $dV_{\text{G}}/dt = 0.5\ \text{V}/\text{s}$ on samples until a current of $1\ \mu\text{A}$ was reached.

3. Results and discussion

Fig. 1a shows the $C\text{--}V$ curves of MOS capacitors before and after various rapid thermal PMAs with annealing temperatures of 400, 450 and 500°C , a temperature rising rate of $700^\circ\text{C}/\text{min}$ and a holding time of 30 s. Clearly, the higher the annealing temperature, the larger the annealing effect, i.e. more significant reduction of the oxide charges and interface trap charges. The annealing temperature of 400°C in rapid thermal PMA seems to be not high enough to anneal out the oxide defects. Thus, from the viewpoint of annealing effect, an annealing temperature of 500°C is suggested for rapid thermal PMA. In addition, the $C\text{--}V$ curves of MOS capacitors before and after furnace PMA with annealing temperatures of 400 and 450°C and an annealing

Fig. 1. $C\text{--}V$ curves of MOS capacitors before and (a) after various rapid thermal PMAs with annealing temperatures of 400, 450 and 500°C , a temperature rising rate of $700^\circ\text{C}/\text{min}$ and a holding time of 30 s and (b) after various furnace PMAs with annealing temperatures of 400 and 450°C and an annealing time of 30 min.

time of 30 min is shown in Fig. 1b. Although the annealing temperature is 400 or 450°C , the long time annealing results in quite large reduction in oxide defects. From Figs. 1a and 1b, it can be seen that the rapid thermal PMA with an annealing temperature of 500°C and a holding time of 30 s provides the same annealing effect as the furnace PMA with an annealing temperature of 450°C and an annealing time of 30 min. Therefore, the PMA by rapid thermal heater can save much more processing time than using a conventional furnace.

Fig. 2a shows the $C\text{--}V$ curves of MOS capacitors with various rapid thermal PMAs before and after a constant current stress (gate biased negatively) of

Fig. 2. C - V curves of MOS capacitors with (a) various rapid thermal PMAs and (b) various furnace PMAs before and after a constant current stress of $J = 0.1 \text{ mA/cm}^2$ for 10 s.

$J = 0.1 \text{ mA/cm}^2$ for 10 s. The gate voltage during stress for all samples is about -11 V . It is noted that positive oxide charges were built up in the MOS capacitors after constant current stresses, i.e. V_{FB} is more negative after stresses. Clearly, the sample with an annealing temperature of 400°C exhibits smaller stress-induced oxide charges and interface trap charges than the ones with 450 and 500°C . It is interesting to note that the poorer the initial annealing effect, the better the resistance to constant current stress. It is possibly due to the reason that the oxide with a poor initial PMA may have many unsatisfied bonds near the SiO_2/Si interface. In such case, the interfacial strain is small which in turn results in a better hot-carrier resistance. The C - V curves of MOS capacitors with various furnace PMAs before and after a constant current stress of $J = 0.1$

mA/cm^2 for 10 s are shown in Fig. 2b. It is noted that the sample with an annealing temperature of 400°C also exhibits smaller stress-induced oxide charges and interface trap charge than the one with an annealing temperature of 450°C .

Figs. 3a and 3b show the C - V curves of MOS capacitors with various rapid thermal and furnace PMAs before and after 1 Mrad ^{60}Co irradiations. It can be seen that the behavior of the radiation-induced oxide charges and interface trap charges is similar to that observed in Fig. 2. That is to say, the poorer the initial PMA, the smaller the interfacial strain, and therefore the better the radiation hardness. It is noted from Figs. 3a and 3b that the rapid thermal PMA samples are more radiation hard than the furnace PMA samples although their constant

Fig. 3. C - V curves of MOS capacitors with (a) various rapid thermal PMAs and (b) various furnace PMAs before and after 1 Mrad ^{60}Co irradiations.

Fig. 4. Time-zero dielectric breakdown (TZDB) distributions of breakdown field E_{BD} of MOS capacitors with (a) various rapid thermal PMAs and (b) various furnace PMAs.

current stress behavior is opposite to that observed in Figs. 2a and 2b.

Figs. 4a and 4b show the time-zero dielectric breakdown (TZDB) distributions of breakdown field E_{BD} of MOS capacitors with various rapid thermal and furnace PMAs, respectively. Clearly, the MOS capacitors with rapid thermal PMAs have better reliability performance than those with furnace PMAs. It is noted that aluminum may penetrate through poly-Si into the SiO_2 layers during the long time annealing in furnace PMA. The local electrical field may be enhanced during breakdown measurement and therefore results in poor dielectric breakdown.

4. Conclusion

In this work, it is found that rapid thermal PMA with a temperature of 500°C for 30 s can effectively reduce the oxide charges and interface trap charges. Much time can be saved by using rapid thermal PMA with respect to furnace PMA. It is also found that samples with a low temperature annealing are more resistant to hot carrier stress and radiation damage than those with a high temperature annealing. Finally, it is suggested that suitable choices of the (short) time and (high) temperature in rapid thermal PMA can result in good reliability performance for thin oxide MOS devices.

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