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Clarification of Nitridation Effect on Oxidation Methods

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The effects of nitridation on oxide properties have been systematically investigated using the nitrogen implantation technique. It is found that the hot-carrier degradation can be improved by nitridation irrespective of oxidation methods. This improvement is attributed to the suppression of interface states generation and the reduction of electron traps in the oxide films. Our extensive investigation concludes that the nitridation of gate oxide films using nitrogen implantation can be very promising for the improvement in reliability in spite of the difference in oxide formation methods.

1. INTRODUCTION

Several challenges have been carried out for realizing highly reliable thin gate oxide films, as device dimensions are scaled down into the sub-quarter micron regime. For this purpose, the wet and the dry oxidation have been well studied. Moreover the CVD stacked gate oxide film is very attractive in fulfilling the requirement of low defect density and the suppression of thinning effect at isolation edges [1]. In recent years, the nitridation of gate oxide films by annealing in an NH_3 ambient or in a N_2O ambient has been widely investigated for the improvement in reliability [2,3]. However, theses methods require high process temperature or generate fixed charges in oxide films. As an alternative nitridation method, we have developed the novel nitridation technique using nitrogen implantation into the polysilicon gate [4,5]. In this paper, we clarify the effect of nitridation on various oxide formation methods using nitrogen implantation.

2. EXPERIMENTAL

We have systematically investigated the dependence of nitridation effect on oxidation methods as shown in Table 1. We examined four types of gate oxide films as follows, (#1) the oxide film formed in a pyrogenic steam ambient, (#2) the oxide film formed in a dry O_2 ambient, (#3) the oxide film formed by CVD, and (#4) the stacked CVD oxide film preceded by thermal oxidation. The thickness of gate oxide films were adjusted to 10 nm. Nitridation of the gate oxide films was performed by nitrogen implantation into the gate polysilicon film to avoid adverse effects such as the fixed charge generation and the variation of oxide thickness, which are usually observed in the other nitridation techniques. The nitrogen dose was $4x10^{15}$ /cm^2. The projected range of nitrogen ions was adjusted to the surface region of the gate polysilicon film to avoid the implantation damage on gate oxide films. Then the dual-gate CMOS was fabricated by the conventional process. The annealing after the nitrogen implantation was performed at 850 °C for 20 min and 800 °C for 60 min. At these heat treatments, the nitrided oxide films can be formed by the pile-up of nitrogen into the gate oxide films.

Table 1. Oxidation and nitridation conditions employed in this study

	Oxidation Method	Nitrogen Dose
#1a	in a pyrogenic steam ambient	——
#1b		$4x10^{15}$ /cm^2
#2a	in a dry O2 ambient	——
#2b		$4x10^{15}$ /cm^2
#3a	CVD TEOS	——
#3b		$4x10^{15}$ /cm^2
#4a	CVD TEOS / thermal oxide	——
#4b		$4x10^{15}$ /cm^2

3. RESULTS AND DISCUSSION

Fig. 1~3 show the hot carrier degradation for NMOSFETs, presenting the threshold voltage shift, the degradation of drain current, and the variation of charge-pumping current caused by DAHC (Drain Avalanche Hot Carrier) injection. The oxide film formed in the dry O_2 ambient shows the highest hot-carrier resistance among the studied samples. However serious degradations by the hot-carrier injection can be observed for the samples with the CVD oxide film and the stacked CVD oxide film. It is found that the hot-carrier hardness can be improved by nitridation for all the oxide films. Especially, the hot-carrier resistance of the CVD oxide

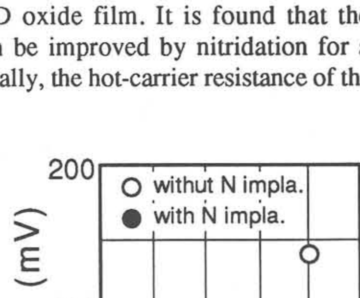

Fig. 1 Threshold voltage shift of NMOSFETs during the DAHC injection. The stress was applied at Vd=4V, Vg=V(Isubmax) for 1000 sec.

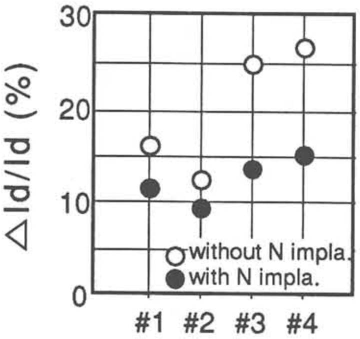

Fig. 2 Degradation of drain current for NMOSFETs during the DAHC injection.

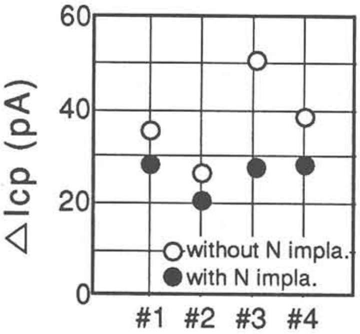

Fig. 3 Variation of the charge pumping current for NMOSFETs during the DAHC injection.

and the stacked CVD oxide can be remarkably improved by nitridation using nitrogen implantation. From the measurement of charge pumping current, the interface state generation can be reduced by nitridation. The nitrogen would fill dangling bonds and weakened bonds in the gate oxide film, since nitrogen atoms into the polysilicon film can easily diffuse and pile-up into the gate oxide film. Fig. 4 and 5 show the hot carrier degradation for PMOSFETs, presenting the threshold voltage shift and the degradation of drain current caused by the DAHC injection. The thermal oxidation exhibits higher hot-carrier resistance compared with the CVD

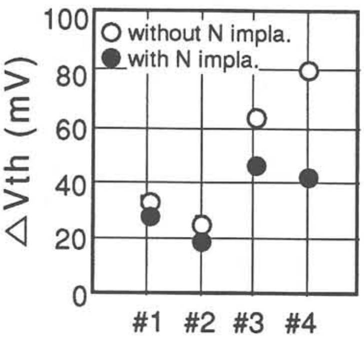

Fig. 4 Threshold voltage shift of PMOSFETs during the DAHC injection. The stress was applied at Vd=-5V, Vg=V(Igmax) for 1000 sec.

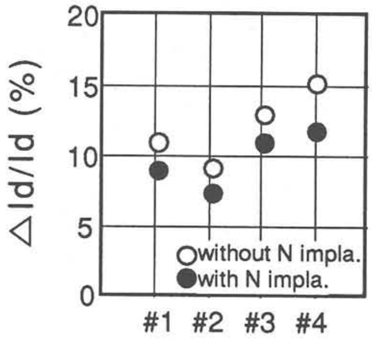

Fig. 5 Degradation of drain current for PMOSFETs during the DAHC injection.

method similar to the NMOSFETs. The hot carrier resistance can be also improved by the nitridation for all the measured samples as well as the case for NMOSFETs. Fig. 6 gives gate voltage shifts under the constant current injection at a current density of 2 mA/cm^2. The large shifts in the gate voltage caused by electron traps can be observed in the samples with the CVD oxide and the CVD stacked oxide. The electron traps can be also reduced by nitridation for all the oxide films. Moreover, the electron traps in the stacked CVD oxide film can be remarkably reduced to the level of the thermal oxide films by nitridation. It should be noted that the

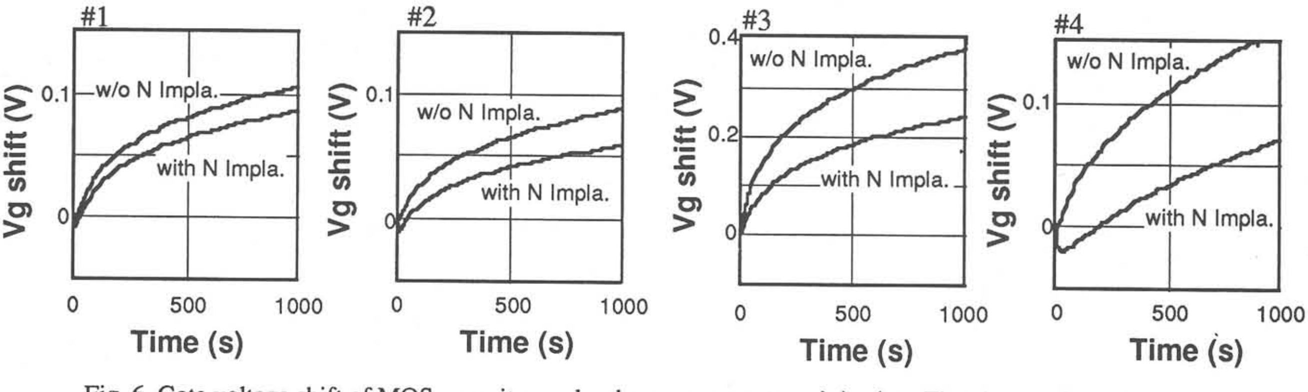

Fig. 6 Gate voltage shift of MOS capacitor under the constant current injection. The electron injection was performed from the substrate at the current density with 2 mA/cm^2.

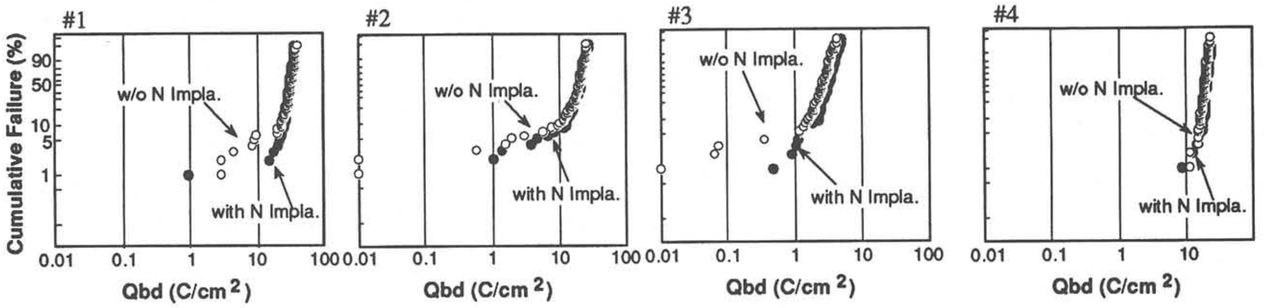

Fig. 7 Constant current TDDB characteristics of MOS capacitor with and without the nitrogen implantation into the gate polysilicon film. The electron injection was performed from the substrate at the current density with 0.1 A/cm^2.

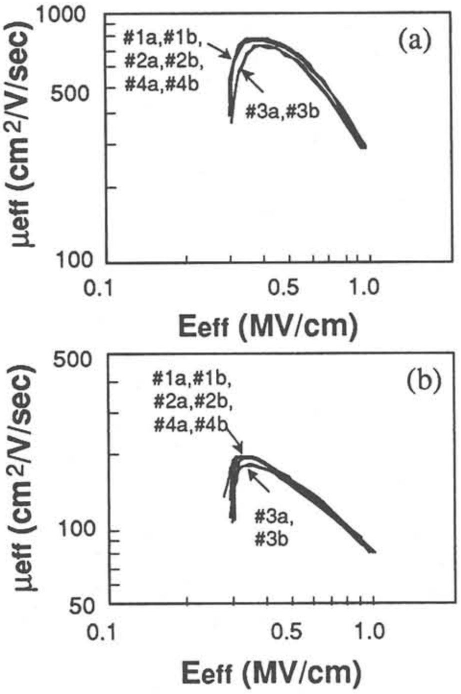

Fig. 8 The effective electron mobility (a) and hole mobility (b) of MOSFETs for various oxide films.

improvement in the hot-carrier hardness by nitridation can be explained by the suppression of interface state generation and the reduction of electron traps in the gate oxide films. Fig. 7 depicts the constant current TDDB characteristics of MOS capacitors, where the electron injection was performed from the silicon substrate at a current density of 0.1 A/cm^2. The CVD oxide film has small charge to breakdown values (Qbd) reaching the 50 % failure as compared with the other oxide films. This is attributed to large electron traps in the oxide films as mentioned before. It is found that the CVD stacked gate oxide shows the excellent TDDB characteristics. The random failures of gate oxide films, which should be attributed to the dopant diffusion into gate oxide films, can be reduced by nitridation for samples with the oxide formed in the pyrogenic steam ambient [6]. On the contrary, the deterioration of the gate oxide films, which can be attributed to the defect-related breakdown, cannot be reduced by nitridation as can be seen in the dry O_2 oxidation. Fig. 8 shows the effective electron and hole mobility of MOSFETs, respectively. The degradation of mobility is one of the major issues for the conventional nitrided oxide film. However, it is found that neither the electron nor the hole mobility is degraded by nitridation, while the reduction of mobility due to the surface scattering can be observed in the sample with the CVD oxide film in comparison with the other oxide films.

4. CONCLUSION

We have systematically studied the effect of nitridation on oxide properties using the nitrogen implantation technique. It is found that the hot-carrier degradation can be improved by the nitridation irrespective of oxide formation methods. This improvement is attributed to the suppression of interface states generation and the reduction of electron traps in the oxide film. Our extensive investigation concludes that the nitridation of gate oxide films using nitrogen implantation can be very promising for the improvement in high reliability in spite of the difference in oxide formation methods.

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