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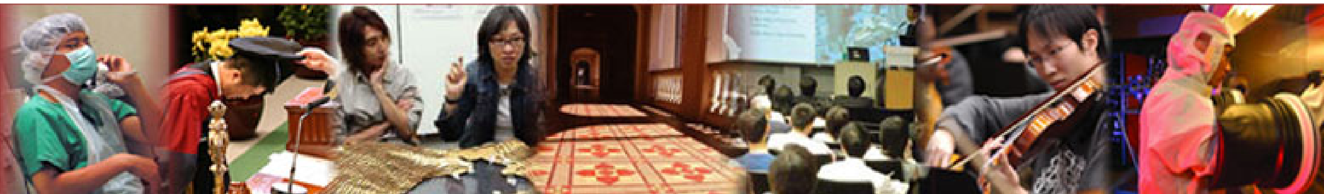

Title	A comparison between NO-annealed O2- and N2O-grown gate dielectrics
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A COMPARISON BETWEEN NO-ANNEALED O_2- AND N_2O-GROWN GATE DIELECTRICS

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Abstract - Qualities of oxynitrides prepared by annealing O_2- and N_2O-grown oxides in NO ambient are investigated. Harder oxide/Si interface, less charge trapping and higher charge-to-breakdown characteristics are observed in NO-annealed N_2O-grown (N2ONO) oxynitride than NO-annealed O_2-grown (O2NO) oxynitride. The involved mechanism lies in higher interfacial nitrogen concentration and total nitrogen content in N2ONO oxynitride than O2NO oxynitride for the same anneal temperature and time.

I. INTRODUCTION

Currently, for satisfying the needs of scaled MOSFET's, high-quality thin gate dielectric is desired, because the properties of conventional SiO_2 films are not acceptable for these very small-sized transistors [1-3]. As an alternative gate dielectric, oxynitrides have drawn considerable attention due to their superior performance and reliability properties over conventional SiO_2 [4-8]. However, NH_3-nitrided oxides suffer from hydrogen-related electron trapping problems [5-6] and N_2O-based oxides require a much larger thermal budget for sufficient nitrogen incorporation [9-10]. To avoid these disadvantages of NH_3 and N_2O, nitric oxide (NO) is proposed as a dielectric-growth/anneal ambient to obtain high quality ultrathin dielectric films [8, 11-16]. Furthermore, NO-annealed process (an initial oxide grown in pure oxygen and then annealed in NO ambient) is preferred to prepare oxynitride with desired thickness in a reasonable growth time, considering the self-limiting nature of the growth process in NO ambient. Recently, our studies show that if the initial oxide is grown in N_2O instead of O_2 and then annealed in NO ambient, much better dielectric film can be obtained.

II. EXPERIMENTAL

The MOS capacitors used in this study were fabricated on p-type (100) silicon wafers with a resistivity of 6-8 Ω-cm by a self-aligned n^+ polysilicon gate process. The initial gate oxide was grown to the same thickness in a conventional horizontal furnace in either dry O_2 or pure N_2O ambient at 950 °C. Then, they were annealed in pure NO ambient at 950 °C for 30 min (denoted as O2NO for O_2 growth and N2ONO for N_2O growth, respectively). Control samples with same film thickness were thermally grown also at 950 °C in dry O_2 (denoted as OX). All gate oxides finally received an *in situ* N_2 anneal at 950 °C for 20 min. Final oxide thickness (measured by C-V) was about 120 Å. Fowler-Nordheim constant-current stress with electron injection from the gate (negative gate bias) was used to evaluate the qualities of these gate dielectrics. In this case, the oxide/Si interface is the collecting electrode and the site of heaviest damage. The area of the capacitors were 10^{-4} cm^2. All measurements were carried out under light-tight and electrically shielded condition.

III. RESULTS AND DISCUSSIONS

Electron and hole trapping characteristics of oxide bulk are examined by monitoring the change in gate voltage (ΔV_G) to maintain a contant current density of 1 mA/cm^2 from the substrate and gate injections. For both injections, as shown in Figs. 1 (a) and (b), initial hole trapping is followed by electron trapping. For substrate injection, the N2ONO sample

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exhibits the highest hole trapping and lowest electron trapping, followed by the O2NO and OX samples. For gate injection, the two NO-nitrided samples suffer from much lower initial hole trapping than the OX sample, with the N2ONO sample the lowest. On the other hand, electron trapping of the three samples looks almost identical. These results are very similar to that in [17], which studied the effect of interfacial nitrogen concentration N_{int} on electron and hole trappings. Hence, it is reasonable to conclude that the N2ONO oxynitride has a higher N_{int} than the O2NO sample, indicating that double nitridation with N_2O growth followed by NO anneal is effective in obtaining higher N_{int} due to additional incorporation of nitrogen during N_2O oxidation. The good oxidation resistance of N_2O-grown oxide gives rise to very small thickness increase after NO annealing.

Hardness of the oxide/Si interface is evaluated by the increase of mid-gap interface-state density (ΔD_{itm}) after a constant-current stress of -10 mA/cm^2 for different times. As shown clearly in Fig. 2, the two nitrided samples exhibit greatly suppressed creation of oxide/Si interface states compared to the OX sample due to interfacial nitrogen incorporation, with the N2ONO sample having better interface properties than the O2NO sample. This should be attributed to higher N_{int} in the N2ONO oxynitride, since more nitrogen incorporation near the oxide/Si interface gives more strong Si-N and N-O bonds and consequently a much harder interface.

Fig. 3 is the corresponding flat-band voltage shift ΔV_{fb} under the same stress conditions as those used in Fig. 2. Like ΔD_{itm}, the N2ONO sample is most resistant to V_{fb} shift. A negative shift in V_{fb} indicates hole trapping which is likely due to generated donor-like interface states [18] and bulk trapping near the oxide/Si interface. So, it can be believed that creation of hole traps at/near the oxide/Si interface is more effectively suppressed for the N2ONO oxynitride than the O2NO oxynitride based on the same reasons as for ΔD_{itm}, although the N2ONO sample has more initial hole trapping for substrate injection, as shown in Fig. 1(a).

Presented in Fig. 4 is the measured charge-to-breakdown (Q_{BD}) of the oxides under a constant-current stress of -100 mA/cm^2. Improved Q_{BD} in oxynitrides relative to thermal oxide is observed, with the N2ONO oxynitride as the best once again. From [19], higher trap generation in oxide and especially at the interface leads to lower Q_{BD}. So, different charge-to-breakdown characteristics of the three gate dielectrics should result from their different oxide and oxide/Si interface hardnesses, as described above. Also, hole trapping seems not to directly affect Q_{BD} of oxynitrides, and this finding also agrees with the results in [17]. Therefore, it can be proposed that the larger amount of N in oxynitride near the interface is effective in considerably suppressing charge trapping and interface weakening.

IV. SUMMARY

Effects of NO-annealing on the qualities of O_2- and N_2O-grown oxides were investigated. It has been demonstrated that NO-annealed N_2O-grown oxynitride has better properties than NO-annealed O_2-grown oxynitride: harder oxide/Si interface, less charge trapping and higher charge-to-breakdown. These are associated with higher interfacial nitrogen concentration and total nitrogen content in the former. Higher nitrogen concentration is also beneficial to resist dopant penetration through the gate oxide, especially in p$^+$ poly-gate p-MOSFET' s of dual-gate CMOS technologies. Therefore, NO-annealed N_2O-grown process could provide a highly reliable gate dielectric for MOS devices.

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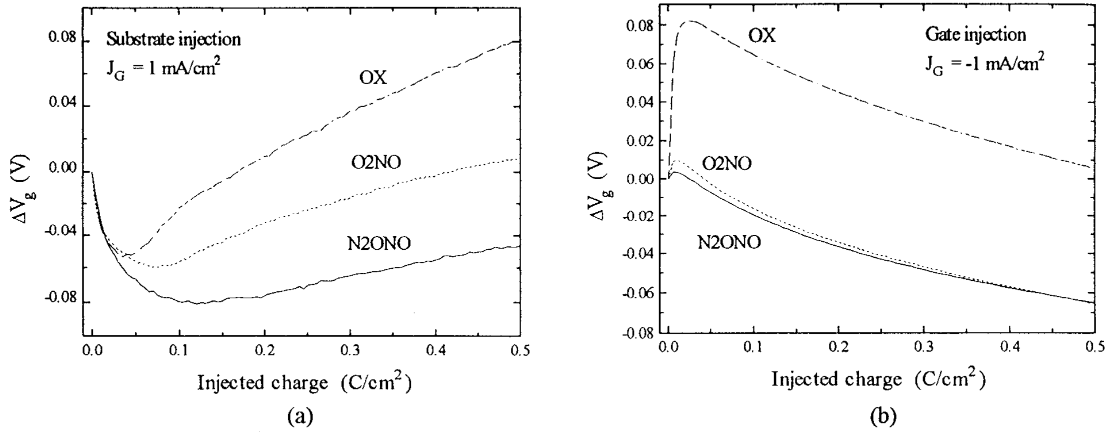

Fig. 1 Change in gate voltage of MOS capacitors under a constant-current stress of 1 mA/cm^2. (a) substrate injection and (b) gate injection.

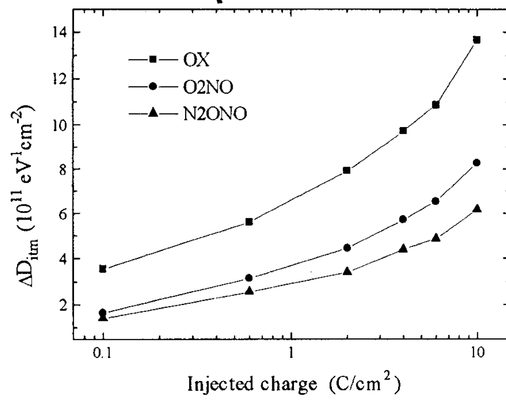

Fig. 2 Increase in midgap interface state density (ΔD_{itm}) of MOS capacitors with different gate dielectrics under a constant-current stress of -10 mA/cm^2.

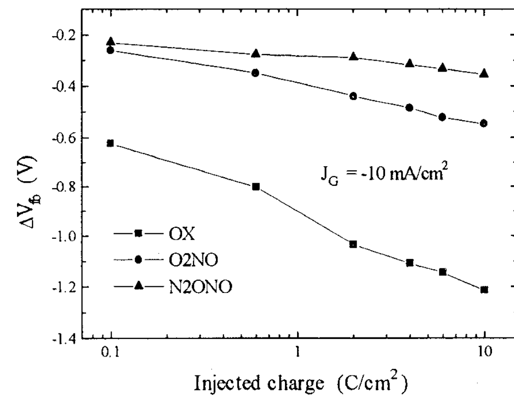

Fig. 3 Flat-band voltage shift of MOS capacitors with injected charge under the same stress conditions as those in Fig. 2.

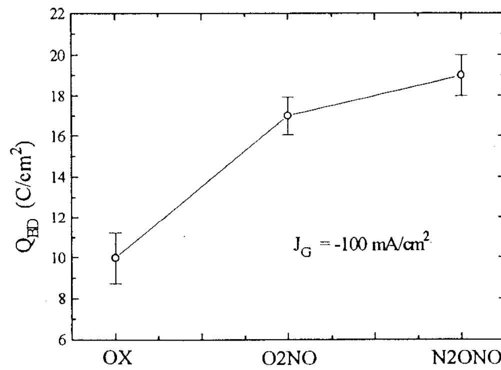

Fig. 4 Charge-to-breakdown (Q_{BD}) of the three gate dielectrics measured under a constant-current stress of -100 mA/cm^2.