CHARGE TRAPPING PROPERTIES OF N_2O-TREATED NH_3-NITRIDED OXIDES UNDER HIGH-FIELD STRESS

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Abstract - A new technique, namely N_2O treatment of NH_3-nitrided oxides (NON2O), is proposed to fabricate thin oxide. It is shown that the N_2O treatment is superior to conventional reoxidation step in improving charge trapping property and interface hardness of oxides under high-field stress.

I. INTRODUCTION

MOS VLSI circuits require devices with very thin gate and tunnelling oxides. The problems associated with charge flow under Folwer-Nordheim or hot carrier injection through such oxides are therefore of primary concern. Both bulk charge trapping and interface state generation take place during the injection and eventually lead to dielectric breakdown. On the other hand, various oxynitride dielectrics fabricated by different techniques have been extensively investigated to replace conventional SiO_2 in submicrometer MOS devices [1-10]. For example, NH_3-nitridation can introduce sufficiently high nitrogen concentration ([N]) at the Si/SiO_2 interface which improves the interface hardness against the hot-carrier bombardment. However, hydrogen is also incorporated in the resulting oxides, which increases electron trapping significantly [1]. Reoxidation of NH_3-nitrided oxides (RONO) can only partially eliminate the nitridation-induced electron traps [1, 2]. Recently developed N_2O-nitrided [3, 4] and N_2O-grown [5] oxides eliminate hydrogen-related species from fabrication environment, but these kinds of oxides may not contain sufficient [N] to prevent boron penetration. In this paper, a new technique, namely N_2O treatment of NH_3-nitrided oxides (NON2O), is proposed. The charge-trapping properties of this kind of oxides under F-N high-field stress is comparatively studied with other four kinds of oxides.

II. EXPERIMENTAL

MOS capacitors were fabricated on 6-8 Ω•cm (100) p-type Si substrates. Five kinds of gate dielectrics were prepared according to the conditions listed in Table 1. All gate oxides were finally annealed in N_2 at 950 °C for 25 min. Polysilicon-gate, 450 nm thick, was then deposited by LPCVD at 625 °C, followed by phosphorous diffusion at 950 °C and annealed in nitrogen at 960 °C for 20 min. Gates were defined by RIE etching. After Al metallization, the wafers were sintered in forming gas at 430 °C for 30 min. The final thickness of gate dielectrics is around 130 Å as measured by CV techniques. No passivation film was used. For this study we used square capacitors with an area of 100×200 μm^2. The experimental set-up used to test and stress the capacitors consisted of an HP 4145B semiconductor parameter analyzer for constant current injections, an HP 4140B pA meter and an HP 4284A precision LCR meter for quasi-static and high-frequency (1 MHz) C-V measurements respectively. F-N injections were performed at a constant current level of -1 mA/cm^2, which corresponds to an average electric field in the oxide of about 10 MV/cm. This current density is comparable to those encountered in E^2PROMs. C-V measurements are alternated with F-N injections to determine the flatband voltage (V_{FB}) and interface state density (D_{it-m}). Measurements show that the interruptions of injection necessary to record the C-V curves only negligibly affect the charges generated in the oxide. Since difference of gate voltages required to maintain constant current injection before and after C-V measurements is negligibly small (< 5 mV).

III. RESULTS AND DISCUSSIONS

Initial fixed charge (N_f) and midgap interface state density (D_{it-m}) extracted from CV data on capacitors with various gate dielectrics are illustrated in Table 2. Like the reoxidation step for RONO samples, the N_2O treatment on

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NO samples reduces the N_f to the similar level as RONO samples, and the D_{it-m} values are comparable among the N2ON, RONO, and NON2O samples.

Charge-trapping properties of NON2O oxides were studied by monitoring the changes in gate voltage (ΔV_G) to maintain a constant current density in MOS capacitors. As shown in Fig. 1, In general, NO oxides show the largest ΔV_G , indicating significant electron trapping by NH_3-nitridation-induced electron traps [6]. On the other hand, NON2O oxides show only a small ΔV_G, suggesting greatly suppressed electron trapping, which is comparable to N_2O-nitrided oxides (N2ON) and superior to RONO and conventional thermal oxides (OX). In detail, in the lower injection fluence region where ΔV_G does not go up linearly, electron trapping mainly takes place in the pre-existing traps. In NO oxides, hydrogen-related species such as -H and -OH bonds produced by the decomposition of NH_3 in the oxide bulk are mainly responsible for these traps [7]. Therefore, results in Fig. 1 indicate that N_2O treatment (NON2O oxide) is more effective in reducing these electron traps than reoxidation process (RONO oxide) by annealing out the hydrogen. The amount of pre-existing electron traps in NON2O oxides is similar to that in N2ON oxides. In the higher injection fluence region where ΔV_G goes up linearly, electron trapping is dominated in the newly generated electron traps. The generation rate is constant and proportional to dV_G/dF, where F is tunnelling fluence [8]. Consequently, the lowest electron trap generation rate is observed in Fig.1 for NON2O oxides.

Fig. 2 gives some typical quasi-static capacitance characteristics after 6 min of high-field injection. The extracted midgap interface-state creation (ΔD_{it-m}) due to constant current stress is presented in Fig. 3. NH_3 nitridation increases ΔD_{it} in pure oxides [9, 10]. However, ΔD_{it} in NON2O oxides is comparable to the N2ON oxides and superior to RONO and OX oxides. Large ΔD_{it} in NO oxides is attributed to a distorted interfacial region due to the formation of mismatched Si-N bonds in the Si-O network. Further N_2O treatment on NO oxides significantly suppresses this undesirable effect, as seen from Fig. 3.

Depicted in Fig. 4 is the corresponding flatband voltage shift (ΔV_{FB}) under the same stress condition. Unlike ΔV_G, which is most sensitive to charges located near the cathode, ΔV_{FB} is the combined effect of charge trapping at the interface states and in the bulk oxide, and mainly reflects charges near the Si/gate oxide interface [11]. A large positive ΔV_{FB} in NO oxide, shown in Fig. 4, indicates severe negative charge trapping, in this case, bulk trapping plays a major role in determining ΔV_{FB}. For the other four dielectrics, a negative ΔV_{FB} is observed, implying the trapping of positive charges. In this case, trapping at the interface dominates since bulk electron trapping is greatly suppressed for the four gate oxides, as is evident in Fig.1. The positive charges are due to the generated donor-like interface states [12], which are positively charged when they are unoccupied under C-V measurement conditions. As seen from Fig. 4, NON2O and RONO oxides exhibit least donor-type D_{it} generation.

IV. SUMMARY

In summary, a new technique of N_2O treatment on NH_3-nitrided oxide is applied to fabricate thin gate oxide. The charge-trapping properties under F-N constant current stress was comparatively investigated. We have found that this new kind of oxides (NON2O) has significantly lower pre-existing bulk electron traps and greatly suppressed bulk electron trap and donor-type interface state generation under F-N high-field stress.

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Table 1. Gate oxide fabrication conditions

samples	oxidation	nitridation	the third step
OX	O_2 , 850 °C, 70 min	-------	-------
N2ON	O_2, 850 °C, 60 min	N_2O , 950 °C, 35 min	------
NO	O_2 , 850 °C, 70 min	NH_3 , 950 °C, 35 min	-------
NON2O	O_2 , 850 °C, 65 min	NH_3 , 950 °C, 35 min	N_2O , 950 °C, 30 min
RONO	O_2 , 850 °C, 70 min	NH_3 , 950 °C, 35 min	O_2 , 950 °C, 15 min

Table 2. Initial properties of MOS capacitors studied

samples	OX	N2ON	NO	NON2O	RONO
N_f (10^{11} cm^{-2})	0.1	0.3	10	5	6
D_{it-m} (10^{11} $eV^{-1}cm^{-2}$)	0.6	1.7	3.0	1.8	1.6

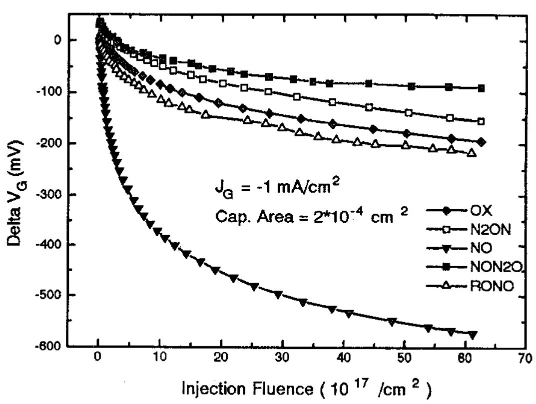

Fig. 1 Changes in gate voltage required to maintain a constant current density stress vs. injected electron fluence with different gate dielectrics.

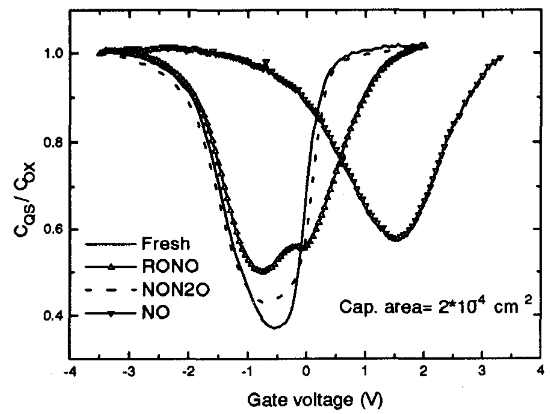

Fig. 2. Typical normalized quasi-static capacitance characteristics after 6 min of injection (J_G = -1 mA/cm^2) for several kinds of capacitors.

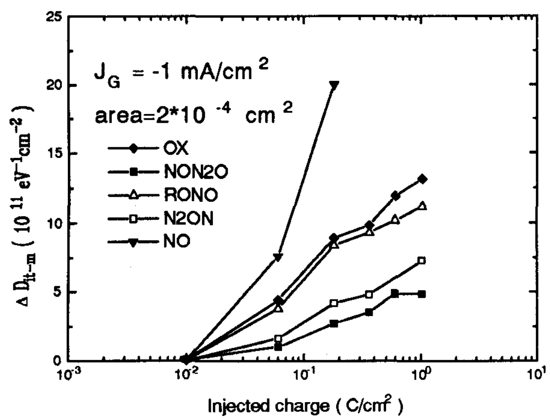

Fig. 3. Increase in midgap interface state density ($\Delta D_{it\text{-}m}$) in MOS capacitors with different gate dielectrics under F-N injection stress.

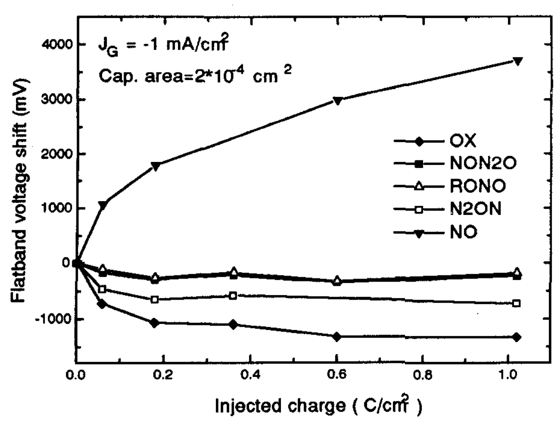

Fig. 4. Flatband voltage shift versus injected charge density for different gate dielectrics.