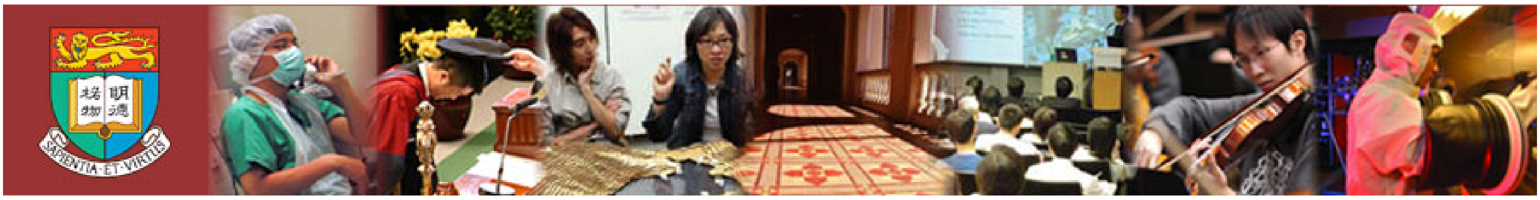

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Electrical Performance and Reliability of n-MOSFET's with Gate Dielectrics Fabricated by Different Techniques

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I. INTRODUCTION

There have been extensive studies on fabricating high-quality and reliable thin gate dielectrics for MOS applications in VLSI technology. Nitrogen incorporation into the gate oxide is one of the promising methods to achieve excellent immunity to hot-carrier degradation, and effective diffusion barrier against dopants. Many techniques have been proposed [1-4], and among these, reoxidized NH_3-nitrided SiO_2 and N_2O-based dielectrics have received most attention. Compared with NH_3-based processes, the N_2O-based processes have an important advantage in addition to the process simplicity, i.e., the absence of any hydrogen-related species during processing, which are believed to be the cause of an increase in electron traps in the gate oxide [5]. In this paper, electrical characteristics and reliability of n-MOSFETs under DC/AC stress are investigated and results are compared among the devices with gate dielectrics fabricated by different techniques.

II. EXPERIMENTAL

n-MOSFETs were fabicated on p-type (100)-oriented silicon wafers (8~10 Ω-cm) by a conventional polysilicon self-aligned MOS process. Four kinds of gate dielectrics were prepared as shown in Table 1. All gate oxides were finally annealed in N_2 at 950°C for 25 min. Oxide thickness was measured by CV technique, the value is 94Å for N_2O-grown oxide, and 99Å for other gate oxides. No passivation film was used. Devices with 1μm/60μm effective channel length/width were used in this work.

Table 1. Preparation sequences of gate oxide employed in this study

sample	oxidation	nitridation	reoxidation
OX	O_2, 850°C, 35min	-------	-------
NO	O_2, 850°C, 35min	NH_3, 950°C, 35min	-------
RONO	O_2, 850°C, 35min	NH_3, 950°C, 35min	O_2, 950°C, 15min
N2OG	N_2O, 950°C, 30min	-------	-------

III. RESULTS AND DISCUSSION

Drain current and transconductance versus gate drive measured in linear and saturation regions (Vd=50mV and 3.5V) are shown in Fig.1 and Fig.2 respectively. Devices with control (OX) and N_2O-grown (N2OG) gate oxides exhibit better subthreshold slopes (~ 125 mV/decade for N_2O-grown oxide and ~150 mV/decade for control gate oxide) than the NO device (~250 mV/decade), as can be seen from Fig.1(a). This agrees well with the interface state density values obatined from MOS capacitors using CV techniques. (~1.5×10^{10} $cm^{-2}\cdot eV^{-1}$ for OX and N_2O-grown oxides and ~3×10^{11} $cm^{-2}\cdot eV^{-1}$ for NO oxide). Fig.1(b) shows that the Gm of the device with N_2O-grown gate oxide is improved in both the low and high Vg regions comparing to the control (OX) device. This result is different from that in the device with NH_3-nitrided (NO) gate oxide [1], [6], where Gm is improved only in the high Vg region but degraded in the low Vg region, also shown in Fig.1(b). The degradation of G_m in NO device in the low Vg region was attributed to Coulombic

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scattering due to nitridation-induced fixed-charge, interface state charge, and/or near-interface electron trapping [7]. The near-interface bulk electron traps can capture electrons tunneled from the channel regions, and thus reduce the density of channel mobile charge. In addition, those trapped electrons serve as additional Coulombic scattering centers, thus the electron mobility is reduced. One possible reason for Gm improvement in the low Vg region for N2OG device is due to the improved charge trapping property demonstrated by small gate voltage shift during constant current stress [8]. This is also verified by the better stability of N2OG device under channel hot-electron injection as presented in Fig.4. Another possible reason is the effect of residual mechanical stress [1]. N_2O-based oxide is supposed to have less compressive stress due to the compensating tensile stress effect through nitrogen incorporation at the interface. Fig.2(a) and (b) illustrate the improved current drivability (Id) and transconductance (Gm) in the saturation region (Vd=3.5V) for n-MOSFET with N_2O-grown gate oxide, as compared to the control and NO devices. Similar results were reported in [9] for n-MOSFET with N_2O-nitrided gate oxide. It is worth noting that Gm starts to degrade beyond $Vg\text{-}V_t \sim 3V$ for the N2OG device. This may result from $\mu_{n,eff}$ degradation at higher vertical field [10]. In Fig.3, better characteristics of N2OG device than OX device were confirmed, especially under high Vg. Even under low Vg, the drivability is comparable to that of the pure gate oxide sample. This is different from the RONO device, which exhibits lower current drivability under low gate drive voltage [11].

Presented in Fig.4 is the stress-time dependence of V_t and G_m instability induced by channel hot-carrier stress (CHCS). The stress condition was chosen to result in channel hot-electron injection into the gate oxide ($Vg=V_d=7V$). V_t shift is much smaller for the RONO and N2OG devices than the control device, implying electron trapping is significantly suppressed by the nitridation steps. The n-MOSFET with N_2O-grown gate oxide shows the least ΔG_m, indicating improved interface hardness against CHCS. The improved interface hardness and suppressed electron trapping are believed to be due to interfacial strain relaxation as well as substitution of Si-O bonds with stronger Si-N bonds through the formation of oxynitride (SiO_xN_y) [12], and the elimination of H-related species during the N_2O nitridation process.

Fig.5 depicts V_t shifts for OX, RONO and N_2OG gate oxide devices subjected to AC stress and then DC stress continuously. As can be seen clearly that N_2O device has very stable V_t under the whole combined AC/DC stress, while OX device has a slight V_t increase (~37mV) in the AC stress session, but a very large increase in V_t (~410mV) in the subsequent DC stress, which results from channel hot electron injection. It should be noted that the V_t shift here during DC stress session is even larger than that shown in Fig.4(a) (~210mV) for fresh OX device, although lower stress voltage ($Vg=V_d=5V$) was employed, suggesting large amount of electron traps was created during the AC stress in the pure thermal gate oxide. On the other hand, the same AC stress did not generate any significant amount of electron traps in the RONO and N_2O-grown gate oxide, indicating device reliability with nitrided gate oxides is also enhanced under dynamic stress. Again, N_2O-grown oxide behaves even better than reoxidized NH_3-nitrided oxide.

IV. CONCLUSION

N_2O nitridation is a more promising technique to incorporate nitrogen into gate oxide than NH_3 nitridation both from the view of electrical performance and stability under CHCS and dynamic stress.

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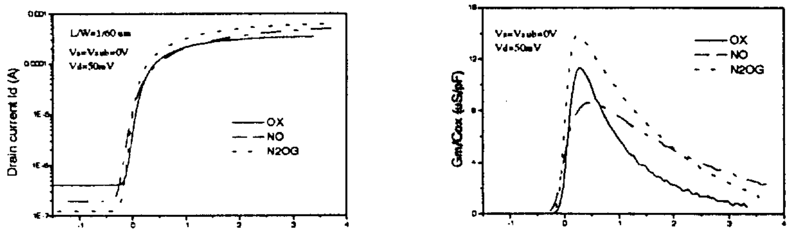
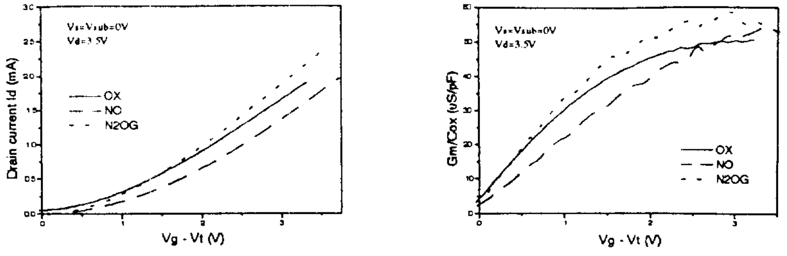


(a) (b)

Fig.1. (a) Id and (b) Gm measured at linear region (Vd=50mV) as a function of gate drive for n-MOSFET's (Leff/Weff=1.0/60 μm) with control(OX), NH_3-nitrided (NO), and N_2O-grown (N2OG) thermal gate oxides.



(a) (b)

Fig.2. (a) Id and (b) Gm measured at saturation region (Vd=3.5V) for n-MOSFETs with control (OX), NH3-nitrided (NO), and N2O-grown (N2OG) thermal oxides.

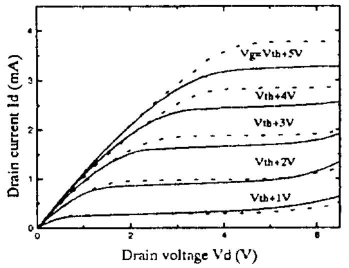


Fig.3. Id - Vd characteristics. Dot lines for N2OG device, and solid lines for control (OX) device.

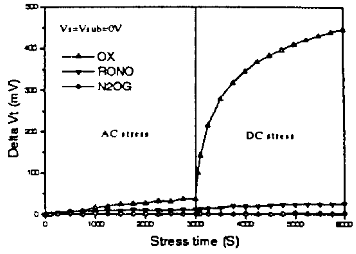
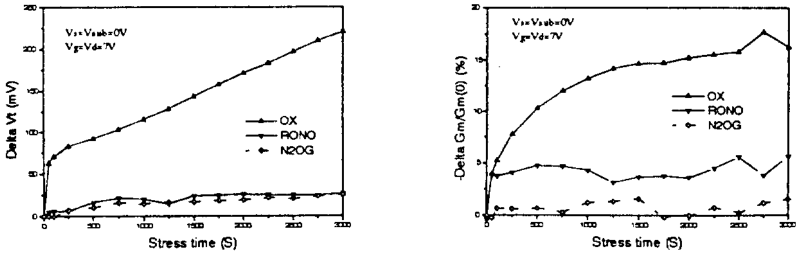


Fig.5. V_t shifts versus stress time during AC stress and subsequent DC stress for OX, RONO, and N2OG devices. For AC stress, Vd = 5V and Vg was pulsed between Vgl =0V and Vgh = 5V at a frequency of 100kHz with 50% duty cycle squarewave. For DC stress, Vg=Vd=5V



(a) (b)

Fig.4. Stress-time dependence of (a) V_t shift and (b) G_m degradation under channel hot electron stress (Vg=Vd=7V) for n-MOSFETs (Leff/Weff=1/60μm) with control (OX), reoxidized NH_3-nitrided (RONO), and N_2O-grown (N2OG) thermal oxides.