

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

Zeng Xu, P. T. Lai, and W. T. Ng

Dept. of Electrical and Electronic Engineering, The University of HongKong.

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 NH₃-nitrided SiO₂ and N₂O-based dielectrics have received most attention. Compared with NH₃-based processes, the N₂O-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-MOSFET's under DC/AC stress are investigated and results are compared among the devices with gate dielectrics fabricated by different techniques.

II. EXPERIMENTAL

n-MOSFET's were fabricated 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 N₂ at 950°C for 25 min. Oxide thickness was measured by CV technique, the value is 94Å for N₂O-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 ₂ O, 950°C, 30min	-----	-----

III. RESULTS AND DISCUSSION

Drain current and transconductance versus gate drive measured in linear and saturation regions (V_d=50mV and 3.5V) are shown in Fig.1 and Fig.2 respectively. Devices with control (OX) and N₂O-grown (N2OG) gate oxides exhibit better subthreshold slopes (~ 125 mV/decade for N₂O-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 obtained from MOS capacitors using CV techniques. (~1.5×10¹⁰ cm⁻²·eV⁻¹ for OX and N₂O-grown oxides and ~3×10¹¹ cm⁻²·eV⁻¹ for NO oxide). Fig.1(b) shows that the G_m of the device with N₂O-grown gate oxide is improved in both the low and high V_g regions comparing to the control (OX) device. This result is different from that in the device with NH₃-nitrided (NO) gate oxide [1], [6], where G_m is improved only in the high V_g region but degraded in the low V_g region, also shown in Fig.1(b). The degradation of G_m in NO device in the low V_g region was attributed to Coulombic

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 G_m improvement in the low V_g 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]. N₂O-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 (I_d) and transconductance (G_m) in the saturation region ($V_d=3.5V$) for n-MOSFET with N₂O-grown gate oxide, as compared to the control and NO devices. Similar results were reported in [9] for n-MOSFET with N₂O-nitrided gate oxide. It is worth noting that G_m starts to degrade beyond $V_g-V_t \sim 3V$ 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 V_g . Even under low V_g , 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 ($V_g=V_d=7V$). 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 N₂O-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 N₂O nitridation process.

Fig.5 depicts V_t shifts for OX, RONO and N₂OG gate oxide devices subjected to AC stress and then DC stress continuously. As can be seen clearly that N₂O device has very stable V_t under the whole combined AC/DC stress, while OX device has a slight V_t increase ($\sim 37mV$) in the AC stress session, but a very large increase in V_t ($\sim 410mV$) 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) ($\sim 210mV$) for fresh OX device, although lower stress voltage ($V_g=V_d=5V$) 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 N₂O-grown gate oxide, indicating device reliability with nitrided gate oxides is also enhanced under dynamic stress. Again, N₂O-grown oxide behaves even better than reoxidized NH₃-nitrided oxide.

IV. CONCLUSION

N₂O nitridation is a more promising technique to incorporate nitrogen into gate oxide than NH₃ nitridation both from the view of electrical performance and stability under CHCS and dynamic stress.

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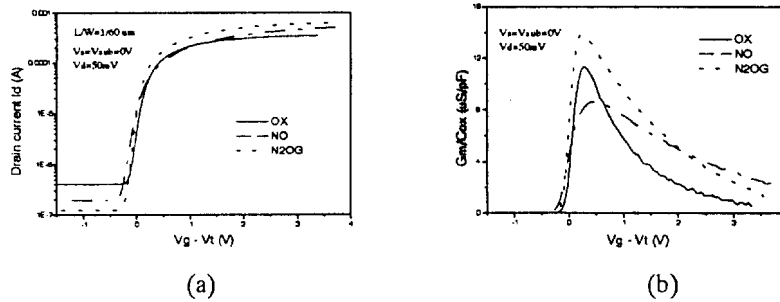


Fig.1. (a) I_d and (b) G_m measured at linear region ($V_d=50\text{mV}$) as a function of gate drive for n-MOSFET's ($L_{eff}/W_{eff}=1.0/60 \mu\text{m}$) with control(OX), NH_3 -nitrided (NO), and N_2O -grown (N₂OG) thermal gate oxides.

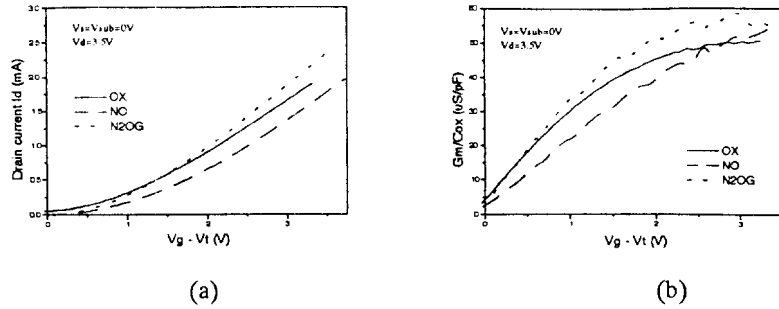


Fig.2. (a) I_d and (b) G_m measured at saturation region ($V_d=3.5V$) for n-MOSFET's with control (OX), NH_3 -nitrided (NO), and N_2O -grown (N2OG) thermal oxides.

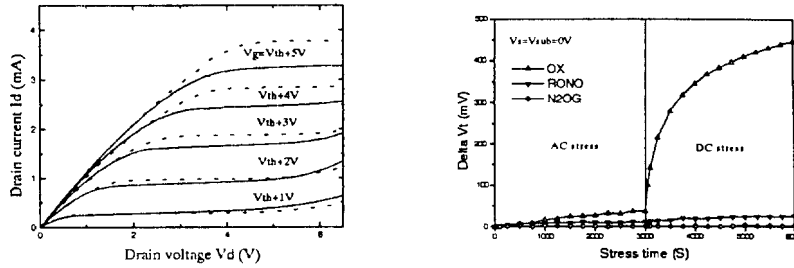


Fig.3. $I_d - V_d$ characteristics. Dot lines for N2OG device, and solid lines for control (OX) device.

Fig.5. V_t shifts versus stress time during AC stress and subsequent DC stress for OX, RONO, and N2OG devices. For AC stress, $V_d = 5V$ and V_g was pulsed between $V_{g1} = 0V$ and $V_{g2} = 5V$ at a frequency of 100kHz with 50% duty cycle squarewave. For DC stress, $V_g = V_d = 5V$

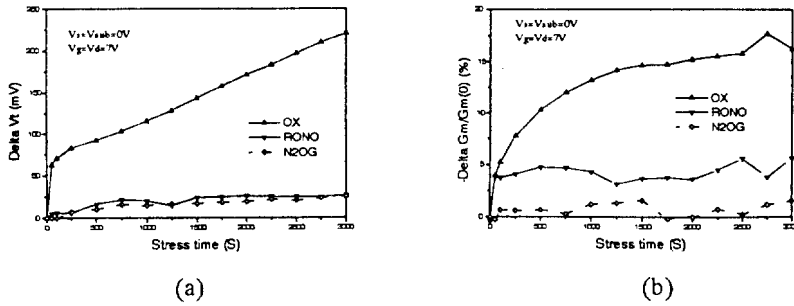


Fig.4. Stress-time dependence of (a) V_t shift and (b) G_m degradation under channel hot electron stress ($V_g=V_d=7V$) for n-MOSFET's ($L_{eff}/W_{eff}=1/60\mu m$) with control (OX), reoxidized NH_3 -nitrided (RONO), and N_2O -grown (N2OG) thermal oxides.