Suppression of Plasma Charging Damage in MOSFET's with Gate Oxynitride by Two-step Nitridation

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INTRODUCTION

Plasma charging effect is likely to make a great impact on the reliability of MOS devices while the thickness of gate dielectric scales down. Strengthening the robustness of the gate dielectric is one of the strategies to reduce the damage induced by plasma charging effect. Many studies imply gate oxynitride formed by Rapid Thermal Process (RTP) in N_2O is effective in reinforcing the robustness of Si/gate-dielectric interface and the gate-dielectric itself [1]-[3]. The Si-N bonds due to nitrogen pile-up at this interface can apparently reduce the strain and the amount of imperfect bond [4],[5], which is advantageous to reduce the traps increment after plasma process. To create a similar nitrogen pile-up at the interface of gate-electrode/oxynitride, the second nitridation is performed at a lower temperature with short time as compared to the first one. Better gate dielectric integrity and interface characteristic by lower temperature in shorter time provides a less possibility of both incremental nitrogen concentration in the oxynitride bulk and reduced nitrogen concentration induced by diffusion at the substrate/oxynitride interface [6]. The nitrogen pile-up at the gate-electrode/oxynitride interface also ensures the reliability improvement in MOS capacitors. Yet, the impact related to the plasma process induced damage in MOSFET's hasn't been discussed.

EXPERIMENTAL

NMOSFET's are fabricated on the (100) 6 inch P-type wafers with resistivity 15~25Ω-cm by standard metal-1 MOS process. In addition to gate oxide as control samples (O),the oxynitride samples include one-step nitridation in N_2O (OR, 900℃/15sec) and two-step nitridation in N_2O (ORR, 900℃/15sec + 850℃/15sec). All gate dielectrics has a thickness of 4.1nm, as verified by ellipsometry. Poly-Si is then deposited on the gate dielectrics and patterned by Electron Cyclotron Resonance (ECR) etching. Metal is sputtered and patterned by Helicon Wave Plasma (HWP) etching. The gate width/length ratio of all devices is 20μm/0.8μm. To investigate the plasma charging effect, different peripheral antennas of Poly-Si (4.2, 80.2, 320.2 mm) are designed with the same antenna area ratio (ARR= area ratio of poly-Si over active gate =10k). The concentration profiles of nitrogen and hydrogen in the oxynitrides were analyzed by the secondary ion mass spectroscopy (SIMS). Hot-carrier-stress with the same maximum substrate current is utilized to characterize the electrical property by HP4156B.

RESULTS AND DISCUSSIONS

The SIMS profiles for gate oxynitrides are shown in figure 1. A nitrogen pile-up formed by the second nitridation is seen at the poly-Si/oxynitride interface in Fig 1(a). The lower temperature in short time of the second nitridation step provides negligible increase of nitrogen concentration in the dielectric bulk. In figure 1(b), the hydrogen concentration is apparently reduced in the sample ORR and the peak value is much away from the oxynitride/substrate interface as compared to that for sample OR. The hydrogen diffused from the poly-Si is obviously suppressed, which is attributed to the nitrogen pile-up at the poly-Si/oxynitride interface. The reduction of detrimental hydrogen diffusion leads to the improved reliability in the gate oxynitride. Therefore, the oxynitride underwent two-step nitidation provides a stronger resistance against plasma charging effect due to the nitrogen pile-up at poly-Si/oxynitride interface.

Figure 2 shows (a) the degradation of maximum transconductance Gm and (b) the shift of threshold voltage Vt of MOSFET's with different antenna periphery after hot carrier stress for 3000 seconds. The degradation of transconductance increases with the antenna length, which obviously verify the existence of plasma charging effect. The degradation increases continuously in sample O while it seems to ease down in samples with nitridation. Once the antenna length starts to raise (4.2 mm to 80.2 mm), sample with two-step nitridation has the smallest increment and clearly shows ability to resist plasma charging damage.

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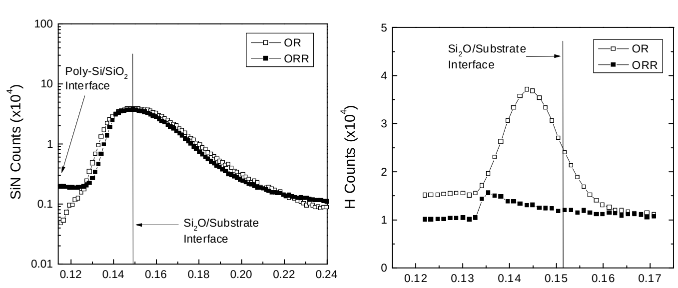

(a) (b)

Figure 1

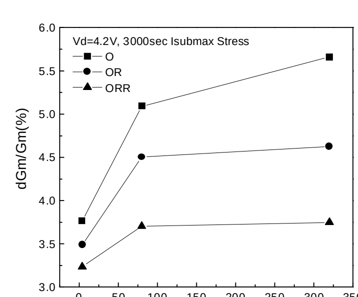

Figure 2