Rapid Thermal and Anodic Oxidations of LPCVD Silicon Nitride Films

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Introduction

For CMOS devices shrink further into the deep submicron range, alternative high k materials should be considered for reducing the gate leakage current. Silicon-based Si_3N_4 is attractive because of the material compatibility and high permittivity (k=7.2). However, non-stoichiometric Si-rich Si_3N_4 films can severely degrade the dielectric quality. In this work, we focus on the post-oxidation effects on the quality of CVD silicon nitride.

Experiment

Ultra-thin Si_3N_4 (T_{ox}=20Å-30Å) is grown by LPCVD with SiH_2Cl_2 and NH_3. These CVD Si_3N_4 films were then oxidized by rapid thermal oxidation at 850℃ in O_2 ambient and constant field anodic oxidation in DI water followed by N_2 annealing. SIMS, XPS were utilized to analyze the depth profile and atomic concentration. Also, electrical property is analyzed by J-V measurement.

Results and Discussions

Oxidant species react with the silicon nitride by substituting the unstable nitrogen bonding or Si dangling bond, and move toward the underneath silicon. Therefore, " SiO_2"–like layers on the surface and around the interface, and " Si_3N_4"– like layer between them are observed as shown in Fig.1. More oxygen was found to be incorporated in the anodic Si_3N_4 film and reduce the nitrogen bonding rather than the thermal oxidation one. Atomic concentration of as grown Si_3N_4 and oxidized Si_3N_4 are observed in Fig. 2. The native oxide is easy to form in the ultra-thin CVD Si_3N_4 as shown in Fig. 2(a). After oxidation, SiO_2-like layers are grown on the surface of both samples as shown in Fig. 2(b) and 2(c). A nearly stoichiometric SiO_2 is observed on the anodic Si_3N_4 surface that may attribute to the field enhanced replacement of unstable nitrogen. We believe the imperfect Si_2=N and Si dangling bonds can be oxidized into Si_2=N-O or SiO_2, and the stoichiometric Si_3≡N bonding is not affected during oxidation. Gate leakage current comparison is shown in Fig.3. Post-oxidation presents a dramatic improvement in the nitride property. Moreover, the Si_3N_4-like layer between two SiO_2-like layers can maintain the high-k characteristic, thus an almost two orders of magnitude lower leakage current than SiO_2 under EOT=20Å is observed. For the rapid thermal and anodic oxidations treated samples under EOT=30Å, the more oxygen incorporation in the anodic Si_3N_4 may account for the lower leakage current since the higher bandgap (~9eV) of SiO_2-like layer can block the carrier from migrating through the dielectric and reduce the trap-assisted tunneling.

Conclusion

Post-oxidation plays an important role to enhance CVD nitride quality. It is found that the O atom is easier to incorporate into the Si_3N_4 film by anodic oxidation than thermal oxidation that is helpful to reduce the gate leakage current. Therefore, if one can well control the oxidation condition, Si_3N_4 could be a promising high-k dielectric for the advanced process utilization.

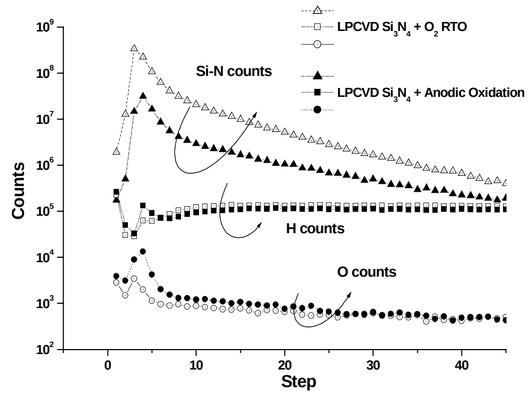

Fig. 1 SIMS depth profile analysis of rapid thermal oxidation and anodic oxidation treated CVD Si_3N_4.

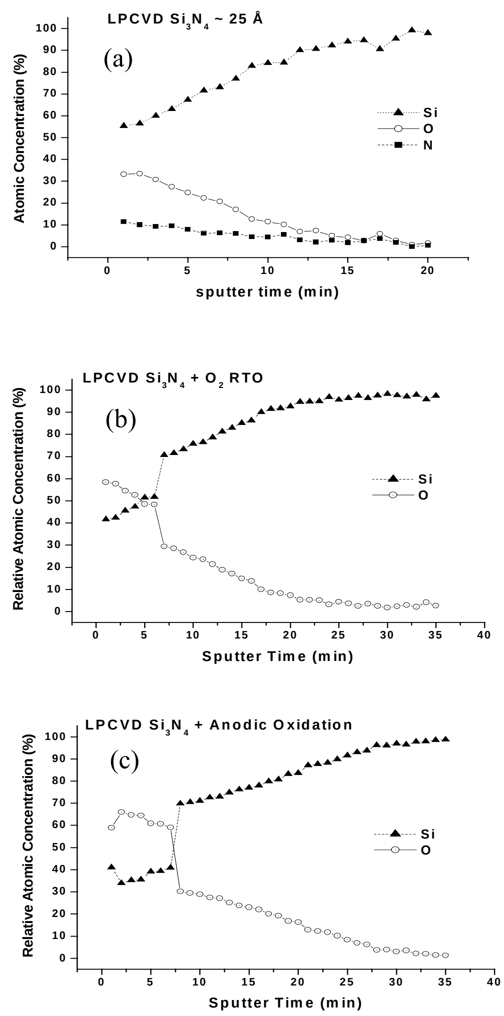

Fig. 2 XPS atomic concentration analysis of (a) as-grown CVD Si_3N_4, (b) followed by rapid thermal oxidation and (c) by anodic oxidation.

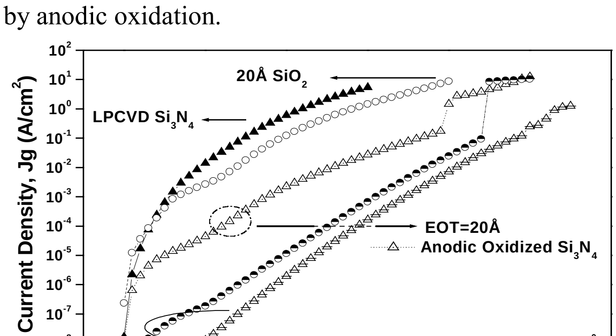

Fig. 3 J-V comparison of conventional SiO_2, as grown CVD Si_3N_4 and rapid thermal oxidation and anodic oxidation treated Si_3N_4.