Electrical Characterization of Directly Deposited La-Sc Oxides Complex for Gate Insulator Application

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Abstract

This study reports the electrical characteristics of La-Sc oxides complex and effect of nitrogen incorporation for applications to high-k gate stack. We found that V_{fb} can be controlled by the ScO concentration. Moreover, large bumps in C-V curves, which indicate high interfacial state density, can be suppressed with large ScO concentration. nMOSFETs using the La-Sc oxides complex in the gate stack are fabricated. In addition, nitrogen incorporation into the La-Sc oxide films was fond to be useful to suppress the EOT growth during annealing at high temperatures.

Keywords: High-k; rare earth oxides; V_{fb} shift; MOSFET;

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1. Introduction

The scaling of the SiO_2 gate dielectric in metal oxide semiconductor field effect transistor (MOSFETs) is approaching its fundamental limit. The thickness of the SiO_2 used as the gate dielectric is so thin that the gate leakage current due to direct tunneling of electrons becomes too high. As a result, power consumption increases to unacceptable level. A solution to the excess tunneling current is to replace SiO_2 with a new material with higher dielectric constant (high-k). One of candidate materials is the lanthanum scandium oxides ($LaScO_3$) which has high dielectric constant and high band offsets [1], [2].

In this study, we investigate the electrical characteristics of the La-Sc oxides complex with various concentrations through the evaluation of MOSCAP and MOSFET characteristics. We also demonstrate nitrogen incorporated oxides (LaScON) for high temperature endurance.

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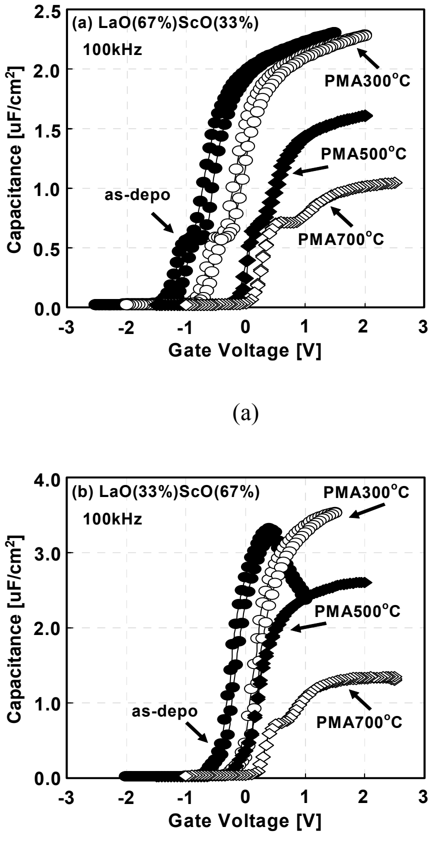
2. Experimental

After the n-Si (100) substrates were cleaned with H_2SO_4/H_2O_2 mixture and diluted HF treatment, La-Sc oxides complex was deposited on the substrates using E-beam evaporation at 300 ºC. For the nitridation process, N was incorporated to the oxides films by irradiation of N radicals generated by RF plasma. Tungsten (W) gate electrodes were formed by RF sputtering without breaking the ultra-high vacuum to avoid absorption of moisture from the air [3]. Post-metallization annealings (PMA) were performed at 300 ºC, 500 ºC and 700 ºC in N_2 ambient for 5 min. The source/drain pre-formed p-type Si (100) substrates were also used to fabricate nMOSFETs. An Al film was evaporated on the back side of the substrate as a contact for electrical measurements.

3. Results & Discussion

Fig. 1 shows the C-V curves of the fabricated La-Sc oxide capacitors with (a) low (33%) and (b) high (67%) ScO concentration. Large bumps in C-V curves, which indicate high interfacial state density, were observed in the case of low ScO concentration. On the other hand, the C-V curves indicating lower interfacial state density as well as small hysteresis were obtained for the high ScO concentration case. Considering the large bump reported for the La_2O_3/Si capacitors [1], the incorporation of Sc into La_2O_3 can play a role to suppress the interfacial state density. The Sc_2O_3/Si capacitors with low annealing temperature showed large hysteresis of 0.3V (Fig.2), therefore small amount of La incorporation to Sc_2O_3 can reduce the charge trapping. The PMA at higher temperature leads to lower capacitance value. This is in contrast to La_2O_3/ Sc_2O_3/Si laminated gate oxide reported in ref [4]. Flatband voltage (V_{fb}) of the as PMA300 ºC capacitors are summarized in Fig. 2. Higher LaO concentration leads to negative shift, which is in good agreement with reported V_{fb} shift reported in [5], and it would be suitable for band edge threshold voltage (Vt) control. However, excessively negative V_{fb} is not desirable for pMOSFETs as the Vt would be high. On the other hand, the Sc_2O_3 film induces positive V_{fb} shift even taking the large hysteresis into account. Therefore, large negative V_{fb} shift induced by La_2O_3 can be



(a)

(b)

Fig.1. High frequency C-V curves of (a) LaO(67%) ScO(33%) and (b) LaO(33%) ScO(67%) capacitors

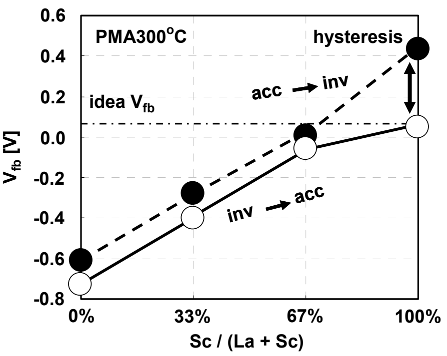


Fig.2. V_{fb} Shift as a function of Sc concentration observed from C-V curves exhibiting hysteresis

controlled by incorporation of the ScO. Considering the ideal V_{fb} of 0.06V obtained on the $W/SiO_2/Si$, 67% of ScO concentration seems to be optimum to cancel the effect of La.

Fig. 3 represents the V_{fb} with different composition ratio as a function of annealing temperature. The results show that the amount of V_{fb} shift increases with concentration of LaO.

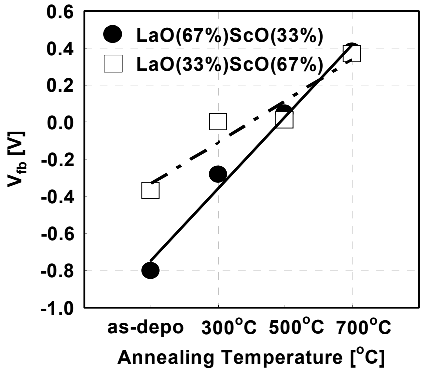


Fig.3. V_{fb} shift as a function of annealing temperature

nMOSFETs with gate dielectric of the La-Sc oxides complex were fabricated and the Vt shifts were investigated. Figure. 4 shows the I_d-V_d characteristic of the fabricated MOSFET annealed at 500 ºC. Figure. 5 shows I_d-V_g characteristics of MOSFETs with oxides complex of ScO(33%) and ScO(67%). The Vt of the MOSFETs annealed at 500 ºC were almost identical, however, there is a Vt shift between MOSFETs annealed at 500 ºC and 700 ºC. This Vt shift due to different annealing temperatures can be understood from the V_{fb} data (Fig.3). In addition, larger transconductance was obtained in the case of ScO concentration of 67%. The large bump in the C-V curve for the low ScO concentration (shown in Fig. 1 (a)), is considered to be related to the low transconductans as shown in Fig. 4. The very low transconductance for the 700 ºC PMA case is also understood by the much larger bump in the C-V curve as shown in Fig. 1 (a). From these results, it is found that high (67%) ScO concentration better for the characteristics in this study.

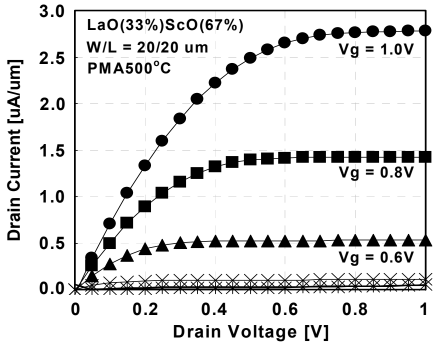


Fig.4. I_d-V_d characteristics of nMOSFET

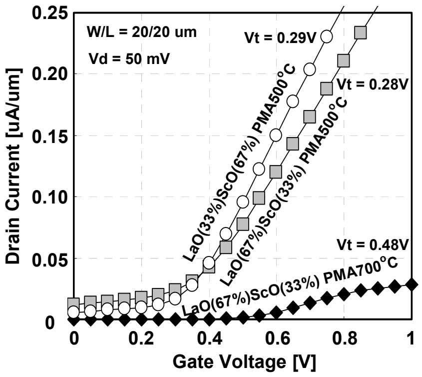
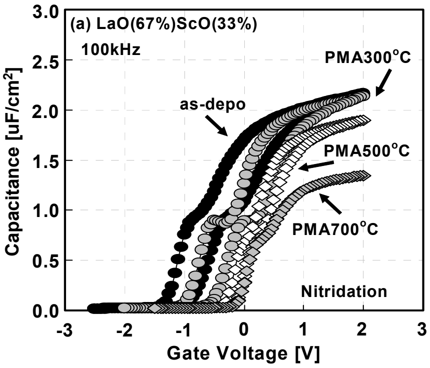
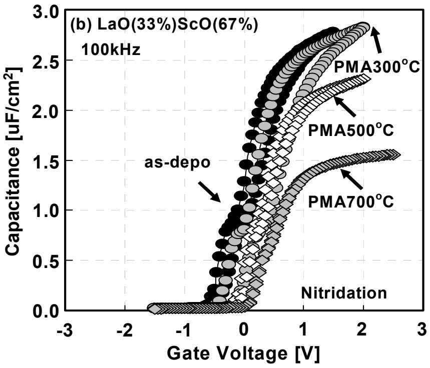


Fig.5. I_d-V_g characteristics of nMOSFET

The EOT after the high temperature PMA increased in all cases. Therefore, the effects of nitrogen incorporation into the La-Sc oxides complex gate insulator were investigated. Figure. 6 (a) and (b) show the C-V curves with low (33%) and high (67%) ScO concentration, in which nitrogen is incorporated. All the samples, except for 700 ºC PMA, showed large hysteresis compared to those of Fig.1. V_{fb} shift along PMA temperature became slightly smaller by the nitrogen incorporation. Besides, V_{fb} shift was much smaller in the case of higher ScO concentration. Figure. 7 shows the EOT change along PMA temperature. Samples with N incorporation showed better endurance, which indicates suppression of low-k interfacial layer formation. However, the large hysteresis induced by the N incorporation could be attributed to degraded interfacial structures. A possible reason for the large hysteresis is due to the SiN_x like defects in the interfacial layer.



(a)



(b)

Fig.6. High frequency C-V of nitrogen incorporated (a) LaO(67%) ScO(33%) and (b) LaO(33%) ScO(67%) capacitors

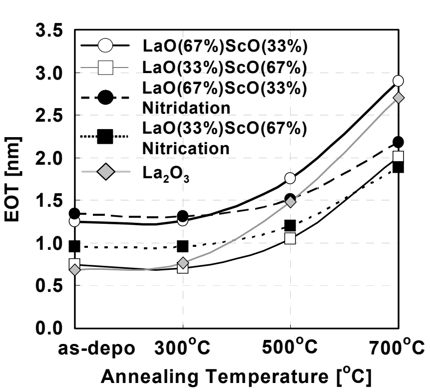


Fig.7. EOT change as a function of annealing temperature

4. Conclusion

We have investigated the electrical characteristics of MOSCAP and MOSFET with La-Sc oxides complex and effects of nitridation of the oxides. The complex films with concentration of 67% ScO exhibited good properties at low temperature PMA. The nMOSFETs performance was also successfully demonstrated using the La-Sc oxides complex. The nitrogen incorporation into the oxide films induced the large hysteresis on the C-V curves, however, suppress the EOT growth at high temperature PMA .

Acknowledgements

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