Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 170–171

A-4-4

A Comparative Examination of Polyoxide Films Performance Grown by Conventional Dry Thermal (900° C) or Plasma Assisted (400° C) Oxidation Techniques

Fuminobu Imaizumi, Tatsufumi Hamada, Shigetoshi Sugawa, Herzl Aharoni[1,2] and Tadahiro Ohmi[1]

Department of Electronic Engineering, Graduate school of Engineering, Tohoku University, Aza-Aoba 05, Aramaki, Aoba-ku Sendai 980-8579, Japan Tel: +81-22-217-7124, Fax: +81-22-263-9395, E-mail: imaizumi@sse.ecei.tohoku.ac.jp, [1]New Industry Creation Hatchery Center, Tohoku University, Aza-Aoba, Aramaki, Aoba-ku Sendai 980-8579, Japan [2]Department of Electrical and Computer Engineering, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel, Fax: +972-8-6472-949 email: herzl@ee.bgu.ac.il

1. Introduction

The poor electrical characteristics of present commercial interpolyoxide films in non-volatile flash memories, grown by conventional thermal oxidation is caused mainly by the roughness of the interpolyoxide/poly-Si interface, resulting from the high interpolyoxide growth temperature(900°C). In this work, polyoxide films are grown by microwave excited high-density plasma technique, at 400°C[1,2], *exhibiting significantly superior performance, i.e. lower leakage currents and sustain higher electric fields.* A first report is made concerning the growth of polyoxinitride films by this technique. These improved properties enhance the data retention capabilities of non-volatile memories.

2. Experimental

Aluminum gate MOS capacitors (Fig. 1) were fabricated, with four types of insulating films. (1) with conventional dry gate oxide film (900 °C) grown on single crystal (100) Si. This capacitor serves as a *reference.* The gate insulators of the other three capacitors were grown on poly-Si film, i.e. (2) polyoxide that was grown by conventional dry gate oxidation at 900°C. The two other capacitors included (3) gate polyoxide and (4) gate polyoxinitride films grown by Kr/O_2(97/3) or $Kr/O_2/NH_3$(96.5/3/0.5) microwave (2.45GHz) excited high-density ($>10^{12}$ cm^{-3}) plasma technique respectively at 400°C.

3. Results and Discussion

Fig. 2 shows transmission electron microscope (TEM) image of a typical aluminum gate MOS capacitor, with Kr/O_2 plasma grown polyoxide film on poly-Si film. Fig. 3 shows atomic force microscope (AFM) image (1μm×1μm) of the: (a) bare poly-Si film surface (before polyoxide film growth), (b) surface of the Kr/O_2 polyoxide film(400°C), (c) surface of the dry thermal polyoxide film(900°C). Both (b) and (c) are grown on poly-Si films. The textures of Fig.3(a) and Fig.3(b), exhibit similar structure, resulting from the low polyoxide growth temperature (400°C), causing only small changes in the grain size of the underlying poly-Si film. Fig.3(a) and Fig.3(c) on the other hand show significant change in the surface texture, which is caused by two main factors. The first is the movement and the growth of the grain size of the underlying poly-Si film due to the high polyoxide growth temperature (900°C). The second is that the conventional dry thermal oxidation is crystal orientation dependent. This is demonstrated in Fig. 4 which show the thickness dependence of SiO_2 films grown on three single crystal substrate orientations. Clearly the thermal oxidation exhibit orientation dependence, while the Kr/O_2 plasma oxidation exhibit practically no orientation dependence. This arise from the generation of O^* in the plasma, which possess smaller size with respect to O_2 and despite the low growth temperature(400°C)[3], diffuse faster than O_2 through the polyoxide growing film, assisted by the Kr ion bombardment. In addition O^* possess higher reactivity with the Si surface than O_2 resulting comparable or higher growth rates, at 400°C then conventionally grown films at 900°C. The overall result is crystal orientation independence growth of the polyoxide film. The differences in the grain size, local film thicknesses, and local interface unevenness, will be shown to affect the electrical performance of the above polyoxides. Fig. 5 show interface trap density at midgap (Dit) for (a) thermally grown and (b) Kr/O_2 plasma grown, gate oxide films grown on three Si orientations. Dit for the Kr/O_2 gate oxides are smaller at each substrate orientation than that of the respective thermally grown oxides. Further, the differences in the Dit of the Kr/O_2 films are smaller than in the thermally grown films. This means, that the Dit values over the various grains of the poly-Si film surface are more uniform in the Kr/O_2 grown films than in thermally grown films. Accordingly the performance of individual devices as well as the spatial uniformity of their parameters are expected to exhibit an improvement. Fig. 6(a) exhibit J-E characteristics of capacitors (1), (2) and (3). While the conventional MOS capacitor(1) and the Kr/O_2 capacitor(3) exhibit comparable J-E characteristics, the MOS with the thermally grown polyoxide(2) exhibit noticeably higher leakage current and sustain lower electric fields. Fig.6(b) shows that the barrier height (Φ_B) of the Kr/O_2 capacitor is very close to that of ideal SiO_2, while the Φ_B of the thermally grown polyoxide is much lower. The inferior behavior of the MOS of the thermally grown polyoxide attributed to the high phosphorus concentration at the poly-Si large grain size boundaries, which diffuse and accumulate there during the 900°C polyoxide growth, locally reducing Φ_B, resulting an increase in the leakage currents.

A first preliminary result is reported, regarding the growth of polyoxinitride(SiON) film by $Kr/O_2/NH_3$ microwave-excited plasma. In Fig.7, despite the fact that the SiON thickness(10.5nm) is about half of that of the Kr/O_2 polyoxide(20.7nm), their J-E and the F-N relations are comparable, exhibiting only a slight increase in the low field leakage current.

4. Conclusion

Polyoxide and polyoxinitride films grown on poly-Si films, at 400°C demonstrated superior MOS capacitors electrical properties in terms of reduced leakage currents and higher sustained electric fields, with respect to polyoxide films grown by conventional dry oxidation at 900°C. These results present a potential for their use in future interpolyoxide or interpolyoxinitride films in flash memories, enhancing their data retention capabilities.

Acknowledgements

The authors would like thank technical officer Ken-Ichi Motomiya of department of geosciences and technology, graduate school of engineering, Tohoku University.

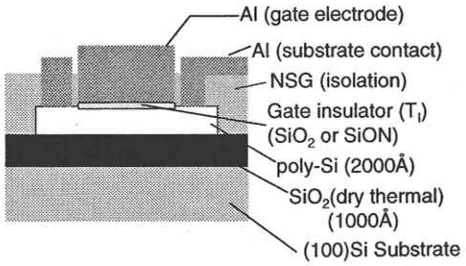


Fig.1 Schematic diagram of the Al gate MOS capacitor.

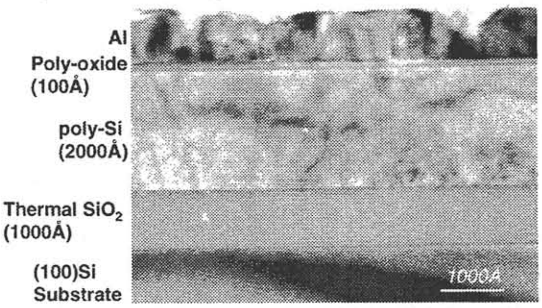
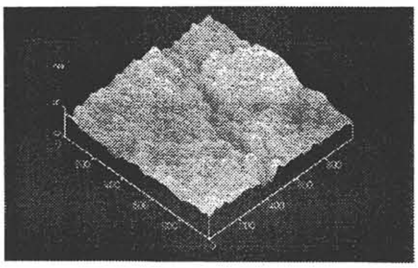


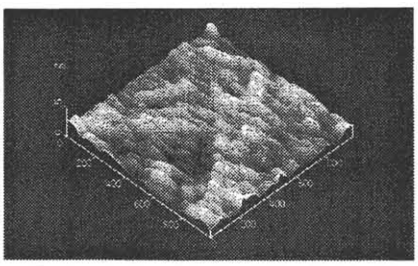
Fig.2 TEM cross-section image of the MOS capacitor of Fig.1.

(a)



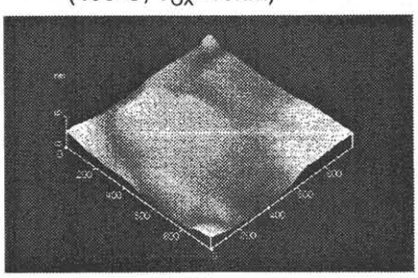
Bare poly-Si surface (before oxidation)

(b)



Surface of Kr/O_2 plasma grown polyoxide film
(400°C; T_{OX}=18nm)

(c)



Surface of Dry thermal polyoxide film
(900°C; T_{OX}=20nm)

Fig.3 AFM images of poly-Si and polyoxide films surfaces.

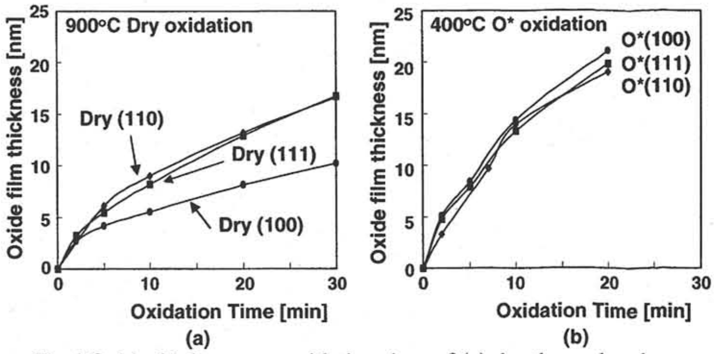


Fig.4 Oxide thickness vs. oxidation time of (a) dry thermal and (b) Kr/O_2 plasma, oxide films, grown on three orientations Si substrates.

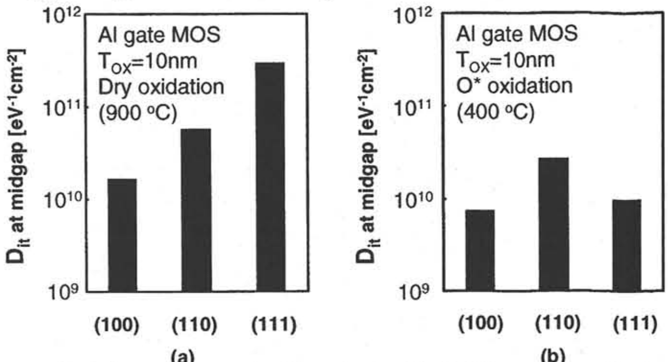


Fig.5 Interface trap densities obtained in MOS capacitors fabricated on three Si substrate orientations with:
(a) dry thermal gate oxides (b) Kr/O_2 plasma grown gate oxides.

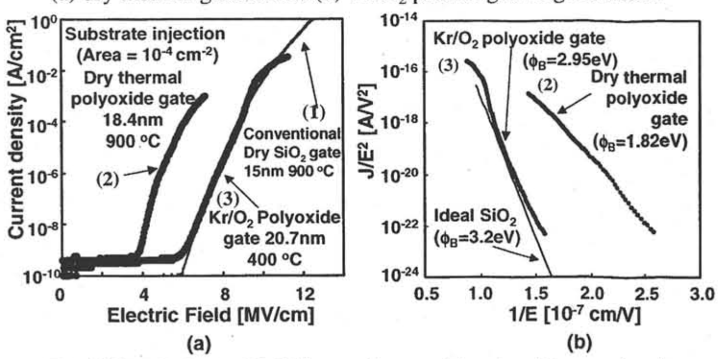


Fig.6 J-E relations of MOS capacitors, with polyoxide gate insulators:
(a) J-E characteristics (b) F-N Plot.

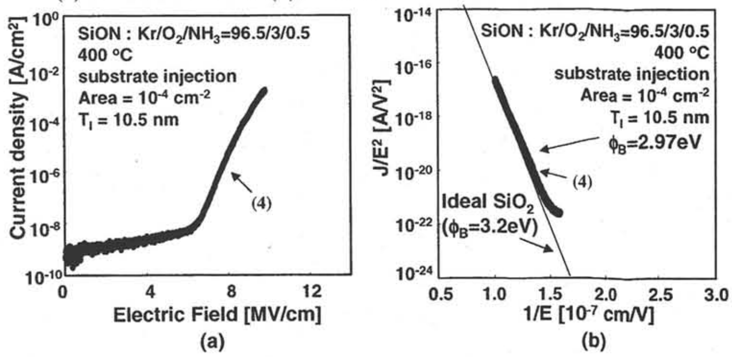


Fig.7 J-E relations of MOS capacitors with polyoxinitride gate insulators:
(a) J-E characteristics (b) F-N Plot.

Reference

[1] M. Hirayama, et al., IEDM Tech. Dig., p249(1999)
[2] K. Sekine, et al., Symp. VLSI Tech., p115(1999)
[3] Y. Saito, et al., SSDM., p152(1999)