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High-Integrity Silicon Oxide Grown at Low-Temperature by Atomic Oxygen Generated in High-Density Krypton Plasma

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1. Introduction

Lowering process temperature of gate oxide formation process is an essential to realize ultra-high integration devices featuring precise doping profile control. The silicon oxide films grown at low temperature, however, have poor dielectric strength, high leakage current in low electric field region, high interface trap and bulk charge, which can not displace thermally grown silicon oxide. Furthermore, the growth rate of oxide film formed at low temperature is too slow to be introduced in mass production [1][2]. Therefore, development of new low-temperature oxidation technology to overcome these faults is strongly required. The purpose of this paper is to demonstrate that high-integrity silicon oxide can be realized for the first time by microwave-excitation Kr/O_2 mixed high-density plasma at 400 °C and confirm that it can displace thermally grown silicon oxide.

2. Experiments

Fig. 1 illustrates a microwave-excitation high-density plasma system [3] used in this study. This system is characterized by low ion bombardment energy less than 7 eV, high plasma density above 10^{12} cm^{-3} and low electron temperature below 1.3 eV. Silicon oxide films were grown by direct oxidation of silicon surface employing this system at 400 °C. The mixing ratio of oxygen to inert gas and working pressure were fixed at 3 % (O_2/Kr or He) and 1 Torr, respectively. MOS [Al/SiO_2/Cz n-type Si (100) 3-5 Ω·cm] capacitors were fabricated to evaluate electrical properties of silicon oxide films. Silicon oxide films formed by dry oxidation at a temperature of 1000 °C were used as a reference.

3. Results and Discussion

Fig. 2 shows oxidation rate of Kr/O_2 and He/O_2 mixed high-density plasma at a temperature of 400 °C. The oxidation rate of Kr/O_2 mixed plasma is faster than that of He/O_2 mixed plasma and nearly the same as that of thermally grown silicon oxide at 1000 °C.

Fig. 3 shows O/Si ratio in silicon oxide measured by X-ray photoelectron spectroscopy (XPS). O/Si ratio is normalized by oxide film formed by dry oxidation at 1000 °C. O/Si ratio in silicon oxide grown by Kr/O_2 plasma is nearly the same as that of thermally grown oxide. From these results, large amount of activated oxygen is generated in Kr/O_2 mixed plasma compared to He/O_2 mixed plasma. The ionization energy of Kr (9.9 eV) is nearer to decomposition energy of O^1D+O^1D (11.6 eV) than that of He (19.8 eV) [4].

Fig. 4 shows interface trap density of silicon oxide with thickness of 10 nm measured by quasi-static C-V technique versus growth condition. The interface trap density of silicon oxide grown by Kr/O_2 mixed plasma is two orders of magnitude lower than that of He/O_2 mixed plasma. Fig. 5 shows high-frequency C-V curve. The C-V curves of silicon oxide grown by Kr/O_2 mixed plasma show excellent fit to that of thermally grown silicon oxide. From the results of Fig. 4 and Fig. 5, It can be said that the interface trap and bulk charge of silicon oxide grown by Kr/O_2 mixed plasma are compatible to those of thermally grown silicon oxide

Fig. 6 shows J-E curve and Fowler-Nordheim (F-N) plot of silicon oxide with thickness of 12.5 nm. J-E curve shows low leakage current in low electric filed region and high breakdown field. These results are comparable with high-quality thermally grown silicon oxide. In five decades, J-E curve shows excellent fit to F-N tunneling. Assuming an effective mass of 0.42 times the free electron mass, the electron barrier height is 3.2 eV, which is same as that of thermally grown silicon oxide.

Subthreshold characteristic and V_D-I_D curve of n^+-poly-Si gate MOS transistors [n^+-poly-Si /SiO_2/Epi n-type Si (100) 4-6 Ω·cm] are shown in Fig. 7 and Fig. 8, respectively. In this case, activation annealing of phosphorus was carried out at 800 °C. The static characteristics of MOSFET with oxide film with thickness of 10 nm grown by Kr/O_2 mixed plasma at 400 °C are equal to those of thermally grown film.

4. Conclusion

The silicon oxide grown by Kr/O_2 mixed high-density plasma at 400 °C represents high growth rate, high dielectric strength, and low interface trap and bulk charge. It is conformed that they can displace thermally grown silicon oxide.

Acknowledgments

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References

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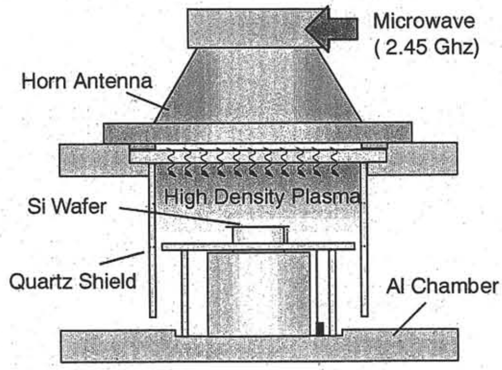

Fig.1 Schematic of microwave-excitation plasma process equipment

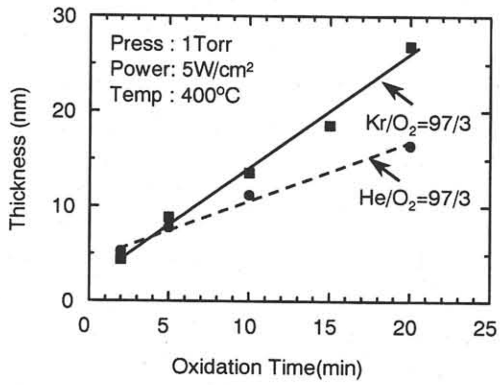

Fig.2 Oxidation rate of Kr/O_2 and He/O_2 mixed high-density plasma at a temperature of 400 °C

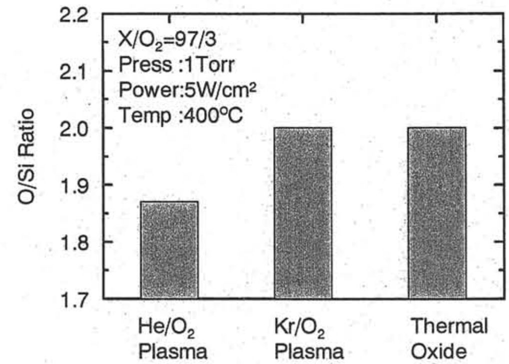

Fig.3 O/Si ratio in silicon oxide grown by Kr/O_2 and He/O_2 mixed high-density plasma at a temperature of 400 °C

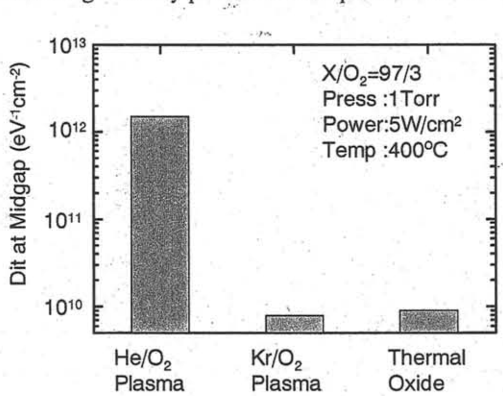

Fig.4 Interface trap density versus growth condition

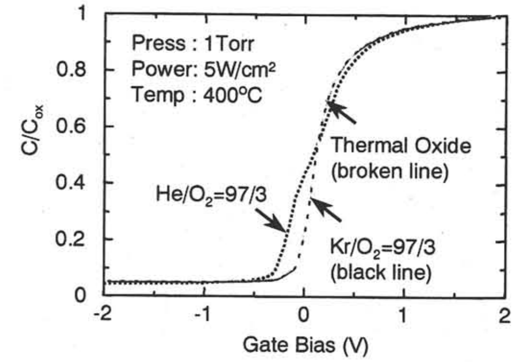

Fig.5 C-V curves of silicon oxide grown by Kr/O_2 and He/O_2

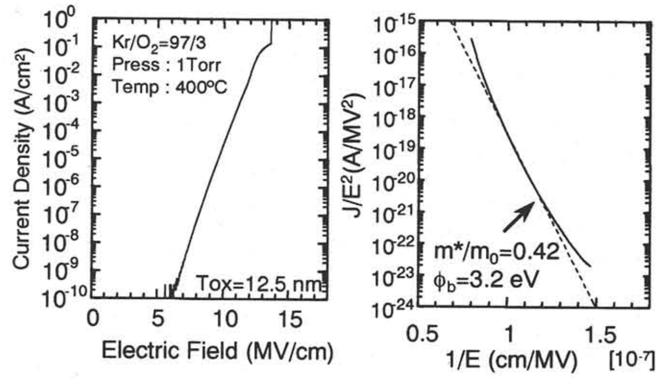

Fig.6 J-E curve and Fowler-Nordheim plot of silicon oxide with thickness of 12.5 nm grown by Kr/O_2 plasma

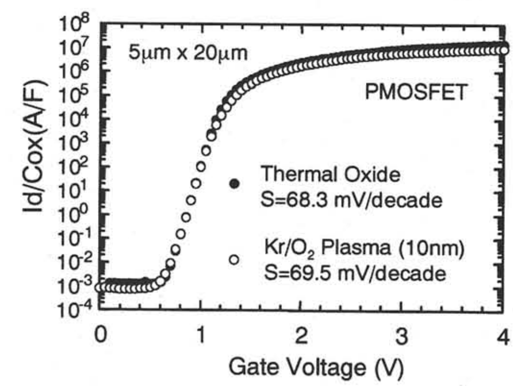

Fig.7 Subthreshold characteristic of silicon oxide grown by Kr/O_2 at 400 °C and thermally grown silicon oxide

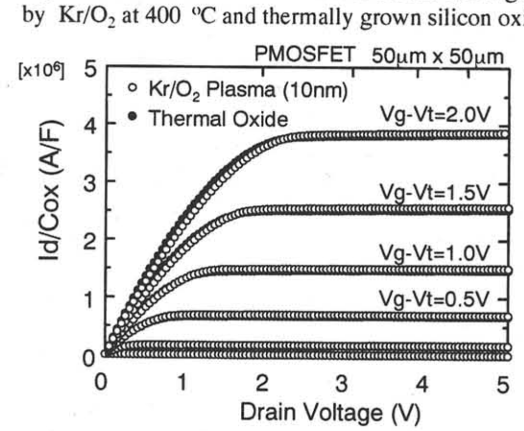

Fig.8 Vd-Id characteristics of silicon oxide