Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 556-558

Study on the Fundamental Electrical Properties of Ultra-Thin Oxides Grown by Low Temperature Microwave Plasma Afterglow Oxidation

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Fundamental characteristics such as the oxide breakdown fields, oxide charges and interface state density of various ultra-thin oxides (≤ 8 nm) grown by microwave plasma afterglow oxidation at low temperatures were investigated. The effective oxide charge density of 600 °C as-grown oxide was as low as 6×10^{10} cm^{-2}. The breakdown fields of the oxides were further enhanced and the interface state densities were reduced by employing fluorination (HF soaked) and low temperature N_2O plasma annealing.

1. INTRODUCTION

When ultra-large-scale integrated circuits (ULSI) miniaturization enters the deep submicron domain, low temperature processes are indispensable to maintain the shallow dopant profiles and reduce the strain in oxide films during the thin oxide growth. The utilization of low-temperature plasma (induced by RF or microwave) oxidation process can satisfy these requirements[1,2].

In this work, microwave plasma afterglow oxidation was utilized to grow ultra-thin oxides (7-8 nm) at 400 °C and 600 °C. The fluorine addition and the low temperature N_2O plasma annealing were performed for the first time in such system. The electrical properties of these ultra-thin oxides were investigated. Some properties of the oxides in this study are superior to those reported previously by the same method[3].

2. EXPERIMENTAL

The schematic diagram of the experimental apparatus is illustrated in Fig. 1. The forward microwave power was 100 W and the oxygen pressure was 1 torr. To fabricate fluorinated oxides, RCA cleaning was followed by soaking in HF solution (DI water:HF = 10:1), and without DI water rinse the samples were directly loaded into the oxidation tube to grow oxides. The N_2O plasma annealed samples were first grown at 600 °C in 1 torr O_2 plasma to a thickness of 6.5 nm. The growth were immediately followed by a 100 W microwave annealing in 3 torr N_2O plasma for 15, 30 and 60 min.

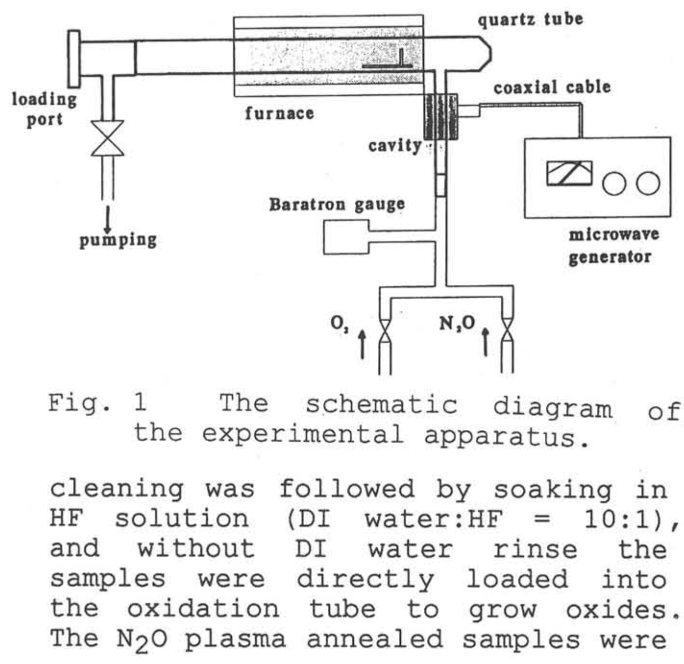

Fig. 1 The schematic diagram of the experimental apparatus.

3. RESULTS AND DISCUSSION

The oxide thickness (d), V_{fb} and Q_{eff} of the as-grown and fluorinated oxides are listed in Table I. The addition of fluorine led to more positive charges in those oxides. The breakdown field of the fluorinated oxides grown at 600 °C could be improved to 11 MV/cm.

Table I Thickness, flat-band voltage and oxide charges of as-grown and fluorinated oxides

Sample preparation	thickness (d)	V_{fb} (V)	Q_{eff} (#/cm^2)
600 °C	8	-0.35	5.8×10^{10}
400 °C	7	-0.36	8.8×10^{10}
600 ° C+F	7.2	-0.37	1.9×10^{11}
400 ° C+F	7	-0.39	2×10^{11}

Figure 2 shows the cumulative failure rate as a function of the electric fields applied to the as-grown and fluorinated oxides. Fluorinated oxides grown at 600 °C had only 20% failure rate at an electric field of 7 MV/cm while others were almost all brokedown.

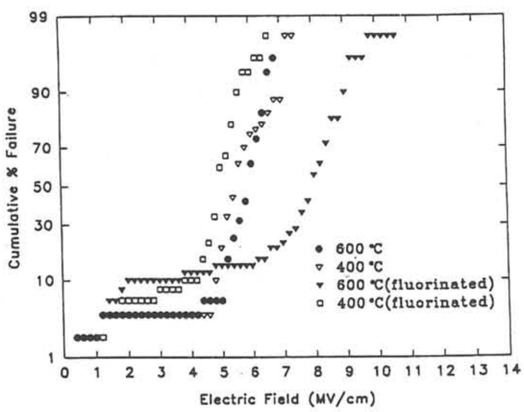

Fig. 2 The cumulative failure rates of the as-grown and fluorinated oxides.

Figure 3 shows the interface state density (D_{it}) of the samples listed in Table I. And the fluorinated process can reduce D_{it} throughout the whole silicon bandgap. The D_{it} at the mid-bandgap (D_{itm}) of the fluorinated oxide grown at 400 °C was still high, but the D_{it} near the valence band edge was significantly reduced. The reduction of D_{it} became more efficient for the 600 °C samples (35%). When 600°C fluorinated oxides was put through the poly-gate fabrication process,

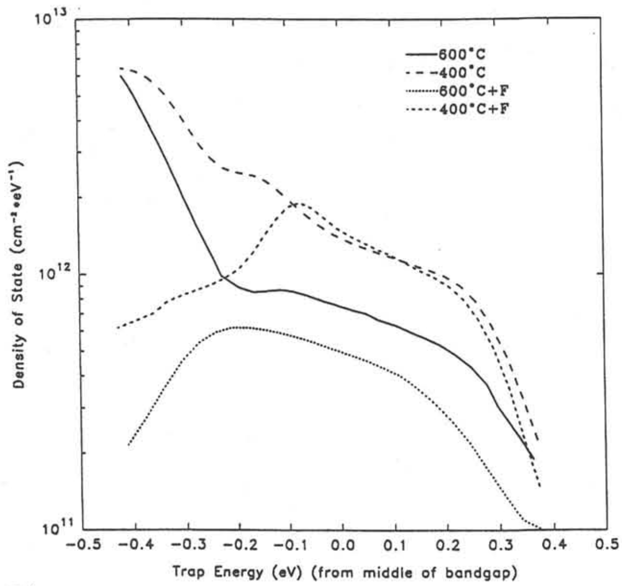

Fig. 3 The interface state densities of the samples listed in Table I.

it was found that the interface state density was further reduced to 5×10^{10} cm^{-2}eV^{-1}. Fig. 4 shows the interface state density of the 600 ° C fluorinated oxide with n^+-poly electrode.

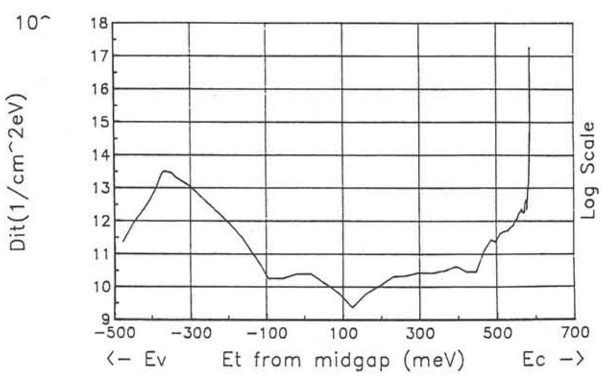

Fig. 4 The interface state density of the 600 °C fluorinated oxide with n^+-poly electrode.

Table II Thickness, flat-band voltage and oxide charges of 600 °C 3 torr N_2O plasma annealing oxides

N_2O annealing time (mins)	thickness (d) (nm)	V_{fb} (V)	Q_{eff} (#/cm^2)
0 (as-grown)	8	-0.35	5.8×10^{10}
15	6.7	-0.44	3.9×10^{11}
30	7.7	-0.44	3.3×10^{11}
60	8	-0.47	3.8×10^{11}

For the N_2O plasma annealed samples, the annealing condition, oxide thickness, V_{fb} and Q_{eff} are listed in Table II. N_2O plasma annealed oxides have higher Q_{eff} than those of the as-grown oxides. The highest breakdown field of the 15 min N_2O plasma annealed oxide was 12 MV/cm. Fig. 5 compares the cumulative failure rate of the N_2O plasma annealed oxides. As the

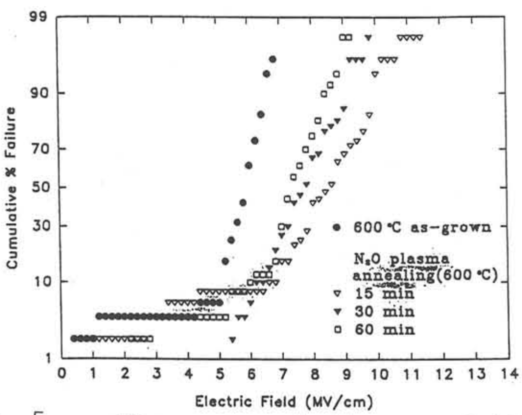

Fig. 5 The cumulative failure rates of the 600 °C as-grown and N_2O plasma annealed oxides.

electric field > 7 MV/cm, the 600 °C as-grown oxides almost all failed(> 90%) and 15 min annealed oxide only had a 20% failure, the 30 min and 60 min annealed oxides failure rates were about 28%-30%. Figure 6 illustrates the interface state density of N_2O plasma annealed oxides. The D_{it} near the valence band of the oxide annealed for 15 min was lower than that of the as-grown oxide, but the D_{itm} was higher. When the annealing time was prolonged to 60 min, the D_{it} became low again, but D_{itm} was still the same as that of the as-grown oxide.

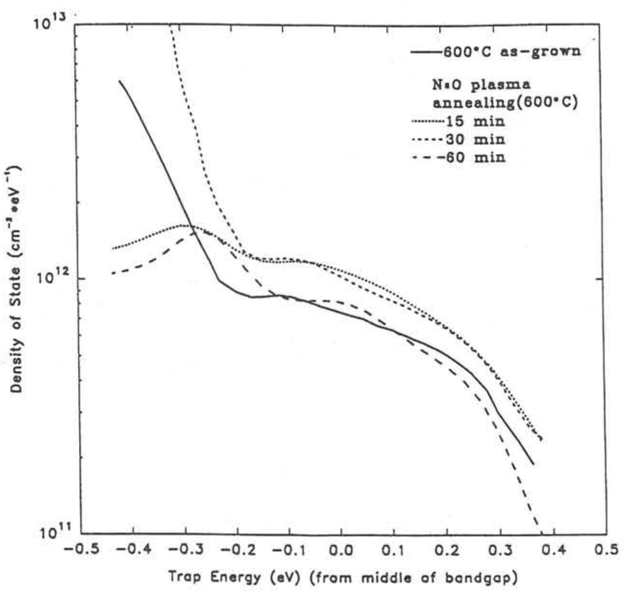

Fig. 6 The interface state densities of the 600 °C as-grown and N_2O plasma annealed oxides.

4. CONCLUSIONS

This study is the first attempt to investigate the inherent electrical properties of the as-grown, fluorinated and N_2O plasma annealed ultra-thin oxides (7-8 nm) grown by 100 W microwave afterglow oxidation at low temperatures (400 °C and 600 °C). The fluorine and nitrogen introduced further positive charges into the thin oxides. The fluorinated process at 600 °C could improve the oxide breakdown property and reduce the interface traps. This provides an appealing option for the oxidation in ULSI.

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