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Ultrathin Oxide/Nitride/Oxide/Nitride Multilayer Films for Mbit DRAM Capacitors

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A new multilayer dielectric film structure for DRAM capacitors is proposed. The film structure is composed of alternate layers of electron-current barriers and hole-current barriers. To realize this structure, oxide/nitride/oxide/nitride(ONON) multilayer films of 4.5 nm- and 5.0 nm-SiO_2 equivalent thickness (t_{OX}) are fabricated. By using the ONON structure, the leakage current is effectively reduced as compared with that of the ON films due to its low carrier mobility and low trap density. The increase of the leakage current at elevated temperature in the ONON film is smaller than that in the ON film. The ONON film with 4.5 nm t_{OX} achieves a low defect density and a long life time.

1. INTRODUCTION

Reduction of cell capacitance, as a result of increasing packing density in dynamic random access memory (DRAM), is one of the most serious problems. To provide sufficient capacitance, the ultra-thin dielectric films must maintain the low-leakage current characteristics and high reliability. Oxide/nitride/oxide (ONO) films[1)2)] and oxide/nitride (ON) films[3)] have previously been investigated to meet these requirements. However, for the ONO film, thin bottom-oxide (<2 nm) layers have not been uniformly formed by thermal oxidation of bottom poly-crystalline silicon electrodes. In the ON films, the leakage current abruptly increases with decreasing SiO_2 equivalent thicknesses (t_{OX}) less than 5 nm[4)].

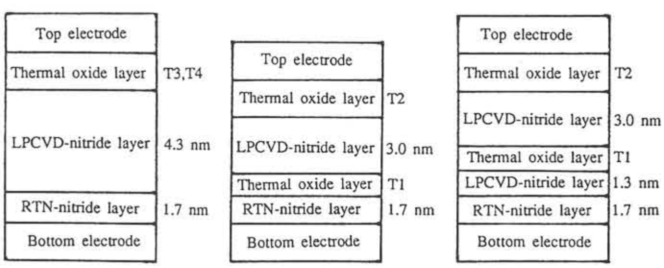
In order to reduce the leakage current of dielectric films consisting of silicon oxide and silicon nitride layers, we propose a new multilayer structure which is composed of alternate layers of electron-current barrier, Si_3N_4[5)], and hole-current barrier, SiO_2[6)].

In the present study, oxide/nitride/oxide/nitride (ONON) multilayer dielectric films of 4.5 nm and 5.0 nm-t_{OX} are investigated and applied to stacked capacitors. With the ONON structure, leakage current of dielectric films is effectively reduced, compared with the ON structure.

2. EXPERIMENTS

Figures 1(a), 1(b) and 1(c) show cross-sectional diagrams of oxide/nitride, oxide/nitride/oxide/nitride (RTN) and oxide/nitride/oxide/nitride (RTN+LPCVD) structures. The ON and ONON films with SiO_2-equivalent thicknesses, 4.5nm and 5.0 nm, are formed.

The ONON and ON film structures were fabricated as follows. After native oxide removal with diluted HF solution, the surface of the bottom polysilicon electrode was nitrided by rapid thermal nitridation (RTN)[7)] at 850°C in NH_3 at 1 atm for 60 seconds. After RTN, the first nitride layer was deposited at 700°C by conventional LPCVD. The RTN nitride film and RTN+LPCVD nitride film were thermally oxidized in



(a) (b) (c)

Fig.1 Schematic cross-sectional diagrams of multi-layer dielectric films.
(a) Oxide/Nitride structures with 4.5nm-t_{OX}(T3) and 5.0nm-t_{OX}(T4).
(b) Oxide/Nitride/Oxide/Nitride(RTN) structure with 4.5nm-t_{OX}.
(c) Oxide/Nitride/Oxide/Nitride(RTN+LPCVD) structure with 5.0nm-t_{OX}.
T1 : Dry oxidation at 800°C, 10 min.
T2 : Wet oxidation at 800°C, 30 min.
T3 : Wet oxidation at 800°C, 15 min.
T4 : Wet oxidation at 800°C, 120 min.

dry oxygen ambient. The second nitride layer was deposited by conventional LPCVD at 700°C. The top oxide layer was formed by wet thermal oxidation. On the other hand, the ON film structure was formed by the deposition of nitride film(RTN+LPCVD) and wet thermal oxidation, as shown in Fig.1(a).

3. RESULTS AND DISCUSSION

Figure 2 shows the oxidation thickness of 1.7 nm t_{ox} nitride film as a function of oxidation time. The thicknesses were measured by multispectral spectroscopic ellipsometry. In the case of wet oxidation at 800°C, the film thickness increased twice as much as the initial nitride film within 10 minutes. The oxidation resistance of the nitride film was lost after 60 minutes. In contrast to wet oxidation, the dry oxidation at 800°C showed no abrupt increase of oxide thickness. The capacitance measurement in stacked capacitors also showed very slow thickness (t_{ox}) increase of 1.7 nm nitride film by dry oxidation at 800°C. Since the increase rate of the thickness was only 0.3 nm for 30 minutes oxidation, the thickness control of the thin oxide film could be achieved by using dry oxidation. Using this technique, bottom oxidized nitride layer of the ONON film structure was formed without oxidizing the underlying polysilicon electrode, shown in Figs. 1(b) and 1(c).

Figure 3 shows Pool-Frenkel plots of the ON and ONON films with 4.5 nm- and 5.0 nm-t_{ox}. By using the ONON structure, the reduction of the leakage current was achieved below 6 MV/cm, especially with positive gate bias.

Figure 4 shows the temperature dependence of leakage current densities at 4MV/cm in 4.5 nm-t_{ox} ONON and ON films. The leakage current density of the ONON film was smaller than that of ON film in the all temperature range from room temperature to 225°C, and its temperature dependence was less than The ON film. Especially positive bias, the large reduction of the leakage current was achieved, and the leakage current did not change below 120°C. On the other hand, the leakage current of the ON film increased with increasing temperature.

The P-F plots and the temperature dependence of leakage currents indicate that the carrier mobility and trap density in the ONON film are lower than those in the ON film. Therefore, it is considered that the leakage current suppression in the ONON film is due to low carrier mobility and low trap density, as a result of formation of alternate layers of electron-current barrier and hole-current barrier.

Figure 5 shows a breakdown-field distribution of a 4.5 nm-t_{ox} ONON film formed on 25,000 poly-Si electrodes. The peak of the breakdown-field distribution is sharp and the breakdown failure in low electric fields is not observed. Therefore, the ONON structure contains low defect density.

Figure 6 shows the time-to-break-down characteristics for 4.5 nm ONON films. The life time of the 4.5 nm ONON film is sufficiently long, allowing it to survive for more than 10 years at a 1.5V cell plate voltage (half Vcc for DRAM).

4. CONCLUSION

We have proposed a new multilayer dielectric film structure composed of alternate layers of electron-current barrier and hole-current barrier, and applied it to DRAM capacitors. The ONON multilayer films with SiO_2 equivalent thicknesses of 4.5 nm showed low leakage current, low defect density and long life time compared with the ON structure due to low carrier mobility and low trap density. The ONON structure is applicable to 64M bit and larger DRAMs.

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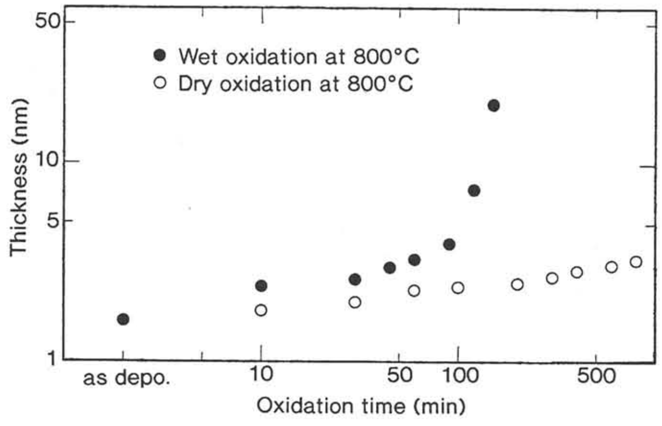

Fig.2 Thickness increase of a 1.7 nm nitride film oxidized in wet and dry ambient as a function of oxidation time.

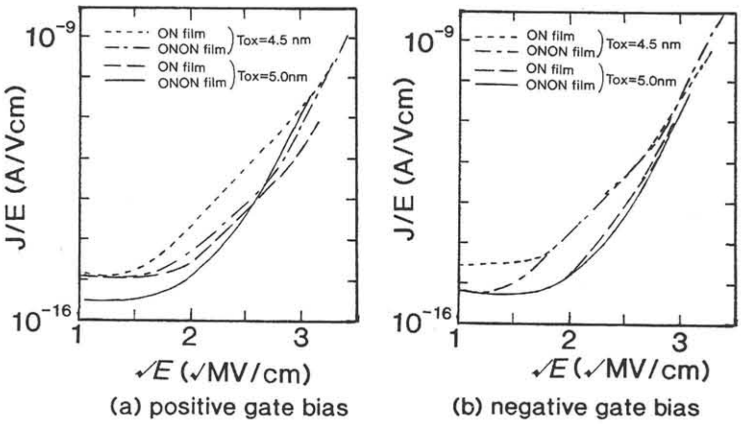

Fig.3 Pool-Frenkel plots for ON and ONON films of 4.5 nm- and 5.0 nm-tox.

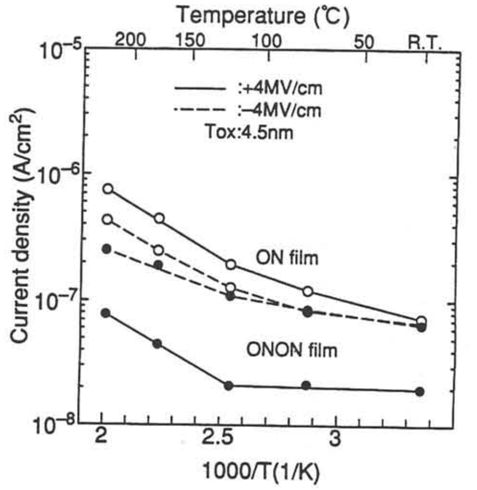

Fig.4 Temperature dependence of leakage current of 4.5nm-t_{ox} ON and ONON films at 4MV/cm.

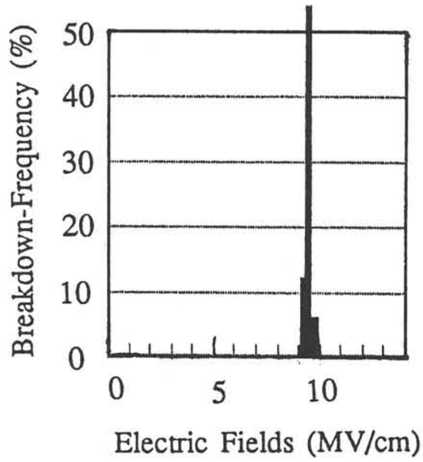

Fig.5 Breakdown-field distribution of a 4.5 nm-t_{ox} ONON film formed on 25,000 stack electrodes (Positive gate bias).

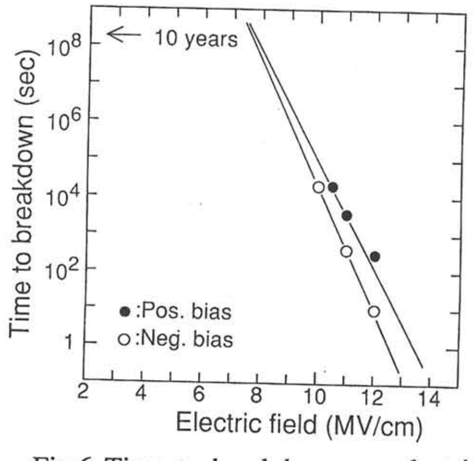

Fig.6 Time to breakdown vs. electric field plots of a 4.5 nm-t_{ox} ONON film.