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A Novel Approach for Leakage Current Reduction of LPCVD Ta_2O_5 Films by Rapid Thermal N_2O Annealing

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A new approach has been developed to reduce the leakage current in the Ta_2O_5 thin film (100-200 Å) prepared by low-pressure chemical vapor deposition. The key process is using rapid thermal annealing in N_2O ambient (RTN_2O) for reducing defect density in the dielectric films. The leakage current was drastically reduced from more than 10^{-3} to less than 10^{-8} A/cm^2 in an electric field of 3MV/cm by the RTN_2O annealing at 800 °C. The decrease in leakage current can be attributed to the incorporation of nitrogen in the Ta_2O_5 films and the reduction of oxygen vacancies by the atomic oxygen generated from the dissociation of N_2O at high temperatures. The effect of RTN_2O annealing temperature on the dielectric properties of Ta_2O_5 films will be discussed.

1. Introduction

Chemical vapor deposited tantalum pentoxide (Ta_2O_5) films have received much attention as a promising dielectric for a storage capacitor in DRAM cells [1] and gate insulators in next generation MOS transistors with high current drivability, because of a much higher permittivity than that of SiO_2 [2,3] and superior step coverage in a stacked and trenched substrate [4,5]. One serious problem in utilizing Ta_2O_5 films is a high leakage current due to the deficiency in oxygen. To fill the vacancies with oxygen and to improve the electrical properties of CVD-Ta_2O_5 capacitors, some oxidization treatment is necessary after deposition. Several annealing techniques for reducing leakage currents, such as dry-O_2 furnace annealing at high temperature, O_2-plasma annealing or rapid thermal O_2 annealing have recently been reported [6-8].

In this paper we report a significant reduction in the leakage current brought about by a new technique using rapid thermal annealing in N_2O. N_2O oxidation has been known to grow a nitrogen-rich layer at the SiO_2/Si interface. The resulting oxide has exhibited some very desirable characteristics such as resistance to charge trapping and good barrier against impurity diffusion. We have applied this technique to anneal the CVD-Ta_2O_5 films after deposition. The RTN_2O annealing temperature effects on the leakage current and the effective dielectric constant of MOS capacitors were also examined.

2. Experimental

Ta_2O_5 films were deposited on n^+ polysilicon substrates at 450 °C by a load-locked, single-wafer cold-wall LPCVD reactor manufactured by Vieetech of Japan from a mixture of tantalum pentamethylate [$Ta(OC_2H_5)_5$] and oxygen (O_2). The sample was mounted on a face-down, rotational type heater opposite to the gas shower plate. This special design has the advantages of minimizing the particle problem and has improved the film thickness uniformity. $Ta(OC_2H_5)_5$ was vaporized at 110 °C, and introduced into the reactor using argon as the carrier gas. The typical deposition pressure in the reaction chamber was 0.6 torr. Typical film thicknesses were around 16 nm. Prior to deposition, all sample wafers were treated by rapid thermal nitridation in pure NH_3 at 950 °C for 60 sec to remove native oxides and resulting in an increase on the effective dielectric constant. This treatment allows a reduction of the SiO_2 equivalent thickness of the capacitor dielectric layer. The RTN nitridation process has also reduced leakage currents and resulted in superior reliability characteristics [9]. After deposition, Ta_2O_5 films were subjected to various heat treatments. Thickness and refractive index of the Ta_2O_5 film were measured using an ellipsometer (Rudolph Auto EL III). MOS capacitors were fabricated using TiN and aluminum as top plate electrodes deposited by reactive sputtering. Leakage current was measured by a dc ramp method at a ramp rate of 0.05 V/s. Capacitance was measured in the accumulation region at 1 MHz for the use of calculating effective dielectric constant and electric field.

3. Results and Discussion

Fig.1 shows current-voltage characteristics of 16-nm Ta_2O_5 films deposited on n^+ poly Si substrates annealed at three different conditions: furnace O_2 (800 °C, 30 min), rapid thermal annealing in O_2 (800 °C, 60sec), and rapid thermal annealing in N_2O (800 °C, 60 sec). Conventional furnace O_2 annealing has been

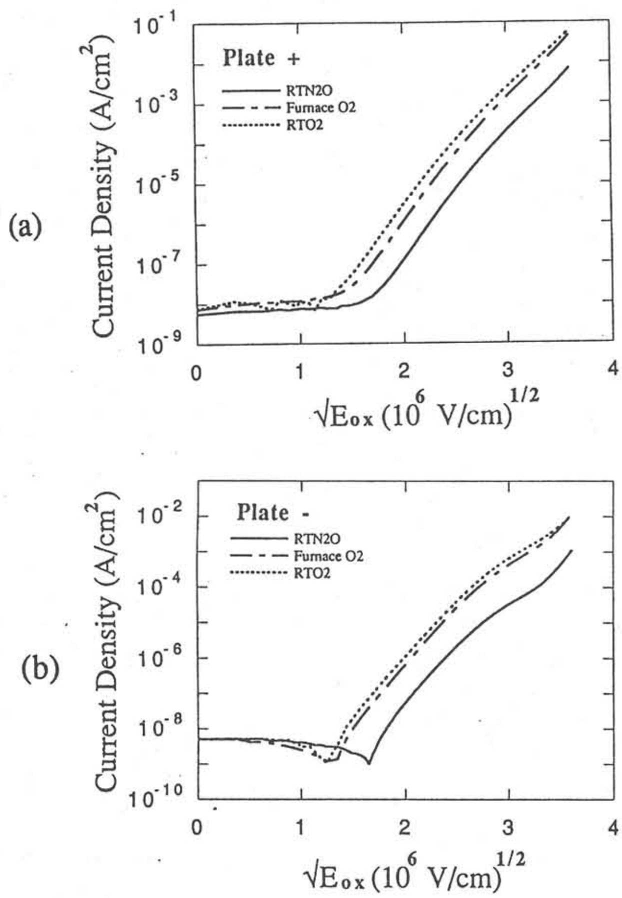

Fig.1 Current-voltage characteristics of the Ta_2O_5 capacitors after annealing treatments: (a) with positive plate voltage, (b) with negative plate voltage.

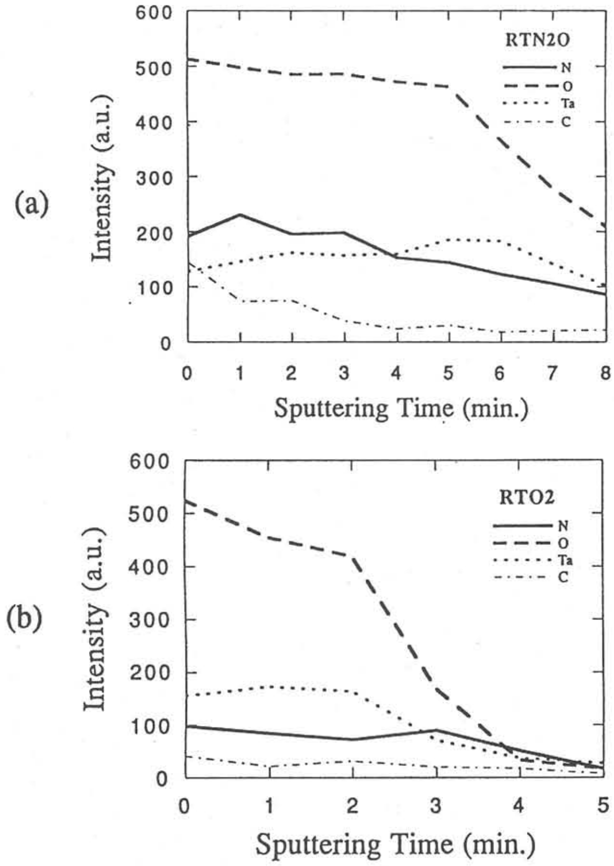

Fig.2 Auger depth profile of Ta, O, N and C atoms of Ta_2O_5 films with (a) RTN2O annealing , (b) RTO_2 annealing at 800 °C

used extensively in annealing Ta_2O_5 films [9,10]. The leakage currents of the Ta_2O_5 films annealed in furnace O_2 at 800 °C are larger than that of the Ta_2O_5 films annealed in RTN_2O, but smaller than that of RTO_2 film. The difference in current-voltage characteristics between furnace O_2 and RTO_2 annealing can be explained from the viewpoint of reduced defect density (oxygen vacancies) and the microstructural change from amorphous to crystalline by the high temperature annealing treatment. Since rapid thermal annealing in O_2 may not provide sufficient time to reduce oxygen vacancies as compared to conventional furnace annealing, this may explain the higher leakages using RTO_2 annealing.

The smallest leakage current in the film found in our investigation is the use of rapid thermal N_2O annealing. The leakage current through as-deposited Ta_2O_5 films at 3 MV/cm field is more than 10^{-3} A/cm^2, and decreases to about 5×10^{-9} A/cm^2 after N_2O annealing at 800 °C. This can be attributed to the incorporation of nitrogen into the Ta_2O_5 films as evident from the Auger analysis shown in Fig.2. Fig.2 (a) shows that films with RTN_2O annealing have almost twice as much the amount of nitrogen as in the films with RTO_2 annealing (Fig.2(b)). High nitrogen concentration in the polysicon film has been known to increase the resistivity of the film [11]. For the same reason, higher nitrogen concentration in the Ta_2O_5 films may result in a lower leakage current. Another plausible mechanism is that reactive oxygen atom radicals formed by N_2O dissociation at elevated temperatures may reduce the density of oxygen vacancies in the film and thus the leakage current.

In addition to low leakage currents, films with RTN_2O annealing also possess a tighter, higher critical field distribution as compared to furnace O_2 and RTO_2 heat treatments. Fig. 3 (a) and (b) show the critical field histograms of Ta_2O_5 capacitors measured at J = 1 μA/cm^2 current density with top electrode biased at positive voltage and negative voltage, respectively.

The effect of of RTN_2O annealing temperature on the leakage current reduction is shown in Fig. 4. N_2O decomposes more into NO and O_2 with increasing temperatures and it has been conjectured that NO is the critical species responsible for the nitrogen incorporation in the interface during oxidations [12]. At 650 °C, the lesser N_2O decomposition has resulted in a higher leakage current. At 1000 °C, despite the high field leakage is further reduced due to a greater percentage of nitrogen incorporation and oxygen vacancies reduction, the low-field leakto the change of crystalline structure of the film at high temperatures and the loss of RTN interfacial layer at Ta_2O_5/n^+ poly interface by oxidations.

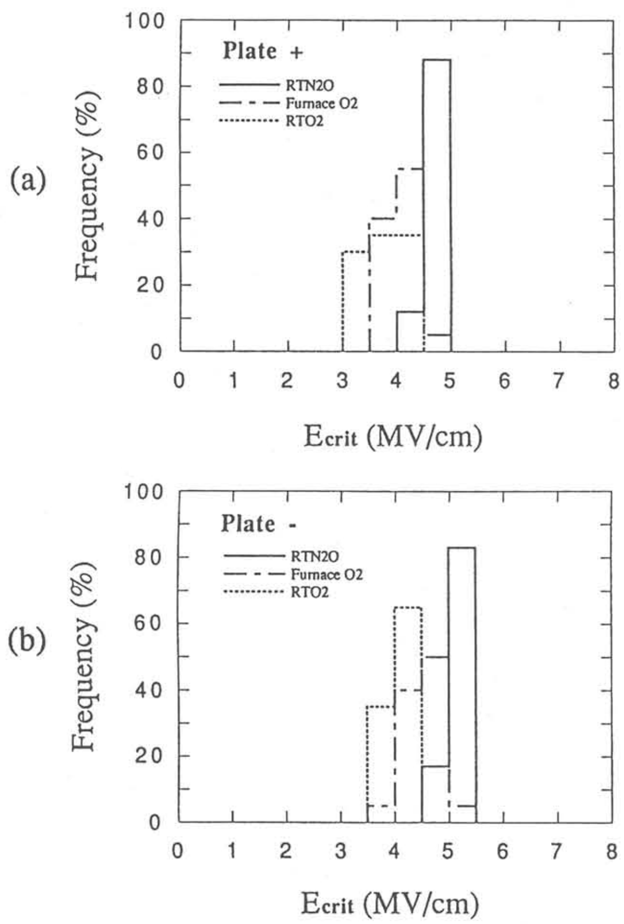

Fig.3 Critical field histograms of Ta_2O_5 capacitors measured at 1 $\mu A/cm^2$ current density with top electrode biased at (a) positive voltage, (b) negative voltage.

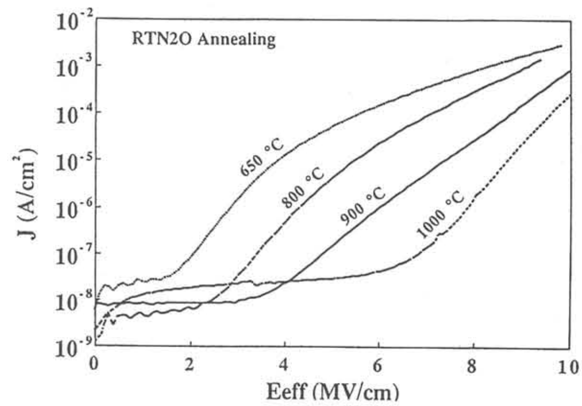

Fig.4 Effect of RTN_2O annealing temperature on the leakage current characteristics

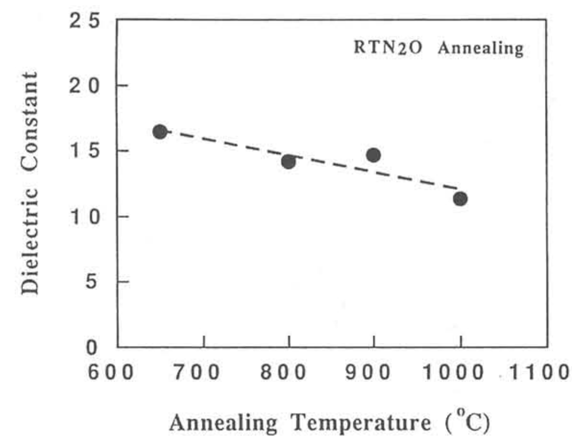

Fig.5 Effect of RTN_2O annealing temperature on the dielectric constant

Fig. 5 indicates that the effective dielectric constant is decreasing with increasing RTN_2O annealing temperature due to the loss of RTN interfacial layer and the increase of SiO_2 at the polySi /Ta_2O_5 interface.

4. Conclusions

The large leakage current which has been considered as a serious problem of LPCVD-grown Ta_2O_5 film is reduced remarkably by rapid thermal annealing in N_2O. Species responsible for the reduction of leakage current is active oxygen atom radicals created by a thermal decomposition of N_2O during rapid thermal process. Very low leakage currents may also be attributed to the nitrogen incorporation in the film from RTN_2O annealing. The temperature effects on both leakage current and effective dielectric constant were investigated. RTN_2O at 900 °C is identified as the optimal annealing temperature.

References

1. Y. Kawamoto, T. Kaga, T. Nishida, S. Iijima, T. Kure, F. Murai, T. Kisu, D. Hamamoto, H. Shinriki, and Y. Nakagome, *Tech. Dig. of 1990 Symp. on VLSI Technology,* (1990) 13
2. W.H. Knausenberger and R.N. Tauber, *J. Electrochem. Soc.*, 120, (1973) 927
3. S. Zaima, T. Furuta, Y. Yasuda, and M. Iida, *J. Electrochem. Soc.*, 137, (1990) 1297
4 C. Isobe and M. Saitoh, *Appl. Phys. Lett.*, 56, (1990) 907
5. Y. Numazawa, S. Kamiya, M. Zenke, and M. Sakamoto, *IEDM Technical Digest,* (1989) 43
6. H. Hiroshi and M. Nakata, IEEE Trans. Electron Devices, 38, (1991) 455
7. H. Suzuki, S. Kamiyama, H. Watanabe, A.Sakai, and A. Ishitani, *Extended Abstracts of SSDM, (1993) 862*
8. J-W Park, S.W. Han, H.S. Moon, and J.S. Lee, *Mat. Res. Soc. Symp. Proc.* 309, (1993) 9
9. S. Kamiyama, P.-Y. Lesaicherre, H. Suzuki, A. Sakai, I. Nishiyama, and A. Ishitani, *J. Electrochem. Soc.,* 140, (1993) 1617
10. H. Shinriki, M. Nakata, Y. Nishioka, and K. Mukai, *IEEE Electron Device Lett.* 10, (1989) 514
11. S.C. Sun, L.S. Wang, and F.L. Yeh, to be published.
12. T.Y. Chu, W.T. Ting, J. Ahn, and D.L. Kwong, *J. Electrochem. Soc.*, 138, (1991) L13