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Properties of Highly Oriented Ta_2O_5 on Metal Electrodes

Koichi Kishiro, Nobuhiko Inoue, Shih-Chang Chen and Masaki Yoshimaru

VLSI R&D Center, Oki Electric Industry Co., Ltd. 550-1, Higashiasakawa, Hachioji, Tokyo 193, Japan

Phone:+081-426-62-6108, Fax:+81-426-67-8367, E-mail:kishiro213@hac.oki.co.jp

1. Introduction

New materials, such as Ta_2O_5, BST, STO and PZT, with high dielectric constant have been studied as the dielectrics in the storage capacitor of DRAM. Ta_2O_5 has an advantage for that the thin film with a good step coverage is easily deposited by using LP-CVD. The dielectric constant of Ta_2O_5 is 20-28. Many works have been reported that the SiO_2 equivalent thickness (t_{eq}) of Ta_2O_5 deposited on Poly-Si was about 3 nm[1][2][3]. However, it was also reported that Ta_2O_5 film deposited on tungsten electrode has a small t_{eq} of 1.6 nm[4]. We studied the properties of Ta_2O_5 film deposited on Pt and Ru electrode, which are more stable than tungsten, during the annealing in oxidation atmosphere.

2. Experiment

Ta_2O_5 thin films were deposited on Pt and Ru electrode by LP-CVD using $Ta(OC_2H_5)_5$ and oxygen. The deposition temperature was 400°C and total pressure was 0.2 Torr. Pt and Ru was sputtered. Ta_2O_5 was also deposited on Poly-Si, on which thin SiN had been deposited. The Ta_2O_5 thickness was measured by ellipsometry and TEM. After the Ta_2O_5 deposition, Ta_2O_5/Pt, Ru and Poly-Si were annealed for 60 seconds with rapid thermal process. The annealing temperature was changed from 600 to 800°C. Ru upper electrode was sputtered, for measuring the electric properties of Ta_2O_5 capacitors. The capacitance was measured by LCR meter with 40 kHz frequency. The crystal structure of the films was measured by XRD and TEM. The interaction between Ta_2O_5 and electrode was studied by using AES.

3. Results and Discussion

Figure 1 shows the XRD patterns of Ta_2O_5 deposited on Pt and Ru annealed at various temperature from 600 to 800°C. Ta_2O_5 deposited on Pt is amorphous with 600°C annealing. All Ta_2O_5 deposited on Pt, Ru and Poly-Si are amorphous after annealing under 600°C. Ta_2O_5 is crystallized by annealing over 700°C and its crystallinity is improved with annealing temperature increase. Ta_2O_5 on Pt and Ru is strongly oriented to (110) and (001) phase, respectively. On the other hand, Ta_2O_5 on Poly-Si is randomly oriented and its peak intensity does not change with over 700°C annealing.

Figure 2 shows AES profiles of Ta_2O_5/Pt and Ru after 750°C annealing. There is no reaction between Ta_2O_5 and Pt. The diffusion of Ta and O into Ru electrode is observed. It is observed that Ru surface is rough and Ru does not react with Ta_2O_5, from its cross-sectional TEM micrographs.

Figure 3 shows t_{eq} of Ta_2O_5 deposited on Pt, Ru and Poly-Si annealed at temperature from 600 to 800°C. The thickness of Ta_2O_5 shown with closed and open characters is 30 and 12 nm, respectively. The t_{eq} of Ta_2O_5(30nm)/Pt, shown with closed circles, decreases with annealing temperature. It is thought that the improvement of Ta_2O_5 crystallinity on metal electrodes relates the t_{eq} decrease. After 750°C annealing, Ta_2O_5/Pt and Ru with 12 nm thickness, shown with a open circle and square, are small t_{eq} of 0.9 nm. On the other hand, the t_{eq} of Ta_2O_5(12nm)/Poly-Si, shown with open triangles, is about 3 nm, even Ta_2O_5 is crystallized with annealing at above 700°C. Crystallized Ta_2O_5/Pt and Ru which is highly oriented with high temperature annealing has a small t_{eq}.

Figure 4 shows the relative dielectric constant (ε) of Ta_2O_5 films annealed at various temperature. Ta_2O_5 on Pt and Ru, which is crystallized and highly oriented at above 700°C, shows ε over 50. But ε of Ta_2O_5 crystallized on SiN is low and not affected with annealing temperature. It is clear that the ε of Ta_2O_5 strongly depends on its crystallinity.

Figure 5 shows the I-V characteristics of Ta_2O_5/Pt annealed at temperature from 600 to 800°C. Ta_2O_5/Pt annealed at 600°C is amorphous and its leakage current is 2×10^{-9} A/cm^2. With annealing above 700°C, the leakage current of crystallized Ta_2O_5/Pt increases to over 10^{-8} A/cm^2 but is constant, in spite of annealing temperature. The leakage current increase may be caused that the grain boundaries of crystallized Ta_2O_5 become current paths.

Generally, thinning dielectric films increases their leakage current. To reduce the leakage current of thin Ta_2O_5, the sample was pre-treated in O_2 at 550°C for 1 hour before crystallization[5]. Figure 6 shows the I-V property of Ta_2O_5(12nm)/Ru with 0.9 nm t_{eq}, crystallized with 750°C annealing. It shows the leakage current of 2×10^{-7} A/cm^2 at 1V.

4. Conclusion

We studied the properties of Ta_2O_5 deposited on Pt, Ru and Poly-Si. The crystallized Ta_2O_5/Pt and Ru is highly oriented and the relative dielectric constant is higher than 50 with annealing above 700°C. The t_{eq} of Ta_2O_5(12nm)/Pt and Ru crystallized at 750°C is 0.9 nm. On the other hand, Ta_2O_5/Poly-Si is randomly oriented and its ε is under 30. It is assumed that the highly oriented Ta_2O_5 on metal electrode is a candidate promising for a Giga-bit DRAM's dielectric.

References

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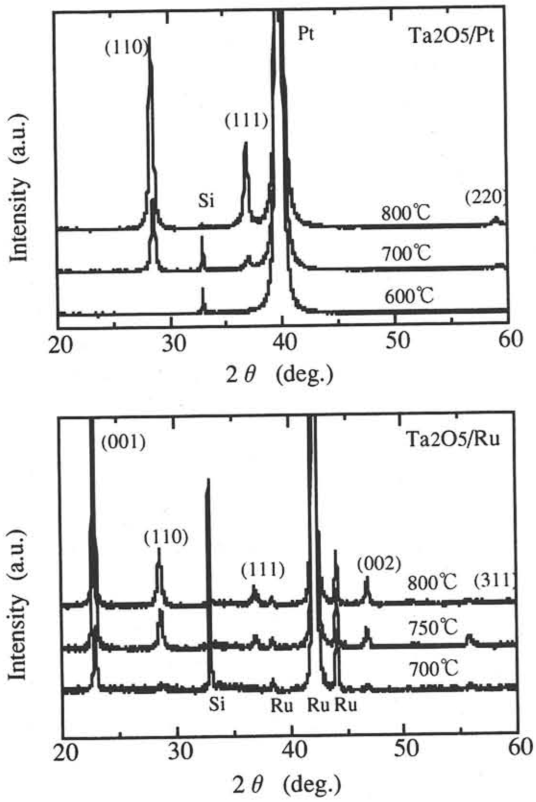

Fig. 1 XRD patterns of Ta2O5/Pt (upper) and Ta2O5/Ru (lower) annealed at various temperature from 600 to 800°C.

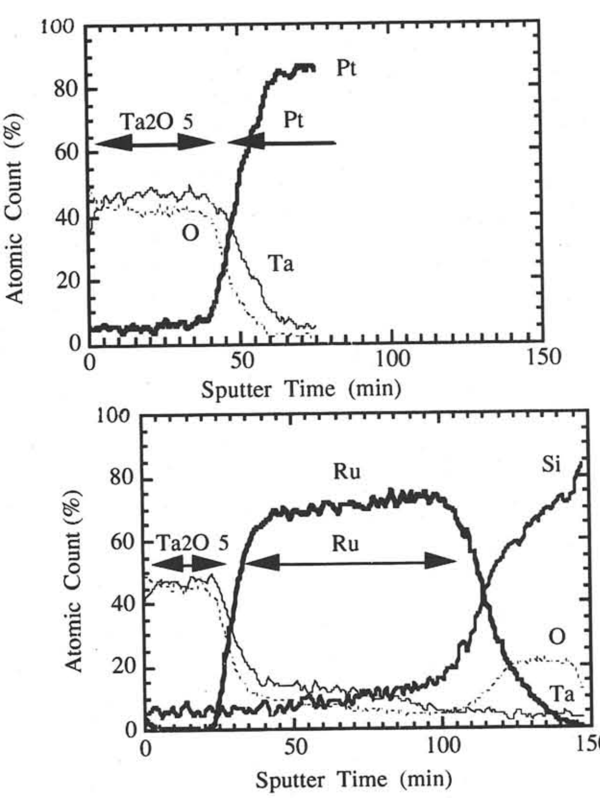

Fig. 2 AES depth profiles of Ta2O5/Pt (upper) and Ta2O5/Ru (lower) annealed at 750°C.

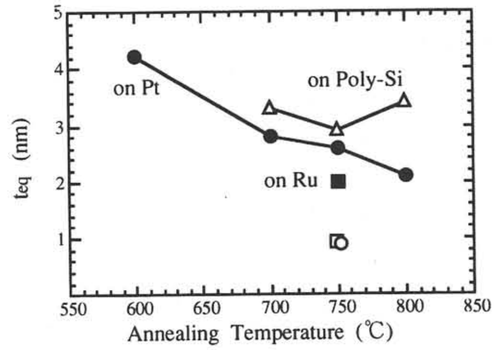

Fig. 3 Teq of Ta2O5/Pt, Ru and Poly-Si annealed at various temperature from 600 to 800°C. The thickness of Ta2O5 shown with closed and open characters is 30 and 12 nm, respectively.

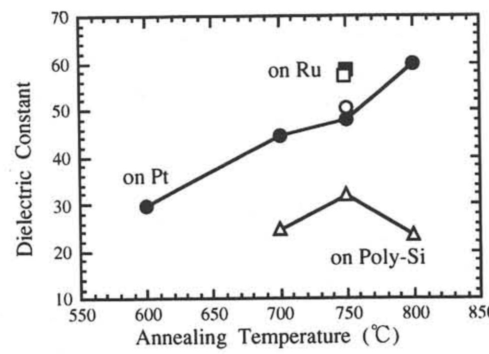

Fig. 4 Relative dielectric constant of Ta2O5 deposited on various electrodes with annealing at 600-800°C.

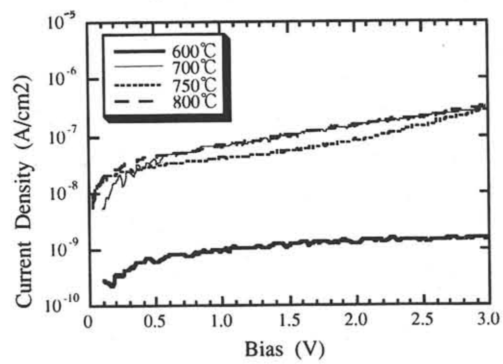

Fig. 5 I-V Characteristics of Ta2O5(30nm)/Pt annealed at various temperature 600-800°C.

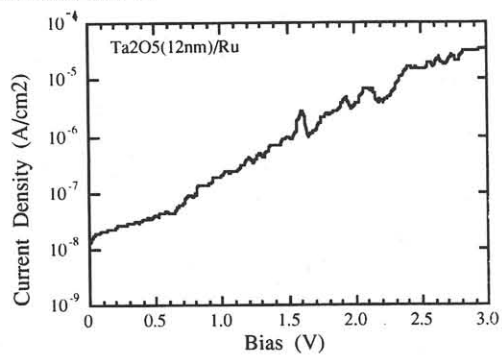

Fig. 6 I-V characteristics of Ta2O5(12nm)/Ru. To reduce the leakage current, the sample was annealed in O2 at 550°C for 1 hour before Ta2O5 crystallization(750°C RTA).