Properties of Highly Oriented Ta2O5 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 Ta2O5, BST, STO and PZT, with high dielectric constant have been studied as the dielectrics in the storage capacitor of DRAM. Ta2O5 has an advantage for that the thin film with a good step coverage is easily deposited by using LP-CVD. The dielectric constant of Ta2O5 is 20-28. Many works have been reported that the SiO2 equivalent thickness (teq) of Ta2O5 deposited on Poly-Si was about 3 nm.[1][2][3] However, it was also reported that Ta2O5 film deposited on tungsten electrode has a small teq of 1.6 nm[4]. We studied the properties of Ta2O5 film deposited on Pt and Ru electrode, which are more stable than tungsten, during the annealing in oxidation atmosphere.

2. Experiment
Ta2O5 thin films were deposited on Pt and Ru electrode by LP-CVD using Ta(OC5Hs)5 and oxygen. The deposition temperature was 400°C and total pressure was 0.2 Torr. Pt and Ru was sputtered. Ta2O5 was also deposited on Poly-Si, on which thin SiN had been deposited. The Ta2O5 thickness was measured by ellipsometry and TEM. After the Ta2O5 deposition, Ta2O5/Pt, Ru and Poly-Si were annealed for 40 and 12 seconds with 800°C. The annealing temperature was changed from 600 to 800°C. Ru upper electrode was sputtered, for measuring the electric properties of Ta2O5 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 Ta2O5 and electrode was studied by using AES.

3. Results and Discussion
Figure 1 shows the XRD patterns of Ta2O5 deposited on Pt and Ru annealed at various temperature from 600 to 800°C. Ta2O5 deposited on Pt is amorphous with 600°C annealing. All Ta2O5 deposited on Pt, Ru and Poly-Si are amorphous after annealing under 600°C. Ta2O5 is crystallized by annealing over 700°C and its crystallinity is improved with annealing temperature increase. Ta2O5 on Pt and Ru is strongly oriented to (110) and (001) phase, respectively. On the other hand, Ta2O5 on Poly-Si is randomly oriented and its peak intensity does not change with over 700°C annealing.

Figure 2 shows AES profiles of Ta2O5/Pt and Ru after 750°C annealing. There is no reaction between Ta2O5 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 Ta2O5, from its cross-sectional TEM micrographs.

Figure 3 shows teq of Ta2O5 deposited on Pt, Ru and Poly-Si annealed at temperature from 600 to 800°C. The thickness of Ta2O5 shown with closed and open characters is 30 and 12 nm, respectively. The teq of Ta2O5(30nm)/Pt, shown with closed circles, decreases with annealing temperature. It is thought that the improvement of Ta2O5 crystallinity on metal electrodes relates the teq decrease. After 750°C annealing, Ta2O5/Pt and Ru with 12 nm thickness, shown with a open circle and square, are small teq of 0.9 nm. On the other hand, the teq of Ta2O5(12nm)/Poly-Si, shown with open triangles, is about 3 nm, even Ta2O5 is crystallized with annealing at above 700°C. Crystallized Ta2O5/Pt and Ru which is highly oriented with high temperature annealing has a small teq.

Figure 4 shows the relative dielectric constant (ε) of Ta2O5 films annealed at various temperature. Ta2O5 on Pt and Ru, which is crystallized and highly oriented at above 700°C, shows ε over 50. But ε of Ta2O5 crystallized on SiN is low and not affected with annealing temperature. It is clear that the ε of Ta2O5 strongly depends on its crystallinity.

Figure 5 shows the I-V characteristics of Ta2O5/Pt annealed at temperature from 600 to 800°C. Ta2O5/Pt annealed at 600°C is amorphous and its leakage current is 2 x 10^-4 A/cm². With annealing above 700°C, the leakage current of crystallized Ta2O5/Pt increases to over 10^6 A/cm² but is constant, in spite of annealing temperature. The leakage current increase may be caused that the grain boundaries of crystallized Ta2O5 become current path.

Generally, thinning dielectric films increases their leakage current. To reduce the leakage current of thin Ta2O5, the sample was pre-treated in O2 at 550°C for 1 hour before crystallization.[5] Figure 6 shows the I-V property of Ta2O5(12nm)/Ru with 0.9 nm teq, crystallized with 750°C annealing. It shows the leakage current of 2 x 10^-7 A/cm² at 1V.

4. Conclusion
We studied the properties of Ta2O5 deposited on Pt, Ru and Poly-Si. The crystallized Ta2O5/Pt and Ru is highly oriented and the relative dielectric constant is higher than 50 with annealing above 700°C. The teq of Ta2O5(12nm)/Pt and Ru crystallized at 750°C is 0.9 nm. On the other hand, Ta2O5/Poly-Si is randomly oriented and its ε is under 30. It is assumed that the highly oriented Ta2O5 on metal electrode is a candidate promising for a Giga-bit DRAM's dielectric.

References
5) K.Kishiro M.Yoshimaru et. al.: JSAP and Related Socs. 44th Meeting, (1997) 29a-F-8
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).