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Improvement of Contact Resistance of Ru electrode/TiN barrier at Ru/Crystalline-Ta_2O_5/Ru Capacitor for 50nm DRAM device

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1. Introduction

Ru/Insulator/Ru (RIR) capacitor has been one of the most promising candidates for 50nm DRAM and beyond due to superior process maturity, feasibility, and reliability [1-2]. While RIR capacitor using crystalline-Ta_2O_5 to increase the permittivity (ε~60) has overcome the leakage current issue by introducing the seed Ta_2O_5 process [3] to be integrated into 3-dimensional high-density structure, the contact resistance (R_C) between the Ru storage node (SN) and the TiN barrier has increased by the high crystallization temperature up to 700º C. It was reported that Ru SN using the PCM sputtering for amorphous Ta_2O_5 capacitor reduced R_C value to ~10kΩ [4]. However, if the temperature increases for the crystallization, R_C value might increase further by a fast diffusion atmosp here. Other researcher has approached to decrease the crystallization temperature by using Nb stabilized Ta_2O_5 [5], but R_C issue has not been reported.

In this study, we have investigated the origins of the R_C increase during the capacitor process and proposed novel concepts to reduce R_C for performing RIR capacitor using crystalline Ta_2O_5 on the future 50nm DRAM device.

2. RIR Capacitor using a Seed Ta_2O_5 Process

Figure 1 shows the electrical properties of RIR capacitor according to the various deposition processes. By using a seed Ta_2O_5 (50Å) followed by a main Ta_2O_5 (100Å), wherein each annealing was involved, we could satisfy the leakage current below 1fA/cell at ±1V within a 8Å Toxeq range in 3-dimensional capacitor structures such as concave and stack type.

3. Contact Resistance of Ru electrode/TiN barrier

Figure 2 shows the schematics of contact string patterns to evaluate R_C of Ru-TiN interface. R_C increased up to a level of giga-ohms after annealing of Ta_2O_5 at 700º C in N_2. To figure out oxygen source, the AES analysis was conducted after Ru was exposed in the atmosphere of Ta_2O_5 deposition. As shown in Fig. 3, high oxygen content was observed both at the interface between Ru and TiN and near the surface of Ru. Such oxygen is supposed to be supplied during both a nucleation step of Ru deposition to accelerate Ru seeding, and an initial step of Ta_2O_5 deposition. Therefore, It is most likely that such oxygen diffuses through Ru grain boundary and oxidizes TiN during the crystallization annealing. To reduce the atmosphere, we annealed Ru films in 10% H_2 atmosphere at 450º C. However, the AES analysis in Fig 4 shows oxygen in Ru still remains after H_2 annealing, but the oxygen content introduced during the initial step of Ta_2O_5 deposition is rapidly dropped. After H_2 annealing, Ru grain growth was also observed. Therefore, we suppose the effect of H_2 annealing is the prevention of further oxygen penetration during Ta_2O_5 deposition due to the decrease of oxygen diffusion path. As a result, R_C decreased to a level of 10kΩ as shown in Fig. 4. But R_C was not uniform in a wafer due to oxygen in Ru film itself.

In order to reduce oxygen in Ru, we tried to use an inserted metal layer to diffuse oxygen out of Ru. Ti layer was deposited between Ru films and annealed at 700º C in N_2. As shown in Fig. 5, oxygen in Ru after annealing migrated toward Ti film in the Ru/Ti/Ru scheme. It is because the inserted Ti can be easily oxidized rather than the TiN barrier. The values of R_C, where Ti was deposited on Ru films followed by annealing at 700º C dramatically decreased less than 1kΩ and its uniformity was improved due to the removal of oxygen in Ru film. TEM image in Fig. 5 shows that there is no TiO_X in the TiN plug after Ta_2O_5 deposition and crystallization. However I-V characteristics were degraded when the inserted Ti was used as shown in Fig 6. Therefore, It is difficult to remove oxygen incorporated in Ru by inserting Ti. We have thus developed the Ru deposition without oxygen by using an ALD process to form a Ru seed. XPS result of ALD Ru on TiN in Fig. 7 reveals that oxygen is not included in the Ru film due to the use of H2 plasma as a reactant instead of oxygen gas. Compared to CVD Ru, the R_C between ALD Ru and TiN barrier was reduced up to 2 kΩ in average after Ta_2O_5 deposition followed by crystallization annealing as shown in Fig 8. It is thought that there still remains oxygen source like adsorption on each surface, but major sources can be successfully eliminated by ALD seed Ru and H_2 treatment.

4. Three-Dimensional Structure for RIR Capacitor

Ru storage node (SN) in 3-dimensional structure should have low RC maintaining the capacitor having low leakage current after the crystallization of Ta_2O_5 and also increase the process throughput during the formation. The bottom Ru was formed by the two-step deposition process. ALD Ru film without oxygen was deposited as a seed layer and then main CVD Ru (Cm) with less amount of oxygen was followed. Because major oxygen is incorporated in Ru film during the CVD seed process with high pressure and oxygen content, ALD seed and CVD main Ru process could reduce R_C and also improve the process throughput. The wet stopper and the buffer layer in 3-dimensional capacitor scheme could effectively prevent wet-attack during the lift-off process to form the SN and any collapse or leaning of it was not observed neither.

5. Conclusions

We suggested several methods to solve the contact resistance issue for integration of RIR capacitor using crystalline-Ta_2O_5 in 3-dimensional high density structure. The oxidation of TiN barrier during Ta_2O_5 crystallization was prevented by using the inserted Ti layer, but the leakage current was increased. Therefore, we developed novel technology using ALD seed and CVD main Ru followed by H_2 annealing to reduce R_C maintaining the electrical properties of RIR capacitor.

References

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[2] W. D. Kim et al., IEDM Tech. Dig., (2001) p.263.
[3] J. H. Choi et al., Korean Conf. Semicon. (2003) p.155.
[4] Y. Nakamura et al., SSDM, (2003) C4-2.
[5] Y. Matsui et al., IEDM Tech. Dig., (2002) p.225.

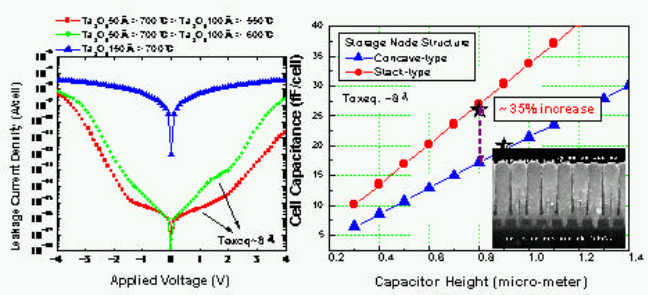

Fig.1. Electrical Properties of RIR Ta_2O_5 Capacitor

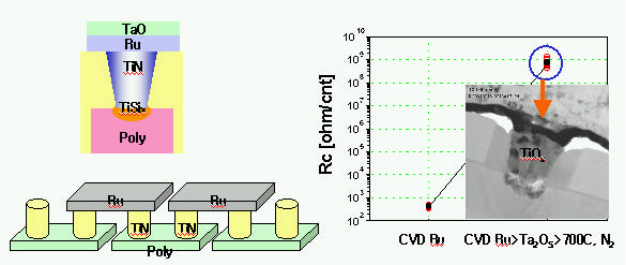

Fig.2. Contact measurement scheme and R_C after annealing at 700° C in N_2.

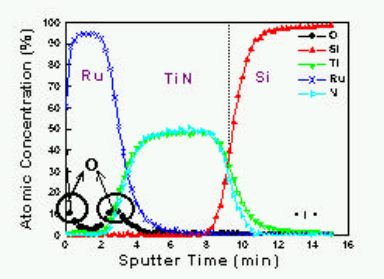

Fig.3. AES analysis of oxygen source causing TiN oxidation.

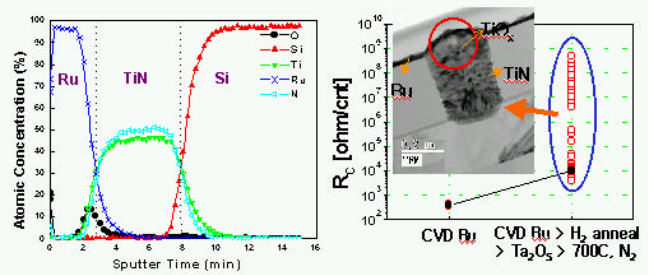

Fig.4. AES analysis and R_C after H_2 annealing followed by Ta_2O_5 deposition and crystallization.

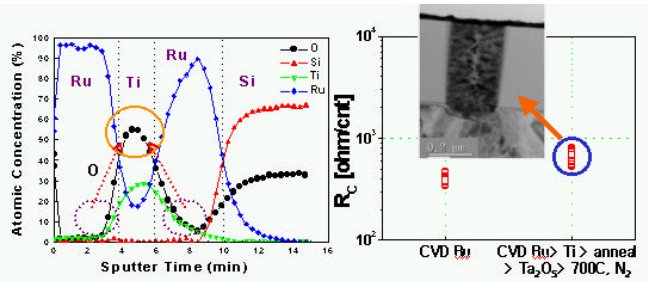

Fig.5. AES analysis and R_C in case of the inserted Ti in Ru.

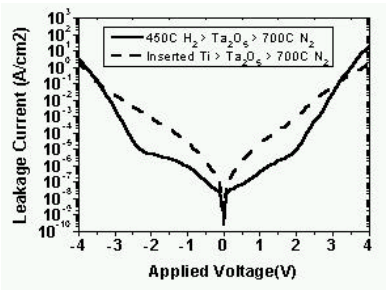

Fig.6. I-V curves of RIR Capacitor using the inserted Ti and H_2 anneal in bottom Ru.

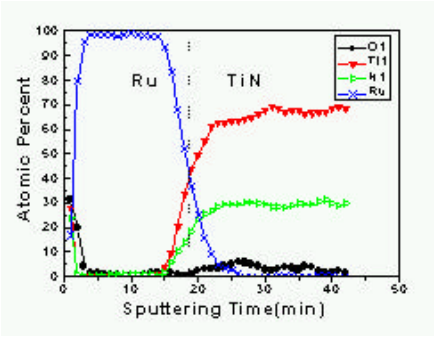

Fig.7. XPS analysis of ALD Ru films on TiN.

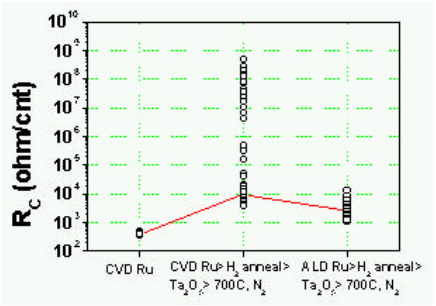

Fig.8. R_C in case of of ALD Ru after crystallization annealing.

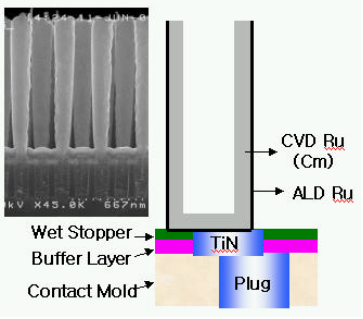

Fig.9. Schematic diagram and SEM image of RIR capacitor for reducing the contact resistance.