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Performance and Reliability of MIM (Metal-Insulator-Metal) Capacitors with ZrO_2 for 50nm DRAM Application

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Introduction

As the design rule shrinks rapidly down to sub-micron level, high dielectric constant materials have been on demand as the alternatives for the current capacitor dielectric materials. Fig.1 shows the relationship between cell capacitance and Toxeq. (Equivalent Oxide Thickness) for 50nm technology. According to this estimation, Toxeq. less than 8Å will be required to offer 25fF cell capacitance for 50nm design rule with 1.6㎛ high cylindrical capacitor structure. [1] So far several studies related with MIM (Metal-Insulator-Metal) capacitors using high-K dielectrics such as HfO_2 or Al_2O_3-HfO_2 bilayer have been reported in order to improve the performance of capacitor dielectrics. But, even with those kinds of materials, Toxeq. less than 8Å for 50nm technology has not been obtained yet [1-2] ; which means other high-K materials that have much higher dielectric constant than HfO_2 or Al_2O_3-HfO_2 should be developed and implemented to overcome this dilemma for 50nm technologies.

In this paper, we would like to introduce one of high-K dielectric materials, ZrO_2 for 50nm and below DRAM capacitor technologies. ZrO_2 has always attracted the attention as an alternative for the future dielectric material of DRAM capacitors because of its high dielectric constant. [3] In this work, we investigated the electrical characteristics of ZrO_2 dielectric films at MIM capacitors with TiN electrodes. We also evaluated the resistance against thermal degradation up to 550℃ and finally we obtained TDDB (Time-Dependent-Dielectric-Breakdown) results that are acceptable enough for 50nm DRAM capacitors with TiN electrodes.

Capacitor Fabrication

For our experiments, we prepared two kinds of MIM capacitor structures such as flat-type capacitor and cylindrical structure. In case of cylindrical MIM capacitor structure with TiN electrodes, the next fabrication sequence was performed. ; First, 1.4㎛ high cylindrical structures were formed with TiN bottom electrode. Etchback process was used to separate each bottom electrode. After a pre-cleaning process, a ZrO_2 film was deposited onto the bottom electrode by ALD (Atomic-Layer-Deposition) process with TEMAZ (Tetrakis-Ethyl-Methyl-Amino-Zirconium) and ozone (O_3) reactant. Top electrode TiN and capping layer were formed consecutively on the top of dielectric layer and the final plate patterning produced our goal structures. To evaluate thermal degradation characteristics, high temperature anneal process was carried out for all samples after plate patterning. Finally, the electrical properties such as capacitance and leakage current were measured by means of HP4282 and HP4155, respectively.

Results and Discussion

Fig.2 shows the I-V characteristics and Toxeq. values of TiN/ZrO_2/TiN capacitors in connection with ZrO_2 film thickness. This result shows that even though Toxeq. went down to 6.4Å, acceptable leakage current density of 4.3E-8A/cm^2 could be obtained. Fig.3 shows the trend of Toxeq. vs leakage current density under the operation voltage of +0.9V. From these results, we could obtain the limitation of Toxeq. as 6.0Å which can meet leakage current density criterion (1.0E-7A/cm^2) even after 550℃ post annealing process. Fig.4 shows the nearly flat C-V characteristics of ZrO_2 dielectric layer at MIM capacitors and according to these results we can see that ZrO_2 can offer the acceptable Cmin/Cmax ratio over 95%. Fig.5 shows the HRTEM images of 95Å thick ZrO_2 film at flat-type capacitor. It could be found out that there was no interfacial reaction between ZrO_2 and each TiN electrode. From the electrical measurement of the same sample, we also obtained 9.1Å of Toxeq. after post annealing at 550℃. Fig.6 shows the linear relationship between Toxeq. and TEM thickness using the three different ZrO_2 samples. Based on this relationship, the dielectric constant of ZrO_2 could be calculated as 41, which is much higher than any other previous results with ZrO_2 for MIM capacitor application and almost twice higher than that of HfO_2. [3] This enhancement of dielectric constant is due to the characteristics of ZrO_2 polymorphs. ZrO_2 has three polymorphous phases such as monoclinic, tetragonal and cubic. Among those three polymorphs, high dielectric constant has been reported for both tetragonal and cubic phases. [4] Comparison of XRD results in Fig.7 shows that ZrO_2 thin film on TiN substrate represented tetragonal structure of high dielectric constant. In HfO_2 case, however, monoclinic phase with low dielectric constant was mainly generated.

For DARM device application, a high conformal ZrO_2 dielectric layer was deposited by ALD method on 1.45㎛ cylindrical TiN electrodes of 70nm design rule. (Fig.8) Using these cylindrical capacitor structures, the electrical properties including capacitance and I-V characteristics could be obtained as shown in Fig.9. At the operation voltage of -0.9V, the measured cell capacitance and leakage current density were 51.6fF and 4.6E-16A/cell, respectively. Fig.10 and Fig.11 show the distribution characteristics of cell capacitance and leakage current density at 200mm wafer. Both results point out that ZrO_2 can produce the fairly good within-wafer-uniformity properties in 70nm technology. Fig.12 shows the TDDB behaviors of ZrO_2 dielectric in 70nm device. These results indicate that MIM capacitor with ZrO_2 can guarantee more than 10-year lifetime.

Conclusions

ZrO_2 has been successfully developed for DRAM capacitor of 50nm technology and below. ZrO_2 fabricated by ALD process showed the dielectric constant value of 41 and the minimum Toxeq. of 6.0Å was obtained within leakage current density criterion. (0.9V@100nA/cm^2). With using ZrO_2 as a dielectric in 70nm cylindrical MIM capacitor structure, 51.6fF of cell capacitance and 4.6E-16A/cell of leakage current density could be obtained at the operation voltage of -0.9V. Finally, TDDB (Time-Dependent-Dielectric-Breakdown) was confirmed to satisfy the 10-year lifetime within the operation voltage range.

References

[1] S.H. Oh et al., VLSI Tech. Dig., p73-74, 2003
[2] J.H. Choi et al., IEDM2003, p661-664, 2003
[3] S.Y. LEE et al., Appl. Phys. Lett., Vol.82, p2874-2890, 2003
[4] Xinyuan Zhao et al., Physical Review B, Vol.65, 075105, 2002

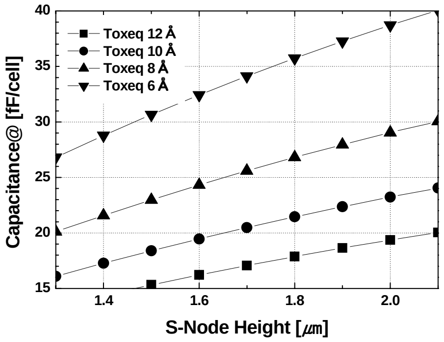

Fig. 1. Relationship between Cell Capacitance and S-Node Height with Cylindrical Capacitor at 50nm Design Rule

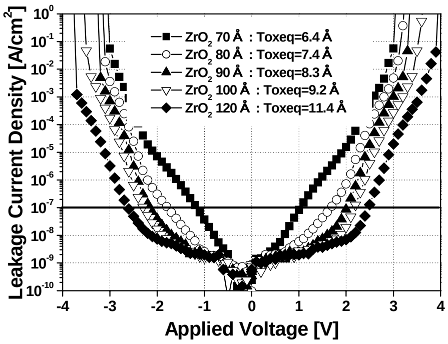

Fig. 2. I-V Characteristics of TiN/ZrO_2/TiN Capacitors

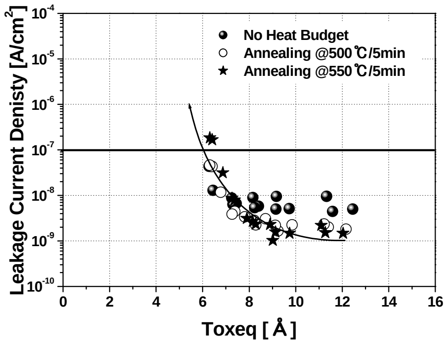

Fig. 3. Relationship between Toxeq and Leakage Current Density of TiN/ZrO_2/TiN (Voltage @+0.9V)

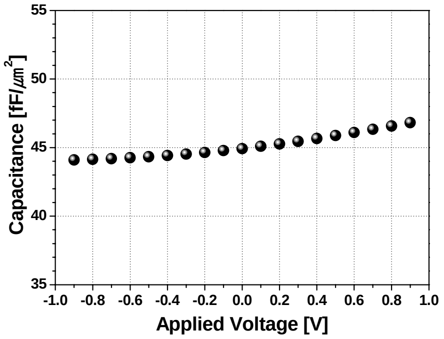

Fig. 4. C-V Characteristics of TiN/ZrO_2/TiN Capacitors

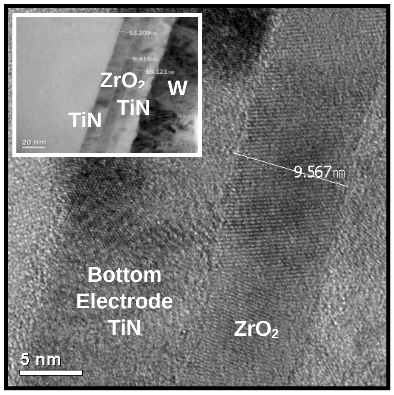

Fig. 5. HRTEM Image of TiN/ZrO_2/TiN Capacitor at Flat-Type Structure (Toxeq=9.2 Å)

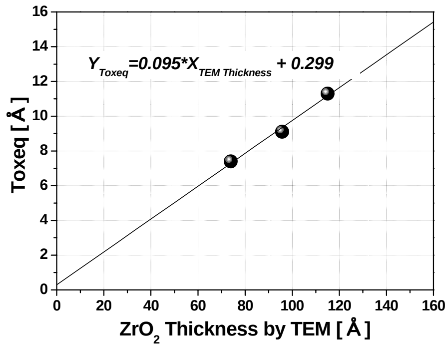

Fig. 6. Relationship between TEM Thickness and Toxeq of ZrO_2 Films

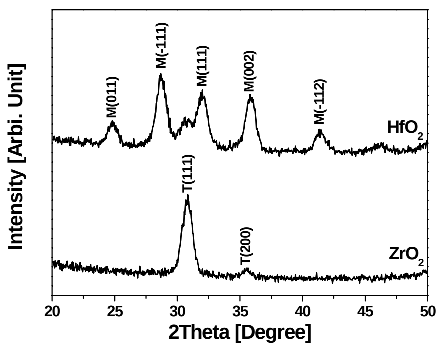

Fig. 7. XRD Profiles of ZrO_2 and HfO_2 Films deposited on TiN Substrates

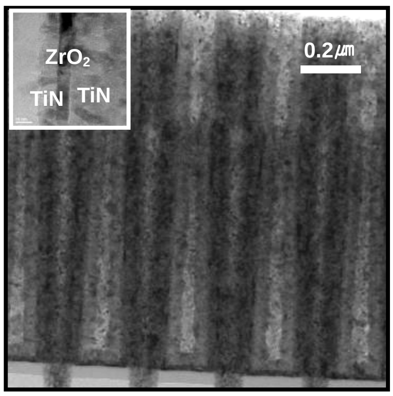

Fig. 8. Cross-Sectional TEM Image of Cylindrical TiN/ZrO_2/TiN Capacitor at 70nm Device

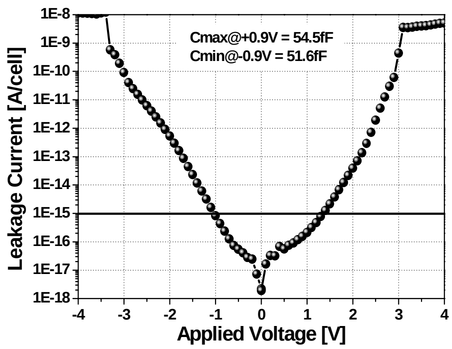

Fig. 9. I-V Characteristics of Cylindrical TiN/ZrO_2/TiN Capacitor at 70nm Device

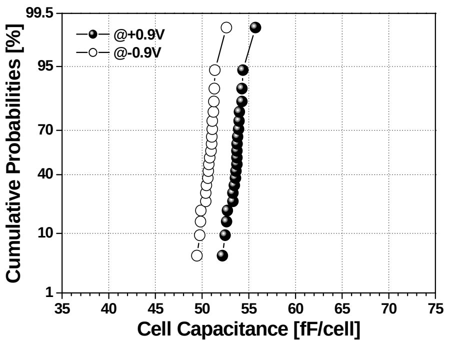

Fig. 10. Distribution of Cell Capacitance of TiN/ZrO_2/TiN Capacitors at 70nm Device

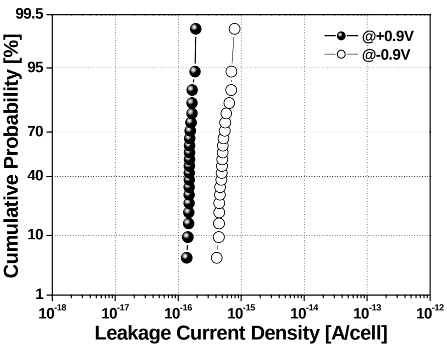

Fig. 11. Distribution of Leakage Current Density of TiN/ZrO_2/TiN Capacitors at 70nm Device

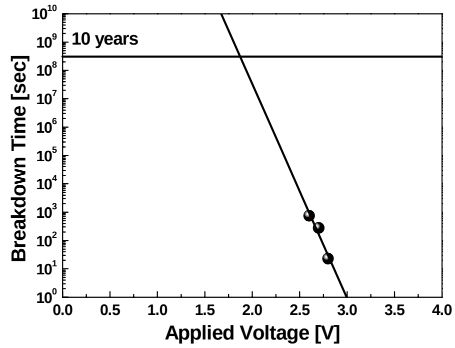

Fig. 12. Time-Dependent-Dielectric-Breakdown (TDDB) Behaviors of TiN/ZrO_2/TiN Capacitors at 70nm Device (Cmin=46.6fF)