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A New Divided Deposition Method of TiN Thin Films for MIM Capacitor Applications

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1. Introduction

With a continuous shrinkage of the memory cell size in eDRAMs, MIM (Metal-Insulator-Metal) structures have received a lot of attention to obtain an enough storage capacitance. [1, 2] Even if the MIM structures are applied to memory cells, very thin capacitor dielectric films are still required to keep the data storage characteristics beyond 90-nm technology node. In addition, it is important to avoid damages for the capacitor dielectric film during the top-electrode formation in order to maintain a low leakage current across the dielectric film. [3]

In this paper, we propose a new TiN-CVD method for the top-electrode formation, which consists of several sets of TiN deposition and *in-situ* NH_3 anneal at a low temperature to achieve excellent properties in TiN/Ta_2O_5/TiN structures.

2. Experimental

Figure 1 shows the fabrication process of TiN/Ta_2O_5/TiN capacitors used in this paper. After the formation of Ta_2O_5 dielectric films, TiN films were deposited from $TiCl_4$ and NH_3 as top-electrodes, ranging from 350 to 500 ˚C in temperature, from 5 to 20 nm in thickness. *In-situ* annealing in NH_3 ambient was carried out to reduce the residual Cl in the deposited TiN films.

The details of TiN-CVD deposition sequences are shown in Fig. 2; (a) is the divided deposition method demonstrated in this paper, and (b) is the conventional method as a control process.

The properties of MIM capacitors were investigated by I-V measurements. The surface morphology of the CVD-TiN films was observed using SEM.

3. Result and Discussion

Figure 3 shows the dependence of the capacitor leakage current on the deposition temperature of TiN in the case of the conventional method. The conventional TiN-CVD process at 450 ˚C can suppress the leakage current, while those over 475 ˚C increase the current.

Figure 4 shows the leakage current of MIM capacitors as a function of the applied voltage for the several NH_3 annealing temperatures. The leakage current in the case of NH_3 annealing at 450 ˚C is the same as that without NH_3 annealing. Over 500 ˚C, the leakage current increases as the annealing temperature increases. This result indicates that the degradation of the Ta_2O_5 film is caused by the reaction with NH_3. We suggest that the increase in leakage current at higher deposition temperatures, shown in Fig. 3, is also due to the reaction of the Ta_2O_5 film with NH_3 or products from NH_3. Therefore, the TiN-CVD process below 450 ˚C would be necessary for the suppression of the Ta_2O_5 degradation and for keeping the low leakage current during the TiN deposition with $TiCl_4$ and NH_3.

Although the TiN deposition below 450 ˚C can suppress the leakage current, a lot of anomalous growth substances are produced on the TiN film surfaces, as shown in Fig. 5. The size is about 50 to 100 nm. The anomalous growth substance is increased for the lower deposition temperature, as shown in Fig. 6. Since such large anomalous growth substances could be the killer defects, the CVD-TiN films deposited below 450 ˚C are not applicable to ULSI fabrication processes. Figure 7 shows the relationship between the leakage current and the density of anomalous growth substance. This result indicates that it is difficult to reduce the leakage current without the anomalous growth substances using the conventional TiN-CVD process.

Figure 8 shows the SEM images of the surface morphology of 5-nm TiN films deposited at 450 and 350 ˚C. It should be noted that the anomalous growth does not occur at both temperatures in such thin TiN films.

However, as shown in Fig. 9, the leakage current increases as the TiN film thickness becomes less than 10 nm in the case of the conventional deposition at 450 ˚C. We propose that this increase in current is attributed to the degradation of the Ta_2O_5 films due to the reaction with NH_3, since the large amount of NH_3 penetrates through such thin TiN films. Therefore, there is no process window in the conventional method for keeping the low leakage current without the anomalous growth.

The penetration of NH_3 through thin TiN films should be reduced in lower-temperature processes. In addition, as indicated in Fig. 8, the anomalous growth does not occur on the 5-nm TiN film formed at 350 ˚C. Therefore we have investigated the effect of the deposition of thin TiN films and the NH_3 anneal at 350 ˚C on the leakage current across the Ta_2O_5 films. Figure 10 shows the leakage current as a function of the process temperature in the case of the divided TiN deposition method, in which several sets of the thin TiN deposition and the NH_3 anneal were repeated, as depicted in Fig. 2(a). The low level of the leakage current is successfully accomplished by using the divided deposition of TiN at 350 ˚C. Figure 11 shows the SEM image of the surface morphology of the 20-nm TiN film deposited by the divided method at 350 ˚C. No anomalous growth is observed. Thus we have demonstrated that the divided deposition method at 350 ˚C provides the low leakage current without the anomalous growth.

4. Conclusions

For the TiN/Ta_2O_5/TiN MIM capacitor structure, we demonstrated that the leakage current could be kept low by using the divided TiN deposition process at 350 ˚C, which is compatible with the suppression of the anomalous growth. The divided TiN-CVD deposition process at low temperature is expected as a promising method for the top-electrode formation for a MIM structure beyond the 90-nm node.

Acknowledgements

We would like to thank Ms. Yukari Imai of Process & Device Analysis Engineering Development Dept. in Renesas Technology for SEM measurements.

References

[1] H. Hu et al., IEDM Tech. Dig. (2003)
[2] Y. L. Tu et al., Symp. on VLSI Tech. (2003)
[3] M. Takeuchi et al., Symp. on VLSI Tech. (2001)

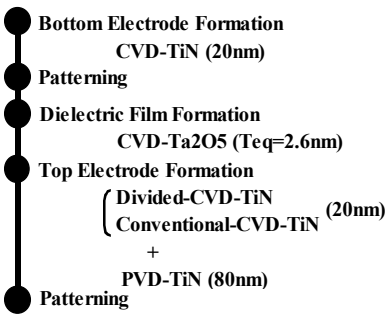

Figure 1. Process flow of the MIM capacitor formation.

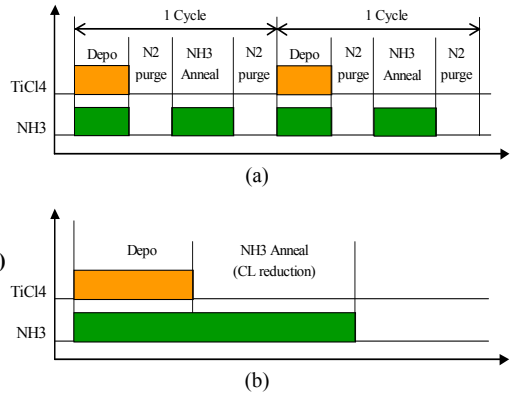

Figure 2. Description of CVD-TiN process sequences. (a) Divided deposition method. (b) Conventional deposition method.

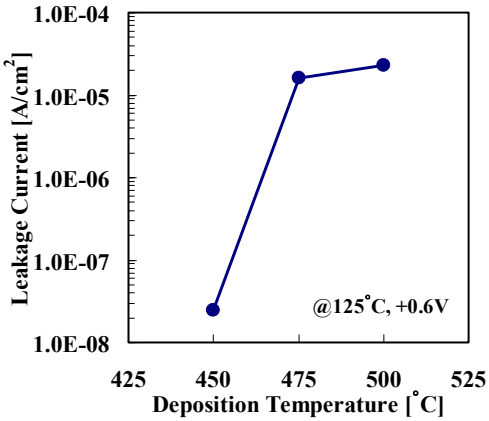

Figure 3. Dependence of the leakage current on the deposition temperature of the conventional method.

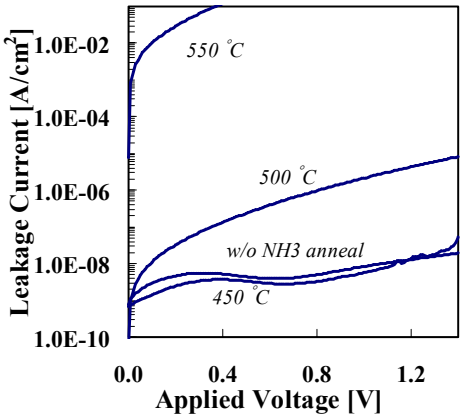

Figure 4. The leakage current of MIM capacitors as a function of the applied voltage for the several NH_3 annealing temperatures.

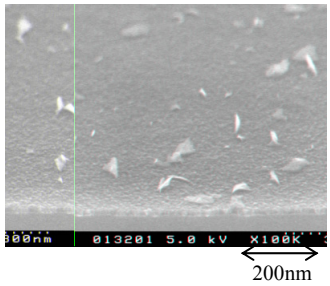

Figure 5. SEM image of the surface of 20-nm CVD-TiN film deposited at 450 ˚C. The size of the anomalous growth substance is about 50 to 100 nm.

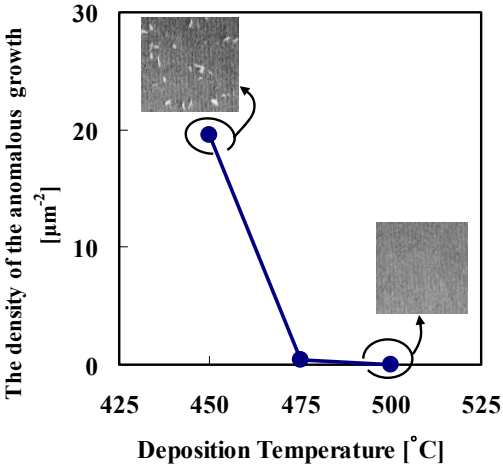

Figure 6. Dependence of the density of anomalous growth on the deposition temperature of TiN films. The SEM images of TiN film surfaces deposited at 450 ˚C and 500 ˚C are inserted.

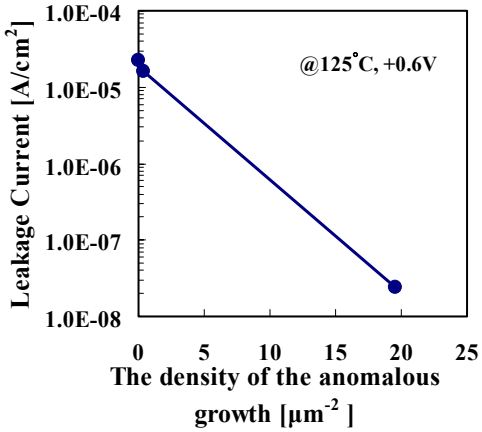

Figure 7. Relationship between the leakage current and the density of anomalous growth substances.

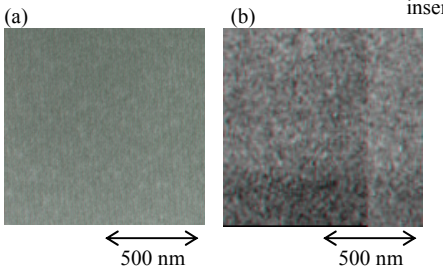

Figure 8. SEM images of the surface of 5-nm CVD-TiN films, (a) deposited at 450 ˚C, (b) deposited at 350 ˚C. There is no anomalous growth on 5-nm films.

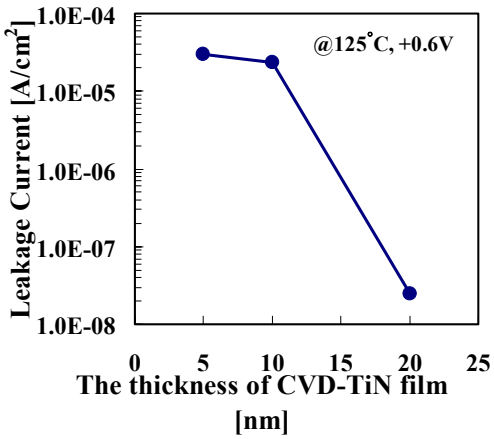

Figure 9. Dependence of the leakage current on the thickness of the conventional-mathod TiN film deposited at 450 ˚C.

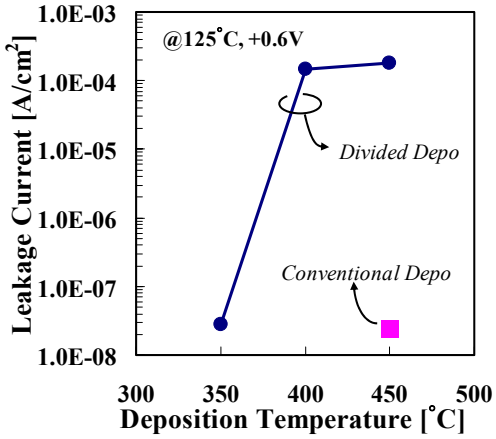

Figure 10. The leakage current as a function of the process temperature in the case of the divided TiN deposition method.

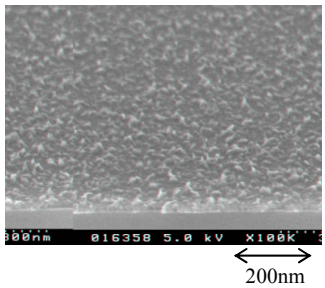

Figure 11. SEM image of the surface morphology of the 20-nm TiN film deposited by the divided method at 350 ˚C