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A Highly Reliable TiN/Al_2O_3/TiN MIM Technology for Embedded DRAMs

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1. Introduction

Metal-insulator-metal (MIM) capacitor using high-k dielectric has been extensively studied for advanced Embedded DRAM, 90nm and beyond, to meet the requirements of high capacitance, low leakage current, and low thermal budget [1-2]. Although with its moderate value of k = ~9, Al_2O_3 is a very promising candidate because it exhibits low electrical leakage, good chemical and thermal stability. Also, the deposition of Al_2O_3 by atomic layer deposition (ALD) technique is getting mature [3].

In this paper, a low-temperature TiN/Al_2O_3/TiN MIM technology resulting in excellent electrical properties is described. With TiN/Al_2O_3/TiN structure, it's found ALD-TiN is a much better top electrode than MOCVD-TiN, not only for better step coverage, but also for lower leakage due to less plasma damage.

2. Capacitor Process Modules

Fig. 1 illustrates the process flow for the MIM capacitor. All process steps were kept below 450C to meet the low thermal budget requirement for embedded DRAMs. The bottom electrode was formed by the deposition of CVD-TiN and patterned. Al_2O_3 with EOT of ~ 20 - 25 Å, was then deposited by ALD process using $Al(CH_3)_3$ (TMA). As for the top and bottom electrodes, both ALD-TiN and MOCVD-TiN are compared.

To characterize the TiN/Al_2O_3/TiN capacitor, electrical properties including leakage current, capacitance, breakdown voltage and time dependent dielectric breakdown (TDDB) were evaluated.

3. Results and Discussions

Based on the evaluation, the electrical properties of Al_2O_3 MIM do not depend on the type of TiN used as bottom electrode. However, because of step coverage concern for small cell size, ALD process is preferred than conventional CVD process for top electrode. And, another major drawback associated with MOCVD-TiN is identified. It's found that the leakage current and breakdown voltage were significantly degraded when MOCVD-TiN was used as top electrode, as shown in Fig. 2 (a) and (b). A reduction of ~ 2fF/cell in cell capacitance was observed as well. The results of I-t measurements, shown in Fig. 3, also indicate the superior ALD-TiN performance over MOCVD-TiN. With ALD-TiN, the leakage did not increase significantly until breakdown occurred. The degradation of electrical properties with MOCVD-TiN top electrode is attributed to the plasma damage caused by the post treatment following the deposition of MOCVD-TiN. Because of the high C and H contents, the as-deposited MO-TiN film usually requires a post treatment, using H_2-based plasma, to reduce leakage. This will cause damage on the underneath Al_2O_3 film. Fig. 4 shows the leakage current as a function of various amount of plasma post-treatment used for MOCVD-TiN. It's found the leakage increased with the increasing amount of plasma treatment. As shown in Fig. 4, the leakage current increased three orders when the amount of plasma doubled. The breakdown voltage was also decreased with increasing plasma treatment. It's concluded that MOCVD-TiN is not suitable for top electrode of TiN/Al_2O_3/TiN capacitor.

Fig. 5 shows the typical IV characteristics of 20Å EOT Al_2O_3 capacitors with a top ALD-TiN electrode. Low leakage current of < 0.5 fA/cell is achieved at 125C @±1V. Also, a very weak temperature dependence of leakage is observed. C-V plot in Fig. 6 indicates no significant fluctuation of capacitance in the voltage range of –2 V to 2 V. The TDDB measurements at 125C are shown in Fig. 7. The lifetime is far greater than the nominal spec. of 10 years.

The present MIM technology can be extended further with thinner Al_2O_3 to serve high capacitance (> 20 fF/cell) requirements. As shown in Fig. 8, the leakage current can be maintained below 1 fA/cell with a safe margin when Al_2O_3 of ~ 40Å is used.

4. Summary

A reliable TiN/Al_2O_3/TiN MIM technology with low thermal budget has been successfully developed for 90nm and beyond embedded DRAMs. It's found that MOCVD -TiN is not suitable for top electrode due to the plasma damage. With ALD-Al_2O_3 and ALD-TiN top electrode, excellent electrical properties such as low leakage of < 0.5 fA/cell at 125C, cell capacitance of > 20 fF/cell, and TDDB much longer than 10 years have been achieved.

Acknowledgement

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References

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[2] J.-H. Lee *et al*., VLSI Tech. Dig. (2002), p. 114.

[3] Y. K. Kim *et al.*, IEDM Tech. Dig. (2000), p. 369.

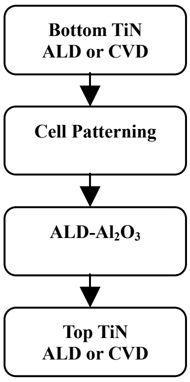

Fig. 1 Process flow of Al_2O_3-MIM capacitors.

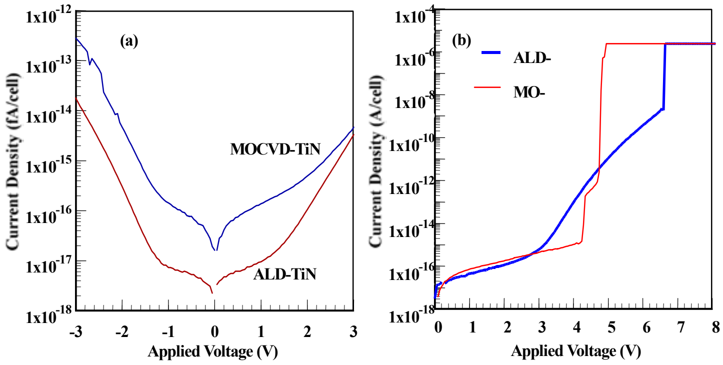

Fig. 2 The effect of top electrode on (a) leakage and (b) breakdown voltage.

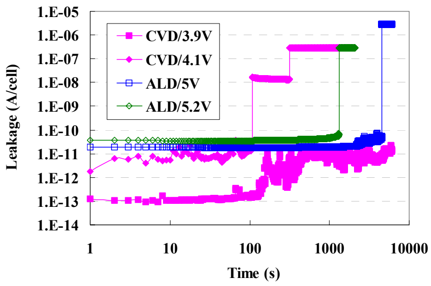

Fig.3 The effect of top electrode on I-t measurement.

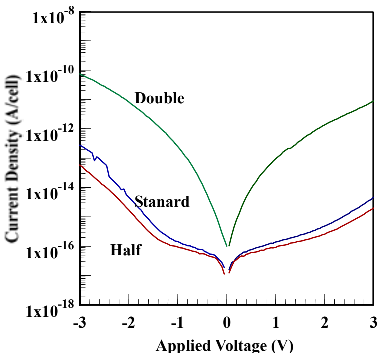

Fig. 4 The effect of plasma amount for MOCVD-TIN on leakage current.

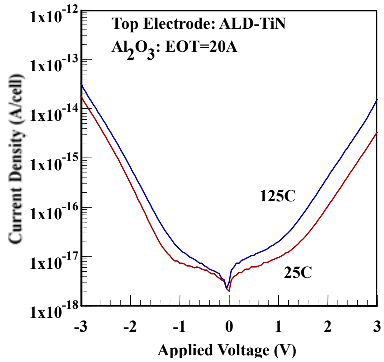

Fig. 5 IV characteristic of Al_2O_3 (EOT=20Å) with ALD-TiN top electrode.

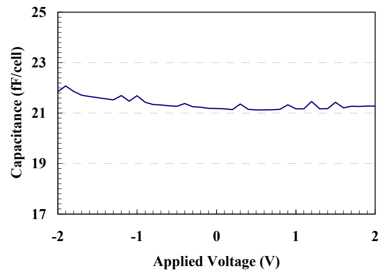

Fig. 6 CV plot of Al_2O_3 with ALD-TiN top electrode.

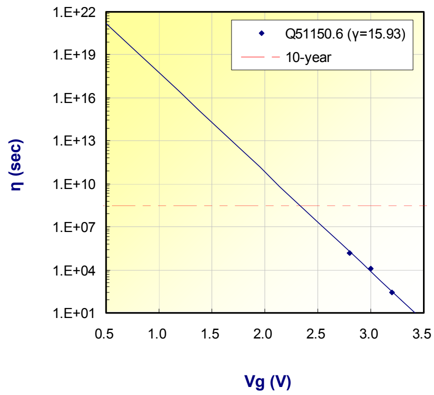

Fig. 7 Results of TDDB Measurements.

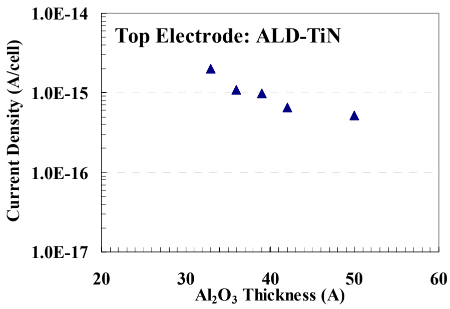

Fig. 8 Leakage current as a function of Al_2O_3 thickness.