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# A Highly Reliable MIM Technology with non-Crystallized HfOx Dielectrics Using Novel MOCVD Stacked TiN Bottom Electrodes

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## Abstract

We have developed a key process technology on HfOx-MIM (Metal-Insulator-Metal) capacitors, which overcomes a crucial issue on incidental TDDB failure. We revealed this failure was induced by the leakage current along the weak path through the micro-crystalline boundary in HfOx films. Novel stacked TiN bottom electrodes, which had amorphous TiN films on the top of crystalline electrodes, were adopted for suppressing the crystallization of the dielectrics. Excellent leakage characteristics below 10fA/cell and TDDB lifetime over 100yrs have been achieved for the concave type HfOx-MIM arrays with Teq of 1.1nm.

## Introduction

A high-speed and low-power on-chip memory device has been strongly demanded for system-on-a-chip (SOC) applications such as digital multimedia. Embedded DRAM (eDRAM) provides a solution to satisfy these requirements, where a MIM capacitor is a promising choice due to its small thermal budget suppressing transistor performance degradation.

HfOx has attracted much attention for dielectric material of MIM capacitors because of its high barrier-height against the TiN electrodes with high dielectric constant of 25. However, poor reliability caused by micro-crystal regions in the HfOx had remained as a crucial issue [1]. In this work, we present a key process technology to realize amorphous HfOx dielectrics by using novel MOCVD stacked TiN bottom electrodes.

## Experimental

The process flow and the cross sectional SEM image of concave-type MIM capacitors are shown in Fig.1 and 2. All process steps were kept below 400℃ not to degrade logic transistors' performance. TiN films for conventional and novel stacked TiN bottom electrodes were deposited by a MOCVD method using TDMAT (Tetrakis DiMethyl Amino Titanium) precursor and $H_2/N_2$ plasma treatment. After the bottom electrodes formation with etch back of the TiN films, HfOx dielectrics were deposited by ALD (Atomic Layer Deposition) process using TEMA-Hf (Tetrakis Ethyl Methyl Amino Hafnium) precursor and Ozone ($O_3$) reactant. TiN top electrodes were formed by a conventional MOCVD method.

## Result and Discussion

### A) Characteristics of conventional HfOx-MIM capacitors

Figure3 shows the I-V characteristics of HfOx-MIM capacitors with conventional TiN bottom electrodes as a function of the equivalent thickness (Teq). Low leakage characteristics below 10fA/cell at 0.7V and 125℃ are obtained even with Teq of 1.0nm. However as shown in Fig.4, the voltage acceleration factor of TDDB decrease as the thickness increases, and enough lifetimes above 10yrs are not achieved for the capacitors with Teq above 1.3nm. Breakdown characteristics of MIM capacitors with Teq of 1.25nm and 1.40nm are shown in Fig.5 (a) and (b), respectively. The leakage currents of both samples decrease slightly with an increment of stress time. It is well known that this phenomenon is attributed to space electric field induced by electron trapping [2] [3]. The incidental TDDB failures, which occur before the leakage currents decreasing, are observed frequently, especially capacitors with thicker Teq. The TEM images of HfOx-MIM capacitors are shown in Fig.6. As the HfOx thickness increases, micro-crystal regions expand clearly in the HfOx dielectrics. From these results, we have considered that these incidental failures were induced by the leakage current along the weak path through the micro-crystalline boundary in the HfOx. The suppression of the growth of crystalline HfOx is extremely important for realizing highly reliable MIM capacitors.

### B) Improvement by using novel TiN bottom electrodes

The micro-crystal regions in the HfOx are located mainly at the bottom of the concave capacitors, where the MOCVD-TiN films of the bottom electrodes are effectively treated and crystallized by the vertically directional $H_2/N_2$ plasma. We have considered that the growth of crystalline HfOx was caused by inheriting the crystal structure of the surface of TiN bottom electrodes. For decreasing the population of the crystal regions in the surface layer of TiN bottom electrodes, we have developed a novel TiN bottom electrode structure consisting of the stacked amorphous/mixed-crystalline film. Amorphous TiN films on the top of electrodes are formed by a MOCVD method without $H_2/N_2$ plasma treatment because of keeping amorphous phase.

The TEM images of MIM capacitors with conventional and stacked bottom electrodes are shown in Fig.7. In the case of stacked bottom electrodes (Fig.7 (b)), amorphous TiN films are formed on the top of bottom electrodes, and it should be noted that the population of micro-crystal regions in the HfOx dielectrics are prominently decreased.

Breakdown characteristics of MIM capacitors with Teq of 1.15nm are shown in Fig.8. No incidental TDDB failure is observed for the capacitors with stacked TiN bottom electrodes. Fig.9 shows the distribution of time-to-breakdown of MIM capacitors. Much longer time-to-breakdown is exhibited in comparison with conventional ones. We have obtained excellent TDDB characteristics for the newly developed HfOx-MIM capacitors by suppressing the crystallization of HfOx.

## Conclusions

We have developed highly reliable HfOx-MIM capacitors with novel MOCVD-TiN bottom electrodes consisting of the stacked amorphous/mixed-crystalline films**.** This structure has brought excellent leakage characteristics and highly reliable TDDB by suppressing the crystallization of HfOx. This process technology has become promising solution for 65nm node and beyond.

## References

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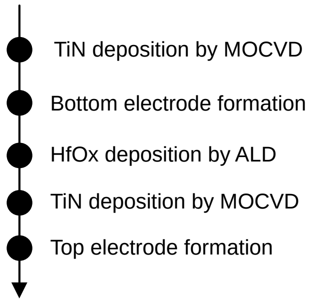

Fig.1 The process flow of HfOx-MIM capacitors.

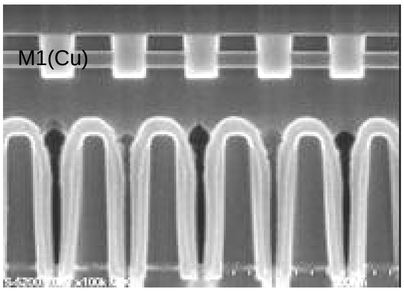

Fig.2 Cross-sectional SEM image of HfOx-MIM capacitors.

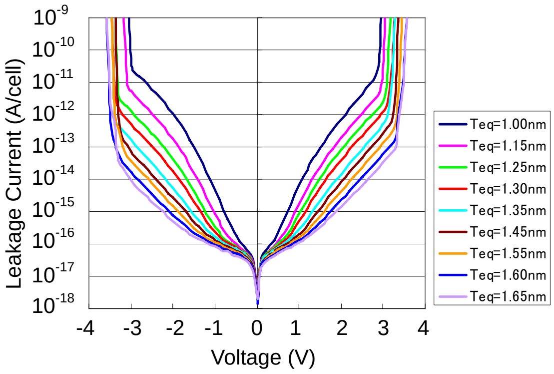

Fig.3 I-V characteristics of HfOx-MIM capacitors measured at 125℃.

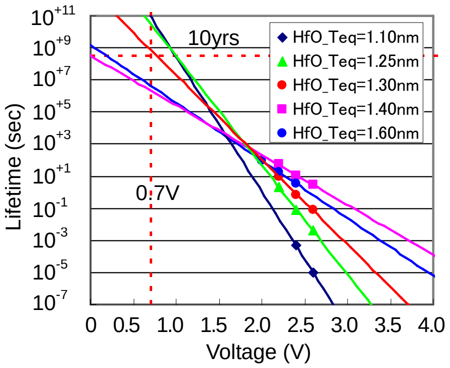

Fig.4 Lifetime projection (0.1% TTF) of HfOx-MIM capacitors.

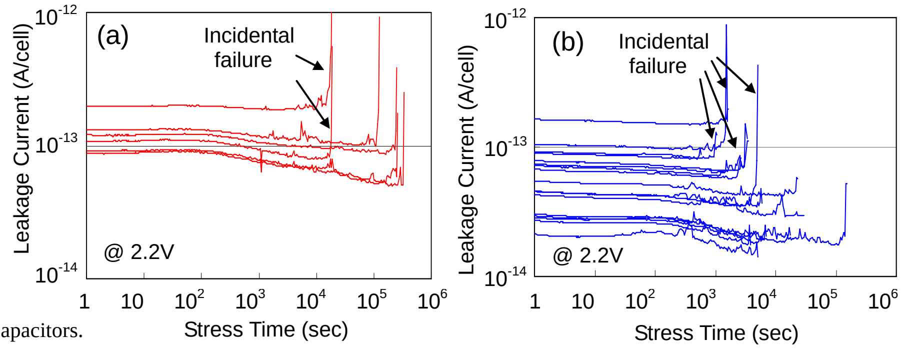

Fig.5 Breakdown characteristics of HfOx-MIM capacitors (a) Teq=1.25nm (b) Teq=1.40nm.

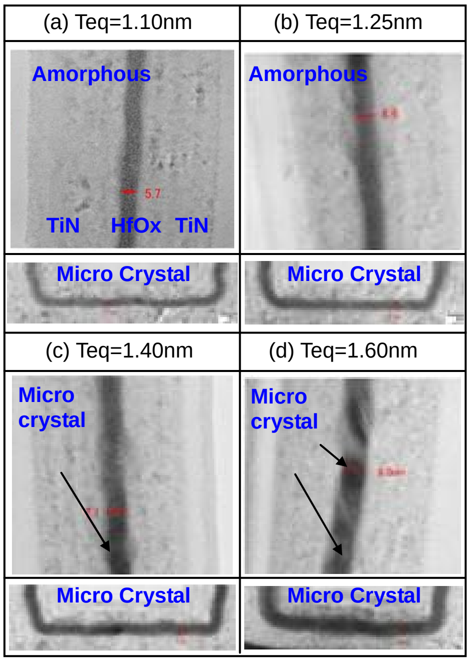

Fig.6 Cross-sectional TEM images of HfOx-MIM capacitors (a) Teq=1.10nm (b) 1.25nm (c) 1.40nm (d) 1.60nm.

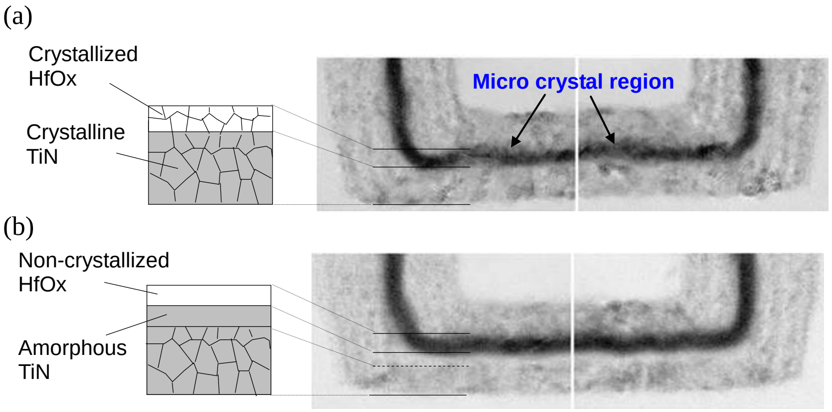

Fig.7 Cross-sectional TEM images of HfOx-MIM capacitors with (a) a conventional electrode (b) a newly developed electrode.

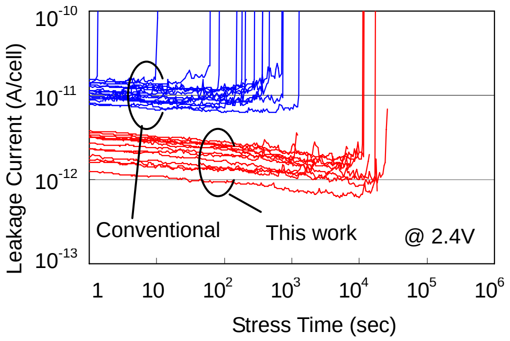

Fig.8 Breakdown characteristics of HfOx-MIM capacitors with newly developed bottom electrodes.

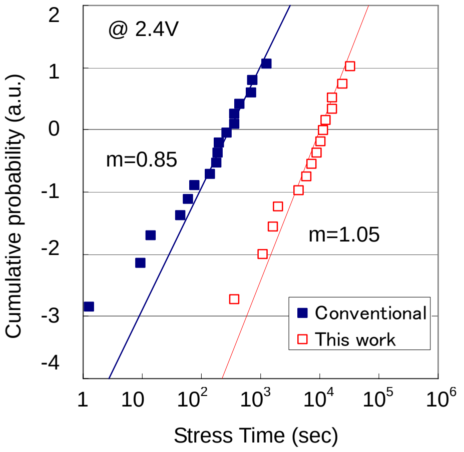

Fig.9 Distribution of time-to-breakdown of capacitors with Teq of 1.15nm. solid and open symbols represent conventional and newly developed bottom electrodes, respectively.