Study on effect of fabrication process on TDDB lifetime of MIM capacitors

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Abstract

The lifetime of MIM capacitor is studied focused on fabrication process conditions. Comparing the lifetime of capacitors cleaned with various reagents, we have revealed that wet cleaning of lower electrode has distinct effect on capacitor lifetime. We have also investigated the effect of plasma ashing on SiN film and found that high-pressure parallel plate etcher is preferred to remote plasma etcher.

INTRODUCTION

Though capacitor is very important unit in ICs, the structure is really simple. MIM (Metal-Insulator-Metal) capacitors are composed of only two components; the dielectric and the electrodes (top plate and bottom plate). About these two components in the capacitor, many studies have been done to improve the performance. The quality of dielectric has been optimized [1, 2], and the roughness of metal has been carefully controlled [3]. The relationship between the reliability and the components has also been well studied [1, 4]. In the study of active devices such as FETs and HBTs, not only the materials like substrate, electrode and interconnect metal but also their fabrication processes have been well investigated and serious effect on device performance have been reported [5]. On the other hand, the fabrication processes of capacitor (patterning of resist, removal of it, wet cleaning and so on) have not been well studied and the effect on capacitor performance have been left unclear.

In this study, we have clarified the effect of the processes on TDDB (Time Dependent Dielectric Breakdown) lifetime of MIM capacitors.

EXPERIMENTAL

The cross-sectional structure and the process flow of the MIM capacitor fabricated in this study are shown in Figure 1. The dielectric film was SiN deposited by PE-CVD (Plasma-Thermo VLR702) and its thickness was 70 nm. The unit capacitance of the capacitor is 1 fF/μm^2 and the breakdown electric field is more than 10 MV/cm. The SiN film was deposited just after wet cleaning of the electrode metal surface. Bottom and top plate metals were both evaporated Ti/Pt/Au. They were formed by bi-layer resist lift-off process. Just before the evaporation of metal, slight O_2 plasma ashing was performed on resist-patterned wafers to remove the residue of the developed resist. The area of fabricated capacitors was 2,500 μm^2 to 300,000 μm^2, but only the capacitor with the area of 2,500 μm^2 was investigated to minimize the effect of defects in SiN film, roughness of metal, and particles in the capacitor.

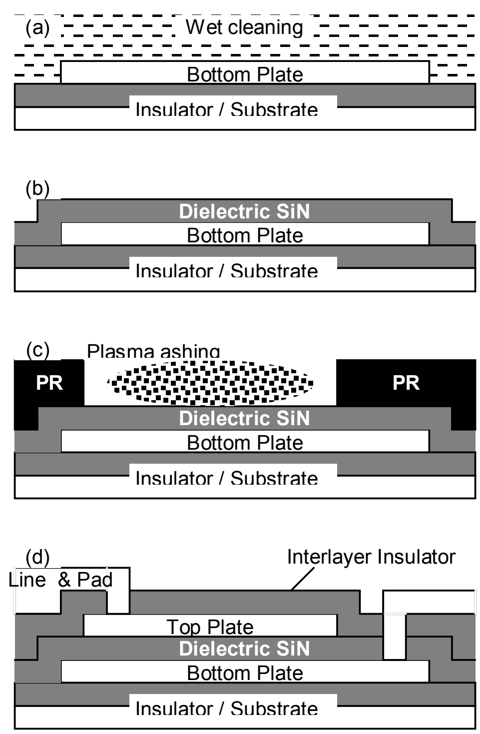

Figure 1. Cross-sectional view and process flow of MIM capacitor.
(a) Wet cleaning of the surface of BP just before SiN deposition.
(b) Dielectric SiN deposition by PE-CVD.
(c) Plasma ashing of PE residue just before TP deposition.
(d) Final cross-sectional structure of MIM capacitor.

In this study, we have focused on the process step that is performed on the bottom plate (BP) metal and the SiN film, that is wet cleaning on bottom plate metal (Figure1 (a)) and plasma ashing on SiN film (Figure 1 (c)), respectively. About these processes, we changed the following conditions.

1) The reagents of wet cleanings:
   H_2O, HNO_3, HCl and NH_4F
2) O_2 ashing machine:
   Remote plasma (down-flow) type and parallel plate type etcher

To evaluate lifetime, TDDB measurement was performed by automatic probing station and parametric tester (4142B, Agilent Technology). Constant voltage was applied to the top plate and the bottom plate was grounded. The time when the leakage current becomes more than 10 mA was defined as TDDB lifetime. The TDDB test was accelerated by electric field and temperature. The applied voltage was around 56 V, which is equal to 8 MV/cm electric field. The probing stage temperature was 125 ^oC. To eliminate the effect of processes such as dicing and packaging, the measurement was performed on the processed wafer. The number of tested capacitor was more than 50 per each process condition to get reliable data and the lifetime was extracted from Weibull plot.

EFFECT OF WET CLEANING

The dependency of TDDB lifetime on the reagent of wet cleaning is shown in Figure 2. Lifetime shows distinct dependency on the reagents and the order of lifetime is H_2O < NH_4F < HCl < HNO_3. The causes of the results are thought to be as follows.

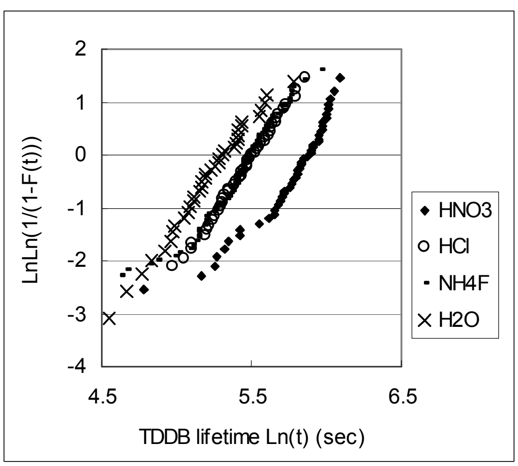

Figure 2. Effect of wet cleaning.
BP surface of capacitors are wet cleaned in various reagents.
The order of lifetime is H_2O < NH_4F < HCl < HNO_3.

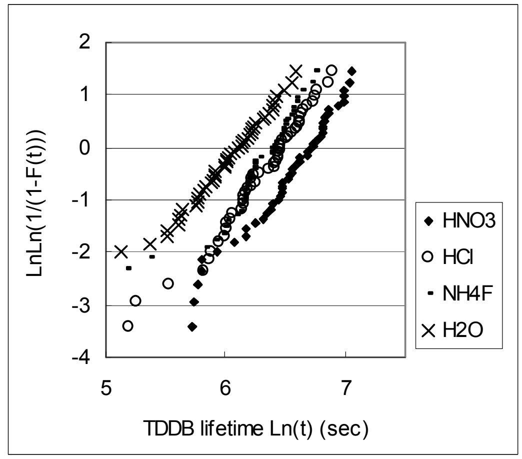

Figure 3. Results of reversed bias TDDB test.
Lifetime order is still H_2O < NH_4F < HCl < HNO_3

1) Effect of residual ionic components of reagent

If ionic components of the reagent remained on the surface of metal (interface between BP metal and SiN film) and such ions moved into SiN film by electric fields of TDDB test, they would create defect spots and shorten the lifetime of the capacitor. In this case, if the polarity of applied voltage was reversed, the order of the lifetime will change because these ions do not exist in the interface between the TP metal and SiN film and any ions will not move into SiN film. The results of reversely biased TDDB test are shown in Figure 3. The order of the lifetime didn't change in the case of reversed bias, so this assumption is not plausible.

2) Difference in surface energy of bottom plate

If the surface energy of BP metal is different in each sample by the effect of wet cleaning, the barrier height between the BP metal and SiN film will vary in each capacitor, which may result in the difference in leakage current and change the lifetime. Now we are investigating this assumption.

3) Difference in SiN growth

If the residues of reagent exist on the surface of BP metal or the surface energy of BP metal is changed, the growth of SiN film will be affected and the quality of interfacial part between the SiN film and BP should vary in each sample, which results in different lifetime for each sample. But even if the interfacial layer exists, it must be very thin and the analysis would be very difficult. So far we have not been able to verify it.

Though last two assumptions are compatible with the results of reversed bias test (Figure 3), we do not have conclusive evidence about them. So we are still investigating the mechanism of the wet cleaning effect on capacitor lifetime.

EFFECT OF PLASMA ASHING

The effect of plasma condition on lifetime is shown in Figure 4. In the case of remote plasma ashing capacitor, lifetime is shorter than that of capacitors with parallel plate plasma ashing. To investigate it, we consider the different factors between the two etchers.

1) Effect of electric field

In the case of remote plasma etcher, voltage is not applied to the wafer. On the other hand, Vdc is applied to the surface of SiN film and the electric fields will be applied to the capacitor in the parallel plate etcher. This may act as TDDB testing and shorten lifetime. But in the chamber of etcher, BP is not grounded. The backside of the wafer is grounded instead of BP. Taking the thickness of substrate and SiN film into account, the electric field applied to the SiN film is too small so that the effect on lifetime must be negligible. In fact, the lifetime of capacitors ashed by parallel plate etcher is longer.

2) Mechanical effect of ion

Between two types of etcher, the kinetic energy of reactants that attack the surface of the wafer is different. The reactants are mainly ions in parallel palate etcher and radicals in remote plasma etcher. The kinetic energy of ions in the parallel plate etcher must be larger than that of radicals of remote plasma because of the existence of Vdc that accelerates ions. Ions with large kinetic energy may generate defects in the SiN film and shorten its lifetime.

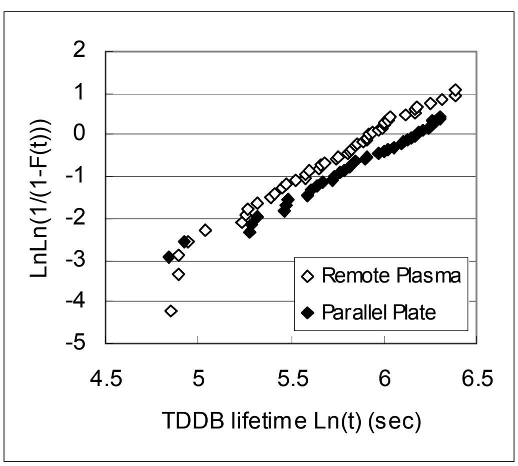

Figure 4. Effect of plasma process.
SiN film was ashed by remote plasma etcher and parallel plate etcher. Lifetime of parallel plate is longer than remote plasma.

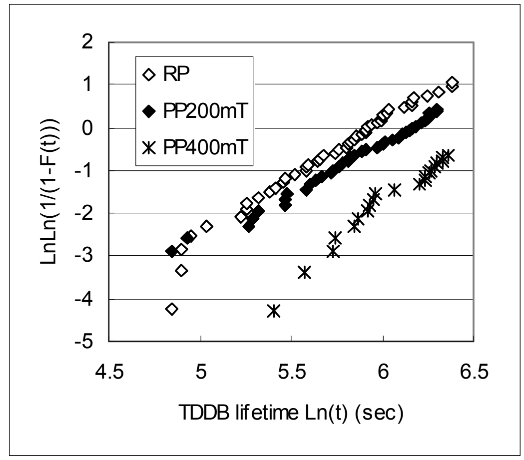

Figure 5. Effect of plasma condition.
RP : remote plasma etcher.
PP200mT : parallel plate etcher of 200 mTorr pressure.
PP400mT : parallel plate etcher of 400 mTorr pressure.
TDDB test time was limited to 600 msec. ln(600) = 6.4.
More than half of PP400mT capacitors did not fail in test time.

To confirm the impact of mechanical effects on lifetime, capacitors were fabricated under various pressures in parallel plate etcher. The higher the pressure is, the smaller the kinetic energy of the ions. The results are summarized in Figure 5. Obviously the higher chamber pressure resulted in longer lifetime. This implies ions in parallel plate etcher mechanically damage SiN film and shorten lifetime of the capacitor. Though the mechanical damage of reactant on SiN film have become clear, the results of Figure 4 cannot be explained.

3) Charge effect of ion

Though the main reactant is chargeless radical in remote plasma etcher, the main reactant is charged ion in the parallel plate etcher. Charged ions may transfer charges into the dielectric and shorten the lifetime. If this is true, the lifetime of the capacitor ashed in remote plasma etcher will become longer. But Figure 4 shows the capacitor ashed in parallel plate etcher has longer lifetime. So this factor must not be the cause of the difference of lifetime.

4) Nature of reactants

Three factors mentioned above cannot explain the shorter lifetime of the capacitor ashed by remote plasma etcher. So we consider the reactivity of reactants.

The main reactant in each etching machine is O^+ ion in parallel plate type and O-radical in remote plasma type. During the process of ashing residual resist, the surface of the SiN film will be oxidized by this radical or ion. In this oxidation process the reactivity of O-radical will be larger than that of O^+ ions, and more SiN layers will be oxidized in remote plasma etcher. This difference in oxidation of SiN film may result in the difference of lifetime.

These considerations indicate the effect of plasma process on SiN film, *i.e.*, the mechanical and chemical effects of reactant. The preferred plasma ashing process for residual resist on SiN can be concluded to parallel plate etching with high pressure.

CONCLUSIONS

We have performed TDDB test on MIM capacitors fabricated with various process conditions. From the relationship between the lifetime and the fabrication process, we have clarified following facts. The cleaning of bottom plate metal just before SiN deposition has serious effect on capacitor lifetime, so we have to select adequate reagent carefully. Also the plasma ashing on SiN film before top plate deposition is important. The remote plasma etcher degrades capacitors, so that parallel plate one is preferred.

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ACRONYMS

MIM: Metal Insulator Metal
TDDB: Time Dependent Dielectric Breakdown
BP: Bottom Plate
TP: Top Plate