Charging Damage in floating Metal-Insulator-Metal Capacitors

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Abstract

In this paper, charging induced damage (CID) to metal-insulator-metal-capacitor (MIMC), is reported. The damage is caused by the build up of a voltage potential difference between the two plates of the capacitor. A simple logarithmic relation is discovered between the damage by this voltage potential and the ratio of the area of the exposed antennas connected to the plates of the MIMC. This function allows to anticipate damage in MIMC devices with long interconnects. The source of the damage is still subject of further investigation.

Introduction

In this paper, charging induced damage (CID) to metal-insulator-metal-capacitor (MIMC), often used in RF circuits [1], is reported. The dielectric in this MIMC is much thicker than MOS gate oxides and the antenna ratios are typically low and even near unity. One therefore does not expect these capacitors to suffer from CID easily compared to thin gate oxides. However, previous studies found thicker oxides to be very sensitive to charging damage. It was argued that thicker oxides require higher voltage but less current to breakdown [2]. It was stated before that MIMCs would be damaged only when the bottom plate is grounded and the top plate is connected to a large conductor (antenna) that is exposed to a plasma [3]. In this paper however, it is demonstrated, to our knowledge for the first time, that floating MIMCs, without any substrate contact are very sensitive to CID:

When both plates of the MIMC are connected to a large antenna with enough difference in area, severe CID occurs as soon as these antennas are exposed to charging.

These configurations can be extrapolated to real cases. In order to prevent reliability loss, design restrictions can be defined.

The impact of the size and the shape of the capacitor and the antennas is investigated and discussed.

Experimental

The vehicle used for this study is a BiCMOS chip with MIMC capacitors. The MIMC is formed with the metal 1 layer as bottom plate, 20 to 60 nm PECVD SiO₂ as insulator and an additional, thin metal layer (TiN-AlCu-TiN) as top plate. Figure 1 shows a schematic of the MIMC.

A range of test structures have been designed and processed in order to investigate and characterize the effect of charging during the processing on the yield and reliability of the MIMC.

MIMCs have been designed with an area of 5 by 5µ, 20 by 20µ and 20 times 5 by 5µ in parallel.

Antennas connected to top and bottom plate were designed in a range from 20µ² up to 120,000µ² or consist just of a connection to the next metal level.

The failure fraction is defined as the fraction of the MIMCs that is broken down. The break down is detected as a leakage current > 1 nA at 3.3V.
To investigate the perimeter effect, antennas have been designed both as combs and plates. In order to define the critical process step that causes the damage, the wafers were evaluated, both right after the patterning of the antennas and after adding the next inter metal dielectric (IMD) and metal layer.

Fig 1: Schematic view of the MIMC

Results and Discussions

The failure mechanism can be dominated by current or by voltage. In the case that current drives the failure mechanism, bigger capacitors show less damage since current density is lower. In Fig. 2 one can see the impact of the antenna area and of the area of the MIMC on the failure fraction. For the same antenna area, the bigger capacitors show a significantly higher failure fraction. This is the opposite from what one would expect when current is the driving force behind the failure mechanism. This means that the failure mechanism is not dominated by current but in fact by voltage: this breakdown is determined by the probability of weak spots and this probability is area dependent.

Fig 2: The effect of the capacitor area size on the failure fraction: for one antenna size, there is more damage on a large MIMC compared to small MIMC.

Fig 3 shows the effect of the area ratio of the top vs. the bottom antenna on the failure fraction, with both antennas on the same metal level and the capacitor isolated from the substrate. When both of the antennas on the top and the bottom plate have the same size, the failure fraction falls back to almost zero. Failure fraction is raising with an increasing difference in antenna size. This proves that the charging generates a voltage potential on the capacitor plate according to the size of the antenna exposed to the charging. When both antennas have the same size, there is no voltage potential difference and as a consequence, there is no CID. When there is a big ratio between both antennas there is a large voltage potential difference causing a high failure fraction.

PID on MOS gate oxides is many times more severe with a comb shaped antenna compared to a plate shaped antenna with the same area. This is caused by electron shading [4]. Fig. 4 shows that for CID on MIMC this is not the case: a comb shaped antenna causes just a little more CID than a plate antenna with the same area. Unlike PID on MOS gate oxides, there is very little electron shading effect. Typically, electron shading is very severe on metal etching and IMD oxide deposition [5]. Because we hardly see any difference between the
impact of comb and plate, we can exclude these processes as being the cause of the damage.

**Fig 4:** the effect of the antenna shape on the MIMC failure fraction for a range of antenna areas.

Fig.5 is demonstrating the very good fit between the log of the ratio of both antennas and the failure fraction. This simple model allows anticipating damages on MIMCs with large difference of antenna size on both plates.

**Fig 5:** Fit between the log of the ratio of both antennas and the failure fraction.

For a test structure where one of the antennas is limited to a very small area required to make the connection to a higher metal level, the failure fraction is found to be almost zero even when the other antenna is very large. Fig. 6 is comparing the effect of a very small antenna (1.36μ²) on one plate vs. a large antenna (10,000μ²) on that plate for a range of antenna sizes on the other plate of the capacitor.

For the small bottom antenna, the failure fraction remains low and is independent of the top antenna size on the other plate. This indicates that there is a threshold value for the antenna area in order to damage the MIMCs. Even though the antenna area ratio is very high when one of the antennas is very small, the MIMCs are not damaged with one of the antennas below the threshold area.

With a small antenna, only a small charge can be exchanged with the other antenna. As long as the leakage of the MIMC dielectric can support this charge transfer, the capacitor is not damaged.

In order to determine the source of the CID, wafers were evaluated right after the patterning of the antennas. On this level no failing MIMCs were observed. Damaged capacitors were found only after processing the next IMD and metal layer. This confirms that the capacitors were not damaged during the patterning of the antennas itself but by the later processing.

Vbd measurements were done to measure to voltage that is required to break the MIMC dielectric. Fig. 7 is showing that potentials between 40 and 50 volts are required to break the dielectric.
Plasmas can support about 20 volts potential differences when considered over the full wafer surface [6]. For the MIMC, the Vbd values are much higher. Clearly the damage must be caused by an other mechanism. The source of the damage is still subject of further investigation.

Summary and Conclusion

Charging induced damage to MIMCs is related to the size and shape of the antennas connected to both capacitor plates. The failure mechanism is not dominated by current but voltage is the main driver. This makes large capacitors more vulnerable than small capacitors for the same antenna area. The damage is caused by the build up of a voltage potential difference on the two plates of the capacitor. It has been proven that there is a direct relation between the failure fraction and the area ratio of antennas connected the plates of the MIMC. A simple log function describes very well the relation between the failure fraction of the MIMC and the ratio of the two antenna areas exposed to charging. For a very small antenna, the failure fraction remains low and is independent of the antenna size on the other plate.

Voltage potentials between 40 and 50 volts are required to break the dielectric.

The source of the damage is still subject of further investigation.

The observations allow to anticipate damage in MIMC devices with long interconnects. The observed damage leads to direct yield impact and make the study of charging on floating MIMC designs a critical issue.

References


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