A New Insight into the PN-Junction Characteristics of ULSI—The Time Dependent Junction Breakdown (TDJB)—

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A new concept of time dependent junction breakdown (TDJB), which shows a close analogy with TDDB, has been proposed as a method for evaluating long-term junction reliability. This paper discusses junction reliability from the viewpoint of time dependent breakdown. In addition to the intrinsic breakdown due to avalanche phenomena, time dependent junction breakdown (TDJB) has been revealed by accelerated lifetests. Intrinsic breakdown due to avalanche phenomena has been found to be caused by the electrons trapped at the perimeter of the junction. These results indicate that not only oxide reliability but also junction reliability will become a key factor in fabrication of future scaled ULSIs.

1 INTRODUCTION

The increased integration density of LSI chips requires even greater reliability at the wafer level because the reliability of each chip must be kept constant however large the system may become. Generally the primary failure mode of MOS memories has been gate oxide breakdown (TDDB) and it has been eagerly investigated to develop highly reliable gate oxides.

However, as is seen from the standpoint of refresh failures in DRAMs, junction reliability is thought to affect ULSI yielding greatly. Moreover, PN-junctions occupy the major part of MOS memories and devices, which means that junction reliability will become increasingly important in future giga scaled LSIs.

To obtain highly reliable junctions, a method for evaluating junction reliability must be established. Refresh failure is thought to be a result of latent defects in a junction. In general, latent defects cause time dependent breakdown in the same way as TDDB and determine long-term reliability. Therefore, the TDJB characteristics can be utilized to evaluate junction reliability and serves to develop highly reliable junctions.

This paper proposes a new TDJB concept as a technique for evaluating long-term junction reliability. Junction reliability is discussed from the viewpoint of time dependent breakdown. Accelerated lifetests have revealed the existence of TDJB. It has been also found that electron trapped at the perimeter of the junction degrades the junction characteristics.

2 EXPERIMENTAL

The experimental setup for measuring TDJB is shown in Figure 1.

Fig.1 Experimental setup for measuring TDJB
A constant voltage or current source is used to apply electrical stress to junctions and leakage current in the reverse direction is measured at certain intervals to monitor breakdown versus time.

Junction characteristics can be divided into two parts, as shown in Figure 2. Region 1 is the leakage region and Region 2 is the breakdown region caused by avalanche phenomena.

![Figure 2 Typical ULSI junction characteristics](image)

To investigate failure modes of junction breakdown, a voltage higher than operation voltage but lower than breakdown voltage should be employed in Region 1 so as not to enhance intrinsic breakdown. On the other hand, the intrinsic breakdown due to avalanche phenomena is revealed by applying a higher voltage than the breakdown voltage in Region 2.

It must be kept in mind that as the leakage current in the reverse direction mostly flows at the perimeter of the junction close to the isolation region (inlet in Figure 2), TDJB data in the reverse direction reveals the reliability at the perimeter of the junction.

3 RESULTS AND DISCUSSION

3.1 TIME DEPENDENT JUNCTION BREAKDOWN (TDJB)

Time dependent junction breakdown is investigated here. A constant stress voltage of 14 V was applied to a sample whose breakdown voltage is 14.5 V. For this accelerated lifetest, the current trigger level to determine junction breakdown was chosen arbitrarily at 10pA with 8V applied to the junction.

The time distributions of junction breakdown are shown in Figure 3. As seen in this Figure, in addition to the initial breakdown mode, three modes of junction breakdown manifest themselves. The first two modes whose peaks are observed at around 10^4 sec and 10^3 sec are thought to be the breakdowns due to latent defects and the last mode at 10^4 sec is intrinsic breakdown. It is noticed that the junctions with latent defects have much shorter lifetimes than those without defects and affect the long-term reliability. In this way, accelerated lifetest has revealed TDJB due to latent defects and is thought to serve as a reliability prescreen for time dependent junction breakdown in ULSIs.

![Figure 3 Time distributions of junction breakdown](image)
plotted as a function of log stress time. The junction characteristics plots as three straight lines representing two breakdowns due to latent defects and intrinsic breakdown.

Arbitrary cumulative % failures can be chosen to determine the lifetime of this junction at this voltage (=14V). If the voltage acceleration factor $f$ is known, the lifetime of this junction at nominal voltage can be predicted.

3.2 INTRINSIC JUNCTION BREAKDOWN

This section discusses intrinsic junction breakdown due to avalanche phenomena. The behavior of the breakdown voltage gives important information. Degradation of junction characteristics due to avalanche phenomena is shown in Figure 5, where the solid lines represent the initial characteristics and the dotted lines represent degraded characteristics.

It can be seen that the breakdown voltage decreases in the n$^+$-P well and increases in the p$^+$-N well, which implies electron trapping in the isolation oxide at the perimeter of the junction. The effect of electron trapping is shown in Figure 6. In the n$^+$-P well (Figure 6(a)), the trapped electrons narrow depletion layer. This results in enhancement of the avalanche phenomena, leading to a decrease in breakdown voltage. On the other hand, in the p$^+$-N well (Figure 6(b)), the trapped electrons widen the depletion layer. This results in reduction of the avalanche phenomena, which increases the breakdown voltage.

The stress time dependence of the current at $V_o = 8V$ are shown in Figure 7 with temperature as a parameter. In this experiment, constant current stress in breakdown region (Region 2 in Figure 2) was chosen because the junction characteristic in the breakdown region has weak voltage dependence and is characterized by the current level. As noted from Figure 7(b) for the p$^+$-N well, two mechanisms of junction degradation are seen. An increase in generation current in the widened depletion layer appears following a
weak time dependent diffusion current. On the other hand, for the n⁺-P well, the current increases drastically at $\tau > 100$ sec. Considering the shrinkage of the depletion layer at the perimeter, the current is increased by the enhanced electric field at the depletion layer close to the isolation oxide.

3.3 TDJB IN FORWARD DIRECTION

TDJB in the reverse direction can be used to evaluate reliability at the perimeter of the junction. On the other hand, as current flows in the forward direction across the junction itself (not in the perimeter), TDJB in the forward direction is thought to clarify the reliability of bulk junction characteristics. Moreover, junction reliability in the forward direction greatly influences the operation of bipolar transistors. In this sense, TDJB in the forward direction is indispensable in evaluating the total junction reliability of ULSIs.

4 CONCLUSION

In conclusion, a new concept of time dependent junction breakdown (TDJB) has been proposed as a technique for evaluating junction reliability.

TDJB due to the latent defects is revealed by the accelerated lifetime test. A junction with latent defects has a much shorter lifetime than one without defects and is thought to affect long-term junction reliability. Also, electron trapped at the perimeter of a junction is found to degrade junction characteristics in the reverse direction. Additionally, the significance of TDJB in the forward direction is pointed out.

In future giga scaled LSIs, not only oxide reliability but also junction reliability will play an important role.

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