Plasma Process-Induced Latent Damage on Gate Oxide ---- Demonstrated by Single-layer and Multi-layer Antenna Structures

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Abstract — In this paper, by using both single-layer (SL) and multi-layer (ML) or stacked antenna structures, a simple experimental method is proposed to directly demonstrate the pure plasma process-induced latent damage on gate oxide without any impact of additional defects generated by normal constant current stress (CCS) revealing technique. The presented results show that this method is effective to study the latent damage.

1. Introduction

For very-large-scale-integration (VLSI) manufacturing of integrated circuits (ICs), the use of high-density plasma-enhanced deposition and anisotropic etching techniques is required. However, this kind of plasma techniques can cause tunneling currents to flow through thin gate oxides, resulting in charge built-up, generation of new oxide traps and generation of interface states. They cause the loss of the reliability of the metal-oxide-semiconductor (MOS) devices or even the totally failure of the devices [1]-[3].

The latent damage induced by a plasma process has been identified as an increased number of neutral electron traps and hole traps in the oxide and passivated interface states [4] [5]. It is indicated by electrical properties shifting as function of antenna area or shape after constant current stress (CCS), which is the typical property of plasma process-induced damage (PPID). Recently, many research groups over the world have made a lot of efforts to evaluate the plasma process-induced latent damage [4] [6]. Normally, a high-field CCS is used to reveal or re-awaken this hidden and inactive damage [7]. However, this high-field CCS also generates additional new defects in the gate oxide simultaneously.

In this paper, a simple experimental method is proposed to directly demonstrate the pure latent damage without any impact of additional defects generated by CCS revealing technique. Single-layer (SL) antenna test structures are used to evaluate PPID of each stand-alone plasma process step. And the cumulative PPID of a few plasma processes is evaluated by multi-layer (ML) antenna test structures. The test structure is considered to suffer PPID when there is an antenna present during a certain plasma process. Therefore, the number of layers determines how many plasma process steps are used to introduce damage to the structures.

The used SL test structure and ML test structure are described in section 2, and the experimental results are presented and discussed in section 3. The presented experimental data clearly demonstrate the existence of latent damage, since the ML structures that were exposed, but did not fail from antecedent PPID, are more susceptible to subsequent plasma process compared with fresh SL structures that are free from antecedent PPID.

2. Experimental Details

In this study, some wafers with SL test structure and ML test structure have been subjected to a 0.35μm CMOS backend-of-line process. After that, the charging sensitive antenna structures [8] of these wafers are evaluated. The gate leakage current (I_{lk}) failure fraction and the wafer maps of SL and ML antenna structures are compared, and the results are discussed.

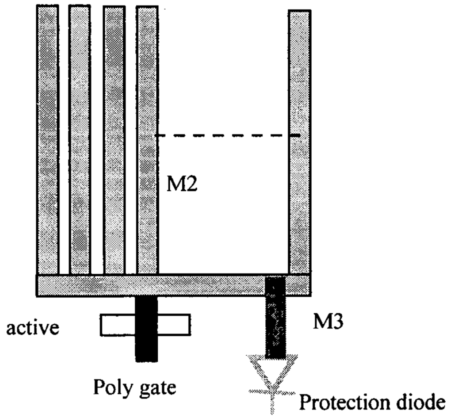

Fig. 1: (a) Schematic layout of metal2 (M2) SL antenna structure with a finger-shaped M2 antenna. A protection

diode is connected on metal3 layer to protect the gate oxide from PPID above M2 layer. This structure is supposed to only suffer damage during M2 process.

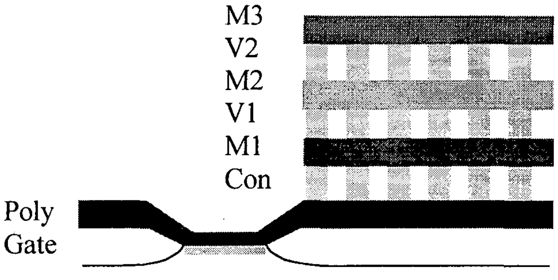

Fig. 1: (b) Cross-section of a Poly, Contact, metal1, via1, metal2, via2, and metal3 (Poly+Con+M1+V1+M2+V2+M3) ML antenna structure. This structure is supposed to suffer PPID during the whole process.

In Figure 1, the schematic of the SL and ML test structures used in our study are depicted. The antenna ratio (AR) of all Poly and metal comb antenna is 10,000. The AR is defined as the ratio between the area of the antenna connected to the transistor and the active area of the latter. Contact or via antenna has 1000 contacts or 1000 vias on a small plate.

3. Results and Discussions

The measurement results of the gate leakage current are presented in Figure 2. The figure shows the wafer maps of failures of SL structures after single plasma process and the wafer maps of failures of ML structures after two or more plasma processes. A plasma process in this paper means the process to manufacture one layer such as M1, M2, and via 1.

As shown clearly in Figure 2, the number of failed devices increases fast with the number of antenna layers (plasma processes). The number of damaged devices from Poly+Con+M1 structures, for example, is more than the sum of the damaged devices from Poly+Con and M1 antenna structures. Compared with the damage that M1 plasma process induced to SL antenna structure, the same M1 plasma process of the Poly+Con+M1 structures causes more failures.

In order to quantitatively compare the plasma damage to different structures, the failure fraction is used in this paper. The failure fraction is defined as the number of failed devices divided by the total number of investigated devices. In the following, the equation, which can extract one plasma process induced extra failure fraction to ML antenna structures, is derived. Without the loss of any generality, the Poly+Con+M1 ML structure and M1 SL structure are used in the following derivations. Define $Y_{Poly+con+M1}$ as the yield of Poly+Con+M1 structures, $Y_{Poly+con}$ as the yield of Poly+Con structures, and $Y_{M1,ML}$ as the yield of M1 plasma process with ML antenna structures. Since

$$Y_{Poly+con+M1} = Y_{Poly+con} \times Y_{M1,ML} \tag{1}$$

and

$$F_{M1,ML} = 1 - Y_{M1,ML}, \tag{2}$$

therefore

$$F_{M1,ML} = 1 - \frac{1 - F_{Poly+con+M1}}{1 - F_{Poly+con}}, \tag{3}$$

where $F_{Poly+con+M1}$ is the failure fraction of Poly+Con+M1 structures, $F_{Poly+con}$ is the failure fraction of Poly+Con structures, and $F_{M1,ML}$ is the M1 plasma process induced failure to ML antenna structures. Because $F_{Poly+con+M1}$ and $F_{Poly+con}$ can be obtained from the experiment, $F_{M1,ML}$ can be calculated. Hence, with equation (3), one plasma process induced extra failure fraction to ML antenna structures can be extracted from the failure fractions of two corresponding ML antenna structures.

The failure fraction comparison of different antenna structures is presented in Table 1. $F_{\text{'one process',SL}}$ is one plasma process induced failure fraction to single-layer antenna structures. $F_{\text{'multi- procesess',ML}}$ is a serial plasma processes induced failure fraction to Multi-layer antenna structures. In the table, $F_{\text{'one process',SL}}$ and $F_{\text{'multi-procesess',ML}}$ are experimental data. $F_{\text{'one process',ML}}$ is one plasma process induced extra failure fraction to ML antenna structures, which is extracted from the failure fractions of two corresponding ML antenna structures with equation (3).

In Table 1, $F_{Poly+con+M1}$=40% and $F_{Poly+con}$=32%, with equation (3), we can get $F_{M1,ML}$= 12%. Therefore, in our case, 12% of the devices that are not damaged during poly and contact plasma processes are damaged during M1 plasma process. However, the same M1 plasma process causes only 0.4% failure on the SL antenna structures. The reason for this phenomenon is plasma process-induced latent damage.

After the poly and contact plasma process, 32% of the total devices failed and the other 68% of the total devices are survived. Those 68% devices do not show failure, but they are much weaker because of the latent damage generated by plasma processes. Therefore, they are more susceptible to subsequent M1 plasma process. On the other hand, SL antenna structures have only one antenna. The devices are fresh and have not suffered plasma damage from antecedent plasma processes. They are more robust. This is the reason why the failure fraction of the M1 plasma process to ML

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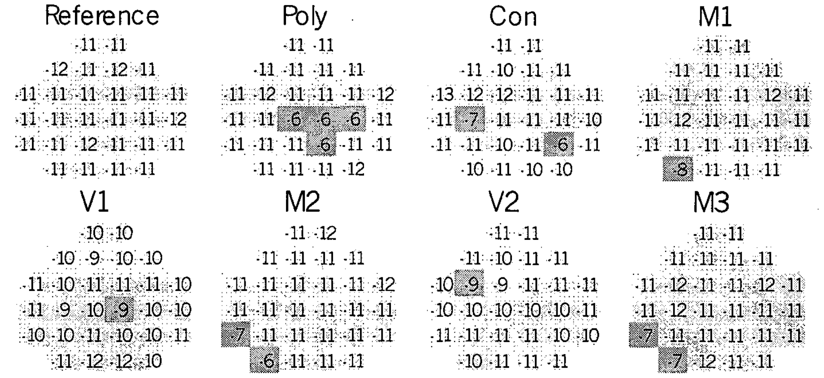
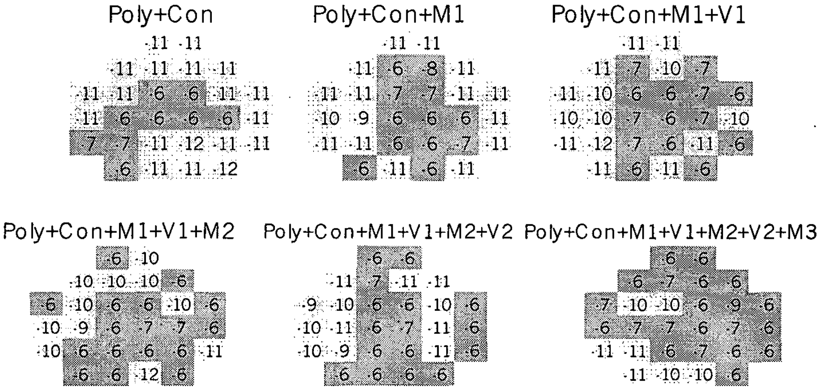
antenna structure is much higher that to SL antenna structure.

With equation (3), the failure fraction of other plasma processes to ML antenna structure are also calculated and listed in Table 1. The comparison of these values to the failure fraction of the same plasma process to the SL antenna structure also show the existence of the plasma-induced latent damage. Moreover, due to the existence of latent damage in ML structures, the value of $F_{\text{'one process',ML}}$ is higher than that of $F_{\text{'one process',SL}}$ in the table.



(a) SL antenna structures.



(b) ML antenna structures

Fig. 2: Wafer map of I_{lk} a) SL antenna structures and b) ML antennal structures. The value presented in the map is the log value of I_{lk} (A). Dark/red area indicates the failure (I_{lk} >1nA).

Table 1: Failure fraction comparison

$F_{\text{'one process',SL}}$		$F_{\text{'multi-processess',ML}}$		$F_{\text{'one process',ML (caculated)}}$	
$F_{poly,SL}$	17%	$F_{poly,ML}$	17%	$F_{poly,ML}$	
$F_{con,SL}$	10%	$F_{poly+con,ML}$	32%	$F_{con,ML}$	18%
$F_{M1,SL}$	0.4%	$F_{poly+con+M1,ML}$	40%	$F_{M1,ML}$	12%
$F_{V1,SL}$	1%	$F_{poly+con+M1+V1,ML}$	44%	$F_{V1,ML}$	7%
$F_{M2,SL}$	6%	$F_{poly+con+M1+V1+M2,ML}$	66%	$F_{M2,ML}$	39%
$F_{V2,SL}$	0.4%	$F_{poly+con+M1+V1+M2+V2,ML}$	65%	$F_{V2,ML}$	-3%
$F_{M3,SL}$	4%	$F_{poly+con+M1+V1+M2+V2+V3,ML}$	86%	$F_{M3,ML}$	60%

In order to make the comparison more clear, the failure fraction of the same plasma process to the SL structure and ML structure are depicted in Figure 3. From the figure, it can be observed clearly that the same plasma process always causes more damage on ML antenna structures. The reason is that the ML structures are suffered latent damage from antecedent plasma process.

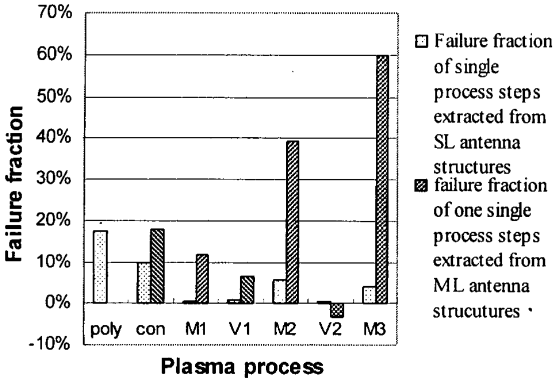


Fig. 3: Comparison of one-plasma-process induced failure fraction between SL antenna structures and ML antenna structures. The small strange value of V2 is probably caused by the noise of the measurement.

4. Conclusions

In this paper, by using SL antenna and ML antenna structures, a new method is proposed to study plasma process-induced latent damage on gate oxide, with which we can study the PPID without other impacts, compared to traditional CCS method.

The presented results show the failure fraction of the same plasma process to the ML antenna structure is higher than that to the SL antenna structure, which demonstrates the existence of the plasma-induced latent damage. Hence, plasma process may generate not only active damage but also latent damage, which may show itself and cause reliability problem in the subsequent processes and application.

Acknowledgments

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