Sensitivity of new characterization technique in ULSI and efficiency of new statistical tool in PTMS.

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Abstract

Development of flash memory is based on building reliable oxide films in ULSI Ultra Large Scale Integration. For MOS devices, the thinning of gate oxide leads to tunneling of carriers through the oxide as a structure is subjected to an external perturbation (for example a strong electric field, or radiation). Reliability requirements at the wafer level have recently introduced a new electrical method based on CP Charge Pumping to quantify exactly charge loss. The detection of defect in very small concentrations in nowadays transistors require the best sensitivity and we achieved $D_{it} \sim 10^8$ $cm^{-2}eV^{-1}$. Development of flash memory is also based on the introduction of new processes. PTMS, Preventive Trouble Management System introduce a new statistical method to evaluate their variability based on AIC Akaike's Information Criterion. This is R tool, which has been compared to Excel, a more general tool. Parameter effect evaluation is done through precise rules and variability needs to be controlled for a great deal of data. R, statistical as same as a powerful graphical tool, has been used to give access to understand process influence for a macroscopic point of view. Discover reason of margin variations in the case of numerous data is a real challenge. These two new methods, a statistical treatment tool and an electrical method produced one patent and several technical reports.

Résumé

Le developpement des circuits integres a base de memoires depend de la fabrication de films d'oxyde minces en ULSI 'Ultra Large Scale Integration'. Pour les composants a base de composants MOS, la reduction graduelle des epaisseurs d'oxydes conduit a une perte de charge des que la structure est soumise a une perturbation exterieure (radiation ou champs electrique). Cela induit une perte indesirable de la dite memoire. Cette fiabilite au niveau du silicium a necessite une methode dite de 'pompage de charge' pour quantifier exactement celle-ci. La detection des defauts en tres petite concentration a ete effectuee par la CP 'Charge Pumping' jusqu'a la concentration de $D_{it} \sim 10^8$ $cm^{-2}eV^{-1}$. Le controle statistique AIC 'Akaike's Information Criterion' des procedes et du design des experiences est utile comme traitement statistique en PTMS, Preventive Trouble Management System. Pour ainsi evaluer les variations des parametres et predire les obstacles suite a l'introduction de nouveaux procedes, un nouvel outil statistique "R" fut utilise. L'evaluation des variations des parametres se fait a l'aide de regles statistiques precises et des data nombreuses doivent etre correctement analysees. Le traitement statistique par R peut detecter la source responsable d'une variation indesirable dans le Process flow. Ces deux methodes ont genere un projet industriel et des rapports de l'ingenieur.

Introduction

The world electronics industry is currently surpassing the automobile, chemical, and steel industries in sales volume and the total semiconductor market is expected to outperform other high tech market. The MOS IC (Metal Oxide Semiconductor Integrated Circuits) shares 90% of the world semiconductor industry sales. In that, the quality of the sub-micrometer MOS technologies is a key issue for the development of advanced devices and circuits. The progressing communications market drives demands for high-speed products and MOS IC device miniaturization and complexity has now advanced to about an integration of 100 million of components per chip. New reliability and statistical test techniques with better sensitivity are necessary for NVM Non Volatile Memory evolutions. Especially, the generation of microscopic oxide defects in gate oxides shifts the threshold voltage and affects the trans-conductance of MOSFET's (Metal Oxide Semiconductor Field Effect Transistor) circuits. These constraints reduce the programming window of nonvolatile flash memories. Control of equipment and data variation are keys for product stability and quality. And then, if statistical and electrical methods are currently used in wafer fabrication chain, numerous data and sensitivity are two challenges. Reliability by CP, charge pumping method and control by R environment will prevent a lot of troubles in many industrial fabrication chains.

1- Wafer level reliability with CP

The charge-pumping method (figure 1) is now widely used to evaluate interface states in MOSFET transistors, especially with a small geometry, mainly due to its convenience and good detection limit [1]. However, the choice of charge-pumping frequency is depending on the structure. Moreover, the geometry of MOSFET structure and tunnelling trap existence complicates analysis [2]. In CP measurements, defect concentrations are difficult to detect with high quality tunnel oxides [3]. Fresh wafers have been characterized in order to push efficiency of CP method in the case of lowest defect density (figure 2). Trap section creation values, σ, are indeed low (about 10^{-19} cm^2 for MOSFET samples after room temperature injection of charge). For these values, interface levels are shallow in the forbidden band gap and defects are of very small dimension. Results are affected with noise at low frequencies (1/f noise) in the case of the smallest structures (0.2 μm channel length) and these instabilities are a challenge in low detection: this is quantum tunnelling as defect tunnel towards silicon [3]. This is avoided for example by operating at high frequency (figure 3) but there is no influence in defect D_{it} calculi. Figure 4 shows that slow-states need to be discriminated from fast-state traps as trap cross sections and defect behaviours are different. They increase the charge pumping current in CPV and traditional notation D_{it}, with "it" for "interface traps", is both for fast-state and slow-state kinds of defects:

$$I_{CP} = A_g fq(\overline{D_{fs}} + \overline{D_{ss}})\Delta E \qquad (1)$$

A new expression for the pulse current by CP where A_g is the surface area, f the frequency and ΔE, the available energy range for probing in forbidden band energy is found. In the case of operating at low frequency, the charge pumping current is increased compared to high frequency because of tunnelling current and both needs indeed to be counted. The CPF line is broken in one or two times in this frequency CP dependence curve (figure 4). The direct contribution of tunnelling traps is calculated by comparison of high frequency and low-frequency CPV signals because it provides a direct measure of I_{CP}. Theoretical limit has been discussed and CP detection limit is considered to be in the lower 10^8 $cm^{-2}eV^{-1}$ range. Below 10^9 $cm^{-2}eV^{-1}$, noise, instability, individual behaviour of traps in CP graphs have been understood by our method even if measurements are becoming more and more difficult. This is a perfect matching between CPV and CPF results as same as in the 10^9 $cm^{-2}eV^{-1}$ range than in the 10^8 $cm^{-2}eV^{-1}$. CP results are depending on technology, structure, geometry and from quality of surfaces but this method give access to the lowest defect density detection. The fast and tunnelling slow state defects are different microscopically but intermingled in electron exchange being boosted with temperature [4]. Oxide defects are seen to be slow-state traps and responsible for long time electrical instabilities in MOSFET. In thinner oxides, electron traps are found to govern defect generation and as oxide thickness is reduced, oxide defects are replaced by interface defects. Quantum mechanical effects, which are associated with slow-state traps (quantum tunnelling) and instabilities, have no influence in CP results [5]. Defects are different from random 1/f noise, that affects CP results in the case of small geometry MOSFET. Sensitivity reaches $D_{it} \sim 10^8$ $cm^{-2}eV^{-1}$.

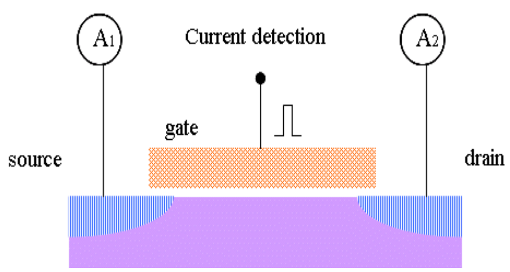

Fig. 1: Pulse introduction and local current detection.

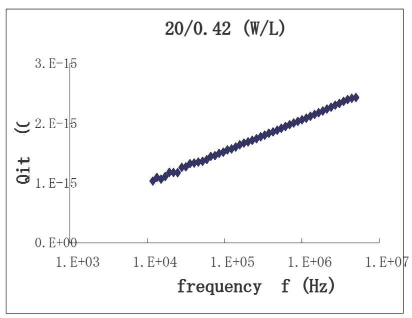

Fig. 3: High. Freq. measurement for small transistors

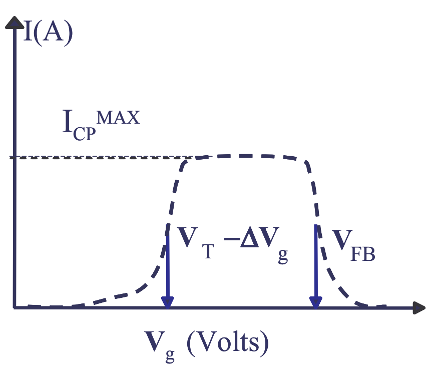

Fig.2: Defect density, proportional to I_{cp}^{max} and V_t

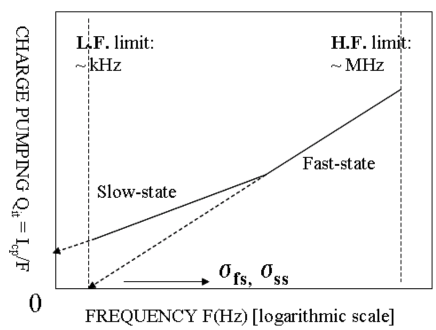

Fig. 4: kinds of defects and important separation

2- Wafer control computational intelligence.

An open source software is a free software that is available through Internet at http://www.r-project.org/ R tool was developed for statistics and for a convenient graphical environment [6]. R statistical and graphical facilities are intended to be an improvement from Excel by using computational intelligence based on Unix. A tool is dependent of scientific interests. Ascertain process relationships, link to reliability improvement and understand process flow influence in wafer fabrication is important. And then, R is applied in DOE (Design of Experiment), SPC (Statistical Process Control) and PTMS (Preventive Trouble Management System) areas. Variance is evaluated for DOE, process controlled for SPC and graphical facilities are for PTMS. Many statistical tools exist, however the important point is background [7]. R is useful in the case of a great deal of data, which occur always in a wafer fabrication chain.

1- R for DOE Design of Experiments

Variations are evaluated by box plots. The goal is to minimize charge loss. For that, DOE experiments were performed. Statistical calculi of S/N ratios are easy. However there is a lot of parameter and experiment (figure 5). Box plots have already shown that variability is smallest for split D. Second important point is for one wafer to another, results are different. S/N calculi have been performed based on charge loss zero and average target difference. The best experiment conditions have been found (see also figure 8 and 9 for a more complete analysis of DOE).

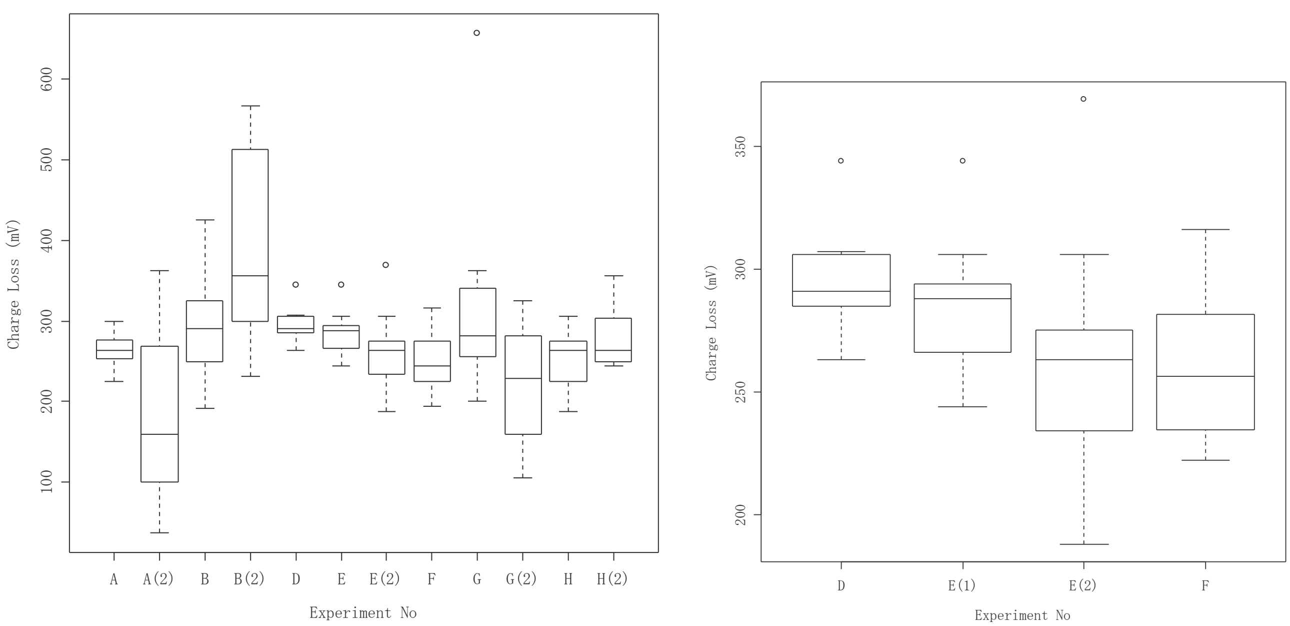

Fig. 5: Charges losses (mV) function of experiments (A, B, C, D, E, F, G, and H) from DOE [8]. A and A(2) refer to different wafer and lots. Second graph show variation for best experimental conditions.

2- R for SPC Statistical Process Control

Graphical modeling is a result of correlation analysis. With R, improvements are made by an effective judgment on effective relationships. R uses AIC Akaike's Control Criterion. It is efficient for a great deal of data. Figure 6 show the responsible for variations in Output FICD is Photo DICD. The most influent parameter is ARC etching (0.35 highest correlation). However, inter -correlations between parameters is also important. B -hard mask has no direct correlation, its inter -correlation has no interest. A lot of correlations are meaningless by Excel as it provides too many judgments less precise than AIC.

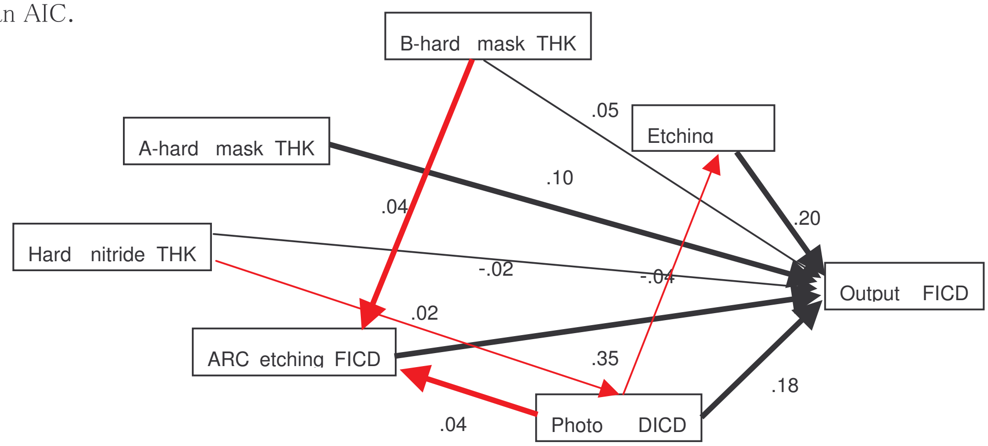

Fig. 6: Graphical modeling is a key word to express relationship (or correlation) between parameters.

Direct relationship is shown on a pie chart (figure 7). Lot ID is the part relative to correlation between lots. This contributes to an error and Excel or R give an explanation at 58%. That is currently enough to do required improvement on this basis in SPC (via estimations).

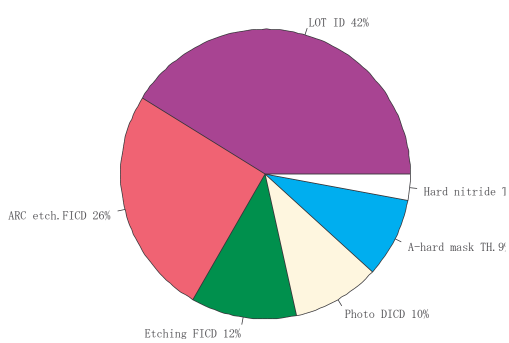

Fig. 7: There is direct relationship and also inter-correlation. From that, everything is not explained by statistical analysis: error factor exist because lots are different one from another.

3- R for PTMS Preventive Trouble Management System

PTMS uses pie charts, histograms and especially matrixes. Matrixes are adequate to analyze failure as there are numerous factors. Preventive actions are decided on the basis of PTMS man dala (failure data base) [9]. R proposed a versatile environment to stress only on important information, if not it becomes quickly a complex tool. S/N measurements on DOE depending on used parameters are called again to show interest of matrixes. The grap hical use of R is shown on these two figures 8 and 9. There are more available user friendly procedures at this excellent link: http://addictedtor.free.fr/graphiques/

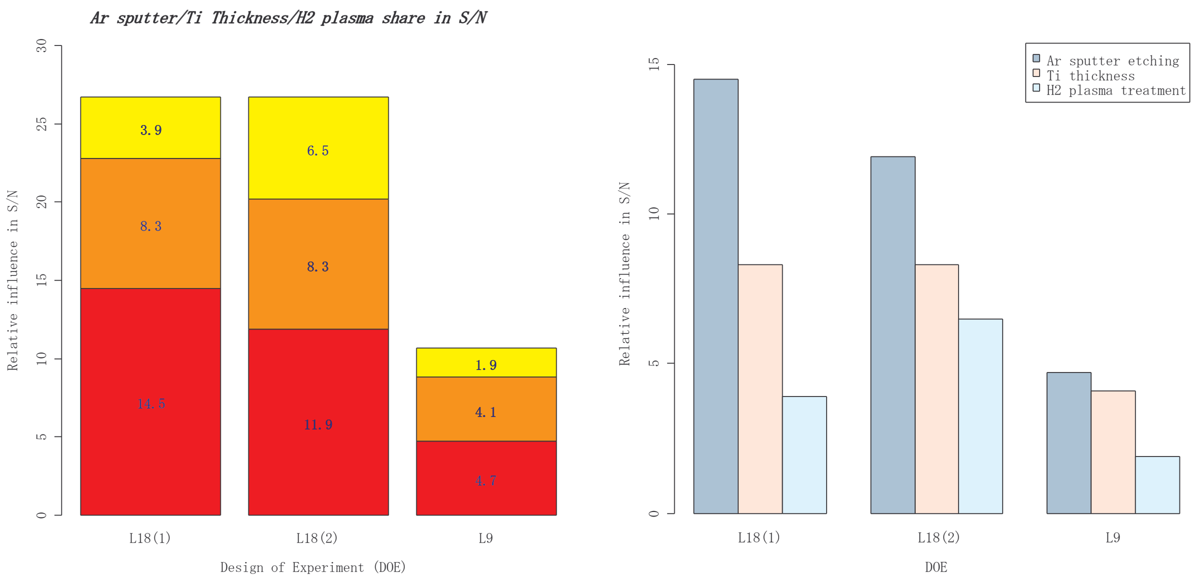

Fig. 8 and 9: S/N measurements in DOE depending on used parameters

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