Study of S/N Ratio by Simulation of Experiment in a Semiconductor Manufacturing Line

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Abstract – Recently, competitive semiconductor manufacturing becomes indispensable to satisfy market requirements for failure prevention and process parameter control is of major concern. Mechanism of designing experiments used for process optimization in a large size fab. with Taguchi method or other statistical tool is not often considered. Instead, minimal design of experiment as with L8 orthogonal array is used because of trend to minimal experimentation. However, limits exist in minimal design, which introduced a lack of precision because of only two parameter levels in L8 for example. Simulation of experiment is suggested as to conciliate cost reduction, minimal experimentation with better design to obtain further and adequate information for process optimization.

INTRODUCTION

Recently, semiconductor manufacturing has required more precise control of critical process to satisfy customer requirements. To better estimate process optimization and reduce variations, the mechanism of designing experiments which determines process optimization was investigated. Although methods of parameter setting have been proposed as Taguchi [1], or JMP [2], optimization versus precision in minimal design becomes a requirement in a large size fab., different from a mini fab., as complex processing require more robust engineering. Optimum conditions to improve Charge Loss in flash memory IC cells are proposed via S/N study and process parameter correlation. Taguchi design is applied to analyze process change data but for simulation purpose, which is to reduce variations from target and identify sources of variations in S/N ratio. Taguchi method is related to statistical process control and design of experiment (DOE) but also to die yield trend via new defined S/N ratio. Optimization is reached by using orthogonal arrays and S/N ratios with quality targets as zero charge loss, low variation around output average and finally, higher die yield rate.

EXPERIMENTS

It has been analyzed two process change proposals to find etching and film process optimum conditions:
1) 1st contact etching and 3rd contact etching equipment switch for 230 nm flash memory NOR technology.
2) 1st barrier metal film process optimization for 110 nm flash memory NOR technology.

By these two experiments, 1st /3rd contact etching equipments are optimized with L4 DOE design orthogonal array as 1st barrier metal process is optimized with sub-system Ar sputter Etching, Ti thickness and H2 plasma treatment optimization conditions by L18 DOE. Goals of those two simulations are:
1) Optimization of processes by robust engineering.
2) Continuous improvement for variation reduction.
3) Charge loss improvement in NOR flash memories.

S/N RATIO ANALYSIS

1st barrier metal process optimization has been evaluated with Ar sputter etching amount, Ti thickness and TiN with H2 plasma conditions of 110 nm kind of NOR flash memory. Figure 1 shows wafer position of nine different value variations according to etching Ar sputter amount, Titanium Ti thickness, and Hydrogen H2 plasma conditions in a critical process for charge loss of actual semiconductor line.

![Figure 1: Variation in charge loss (mV) between wafer positions (N1 to N9) and experiment No.1 to 6 conditions.](image-url)

With noise analysis, standard deviation, output average and die yield kinds of S/N ratio are obtained. Quality targets are chosen to be “Charge loss reduced to zero”, “average is best” or “die yield is best”. S/N ratios are compared and it is judged experiment 3 is the best. This is difficult to see based only on Figure 1 variations, Experiment 6 is also an enough good design and it was at first judged as best by experimental team, however this is not the best result from the point of view of S/N ratio analysis. Die yield S/N ratio (y%) is
provided as the quality of experiment results is also considered to be judged efficiently by die yield rate. It confirms more the robust engineering than the engineering team choice: Table 1.

\[
S/N = -10 \log (1/y) \tag{1}
\]

Table 1: Process change experiments and parameter values.

Two partial DOE L18 (orthogonal arrays) evaluate parameter weights by Excel Statistics. This is simulation: at each parameter is associated a number 1, 2 or 3 and combination of them is found where it is possible in the traditional L18: table 2. [0, 1] reduction is needed for using Taguchi method with Excel regression analysis. The three columns of table 2 are decomposed into six columns with only 0, 1 values [3].

Table 2: partial L18 orthogonal arrays as chosen into the 18 experiments and 8 parameters (1 to 8) of complete DOE L18 after [0, 1] reduction [3] (column without value “2”).

Results seem imprecise because of only a few experiments. However, two simulations lead to same relative weights (L18-1 and L18-2 in table 3 give respectively A = 14.5 and 11.9, B = 8.3 and 8.3 and C = 6.5 and 3.9 averaged in Figure 2). Secondly, the merit of optimization is shown, S/N ratios between optimized and normal conditions is S/N [L18-1] - S/N (normal) = 26 db - 11 db = 15 db. Since S/N [L18-2] = 25 db, precision is about 2db, which is compensated by the 15 db gain. Correlatively, important gain always justifies the necessity of experiments as optimization is not yet reached.
For the first set of experiment, second wafer data lead to more precise S/N by averaging but except in split 1 for which average values are different, one wafer value as in split 3 is enough. Precisely, for split 1, wafer averages are different and average S/N ratio is doubtful, but this split (normal conditions) is already rejected [Table 1]. Averaging also reduces discrepancy. Results will be different for the second set of experiments: evaluation in this case is more precise by S/N standard deviation ratio. Partial L4 only gives effective information, intended to improve charge loss but with equipment as parameter. Table 3 shows a simulation of two etching process manufacturing, 1st contact etching and 3rd contact etching with two equipment trials, Type A and B (for 1, 1 = B, and 2 = A, for 2, 1 = A and 2 = B). Average S/N ratios do not produce relevant results; average wafer discrepancy is important in N1 to N9 with DOE-1 to 4 experiments and standard deviation S/N is convenient. DOE-3 is judged best against charge loss with result more significant for 1st contact etching than for 3rd contact etching (weight of 2.9 against 0.3 in Table 6 Excel regression table). DOE-4 is satisfactory: as Wafer level bake (WLB) was not performed on DOE-4, this is a new result.

Table 4: partial L4 orthogonal array with charge loss quantities and results of standard variation S/N ratios from:

\[
S/N = -10\log \sigma^2 = \frac{\sum(y-y_i)^2}{n}
\]  

(3)

Figure 3: Equipment choice for optimization is different for both process. \( C_p \) decreases of around 40%.

Table 5: WLB qualification results for Type A/ B (tail to tail charge loss versus sigma) with wafer charge loss results.

<table>
<thead>
<tr>
<th>DOE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>S/N</th>
</tr>
</thead>
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<tr>
<td>DOE-1</td>
<td>1</td>
<td>1</td>
<td>725</td>
<td>600</td>
<td>500</td>
<td>763</td>
<td>775</td>
<td>556</td>
<td>741</td>
<td>638</td>
</tr>
<tr>
<td>DOE-2</td>
<td>1</td>
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<td>461</td>
<td>488</td>
<td>279</td>
<td>569</td>
<td>369</td>
<td>463</td>
<td>291</td>
<td>444</td>
</tr>
<tr>
<td>DOE-3</td>
<td>2</td>
<td>2</td>
<td>110</td>
<td>144</td>
<td>154</td>
<td>206</td>
<td>154</td>
<td>219</td>
<td>213</td>
<td>181</td>
</tr>
<tr>
<td>DOE-4</td>
<td>2</td>
<td>1</td>
<td>158</td>
<td>181</td>
<td>207</td>
<td>288</td>
<td>260</td>
<td>113</td>
<td>269</td>
<td>281</td>
</tr>
</tbody>
</table>

Table 4: partial L4 orthogonal array with charge loss quantities and results of standard variation S/N ratios from:

Figure 4 and table 6: Excel regression to study correlation between parameters, further shown in the upper graph.

DOE-1 trial is found to be the worst case for charge loss. DOE-3 trial is the best for charge lost was also reported in process change proposal. There is not a lot of information available in L4 to change previous process team conclusions. However, DOE-4 has also good signal/noise ratio as 3rd contact etching has only little influence in 1st/3rd rapport. With wafer position as noise factor, variations in charge loss are less affected by 3rd than 1st and DOE-3 and 4 are quite similar. As WLB was only performed on DOE 1 and 3, DOE-4 status could not be guessed.

**DISCUSSION**

Charge loss distributions have been evaluated: 230 nm PC Qualification WLB results of 1st barrier metal optimization Trial for BL Contact Resistance Lowering and 110 nm PC Qualification WLB Results of Type A trial for 3rd contact etching process and Type B trial for 1st contact etching process. Table 5 and 8 displays CL average and sigma data, which are imprecise and justify to perform S/N calculation. From simulation of experiment in Table 7, fourth level parameter is introduced with DOE-7: this is not a fourth parameter as RF electrode which was added in further experiments but TiN with H2 plasma treatment to be longer. Conclusion is positive: this is the second higher S/N, this good conditions were not commented by the process team. Furthermore, in Figure 5, it is concluded Ar sputtering etching rate need to be decreased. If [0, 1] method is not used,
Table 9 show further evaluation of parameter influence and if other partial L18 DOE is proposed, with RF electrode for example as a fourth parameter, partial L8 DOE is also suitable. However, with only two level parameter, complete L8 is better. Inline set-up is also possible to find effective root cause online [4] and reducing C_p as in L4 SOE and C_pk especially for new technologies [5].

Table 8: 1st barrier metal process full experiments with DOE-7 results and L18 regression analysis statistical table.

CONCLUSION

Design of Experiment has been used in product design, process development, and problem solving. It has been used minimally at least and process optimization is confirmed by evaluation of S/N ratio. DOE orthogonal arrays are all partial but precision is pondered by gain optimization. Control of parameter is suggested to minimize difficult optimization in experiments especially for new technologies when variations remain high. In statistical process control, failures are sensed by higher or lower variations in data. Design by robust manufacturing via two level parameter L8 DOE is popular and even L4 DOE is valuable. However, partial L18 simulation of experiment until eight parameters and eighteen line experiment kept a better relationship between fast and minimal analysis and information gain with more precise results from three level parameters is available. Die yield rate S/N ratio is also introduced as compared to other S/N ratio for a more accurate judgment of product quality.

REFERENCES


AUTHOR BIOGRAPHY

Jean-Yves Rosaye, received Ph.D degree in Microelectronics from the Univ. of Perpignan and the Univ. of Nagoya, France & Japan (2001), Mc.S degree from the Univ. of Reims (1996), France, and expertise in Robust Engineering from JSA (Tokyo, 2006). He entered Fujitsu AMD Semiconductor Ltd (FASL, 2001), by now Spansion Inc., in Process and Quality Ctrl. PTMS (Preventive Trouble Management System) and Research awards from Microelectronic International (2004).