YIELD, STATISTICS AND JMP

Yield JMP: a Statistical Tool for Yield Enhancement in Semiconductor Industry

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Alexandre Couvrat graduated from the Engineering School of chemistry and Physics from Bordeaux, France in 2000. He worked for Philips Semiconductors during 6 years – now titled NXP Semiconductors- as a defectivity engineer focusing on defect reduction and metrology tool ownership. In 2007, he joined Soitec, a high tech semiconductor company supplier of engineered substrates, as a senior yield engineer. His main mission is yield enhancement though close follow-up of product parameters.

Context, motivation of the study

Semiconductor is a very complex industry, dealing with hundred of operations (process stages) and hundred of parameters, with products sensitive to particles as small as 0.1 microns, and leading edge technologies at work. SOITEC is manufacturing substrate wafers based on a technology called SOI - Silicon On Insulator, providing key chipmakers with raw material allowing low consumption and high performance. In a large volume wafer fab, with very strong customer requirements in terms of quality, new process control tools are necessary in order to quickly detect any faulty process tool, and also to find root cause of complex yield issues related to some process stages, but not tool dependant.

The key requirement from the yield engineers is a statistical tool with two characteristics: automatic enough to quickly highlight a very limited set of process parameters (among hundred) responsible for yield losses, interactive enough to be able to tune the analysis taking into account “engineering knowledge“.

JMP software was selected for 3 reasons: it is using advanced statistical method adapted to semiconductor complexity, it is very user friendly and all engineers can perform additional stats with no pain, it includes a powerful programming language, JSL, to develop automatic analysis for thousand of input and output parameters.

Approach and techniques

The approach was first to take into account the needs of the yield engineers:

- Need for a tool being able to quickly detect any process tool responsible for yield losses or product capability drift, with a very limited rate of false alarms and without being over-sensitive.
- Need for a tool user friendly so that any yield engineer ~~of~~ or technician is able to extract and analyze huge amount of final product data in a few minutes, and to report within its organization any findings with the same graphical output material.

Additional advanced capabilities were implemented to deeply analyze process information contained in manufacturing and test database. We will present several examples of *innovative statistical methods*, including a live utilization of the yield enhancement software developed by *Ippon Innovation* and SOITEC. We will present two new statistical methods:

- Analysis of binary data vs. all process tools.
- Yield or final parameters drift detection using process dates.

Yield JMP is composed of several JSL solutions including:

- Tool to Tool comparisons: this is a set of statistical tests, including ANOVA, Kruskal Wallis and the new likelihood ratio test for binary response (example: presence of a signature on the part). Tool to Tool is performing the adapted test for each response variable, analyzing all process operations, and providing the list of statistically significant process stages only … For these stages, a pareto of suspicious process tools is given, then comparative box plots with statistical impact on final data and a trend chart of the yield vs. the process date. In addition a contingency analysis is performed on all suspicious stages to quickly highlight any possible interactions (chronological or process dependant). The yield engineer is then able to quickly highlight issues and to give a rapid feedback to the process team
- Drift Detector is a new tool working as follow: for each process stage, a smoothing spline (JMP: Fit Y by X > Fit Spline) is used, the best smoothing based on the R-squared criteria means that the transition between good and bad lot is the strongest. All the process stages are than ranked with this criterion, and the better smoothing at a stage means that something has occurred at the stage: it is the suspicious one!
- A set of other automatic tools has also been developed, including a systematic correlation, a systematic comparison, a repetition detection, a commonality analysis at multiple stages by tool type…

Tool to Tool and Drift Detector will be used during the presentation, using JMP, the JSL code will be discussed, and statistical details will also be given, especially for the likelihood ratio test and the smoothing splines.

Yield, Statistics and JMP

The challenge we face in semiconductor industry is to deal with thousands of variables. The process is very complex and hundred of operations are necessary. It is important to analyze all process parameters and to have an efficient screening of statistically significant parameters only. Yield is never too high and any improvement opportunity is good. In that context statistics is very important, and non standard methods are extensively used: non-

parametric Kruskal Wallis test for strongly non-normal data, smoothing splines to detect any drift linked to a process stage, likelihood ratio test to deal with binary parameters… Here JMP appears: to develop a fully automatic script that analyzes hundred of process parameters in a few minutes, allowing the user to interactively use graphs and JMP capabilities. An advanced JSL program has been developed and is used daily at SOITEC high tech facility near Grenoble, France. This JSL program uses projects capabilities, and outputs can be analyzed by yield engineers. In addition, to share information with process and maintenance team, html outputs are also provided. Compared to existing yield tools in semiconductor, *Yield JMP* has a great advantage: is it automatic enough to summarize the information contained in huge dataset, and it is interactive enough to use all great JMP capabilities to go deeper in the investigations!

Results, conclusion and perspectives

To achieve faster line drift detection and to highlight yield enhancement opportunities, Yield JMP was also deployed through systematic review of findings within a new yield meeting format with large process and maintenance representatives. Yield was improved using the statistical toolkit, and the quality of the product was also improved because of defects reduction. Statistical methods adapted to special distributions, often strongly non-normally distributed, or not continuous, are used, and we will present several examples. It is very important to note that yield engineers are using daily the statistical toolkit.

In terms of payback, 1% yield enhancement has been obtained in less than 6 months using Yield JMP, allowing savings of millions $ without any additional expenses. Next steps now are to generalize the concept to:

-the preparation of raw material used to produce wafers to save additional yield points and to decrease particles more and more

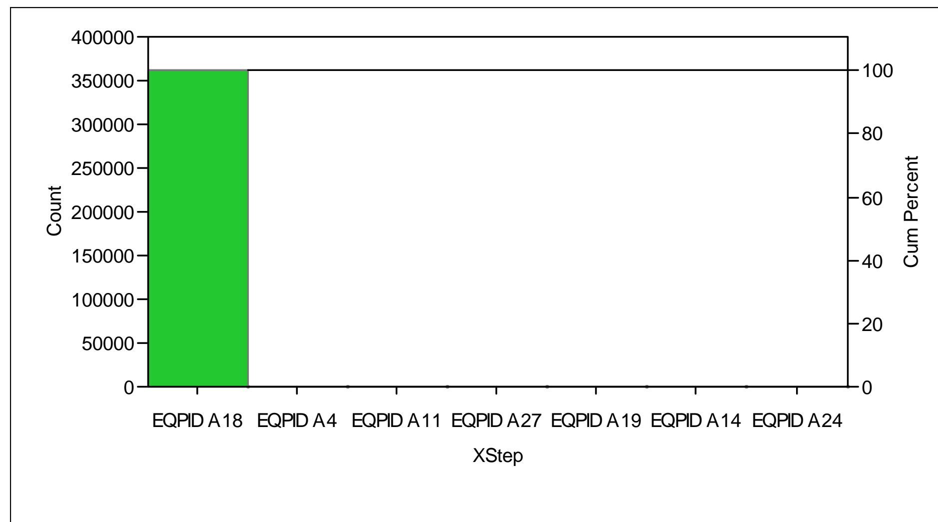
-the available inline metrology data on key inline parameters to achieve early drift detection

In addition, to fulfill process and maintenance team's demands, an ambitious automatic version of Yield JMP is being developed using JMP html outputs to make information such as golden or worsen tool by stage available.

SOITEC is now using extensively *yield JMP*, and the quality level of the wafer produced has been increased by reducing the number of defects!

Illustrations

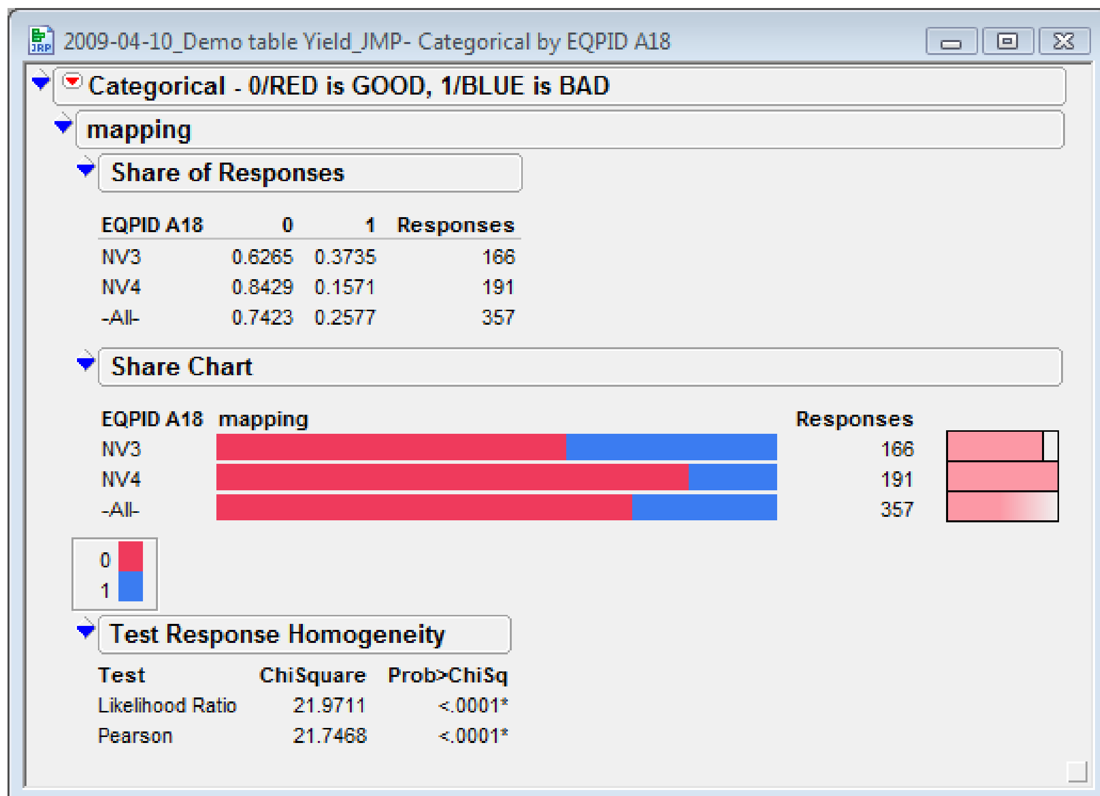
Detection of a faulty process tool



X-axis: process tools, Y-axis: statistical criteria developed to highlight key significant effects

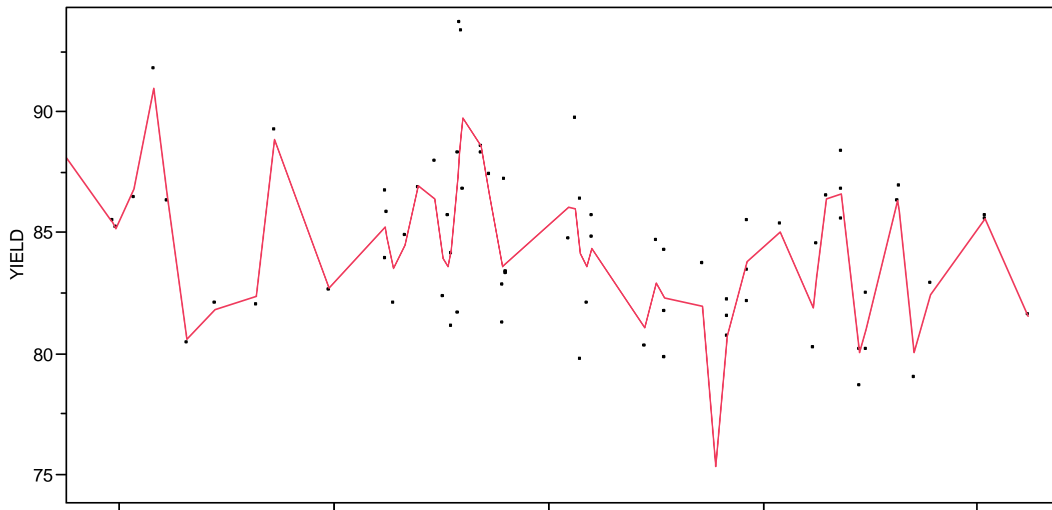
A18 process stage in that example is clearly the bad one in terms of suspicious process tool!

The categorical menu can be used to deal with binary responses:



NV3 process tool is statistically giving a higher proportion of defects (in blue)!

Detection of a faulty process stage



X-axis: dates of processing, Y-axis: yield

Process stages are ranked by order of suspicion: graph of the most suspicious stage is displayed here