Statistical modeling: role and position in semiconductor industry

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- **MOTTO 1: *Statistical modeling* is necessity in the design of today's integrated circuits (ICs).**
- **MOTTO 2: Statistical models must represent silicon in *long term perspective*.**

Goal of the contribution

In order to make the statistical models relevant in the course of process lifetime, feedbacks to manufacturing must be established and process control tools developed. The goal is to demonstrate *basic features and links* between the following tools:

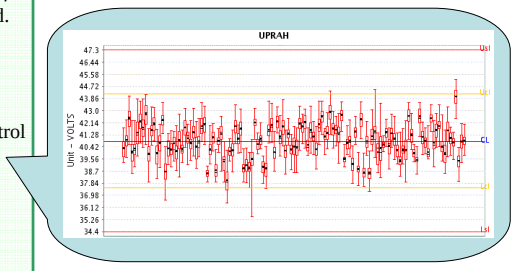
- **Tool 1:** to define targets, specification limits and control lines in accord with industry standards.
- **Tool 2**: to create statistical models available in design kits.
- **Tool 3**: to run Statistical Process Control over a critical set of PC data (SPC on PC).
- **Tool 4**: to perform regular process monitoring verifying the validity of statistical models and process stability.

Satisfied customer buying stable products with predictable behavior

Tool 1: Database of targets & specs & control lines

Responsible:
• technology development
• manufacturing
• approved by design managers

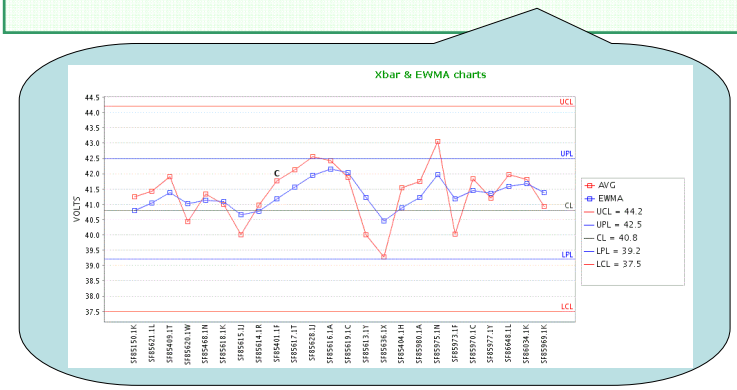
- *PCM data driven* approach necessary [4,5].
- Data must be gathered in the course of sufficient time period to capture *all natural sources of variation* in the process. As a rule of thumb, at least 3 months & 25 lots need to be evaluated.
- Correct *outlier elimination* necessary. 2-step elimination is robust [6]:
  1. Remove hard outliers X: |X|>Upper Boundary OR |X|<Lower Boundary.
  2. Use inter-quartile range (IQR) elimination, IQR=Q3-Q1.
- Definition of *control lines* for *SPC on PC*. Types of control charts must be selected, the control charts must be appropriate for batch processes with several sources of variability (predominantly batch-to-batch & intra batch).
- Definition of *specification limits* for scrapping lots in production. Corresponding CP, CPK must be reasonable.
- *Revision control* of the database.



Responsible:
• manufacturing

Tool 3: Statistical Process Control (*SPC on PC*)

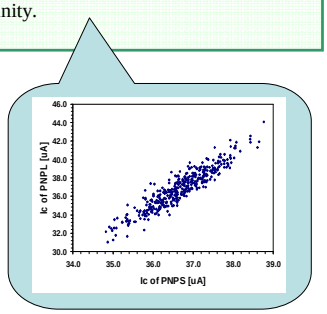
- Targets and control lines obtained from the database.
- *X-bar, EWMA and S-charts* represent a good choice for control charts [4,5].
- Symptoms of statistical instabilities evaluated in *critical PCM parameters* (<50).
- If some *symptoms are detected*, then a report is generated and sent to responsible engineers in fabs.
- On receiving the report, *actions follow* based on Out of Control Action Plan (OCAP).
- "6σ process" rules implemented.



Tool 2: Statistical modeling

- Targets and process variations obtained from the database.
- Create nominal models based on measurements of 1 typical wafer.
- Tune the models to targets in the database using [1,2,3]:
  - *forward propagation of variance*: capacitors, diodes, simple resistors.
  - *backward propagation of variance*: BJTs, MOSFETs, pinch resistors.
- Introduce correlations among devices.
- Verify the statistical models by Monte Carlo simulations.
- Make the models compatible with tools for design centering & layout optimization (possible external vendors).
- Release of Design Kits to design community.

Responsible:
• modeling engineers
• EDA engineers



Tool 4: Process monitoring

Responsible:
• manufacturing
• modeling engineers
• widely used by design, product engineers & management

- Regular monitoring of *all PCM tests* in the process, not only the critical ones as in *SPC on PC*.
- Reports contain box plots, histograms and basic statistics (CP, CPK).
- Reports generated automatically and sent to responsible engineers & managers.

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