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Investigation of predictive modeling for process control in plasma activated wafer bonding for integrated sensors

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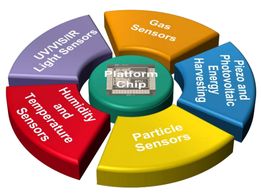
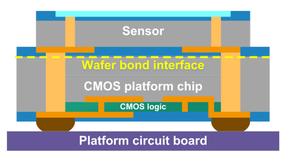
Multi Sensor Platform for Smart Building Management (MSP) Project

- European multi-project wafer (MPW) service for flexible 3D-integration of components and sensors on CMOS electronic platform chips



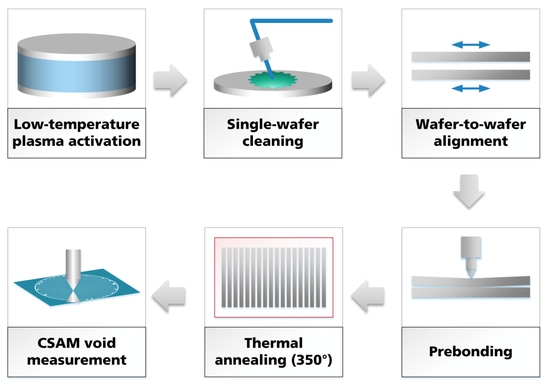
Principle of integration (TSV last + second CMOS)



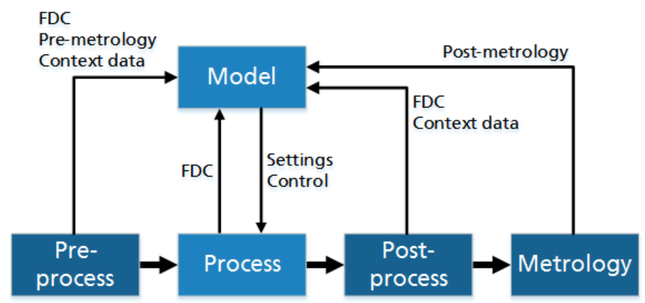
- Key processes: Wafer-to-wafer (WtW) bonding and connection by Through-Silicon-Via (TSV) technology

Wafer bonding process flow and control concept

Basic process steps in plasma activated wafer bonding



Generic APC concept for the wafer bond process



- Wafer-to-wafer bonding processes require tight process control to reduce voids
- Solution: Apply predictive, data based optimization in wafer bonding

Overview of data provided and data aggregation

Wafer bonding process

- Logistic and equipment/ process data for wafer cleaning, plasma activation, wafer alignment
- Data are comprised of already condensed indicators (key values), time resolved trace data and separate indicators (activation)

CSAM quality control

- Location and size of bond defects on wafer together with logistic wafer information

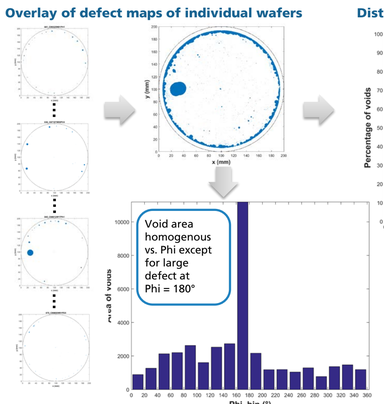
Data aggregation in the individual steps

Activation	Wafer cleaning	Alignment	CSAM data
■ Data from context activation, indicators activation and additional key numbers from trace data ■ Eliminate invariant categories, invariant numeric variables, redundant variables ■ Handle twice processing of wafers ■ Eliminate non matching contexts (processes) ■ Data arrangement to consider wafer (W1) to partner wafer (W2) correlation	■ Data from context cleaner and additional key numbers from trace data ■ Eliminate invariant categories, invariant numeric variables, redundant variables ■ Handle twice processing of wafers ■ Data arrangement to consider wafer (W1) to partner wafer (W2) correlation	■ Data from context alignment, and additional key numbers from trace data ■ Eliminate invariant categories, invariant numeric variables, redundant variables ■ Define reference sorting of processes for matching of activation, cleaning and CSAM data	■ Identify number of voids and void area per wafer ■ Sort data to match arrangement in the wafer bonder data ■ Derive key parameters to be used as target values in modeling ■ Use cumulative plot of data as starting point

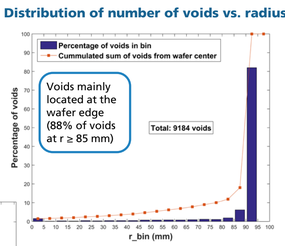
CSAM (C-mode Scanning Acoustic Microscopy) data – extraction of key parameters

Analysis of the characteristic void distribution on the wafers

Overlay of defect maps of individual wafers

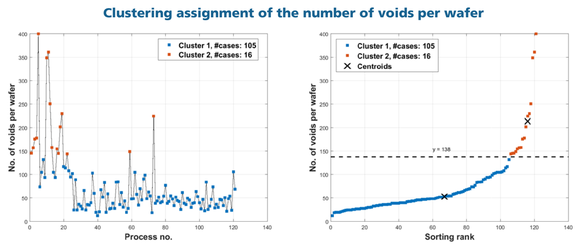


Distribution of number of voids vs. radius



Clustering of the number of voids per wafer

Clustering assignment of the number of voids per wafer

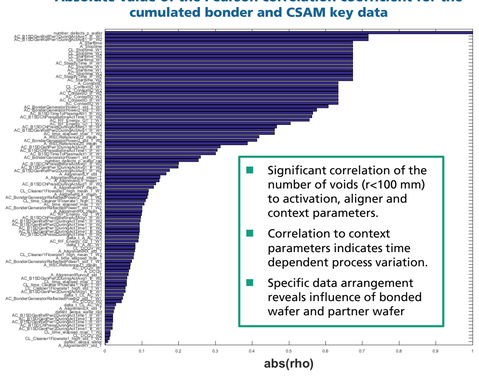


- Extraction of key parameter for void measurement independent of die information
- Especially in the first 20 processes, larger number of voids per wafer
- Clustering by k-means algorithm indicates two well separated clusters

Analysis of the wafer bonder and the CSAM data

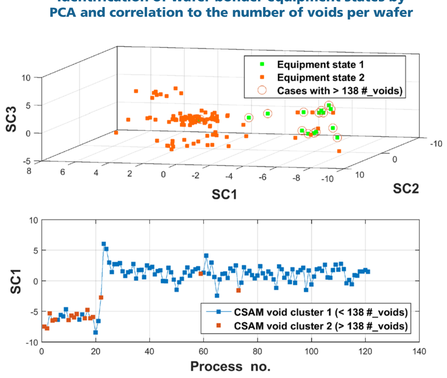
Correlation of the total void area to the wafer bonder parameters and the equipment states

Absolute value of the Pearson correlation coefficient for the cumulated bonder and CSAM key data

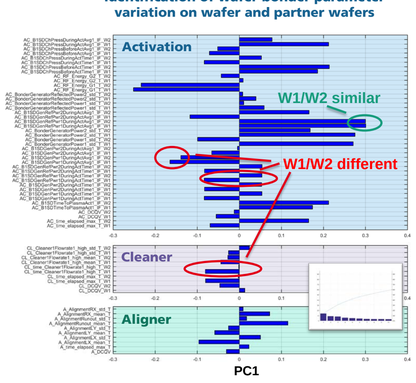


- Significant correlation of the number of voids (r<100 mm) to activation, aligner and context parameters.
- Correlation to context parameters indicates time dependent process variation.
- Specific data arrangement reveals influence of bonded wafer and partner wafer

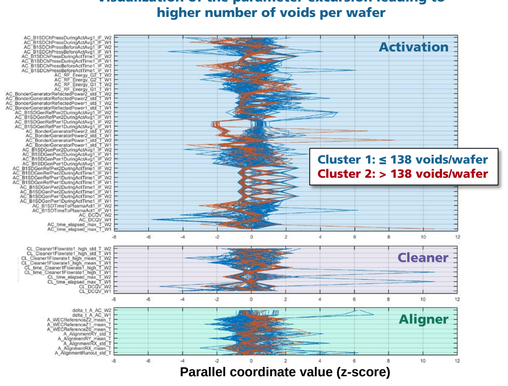
Identification of wafer bonder equipment states by PCA and correlation to the number of voids per wafer



Identification of wafer bonder parameter variation on wafer and partner wafers



Visualization of the parameter excursion leading to higher number of voids per wafer



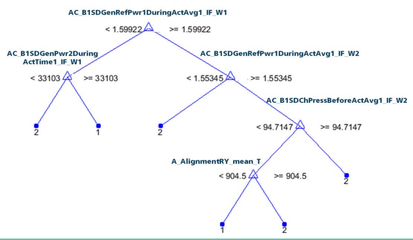
Principal Component Analysis (PCA) of the wafer bonder parameters reveals

- Bonder parameter variation on wafer and partner wafers
- Equipment states identified by k-means clustering and correlation to increased generation of voids
- Time dependence of equipment states and correlation to increased generation of voids

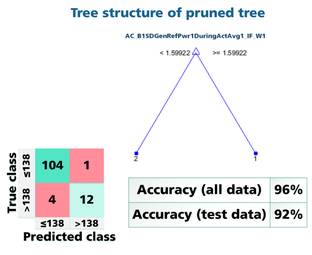
Prediction model for the class of voids per wafer

Analysis of classification tree on data set

Tree structure of full tree



Tree structure of pruned tree



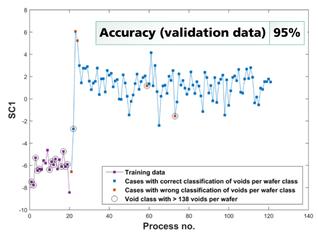
True class \ Predicted class	≤138	>138
≤138	104	1
>138	4	12

Accuracy (all data)	96%
Accuracy (test data)	92%

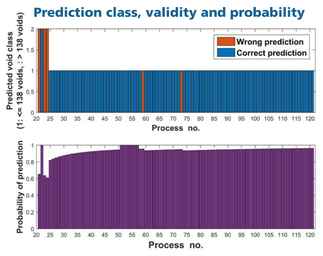
- Pre-evaluation: Classification tree suitable for prediction on data set
- Analysis using 5-fold CV on training/test data with pruning of model

Training and prediction during runtime, start with 20 training cases

Prediction visualized for SC1



Prediction class, validity and probability



- Pruned tree depends on CV sample: Full tree or stub
- Good accuracy in static and dynamic analysis

Summary and outlook

- Analysis of wafer bonder data and CSAM data to analyze dependencies on wafer and partner wafer
- Identification of key parameters for void formation
- Identification of the wafer bonder parameters and equipment states; correlation to void formation
- Classification model to predict void class from wafer bonder data with an accuracy of 95%
- Outlook: Include information from processing steps prior to wafer bonding and increase data volume to further improve prediction of void formation

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