# Prediction and Stabilization of MOSFET Threshold Voltage by VM-APC using Factory Data

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## 1. Introduction

Early detection of variations in product characteristics and improvement of production yield by using virtual metrology (VM) and advanced process control (APC) with various types of semiconductor factory data attract increasing attention as a differentiation technique for production factories. We have reported some evaluation examples of VM and APC using our applied original predictive methods and algorithm.[1~3)]

The target characteristic of this paper is the transistor threshold voltage (Vth), which is one of the important electrical characteristic which is common to all semiconductor products. An efficient method of parameter extraction and a dynamic PLS method [4)] are adapted for improving the accuracy and maintainability of prediction models. We also report an evaluation example of the reduction of dispersion in Vth characteristics by VM-APC using the prediction model and selective fitting.[5)]

## 2. Experimental

### 2.1 MOSFET Vth

As targets of VM and VM-APC, we selected two kinds of Vth of the standard-voltage (SV) and the low-voltage (LV) transistor, which were located on the wafer surface as test element groups (TEG).

### 2.2 Data Analysis and Modeling Method

Candidates of model parameter were extracted by two data analytical flows, the first one is that used measurement data on intermediate characteristics of products (e.g., layer thickness, pattern dimensions, and superposition of lithography process) and second one is that used data on equipment use histories in the entire FEOL process (Fig. 1). In the second flow, key processes were selected according to data analytical results and engineer knowledge. Equipment signals, equipment quality control (EQC) data, and equipment use histories related to those processes were then extracted as candidate model parameters.

We built the Vth prediction model by PLS using the candidate model parameters described above. The final parameters used for the prediction model were selected by using an orthogonal array. [6)] The criterion for selection was the root mean squared error (RMSE) in the cross validation method.

## 3. Results and Discussion

### 3.1 Extraction of Key Parameters and Modeling

Table 1 shows a part of the final model parameters. The structure of an ordinary MOSFET is shown in Fig. 2.[7)] The extracted gate length (L), width (W) and oxide layer depth (d), which are common to both types of transistors, are important parameters for variation in transistor characteristics. That result suggests that the analysis results are consistent with device-specific knowledge. Simulation results of PLS models are shown in Fig.3. We used dynamic PLS regression models[4)] built with model parameters listed in Table 1 to achieve highly-accurate Vth characteristic prediction.

### 3.2 Early Detection of Anomaly Vth Trend by VM

An example evaluation of Vth prediction and the early detection of an anomalous trend are shown in Fig. 4. By the investigation about detection of the downward trend in predicted Vth values, we confirmed an increase in the thickness of the gate oxide layer, which is one of the model parameter. This result suggests that the model can predict the Vth characteristic and thus prevent the occurrence of large quantities of defects.

### 3.3 Reduce of variations in Vth by VM-APC

An evaluation example of VM-APC with selective fitting [5)] is shown in Fig. 5. We classified wafers and equipment groups used in following process into three. Wafers were classified on the basis of the Vth prediction value calculated by VM, and equipment groups were classified by the measured Vth value in historical data (e.g., High, Middle, and Low). These classification results were used to choose the optimum pairing of wafers and equipment, and wafers were processed by chosen equipment. As a result we achieved a reduction in variation in the Vth characteristic by applying VM-APC with selective fitting (Fig. 6).

## 4. Conclusion

This paper presents VM and VM-APC for the transistor threshold voltage (Vth). Our proposed methods, parameter selection by orthogonal arrays and selective fitting, are effective for early detection of variations in Vth and stabilizing of the characteristic in the mass production line.

References

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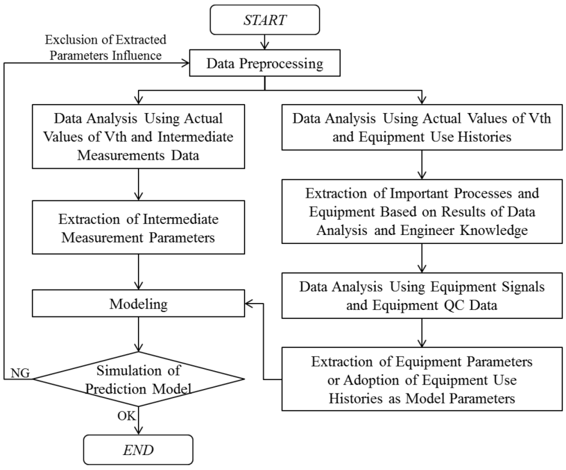


Fig.1 Data Analysis and Modeling Flow

Table.1 Key Parameters of PLS Models

| Key Parameters | SV Transistor Vth | LV Transistor Vth |
|---|---|---|
| Intermediate Measurement | Gate L | |
| | Gate W | |
| | Gate Oxide d | |
| | - | Side Wall |
| Equipment Signal | Signal X | Signal Y |
| Equipment QC | - | Ion Implantation |
| | - | Ramp Anneal |
| Equipment Use Histories | Ion Implantation | |
| | Lithography | Dry Etching |
| The Number of Model Parameters | PLS-VIP: 7 | PLS-VIP: 9 |
| | Orthogonal Array/RMSE: 10 | Orthogonal Array/RMSE: 11 |

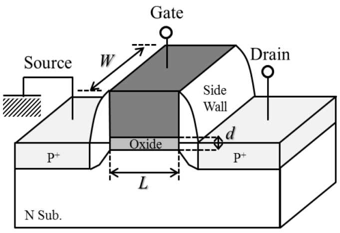


Fig.2 Structure of PMOSFET 7)

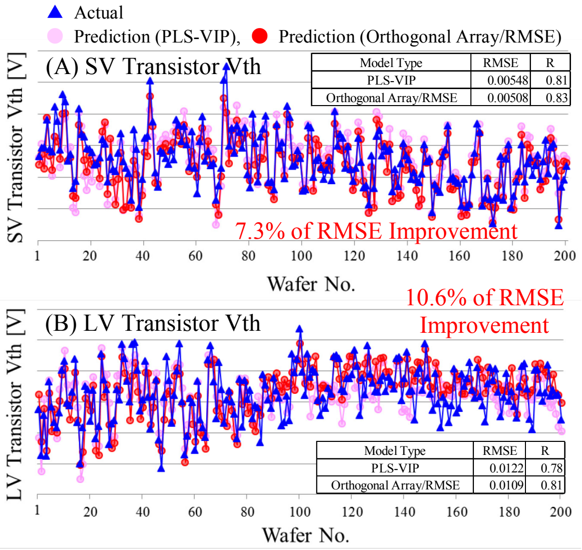


Fig.3 Simulation Results of PLS Models

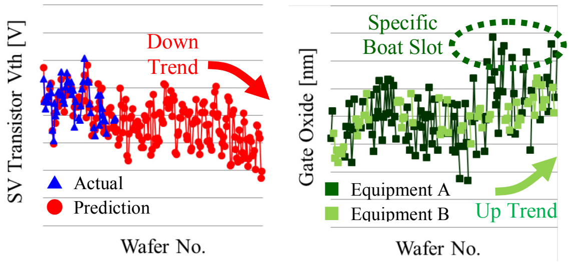
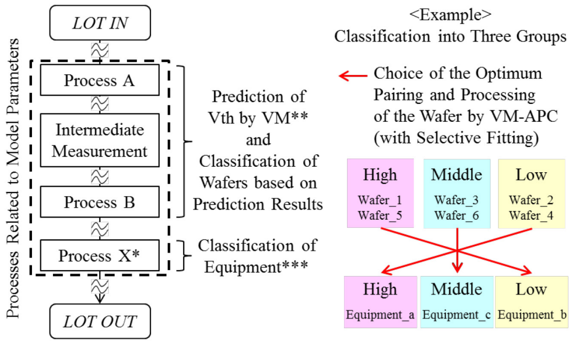


Fig.4 Early Detection of Anomaly Vth and Gate Oxide Thickness Trends by VM



*The Parameter of process X is the equipment use history .
**Prediction values of Vth by VM are calculated under the supposition that all wafers are processed by an average equipment in process X.
***Equipment groups are classified by the measured Vth value in historical data.

Fig.5 Evaluation of VM-APC with Selective Fitting

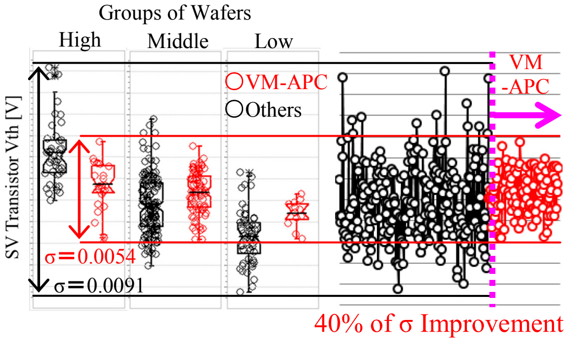


Fig.6 Reduce of variations in Vth by VM-APC