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Stabilization of Etching Oxide Thickness using VM-APC of Polymer Wet Etching

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1. Introduction

The yield degradation from the variation in equipment conditions is a serious problem in a nanoscale semiconductor device. However, in order to prevent the yield degradation, it is not realistic to increase the inspection of a device or the quality check of the equipment from the viewpoint of cost. The fault detection and classification (FDC) technology and the virtual metrology (VM) technology that predicts a process characteristic is an effective means to successfully increase the yield as well as reduce the inspection cost. Recently, these technologies have attracted considerable attention [1].

This paper describes the virtual metrology advanced process control (VM-APC) in polymer wet-etching process for stabilization of the etching oxide thickness.

2. Experiment

Figure 1 shows the schematic drawing of the polymer wet-etching equipment. The main purpose of polymer wet-etching is the removal of the polymer residual after dry-etching. The chemical solution is a mixed solution containing ammonium fluoride and is supplied to the process chamber from the chemical tank. Moreover, after the chemical solution is dispensed on a wafer, it is collected in the chemical tank. The chemical solution in the chemical tank is replaced with a new one when the number of processed wafers reaches a fixed number or when the use time of the chemical solution reaches a fixed time. In this equipment, parameters such as temperature, flow, wafer rotations, and chemical lifetime are acquired with a monitoring tool. As a statistical analysis method of the equipment engineering system (EES) data, partial least square (PLS) analysis [2-4] was performed to find out the root cause of variation of the oxide etching rate. Next, a VM of the oxide etching rate was developed on the basis of the physical model assumed from the parameter extracted by the PLS analysis. In order to reduce the variation in the etching oxide thickness, VM-APC was introduced.

3. Results and Discussion

3-1. PLS analysis results

Figure 2 shows the variable importance projection (VIP) values calculated by the PLS analysis for the oxide etching rate of the polymer wet-etching process. From the VIP values, it was found that the accumulative numbers of processed wafers (life count) from the time of the replacement of the chemical solution were important.

3-2. Consideration of physical model

The following physical model was considered on the basis of the results of the PLS analysis. The fluoride concentration increased with an increase in the evaporation of the water in the chemical solution when this solution was dispensed on the wafer and during the circulation of the chemical solution. Therefore, the oxide etching rate can be given by Eq. (1) as follows:

$$R_E = f(C_F, T_s) \qquad (1)$$

Here, R_E is the oxide etching rate, C_F is the fluoride concentration, and T_S is the temperature of the chemical solution. The fluoride concentration in the chemical solution was difficult to maintain the accuracy of the in-situ measurement for a long period of time, and hence, the prediction equation of the fluoride concentration was devised according to Eq. (2).

$$C_F = C_0 + a_1 T_d + a_2 T_c \qquad (2)$$

Here, C_0 is the fluoride concentration immediately after the chemical solution exchange, T_d is the elapsed time at which the chemical solution was dispensed on the wafer, T_c is the lifetime of the chemical solution, and a_n is the constant. Figure 3 shows the predicted oxide etching rate by VM. The correlation factor between the measured rate and the predicted rate by VM was around 0.90.

3-3. Validation results

Figure 4 shows the trend of the etching oxide thickness before and after introducing VM-APC. The variation in the etching oxide thickness was reduced to approximately 48% after the introduction of VM-APC. Furthermore, approximately 80% of the non-product wafers (NPWs) were reduced by a decrease in the number of quality checks of the equipment. Figure 5 shows the relationship between the number of Cu void defects on the dual damascene interconnection and the life count of the chemical solution before and after the introduction of VM-APC. Before the introduction of VM-APC, the number of defects increased with the increase in the life count of the chemical solution. The increase in the etching oxide thickness changed the shape of the trench. On the other hand, as shown in Fig. 4, the etching oxide thickness was stable after the introduction of VM-APC. Consequently, the number of defects was reduced. Moreover, approximately 30% of the cost of the chemical solution was reduced by extending the exchange cycle of the chemical solution.

4. Summary

The VM of the oxide etching rate in polymer wet-etching was developed on the basis of the presumed physical model by using the results of a PLS analysis. The predicted value of the oxide etching rate by VM was in good agreement with the measured value. By controlling the process using VM-APC, we decreased the variation in the etching oxide thickness and the number of void defects. Moreover, the cost of the chemical solution was reduced by extending the exchange cycle of the chemical solution.

5. References

[1] T. Tanaka et al., ISSM2011, accepted.
[2] S. Imai et al., ISSM2008, pp265, 2008.
[3] S. Yasuda et al., AEC/APC Asia 2009.
[4] M. Kitabata et al., ISSM2010, pp121, 2010

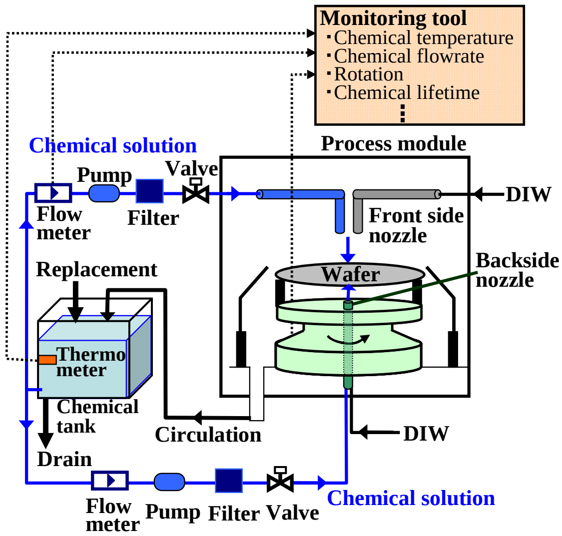

Fig.1 Schematic drawing of polymer wet-etching equipment including monitoring tool.

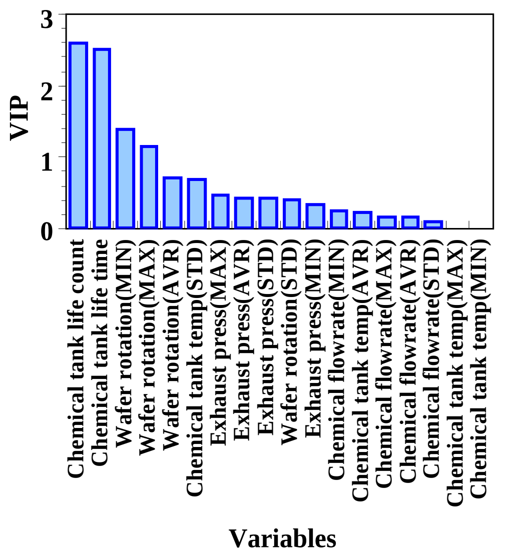

Fig.2 Variable importance values calculated by PLS analysis for the etching rate as the objective variable.

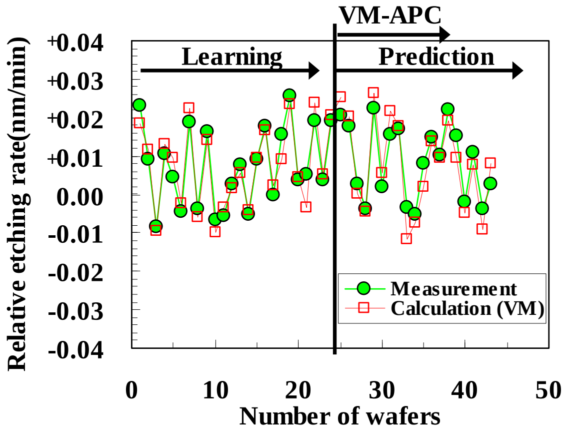

Fig.3 Trend chart of the measured etching rate and the predicted etching rate by VM.

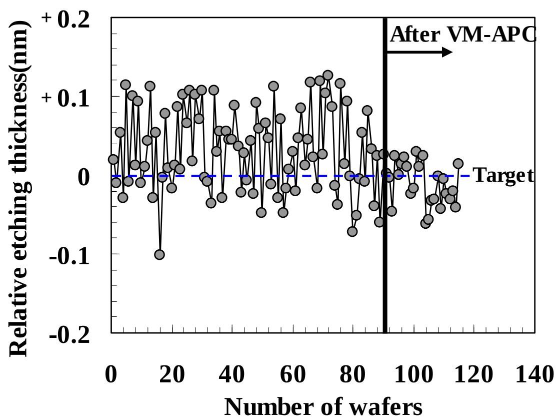

Fig.4 Etching oxide thickness behavior before and after introduction of VM-APC.

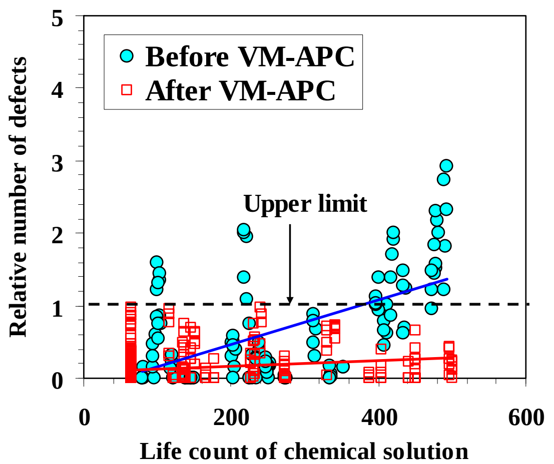

Fig.5 Cu void defects as function of life count of chemical solution before and after introduction of VM-APC.