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Virtual Metrology of Dry Etching Process Characteristics using EES and OES

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1. Introduction

Recently, virtual metrology (VM) has been actively attempted in the semiconductor manufacturing process[1]. Meanwhile, the methods for statistical VM modeling and determining equipment parameters have been gradually improving[2]. In this paper, we try to predict critical dimension (CD) value in order to adapt quality control and equipment control of dry etching equipment.

2. Approach & Results

A parallel-plate dual-frequency CCP system was used for SiO_2 contact hole etching. (Fluorocarbon gas and O_2/Ar gas mixture)

(1) Predictor variables

We used about 20 signals of equipment data and optical emission spectroscopy (OES) data (200 to 800nm) for statistical analysis. Generally, intensity of optical emission (I_x) depends on plasma density (n_e), electron energy (T_e), collision cross section (σ) and density of atoms or ions (N_x).

$$I_x = N_x n_e \int \sigma(\varepsilon) v(\varepsilon) f(\varepsilon) d\varepsilon$$

where, v, ε, and f are electron velocity, electron energy, and distribution function, respectively. We used Ar emission (I_{Ar}, 750.4nm) as an actinometer[3] and OES signal at each wavelength was divided by I_{Ar} to eliminate the effect of variation of n_e and/or T_e. I/I_{Ar} can be roughly related to radical or ion density in plasma.

$$N_x \propto \frac{I_x}{I_{Ar}} N_{Ar}$$

Figure 1 shows an example of an OES signal (CO) as a function of etching time. We calculated the average value of I_F/I_{Ar} as shown in Fig.2.

(2) Parameter selection approach

After we decide population sample and criterion variable, the parameter selection approach is as follows.

(A) Estimation of Correlation Matrix
(B) Eliminate Multicollinearity
(C) Stepwise Regression

For example, Table 1 shows selected predictor variables that we use to predict CD.

(3)Comparison to physical phenomenon

We found CD values strongly correlated with i) mask CD, ii) OES signal of O and F, and iii) wall temperature (see Table 1). Figure 3 shows the reaction model during dry etching of dielectric materials. When we used fluorocarbon plasma in SiO2 etching, ΔCD was basically determined by the valance between the deposition rate of C-F polymer on the sidewall that can be related to CF_x/O ratio and isotropic etching rate by F radicals. When O density was high, excess deposition of CF polymer on the etched sidewall could be suppressed. CF_x radical density depended on both the “generation” by electron impact dissociation of fluorocarbon molecules in bulk plasma and the “loss” at the chamber wall (or pumping out). Figure 4 shows the etching chamber. When wall temperature lowered, CF_x density decreased because the “loss” rate (sticking probability at chamber walls) of CF_x is increased. Thus, the physical model also indicates that both the higher density of O, F and the lower wall temperature decreases ΔCD, which is consistent with statistical analysis results.

(4)Prediction method (PLS+Population renewal)

Figure 5 shows a trend chart of predicted value and measured value of CD in real-time simulation. Because predictive model is ageing, in addition to PLS regression, the population is sequentially renewed. According to Fig.5, we obtain good CD prediction results using equipment parameters and the optical parameters. We are trying to apply wafer-line for quality control and equipment control.

3. Summary

We used both equipment data and OES data for CD prediction, and utilized stepwise regression for parameter selection, and then compared physical phenomenon and each selected parameter. We obtained good CD prediction result by PLS regression, the population of which is sequentially renewed.

References

1) J. Yamamoto *et al.*, in Proc. of AEC/APC Symposium Asia, FD-O-056, Kumamoto, Japan (2007).
2) H. Takagi *et al.*, in Proc. of AEC/APC Symposium Asia, Hsin Chu, Taiwan (2008).
3) J.S. Janq *et al.*, Plasma Sour. Sci. Technol. 3 (1994) 154.

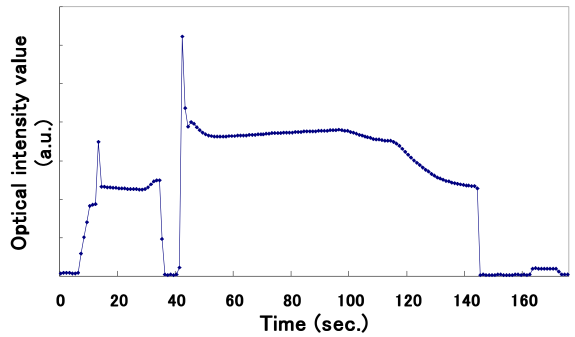

Fig. 1 OES signal of CO.

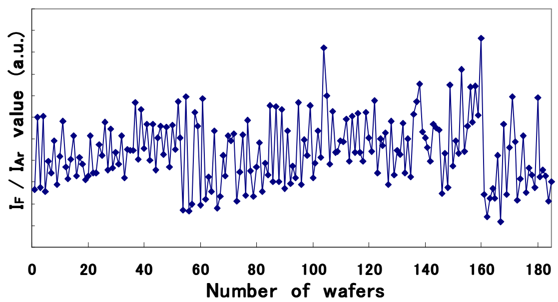

Fig. 2 Trend chart of F density.

Table 1 Selected predictor variables.

Explanatory variable	Partial correlation coefficient	Standardized partial regression coefficient
Mask CD [um]	0.5907	0.4083
Matching_Position_1 STDEV [n/a]	0.2687	0.1569
Wall_Temperature Average [degC]	0.2756	0.1645
Wall_Temperature STDEV [degC]	−0.2730	−0.1578
Wavelength_O2 Average [Fk]	−0.4318	−0.2951
Wavelength_F Average [Fk]	−0.5329	−0.3808

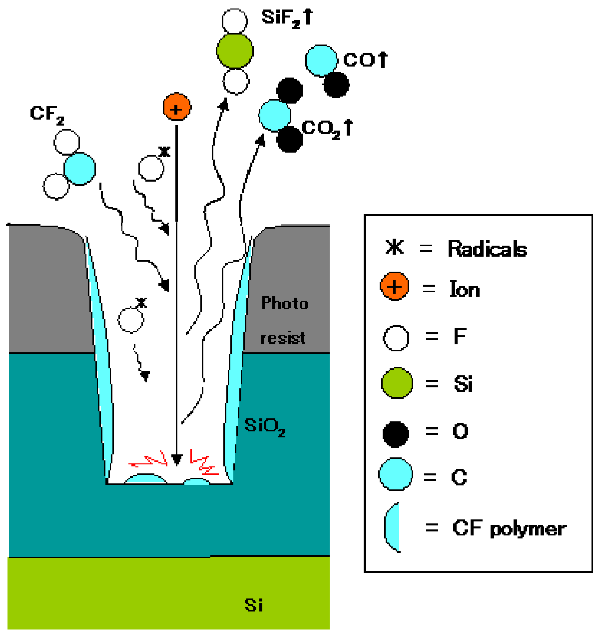

Fig. 3 Reaction model of during dry etching of dielectric materials.

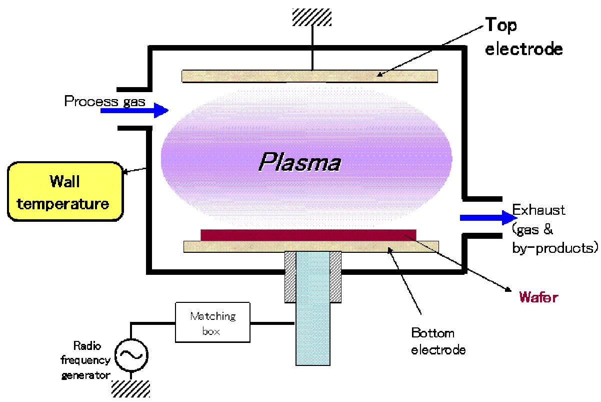

Fig. 4 Etching chamber.

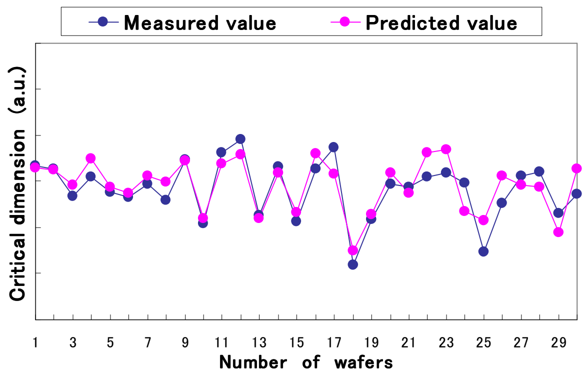

Fig. 5 Trend chart of predicted value and

measured value to CD in real-time simulation.