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Optimal Process Parameter Extraction with Quality Engineering-Nobuichi Kuramochi

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Trench formation with RIE is one of the most basic processes in LSI fabrication and enormous experiments have been executed. Then, we can access huge accumulated data with respect to process parameters and resultant trench shapes. In this study, we made an attempt to extract the optimal process parameters for the desired trench shape formation from the existent data without further experimental runs. The tools we applied here were the dynamic characteristic analysis and the T method both have been developed in the quality engineering (Taguchi Method). In the dynamic characteristic analysis, Y, the response of the system changes according to the input signal M as well as control parameters X's and a simple proportionality between M and Y is assumed where a proportionality is usually described as a sensitivity by logarithmic conversion. Y is also affected by noises and the deviation from the proportionality can be expressed by the SN ratio. The higher SN ratio means better quality of the system (Fig 1). The T method is a new approach to obtain a linear regression equation for Y with multiple predictors (X's), which is principally different from the multivariate analysis using the least square method. The T method is thought to be an application of a dynamic characteristic analysis to the estimation of the response based on the SN ratios and the proportionality between Y and X's (Fig.2).

The data base for the trench formation consists of process parameters for each etching step such as gaseous type, pressure, temperature etching time etc. and characteristic dimensions of the trench shape such as critical distance, inclination or curvature evaluated along the trench wall (see Fig.3). We can select such data to which the objective trench shape has some similarities. Data processing procedures to extract the optimal process parameters are as follows;

1. Geometrical dimensions for the ideal trench shape corresponding to those of the data base are determined and treated as signals.

2. Characteristic trench dimensions in the data base are reduced to the SN ratios and sensitivities by the dynamic characteristic method. Data set is converted to the SN ratio, sensitivity and process parameters for each experimental condition.

3. Linear regression equations for the SN ratio and the sensitivity as functions of process parameters are calculated with the T method.

4. The optimal process parameters can be estimated to find the process parameter set that maximizes the SN ratio and brings the sensitivity to zero as nearly as possible. Zero-sensitivity is realized when the estimated dimensions show complete accordance with the ideal ones (transcription).

Validity of this method was examined with the problem to fabricate a specific trench shape using data base obtained from previous trials to make similar trench shape. 14 data were collected and they had 29 parameters. Since the number of process parameters exceeds that of data sets, traditional multivariate analysis cannot be applied. On the other hand, the T method is in principle not restricted by the number of data sets even if they are less than the number of process parameters. Further, T method is more reliable for extrapolation as the regression equation is obtained by assuming dynamic proportionality between Y and X's. Based on the extracted regression equations for the SN ratio and the sensitivity, factor effects for process parameters can be expressed graphically. Figs. 4(a) and (b) show the variation of the factor effects with respect to the selection of process parameter level for the SN ratio and the sensitivity respectively. Level 2's in the figures are mean values in the data base. The optimal process parameters can be selected according to criterion 4 described in the data processing procedure. Filled circles in the figures are selected levels for the optimal process. The verification with those parameters was carried out and dimensions evaluated were compared with the specification as shown in the Fig.5. Experimental result satisfied required specification successfully. In conclusion, application of the quality engineering method to extract the optimal process parameters from the data in hand is promising and worth applying to other fields.

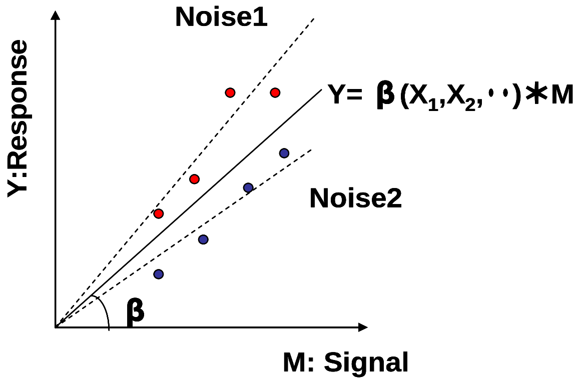

Fig.1 Concept of the dynamic characteristic method. Deviation from the linearity is measured by the SN ratio.

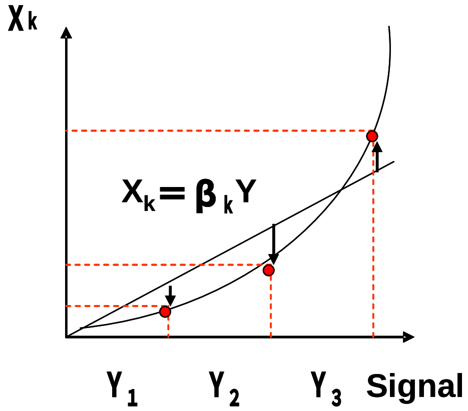

Fig.2 Principle of the T method. Responses are treated as signals for each process parameters. Regression equation for Y is given by

$$Y=\Sigma(\eta_{Di}X_i/\beta_i)/\Sigma\eta_{Di}.$$

η_{Di} and β_i are the SN ratio and proportionality for each process parameter(xi).

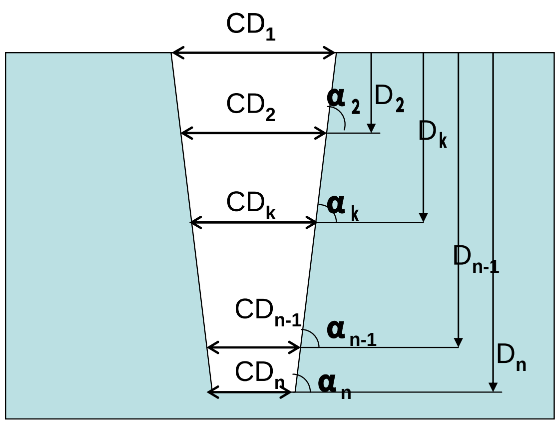

Fig.3 Example of characteristic dimensions of trench.

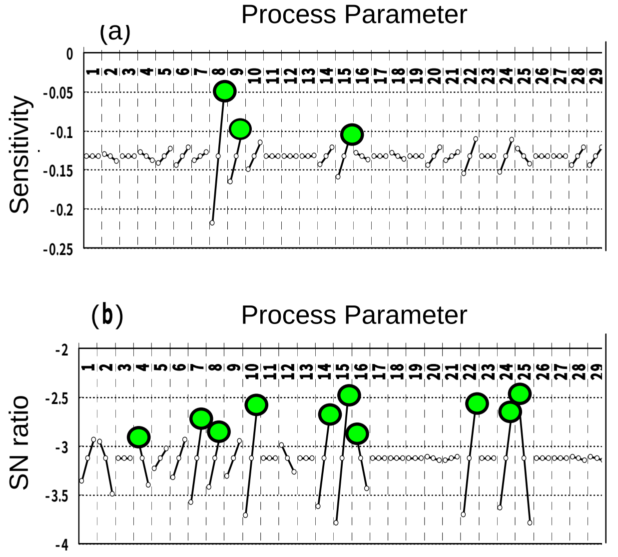

Fig.4 Factor effects for 29 process parameters estimated with regression equation given by the T method. (a) and (b) are for the sensitivity and the SN ratio respectively. Each parameter has 3 levels where the 2nd level is a mean value of the data base while the 1st and the 3rd level are deviation from the mean value.

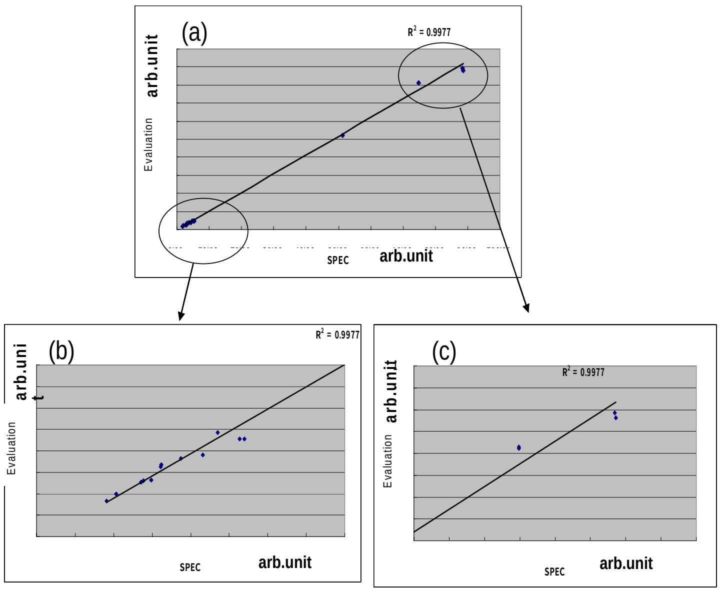

Fig.5 (a);Comparison of specification with evaluated dimension of trench fabricated with the optimal process parameters. (b) and (c) show in enlarged scale for lower and higher region in (a).