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Optimizations of a photoresist coating process for photolithography in wafer manufacture via a radial basis neural network: A case study

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ABSTRACT

This investigation applied a hybrid method, which combined a trained radial basis network (RBN) [S. Chen, C.F.N. Cowan, P.M. Grant. Orthogonal least squares learning algorithm for radial basis function networks. Neural Networks 2(2) (1991), 302–309] and a sequential quadratic programming (SQP) method [R. Fletcher, Practical Methods of Optimizations, vol. 1, Unconstrained Optimization, and vol. 2, Constrained Optimization, John Wiley and Sons Inc., New York, 1981], to determine an optimal parameter setting for photoresist (PR) coating processes of photolithography in wafer manufacture. Nine experimental runs based on an orthogonal array table were utilized to train the RBN and the SQP method was applied to search for an optimal setting. An orthogonal array table provided an economical and systematic arrangement of experiments to map the relationship between controlled parameters and desired outputs. In this study, a mean thickness and non-uniformity of the thickness of the PR were selected as monitored quality targets for the PR coating process. In addition, the PR temperature, the chamber humidity, the spinning rate, and the dispensation rate were four controlled parameters. The PR temperature and the chamber humidity were found to be the most significant factors in the mean thickness and non-uniformity of the thickness for the PR coating process from the analysis of variance (ANOVA).

1. Introduction

Photolithography is a patterning process that transfers a design from a mask to the PR on a wafer surface. Photolithography was first adapted in the semiconductor industry for the transistor and the integrated circuit manufacturing in the 1950s. It is the most critical steps in the IC fabrication since devices and circuit designs are transferred onto a wafer by etching or ion implantation through a pattern defined on the PR of the wafer surface via the photolithography process [3–7].

The PR is a photosensitive material used to temporarily coat a wafer and transfer the optical image of a chip design on a mask to the wafer surface. The PR temperature, the chamber humidity, the spinning rate, the dispensing rate, spinning time, and the acceleration rate affect the quality of a PR film such as the mean thickness and non-uniformity of the thickness. Process parameters of the PR coating vary for different types of PR. A trial and error method was mostly applied to find a suitable combination of process parameters. However, that approach is time-consuming and can not obtain an optimal process condition.

In this study, four factors including the PR temperature, the chamber humidity, the spinning rate, and the dispensing rate are selected as the controlled parameters based on the manufacturer suggestion [8]. Furthermore, the planning of experiments follows an orthogonal arrays L_9 table [9]. The mean thickness and non-uniformity of the thickness of the PR are the monitored quality targets of the PR coating process.

To resolve this type of multi-output parameter design optimization problems, Das [10] proposed to select one response variable as a primary variable, which was then optimized by adhering to the other constraints set by criteria. Tong et al. [11] determined a multi-output signal-to-noise (MRSN) ratio through integrating the quality loss of each response and Liao [12] incorporated an artificial neural network, data envelopment analysis (DEA), and an improved Taguchi method to optimize a multi-output problem. Su and Chiang [13] adapted a back-propagation network and genetic algorithms to optimize the IC wire bonding process with some intelligent guess on the structure of the neural network. However, these methods are either incomplete or difficult to determine an effective objective function. Moreover, some methods can only identify an optimal setting restricted to some discrete values.

Hence, to obtain an optimal parameter setting with a better control over the mean thickness and non-uniformity of the thickness of the PR, this study proposed to train an RBN by experimental data from a Taguchi L_9 design setup and then implemented SQP to solve a multi-output constrained problem.

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2. Photoresist coating

The PR coating is a deposition process in which a thin layer of photoresist is applied on a wafer surface. A wafer is positioned on a spindle using a vacuum chuck that can hold the wafer during a high-speed rotation. Then, the liquid PR is applied on the wafer surface, and the centrifugal force from the wafer rotation spreads the liquid over the whole wafer. A typical PR thickness in photolithography is between 5000 Å and 30,000 Å.

The PR can be dispensed by either a static or a dynamic method. In a static method, the PR is dispensed onto a stationary wafer surface, and is permitted to spread over parts of the wafer surface. For dynamic dispensing, the PR is applied at the center of a wafer while it is rotated at a low spinning rate. After the PR is dispensed, the wafer spinning is accelerated to 7000 rpm to spread the PR uniformly across the wafer surface. A dynamic dispensing method is used in this study.

2.1. Photoresist properties

Currently, most advanced semiconductor fabs use a positive PR since it can achieve a high resolution required for a submicron feature size. A PR grade number of AZ DX5106 from Taiwan/Clariant (Japan) K.K. is used in this study.

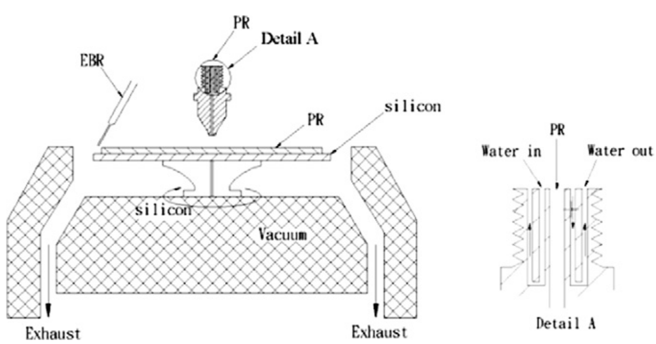

Fig. 1. A schematic of a PR spin coater.

Table 1
Experimental factors and factor levels

Level of experimental factors	A (°C)	B (%)	C (rpm)	D (ml/s)
1	22.0	37	2900	0.75
2	22.5	40	3100	1.00
3	23.0	45	3300	1.50

2.2. Schematic of a PR spin coater

Fig. 1 illustrates a PR spin coater used in the PR coating process. The PR is brought into a dispensing nozzle via a tube with a water sleeve, in which water from a heat exchanger is used to maintain a constant PR temperature. The spin rate, the spin rate ramp, the air flow temperature, and the air flow rate in the coater are precisely controlled since they can affect the drying characteristics of the PR.

3. Experimental procedures and test results

3.1. Experimental design

The product quality of the PR coating is influenced by process parameters such as the PR temperature, the chamber humidity, the spinning rate, the dispensing rate, the spinning time, the acceleration rate, etc. In this study, we have selected the PR temperature, the chamber humidity, the spinning rate, and the dispensation rate as controlled parameters in the PR coating process. Accordingly, four controllable 3-level factors and two response variables are chosen. Table 1 lists four controlled factors, which include the PR temperature (i.e., a factor "A" in °C), the chamber humidity (i.e., a factor "B" in %), the spinning rate (i.e., a factor "C" in rpm), and the dispensation rate (i.e., a factor "D" in ml/s) with three levels for each factor. Namely, the experiment runs follow an orthogonal array L_9 design.

Two response variables are the mean thickness (tm in Å) and non-uniformity of the thickness (tu in Å) on a wafer surface after the coating process. An acceptable mean thickness range is from 5270 Å to 5330 Å; 5300 Å is the most desirable mean value of the PR coating thickness. The mean thickness was also based on the manufacturer suggestion on the PR coating process for the 8-in. wafer fabrication.

3.2. Measurement of the thickness

The mean thickness and thickness non-uniformity were measured by an OPTI-PROBE analyzer of Therma-Wave Co. The mean thickness is an average value of 49 predetermined points on each wafer surface in a polar direction. Non-uniformity of the thickness is defined as the difference between a maximum readout and a minimum value amongst measured 49 points on the wafer surface. The measured results of the mean thickness (tm) and non-uniformity of the thickness (tu) are listed in Table 2.

4. Optimization processes

Fig. 2 illustrates processes of finding an optimal setting for the PR coating process. Details of each step are shown in the following sections.

Table 2
Orthogonal array L_9 of the experimental runs and the results

Exp. no.	A: PR temp., °C	B: Chamber humidity, %	C: Spinning rate, rpm	D: Dispensation rate, ml/s	tm (Å)	tu (Å)
1	22.0	37.0	2900	0.75	5312.40	20.60
2	22.0	40.0	3100	1.00	5314.90	20.63
3	22.0	45.0	3300	1.50	5300.30	41.22
4	22.5	37.0	3100	1.50	5308.20	27.57
5	22.5	40.0	3300	0.75	5310.90	12.84
6	22.5	45.0	2900	1.00	5296.40	25.04
7	23.0	37.0	3300	1.00	5308.70	13.48
8	23.0	40.0	2900	1.50	5301.50	26.91
9	23.0	45.0	3100	0.75	5296.20	18.68