Optimization of Post-CMP Cleaning Process for LAO Wafers Using Grey Relational Analysis

MING FU YANG,MIN LIN HUANG ,MING JONG TSAI

Graduate Institute of Automation and Control, National Taiwan University of Science and Technology, Taipei, Taiwan

E-MAIL: M9812101@mail.ntust.edu.tw_M9912003@mail.ntust.edu.tw_mjtsai@mail.ntust.edu.tw

Abstract- It is an important topic for green industry development with light emitting diode technology. This study focused on the efficient cleaning for LAO hydrolysis material substrate. The 99.5% ethanol or an alternative solution is used to clean the substrate and dry with the help of anhydrous gas. To improve the cleaning performance, we employ the Taguchi method of experimental planning analysis and the Grey Relation Analysis to optimize the parameters for minimizing the residual traces of impurities and water, mark after completing the new water cleaning process for LAO substrate. With the new cleaning process the surface foreign matter removal rate of target 80% and the residual water marks of under 20% are achieved.

Keywords-lithium aluminium oxide (LAO) , Grey Relation Analysis (GRA),hydrolytic material substrate, chemical mechanical polishing

I. INTRODUCTION

The main material of GaN blue LED in the United States before the advent of the 1950s, experienced several years to truly become a production-ready technology [1]. Because the aluminum lithium ($LiAlO2$: LAO) is similar to GaN structure, it is expected to become the new light-emitting diodes advantage substrate[2].

There are wet cleaning and dry cleaning modes after CMP(chemical mechanical polishing). The cleaning part for LED substrate has been developed a number of ways. However, the majority is still relied on wet cleaning process, and removal of particles has been attracted of a lot of attentions in the post-CMP cleaning process. There are more and more people become involved in this researches[3][4]. Small size particles, such as micron size, can be ignored. However, the large size of the force becomes impossible to ignore, such as van der Waals forces that is in the small size with a huge impact. The particles, immersed in liquids, may be due to charged particles and liquid molecular dissociation of charged ions , which may produce an Electrical Double Layer(EDL) effects[5][6].

The CMP is using mechanical grinding and chemical etching to join the pharmaceutical method. The wafer achieves the comprehensive flattening in chemical and mechanical of purpose. Three major affected elements are Slurry, Wafer, and the Polishing Pad of CMP in the reaction focus as shown in figure1. [7]

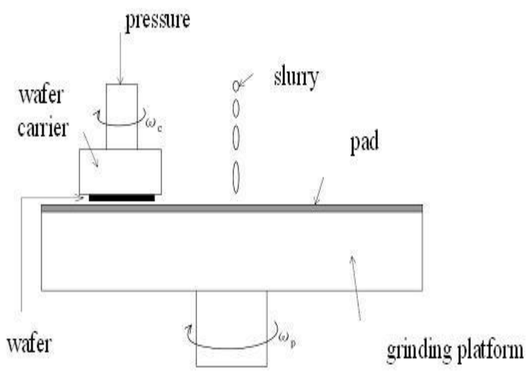

Fig.1 rotary grinding machine [7]

The purpose of cleaning the wafer is not damage or degraded under the premise of the wafer surface. The wafer surface is attached to remove dust and impurities. It is required to effectively remove all types of surface contaminants in the cleaning process of a silicon wafer, and the silicon or silica does not etch or damage on surface. Therefore, high-purity volatile chemicals are used to clean such a substrate.

II. CLEANING PROCESS OF LAO

After a LAO substrate is polished and removed from the template, there is residual slurry status in the front or back of the LAO substrate shown in Figure 2. First, the most effective method for removing residue is to use 99.5% ethanol and PVA sponge to scrub the surface. The wash conditions are described as follows: (1) scrubing time: the need to control in 40 to 80 seconds. (2) scrubing order: first the back, then front (the front must be rotated 90°and repeated twice).

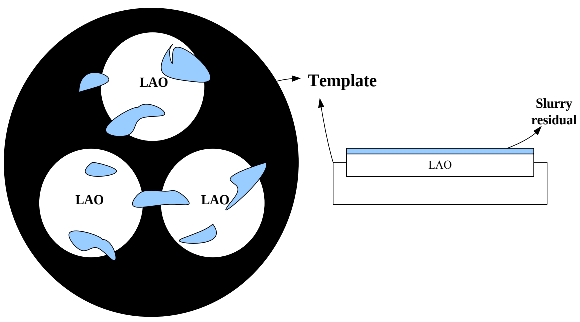

Fig.2 Polished Slurry residue

III. THE LEVEL OF PROCESS PARAMETERS

In this paper, power foreign matter removal rate and residual rate of water marks are main concerned qualities of optimization places. Four main parameters affecting foreign matter removal rate and residual rate of water marks are cleaning time, soaking time, PVA sponge type and drying method.

Symbol A is the cleaning time. This study assigned the value of 40s to level 1, 60s to level 2, and 80s to level 3. Symbol B is the soaking time. So this study assigned the value of 30s to level 1, 60s to level 2, and 90s to level 3. Symbol C is the PVA sponge species. This study assigned the value of PVA sponge towel to level 1, PVA sponge with high density to level 2, and PVA sponge roller to level 3. Symbol D is the drying methods. This study assigned the value of air dry(5~8s) to level 1, Soaked in IPA + dry air (5~8s) to level 2, and lens-cleaning tissue(3~5s) to level 3. This study examines four input parameters to obtain multiple quality characteristics. This paper conducted nine experiments to assess the significance of these factors using GRA of multiple quality characteristics. Table 1 shows the level of process parameters.

Table1.LAO washing method level of process parameters

factor	explain	Level 1	Level 2	Level 3
A	cleaning time(sec)	40	60	80
B	soaking time(sec)	30	60	90
C	PVA sponge type	PVA sponge towel	PVA sponge with high density	PVA sponge roller
D	drying method	air dry (5~8sec)	Soaked in IPA + dry air (5~8sec)	lens-cleaning tissue (3~5sec)

IV. GREY RELATIONAL ANALYSIS(GRA)

It is obvious that GRA utilizes mathematical methods to analyse correlations between series data comprising a grey relational system, and thereby determine the difference in contribution between a reference series and each compared series. The compared series are alternative vectors created from sets based on attribute characteristics, which might be the larger-the-better and the smaller-the-better, or optimization of specific values between the desired maximum and minimum values of each attribute. Applying a GRA algorithm can rank different alternatives by determining their grey relational grades. The grey relational grades of different series can be used to rank various alternatives, where higher values indicate superior alternatives as Lu and Wevers [8] described.

A. Data Pre-Processing

Data pre-processing is the first step in the procedure for using GRA. Data pre-processing involves transforming an original sequence into a comparable sequence. Experimental results are thus normalized in a range of 0–1. Equation (1) shows the calculations for the larger-the-better case, equation (2) shows those for the smaller-the-better case, and equation (3) shows those for the case in which a definite target value must be achieved as You et al. [9],

$$x_i^*(k)=\frac{x_i^{(0)}(k)-\min\limits_{all(i)}\cdot x_i^{(0)}(k)}{\max\limits_{all(i)}\cdot x_i^{(0)}(k)-\min\limits_{all(i)}\cdot x_i^{(0)}(k)} \quad (1)$$

$$x_i^*(k)=\frac{\max\limits_{all(i)}\cdot x_i^{(0)}(k)-\cdot x_i^{(0)}(k)}{\max\limits_{all(i)}\cdot x_i^{(0)}(k)-\min\limits_{all(i)}\cdot x_i^{(0)}(k)} \quad (2)$$

$$x_i^*(k)=1-\frac{\left|x_i^{(0)}(k)-OB\right|}{\max\limits_{all(i)}\cdot\{O_1,O_2\}} \quad (3)$$

where $x_i^*(k)$ is the i th grey datum following grey generation for experiment k, $x_i^{(0)}(k)$ is the original i th quality datum of experiment k, $\max\limits_{all(i)}\cdot x_i^{(0)}(k)$ is the maximum value in original sequence, $\min\limits_{all(i)}\cdot x_i^{(0)}(k)$ is the minimum value in the original sequence, OB is the target value, $O_1=\max\limits_{all(i)}\cdot x_i^{(0)}(k)-OB$, and $O_2=OB-\min\limits_{all(i)}\cdot x_i^{(0)}(k)$.

Table2. Experimental results of control factors and multiple performance data.

					Quality1(%)	Quality2(%)
	A	B	C	D	$X_i^0(1)$	$X_i^0(2)$
reference					99.07	0.2
Exp.1	1	1	1	1	84.89	7.8
Exp.2	1	2	2	2	98.13	0.8
Exp.3	1	3	3	3	97.77	0.7
Exp.4	2	1	2	3	85.82	7.4
Exp.5	2	2	3	1	90.30	4.6
Exp.6	2	3	1	2	96.08	1.8
Exp.7	3	1	3	2	79.67	10.6
Exp.8	3	2	1	3	99.07	0.2
Exp.9	3	3	2	1	92.16	3.9

Quality1: foreign matter removal rate (%), larger-the-better
Quality2: residual rate of water marks (%), smaller-the-better

In this investigation, the larger-the-better case is selected for the quality characteristic of foreign matter removal rate and the smaller-the-better case is selected for the quality characteristic of residual rate of water marks. This study conducted nine experiments in which LAO washing ways were packaged using different parameters. Table 1 lists the control factors and their levels. Table 2 describes the parameter combination of the nine experiments and the values of multiple quality characteristics.

B. Grey Relational Coefficient and Grey Relational Grade

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between an ideal and an actual normalized experimental result. Initially, the deviation sequence of the reference sequence is calculated using equation (4). The grey relational coefficients were obtained to integrate the values obtained from equation (5) and from equation (6) into equation (7).[9]

$$\Delta_{oi}(k) = \left\| x_0^*(k) - x_i^*(k) \right\| \quad (4)$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left\| x_0^*(k) - x_j^*(k) \right\| \quad (5)$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left\| x_0^*(k) - x_j^*(k) \right\| \quad (6)$$

$$\xi_i(k) = \frac{\Delta_{\min} + \xi \cdot \Delta_{\max}}{\Delta_{0i}(k) + \xi \cdot \Delta_{\max}} \quad (7)$$

Where $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $x_0^*(k)$, $x_i^*(k)$ is the comparability sequence, and ξ is the distinguishing or identification coefficient ($\xi \in [0,1]$). The calculated grey coefficient is employed by choosing $\xi = 0.5$, which is generally adopted in most studies. Following acquisition of the grey relational coefficient, equation (8) is used to derive the grey relational grade γ_i by taking the average of the grey relational coefficients or applying the different weight to both qualities under investigation. [10-11]

$$\gamma_i = \sum_{k=1}^{n} \xi_i * \beta(k) \quad (8)$$

Where γ_i is the i th grey relational grade of each experiment obtained by taking the grey relational coefficients, n is the quality number and β is the weighty factor for each quality.

The grey relational grade, as depicted in Table 4, shows the important relationships among the sequences and indicates their degree of influence.

Table3.The deviation sequence of the reference sequence

	$X_i^*(1)$	$X_i^*(2)$	△0i(1)	△0i(2)
reference	1	1		
Exp.1	0.2691	0.2692	0.7309	0.7308
Exp.2	0.9515	0.9423	0.0485	0.0577
Exp.3	0.9330	0.9519	0.0670	0.0481
Exp.4	0.3170	0.3077	0.6830	0.6923
Exp.5	0.5479	0.5769	0.4521	0.4231
Exp.6	0.8459	0.8462	0.1541	0.1538
Exp.7	0.0000	0.0000	1.0000	1.0000
Exp.8	1.0000	1.0000	0.0000	0.0000
Exp.9	0.6438	0.6442	0.3562	0.3558

Table4. Calculated grey relational coefficients (weighting) and grey relational grade

	δ=0.5			
	$\gamma(x_i(1))$	$\gamma(x_i(2))$	Grey rational grade	GRA order
reference	60%	40%		
Exp.1	0.4062	0.4063	0.4062	8
Exp.2	0.9117	0.8966	0.9056	2
Exp.3	0.8818	0.9123	0.8940	3
Exp.4	0.4227	0.4194	0.4213	7
Exp.5	0.5252	0.5417	0.5318	6
Exp.6	0.7644	0.7647	0.7645	4
Exp.7	0.3333	0.3333	0.3333	9
Exp.8	1.0000	1.0000	1.0000	1
Exp.9	0.5840	0.5843	0.5841	5

*Identification coefficient δ = 0.5
* Weight ratio $\beta_1 = 0.6$, $\beta_2 = 0.4$

V. EXPERIMENTAL RESULTS AND DISCUSSIONS

This study is focused on multiple characteristics of LAO washing method process. GRA is applied to determine the optimal factor level conditions. Table 2 lists the performance characteristics of the foreign matter removal rate and residual rate of water marks with different processing parameters. The smaller-the-better case for the foreign matter removal rate and residual rate of water marks are desirable in terms of quality characteristics with the deviation sequence of the reference sequence in table3. In total, nine experiments were conducted to identify the four important input control parameters and to normalize the data of the two quality characteristics. Notably, GRA mathematical conversion enables limited experiments to obtain comparable coefficients and grades. The grey relational grade can be used to determine the optimal combination of control factors and to determine the effective contribution of each experimental factor.

The grey relational grade for each factor level was derived from the factor levels (Table 2), which are related to the grey relational grades (Table 4). The grey relational grade of each factor level is calculated as the average for the same level in each column; the grey relational grades are shown in intersecting rows.

According to the GRA results in Table 4, the processing parameter setting from the eighth experiment has the highest grey relational grade. It indicates that the best multiple performance characteristics were obtained with the combination of A1B2C1D3 for the nine experiments presented in Table 5.Figure 3 and Table 5 lists the average grey relational grade for each factor level and its grey relational grade. Since grey relational grades represent the correlation between the reference and comparable sequences, a large grey relational grade means the comparability sequence is closely correlated with the reference sequence. This investigation selects the level that provides the largest average response. Furthermore, these optimal parameters with their levels A1, B2, C1 and D3 list the highest grey relational grade for factors A, B, C and D respectively. Thus, A1B2C1D3 comprises the optimal parameter combination for the LAO washing process. This optimal parameter combination is cleaning time of 40s, soaking time of 60s, PVA sponge species of PVA sponge towel, drying methods of lens-cleaning tissue. Part images of a LAO wafer are shown in Fig4 (before cleaning) and in Fig5 (after cleaning).

Table5. Response table for the grey relational grade

Level effect	A	B	C	D
Level 1	**0.7353***	0.3870	**0.7236***	0.5074
Level 2	0.5725	**0.8125***	0.6370	0.6678
Level 3	0.6391	0.7475	0.5864	**0.7718***
Optimal level	A1	B2	C1	D3
	40sec	60sec	PVA sponge towel	lens-cleaning tissue

- Optimal level.

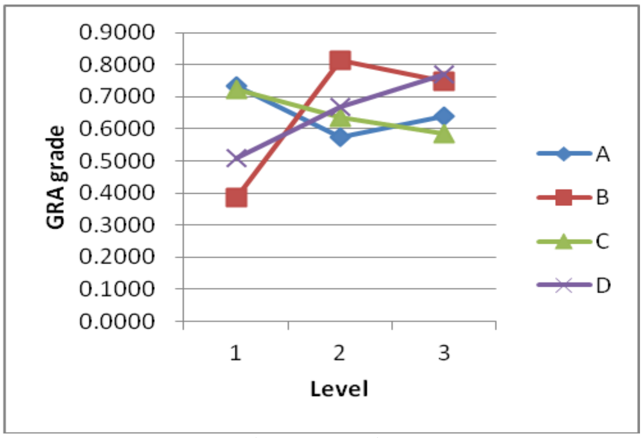

Fig.3 GRA grade

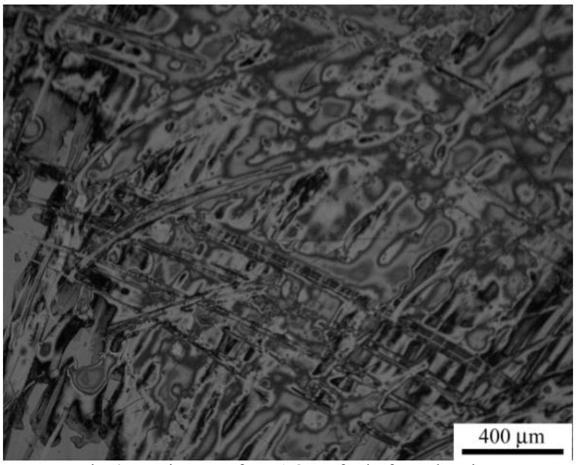

Fig.4 Part image of a LAO wafer before cleaning

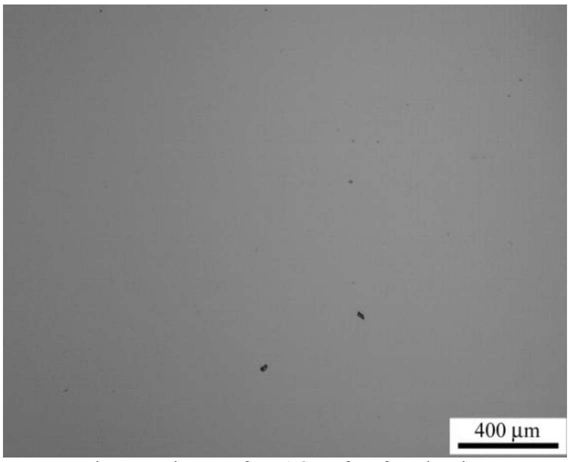

Fig5. Part image of a LAO wafer after cleaning

VI. Conclusions

In LAO hydrolysis material substrate, the foreign matter removal rate may affect the cleaning process. For the analytical data generated by the nine experiments using four processes of control factors (cleaning time, soaking time, PVA sponge type, drying method), GRA obtained the grade distribution and verified the post-CMP cleaning process parameters that demonstrated optimal performance characteristics (foreign matter removal rate and residual rate of water marks) . By employing GRA, the contribution of each factor was weighted according to its importance. One additional experiment using the optimal parameters was also performed to confirm the effects of different parameters. The new cleaning process parameters were obtained successful.

REFERENCES

[1] Jane Zhao Yan, “a high uniformity of LED lighting design and production aids, Tatung University, Mechanical Engineering 2008,

[2] Yang Chiou Jung, wafer-level packaging of the LED, Da-Yeh University, Electrical Engineering, 2007.

[3] G. Zhang, G. Burdick, F. Dai, T. Bibby, S. Beaudoin, “Assessment of Post-CMP Cleaning Mechanisms Using Statistically-Designed Experiments,” Thin Solid Films, 332, pp. 379-384, 1998.

[4] H. C. Wang, "Effects of Inceptive Motion on Particle Detachment from Surfaces," Aerosol Science and Technology 13, pp. 386-393, 1990.

[5] F. Zhang, A. Busnaina, "Submicron Particle Removal in Post-Oxide Chemical-Mechanical Planarization (CMP) Cleaning," Applied physics. A 69, pp. 437-440, 1999.

[6] A. A. Busnaina, H. Lin, N. Moumen, J. W. Feng, J. Taylor, "Particle Adhesion and Removal Mechanisms in Post-CMP Cleaning Processes," IEEE Transactions on Semiconductor Manufacturing. Vol. 15, No. 4, november 2002.

[7] Kenneth W. Tobin, Jr., Thomas P. Karnowski, Fred Lakhani, "Integrated Applications of Inspection Data in the Semiconductor Manufacturing Environment,"SPIE, Metrology-based Control for Micro-Manufacturing, Vol. 4275.

[8]M. Lu, and K. Wevers, Grey system theory and applications: a way forward, J Grey Syst, 10(1), 47-54, 2007.

[9]M. L. You, C. W. Wang, and C. K. Yeh, The development of completed grey relational analysis toolbox via Matlab, J Grey Syst, 9(1), 57-64. 2006.

[10] C.H. Li, Ming-Jong Tsai, "Multi-objective Optimization of Laser Cutting of Special Shape Flash Memory Modules using Grey Relational Analysis", Optics and Laser Technology, 41 (5), pp. 634-642, July, 2009.

[11]Ming-Jong Tsai, Chen-Hao Li, "The use of grey relational analysis to determine laser cutting parameters for QFN packages with multiple performance characteristics", Optics and Laser Technology, 41 (8), pp. 914-921, Nov. 2009.