Manufacturing Analysis on Planarization of Hydrolysis Material Wafers

Chao-Chang A. Chen[1], Ping-Shen Chou[2], Chi-Hsiang Hsieh[3], Ming-Hui Fang[4], Yan-De Lin[5]

[1,2,3]Department of Mechanical Engineering, National Taiwan University of Science and Technology

43, Sec.4 Keelung Rd., Taipei, 106, Taiwan

[4,5]Crystalwise Technology Inc., Hsinchu, Taiwan

[1]artchen@mail.ntust.edu.tw, [2]M9903244@mail.ntust.edu.tw, [3]M9803204@mail.ntust.edu.tw

Abstract - Hydrolysis material substrates mainly include single crystal sodium chloride, potassium dihydrogen phosphate (KH2PO4, KDP) and lithium aluminum (LiAlO2, LAO). The LAO substrate can be potentially a novel high brightness LED substrate due to its percentage of the lattice mismatch with gallium nitride (GaN) epitaxial layer as only 1.4%. The challenges of LAO substrate planarization and polishing process is to control the hydrolysis phenomenon during process and surface non-uniformity (N.U.). Currently controlling the LAO polishing process usually depends on empirical methodology. This paper is to develope a manufacturing analysis method based on feedback control theorem that can be adopted to construct system modeling of LAO substrate polishing processes. Temperature effects of LAO polishing is an testing case for verifying the developed process. Experimental results show that the increase of temperature can achieve higher material removal rate but lower surface uniformity. Compromise of the temperature effect needs to be solved by such modeling methodology. Results of this study can further applied for LAO production line development.

Keywords - Hydrolysis material substrate, LAO polishing, LED Substrates.

I. INTRODUCTION

The high brightness light emitting diode (HB-LED) industry currently is adopted the sapphire materials as substrate materials. An alternative substrate material, the lithium aluminum (LAO) is one of the promising candidate that can potentially replace sapphire wafer substrates due to its 1.4% lattice mismatch with the GaN or ZnO. Therefore, the GaN epitaxial layer can be even directly deposited without buffer layer [1]. Challenge of the LAO substrate polishing process is the requirement of surface non-uniformity lower than 1% and that the hydrolysis characteristic of LAO substrate inducing unstable polishing process [2-3]. The degree of hydrolysis situation also varies with polishing time and conditions [4].

The LAO polishing process usually depends on empirical methodology, the control model becomes an important issue of investigation. This paper is to establish a feedback control process model of LAO polishing by manufacturing analysis method (MAM) and experimental analysis. As shown in Fig.1, there are four steps in MAM, step one is to define the process taxonomy, step two is to classify the effect of process parameters, the process model can be established in step three, and step four is to develop the model analysis and control. The model can further apply to find the optimal LAO polishing process and to control the process stability.

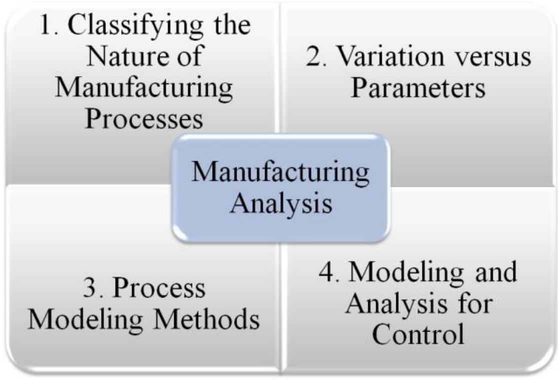


Fig.1 Manufacturing analysis method (MAM)

II. PROCESS MODEL DEFINITION

The LAO polishing process can be defined by the process taxonomy of manufacturing analysis method (MAM) [5]. The process taxonomy includes serial interaction and parallel interaction, as shown in Fig.2, the serial interaction can be defined as the area of applied transformation energy including mechanical, thermal, chemical and electrical energy. Usually the engaged area of working energy is much less than the total area of work piece. Conversely, the parallel interaction is the engaged area of applied energy almost the same as the total area of the workpiece. Following the process taxonomy, LAO polishing process can be classified as shown in Fig.3.

The feedback control process model shown in Fig.4 is to analyze the effect of energy input and process parameters. The process parameters (α) including equipment properties (e_p), equipment states (e_s), material properties (m_p) and material states (m_s), are shown in Table 1. The e_p includes the characteristics of polishing machine and other consumables like pad hardness, slurry pH value, and others. The e_s includes operation parameters like polishing plate speed, down force, temperature, slurry flow rate, and others. The m_p is the initial property of the specimen like wafer thickness, hardness, and others. The m_s includes two parts, one is the initial energy state of specimen, like surface roughness, temperature, and et cetera, another is the energy state between material and equipments like friction force between material and pad, and et cetera. For optimal results, the variation equation is utilized to control the process stability as shown in following:

$$\Delta Y = \frac{\partial y}{\partial \alpha}\Delta\alpha + \frac{\partial y}{\partial \upsilon}\Delta\upsilon \qquad (1)$$

where ΔY is variation, $\partial\alpha$ is disturbance, Δυ is control inputs, $\partial y/\partial\alpha$ is disturbance sensitivity, and $\partial y/\partial\upsilon$ is control sensitivity.

From Equation (1), the way to obtain statistical process control is to hold υ fixed (Δυ=0) and minimize disturbances ($\Delta\alpha \rightarrow \Delta\alpha_{min}$). For process optimization, holding υ (Δυ=0) and minimize the disturbance sensitivity term can be performed. By compensating disturbances and manipulating control inputs, the goal of feedback control of LAO polishing process can then be achieved.

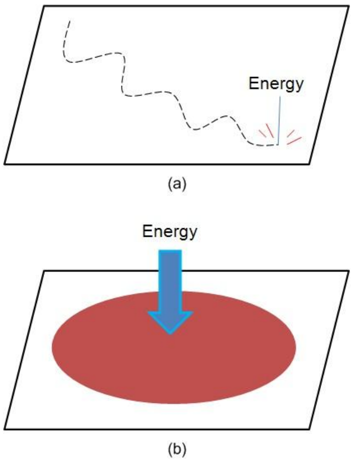


Fig.2 Schematics of process taxonomy (a)serial interaction (b)parallel interaction[5]

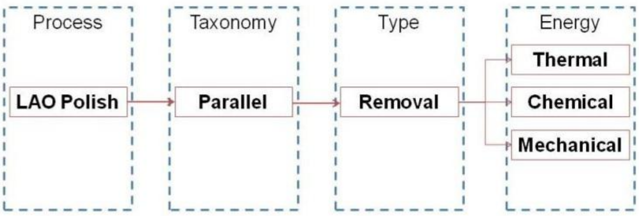


Fig.3 Classification of LAO polishing process

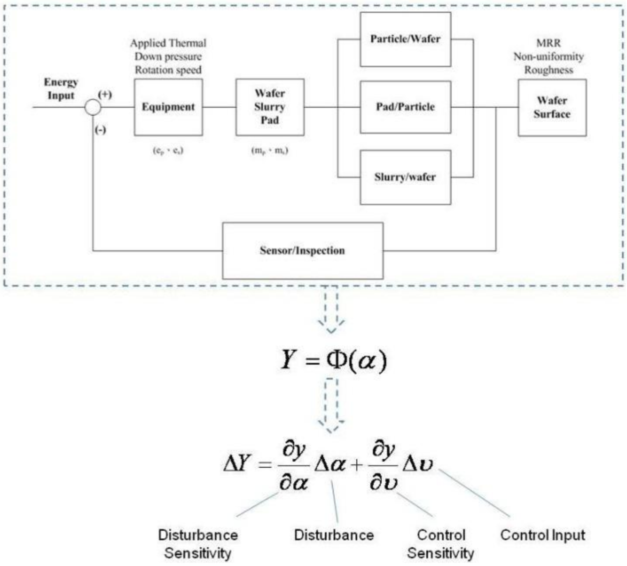


Fig.4 LAO polishing process model

TABLE 1 PROCESS PARAMETERS IN LAO POLISHING

Sign	Definition	Parameters
e_p	Equipment property	Machine Stiffness, Hardness of pad, Groove shape of pad, Type of slurry, Chemical additive, pH value of slurry, Size of abrasive particle
e_s	Equipment state	Polishing plate speed, Slurry flow rate, Temperature of slurry, Down force
m_p	Material property	Hardness of LAO wafer, Stiffness of LAO wafer, Hydrolysis situation of LAO wafer
m_s	Material state	Surface roughness of LAO wafer, Temperature of LAO wafer, Shear stress between LAO wafer and pad

III. EXPERIMENTAL SETUP

A Logitech PM-5 polishing machine has been utilized for setup of LAO polishing process. Polishing pad applied on the process is SUBA800. A M-type slurry which provide by a local supplier contains colloidal silica, GC, surfactants and pH 10 chemicals. In the polishing process, the rotational speed and down pressure loaded on the wafer were set as 70 rpm and on 3 psi. The slurry feed rate was 30 ml/min and the polishing time was 90 min. The as-lapped LAO wafer used in the experiment is (100) orientation with double side lapped provided a local supplier. The slurry temperature were controlled from room temperature 25˚C , 50˚C to 70˚C respectively. After polishing process, the material removal rate (MRR) has been calculated by weight loss of the LAO wafers. Atomic force microscope (AFM) is used to investigate the wafer surface roughness after polishing process with different temperature of slurries. The surface non-uniformity (NU.) was measured and the optimal LAO operating region can be verified via the process model and experimental results.

IV. RESULTS AND DISCUSSIONS

Fig.5 shows the MRR results of LAO polishing with different slurry temperature. The material removal rate reaches 47.44 nm/min at 25℃, 63.68 nm/min at 50℃ and 71.9 nm/min at 70℃, respectively. Because the thermal effect enhances chemical react between slurry and LAO wafer, the MRR is proportional to the slurry temperature. However, the non-uniformity of wafer surface increases when the slurry temperature adjusts to 50℃ and 70℃ as shown in Fig.6. However, the spec form of mass production requirement, N.U. needs to be controlled under 1%. As comprised with MRR and N.U. results, the suitable slurry temperature is around 50℃ to 55℃ as shown in Fig.7. Optical microscope is used to observe LAO wafer surface after polishing process. Five positions on each piece are taken to examine the hydrolysis phenomenon. Fig. 8 shows wafer surface state after LAO polishing process with different slurry temperature. There are some defect spots at the center or the edge of LAO substrate surface, but the amount of defect spot does not proportional to slurry temperature. Therefore, some parameters of polishing parameters are necessary to adjust for removing the damage layer, and some chemical additives needed to suppress the hydrolysis situation that may occur in polishing process based on our manufacturing process model and observation.

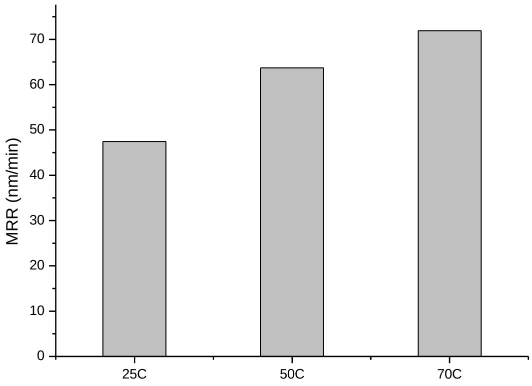
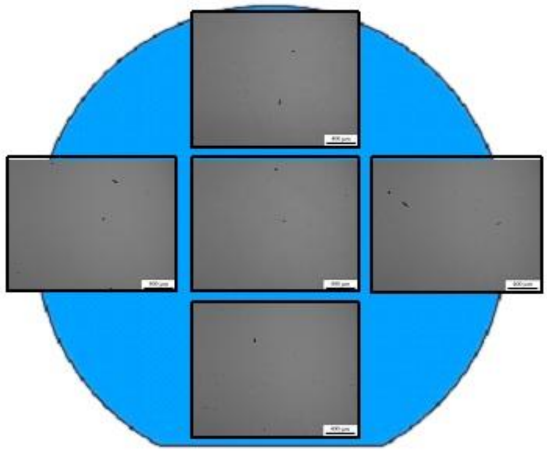


Fig.5 Relationship between slurry temperature and MRR



(a)

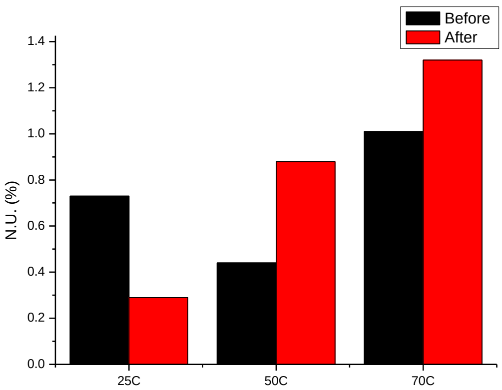
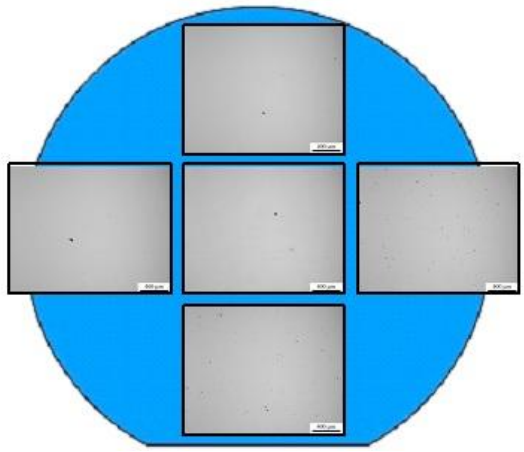


Fig.6 Relationship between slurry temperature and non-uniformity



(b)

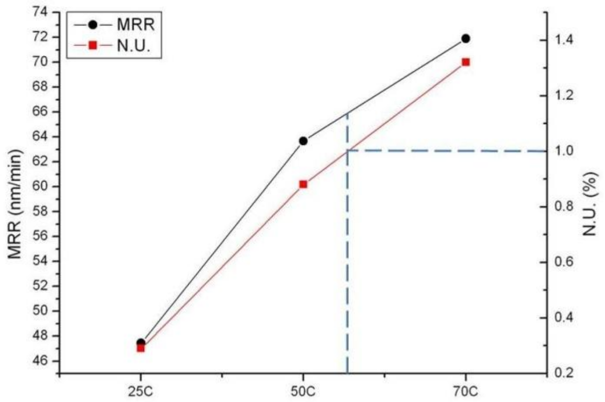
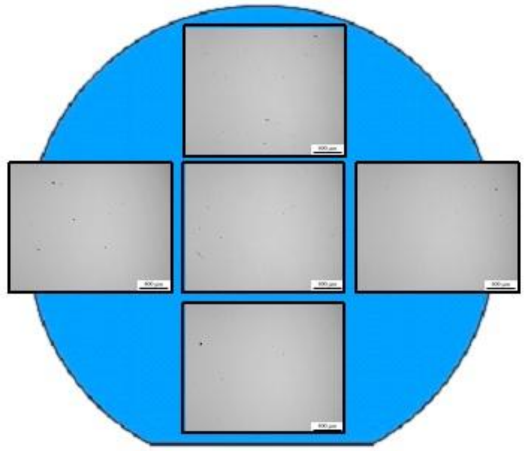


Fig.7 Suitable slurry temperature control region



(c)

Fig.8 Surface inspection after LAO polishing with slurry temperature (a)25˚C (b)50˚C (c)70˚C

V. SUMMARY

In this paper, the LAO polishing feedback control process model has been established by manufacturing analysis method. Temperature effects have been observed from experimental results. The variation equation has been utilized to define the relationship between disturbance, disturbance sensitivity, control input and control sensitivity. LAO polishing experiment is to verify the feasibility of the control model. Through the experiment, slurry temperature can be regarded as energy input, and the wafer surface including material removal rate and non-uniformity can be regarded as output. Experimental results show that higher slurry temperature can cause higher material removal rate (MRR), but the surface uniformity may decrease as increasing the slurry temperature. Based on the specification of NU, suitable slurry temperature could be controlled between 50℃ and 55℃ for obtaining the higher MRR. From results observed by the optical microscope, the hydrolysis phenomenon which occurred on wafer surface after polishing process can be detected. Therefore, some conclusion can be drawn from above results. The polishing temperature control is very critical for current set-up of chemical-mechanical polishing (CMP) of LAO wafers. Results have shown a significant improvement of LAO polishing performance and it can further applied to achieve higher efficiency of removal rate as well as the non-uniformity from the further closed-loop control on manufacturing process model.

ACKNOWLEDGMENT

The authors would appreciate for the National Science Council (NSC), Taiwan for providing the financial support to this study under grant number NSC 99-2622-E-011-010-CC2.

REFERENCES

[1] Mitch M.C. Chou, Pei Chun Taso, Hul Chun Huang, "Study on Czochralski growth and defect of LiAlO2 single crystals", Journal of Crystal Growth 292, 542-545, (2006).

[2] Jun Zou, Yaming Dong, Shengming Zhou, Yang Sun, Wang Jun, Jianhua Zhou, Taohua Huang, Shubai Yang, Haiqing Zhou, "Study on the hydrolytic property and thermal stability of LiAlo2 substrate", Journal of Crystal Growth 294, 339-342, (2006).

[3] Chao-Chang A. Chen, Ming-Hui Fang, Yan-De Lin, Yu-Lung Jeng, Josh Ma, Wu-Chi Tsai, Chun-Yen Lin, "CMP of LiAlO2 Substrates, Proc. of International Conference on Planarization/CMP Technology", 1251-1256, (2008).

[4] Hui Lin, Shengming Zhou, Hao Teng, Tingting Jia, Xiaorui Hou, Shulin Gu, Shunming Zhu, Zili Xie, Ping Han, Rong Zhang, "Polishing of (1 0 0) γ-LiAlO2 wafer and its effect on the epitaxial growth of ZnO films by MOCVD", Journal of Alloys and Compounds, 479, L8-L10, (2009).

[5] David E. Hardt, Manufacturing processes and process control, Reading, MIT, Cambridge MA, (2004).

[6] Chao-Chang A. Chen, Jr-Rung Chen, Yuan-Chieh Cheng, Wei-Yao Hsu, David Lee Butler, "Modeling and Machining Error Compensation for B-axis Single Point Diamond Cutting", Proceedings of 4th CIRP International Conference on High Performance Cutting, (2010).

[7] Chao-Chang A. Chen, Ming-Hui Fang, "Compassion of Voltage Control Mode and Current Control Mode for AF-ECMP of Copper", Proc. of The Electrochemical Society, (2010).

[8] C-C. A. Chen, Chi-Hsiang Hsieh, "Effect of Inhibiter Concentration on Cu CMP Slurry Analyzed by a Cu-ECMP System", Proc. of The Electrochemical Society, (2010).