한국기계가공학회지, 제18권, 제7호, pp.56～62(2019.07) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 18, No. 7, pp.56~62(2019.07) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2019.18.7.056

A Study on the Process Simulation Analysis of the High Precision Laser Scriber

Hyun-Jin Choi*,#, Kee-Jin Park*
*Daegu Mechatronics & Materials Institute

고정밀 레이저 스크라이버 장비의 공정 시뮬레이션 분석에 관한 연구

최현진*,#, 박기진*
*대구기계부품연구원

(Received 3 June 2019; received in revised form 24 June 2019; accepted 6 July 2019)

ABSTRACT

The high-precision laser scriber carries out scribing alumina ceramic substrates for manufacturing ultra-small chip resistors. The ceramic substrates are loaded, aligned, scribed, transferred, and unloaded. The entire process is fully automated, thereby minimizing the scribing cycle time of the ceramic substrates and improving the throughput. The scriber consists of the laser optical system, pick-up module of ceramic substrates, pre-alignment module, TH axis drive work table, automation module for substrate loading / unloading, and high-speed scribing control S/W. The loader / unloader unit, which has the greatest influence on the scribing cycle time of the substrates, carries the substrates to the work table that carries out the cutting line work by driving the X and Y axes as well as by adsorbing the ceramic substrates. The loader / unloader unit consists of the magazine up / down part, X-axis drive part for conveying the substrates to the left and right direction, and the vision part for detecting the edge of the substrate for the primary pre-alignment of the substrates. In this paper, the laser scribing machining simulation is performed by applying the instrument mechanism of each component module. Through this study, the scribing machining process is first verified by analyzing the process operation and work area of each module in advance. In addition, the scribing machining process is optimized by comparing and analyzing the scribing cycle time of one ceramic substrate according to the alignment stage module speed.

Key Words : Laser Scriber(레이저 스크라이버), Process Simulation(공정 시뮬레이션), Ceramic Substrate (세라믹 기판), Cycle Time(사이클 타임), Full Automation(완전 자동화)

1. Introduction

The high-precision laser-scriber system performs scribing on alumina ceramic substrates in order to manufacture ultra-compact chip resistors. Various processes are involved in manufacturing ultra-compact chip resistors. After the primary conductor, resistor, and shield are printed, a groove is cut using a laser. The resistor shield is then printed, the top and bottom conductors are connected, and an anti-oxidation coating is formed. The scribing

---

Corresponding Author : knut21c@dmi.re.kr
Tel: +82-53-608-2031, Fax: +82-53-608-2079

process, which consists of the precise carving of 0.05 m grooves (with 0.4 mm pitch gaps at a thickness of 0.2 mm or less) on the front and rear surfaces of a ceramic substrate, has a significant impact on chip-resistance performance and quality. Ceramic-substrate scribing requires a horizontal, vertical, top, and bottom precision of ±10 ㎛ or less. Therefore, both high-precision equipment and the mass-production of scribing technology are required to achieve target performance and yields. The laser-scriber system performs loading, aligning, and scribing, as well as the transfer and unloading of the ceramic substrates. For this study, we attempted to improve the working yield by minimizing the scribing cycle time of the ceramic substrate through full automation of the entire process. In this study, we performed a scribing-process simulation by applying an operating mechanism to each component module of the laser-scriber system. We verified the scribing process in advance by estimating the workability and working area of each component module. Furthermore, we established a scribing process by comparing and analyzing the scribing cycle time for one ceramic substrate by the module speed in the alignment stage.[1-3] Fig. 1 shows the ultra-compact chip resistor manufactured using the scribed ceramic substrate.

2. Structure of Laser-Scriber System

The scriber system is composed of a laser optical module, a ceramic substrate pick-up module, and a pre-alignment module, The TH-axis drives the work table, substrate loading and unloading automation module, and the high-speed scribing-control software. The pick-up part includes the Z-axis driving unit, which can move the substrate up and down for loading and unloading, and the TH-axis driving unit, which can rotate the substrate clockwise and counterclockwise for pre-alignment. Both the magazine up–down unit and the substrate pick-up part contain magazines loaded with substrates to undergo scribing, and already scribed substrates in parallel, so that they can be adsorbed simultaneously. Thus, it can load and unload substrates in the magazine at the same time.

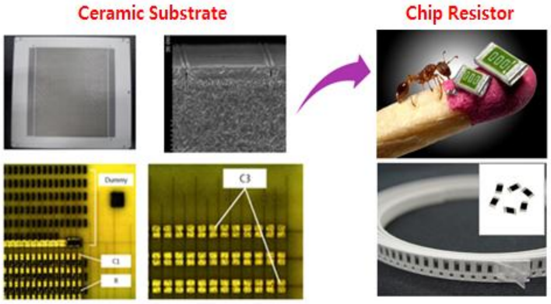

Fig. 1 The ultra-compact chip resistor

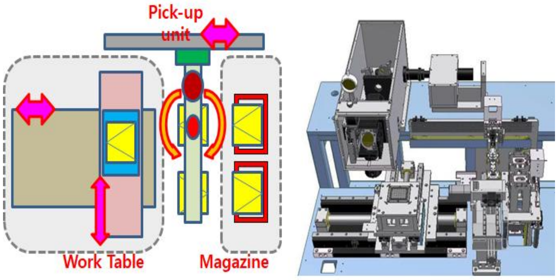

Fig. 2 Structure of laser-scriber system

The loader and unloader unit transfers substrates to the work table, which performs the scribing task while adsorbing the ceramic substrate and moving it along the X- and Y-axes. The loader and unloader unit is largely composed of the magazine up–down part, the X-axis driving part, which can transport the substrate to the left and right, and the vision part, which detects the edge of the substrate for primary pre-alignment. Fig. 2 shows the structure of the laser-scriber system.

3. Scriber System Driving Simulation

3.1 Purpose and scope of simulation

Fig. 3 shows 3D layouts of the laser-scriber system, as well as the analysis software, DELMIA V5 DPM ASSEMBLY, that were used for simulation analysis.[4] We simulated and analyzed problems with the workability through implementation of kinematics for the loading and unloading pick-up module, work table, alignment stage module, and the loading and unloading magazine module, which are the core driving modules of the laser-scriber system. Furthermore, we verified the laser-scribing work process of the alignment stage in advance through simulation and analysis of the cycle time. Fig. 3 shows a 3D layout of the laser-scriber system for simulation analysis.[5]

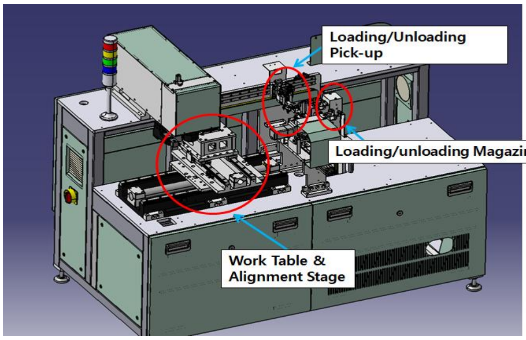

Fig. 3 3D layout model for simulation analysis

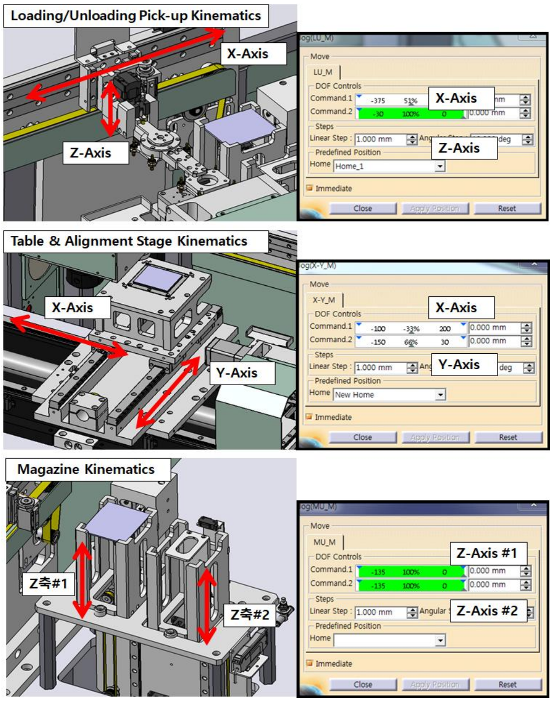

Fig. 4 Prismatic kinematics of simulation for each module

The loading and unloading pick-up module for ceramic substrates is driven by a double-axis, gantry-robot-type kinematic structure. The prismatic kinematic structure was defined for both X- and Z-axes. Fig. 4 shows the kinematic structure's application in the movement range of –375~120 mm along the X-axis, and –30~0 mm along the Z-axis. Furthermore, for the work table and alignment stage modules, the kinematic structure was applied in the movement range of –100~200 mm along the X-axis, and –150~30 mm on the Y-axis. The loading and unloading magazine module is belt-driving, and has a Z-axis up–down function. The two units have the same specifications, and the prismatic kinematics was defined for the movement range of –135~0 mm along the Z-axis.[6,7]

3.2 Verification of operating mechanism and workability analysis

We performed a simulation of the pick-up work of ceramic substrate on the magazine using the pick-up module. As shown in Fig. 5, we observed during the pick-up of the ceramic substrate that the module can safely touch the ceramic substrate without interfering with the magazine. Fig. 6 shows unloading of the ceramic substrate during the alignment stage module after the ceramic substrate is picked up. The simulation revealed that the gap between the pick-up module motor unit and the laser optical module is narrow—less than 1 mm—during the ceramic substrate unloading, and that no interference occurred. However, we decided that the module needed to be modified because collision by interference was expected in actual prototype driving. However, the gap between the laser optical module and ceramic substrate was approximately 6.5 mm, so we hypothesized that there would be no interference during the repeated movement along the X- and Y-axes of the stage.

3.3 Analysis of scribing process

The scribing task is performed in fixed intervals throughout the entire area of the ceramic substrate

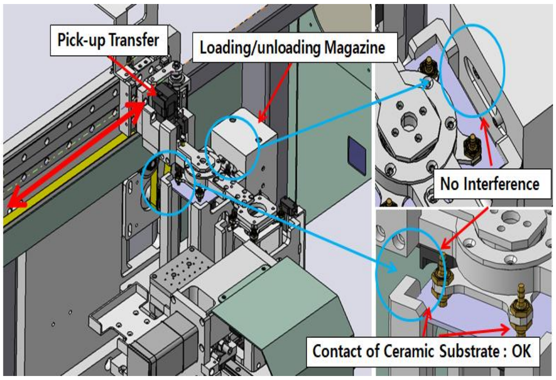

Fig. 5 Checking interference during pick-up of ceramic substrate

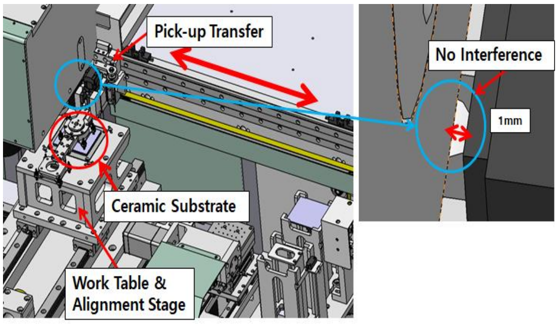

Fig. 6 Checking interference during ceramic substrate unloading work

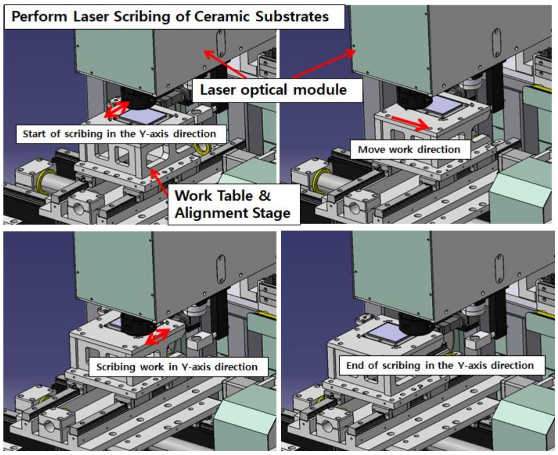

Fig. 7 Simulation of scribing work process

while the laser optical module is in a fixed state, and the alignment stage module moves quickly along the X- and Y-axes. As shown in Fig. 7, when laser scribing is performed along the Y-axis, the alignment stage module moves in a back-and-forth motion from the Y-axis edge, and finely moves along the X-axis at the same time. Therefore, the cycle time of the laser-scribing work process receives the largest effect from the transfer speed of the alignment stage module. The cycle time of the laser-scribing process was compared, according to the changing transfer speed of the alignment stage module, with the simulation input value.

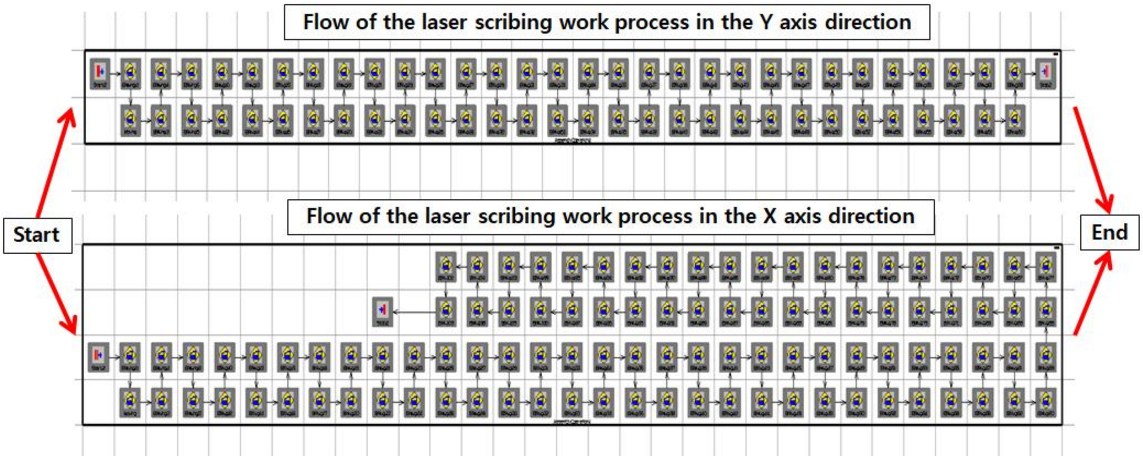

Fig. 8 Flow chart for laser-scribing process for ceramic substrate

For the transfer speed of the alignment stage module in the simulation analysis, the average value was applied by assuming the condition of uniform motion while excluding the effect of acceleration and deceleration.

substrate, as shown in Fig.8, 60 reciprocations on the Y-axis and 100 reciprocations on the X-axis were applied to the process flow chart.

Table 1 Total working time of scribing by feeding speed

No.	Case1	Case2	Case3
Alignment Stage module Feeding speed (mm/sec)	150	200	250
Max. speed (300mm/sec) : Application speed(%)	50%	67%	83%
Scribing cycle time of one ceramic substrate (sec)	187.6	140.5	112.4

In the process flow chart for the ceramic substrate laser scribing of the alignment stage module, conditions to define a detailed time table can be implemented. The time is defined by converting the transfer speed of the alignment stage module and the laser-scribing distance of the ceramic substrate, and the time value is input as property information in the time table.

The total process When three cases of transfer speed (150, 200, and 250 mm/s), were applied to each process, the total laser-scribing work times in Table 1. Thus, we estimated that the work time the were measured at 187.6, 140.5, and 112.4 s as For number of laser scribing for the ceramic shown can

Table 2 Comparative analysis of process cycle time by case

work procedure		#1	#2	#3			#4	Total (Time)
		Substrate edge inspection (corner)	Substrate edge inspection (extent)	Alignment Stage module Feeding speed			Inspection and unloading	
Description		Stage Transfer	Stage Transfer	Y-Axis Scribing	Stage Transfer	X-Axis Scribing	Stage Transfer	-
case 1	Speed (mm/sec)	150						-
	Time (sec)	6.7	5.3	60	0.67	103	12	187.67
case 2	Speed (mm/sec)	200						-
	Time (sec)	5	4	45	0.5	77	9	140.5
case 3	Speed (mm/sec)	250						-
	Time (sec)	4	3.2	36	0.4	61.6	7.2	112.4

Table 3 Second simulation result of cycle time by process

work procedure	#1	#2	#3			#4	Total (Time)
	Substrate edge inspection (corner)	Substrate edge inspection (extent)	Alignment Stage module Feeding speed			Inspection and unloading	
Description	Stage Transfer	Stage Transfer	Y-Axis Scribing	Stage Transfer	X-Axis Scribing	Stage Transfer	-
Speed (mm/sec)	250	250	180	250	180	250	-
Time (sec)	4	3.2	51	0.4	87.4	7.2	153.2

be shortened by up to 40% as the transfer speed increases. Table 2 shows the laser-scribing cycle time of one ceramic substrate, considering that the maximum allowable speed of the X- and Y-axes applied to the alignment stage is 300 mm/s.

In terms of minimizing the scribing cycle time for ceramic substrate for process productivity, the scribing yield is best when the transfer speed is 250 mm/s, which is 83% of the maximum allowable speed of the alignment stage module. However, a high scribing-process pitch precision of the substrate of below ±10 ㎛ is required in the field, currently. To consider the transfer safety factor, it is necessary to achieve both process productivity and precision by setting the scribing transfer speed of the X- and Y-axes that has the largest effect on the process precision to below 200 mm/s, and the transfer speed of the stage transfer process for inspection and release of ceramic substrate to 250 mm/s. Therefore, as shown in Table 3, the transfer speed conditions for the second process simulation was set to 250 mm/s for the substrate loading, unloading, and inspection sections, and to 180 mm/s for the scribing-process section. As a result of the second simulation, the scribing cycle time for one substrate was measured at 153.3 s.

4. Conclusion

In order to increase the working yield of the laser-scriber system, many have attempted to minimize the scribing cycle time of the ceramic substrate through full automation of all processes, including loading, alignment, scribing, transfer, and unloading of ceramic substrates. In this study, we simulated the scribing process by applying the operating mechanism of each component module to the laser-scriber system. We obtained the following conclusions.

1. The analysis of the process workability and working area of each component module of the laser-scriber system revealed that it was possible to safely contact the ceramic substrate without interfering with the magazine during the ceramic substrate pick-up, suggesting good workability. However, collision by interference is still expected in the prototype driving, as the gap between the motor unit of the pick-up and laser optical modules is very narrow (less than 1 mm). Therefore, modification of the module is required.
2. The scribing cycle time for one ceramic substrate was derived for different cases by applying the same transfer speed of the alignment stage module within the maximum allowable speed.
3. Considering the transfer safety factor and process precision, the transfer speed of the second process was set to 250 mm/s for the substrate loading, unloading, and inspection sections, and 180 mm/s for the scribing-process section. As a result, the scribing cycle time for one substrate was determined to be 153.3 s.
4. In the future, we plan to validate the simulation results by applying the same process to the driving of an actual laser-scriber system. We can then conduct a study to develop an automation-based interface software that can immediately apply the parameters of simulation to the system process.

Acknowledgement

“This study was performed as part of the global hidden champion technology development project (project no. S2570694) sponsored by the Ministry of SMEs and Startups. We would like to express our gratitude for the support.

REFERENCES

1. Kim, B. S., Jeong, S. H., "Production Simulation for Process Optimal Placement of Retainer

Automatic Sorting System", Proceedings of the KSMPE Autumn Conference, pp. 149, 2018.

2. Kuk, Y. H., Park, S. R., Park, K. J., and Choi, H. J., "A Study on Process Simulation Analysis of the Water Jet Cleaning Robot System for Micro Drill-bits", Transactions of the Society of CAD/CAM Engineers, Vol. 20, No. 3, pp. 291-297, 2015.
3. Park, K. J., Son, J. H., Cho, C. J., Kim, B. S., and Kim, N. H., "Development of the Heat Treatment Automation System for the Car-Body Mold", SAE Technical Paper, 2014-01-2010, 2014.
4. Park, K. J., Kim, Y. S., Kim and Yoon, S. H., "A study on the car-body mold heat treatment automation process based on the robot OLP simulation", Proceeding International Journal of Manufacturing Technology Engineers, 2013.
5. Ro, Y. S., Kang, H. J., and Suh, Y. S., "Development of a material handing automation simulation using a virtual AGV", CICS'06, pp. 563-566, 2006.
6. Kang, J. Y., Lee, H. C., and Um, I. S., "A Study for Design Optimization of an Automated Distribution Center using the Simulation and Metamodel", Journal of the Korea society for simulation, Vol. 15, No. 3, pp. 103-114, 2006.
7. Park, Y. K., Um, I. S. and Lee, H. C., "Design of Experiment and Analysis Method for the Integrated Logistics System Using Orthogonal Array", Journal of the Korea Academia - Industrial Cooperation Society, Vol. 12, No. 12, pp. 5622-5632, 2011.
8. Shin, H., Ryou, H. S., Ko, H. J., and Jung, Y. G., "The Evaluation of Machining Accuracy and the Machine Simulation for Parallel Kinematic Machine Tool(PKMT)", Journal of the Korean Society of Manufacturing Process Engineers, Vol. 8, No. 4, pp. 41-47, 2009.
9. Chun, C. U., Park, S. B. and Song, J. I., "Study on the Load Analysis in Accordance with the Contact Position between a High-Load Long-Pitch Roller Chain and Sprocket," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 16, No. 1, pp. 51-57, 2017.