CARBON REMOVAL OF MOLD SAMPLE BY FEMTOSECOND LASER

MOHAMAD AIZAT BIN ABU BAKAR

UNIVERSITI TEKNOLOGI MALAYSIA

CARBON REMOVAL OF MOLD SAMPLE BY FEMTOSECOND LASER

MOHAMAD AIZAT BIN ABU BAKAR

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Faculty of Science
Universiti Teknologi Malaysia

AUGUST 2018

For my supervisor and my family

ACKNOWLEDGEMENT

This thesis becomes a reality with the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

Foremost, I want to offer this endeavour to our God Almighty for the wisdom he bestowed upon me, the strength, peace of my mind and good health in order to finish this research. I would like to express my gratitude towards my family for the encouragement which helped me in completion of this paper. I am highly indebted Faculty of Science and Laser Center for their guidance and constant supervision as well as providing necessary information regarding this research and also for their support in completing this endeavour.

I would like to express my special gratitude and thanks to my adviser, Prof. Dr. Noriah Bidin and PM. Dr. Hazri Bakhtiar for imparting their knowledge and expertise in this study. My thanks and appreciation also go to my colleague and people who have helped me out with their abilities.

ABSTRACT

Clean mold tool is important in large scale production of high quality integrated circuit chip. Conventional mold tool cleaning techniques often involve chemicals as cleaning agent which is costly and polluting process hence light is suggested as a non-chemical agent alternative. High intensity light energy released in very short pulse duration can remove the contaminant particles from mold tool surface. Femtosecond laser of 1025 nm wavelength and pulse duration of 400 fs is utilized to remove carbon particle on chromium nitride surface. The effectiveness of carbon removal is determined by the comparison of surface imaging, elemental composition distribution and the surface roughness value of the mold tool surface condition before and after laser ablation at different powers and distances. The obtained result shows great carbon content removal of 75% and lowest induced damage percentage of 10% at laser power 1.7 W and ablation distance of 29.0 mm while highly preserving structure of the mold tool surface roughness value of 0.273 nm. Effective and precise carbon removal is achieved by using the optimum laser power and ablation distance onto target surface for laser cleaning on mold tool. The main advantage of this method is chemical free process and leading to a green technological innovation in mold tool cleaning industries.

ABSTRAK

Alat pembentuk yang bersih adalah penting dalam penghasilan cip litar bersepadu berkualiti tinggi pada skala besar-besaran. Teknik pembersihan alat pembentuk konvensional sering melibatkan penggunaan bahan kimia sebagai agen pembersih yang menelan kos tinggi dan merupakan proses yang mencemarkan justeru penggunaan cahaya sebagai agen pembersih adalah dicadangkan sebagai alternatif. Tenaga cahaya berkeamatan tinggi yang dibebaskan dalam tempoh denyut yang singkat mampu menyingkirkan zarah pencemar daripada permukaan alat pembentuk. Laser femtosaat dengan panjang gelombang 1025 nm dan durasi denyut 400 fs telah digunakan untuk menyingkirkan zarah karbon daripada permukaan kromium nitrida. Keberkesanan penyingkiran karbon ditentukan berdasarkan perbandingan pengimejan permukaan, taburan komposisi unsur dan nilai kekasaran permukaan alat pembersih sebelum dan selepas tembakan laser pada kuasa dan jarak yang berbeza. Hasil menunjukkan pengurangan kandungan karbon sebanyak 75% dan kerosakan susulan paling rendah sebanyak 10% pada kuasa laser 1.7 W dan jarak ablasi 29.0 mm di samping mengekalkan struktur nilai kekasaran permukaan alat pembentuk pada 0.273 nm. Penyingkiran karbon secara berkesan dan tepat telah dicapai pada kuasa laser dan jarak ablasi yang optimum ke atas permukaan sasaran untuk pembersihan alat pembentuk menggunakan laser. Kelebihan utama kaedah ini adalah merupakan proses yang bebas kimia dan menerajui ke arah inovasi teknologi hijau dalam industri pembersihan alat pembentuk.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Fast and effective cleaning process for mold tool is vital in large scale production of high quality integrated circuit (IC) packages. During mold transfer process, the ingredient of epoxy compound will gradually stain the mold tool after consecutive shots. The stain is submicron sized particles left from epoxy used to encapsulate the integrated circuit. The accumulated residue particles can cause defect on IC structure and reducing the packages reliability (Kharchenko, 2015).

Several cleaning techniques have been applied by industries such as dry ice pellet blasting, melamine compound cleaning and ultrasonic treatment (Johnson, 2007). These methods can remove the stain out of tool effectively but damaging the equipment and decreasing the overall equipment effectiveness (OEE) up to 15 % as estimated from Logic Segment, Infineon Industries. It also consumes a substantial amount of chemicals and generates chemical waste. Hence, there is need to introduce an effective and chemical free method to overcome this problem.

Laser has been first invented by Maiman in 1960. It becomes a game changer in recent science and technology era due to its unique properties and versatility. Laser technology is described as a solution in searching for a problem (Hect, 2005). From a pointer in classroom to advance outer space application, it is proven to be helpful in most application. The ability to deliver photon energy in short time become of interest especially in ablating target material for difference research discipline. Few researchers report the application of laser ablation in synthesizing nanoparticles (Zhang et al., 2017), art preservation (Senesi et al., 2016) and generating fusion energy (Azechi et al., 2016).

Laser has also been utilized in removing contaminant from solid surface. It is called laser cleaning method. The first commercial cleaning system by using laser technology for IC industry is reported in 2000 (Lu et al., 2000). It was asserted as a technological breakthrough, which enables faster cleaning and chemical free process. They are using Nd:YAG laser for cleaning. However, this laser nowadays is considered producing long pulse and still induced damage on the surface after treatment.

Therefore, shorter laser pulse is desired to be considered for overcoming the drawback. In this work, a femtosecond laser is proposed to be used as an alternative for cleaning mold tool. Ultrafast laser pulse is utilized in ablation of stain on mold tool for finer and more efficient cleaning. This approach will have a minimal damaging effect on tools and a green technology breakthrough in IC industries. This method may be a suitable replacement for existing cleaning method in the future.

1.2 Problem Statement

Formation of carbon particulates on IC mold tool surface cause a defective IC structure on large scale production. Removal of the carbon contaminant by conventional chemical methods are raising concern over environmental and health issue. Laser as cleaning agent is suggested to overcome such problem. However, laser cleaning method is not widely accepted by IC manufacturer. Apart from the huge initial investment cost, the effectiveness of the technique is apparently the greatest doubt. Furthermore, the potential damages of the mold tool which induced by laser are typically the foremost concern. Current laser cleaning system uses Nd:YAG laser which produce pulsewidth in nanosecond regime. Nanosecond pulse is prone to induces damage on the metal surface on microscopic level (Urech et. Al, 2006) thus, a shorter laser pulsewidth is suggested to overcome such problem. The shortest laser pulse nowadays is produced by femtosecond laser is still a foreign in cleaning technology. The signature properties of femtosecond regime could potentially increase the effectivity in removing carbon contaminant leading to a a cleaner IC mold tool. Therefore, ther is a need to study the femtosecond laser ablation parameter for maximum carbon content removal from mold tool surface.

1.3 Objective of the Study

This research focuses on the following objectives:

(a) To perform femtosecond laser ablation on chromium nitride surface
(b) To characterize the femtosecond laser ablation effect
(c) To determine the influence of laser power and distance on carbon, oxygen and chromium distribution.

1.4 Scope of the Study

This study intends to perform the carbon removal from mold tool in research scale. The chromium nitride block was used to represent the material of IC mold tool. Epoxy tubes provided by Infineon Technology industry were used as contaminant materials. Molding process is replicated by using hot plate to melt the epoxy tube within a temperature of 175 °C on the chromium nitride surface. Femtosecond laser was used as a source of laser ablation. The power of laser was used in the range of 1.3 W to 1.9 W. The laser is operated at fundamental wavelength of 1025 nm at 100 kHz output frequency. The femtosecond laser is ablated in straight line across the molded area forming zig zag pattern which represent each studied parameter. Morphology and elemental analysis will be done on the ablation line. The surface condition of chromium nitride substrate before and after laser ablation is examined by using high magnification optical microscope to observe any visible surface damage. Detailed analysis is done along the ablation line by using scanning electron microscope (SEM) provide a deeper insight at substrate's microscopic level images while energy-dispersive X-ray spectroscopy (EDX) is for characterization of chemical element distribution along the ablation target. Further surface morphology analysis will be done by Gwydion software by utilizing high resolution images from SEM. The amount of carbon will be the indicator of the contamination level while oxygen content will reflect the amount of damage sustained by the mold sample. The definition for the best cleaning is the lowest amount of carbon and oxygen content left after femtosecond laser ablation. This initial study can be used for future laser cleaning purpose.

1.5 Significance of the Study

By utilizing light, one of the world most natural thing as the cleaning agent, the cleaning of IC mold tool would be a chemical free process. Optical photon does not have chemical reaction with material due to absence of electron hence, making it contaminant free cleaners. Stains on mold tool is instantly vaporized by high intensity photon burst without leaving any chemical by-products thus eliminating the additional cost for chemical waste treatment which can take up to million ringgits. Precise cleaning by using femtosecond pulse beam can preserve mold tool surface structure over a long period. This can maintain the production yield of high quality IC packages which will be used for worldwide electronic devices.

1.6 Thesis Summary

This thesis documented the complete work of this research. It consists of five main chapters whereby, in every chapters are divided into several subchapters. Chapter 1 present the overview of the thesis, problem statement, research objectives, scope of study as well as significance of this study. As in Chapter 2, it provides extensive literature review of integrated chip mold tool cleaning process by previous researchers including current problems on the cleaning methods. Laser cleaning methods is also discussed theoretically as suggested alternative. While Chapter 3 describes details information regarding the instruments and description of sample properties which has been used in this work. Furthermore, it also discusses the calibration procedure and research methodology of research development. There is also discussion on the analysis method used to characterize and analyse the changes of the sample structure over varied parameter. All the result is presented in Chapter 4. The initial work comprises of surface analysis before and after laser cleaning followed by analysis on the cleaning and damages percentage for each laser ablation. Comparison with laser ablation by Nd:YAG laser is explained to observe the effectiveness of the femtosecond laser ablation in removing carbon from mold tool surface. Finally, Chapter 5 concluded the finding of this study. It also contained the recommendation for future study.

REFERENCES

Arnold, N. (2003). Theoretical description of dry laser cleaning. *Applied Surface Science*, *208*, 15-22.

Azechi, H. (2016). A pathway to laser fusion energy in Japan. *Journal of Physics: Conference Series*, 717(1), 012119

Balling, P., & Schou, J. (2013). Femtosecond-laser ablation dynamics of dielectrics: basics and applications for thin films. *Reports on Progress in Physics*, 76(3), 036502.

Bauerle, D. (2002). Laser processing and chemistry: recent developments. *Applied Surface Science*, 186(1-4), 1-6.

Brautbar, N., & Williams, J. (2002). Industrial solvents and liver toxicity: risk assessment, risk factors and mechanisms. *International journal of hygiene and environmental health*, *205*(6), 479-491.

Becker, J. R. (2001). U.S. Patent No. 6,174,225. Washington, DC: U.S. Patent and Trademark Office.

Bertrand, G., Mahdjoub, H., & Meunier, C. (2000). A study of the corrosion behaviour and protective quality of sputtered chromium nitride coatings. *Surface and Coatings Technology*, 126(2-3), 199-209.

Burmester, T., Meier, M., Haferkamp, H., Barcikowski, S., Bunte, J., & Ostendorf, A. (2005). Femtosecond laser cleaning of metallic cultural heritage and antique artworks. *Lasers in the Conservation of Artworks*, 61-69.

Chen, H. W., Chang, G., Xu, S., Yang, Z., & Kärtner, F. X. (2012). 3 GHz, fundamentally mode-locked, femtosecond Yb-fiber laser. *Optics letters*, 37(17), 3522-3524.

Chichkov, B. N., Momma, C., Nolte, S., Von Alvensleben, F., & Tünnermann, A. (1996). Femtosecond, picosecond and nanosecond laser ablation of solids. *Applied Physics A*, *63*(2), 109-115.

Dobler, V., Oltra, R., Boquillon, J. P., Mosbacher, M., Boneberg, J., & Leiderer, P. (1999). Surface acceleration during dry laser cleaning of silicon. *Applied Physics A: Materials Science & Processing*, 69(7), 335-337.

Engelsberg, A. C. (1995). Alternative Technology: Chemical-Free, Laser-Assisted Cleaning. *Precision Cleaning*, 370-382

Fernandes, A. J., & Kane, D. M. (2006). An overview of experimental research into the laser cleaning of contaminants from surfaces. *Laser Cleaning II. Edited by KANE DEB M. Published by World Scientific Publishing Co. Pte. Ltd., 2006. ISBN# 9789812706843, pp. 29-78*, 29-78.

Fernandes, A. J., & Kane, D. M. (2004). Enhanced laser cleaning via direct line beam irradiation. *Applied Physics A*, 79(4-6).

Feng, Q., Picard, Y. N., Liu, H., Yalisove, S. M., Mourou, G., & Pollock, T. M. (2005). Femtosecond laser micromachining of a single-crystal superalloy. *Scripta Materialia*, 53(5), 511-516.

Gamaly, E. G., Rode, A. V., Luther-Davies, B., & Tikhonchuk, V. T. (2002). Ablation of solids by femtosecond lasers: Ablation mechanism and ablation thresholds for metals and dielectrics. *Physics of plasmas*, 9(3), 949-957.

Gregorcic, P., Lukač, N., Možina, J., & Jezeršek, M. (2016). In Vitro Study of The Erbium: Yttrium Aluminium Garnet Laser Cleaning of Root Canal by The Use of Shadow Photography. *Journal of biomedical optics*, *21*(1), 015008-015008.

He, L., Sheehy, K., & Culbertson, W. (2011). Femtosecond laser-assisted cataract surgery. *Current opinion in ophthalmology*, 22(1), 43-52.

Huynh, J., Smrž, M., Miura, T., Endo, A., Čech, M., & Mocek, T. (2017, June). Femtosecond Yb: YGAG ceramic regenerative amplifier. *European Conference on Lasers and Electro-Optics* (p. CA_P_25). Optical Society of America.

Jeff Hecht (2005). Beam: The Race to Make the Laser. *Optics and Photonics News*, 16(7), 24-29.

Johnson, S. (2007). Cleaning molds, part III: Ultrasonics make life easier. *Plastics Technology*, 9.

Kane, D. M. (2006). *Laser cleaning II* (Vol. 4). World Scientific.

Kim, J. T., & Choi, H. K. (2017). Femtosecond micromachining of optical elements. *Bulletin of the American Physical Society*, 62.

Litchfield, R. E., Critchlow, G. W., & Wilson, S. (2006). Surface cleaning technologies for the removal of crosslinked epoxide resin. *International journal of adhesion and adhesives*, 26(5), 295-303.

Lu, Y. F., Song, W. D., & Low, T. S. (1998). Laser cleaning of micro-particles from a solid surface—theory and applications. *Materials chemistry and physics*, 54(1-3), 181-185.

Lu, Y. F., Song, W. D., Hong, M. H., Ren, Z. M., Chen, Q., & Chong, T. C. (2000). Laser cleaning of IC mould and its real-time monitoring. *Japanese Journal of Applied Physics,* 39(8), 4811-4813.

Maffini, A., Uccello, A., Dellasega, D., & Passoni, M. (2016). Laser cleaning of diagnostic mirrors from tungsten–oxygen tokamak-like contaminants. *Nuclear Fusion*, *56*(8), 0860081-0860089.

Malinauskas, M., Žukauskas, A., Hasegawa, S., Hayasaki, Y., Mizeikis, V., Buividas, R., & Juodkazis, S. (2016). Ultrafast laser processing of materials: from science to industry. *Light: Science & Applications*, 5(8), e16133.

Mottner, P., Wiedemann, G., Haber, G., Conrad, W., & Gervais, A. (2005). Laser cleaning of metal surface—laboratory investigations. *Lasers in the Conservation of Artworks* (pp. 79-86). Springer, Berlin, Heidelberg.

Musazzi, S., & Perini, U. (2014). Laser-induced breakdown spectroscopy. *Springer Series in Optical Sciences*, 182.

Öktem, B., Pavlov, I., Ilday, S., Kalaycıoğlu, H., Rybak, A., Yavaş, S., ... & Ilday, F. Ö. (2013). Nonlinear laser lithography for indefinitely large-area nanostructuring with femtosecond pulses. *Nature photonics*, 7(11), 897.

Plastics Molding & Manufacturing. (2017). Wikibooks, The Free Textbook Project. Retrieved 12:56, January 27, 2018 from https://en.wikibooks.org/w/index.php?title=Plastics_Molding_%26_Manufacturing&oldid=3264715.

Radojković, B., Ristić, S., Polić, S., & Jančić-Heinemann, R. (2017). Surface Modification of Aqueduct Ceramics Induced by Nd: YAG Pulsed Laser Treatment. *Lasers in Engineering (Old City Publishing)*, 36, 373-390.

Rethfeld, B., Sokolowski-Tinten, K., Von Der Linde, D., & Anisimov, S. I. (2004). Timescales in the response of materials to femtosecond laser excitation. *Applied Physics A*, 79(4-6), 767-769.

Rethfeld, B., Kaiser, A., Vicanek, M., & Simon, G. (2002). Ultrafast dynamics of nonequilibrium electrons in metals under femtosecond laser irradiation. *Physical Review B*, 65(21), 214303.

Steve Johnson (2004). Cleaning Molds. *Mold Making Technology*. 12 January 2017

Senesi, G. S., Carrara, I., Nicolodelli, G., Milori, D. M. B. P., & De Pascale, O. (2016). Laser cleaning and laser-induced breakdown spectroscopy applied in removing and characterizing black crusts from limestones of Castello Svevo, Bari, Italy: A case study. *Microchemical Journal*, *124*, 296-305.

Spur, G., Uhlmann, E., & Elbing, F. (1999). Dry-ice blasting for cleaning: process, optimization and application. *Wear*, *233*, 402-411.

Steve Johnson (2007) Cleaning Molds: Part 1. *Plastics Technology*. http://www.ptonline.com/articles/cleaning-molds-part-i(2) 12 January 2017

Song, W. D., Hong, M. H., Lukyanchuk, B., & Chong, T. C. (2004). Laser-induced cavitation bubbles for cleaning of solid surfaces. *Journal of applied physics*, *95*(6), 2952-2956.

Spence, D. E., Kean, P. N., & Sibbett, W. (1991). 60-fsec pulse generation from a self-mode-locked Ti: sapphire laser. *Optics letters*, *16*(1), 42-44.

Urech, L., Lippert, T., Wokaun, A., Martin, S., Mädebach, H., & Krüger, J. (2006). Removal of doped poly (methylmetacrylate) from tungsten and titanium substrates by femto-and nanosecond laser cleaning. *Applied surface science*, *252*(13), 4754-4758.

Uthaijunyawong, T., Siriwattanayotin, S., Viriyarattanasak, C., & Tangwarodomnukun, V. (2017). Laser cleaning performance and PAHs formation in the removal of roasting marinade stain. *Food and Bioproducts Processing*, *102*, 81-89.

Veiko, V. P., & Poleshchuk, A. G. (2014). Laser-induced local oxidation of thin metal films: physical fundamentals and applications. In *Fundamentals of Laser-Assisted Micro-and Nanotechnologies* (pp. 149-171). Springer, Cham.

Vyacheslav A. Kharchenko. (2015). Problems of reliability of electronic components. *Modern Electronic Materials*, 1(3), 88-92.

Xu, C., & Wise, F. W. (2013). Recent advances in fibre lasers for nonlinear microscopy. *Nature photonics*, 7(11), 875.

Zeng, X., Zhou, K., Zuo, Y., Zhu, Q., Su, J., Wang, X. & Guo, Y. (2017). Multi-petawatt laser facility fully based on optical parametric chirped-pulse amplification. *Optics letters*, 42(10), 2014-2017.

Zhang, D., Gökce, B., & Barcikowski, S. (2017). Laser Synthesis and Processing of Colloids: Fundamentals and Applications. *Chemical Reviews*.