FUNDAMENTAL ABLATION OF ARGON-FLOURIDE EXCIMER LASER ON POLYMETHYL METHACRYLATE BY INTERFEROMETY TECHNIQUE

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To my beloved husband, parents, and families

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ABSTRACT

A fundamental study is carried out to fabricate or in other words to ablate an optical material by using a single pulse of ultraviolet light. In this case, argon fluoride excimer laser has been used as the ultraviolet light source while polymethyl methacrylate (PMMA) sample is used as the optical material. The laser ablation was conducted in between 1 to 20 pulses as a fundamental ablation. The ablation effects on the PMMA sample were analysed by using interferometry method. Straight line and equidistance fringes pattern is an indicator for smooth and flat surface. The effect of ablation was quantified by measuring shifted distance, intensity changes, and spacing reduction of fringes. The initial fringes shifted were notified as ablation threshold. This occurred after 9 pulses of exposures with corresponding threshold fluence of 3.18 mJ/mm^2. The fringes pattern becomes peculiar and difficult to trace at higher exposures. This contributed the increasing in shifted distance and fluctuating in the fringes intensity. High degree of surface roughness is indicated by the large fraction number of half wavelength and speckle existence. The re-solidified of removal particles are possibly responsible to cause the refractive index of the tested region become fluctuated in the range of 1.43 to 1.49. By increasing number of laser pulses from 10 pulses to 20 pulses after ablation threshold, the ablation depth on the tested region was estimated and found that the depth varied in between 40 nm to 800 nm. The corresponding laser fluence had given were in between 3.6 mJ/mm^2 to 7.3 mJ/mm^2. Hence the fundamental study succeeds to ablate the PMMA material by using ultraviolet light of excimer laser.

ABSTRAK

Satu kajian telah dijalankan bagi memfabrikasi atau dalam kata lain mengablasi bahan optik menggunakan satu denyut cahaya ultraungu. Dalam kes ini, laser eksimer argon-florida telah digunakan sebagai sumber cahaya ultraungu manakala sampel polimethil methakrilat (PMMA) digunakan sebagai bahan optik. Pengablasian laser telah diuji pada asasnya menggunakan 1 hingga 20 denyutan laser. Kesan ablasi ke atas sampel PMMA telah dianalisis menggunakan kaedah interferometri. Garis lurus dan jarak pinggir interferens yang sama menunjuk suatu permukaan yang rata. Kesan ablasi telah dikuantitikan dengan mengukur perubahan jarak anjakan, keamatan dan kelebaran jalur pinggir. Anjakan pertama yang berlaku pada pinggir dikenalpasti sebagai takat ablasi. Ia berlaku pada 9 bilangan denyut laser iaitu bersamaan dengan 3.18 mJ/mm^2 takat ablasi. Ini meliputi pertambahan dalam anjakan dan perubahan pada keamatan pinggir. Darjah kekasaran permukaan yang tinggi dapat dilihat berdasarkan kepada nombor pecahan separuh panjang gelombang yang besar dan kewujudan bintik laser. Pengerasan semula zarah bahan yang terkeluar berkemungkinan menjadi punca kepada perubahan indeks biasan yang berlaku pada kawasan ujian di mana ia telah berubah di antara 1.43 hingga 1.49. Dengan meningkatkan bilangan denyut dari 10 denyut ke 20 denyut selepas takat ablasi, kedalaman ablasi pada kawasan ujian telah dianggarkan dan didapati berada di antara 40 nm ke 800 nm. Tenaga per unit kawasan yang terlibat ialah di antara 3.6 mJ/mm^2 hingga 7.3 mJ/mm^2. Oleh itu, kajian asas berjaya mengablasi bahan PMMA dengan menggunakan cahaya ultraungu daripada laser eksimer.

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A	-	Area of high intensity distribution
$[A]$	-	Amplitude of wave
c	-	Speed of light in vacuum
d	-	Ablation depth
E	-	Pulse energy
$[E]_{\parallel}$	-	Light with electric vector
$[E_r]_{\parallel}$	-	Reflected light
$[E_t]_{\parallel}$	-	Transmitted light
F	-	Flatness
I	-	Intensity
L	-	Working distance
m	-	Integer
M	-	Order of interference
N	-	Number of pulses
n	-	Refractive index
P	-	Power
Δp	-	Optical path difference
t	-	Thickness
Δt	-	Changes thickness
V	-	Discharged voltage
W	-	Normal spacing (before exposure)
w	-	Fringes spacing after exposure
Δx	-	Shifted fringes
θ_i, θ_1	-	Incidence angle
θ_t, θ_2	-	Refraction angle
θ_p	-	Brewster's angle
ϕ	-	Optical phase
λ	-	Wavelength

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CHAPTER 1

INTRODUCTION

1.1 Overview

Micromachining technology is an exciting and emerging area of modern technology because it allows compact and minifeature sizes to be fabricated. It has been widely applied to various micro-systems, micro-sensors, micro-actuators, and micro-optics. Miniaturising devices using micro-optics revolutionise many electro-optical systems such as video cameras, video phones, compact disk data storage, robotics vision, optical scanners and high definition projection displays (Jay and Stern, 1994). Both higher accuracy and lower cost microlens array fabrication methods (Naessens *et al.*, 2003, and Pan and Shen, 2004) are needed to meet the rapid growth for these commercial devices.

The traditional mechanical approaches of cutting, drilling, and shaping materials are no longer satisfactory for fabricating micronscale structures. Instead, fabrication using beam techniques based on photons, electrons, and ions are used to produce high-resolution structures. Lasers have been proven as effective tools in micromachining. They have been used to solve fine machining problems in numerous fields such as medical devices, telecommunication, microelectronics, fibre optics, data storage, instrumentation, and micro optics. Although lasers battle with other technologies for micromachining applications, they are suitable for those application that demand more precision, speed, and “direct-write” capability. Lasers can also work on most materials and environmentally friendly (Chang and Molian, 1999).

Laser machining or laser ablation is a surface structuring technique based on the interaction of intense laser pulses with a material. It is extremely well suited for fabricating the microstructures on polymer surfaces. Laser machining has been proven to be a versatile technique for producing high accuracy dimension and repeatability of features in a wide diversity of materials. Due to the non-contact and direct-write nature of the process, the fabrication of the microstructure can take place in a very late stage of a heterogeneous assembly. This makes laser ablation very attractive for fabricating micro-optical components on opto-electronic assemblies in comparison to other fabrication technique like injection molding, embossing, and standard micro-electronic manufacturing process (Naessens *et al.*, 2000).

1.2 Laser Machining

High-power short-pulse laser ablation has been extensively applied in micro machining technology in recent years. Laser ablation (also known as laser machining) is most usually associated with the use of excimer lasers. Excimer laser ablation is a valuable micro-fabrication technology, which is particularly well-suited for surface structuring of polymers because of their excellent UV absorption and highly non-thermal ablation behaviour (Naessens *et al.*, 2003). It is now twenty three years since first appeared on using UV excimer lasers to ablate the material such as polymer (Dyer, 2003). Dyer has reviewed the basic mechanistic aspects of the UV laser-polymer interaction; photophysical and photochemical mechanisms. The interaction also accompanied by a visible plume, that is, the expanding cloud of volatile products that are expelled from the irradiated surface by each laser pulse.

Particularly, laser ablation was started by Srinivasan and Mayne-Banton (1982). They reported that the surface of polymer like PET (polyethylene terephthalate) could be ablated and etched by radiation of 193 nm (ArF excimer laser) wavelength without any subsequent processing. Since that time, the interaction of pulsed, ultraviolet laser radiation from an excimer laser (193 nm, 248 nm, 308 nm, or 351 nm) with organic polymer surface has been the subject of intense research activity (Dyer, 1992). Until now, many research efforts are carried out to have a better understanding of excimer laser ablation of polymer.

Oldershaw (1993) has observed two features of excimer laser ablation. Firstly, the interaction between the UV radiation and polymer is much localised, so that patterns of high definition and controlled depth can be etched in the surface. Because of the strong absorption of many polymers at 193 nm ArF laser, the depth of etch for a single laser pulse is very small, usually less than 1 μm. Secondly, there is threshold laser fluence before it can ablate the surface. In discussing the UV-polymer interaction, Srinivasan (1993) has considered the power density of the radiation at the polymer surface instead of the fluence as it is commonly done.

In 1996, Dyer's group have done research on excimer laser ablation of low and high absorption index polymers. They have used High Speed Shadow Photography (HSSP), Probe Beam Deflection (PBD), and Time Resolved Interferometry (TRI) techniques to provide information about the ablation process. What has become clear from this activity is that laser parameter such as wavelength, pulse duration, and fluence, each of them has contributing effects to the ablation process and not all polymers exhibit the same ablation characteristics with a given set of irradiance conditions. A given polymer can exhibit a variety of ablation characteristics depending on the irradiance parameters applied (Dyer *et al*., 1996).

Beside that, it is shown that the acoustic waves generated during laser ablation can be used to determine the ablation threshold and the ablation rate for different fluences and depths, and also to characterize the different regions of the process (Efthimiopoulus *et al*., 1998). The ablation process was also analysed experimentally in terms of material removal rate, optical emission of the laser-induced plasma, hole geometry, debris production at the hole edge, and chemical changes in the polymer induced by the laser irradiation (Wesner *et al.*, 1999).

Optics for high power laser systems in fusion research requires very precise control of phase distribution for obtaining uniform irradiation intensity on the pellet target. In the conventional optical fabrication, the control of the phase in the optics has been made by polishing the optics until the phase error is less than λ/8. This requirement causes very expensive prices of optical components for high power lasers. But then, Jitsuno (1999) has introduced a phase compensation technique, which is a cheap and rapid fabrication process of precise optical elements. This approach provides the way to control the phase of the optics, which is very important for many other applications in optics.

In order to fabricate micro channels, Wagner and Hoffman (1999) have performed multiple pulse laser ablation of stretched polymer with an ArF excimer laser (193 nm). The surface structure remaining after 'scanning ablation', is compared to the known results upon 'static ablation'. Yang and Pan (2003) used a numerical simulations technique to predict the profile of analogous microstructures following excimer laser ablation to obtain desired micro-optical components.

Naessens *et al.* (2003) have applied a fabrication technique for microlenses and arrays of microlenses using excimer laser ablation process. The process is based on scanning a polymer surface with a pulsed excimer beam along well-chosen multiple concentric contours and in this way microlenses of arbitrary shape can be realized. Once again, numerical simulation was used to predict the profile of a three-dimensional aspherical microlens and a microprism array (Pan and Shen, 2004). Based on the simulated results, the desired micro-optical lens profile was obtained using excimer laser ablated polymer. Recently, Jensen *et al.* (2005) has demonstrated a new method for forming microlenses or microlens arrays, which utilizes excimer laser degradation of PMMA followed by a thermal treatment.

From all research efforts, laser ablation and processing are applied in many area which covering fabrication of optical material, material removing, surface modification, surface cleaning and many more. It gives us an interest to study and characterize the fundamental of laser ablation. Although the application is wide, our interest study is lay on interaction of excimer laser with polymer material and our research in this field focusing towards the optical fabrication.

1.3 Interferometric Observation

Optical techniques are powerful for deformation analysis. Contour measurement by interferometry is used widely to determine the shape of a surface. Information about the surface of a static object can be obtained from interference fringes whose contour lines or fringes characterize the surface on which they are formed. There are two basic methods for measurement of surface shape or height profile by optical contouring: phase shifting and the Fourier transform.

In 1995, Jitsuno's group have made some basic fabrication experiments on the measurement of the ablation rate. They made on a different kinds of optical plastics and in situ interferometric observation of the surface figure of a PMMA plate. A new approach for mitigate some important disadvantages of optical plastics such as the bulk non-uniformity, the index drift due to the humidity absorption and the strong birefringence have been proposed using the plastic-glass hybrid component to reduce the thickness of plastic.

Scully *et al.* (1999) used a Fabry-Perot interferometer method to measure small changes in optical path length in the sample as a function of laser power, fluence, repetition rate and total accumulated energy of number of pulses.
They were using 3 mm thick PMMA slab as a Fabry Perot etalon for measuring the optical path length changes at a selection of UV wavelength. When the UV irradiated was illuminated with a green He-Ne laser at 548 nm, shifts in reflected interference fringes were observed. These shifts indicate changes in sample thickness, refractive index, and penetration depth in agreement with other researchers.

The dynamic processes during laser ablation of polymers also have been studied by Hauer *et al.* (2003). They were using nanosecond-interferometry and shadowgraphy to compare the influence of the two absorption sites in the same and the two different polymers. Both methods have the potential to give strong indicating for the underlying mechanism.

Dennis *et al*. (2001) report on the technique for determining the change in the refractive index of photosensitive glass. They demonstrated interferometer-based technique on fibre perform and bulk glass samples, achieving an optical-path-difference (OPD) repeatability of 0.2 nm. But their technique was found to be insensitive to the effects of photodarkening and material compaction. Karaalioglu and Skarlatos (2003) have observed the surface profile of an aluminum (Al) thin film and its thickness by electronic speckle pattern interferometry. The Michelson interferometer was used as their basic interferometric system to obtain interference fringes on a CCD camera. These interference fringes depend on the path difference due to the surface contours of thin film. Then, they analyzed the interference fringes with the fast Fourier transform method.

Regarding to some of the papers reviewed, it encourages us to observe the result of fabrication process by using interferometry technique. Interferometer is a sensitive detector, which is suitable to observe any changes on the surface shape even though by a fundamental shot of excimer laser ablation.

1.4 Research Objective

This research was carried out in order to achieve the following objectives:-

1. to diagnose the ablation source
2. to determine the ablation threshold
3. to characterize the ablation effect by interferometry method
4. to estimate the ablation depth

1.5 Research Scopes

The ablation was conducted using UV light of ArF excimer laser. The laser was triggered externally in order to vary the number of pulses from 1 to 20 pulses. The optical material of polymethyl methacrylate (PMMA) was chosen as a specimen. The multi exposure from single pulse was directed on the same spot. The ablation was verified based on the laser parameters including pumping voltage, working distance, and number of pulses. The ablation effect was measured and calculated using interferometry method. The quantifying involved, including shifted, intensity, and spacing of the fringes. Depthness of the sample at the ablated area was estimated by knowing its refractive index.

1.6 Thesis Outline

This thesis is divided into seven chapters. The first chapter is introducing the application of micromachining technology and its advantages upon traditional approaches. Some previous researches which are related to the laser machining or laser ablation and interferometric technique are reviewed. This chapter also emphasize the aim of this research.

Chapter 2 discuss the theories that are related to the research. These include mechanism of laser ablation, optical material and its affect on UV light, optical properties of the material that is refractive index, and also about the interference phenomenon.

Chapter 3 describes about methodology and equipments employed in this research such as excimer laser system, which include internal structures and external triggering. Measurement of pulse energy of excimer laser beam and its beam profiles were discussed. This chapter also describes about sample preparation and interferometer set up.

Characterization the source of ablation that is an excimer laser beam is found in Chapter 4. Firstly, it involved the pulse energy and peak power of the beam upon various laser parameters such as discharged voltage and number of pulses. Secondly, the beam profiles of the laser beam upon working distance and discharged voltage are described. Then, how to calculate the laser fluence are explained. This is done in order to determine the appropriate laser energy or power needed during ablation works.

Chapter 5 explains about laser ablative figuring. The ablation effects occurred on the PMMA surface can be traced using interference method. The first disturbance detected was referred as ablation threshold. Then the deformation fringes were analyzed and quantified based on shifted, intensity, and spacing changes.

The estimation of ablation depth on PMMA sample is obtained in chapter 6. Prior to calculate the depth, the changes of refractive index of the exposed material was measured using Brewster angle. The depth was estimated based on refractive index, shifted fringes, and normal spacing.

Finally, chapter 7 conclude of the whole project. These provided with the problems involved during perform the project. Last but not least, some works to be carried out in the near future are suggested.

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