

**DEVELOPMENT OF ARGON FLUORIDE (ArF) EXCIMER LASER ABLATION  
SYSTEM AND ITS DIAGNOSIS ON OPTICAL MATERIALS**

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***Dedication to my beloved father, mother, family and friends...***

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## ABSTRACT

The growing interest in precise fabrication of micro and nano-structures such as optical components, sensors and devices make the conventional approach no longer satisfactory for micro scale structure. Excimer laser ablation is particularly well suited for material such as polymer because of their excellent properties and ablation behavior. The objective of the project is to diagnose the ablation work for optical material. An ArF excimer laser was utilized as a source of energy. As a preliminary work, the laser was calibrated to determine the best performance of the laser beam. Various materials including thermal paper, high-density polyethylene (HDPE), plasticised polyvinyl chloride (PPVC) and polymethyl methacrylate (PMMA) material were employed as an ablating target. Each specimen was ablated with excimer laser which was operated at various parameter comprising of working distance, high voltage, repetition rate and number of pulses. The ablated materials were analysed by using Matrox Inspector 2.1, Video Test 5.0 and Ms Excel software. The changes in the refractive index of PMMA sample were analysed using Brewster angle. The results obtained showed that the ablation on these materials depended on working distance. A short working distance offered the best performance for ablation which was 30 cm, since less energy were lost during the propagation. The ablation work also depended on the high voltage in the range of 13 kV – 14kV, suitable for ablation process. The ablation work was also found to be independent with the repetition rate of the laser. Finally, the ablation was found sharply increased with respect to the number of pulses. The best performance for this study was found at 400 pulses. Two of the tested materials, PPVC and PMMA demonstrated good performance for the ablation work. The 3D image analysis, offer an estimation of depth of the ablation spot area. The refractive index of PMMA decreased from 1.46 to 1.23 in the range of 200 to 500 pulses.

## ABSTRAK

Peningkatan kehendak dan minat terhadap pembuatan peranti dalam skala mikro dan berstruktur nano seperti komponen optik, pengesan dan peranti termaju menjadikan pendekatan biasa tidak lagi memenuhi kehendak terutama berskala mikro. Sistem ablasi menggunakan laser terhadap bahan polimer dipilih untuk tujuan pembuatan ini disebabkan ia mempunyai ciri-ciri yang terbaik terhadap proses ablasi. Objektif utama projek ini adalah untuk mengenalpasti kesan dan keadaan untuk sesuatu bahan optik semasa proses ablasi dilakukan. Eksimer laser jenis argon fluoride (ArF) digunakan sebagai sumber tenaga. Untuk permulaan kajian, penentu ukuran dilakukan terhadap laser untuk menentukan keupayaan yang terbaik sebelum memulakan proses ablasi. Bahan-bahan optik seperti kertas haba, 'high-density polyethylene (HDPE)', 'plasticised polyvinyl chloride (PPVC)' dan 'polymethyl methacrylate (PMMA)' telah digunakan sebagai sampel. Setiap bahan disinari dengan laser eksimer, pada masa yang sama beberapa parameter diubah seperti jarak kerja, voltan tinggi, kadar ulangan dan jumlah keluaran denyut. Bahagian yang telah disinari dianalisis menggunakan perisian Matrox Inspector 2.1, Video Test 5.0 dan Ms Excel 2000. Perubahan index biasan pada bahan PMMA ditentukan menggunakan kaedah sudut Brewster. Jarak kerja yang hampir adalah terbaik diperolehi iaitu 30 cm. Voltan tinggi yang sesuai untuk proses ablasi adalah dalam julat 13kV – 14kV. Kerja-kerja ablasi didapati tidak bergantung kepada kadar ulangan laser. Akhirnya ablasi didapati bertambah secara eksponen terhadap bilangan denyut. Jumlah denyut yang terbaik adalah 400. Dengan memanipulasikan data yang diperolehi kepada pandangan 3 dimensi, kedalaman dapat ditentukan. Indeks biasan bahan PMMA menurun dari 1.46 kepada 1.23 apabila alur laser dikenakan di antara julat 200 sehingga 500 denyut.

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## LIST OF SYMBOLS

$\beta$	-	Absorption coefficient
$P_o$	-	Power before
$P$	-	Power after
$\alpha_\beta$	-	Brewster's angle
$n_{mat}$	-	Refractive index of material
$n_2$	-	Refractive index of material (2)
$n_1$	-	Refractive index of air
$C_{vac}$	-	Speed of light in vacuum
$C_{mat}$	-	Speed of light in material
$\theta$	-	Angle
$h$	-	Planck's constant
$d$	-	Diameter [m]
$E$	-	Energy

## CHAPTER 1

### INTRODUCTION

#### 1.1 Overview

The growing interest in precise fabrication of micro and nano-structures such as optical component, lenses, sensor and devices makes the conventional approach no longer satisfactory for micro scale structure. Now, nano-technology has a big potential to revolutionize everything from medicine, industrial manufacturing and to computer within a few decades. Recently laser ablation of optical material have been carried out by a few group of researches including Srinivasan *et al.* (1982), Wee and Pak (2001), Pissadakis *et al.* (1999), Jitsuno *et al.* (1995), Dyer *et al.* (1996) and Naessens *et al.* (2003).

Since the pioneering worked by Srinivasan *et al.* (1982), laser ablation of polymer materials have been the object of growing interest due to potential applications in electronic technology and the lure of discovering their fundamental properties (Wee and Pak, 2001). Polymer-based materials are becoming ubiquitous in a variety of high-tech application, e.g. specialty coating, automotive, aerospace, semiconductors and optical components. A constantly increasing use of polymer-based material has highlighted the need for better understanding of their physical, chemical and mechanical properties (Diakoumakos and Raptis, 2003). The polymer exhibits a variety of ablation characteristics depending on the irradiance parameters applied as described by Dyer *et al.* (1996). In optical fabrication, optical properties such as absorption, refractive index and others are the most important parameters to



be concerned, since the material can be controlled according to the requirement of application.

Polishing and coating of optical materials are very important to determine a good quality of light distribution. In that case, precise and good quality material will lead the cost of the process become very expensive. Mechanical polishing will not guarantee to meet the requirement of the need of high power laser interaction where quality of the beam depended on the optical component either to focus, reflected or bending the beam. Therefore, to make a fast, cheap and good quality polymer fabrication other alternative need to be explored.

## **1.2 Laser Ablation**

Laser ablation has found many practical applications in recent years. It is a valuable microfabrication technology, which is particularly well suited for surface structuring of material. It is now twenty years since it first appeared, on using UV excimer lasers to ablate materials such as polymer (Dyer, 2003). Particularly strong interest was generated by a report from Srinivasan and Mayne-Banton (1982) which showed that the polymer of PET (polyethylene terephthalate) could be ablated and etched the surface of material. Since that time, a number of reviews have appeared over the years charting the progress made at various stages of development and broaden into interdisciplinary field found by Srinivasan and Braren, (1989), Dyer *et al.* (1992), Drinek *et al.* (2001), Kruger *et al.* (2002), and Naessens *et al.* (2003). Recently, Calsteren, (2003) and Vorle, (2003) have provided an overview of scientific application of laser ablation and processing, covering material removing, surface modification, and many more.

In early studies of the ablation, work was only limited to the measurement of etch-rate (depth of material rejected per pulse) as a function of laser fluence or energy per unit area (Dyer *et al.*, 1996). Photo-induced etching can lead to physical and chemical alteration of surface properties (Kogelschatz *et al.*, 2000). The laser ablation technique is also attracting the interest in providing a new thin film

deposition method in commercial use, called Pulsed Laser Deposition method where the laser ablation mechanism takes place at the target surface (Kobayashi, 1999).

In a conventional optical fabrication, the control of the phase in the optics has been made by polishing the optics until the phase error should be less than  $\lambda/8$  (Jitsuno, 1999). The polishing process is based upon a complex interrelationship of a large number of variables such as physical and chemical properties, tool material, and relative motion between tool and workpiece during the fabrication (Oliver and Hedser, 1999). This requirement causes very expensive prices of optical component for high power laser. In order to reduce the fabrication cost of optics, a cheap and rapid fabrication for precise optical elements is investigated. This can be achieved by introducing a phase compensation technique whereby the phase distribution of optical component will be corrected by using laser ablative figuring (Jitsuno, 1999). In this field, it has been found that laser ablation on a glass surface produces of high smoothness without generating extensive surface damage in the form of crack, in contrast to the effect of ablation with longer wavelength (Pissadakis *et al.*, 1999).

The ability of laser ablation to etch different materials via a photochemical and photothermal mechanism has been extensively investigated by some research group such as Houle *et al.* (1982), Chuang *et al.* (1984), O'Driscoll *et al.* (2000) and Wee and Pak (2001). The absorption of metals in UV region is high, so that the photons from an ArF excimer laser would not only dissociate oxygen molecules into reactive radical, but would also be absorbed very close to metal surface (O'Driscoll *et al.*, 2000). Further discoveries found that the various ambient gases also influence the target during the laser ablation process. The chemical composition of sample and physical structure can be affected by ablation parameter configuration and condition properties was synthesised by Wesner *et al.* (1999) and Zbronic *et al.* (2002).

In the field of optical communication, a single mode optical fibre is very important element for connecting light source to the detector. However, it has very small core and requires a very precise connector to avoid loss. The ArF excimer laser is irradiated on to the surface on the optical plastic material coated on a glass plate to ablate the surface for controlling the transmitted or reflected wavefront (Jitsuno *et al.*, 1995) and (Jitsuno *et al.*, 1999). Now, they are trying to improve the

surface roughness by changing the polarity of the irradiation beam and the beam pattern on the surface. Regarding the optical characteristic, UV laser ablation induced to the refractive index changes in polymethyl methacrylate and plastic optical fibre were investigated by Scully *et al.* (1999).

Excimer lasers with 193-351 nm of wavelength are extensively used for photo ablation, chemical etching, lithography and surface cleaning. The benefits of excimer laser are attributed to their short wavelength, high energy per pulse, no contamination and ease automation (Chang and Molian, 1999). The reaction can be attributed to high absorption cross section of the films for the radiation which results in the energy trapped (Dyer *et al.*, 1996).

Latest research regarding the laser ablation technology is for cleaning ancient artwork, founded by research team in Art Innovation BV of Angelo, Netherlands. It removes years of dirt, oil and wax from painting. This system also cleans the surface with submicron-depth accuracy and does not ablate the paint underneath (Vorle, 2003). To gain a better understanding of the history of the earth, scientist have learned to peel back the layer of time, observing the growth rings of living organism or sediment. A single pulse of 193 nm excimer laser, can ablate a 50  $\mu\text{m}$  diameter pit from coral that weight 1.2 ng and that contain approximately 140 atom of  $^{230}\text{Th}$ , enabling researcher to analysis the uranium decay in reef by using sensitive mass spectroscopy and dating up to approximately 400,000 years (Calstreen, 2003).

As summarization, from all the papers and articles reviewed of laser ablation application in interdisciplinary field, it driven us an interest to study, diagnose and characterize the fundamental of laser ablation. Although the application is wide, our interest study is lay on interaction to the polymer material and have to focus our research in this field towards the optical fabrication and in order to find new applications.

### 1.3 Laser Interaction with Polymer Material

Generally, polymer consists of long chain molecules of repeating groups that are largely covalently bonded. Common elements within the chain backbone include C, O, N and Si. The bonds within the backbone are all covalent, so the molecular chains are extremely strong. It was first reported by Srinivasan and Mayne-Banton (1982) that when pulsed UV laser radiation falls on the surface of a polymer, the material on the surface is spontaneously etched away to a depth of 0.1 micrometer. Subsequently, the responses of numerous polymers to UV laser have been investigated and reported; some polymers are easier to ablate than others (Chang and Molian, 1999).

The strong interaction between the excimer laser beam and polymeric materials lead to depolymerization bond breaking, thermal degradation, and decomposition. The capability of an excimer laser to ablate a polymer depends on its absorption characteristics (Hilton *et al.*, 2002). The interaction between laser beam and polymer also accompanied by visible plume (Dyer, 2003).

New applications for ablation are foreseen with the growth of interest in organic materials for photonic devices, e.g. OLEDs (Organic Light Emitting Diodes). Excimer laser ablation maybe exploited as a means of patterning for organic films for display use. It also offers the possibility of growing novel organic layer by ablation deposition (Farrar *et al.*, 2000). The synthesised polymers, polyurethane are selected with good ablation properties in term of no debris formation and cavities with high dimensional quality (Callewaert *et al.*, 2003).

Among many polymeric materials, PMMA has been the most intensively examined target material to elucidate ablation mechanisms (Wee *et al.*, 2001). Light induced refractive index changes in PMMA because of photopolymerization of residual monomer sample (Kopietz *et al.*, 1984). In the case of weak absorber such as PMMA, only after a few pulse it will give a constant etch depth (Srinivasan, 1989). According to Wesner *et al* (1999), the important characteristic of ablated surface to be investigated includes material removal rate, hole geometry, debris production and chemical changes. Such characteristics also depend on fluence of the

laser, material optical absorption and ablation threshold of material. For PMMA plates, 0.5 mm in thickness the threshold ablation fluence of Krypton Fluoride (KrF) excimer laser was  $0.1 \text{ J/cm}^2$  (Wesner *et al.*, 1999).

#### **1.4 Research Objective**

The main objective of this research is to develop an ablation system by using ArF (Argon Fluoride) excimer laser and diagnosis the ablation effect on optical materials.

#### **1.5 Research Scope**

To set up an ablation system using ArF excimer laser and diagnose the power of the beam by altering several other laser parameters. The laser beam is then exposed onto the samples and the ablated area on the sample is analysed by using imaging software.

#### **1.6 Thesis Outline**

This thesis is divided into eight chapters. In the first chapter, it is reviewing some of previous research related on laser ablation system and application. This chapter also emphasising interest aim of doing the research.

Chapter II reviews the background or the theory that related to the research. This will cover the fundamental of excimer laser itself, UV light interaction effect on the samples, absorption and refractive index changes for certain polymers.

Chapter III describes the sample preparation and methodology for ablation works. This would include image processing software and experimental setup.

Chapter IV discusses the diagnostic result of excimer laser. Various laser parameters are tested such as working distance, high voltage, repetition rate and number of pulses in order to utilize the laser at optimum power during the ablation works.

Chapter V reviews the ablation by an absorption mechanism when the laser beam strike on to the samples. Matrox Inspector version 2.1 is used to analyse the ablated spot area according to the darkness or the effect of carbonised spot.

Chapter VI, examines the damages induced by excimer laser was studied. Metallurgical method was employed to measure the damage and Video Test version 5.0 software was used to analyse the damage according to laser parameter such as working distance, high voltage, repetition rate and duration of exposure. The damage is also viewed in three dimensions to study the damage in different perspective, and to estimate the depth of ablation target.

Chapter VII, discussed the results of laser interaction with PMMA. Since the damage produced without the carbonised effect, refractive index of the exposed material was measured using Brewster's angle method.

Finally, the conclusions of the project are made in Chapter VIII. These provided with the summarization of the whole project, the problems involved and experience during the performance of the project and last but not least, some works to be carried out in the near future are suggested.

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