Optik - International Journal for Light and Electron Optics 171 (2018) 431–436

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Theoretical and experimental investigations of the influence of overlap between the laser beam tracks on channel profile and morphology in pulsed laser machining of polymers

Hedieh Pazokian

Photonics and Quantum Technologies Research School, NSTRI, Iran

ARTICLE INFO

Keywords:
Pulsed CO_2 laser
PMMA
Pulse overlap
Micro channel

ABSTRACT

Pulsed laser machining is a method used for the fabrication of microchannels in different materials. There are various laser parameters and material properties which affect quality and dimension of the manufactured channel. The pulse overlapping is a process parameter which has significant effect on the resultant channel depth and morphology. In spite of many investigations on the effect of the pulse overlapping on laser machining, there is no theoretical equation for predicting the channel depth and profile, which involves this parameter explicitly as a function of the scanning velocity and the pulse repetition rate. In this paper, CO_2 pulsed laser was used for the fabrication of channels in polymethylmethacrylate (PMMA). The temporal shape of the laser pulse and the corresponding overlap of each pulse over the spot area were added as two processing parameter to the theoretical equation. The influence of pulse overlapping on the morphology at the bottom of the channels is also studied. The results offer a simple way to predict the channel depth, profile and morphology for pulsed laser machining of polymeric materials which has good absorption at the laser wavelength.

1. Introduction

Microfluidic chips have gained important applications in many areas of the research such as chemical synthesis, biology and optofluidic technology because of their advantages (like high sensitivity, speed of analysis, low sample and reagent consumption, and measurement automation and standardization) over conventional methods [1].

Different methods like hot embossing, soft lithography and laser ablation are used for the fabrication of microfluidic devices. The importance of each method depends on the goal of mass production or rapid fabrication [2].

Fabrication of microfluidic chips commonly involves two steps including construction of open channels and bonding. Etching, which is mostly used for the fabrication of open channels, especially for electronic devices, is expensive and relatively slow [3]. On the other hand, laser micromachining is one of the most important manufacturing methods used for drilling, welding, surface structuring and/or modification. High resolution micromachining is allowed with a wide range of wavelengths, pulse durations (from femtosecond to microsecond) and repetition rates.

CO_2 and Nd:YAG lasers are the most common lasers used for industrial processing because of their unique combination of high average power and high efficiency [2]. On the other hand, most polymers have suitable infrared absorption bands. Polymethylmethacrylate, more often called PMMA, is among the various polymeric materials used for the fabrication of microfluidic devices, because of its low cost, high transparency and biocompatibility.

E-mail address: H_pazokian@iust.ac.ir.

https://doi.org/10.1016/j.ijleo.2018.06.066
Received 25 April 2018; Accepted 13 June 2018
0030-4026/

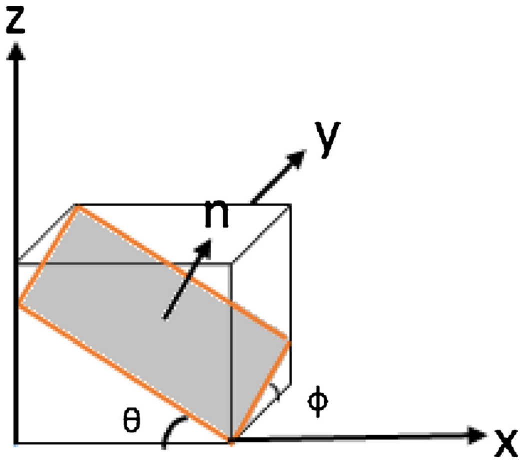

Fig. 1. The control volume for heat conduction in the conduction direction, n.

A number of experimental and theoretical investigations have been done on laser ablation of polymers for the fabrication of microstructures [4–9]. The theoretical models were mostly done based on the energy balance and for continues wave laser systems. For example, Dajun et al have developed a theory for continues wave CO_2 laser machining of PMMA at laser powers ranged from 0.45 to 1.35 W and scanning speeds ranged from 2 to 14 mm/s [9]. However, this model must be modified when low frequency (repetition rate) pulsed laser is used. In the present study, machining of microchannels in PMMA with a pulsed CO_2 laser is investigated. Two repetition rates of 1 and 3 Hz and very low scanning speeds (63-500 μm/s) were used in the experiment. The temporal shape of the laser pulse and the corresponding overlap of each pulse over the spot area is incorporated to the energy balance equation to predict the channel depth and profile. In addition, the influence of pulse overlapping on the morphology at the bottom of the channels is studied.

2. Theoretical analysis

The heat balance equation is used for investigation of the channel depth and geometry. The energy losses due to the radiation and conduction, and the laser beam attenuation by the volatiles are neglected [9].

To derive a governing equation for determining channel depth, an infinitesimal volume in the heat conduction direction is considered as is shown in Fig. 1 [6]. The control volume consists of two isothermal surfaces normal to the heat conduction direction and is inclined θ and $\varnothing$ with respect to the x and y axes, respectively. i.e:

$$\frac{\partial z}{\partial x} = \tan\theta \quad \frac{\partial z}{\partial y} = \tan\varnothing \tag{1}$$

The energy balance in the control volume can be written as follows [9]:

$$E_{laser}\, dA_1 = E_{conduction}\, dA_2 + E_{decomposition}\, dA_1 \tag{2}$$

Where $dA_1 = dx\, dy$ and $dA_2 = |\nabla \boldsymbol{n}|\ dxdy$, which **n** is normal vector in the heat direction.

A Gaussian laser beam intensity, irradiated on a polymer sheet with semi finite thickness and finite length moving in the positive x direction with uniform velocity v, is considered.

While scanning the material surface during irradiation, several laser pulses interact within a spot area subsequently. The total effective energy, E, incident on a spot area due to N pulses is then given by [10].

$$E = \sum_{n=1}^{N} S_{pulse} \times e, \quad S_{pulse} = \frac{2r - (n-1)b}{2r} \tag{3}$$

Where, N is the number of pulses required to process this area, S_{pulse} is the corresponding overlap of each pulse over the spot area and e is the energy of the individual laser pulse.

The input laser energy density to the surface element depends on the absorption of the material at the laser wavelength and is given by

$$E_{laser} = a.\, E \tag{4}$$

Where, a is the absorptance of polymer at the laser wavelength.

For the laser beam moves with a constant velocity v, the number of laser pulses, N, required to process an area equal to the beam spot diameter (2 r), is given by

$$N = \frac{2r}{b} \tag{5}$$