INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

Name of the Student	:	UPASANA SARMA
Roll Number	:	166103017
Programme of Study	:	Ph.D.

Thesis Title: Experimental and Numerical Investigations into Laser-Induced Plasma Assisted Ablation (LIPAA) of Transparent Polycarbonate for Fabrication of Microchannels

Name of Thesis Supervisor(s)	:	PROF. SHRIKRISHNA N. JOSHI
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SHORT ABSTRACT

Microchannel-based devices are widely used in microelectronic devices, turbine blade cooling, microfluidics for drug delivery devices, etc. Therefore, microchannel-based devices require the use of materials with high optical, chemical, and mechanical properties, and thus, transparent materials have become a significant material for the production of microchannels.

Transparent polycarbonate (PC) is a highly durable material, making it resistant to impacts and fracture, providing safety and comfort in applications that demand reliability and high performance. As such, PC can be considered as an ideal material for the biomedical and optical industries.

PC-based microchannels can be fabricated using a variety of processes such as lithography, wire moulding, micro-milling, laser micro-machining etc. Nonetheless, the mentioned techniques have limited applicability. Further, the high transmissivity of PC over a wide range of wavelength makes the laser based fabrication of microchannels on it a challenging task. However, with Laser-Induced Plasma Assisted Ablation (LIPAA), lasers may have the potential to process transparent PC. In view of this, in the present research work, systematic and extensive experimental as well as numerical studies have been carried out to assess the feasibility, productivity and product quality during LIPAA for microchannel fabrication on PC.

LIPAA is a technique, by which transparent materials can be ablated on its rear side with the aid of laser-induced plasma. The first phase of the research work presents the successful fabrication of microchannels on transparent PC using the LIPAA technique. Besides, the effect of properties of metal targets on microchannel fabrication was also investigated. Three different metal targets utilized during the process are namely aluminium, copper and stainless steel. Evaluation was then performed to investigate the influence of metal target properties such as thermal conductivity and specific heat on the geometrical characteristics of the microchannels. The study concludes by stating that the higher thermal conductivity value of the metal target leads to the formation of a narrow microchannel,

while the higher specific heat value leads to a deeper microchannel fabrication. In addition, the metal target resulting in the highest microchannel aspect ratio was recommended for further study in our research.

In second phase of research work, experiments are carried out based on a full factorial 34 experiments on PC by the appropriate selection of the laser parameters viz. pulse power density, pulse repetition rate, pulse duration and laser scanning speed. The influence of the laser parameters on channel width, channel depth and the channel roughness has been studied. Analysis of Variance (ANOVA) is also carried out to determine the most influential parameters. Second order mathematical relations among the input laser parameters, their interactions and the responses were developed. To analyse the accuracy of the developed mathematical model, confirmation experiments are performed and is found to be in good agreement. Based on the confidence gained from the confirmation experiments performed, multiple objective (response) optimization of the input parameters to predict a better quality channel geometry and channel roughness is carried out. For a width of 250 μm, depth of 150 μm and minimum roughness on a single pass, the optimized condition of laser parameters is found to be 40 Hz repetition rate, 2 ms pulse duration and 4.79 MW/cm^2 pulse power density. Using the optimal laser parameters, open microchannels are fabricated and were closed by using a thermal bonding process. Further, a fluid flow test carried out on the closed microchannel to prove its potentiality to be used as a microfluidic device has also been described in the chapter. Different configuration channels on PC have also been fabricated using the optimal laser parameters.

The third phase of the work represents a two-dimensional transient numerical model to understand the physics of material removal during the LIPAA process. A realistic model is developed concerning the effect of plasma along with the effect of input laser irradiation. The channel dimensions, i.e., the width and the depth of the channel, were computed from the numerical study. The computed results have been duly verified with our experimental results and found in good agreement. Also, considering the effect of moving heat flux, it is witnessed that the peak temperature attains a constant value on reaching a certain distance, thus assuring a channel of uniform dimension.

A three-dimensional nonlinear transient modelling was also developed to simulate the LIPAA process for microchannel fabrication on transparent polycarbonate. The merit of the approach lies in simulating simultaneous ablation of both transparent polycarbonate and aluminium metal target during the process. The developed model has the potential of estimating spatial-temperature distribution along the traverse direction and direction perpendicular to it. The spatial distribution lent a hand in predicting the width and depth of the microchannel. Temporal-temperature distribution for pulse-on and pulse-off time was also explored. A channel index (CI) has also been estimated which determines channel formation in or out of the micron-scale (1-999 μm) for a selected set of process conditions.