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Determination of Parameters for Micromachining of Microfluidic Mixers with Complex Geometry in Glass Using ultra-short laser pulse

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Abstract: Femtosecond laser micromachining was adopted to make a glass mixer with complex geometry. This special design promotes more efficient mixing in microreactor with gas-liquid flux at low flow rates, compared to conventional serpentine mixers.

1. Introduction

Several techniques are used for the development and manufacture of microreactors for microfluidic and optofluidic circuits, among which, lithographic processes, 3D printers, and laser machining are presented in the literature as the most commonly used [1]. In laser machining systems, one of the great highlights regarding the applicability, in microfluidic scale micromanufacturing processes, is the use of ultrashort pulse lasers, which allow high precision machining in various materials classes, including glass and alumina. Another advantage of using ultrashort pulses is the reduced alteration of the material physical and chemical properties in the etched region an in its surroundings [2, 3].

In microfluidic devices, the fluid flow regime is predominantly laminar, and the mixing process is by diffusion, which can be very slow for certain applications. In general, microreactors have a mixer whose purpose is to generate a disturbance in the system through secondary flows, so that as more secondary flows are formed (or more intense), greater will be the level of mixing in this type of microsystem [1, 4]. Clearly, several works have addressed the importance of the development and new applicability studies in the follow-up of passive mixers, whether for synthesis, biochemical analysis, microreactors, or other uses [4, 5]. Faced with this challenge, a Mixer Speedy and Recombination (M-SAR) was micromachined by ultrashort pulses with the purpose of building a microreactor that uses a derivatization technique could identify two chemical species (glyoxal and methylglyoxal) present in the troposphere, which are precursors of tropospheric ozone formation and secondary organic aerosols.

2. Materials and Methods

The mixer was machined in a workstation that uses a titanium-sapphire ($Ti:Al_2O_3$) CPA laser system, model FEMTOPOWER^{TM}, with polarized pulses centered at 800 nm, with a temporal width of 30 fs (FWHM). The system generates a beam with up to 200 μJ per pulse, and a repetition rate of 10kHz. The station also comprises a translation table with CNC control by ISO programming of "G" codes with 3 axes (X, Y and Z) with a precision of ± 10 nm (Aerotech Inc., model ATN-130). In order to enable the micromachining of the M-SAR, three critical points were studied: distance from the origin at which the displacement table reaches above 70% of the programmed speed; the energy per pulse associated with the repetition rate and the strategy of the type of laser beam path displacement to be adopted. Such a study is justified for complex geometries due to the deepening at the ends of the channels and/or geometry (Fig.– 1B and C), which are due to the process of acceleration and deceleration of the displacement table, which are directly related to these points. Fig. 1 presents the M-SAR design, highlighting its dimensions and showing one of the challenges to be overcome for a good micromachining, which must have a low degree of irregularity at the bottom of the channels and walls with an inclination greater than 70º degrees.

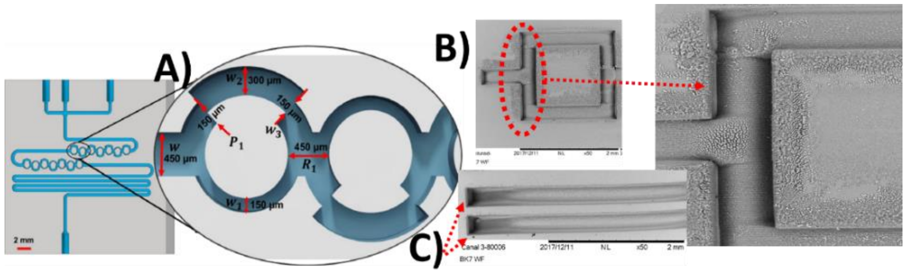

Fig. 1. M-SAR defects caused by the stage travel acceleration and deceleration process A): M-SAR dimensions, B): deepening on the surface of 200μm channels, C) deepening at the channels ends.

3. Results

For the study of the distance at which the stage reaches 70% of the machining speed, a value of 30 mm/s was chosen, resulting in a distance of 156μm from the origin to reach 80% of the final speed. Two energy values were used (25 µJ and 17.5 µJ), both with a repetition rate of 10 kHz, and the lowest energy value was the one that offered the greatest efficiency in reducing the depth and best inclination of the walls. Finally, among the three focal point path displacement strategies used (zig-zag 0°, zig-zag 90º and true spiral), zig-zag 0º was the one that offered the highest quality both in the bottom surfaces, as well as in the degree of inclination of the walls. Fig. 2 shows the final result of the micromachining of the M-SAR, which obtained a wall inclination above 84°, at the most critical point of the geometry with channel height/width ratio $h/w \cong 1$.

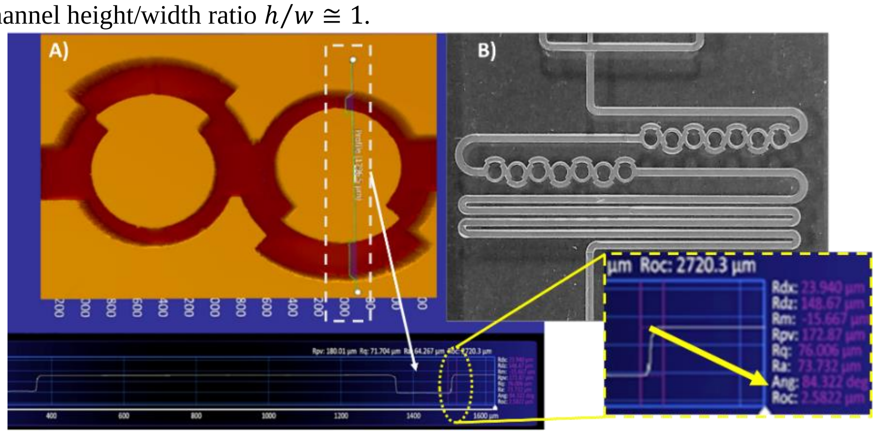

Fig. 2. Optical profilometry of the M-SAR after the micromachining process. A): profilometry of the critical point of the M-SAR after micromachining (emphasis on the angle of inclination), B): image of the microcircuit

4. Conclusion

In determining the parameters for micromachining of the M-SAR presented, in addition to showing the excellent accuracy in the characteristics of the proposed mixer's design, the results obtained at the most critical point of the geometry ($h/w \cong 1$). This is the first reporting, to our knowledge, of these good results for micromachining of optical glass with a femtosecond laser, in this kind of geometry

5. References

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