Microfluidic device for high flow rates: Millipede system in LTCC substrate

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Abstract: *Microfluidic devices offer a strategic way to produce single and double emulsions with narrow size distribution. However, the typical low flow rates are still a challenge for industrial applications. In this work is presented a Millipede microfluidic system, consisted by a set of hundreds microchannels on the same system. Here, the Low Temperature Co-fired Ceramic is used as substrate, offering the possibility to pile up multiple 3D devices. Two systems were designed (268 and 536 microchannels) and, are presented the microfabrication procedures optimized in order to obtain the channels. Laser ablation was used as technique to produce channels with depths from 13 up to 100 µm, varying laser power and steps number. The complete process and the final system were observed by Confocal Microscopy and X-Ray Tomography. The Millipede will be used to produce single emulsions in higher flow rates.*

Key-Words: *Emulsions; LTCC; multilayer system; laser ablation; high flow rates*

Introduction: Emulsions are systems of droplets dispersed in another immiscible phase and are strongly applied in Chemical, Pharmaceutical and Food Industries. Microfluidic devices have been used with success in the production of single and double emulsions. Microfluidics offer a great number of advantages already know by scientific society, and combined to these characteristics, the devices offer a continuum process, with droplet sizes controlled by the combination of fluid flow rate and the device geometry. In despite of many advantages, microfluidic devices present a challenge in terms of production range required for industrial applications. Ordinary devices commonly work in ranges of dozens to hundreds of µL/min. In order to figure out this problem some devices are design with the numbering-up idea, this concept consists on the presence of multiples microchannels on the same substrate [1].

Multiply the number of channels keeping the same transport characteristics obtained in simple microfluidic devices is a critical issue. Some solutions are found in the literature to figure out the problem of fluid flow distribution. One of the most famous strategies is the Murray's Law, with microchannels respecting the vascular distribution. Besides, it is possible to find techniques such as flow distribution by big reservoirs, by porous membrane, by headset systems or multilayer systems [2,3]. In this direction, it was presented the Millipede device by Weitzlab Group at Harvard University µm [4,5]. This system could be compound by five hundred channels in PDMS substrate and is able to process fluid flow rates at 10 mL/h. An improvement of this system was done in glass substrates; in order to produce emulsions consisted by organic solvents, not supported by polymers. Although these devices work in adequate range for industrial applications, the microfabrication procedures still present some challenges. PDMS offers limitations in high pressures and glasses present difficulties in microchannels assembling.

With the purpose to overcome the substrates limitations, we are presenting in this work the Millipede design in Low Temperature Co-fired Ceramic substrate. Among many advantages offered by LTCC, we highlight compatibility with silicon technology, thermal and chemical stability, robustness and systems suitable for high pressures, the possibility to design 3D structures and multilayers systems[6,7]. It was designed two millipedes models, a single millipede with 268 microchannels and a double one, with 563 microchannels. In this moment we present the optimization of microfabrication parameters in order to obtain the systems. Parameters such as laser power and number of steps were evaluated and the results are observed by Confocal Microscopy and 3D X-Ray tomography. This work is still in progress and further, oil-in-water emulsions will be produced, and will be observed droplets size, frequency of production, variation coefficient and maximum flow rates for both systems.

Experimental: *Microfabrication:* It was used LTCC sheets of 225µm of thickness from DUPONT. The LTCC sheets were assembled on the Photolaser U3 model, from LPKF Laser and Electronics Company. The first step was optimizing the laser conditions to cut and do the ablation of the LTCC sheets. Depth channels were assembled by varying parameters such as laser power (0.6-1.2 % of 40W) and number of steps. The results were observed and measured using Confocal Microscope (Confocal Zeiss, Axio CSM 700 Controler). Lamination and sintering process were done by standard procedures, and graphite sheets were used in sintering process as sacrificial material. Two designs were studied here, the first one has 268 microchannels and the second with 536, exploring the idea to produce systems with multiple piled up layers. The smallest channel was designed to have depths of 60µm and the reservoirs are at least 6 times higher. In width, the dimensions varying from 40 to 700 µm. Final systems were evaluated in terms of sintered size and quality in 3D X-Ray Tomography machine. Single emulsions will be prepared using mineral oil as dispersed phase and water as continuous one. The continuous phase will be prepared using 10% wt of Polysorbate (Tween 20) as surfactant. Emulsion characterization will be done using optical microscopy.

Results and discussion: Millipede devices are a 3D structure, which has big reservoirs at least six times higher than side channels where the droplets are produced. The first step to produce this microfluidic system was defining the laser conditions to obtain the side channels, which has depths smaller than reservoirs. In the Fig.1 is presented the depths obtained for different lasers conditions. Varying laser power from 0.6 up to 1.2, it was obtained depths from 13 up to 100 µm. As expected, with high values of laser power and number of steps it was obtained higher depths. However, with highest laser power the channels contour presented more damages. In order to do the ablation of the side microchannels it was used the power of 1.0 and six laser steps. In this condition it is possible to reach depths of 80µm with low damages on the LTCC surface. The complete system sintered is shown in Fig.2 and Fig.3 it is shown an X-Ray tomography image from the system. Microchannels details and challenges obtained in the fabrication process will be presented further. It is expected that Millipede will have operation flow rates between 5-10 mL/min considering the dimensions designed.

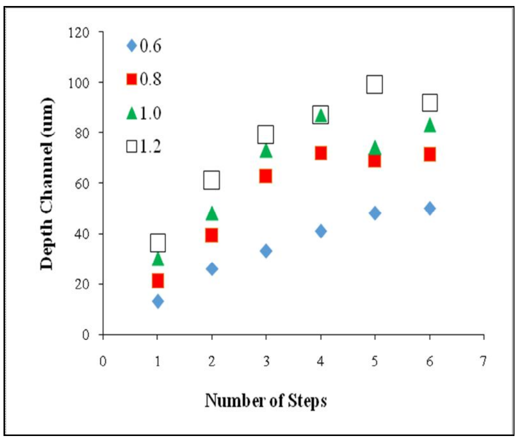

Fig.1

Fig. 2

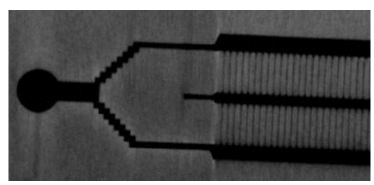

Fig.3

Figures: Fig.1 Depth channels obtained by variation of laser power (0.6 up to 1.2) and number of steps (1-6); Fig.2 Sintered system and Fig.3 X-Ray tomography showing the side microchannels and reservoirs from Millipede.

Conclusion: In this work it is shown the improvements of LTCC microfabrication procedures with laser in other to obtain a Millipede systems. Two examples were designed, one with 268 microchannels and other with 536. This last one is consisted of two millipedes in different levels. Laser conditions defined the quality and depths of microchannels obtained. It is expected that the systems will operate in flow rates over mL/min and will be tested in single emulsion production.

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