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Top-hat profile beam to weld polymeric microfluidics chips with ultra-short pulsed laser

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Abstract

The microfluidics field, due to its various possibilities in the study of chemical and biological reactions with only few consumables, is expanding significantly. To follow this growing, we have developed a flexible solution, based on ultra-short pulsed laser technology, to engrave different microfluidic channels on a chip, and to seal them with a complete, hermetical, and resistant welding.

In order to improve the competitiveness of our solution for industrial production purpose, we have focused in particular our work on the improvement of the welding's speed. Using the Canunda-Pulse[®] solutions from Cailabs for manipulating high-power femtosecond lasers, we have made a complete study on laser welding parameters with a top-hat profile beam. Canunda-Pulse[®] is a fully reflective passive optical module based on the Multi-Plane Light Conversion (MPLC) technology. Thanks to this beam shaper, we have deduced advantages of a top-hat profile beam, compared to a gaussian profile beam.

Keywords: ultra-short pulsed laser; welding; transparent polymer; microfluidics; beam shaping

1. Introduction

The microfluidic field is a research domain targeting the production of micro-chips having similar functionalities as a biological system like blood vessels or as a mini reactor for chemical reactions for example, with a goal of miniaturisation. Those micro-chips are also described as "lab-on-chips". Polymers are interesting matters for microfluidics (Azouz and all, 2014) and two main steps, engraving and sealing are necessary to

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create a microchip. In previous work, the demonstration was made of the achievement of these two steps with the same femtosecond laser in only one machine (Décultot and all, 2019), and a gaussian profile beam.

Research has been conducting to improve the process, with testing of different technologies, like beam-shaping of the laser beam. Beam shaping of USP lasers is key to improve the quality and yield of the processes. Indeed, an optimal intensity profile on the material to be processed avoids wasting energy below the ablation threshold as it might be with a standard Gaussian profile, it may reduce the conicity while drilling, or obtain a given energy seen by the material while scanning with a given overlap. Nevertheless, shaping USP lasers is challenging as on one side the pulse duration has to be preserved through the system, the instabilities of the laser have to be handled in order to avoid frequent realignment, and at last the shape of the beam has to be preserved over the large field of view of an F-theta lens despite the broad spectrum of the beam. Multi-Plane Light Conversion (MPLC) enables a shaping of a USP laser beam solving those challenges.

The different technologies developed by LASEA have been tested in combination with the module of CAILABS for the sealing part. The advantage of Top-Hat profile beam has been demonstrated, without additional layer absorption (Volpe and all, 2015 and Roth and all, 2017), but with a transparent substrate.

2. Experimental setup

2.1. Beam shaper

Multi-Plane Light Conversion is a unique way to think beam propagation and beam modification. Indeed, the light is modified through multiple phase plates with propagation in between. The shaping of the beam is free-form and the quality up to the limit of diffraction. Concretely top-hat profiles might be generated as well as more complex profiles such as a profile with less energy in the center of the beam. The sharpness of the generated profiles is limited by the set-up numerical apertures, reaching therefore the limit of diffraction of the set-up. The MPLC is implemented in a reflective way in order to handle high energy and high power without having thermal effect, to transform the beam without impact on the pulse duration, and at last to have a compact implementation.

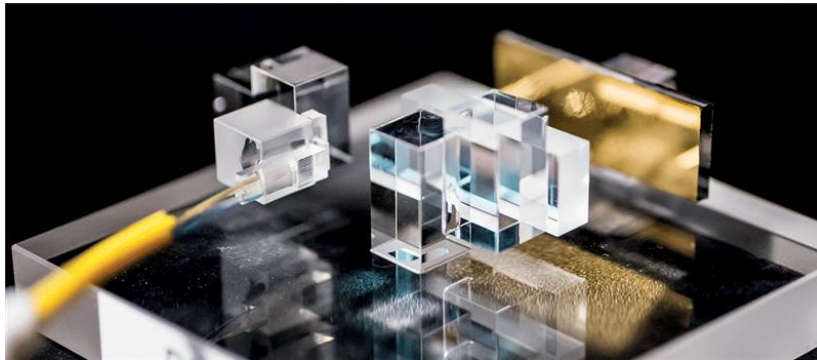


Fig. 1. A MPLC for telecommunication applications.

Besides, the mode-cleaning feature is implemented thanks to the MPLC technology. It enables USP beam stabilization including handling of beam shift or tilt over time as well as astigmatism or ellipticity. The imperfections of the beam profile and instabilities over time are considered as higher order modes and are following a specific path through the beam shaper and dumped. On the other side the energy in the main

Gaussian mode is following another path and getting out of the beam-shaper with a stable shape. This is done at a certain cost in terms of transmission, which depends on the input laser quality.

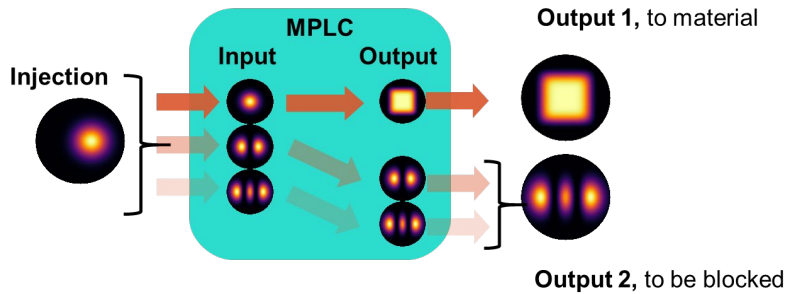


Fig. 2. Mode-cleaning using MPLC technology.

In addition of being stabilized, the beam may be shaped through the MPLC. In this study a specific shape has been generated: a round profile with less energy in the center of the beam. The beam diameter at the output of the module is close to 600 μm . The sharpness (ratio between the transition length defined as the length from 90 % to 13,5 % of the maximum energy, to the plateau length defined as the diameter of the larger circle at 90 % of the maximum energy) is 0.12, more than 5 times sharper than a Gaussian beam.

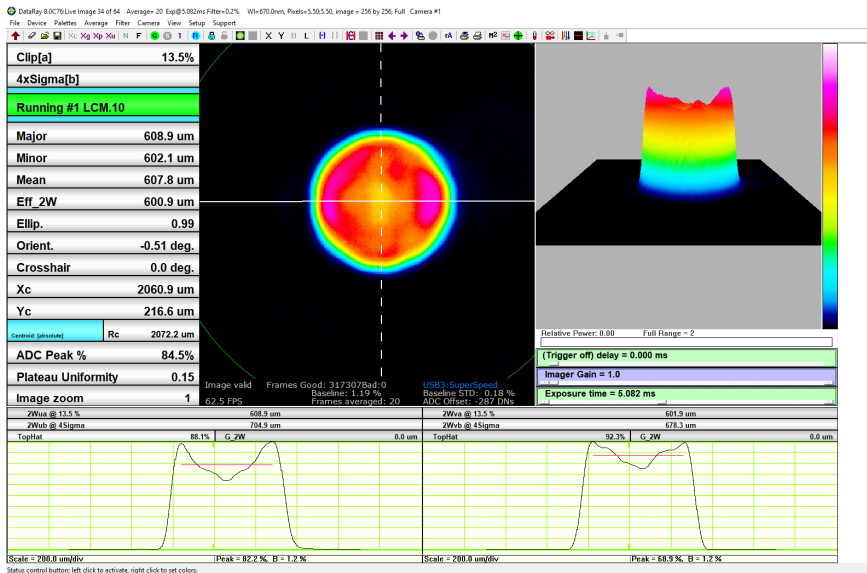


Fig. 3. Beam profile at the output of the beam-shaper.

The transmission of the system for an ideal Gaussian input beam is 93 %. At last depth of field of the shaped beam is preserved compared to the initial Gaussian beam. The phase of the shaped beam is managed with MPLC providing a depth of field after the module and in the processing plane close to the Rayleigh range preserving the process robustness compared to other beam shaping technologies.

2.2. Laser sources and others optical devices

A femtosecond laserbeam at 1030 nm with an energy per pulse limited to 100 μJ is used with the module. To correctly inject the laser in the module, we used a couple of lenses and their positions were precisely adjusted thanks to the software of LASEA, LS-Light® (Fig 4).

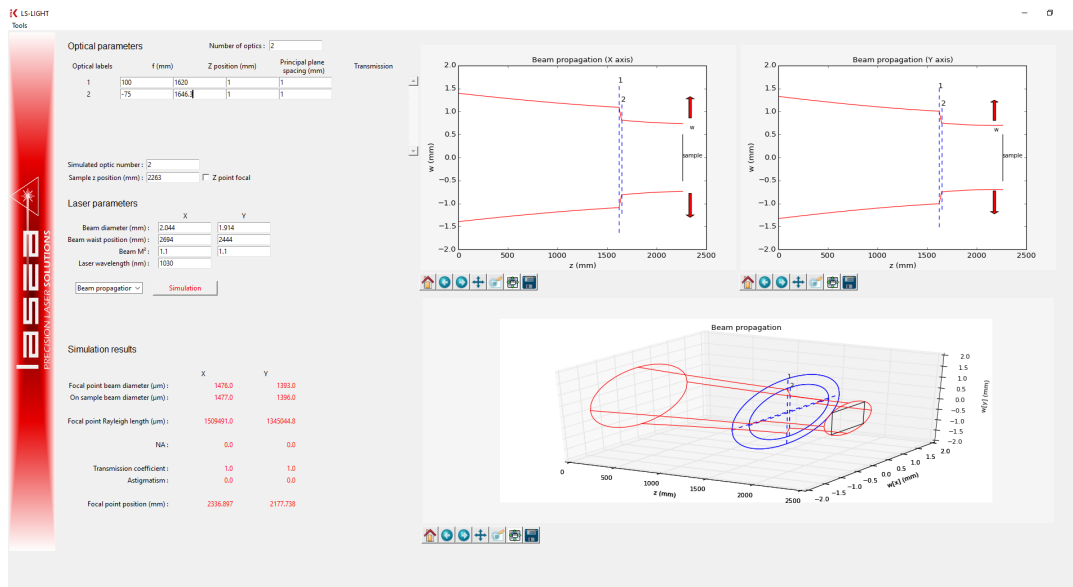


Fig. 4. Simulation of LS-Light® to adjust the position of the lenses.

After the module, a focal lens of 1000 mm is paired with a LS-Scan® (galvo-scanner of LASEA) equipped with a F-theta objective of 100 mm. This scanner head is controlled by the LASEA's software called KYLA™.

In microfluidics sealing, the close contact between the substrates is key. To clamp films and chips together and to have good contact between them, the electrostatic clamping solution, patented by LASEA, has been used. This system ensures a complete non-contact process, the clamping forces are more homogeneous, and the damages on the film due to the use of a mechanical plate for applying the pressure could be avoided.

3. Welding with Top-Hat profile beam and comparison with Gaussian profile beam

In previous work, the feasibility of hermetical and strong sealing of the chip was proved with a gaussian beam. Chips sealed with a top-hat profile beam show hermeticity and strong sealing too. But differences have been observed.

With a gaussian beam of 14 μm size, the size of the weld seam is around 100 μm (80 μm for the smallest) and with irregular edges. With a top hat of 65 μm size, the size of the weld seam is around 70 μm , with more regular edge (Fig 5).

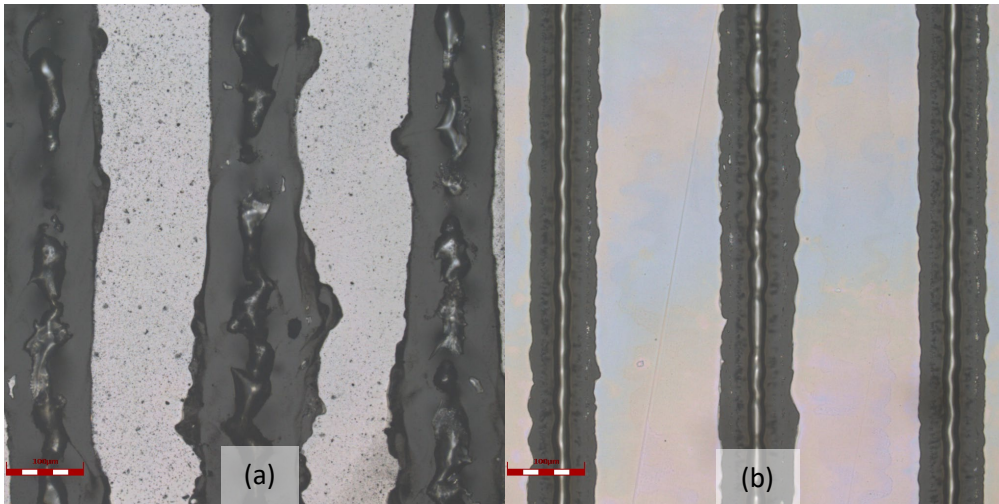


Fig. 5. Comparison at microscope, between weld seam obtained with (a) the gaussian profile and (b) the top-hat profile.

The centre of the weld seam processed with a gaussian beam presents bubbles and burnings matters. It is limited to the centre of the weld seam and does not affect liquid in the channel, but it gives a dark aspect to the product. This effect is not present with the top-hat beam, giving a clear aspect to the product (Fig 6).



Fig. 6. Comparison of aspect between a chip sealed with (a) the gaussian profile, and with the (b) the top-hat profile.

At high speed and high energy with gaussian beam, cracks and more burns emerge. To keep the hermeticity, low energy and low speed has been chosen. When the speed and the energy per pulse have been increased with top-hat beam, no cracks or burns have been observed. The process with this beam is, at least, seven times faster.

The hypothesis to explain these differences is a better repartition of the energy. Thanks to the top-hat profile and homogeneous repartition of the energy, overreactions on inhomogeneity of the polymers are avoided, in comparison with the little zone of irradiation with gaussian beam. Thanks to this better repartition of energy, we are confident that no heat damage on organic materials in the channels, observed with gaussian beam, are also maintained with this kind of profile.

4. Conclusion

This work proves that combining CAILAB's technologies and LASEA's technologies, a better weld seam is achieved, than with a classical gaussian beam. Less burnings, no cracks and a more regular and precise weld seam are advantages of this process. The process is also, at least, seven times faster, and able to maintain a local and controlled heating to avoid damages on organic materials potentially present in the channels of the chip.

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