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DOI:
10.1364/CLEO_AT.2018.AM1M.5

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Laser-based fabrication of microfluidic devices for porous media applications

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Abstract: A picosecond laser is used for rapid prototyping of enclosed microfluidic devices from borosilicate glass substrates. The fabrication method and applications of these devices for the investigation of subsurface flow processes in porous media are presented.
OCIS codes: (140.3390) Laser materials processing; (160.2750) Glass and other amorphous materials; (320.7090) Ultrafast lasers

1. Introduction

Microfluidic devices have found a wide range of applications in many industrial and research areas, primarily in chemistry, biology, medicine and pharmacology. These devices enable the direct observation and investigation of various physical, chemical and biological processes occurring at small (even submicron) scales. Microfluidic devices have also found use in geological and petroleum engineering research as micromodels, investigating various subsurface processes, e.g. fluid flow in porous media [1]. These micromodels contain structures of interconnected pores whose arrangement and shapes are designed in such a way to represent simplified versions of the geometries typically found in the subsurface.

Micromodels for geological and petroleum engineering research can be manufactured from various materials, such as glass-beads, photoresist, PMMA, PDMS, glass or silicon [1, 2]. Glass is often a preferred substrate over polymers and silicon for the fabrication of microfluidic devices due to its unique combination of high transparency, hardness, thermal stability, and chemical resistance. However, conventional manufacturing of glass-based microfluidic devices is a complex, multistep process that involves photolithography, (dry or chemical) etching, and finally anodic bonding [3]. This means that the whole fabrication process of glass microfluidic devices is expensive and time consuming.

In this paper, we present a relatively inexpensive laser-based process for the manufacturing of enclosed porous network structures using borosilicate (Schott Borofloat®33) glass substrates. A single picosecond laser is used for (i) machining the network of pores and microchannels, and (ii) bonding two glass plates together; thus providing an enclosed porous structure to which access is provided by inlet and outlet ports.

2. Fabrication and testing of microfluidic devices

An ultrashort-pulsed laser can be an effective tool for micro-machining a wide range of materials, including glass which is normally transparent for most laser wavelengths [4, 5], as well as for welding glass to glass or even glass to metal [6]. The broad flexibility of these lasers has been utilized in this work for the rapid fabrication of enclosed microfluidic devices to represent porous media. Figure 1 shows an example of the laser-generated microfluidic device which was manufactured from two 75 mm × 25 mm × 1.1 mm thick glass plates. The device contains a grid of microchannels spaced at 50 μm. Each channel within the grid is 14 μm wide (measured as FWHM) and approximately 40 μm deep. Access to the grid is provided by two ports (inlet and outlet) which are connected with the grid via two 14 μm wide channels. The entire structure was generated using a picosecond laser (TRUMPF TruMicro 5x50) that produced 6 ps long pulses at a 515 nm wavelength. In order to provide strong bond between a cover glass and the glass containing the microstructure, these two glass plates were welded together using the same laser but this time the laser operated at a 1030 nm wavelength.

In order to check if the laser-generated welds provide a good seal, we performed a series of fluid flow tests in which water was injected into the micromodel at a pressure of approximately 1 bar. Figure 2 (a) shows the distribution of water within the grid of microchannels while performing one of the fluid flow tests. During the tests we did not observe any water leakage from the micromodel. Moreover, as shown in Figure 2 (b), using an optical microscope it was possible to clearly differentiate between those microchannels filled with water and those filled with air. Hence, the test results clearly indicate that these laser-generated glass micromodels can be useful tools to study flow of different fluids in porous media.

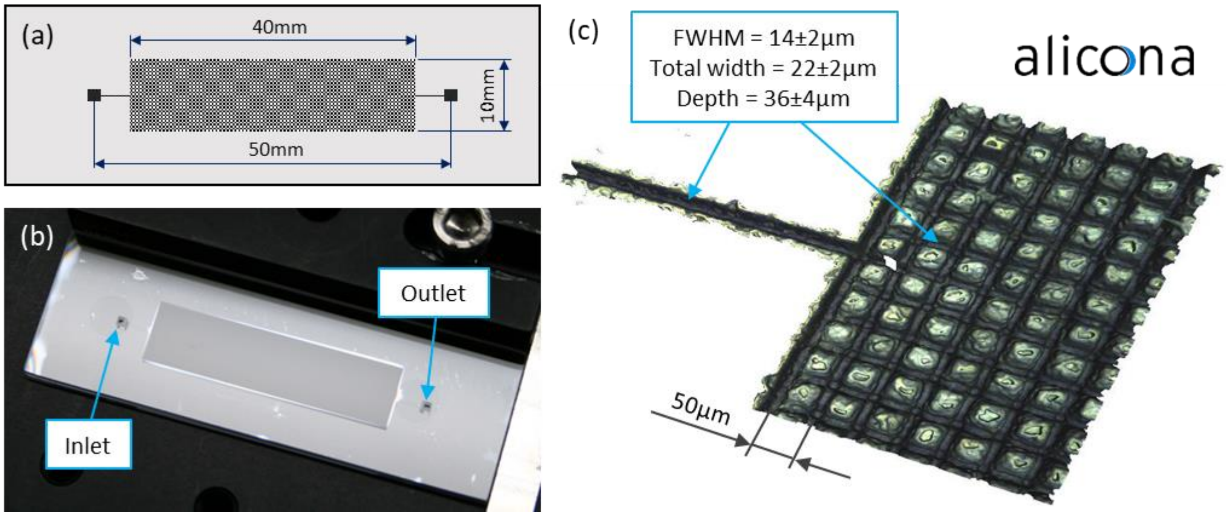

Fig. 1. Laser-fabricated glass model containing a grid of micro-channels: (a) design, (b) photograph, and (c) 3D surface profile of a small area of the micromodel structure.

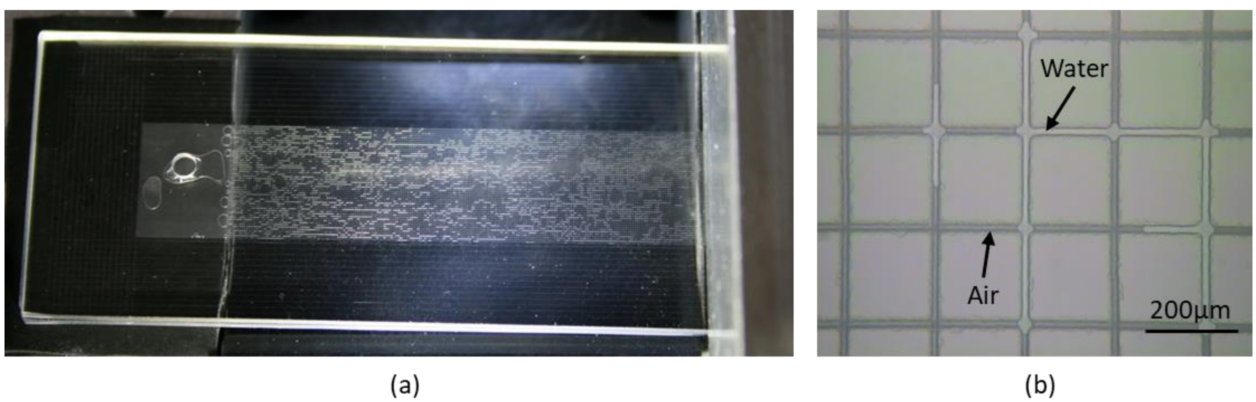

Fig. 2. Snapshot taken during a fluid flow test performed for one of the laser-manufactured micromodels.

3. Acknowledgements

This project has received funding from the European Research Council (ERC) under the European Union Horizon 2020 Research and Innovation programme (MILEPOST, Grant agreement no.: 695070). This paper reflects only the authors' view and ERC is not responsible for any use that may be made of the information it contains. In addition, the authors want to acknowledge Mr. Thomas McGravie and Prof. Eric Mackay (Institute of Petroleum Engineering, Heriot-Watt University, UK) for providing support to perform initial fluid flow tests in the laser-generated models.

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