DIRECT SCANNING LASER WRITING OF 3D MULTULAYER MICROSTRUCTURES

Hui Yu, Biao Li, and Xin Zhang

Department of Manufacturing Engineering and Fraunhofer USA Center for Manufacturing Innovation, Boston University; 15 Saint Mary's Street, Boston, MA 02215
E-mail: ghy@bu.edu; Tel: 617-358-1631; Fax: 617-353-5548

ABSTRACT

Material processing with lasers is an expanding field since it not only makes manufacturing cheaper, faster, cleaner, and more accurate but also opens up entirely new technologies and manufacturing methods that are simply not available using standard techniques. In this paper, we demonstrate the use of a simple beam-scanning laser system for the rapid prototyping of 3D microstructures with different materials as well as the reentrant geometries favorable for photoresist lift-off technique. With the aid of an auxiliary laser alignment setup, this technology could be readily adopted for flexible fabrication of 3D multilayer microstructures.

1. INTRODUCTION

The interest in microstructures with true 3D geometries has dramatically increased in microsystems applications in recent years [1]. To promote the wide applications of such 3D microstructures, the materials and patterning technologies for their fabrication should be inexpensive. A good example would be disposable chips in biomedical applications. Advanced lithographic techniques have been developed to create multidimensional 3D structures with SU-8 negative photoresist such as embedded micro-fluidic channels [2,3], structural parts of micro motors [4] for (bio-) chemical and medical applications. However, those 3D microstructures are fabricated with tedious fabrication processes. Alternative technique, proton beam, has been adopted as direct writing micro-machining method to form embedded micro-channels; but it requires costly facility [5].

Material processing with lasers is an expanding field [6] since it not only makes manufacturing cheaper, faster, cleaner, and more accurate but also opens up entirely new technologies and manufacturing methods that are simply not available using standard techniques. This paper introduces a new, revolutionary 3D manufacturing approach for rapid processing of freeform multi-layer microstructures using a scanning laser system. This technique combines the best features of photolithography techniques in multi-layer processing with the versatility of existing 3D prototyping technologies. The fabrication process is extremely versatile. An apparatus has been built for precise multilevel microstructure alignment, enabling manufacturing of a large number of multi-layered, complex microstructures. In addition, the new fabrication process provides the capability to generate flexible freeform structures using CAD which greatly reduces the development cycle, potentially reaching hours or less design-to-fabrication turnaround time.

2. EXPERIMENT SETUP

2.1 Scanning Laser Direct Writing System

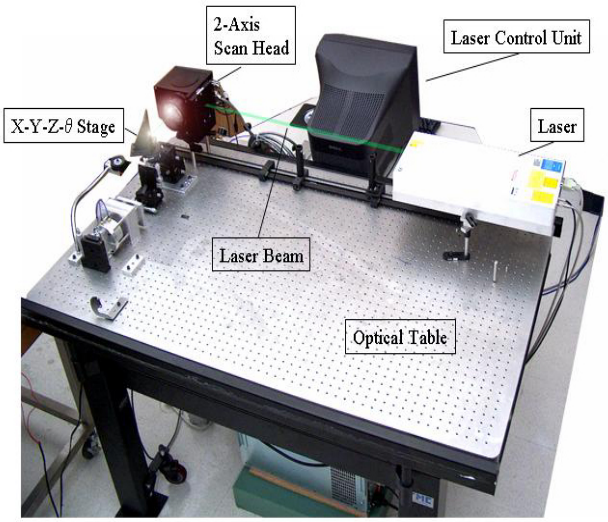
Figure 1a describes experimental apparatus. A diode-pumped, high repetition rate (~100KHz), nanosecond pulse duration 3rd harmonic Nd:YAG laser BL8-355Q operating at a wavelength of 355nm was used as the light source. The laser produces a maximum average power of larger than 400mW at 20kHz. The output energy can be adjusted by varying the pump diode current or by altering the repetition rate. An x-y-z-θ stage was built to translate a sample in four degrees-of-freedom. The laser light is directed through a 2-axis Scan Head before it reaches the sample. The principle of the 2-axis Scan Head is as follows: the laser beam passes through and is steered by a set of x and y mirrors that are coupled to galvanometers. The orthogonal arrangement of the x and y mirrors directs the beam down toward the work piece and over the length and width of the scan field. Field distortion is compensated with an *F-Theta* lens after the two-mirror system. This enables both a large scan field (100×100 mm^2) and a small spot size (~5 μm). ScanWare laser scanning control software developed by Nutfield Technology was used to generate the desired micro-patterns.

In previous work, we have demonstrated various 3D microstructures such as micro-peg array, T-plug, embedded channels fabricated using multi-step inclined scanning laser writing with various incident angles [7].

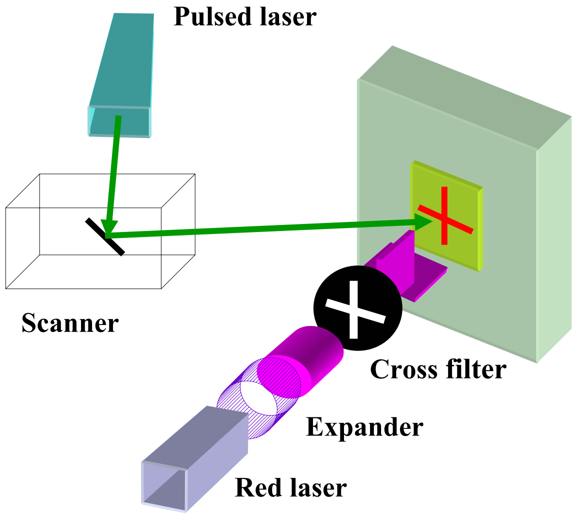
2.2 Apparatus for Multi-layer Alignment

Since the pulsed UV laser is not easily visible, an auxiliary red alignment laser was used as a target for multilevel microstructure alignment. Figure 1b shows the schematic diagram of the experiment setup. The alignment procedure between different layers is as follows: An alignment mark was permanently carved on a target sample using pulsed laser writing. A cross pattern was then generated with the alignment laser and aligned to the mark.

By maintaining the position of the alignment laser cross pattern in place, the sample can be easily unloaded for multilayer processing and then reloaded on the stage for further laser processing. This method works for both front-to-front and front-to-backside alignment.



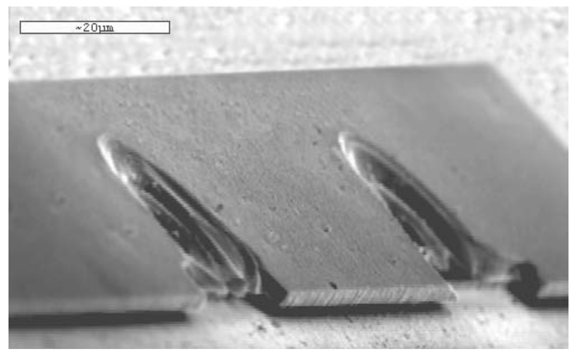
(a)



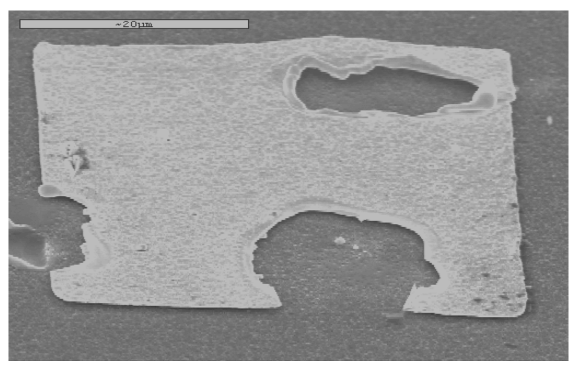
(b)

Figure 1: *(a) Photograph of the scanning laser direct writing system. (b) Schematic diagram of the experiment setup for multi-layer alignment.*

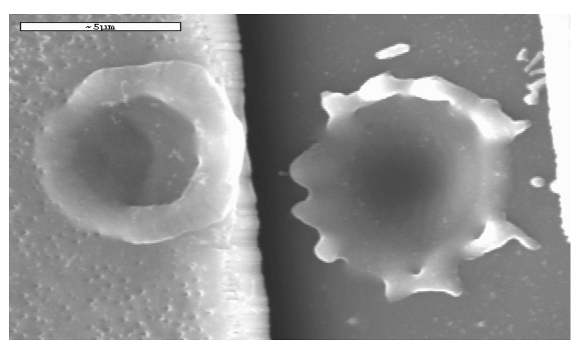
The best-established application of laser processing is abrasive laser machining such as drilling, cutting and trimming etc. With the auxiliary laser, we can align the pulsed laser to micro-machined structures for micro-surgery such as trimming of resistors, which can significantly increase the yield in the processing of resistive elements. In electronics industry, resistors are fabricated with intentionally low values of resistance and then trimmed by removing material from the conducting path due to the difficulty of controlling the value of the resistance to within the tolerances required by the circuit. Laser trimming offers the advantages of better cleanliness and better control over the final resistance. Figure 2a illustrates resistance modification of poly-Si resistors realized by using a second source of laser (auxiliary red laser) for alignment, and the UV pulsed laser for trimming. Much more functionalities were demonstrated, for example metal sputtered etching on Au film shown in Figure 2b and micro-hole drilling illustrated in Figure 2c. The different geometries of ~4μm diameters holes created on poly-Si and Si substrates may be caused by thermal conductivity difference between the two materials.



(a)



(b)



(c)

Figure 2: *(a) Resistance modification for a poly-Si resistor using laser trimming. (b) Metal sputter etching. (c) Etching holes in Si and poly-Si using one laser pulse.*

3. CHARACTERISTICS AND APPLICATIONS

3.1 Microfabrication Using Gaussian Laser Beam

Since the Gaussian-distributed light intensity of UV laser pulse can generate a Gaussian geometry in photoresist, negative wall angle will be formed which is favorable for metal lift-off technique (Figure 3). As can be seen, positive photoresist is subjected to laser pulsing from the backside of a glass substrate. After photoresist developing, an inverse funnel (reentrant) structure is formed. Figure 4a shows the SEM photography of the Gaussian geometry in photoresist generated by Gaussian intensity laser pulsed from backside. Figure 4b demonstrates a micro-heater on glass substrate fabricated using lift-off technique. The fabrication process is as follows: a glass substrate was prepared by cleaning with Piranha (3 sulfuric acid: 1 hydrogen peroxide) for 10 minutes. HMDS was applied by spin-coated at 900 rpm for 5 s, followed by 4000 rpm for 60 s. Shipley 1813 resist was then spin-coated at 900 rpm for 5 s; ramp to 2000 rpm and hold for 60s. The resist was soft-baked and allowed to cool back to room temperature. After the exposure of resist to UV light from backside and developing in MF319 for 1 minute, the sample was hard-baked for 3 minutes at 120°C. A thin film of Au (~230 nm) was sputtered onto the patterned resist. Finally, Acton was applied to strip the resist. When the resist is stripped, the metal on top of the resist is "lifted-off".

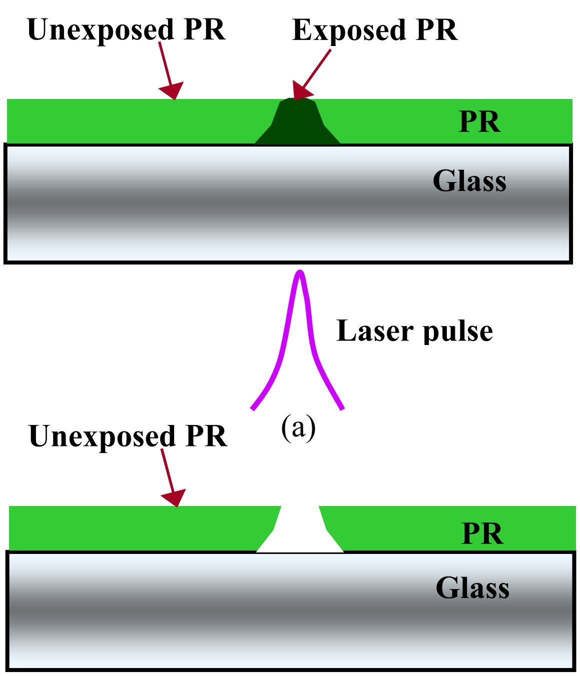
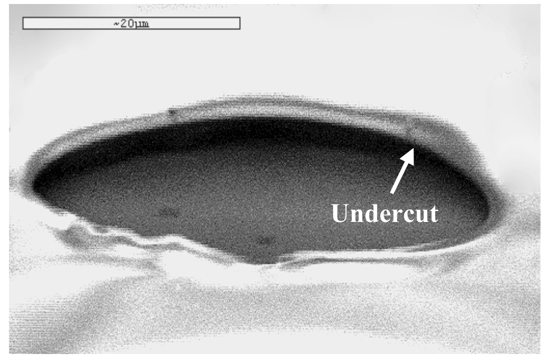
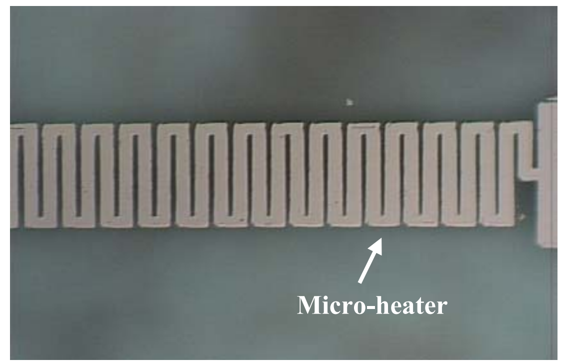


Figure 3: *The inverse funnel (reentrant) structure favorable for metal lift-off technique. (a) Positive photoresist subjected to backside laser pulsing. (b) Reentrant geometry formed after photoresist developing.*



(a)



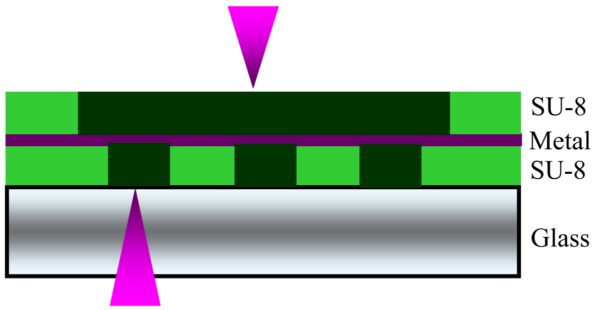
(b)

Figure 4: *(a) SEM photography of the Gaussian geometry in photoresist generated by Gaussian intensity laser pulse from backside. (b) Picture of micro-heater fabricated using our lift-off technique illustrated in Figure 3.*

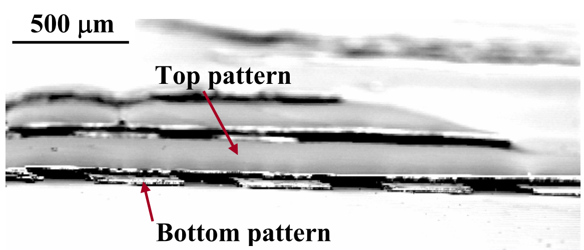
3.2 Three-dimensional Multi-layer Manufacturing

In general, complex 3D structures fabricated from single layer deposition are limited. Multi-layer alignment and fabrication are required with the increase of geometry complexity. The alignment function in a conventional photolithography is realized by using alignment marks to align structures in different layers. Similar to those align marks, with the auxiliary red alignment laser system, a variety of multi-layer 3D structures, which otherwise remain challenges for other scanning laser 3D micro-fabrication techniques, could be readily realized especially for those need the alignment from both the front-side and backside. A schematic diagram of double-side laser writing on two SU-8 layers with a thin metal interfacial layer is illustrated in Figure 5a. A glass sample was first prepared by cleaning in a piranha solution (sulphuric acid:hydrogen peroxide, 3:1) for 10 minutes and dehydrating on a hot plate at 95°C for 5 minutes. SU-8 2025 was then spin-coated to produce a film approximately 60 µm in thickness. The resist was soft-baked and a thin film of Au (~230 nm) was coated by sputtering. Following the sputtering, the spin-coating and pre-bake steps were repeated to coat a second layer of

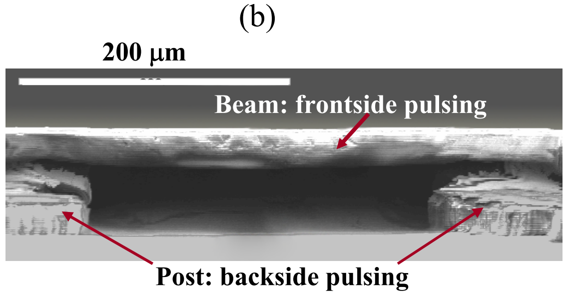
SU-8 onto the Au film. Then the first layer of SU-8 was exposed from the back-side, while the second layer of SU-8 was exposed from the front side. After the post-exposure baking, both resist layers were finally developed in propylene glycol methyl ether acetate (PGMEA). Figures 5b and 5c illustrate double-side-aligned microstructures using laser pulsing from both sides and a magnified embedded channel, respectively.



(a)



(b)



(c)

Figure 5: *(a) Schematic diagram of double-side laser writing on two SU-8 layers with a thin metal interfacial layer. (b) Proof of concept double-side-aligned structures fabricated using laser pulsing from both sides. (c) The magnified embedded channel.*

4. CONCLUSIONS

In summary, we have developed a novel beam-scanning laser system for 3D microstructures fabrication with different materials. By applying the laser-scanning direct writing technique, it was demonstrated that the high resolution, high speed and low cost of the scanning laser direct writing system opened up a variety of applications for example embedded channels, metal lift-off favorable structures etc. Moreover, it is readily to be extended to other materials and microstructures manufacturing which are challenging to achieve by conventional lithography and etching techniques.

ACKNOWLEDGEMENT

This work has been supported in part by National Science Foundation CAREER Award under Contract No. DMI 0239163 and Air Force Office of Scientific Research (AFOSR) under Contract No. F49620-03-1-0078. The authors would like to thank all the other members at the Laboratory of Microsystems Technology (LMST), Boston University for their help and support, especially Alexander Gruentzig, Robert Baranowski, David Mabius, and Jeremy Moyers.

REFERENCES

[1] M. Han, W. Lee, S. Lee, and S.S. Lee, “Microfabrication of 3D Oblique Structures by Inclined UV Lithography,” Proceedings of μTAS 2002, 106, 2002.

[2] R.J. Jackman, T.M. Floyd, R. Ghodssi, M.A. Schmidt, and K.F. Jensen, “Microfluidic Systems with On-line UV Detection Fabrication in Photodefinable Epoxy,” J. Micromech. Microeng. 11, 1, 2001.

[3] Y. Chuang, F. Tseng, J. Cheng, and W. Lin, “A Novel Fabrication Method of Embedded Micro-channels by Using SU-8 Thick-film Photoresists,” Sensors and Actuators A103, 64, 2003.

[4] V. Seidemann, S. Butefisch, and S. Buttgenbach, “Fabrication and Investigation of In-plane Compliant SU8 Structures for MEMS and Their Application to Micro Valves and Micro Grippers,” Sensors and Actuators A97-98, 457, 2002.

[5] F.E.H. Tay, J.A.V. Kan, F. Watt, and W.O. Choong, “A Noval Micro-machining Method for the Fabrication of Thick-film SU-8 Embedded Micro-channels,” J. Micromech. Microeng. 11, 27, 2000.

[6] Dieter Bäuerle, Laser Processing and Chemistry, Springer, 2000.

[7] Hui Yu, Alexander Grüntzig, Yi Zhao, Andre Sharon, Biao Li, and Xin Zhang, “Rapid Prototyping 3D Microstructures on Soft and Rigid Templates Using A Scanning Laser System”, Proceedings of μTAS 2003, 347, 2003.