Journal of the Optical Society of Korea, Vol. 9, No. 3, September 2005, pp. 92-94

Femtosecond Laser Application to Optical Memory and Microfluidics

Ik-Bu Sohn* and Man-Seop Lee

Optical Network and Systems Laboratory, Information and Communication University 119, Munjiro, Yuseong-gu, Daejeon, 305-714, KOREA

Jeong-Sik Woo, Sang-Man Lee and Jeong-Yong Chung

Phoco Co. Ltd. ICU T113, 119, Munjiro, Yuseong-gu, Daejeon, 305-714, KOREA

(Received May 23, 2005 : revised July 21, 2005)

We present a novel method for three-dimensional optical memory and microchannel embedded in fused silica glass. Three-dimensional dot patterning with a femtosecond laser pulse and observation with optical microscope are performed. Dot patterns are created by use of a 0.42 N.A. objective to focus 100 fs laser pulses inside the material. We demonstrate data storage with 2 μm dot pitch and 7 μm layer spacing (36 Gbit/cm^3). A three-dimensional microchannel acting as microfluidic and microoptical components is directly fabricated inside a silica glass. The optical micrographs of the microchannel are obtained by a digital camera of a microscope.

OCIS codes : 050.1950, 140.3390, 230.7370, 230.1360.

I. INTRODUCTION

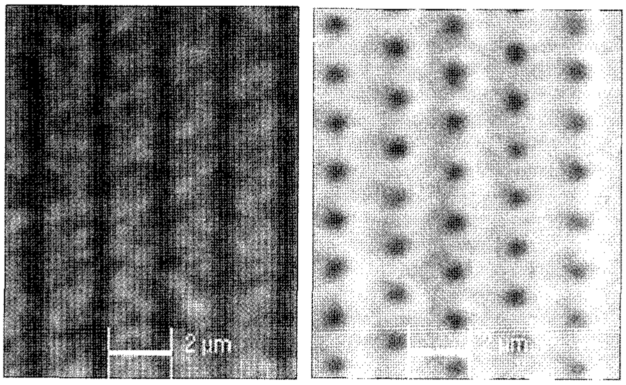
Laser processing of materials is widely used for fabrication of devices in areas such as nanotechnology (carbon nanotubes and nanopatterning), Micro-Electro-Mechanical-Systems (MEMS), laser crystallization of Si for solar cells and displays, surface texturing, advanced lithography and surface modification. Lasers can provide unique material processing solutions. Laser-solid interactions will develop new fields of nanoscience and technology. Well-controlled nanostructures can be synthesized and manipulated by lasers for future nanodevices. Femtosecond lasers are an exciting new technology for materials processing [1,2] and optical devices fabrication [3-9] as it is independent of the optical properties of the materials. We present some results obtained with the femtosecond laser for 3-D optical memory and microfluidics. Submicron dot patterning, which is applicable to optical memory, and 3-D microchannel embedded in fused silica glass are described.

II. EXPERIMENTS AND RESULTS

1. Femtosecond laser application to optical memory

When a femtosecond laser pulse is tightly focused inside a transparent material, the laser intensity at the focus becomes high enough to induce nonlinear absorption through a combination of multiphoton absorption, tunneling ionization, and avalanche ionization. If the absorption deposits enough energy in the material, permanent structural changes are produced. These structural changes are confined to the focal volume because of the nonlinear nature of the absorption. By scanning the laser focus of a continuous pulse train inside the sample, the refractive index can be changed in regions of any desired three-dimensional shape. We have used this technique to create line and dot patterns as a localized structural change for the 3-D optical storage in a fused silica glass.

Using 1 kHz pulse trains of 100 fs laser pulses focused by a 0.42 NA microscope objective, we fabricated submicron line and dot patterns using an 800 nm Ti:sapphire laser. When the laser pulses were focused inside the fused silica glass, a modification of the optical properties was observed along the optical axis of the laser pulses. The visible laser damage can be formed only inside the focused region because nonlinear optical processes, such as multiphoton absorption, occur in regions with high optical intensity above the damage threshold. Modification of the sample is visible in a transmitted light optical microscope. We created 2-D line and dot patterns using a single shot of femtosecond laser beam. Figure 1 shows the microscope image of line and dot patterns directly written inside fused silica glass by femtosecond laser pulses with pulse energy of 320 nJ and a 50 × microscope objective as the focusing lens. The line and dot patterns are separated by 2 µm and the line width and dot diameter are 500 nm, respectively. In Fig. 1(a), each line represents the optical modification inside the glass in the region where laser pulses were focused. The scan speed was 10 µm/s, and only a single scan was performed for each line. As shown in Fig. 1(b), submicron dot patterning is applicable to optical memory and photonic crystals. Fig. 2 shows the map of Korea. The conditions of femtosecond laser processing are the same as shown in Fig. 1(b). Also, we tightly focus femtosecond laser pulse inside a fused silica glass to create localized structural changes, thereby altering the refractive index of the substrate. This process can be used to record digital information in three-dimensions as shown in Fig. 3. Optical microscope image of 3-D dot patterns is shown in Fig. 4, which consists of three layers. The first, second and third layers display the letter of I, C, and U, respectively. The layer gap and dot pitch are 7 µm and 2 µm, respectively. Femtosecond laser submicron line and dot patterning has the potential to fabricate Bragg gratings, optical memory, and photonic crystals.



(a) (b)

FIG. 1. Microscope image of a 2-µm period (a) line and (b) dot patterns directly written inside fused silica with 320 nJ pulse energy. Line width and dot diameter are 0.5 µm.

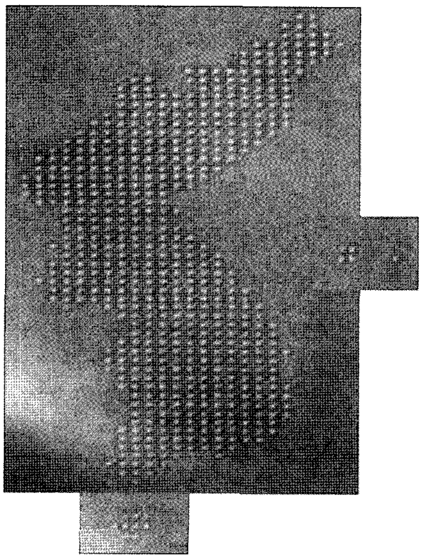


FIG. 2. Optical microscope image of map of Korea. The dot diameter and pitch are 0.5 µm and 2 µm, respectively.

2. Femtosecond laser application to microfluidics

There has been rapid progress in the research and development of Bio-MEMS and microfluidics. Currently, fabrication of microchannel relies on the use of a semiconductor processing technique using photolithography. Although that technique has been well established, the fabrications of true three-dimensional microstructures currently require multilayer and multistep processes

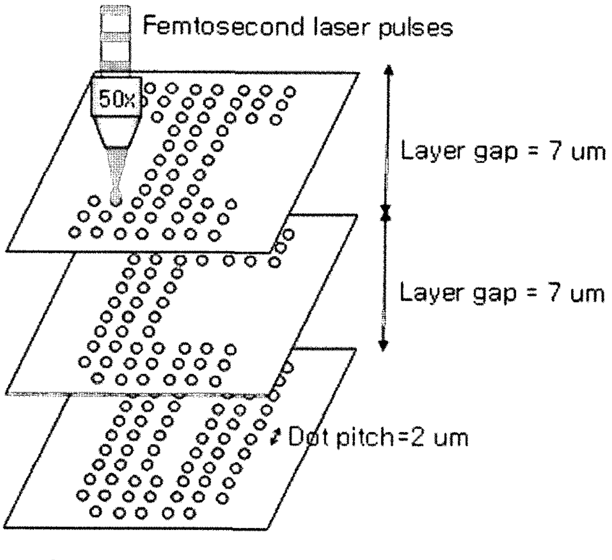
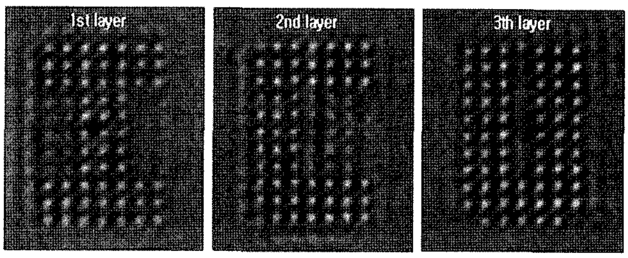


FIG. 3. Schematic diagram of 3-D optical memory.



(a) (b) (c)

FIG. 4. Optical microscope image of 3-D dot patterns consisted of three layers, which is applicable to optical memory. The first, second and third layers display the letter (a) I, (b) C, and (c) U, respectively. The layer gap and dot pitch are 7 µm and 2 µm, respectively.

including stacking and bonding substrates. We fabricated a 3-D microchannel embedded in silica glass as shown in Fig. 5. A femtosecond laser with pulse energy of 430 nJ and a 20 × microscope objective was used to form 3-D microchannels embedded in silica glass. The channel width and length are 25 μm and 170 μm, respectively. The two hollows on the surface at the left-hand side serve as solution inlets, and the other one on the right-hand side serves as the solution outlet. For testing this microchannel, the solutions were driven through the microchannel and went out to the right hollow when the solutions with red inks were introduced in the left hollow. Fig. 6 shows the optical micrographs of the flowing process at the microchannel, which was captured by a digital camera of a microscope for the time before the solutions entered into the channel and after the solution entered into the channel. The 3-D microchannels are realized only one step process including femtosecond micromachining without any other techniques, such as heat annealing and chemical etching. This process has a great interest for the fabrication of 3-D microfluidic systems.

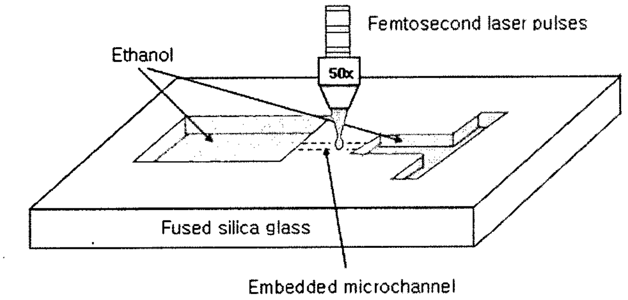


FIG. 5. Schematic illustration of the femtosecond micromachining for fabricating a 3-D microchannel embedded in silica glass.

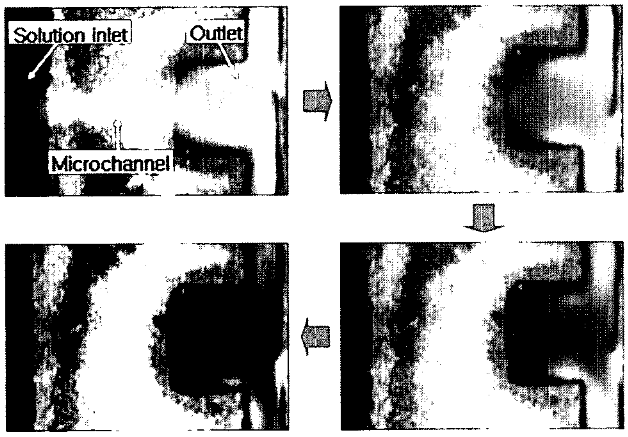


FIG. 6. Optical micrographs of the flowing process at the microchannel, which was captured by a digital camera of a microscope for the time before the solutions entered into the channel and after the solution entered into the channel.

III. CONCLUSION

We have demonstrated a novel method for high-density 3-D optical memory that uses femtosecond laser pulses. The 3-D patterning is done with ultrafast-laser-induced microexplosions, producing localized submicrometer-diameter structures with high contrast of refractive index. We observed the binary data patterns being stored inside fused silica glass with an optical microscope using transmitted light. Also, 3-D microchannel for microfluidics was fabricated inside glass. This structure can be directly formed inside an integral glass-chip without bonding and stacking processes, thus the process is free from assembling and packaging steps. In the future, the microfluidic circuit and the microoptical circuit can be integrated onto one chip, making it possible to enhance the functions of both lab-on-a-chip and optoelectronic devices.

*Corresponding author : ibson@icu.ac.kr

REFERENCES

[1] S. Juodkazis, S. Matsuo, H. Misawa, V. Mizeikis, A. Marcinkevicius, H. B. Sun, Y. Tokuda, M. Takahashi, T. Yoko, J. Nushii, "Application of femtosecond laser pulse for microfabrication of transparent media," *Appl. Surf. Scien.*, 197-198, pp. 705-709, 2002.

[2] Ik-Bu Sohn, Man-Seop Lee, and Jeong-Sik Woo, "Femtosecond micromachining applications for optical devices," *J. Optical Society of Korea*, vol. 8, pp. 127-131, 2004.

[3] K. Hirao and K. Miura, "Writing waveguides and gratings in silica and related materials by a femtosecond laser," *J. Non-Cryst. Solids.*, vol. 239, pp. 91-95, 1998.

[4] D. Grobnic, C. W. Smelser, S. J. Mihilov, R. B. Walker, and P. Lu, "Fiber Bragg gratings with suppressed cladding modes made in SMF-28 with a femtosecond IR laser and a phase mask," *IEEE Photon. Technol. Lett.*, vol. 16, pp. 1864-1866, 2004.

[5] C. Florea and K. A. Winick, "Fabrication and characterization of photonic devices directly written in glass using femtosecond laser pulses," *J. Lightwave Technol.*, vol. 21, pp. 246-253, 2003.

[6] Ik-Bu Sohn, Man-Seop Lee, Jung-Yong Chung, and Sung-Hak Cho, "Nano-structuring of transparent materials by femtosecond laser," *J. Optical Society of Korea*, vol. 9, pp. 1-5, 2005.

[7] E. N. Glezer, M. Milosavljevic, L. Juang, R. J. Finlay, T. H. Her, J. P. Callan, and E. Mazure, "Three-dimensional optical storage inside transparent materials," *Opt. Lett.*, vol. 21, pp. 2023-2025, 1996.

[8] Ya Cheng, Koji Sugioka, Katsumi Midorikawa, "Microfabrication of 3D hollow structures embedded in glass by femtosecond laser for Lab-on-a-chip applications," Appl. Surface Science, 2005.

[9] C. B. Schaffer, T. N. Kim, K. N. Campbell, A. N. Groisman, D. N. Kleinfeld, "Machining microfluidic devices in PDMS using femtosecond laser pulses," *Photonics West*, 5713A, 2005.