Journal of Ceramic Processing Research. Vol. 10, No. 6, pp. 848~850 (2009)

J O U R N A L O F
Ceramic Processing Research

Formation of microdots on the surface of cobalt-doped borosilicate glass by a Nd:YAG laser

T.H. Kim[a], K.H. Lee[a], Y.J. Jung[a], Y.S. Kim[a], H.J. Chin[a], H.S. Yoon[b], J.H. Kang[b] and B.K. Ryu[a,*]
[a]*Division of Materials Science and Engineering, Pusan National University, Busan 609-735, Korea*
[b]*Kortherm Science, Buyeong-Gu, Incheon-City, 403-030, Korea*

We have demonstrated the formation of microdots on the surface of a cobalt-doped borosilicate glass by laser irradiation. The glass was irradiated by a Q-switched Nd:YAG (SHG) laser. A bump with a Gaussian shape was formed in a small area on the glass surface after irradiation. The distribution of temperature on the irradiated surface due to the laser beam profile, optical absorption and thermal diffusion was inferred as the origin of the bump shape. The maximum peak height was about 16 μm and the diameter was 262.3 μm. This process gives us the possibility for a micro lens fabrication process with the use of borosilicate glass and a Nd:YAG laser.

Key words: Glass, Laser, Microdot, Cobalt, Bump, Thermal diffusion.

Introduction

Glass is one of the most important materials for micro-optics and optoelectronics application. Micro-lenses and optical waveguides are key components for optical communication. For the production of these optical parts, microfabrication of glass is important. Such a micro fabrication process has been performed using lithography and etching technology until now. On the other hand, laser machining is an attractive approach for the microfabrication of glass. Laser machining using CO_2, Nd:YAG and excimer lasers has been applied to metals, ceramics and polymers. Generally laser machining of glass has been reported using CO_2 and excimer lasers [1-5].

However, Nd:YAG lasers have a strong potential for use in laser machining because of their compactness and ability to emit light of several wavelengths through nonlinear optical crystals. Some types of Nd:YAG lasers have a long coherent length with high power so they can be used for interference pattering. However, there are few reports of the use of a Nd:YAG laser in glass machining applications. The reason for this is both the transparency and brittleness of glass. In such a case, machining of the glass is difficult due to the low degree of interaction of the glass with laser light. Thus, it is necessary to develop suitable glasses which can be interacted appropriately with a Nd:YAG laser [5-7].

In this paper, we describe three factors. First, we establish a proper dopant which absorps the given laser light. Because generally glass transmits visible light rays. Second, we determine the proper portion of dopant to add to the host glass matrix. Third, we verify the results when a laser pulse is applied to the glass at a given power.

*Corresponding author:
Tel : +82-51-510-2384
Fax: +82-51-517-8838
E-mail: bkryu@pusan.ac.kr

Experimental procedure

To find out the which dopant best absorps the 532 nm laser light, UV-vis (Agilent 8453) experiments were carried out. Then the selected dopant was added to the glass. The main composition of the glass used in this study was $10Na_2O$-$10CaO$-$10B_2O_3$-$70SiO_2$ which is a composition similar to that used generally in windows. Dopant was added into the glass from 0.2 mol% to 3 mol%. Each glass was melted at 1,400 °C for 2 hours in a platinum crucible in an electric furnace. The molten glass was quenched onto a heated iron plate and heat treatment was carried out at 500 °C for 30 minutes. Then the molted glass was mechanically polished with CeO_2 powders to a mirror finish.

The laser used for irradiation was a Q-switched Nd:YAG laser with a 2nd harmonic (532 nm) beam. The pulse duration was around 10ns and the repetition frequency was 10 kHz. Experiments were performed as follows. Glass was placed between the lens and its focal point and the energy of irradiation was increased from 10 J/cm^2 to 990 J/cm^2. After irradiation with the laser, the texture of the glass surface was observed with FE-SEM (JSM6330F Jeol. co.) and the height and diameter of the irradiated region were observed with an Alpha-step (AS-IQ, KLA TENCOR).

Results and Discussion

It is well known that borosilicate glass transmits visible light [8, 9]. A dopant material is needed to give an

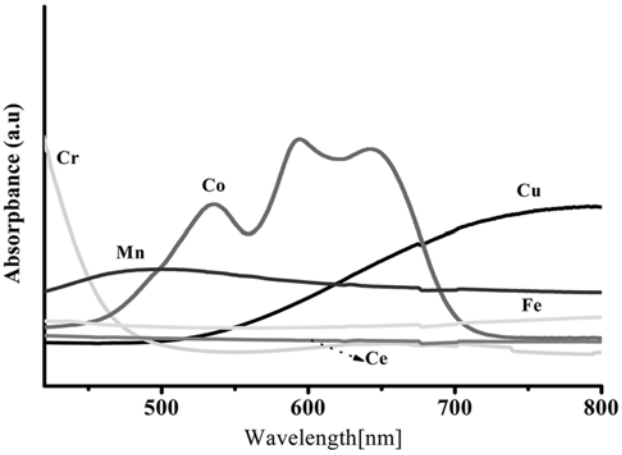

Fig. 1. Absorption spectra of various materials.

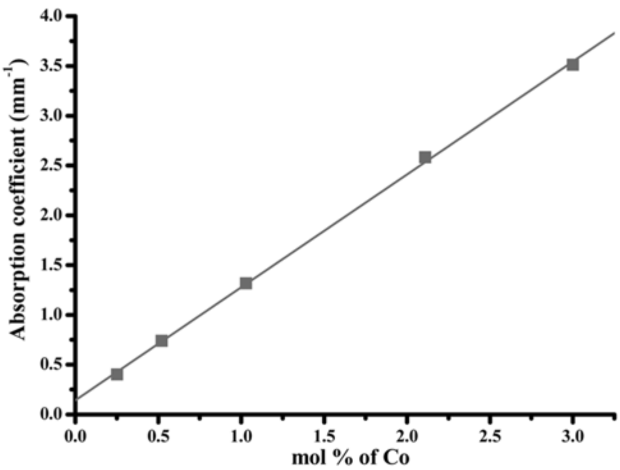

Fig. 2. Degree of change of absorption of the glass sample as a fraction of cobalt mol%.

absorption band to the glass at 532 nm pulse. Fig. 1 shows the absorption spectra of various materials from 400 to 800 nm. With a 532 nm pulse, cobalt has the highest absorption when compared with other materials. Absorbance depends on the concentration. Therefore, cobalt dopant was added from 0.2-3 mol% to the glass and the absorption spectra were analyzed. Fig. 2 shows the results. With an increase of the proportion of cobalt the absorption intensity also increased. But the absorption intensity was not easy to detect in the case of more than

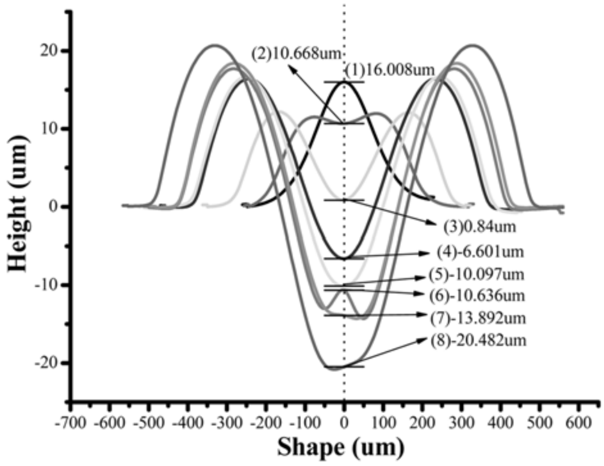

Fig. 3. Shape change of surface bump on the glass according to the laser energy. (1) 366 J/cm^2 (2) 443 J/cm^2 (3) 525 J/cm^2 (4) 622 J/cm^2 (5) 710 J/cm^2 (6) 799 J/cm^2 (7) 884 J/cm^2 (8) 990 J/cm^2.

2 mol% because of an excess coloring effect. Furthermore cobalt is well known as a colorant in the glass industry. Excess additions of cobalt can cause a decrease of optical properties. So we chose 1 mol% dopant. When a laser is applied to the glass, cobalt ions act as an absorption band in the glass matrix. This is related to the surface plasmon resonance of Co ions [10]. It is considered that Co ions initiate the laser reaction and contribute to the reduction of the threshold energy [6, 10].

Figure 3 shows the shape change against beam power. In this figure a cross section image of the bump revealed a Gaussian-like shape with a maximum peak height of about 16 μm and radius of 262.3 μm. The first reason for these results is due to the increase at the beam center in the maximum temperature that resulted in the evaporation of the glass [5, 11]. The second is related to multi-photon absorption and a change in the absorption coefficient during the irradiation. The change in the absorption coefficient is related to the color centers in the glasses generated by the laser irradiation [6, 12]. The height of bumps in the glass host depends on the increase of fluency. With an increase in laser energy the height of the bump in the glass host increased. But if the laser power was too high so as to disconnect the glass bonding, a pit is generated rather than a bump. Figure 4 shows SEM images of the irradiated areas.

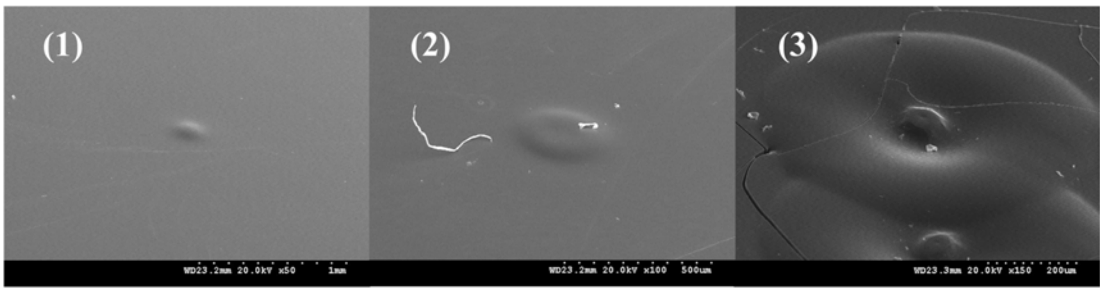

Fig. 4. SEM images of the irradiated areas. (1) 366 J/cm^2. (2) 443 J/cm^2 (3) 799 J/cm^2.

Conclusions

We found that cobalt acts as an absorption material to a SHG(532 nm) Nd:YAG laser light by adding this dopant to a $10Na_2O$-$10CaO$-$10B_2O3$-$70SiO_2$ glass. Also this glass matrix is suitable for laser machining and an ablation process using a Nd:YAG laser in the low power region. Co ions provide glasses with laser machinability. The shape of the irridiated area was changed according to the beam power. Also we were able to control the bump height with a beam power change. This process gives us the possibility for a micro-lens fabrication process with the use of borosilicate glass and Nd:YAG laser.

Acknowledgement

This work was supported by a grant-in-aid for the National Core Research Center Program from the Ministry of Science & Technology and the Korea Science & Engineering Foundation (R15-2006-022-02001-0).

References

1. C. Buerhop, B. Blumenthal, N. Lutz and S. Biermann: Appl. Surf. Sci. 46 (1990) 430.
2. B. Braren and R. Srinivasen: J. Vac. Sci. & Technol. B 6 (1988) 532.
3. R. Nowak, S. Metev, G. Sepild and K. Grobkof: Glastech. Ber. 66(1993) 227.
4. S.R. Jackson, W.J. Metheringham and P.E. Dyer: Appl. Surf. Sci. 86 (1995) 223.
5. X. Liu, D. Du and G. Mourou. IEEE J. Quantum Electrinics, vol 33, 1706-1716.
6. T. Koyama and K. Tsunetomo, Jpn. J. Appl. Phys. Vol. 36 (1997) pp. 244-247.
7. F.M. Ezz Eldin, N.A. El Alaily, Materials Chemistry and Physics 52 (1998) 175-179.
8. Y.K. Sharma, S.S.L. Surana, R.K. Singh, R.P. Dubedi, Optical Materials 29 (2007) 598-604.
9. D. Manikandan, S. Mohan, K.G.M. Nair, Physica B 337 (2003) 64-68.
10. R.H. Magruder III, J.E. Wittig and R.A. Zuhr: J. Non-Cryst. Solids 163 (1993) 1035.
11. N. Kitamura et al. Jpn. J. Appl. Phys. Vol. 42 (2004) Pt. 2, No 6B.
12. S.D. Stookey, "Recent Developments in Radiation Sensitive Glasses," Ind. Eng. Chem., 46. (1954) 174-76.