Composition Change of Glass Materials in Microlenses Formed by CO_2 Laser

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The aim of our research is to develop the fabrication process of microlens which is formed directly on a surface of a glass plate using CO_2 laser. This method has the merit of complete dry processing and presents the simple way of microlens fabrication. We discuss about the formation process and mechanism for different laser irradiation parameters and glass compositions. When the surface of a glass plate is heated locally to a characteristic temperature of the glass material by a focused CO_2 laser beam, a microlens is formed owing to surface tension. It was found possible to fabricate microlens easily for the glass plate placed at different focal position by controlling the laser power and the irradiation time. The volume of the fabricated microlens was found to depend on laser irradiation energy (laser power x irradiation time) and the focusing condition. In this experiment, microlenses shapes with both convex and concave lenses were obtained. Moreover, the concave microlens was observed at the early stage of the formation process (0.03 seconds or less) of the convex shape. It was found that final shapes of the microlenses depended on the irradiation condition of the laser and the material of the substrate.
DOI: 10.2961/jlmn.2007.01.0008

Keywords: CO_2 laser, microlens, focused laser beam, surface tension, glass plate,

1. INTRODUCTION

The technology to fabricate a small optical component is becoming more important for various optoelectronics applications. Miniaturization of the lens size is especially important in the optical components. There are many applications of microlenses and microlens arrays, including a beam collimator, a lens array set on the top of a two-dimensional (2-D) CCD image sensor, and optical systems for optical switching and optical parallel information processing. There are various microlens fabrication methods, such as the Ion exchange method and the machining method [1-6]. But, these methods require a complicated fabrication process. As an alternative method, we have researched the fabrication technique of microlens using a CO_2 laser. This method has the merit of complete dry processing. Therefore, fabrication of microlens is easily possible. Basic research on the thermal effect of a CO_2 laser on glass plates was carried out by Veiko et al [7]. They classified the effect in three regimes: soft laser heating, hard laser heating, and evaporation regimes [8]. They showed typical examples for each regime, and treated the process behavior of a submicron system with the lens diameter ranging from 0.5 to 6 mm. Microlens and microlens arrays with a lens diameter ranging from 100 to 200 µm were fabricated by Wakaki et al. [9-11] by focusing the CO_2 laser on a glass plate. In this paper, we discuss about the formation process and the mechanism through the characterization of the irradiation parameters and the glass composition.

2. EXPERIMENTAL PROCEDURES

The experimental setup for fabricating a microlens is shown schematically in Fig. 1. An output beam of the CO_2 laser was focused normally on the surface of a glass plate through a ZnSe lens with a 63.5mm focal length. The irradiation power of 1.0-10.0W and the irradiation time of 0.01-100sec were used. The irradiation position of glass plate was changed around focal point along the laser beam direction to observe the volume change of the microlens. The irradiation positions were set at 5points ranging 8mm back and forth of a focal point (Fig.1). Several glass substrates such as fused silica glass, Corning TEMPAX glass, Schott B-270 glass and Corning 7059 glass plates were used. A Corning 7059 glass plate was selected as a substrate for its small thermal expansion and high melting points of the oxide added with Al_2O_3, B_2O_3, and BaO. We selected glasses in consideration of content of SiO_2. A fused silica was selected as the substrate with mono element of SiO_2. A Schott B-270 and TEMPAX glass were selected as the substrate, because the content of SiO_2 element took the amount in the middle of the fused

Table 1 Typical parameters of glass substrates

(a) Quartz glass, TEMPAX glass

	Quartz glass		TEMPAX glass	
Composition [wt%]	SiO_2	99.9	SiO_2	80.0
			Al_2O_3	2.5
			B_2O_3	13.0
			Na_2O, K_2O, etc	1.0
Coefficient of thermal expansion	0～100℃ 5.4×10^{-7}/℃		32×10^{-7}/℃	
Strain P.	1070℃		522℃	
Annealing P.	1150℃		568℃	
Softening P.	1650℃		815℃	
Working P.	-		562℃	
Density	2.203 g/cm^2		2.23 g/cm^2	
Young modulus	852,000MPa		62,959MPa	
Poisson's ratio	0.14		0.22	
Refractive index	1.45845 (587.56nm)		1.472(588nm)	

(b) B-270 glass, 7059 glass

	B-270 glass		7059 glass	
Composition [wt%]	SiO_2	70	SiO_2	49
	CaO	8	Al_2O_3	10
	BaO	2	B_2O_3	15
	Na_2O,ZnO,K_2Oetc	20	BaO	25
Coefficient of thermal expansion	20～300℃ (9.4±0.1) ×10^{-6}/℃		0～300℃ 46.0×10^{-7}/℃ 25℃～Setting Temperature 50.1×10^{-7}/℃	
Strain P.	511℃		593℃	
Annealing P.	541℃		639℃	
Softening P.	724℃		844℃	
Working P.	1006℃		1160℃	
Density	2.55 g/cm^2		2.76 g/cm^2	
Young modulus	7,150MPa		67,500MPa	
Poisson's ratio	0.22		0.28	
Refractive index	1.5251(588nm)		1.5333(589.3nm)	

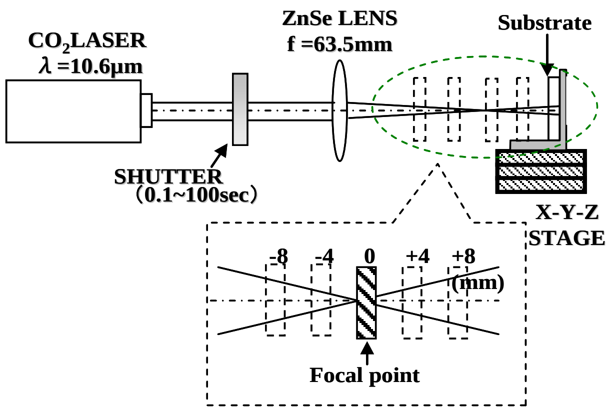


Fig.1 Schematic drawing of the irradiation positions for the fabrication of microlens.

silica glass and Corning 7059 glass. However, these glasses were different at the element relating with the surface tension. The typical physical parameters of each glass were shown in Table 1. A heat-resistant glass is proof against thermal shock caused by laser irradiation, which causes cracks for glasses with poor heat-resistant properties. The occurring of the crack by the heat stress could be controlled by the annealing [9]. In this study, we did not anneal the glass substrate to observe the composition change and stress change of the glass. The shape of the microlens was observed by an optical microscope, an AFM (atomic force microscope) and a SEM (scanning electron microscope). The composition of the glass was characterized by using EDX (energy dispersive spectroscopy). The behavior of thermal conduction during the micro lens formation was analyzed by using the thermal conduction analysis software (CFD2000).

3. Results and Discussions

The laser power and the irradiation time of the CO_2 laser must be selected appropriately to form a microlens. The radiation at the extremely high laser power level tends to ablate the glass, generates residual microbubbles and also refractive-index distribution. The radiation at the too low laser power level does not deform the surface of the glass plate (Fig.2). Moreover, the concave shape was observed at very high laser power irradiation according to the evaporation of the material. The optical characteristic of this concave lens was not so good. Appropriate power and irradiation time to obtain a microlens depend on the thermal and mechanical properties of the glass. The diameter of the microlens can be controlled to some extent by a spot diameter and the intensity of an irradiated CO_2 laser beam. The diameter of the microlens depends on the

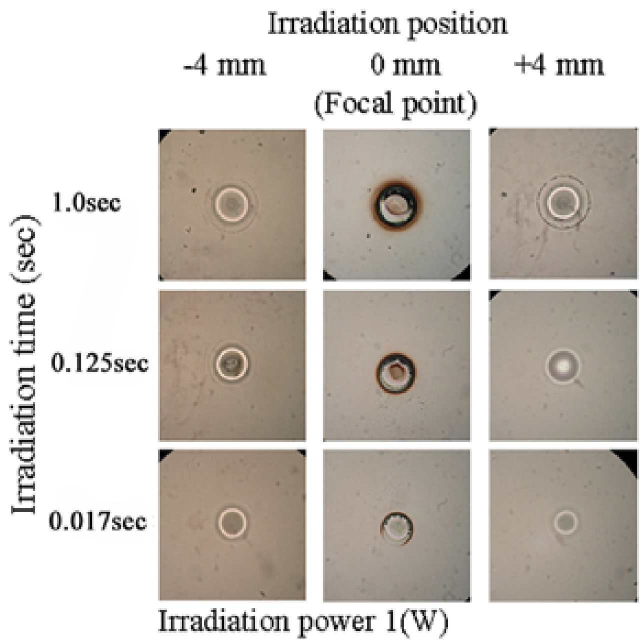


Fig.2 CO_2 laser irradiation region of Corning 7059 glass substrates observed with optical microscope.

laser irradiation energy (laser power x irradiation time).

Microlenses with the diameters ranging from 100 to 500 μm were fabricated by this method. The diameter increased with irradiation time and became nearly saturated after 0.5sec irradiation at Corning 7059 glass. Cross section SEM images and EDX images of microlens were shown in Fig.3-6. The convex microlens was fabricated using Corning 7059 glass (Fig.3). But, the concave microlens was observed at the early stage of the formation process (0.03 seconds or less) (Fig.4 (a)) of the concave shape. The result of the thermal conduction analysis

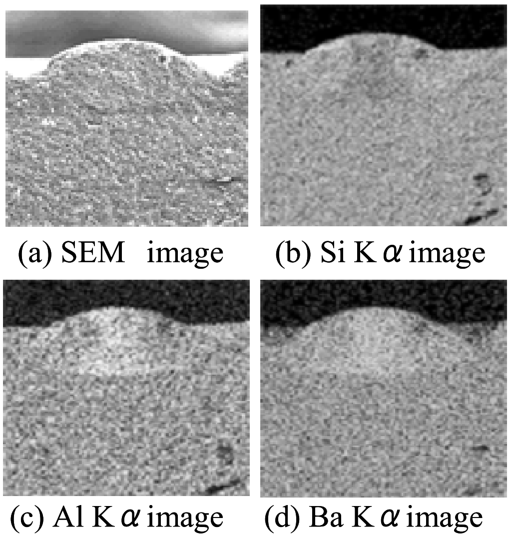
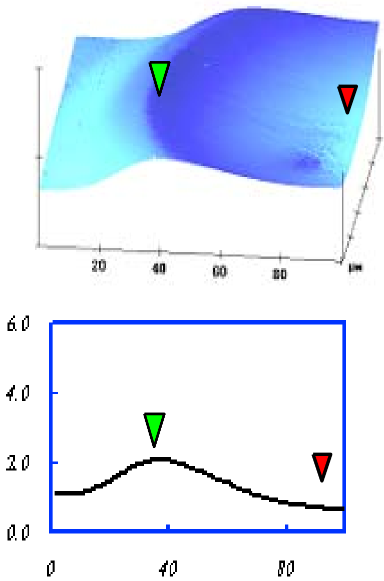
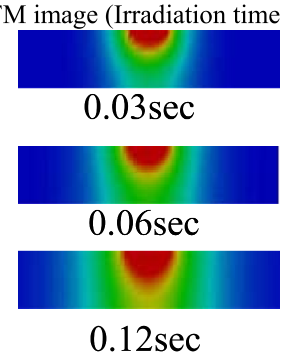


Fig.3 Cross section SEM and EDX images of microlens of Corning 7059 glass substrates. (Irradiation power 2W, Irradiation time 10sec, Irradiation position -4mm)



(a) AFM image (Irradiation time 0.03sec)



(b) Thermal analysis images

Fig.4 Microlens shape observation by AFM (a) and thermal analysis by CFD2000 (b) at 7059 glass. (Irradiation power 1W, Irradiation position -3mm)

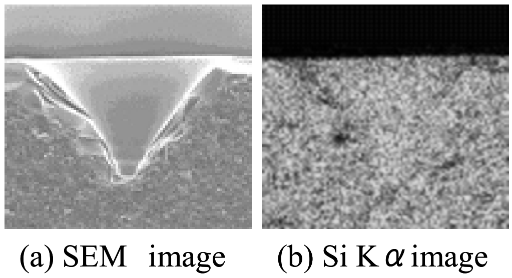


Fig.5 Cross section SEM and EDX images of microlens of fused silica glass substrates. (Irradiation power 2W, Irradiation time 8sec, Irradiation position -2mm).

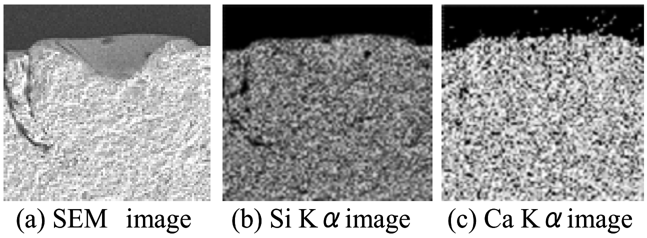


Fig.6 Cross section SEM and EDX images of microlens of Schott B-270 glass substrates. (Irradiation power 1W, Irradiation time 50sec, Irradiation position +4mm)

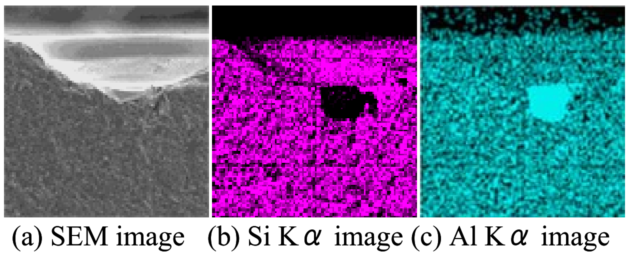


Fig.7 Cross section SEM and EDX images of microlens of TEMPAX glass substrates. (Irradiation power 3W, Irradiation time 10sec, Irradiation position -2mm).

showed that the irradiation time influenced the thermal conduction to the direction of the depth of the substrate (Fig4. (b)).

The irradiation position influenced the thermal conduction to the horizontal direction of the substrate as the result of thermal analysis. The inhomogeneous distribution of elements Al and Ba was observed at the lens formation region by EDX (Fig.3 (c), (d)). Moreover, the evaporation of SiO_2 with a relatively low melting point compared with other elements was observed by EDX in this area (Fig.3 (b)).The temperature around lens formation area can be estimated as about 2000 °C by this result. The threshold of the irradiation energy is estimated as about 100 (μJ/μm^2), if the temperature is assumed lower than 2000 °C at the formation of microlens. Moreover, it is thought that the convex shape was formed as the result of the enhancement of surface tension by inclusion of Ba ion. A funnel shape hole was formed in the case of a fused silica (Fig.5). It is thought that the fused silica took shape corresponding to the spacial distribution of laser beam energy as the result of the rapid evaporation of the surface layer after melting of SiO_2 according to the low thermal conductivity. The concave lens shape was formed in the case of a Schott B-270 glass (Fig.6) and TEMPAX glass (Fig.7).

It is thought that such shape was formed in the Schott B-270 glass and TEMPAX glass because the content of SiO_2 took the amount in the middle of the fused silica and Corning 7059. The homogeneous distribution of the composition element was observed by EDX in the B270 glass (Fig.6 (b), (c)). The segregation of Al_2O_3 was observed in the TEMPAX glass like the 7059 glass (Fig.7). It is thought that such segregation of Al_2O_3 is due to the high boiling point of Al_2O_3.

4. CONCLUSIONS

This method has the merit of complete dry processing. We can easily fabricate microlenses by controlling a laser power and a focusing condition. The irradiation at higher laser energy tends to evaporate the glass and at lower laser energy level does not deform the surface of the glass plate. The diameter of the microlens can be controlled to some extent by a spot diameter and the intensity of an irradiated CO_2 laser beam. Microlenses with the diameters ranging from 100 to 500μm were fabricated by this method. In this experiment, microlens shapes with both convex and concave lenses were obtained. Moreover, the concave microlens was observed at the early stage of the formation process (0.03 seconds or less) of the convex shape. It was found that final shapes of the microlenses depended on the irradiation condition of the laser and the material of the substrate. It is considered that the shape of the microlens was influenced by the content of SiO_2 and the kind of the additive element.

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(Received: May 16, 2006, Accepted: February 2, 2007)