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Proposal of laser assisted hot embossing technology for glass

Tsuneo Kurita*, Ichiro Ogura, Kiwamu Ashida

Advanced Manufacturing Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), AIST Tsukuba East 1-2-1 Namiki, Tsukuba, Ibaraki, 305-8564, Japan

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ABSTRACT

An embossing process in which a glass substrate is pressed by a mold and the mold is heated by laser is proposed. To demonstrate the process, an experimental setup is constructed. The setup can perform embossing and measure the embossing states, such as the process temperature and mold displacement. It is shown that pulsed laser heating has better processing efficiency and a smaller heat affected zone than continuous laser heating. The embossed shape accuracy is discussed by comparing the embossed shapes resulting from pulsed laser heating and continuous laser heating.

1. Background

Glass is an essential material for optical, electronic, mechanical, building, chemical, energy, and medical devices because of its many useful physical characteristics, such as its transparency, chemical stability, and durability. While micro-structuring processes can maximize the performance of a glass surface, it is difficult to fabricate micro shapes on glass. In order to achieve this with conventional processing technologies such as machining and chemical processes, large/complex machine tools, long processing times, and high costs are needed. Thus, the cost and time are the barriers to the production of glass devices for practical use.

Chou et al. (1995) proposed a new imprinting technique for microscopic fabrication. A mold and the work material are opposed in the imprinting process. The microscopic shapes on the mold are copied to the work material by pressure and heat. This was expected to be a high-precision and low-cost glass fabrication method because it is simple and can produce high-resolution shapes. Tao (2005) fabricated to PMMA surface. Ahn et al. (2005) fabricated aluminum wire grating with the combination of imprint fabrication and reactive ion etching. Youn et al. (2007) performed imprint fabrication on a glass surface with a glassy carbon micro-mold. The micro-mold was processed with an ion beam, femtosecond laser, and excimer laser. The roller-shaped mold was applied to imprint fabrication. Youn et al. (2008) performed to polymer and Chang et al. (2006) performed to glass. The fabrication showed the potential for high-efficiency and low-cost processing for optical devices.

While imprinting techniques are effective for optical devices, the fabrication time is long due to the required heating and cooling processes (which are on the order of an hour), and these processes cause thermal expansion of the mold, the work material, and the frame of the machine tool. The expansion results in a low processing accuracy. If a new fabrication method can be developed that can reduce the heating/cooling time and the thermal deformation during the heating/cooling process, the use of glass might be expanded. Therefore, an embossing method is proposed that reduces thermal expansion during the heating process. The heating time and area can be reduced by changing the heating method from electrical resistance heating to laser heating.

The authors are also proposing complex machining (CM), which is a highly efficient precise machining technology sequentially/simultaneously combined with more than one machining method on the same machine tool for hard-to-cut materials and hard-to-cut shapes. Kurita and Hattori (2006) demonstrated electrical discharge (EDM) and electrochemical (ECM) complex machining. Kurita and Hattori (2005) developed a concept for a new machine tool for complex machining. Kurita et al. (2008) developed mechanical/electrical complex machining technologies and a complex machine tool. Kasashima and Kurita (2012) produced a laser and ECM complex machine tool that machines hard-to-cut materials such as microscopic tubes. Within CM, combined machining methods that are performed sequentially are considered sequential complex machining (SQCM), and complex machining methods that are performed simultaneously or changed in under 1 s are considered simultaneous complex machining (SMCM).

The new processing method that is shown in this paper is categorized as a laser and embossing SMCM because the process contains laser processing and embossing, and both processes are performed simultaneously. Laser and embossing CM has the potential to perform high-efficiency and precision fabrication with low energy consumption and cost.

* Corresponding author.
E-mail addresses: t.kurita@aist.go.jp (T. Kurita), ogura.i@aist.go.jp (I. Ogura), ashida.k@aist.go.jp (K. Ashida).

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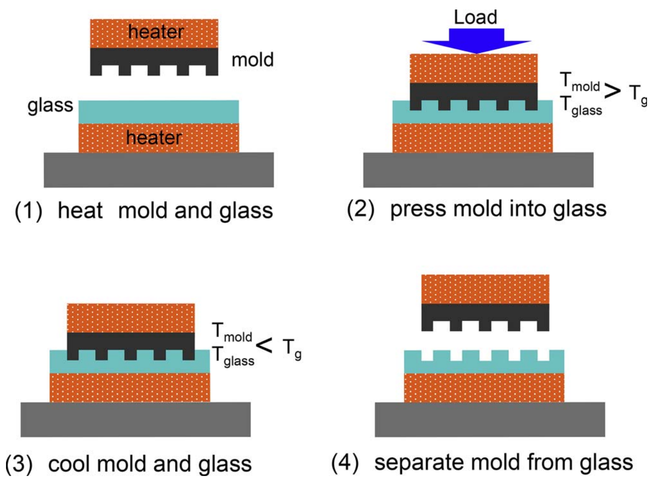

Fig. 1. Process sequence for conventional glass embossing.

In this paper, the experimental setup (which performs laser and embossing CM and measures the embossing states such as the process temperature and mold displacement) is first constructed. Secondly, CM is demonstrated experimentally with the setup. Thirdly, laser and embossing CM is performed to optimize processing conditions such as the laser irradiation method and the mold pressure. Finally, the fabricated shape accuracy is investigated by comparing the embossed shapes using pulsed laser heating and continuous laser heating.

2. Laser and embossing CM

Fig. 1 shows the processing sequence for conventional glass embossing. A mold and a glass workpiece are opposed and heated to the glass-transition temperature by heating the mold. Significant thermal energy is needed compared to the energy used for glass forming because the mold and glass temperatures are kept uniform. Furthermore, fabrication errors caused by thermal expansion and long cooling times are disadvantages of the process.

Fig. 2 shows the processing sequence for laser and embossing CM. The laser irradiates the back side of the glass. The beam travels through the glass and irradiates the mold. The heated mold heats the glass by thermal conduction between the two materials. The temperature around the contact area rises to the glass-transition temperature of the glass. The shape of the mold is copied to the softened glass. While laser and embossing CM can be applied only to transparent materials, the CM can heat just the deformable region in a short amount of time. The time- and space-efficient heating enables low-energy and low-thermal-expansion precision processing. Furthermore, it is expected that the lifetime of the mold is extended because the time- and space-efficient heating reduces the damage to the mold. Because only around the contact area rises to glass-transition temperature; and the high temperature duration was kept short with the thermal conduction cooling.

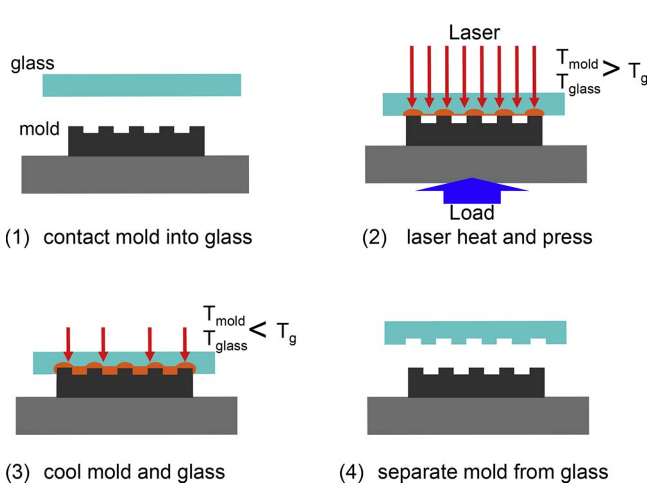

Fig. 2. Process sequence for laser embossing CM.

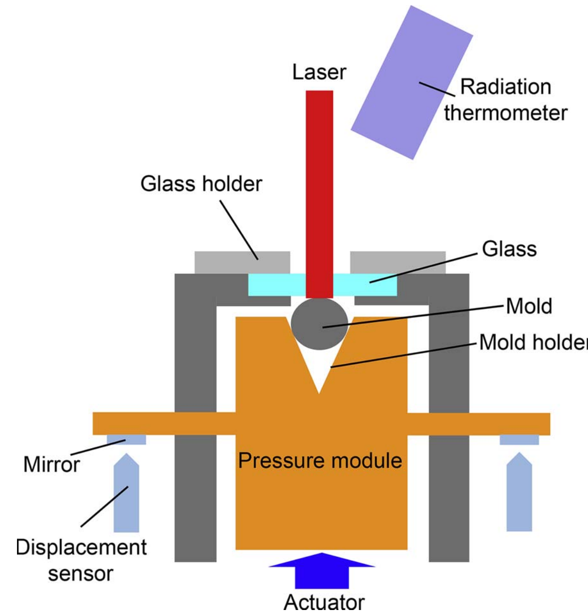

Fig. 3. Schematic of laser embossing CM setup.

3. Experimental method

Fig. 3 shows the laser embossing CM setup, and Fig. 4 shows a photograph of the test setup. The mold is located on a pressure module, which has a mold holder (coronial hole), mirrors for displacement sensing, and an actuator (Beloffram cylinder). A ball with a diameter of 3 mm is used as the mold for the experiment. It is made from Si_3N_4 because of its high heat resistance and large optical absorption coefficient. The absorption coefficient contributes to a high glass-transition temperature and low laser energy loss processing. Furthermore, the ball mold eliminates the locating error between the mold and glass, as shown in Fig. 5. In the case of a rectangular mold, the parallelism between the mold and the glass directly affects the processed shape. On the other hand, with a ball-shaped mold, the parallelism between the

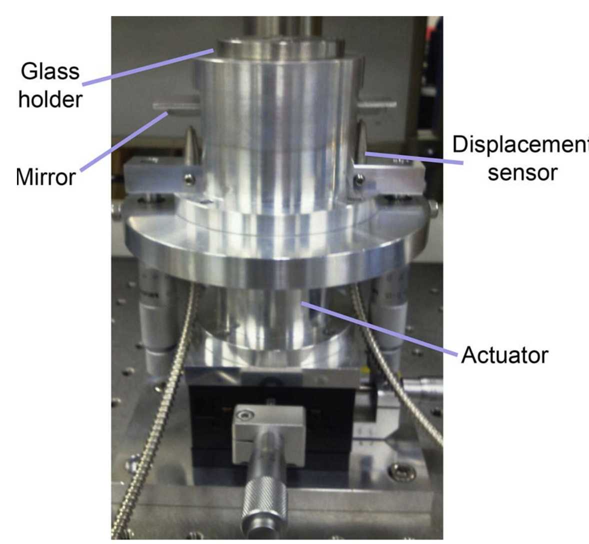

Fig. 4. Photograph of experimental laser embossing CM setup.