

# A Novel Polymer Processing Assisted by Infrared Radiation to Attain a High Precision Transcription

Yasuo Kurosaki and Kimitoshi Sato  
Department of Mechanical Engineering and Intelligent Systems  
University of Electro-Communications  
Chofu, Tokyo 182-8585, Japan

## 1. Introduction

Some unfavorable phenomena often appear in plastics processed by polymer injection molding : shape deformation, residual stress, birefringence, and ill transcription. The ill transcription is one of the most fatal defects for precision components such as memory disks, camera lenses, electronic devices and parts of MEMS. It is therefore very important for polymer mold fabrication to obtain the high quality transcription of surface in plastics<sup>1,2</sup>.

An innovative injection molding process was developed to improve transcription from a heat transfer point of view<sup>3,4</sup>. The process is able to improve both the optical quality and the transcribability of plastic components by applying infrared radiation through the window provided on the mold wall on the moving polymer melt injected in the mold cavity. In this paper, another novel processing having two stages such as a molding and a transcribing process is proposed to improve transcribability. The concept of this method is shown in Fig.1. In the first stage of the process, blank workpieces are processed by a conventional injection molding process. Then, in the second stage a blank workpiece is inserted into another precise mold with the wall transparent to infrared radiation having the primary surface to be transcribed, and is radiated by an external infrared radiation source. One of advantages is that the pressure in the second stage is quite low to compare with the first one. The window for infrared radiation is therefore enough to bear the pressure in the process. Further, the mold is quite simple, and the cost of this molding process is lower than the case of the moving polymer irradiated. Besides, the process cycle time is quite short.

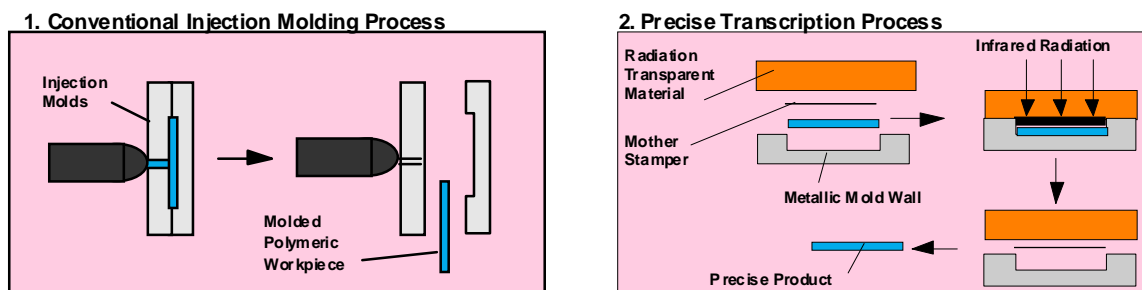


Fig.1 Schematic of the two-stage transcription process assisted by infrared radiation

## 2. Experimental Setup

A two-stage transcription process system proposed here has two independent facilities. In the first stage, an injection molding system is used to process blank workpieces by conventional procedure; the workpieces in this stage not always require a high degree of accuracy. In the second stage, a special mold having a cavity with a window transparent to infrared radiation is prepared as shown in Fig.2. A workpiece molded in the first stage is inserted into the cavity, and is covered with an infrared-transparent glass plate (ZnSe); then, an infrared radiation of CO<sub>2</sub> laser is applied to the inserted one for certain duration about a few tens seconds. Since the temperature of the thin layer of resin near surface rises due to absorption of radiation, the fluidity of polymer in the thin layer consequently increases, and also the pressure in the cavity increases due to a volume expansion. The information “roughness” on the surface of the infrared-transparent glass contacted with the resin is able to be efficiently transcribed to the surface of workpiece.

In our experiment, a polystyrene disk, 25 mm in a diameter and 2 mm in thickness, was conventionally processed in the first stage. In the second stage, two kinds of precise mold were adopted; the details of those molds were shown in Fig.3. The first one shown in Fig.3 (a) has a ZnSe mold wall on the surface of which a few precise fine grooves were formed to evaluate the transcribability. The details of the grooves are shown in Fig. 4. When this mold is used, the infrared radiation through the window directly radiates the surface of an inserted disk, and heats up the thin layer of resin. The second one shown in Fig.3 (b) has a thin metallic stamper plate pasted on the surface of ZnSe; in this experiment, a part of a mother stamper of CD disk, 0.3 mm in thickness, was used as a mother surface for transcription. The surface of the stamper faced

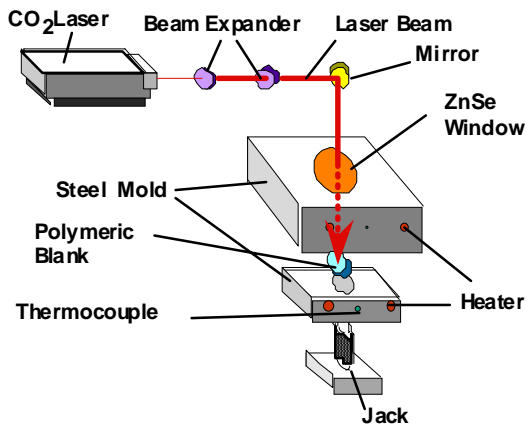


Fig.2 Experimental setup for the precise transcription process

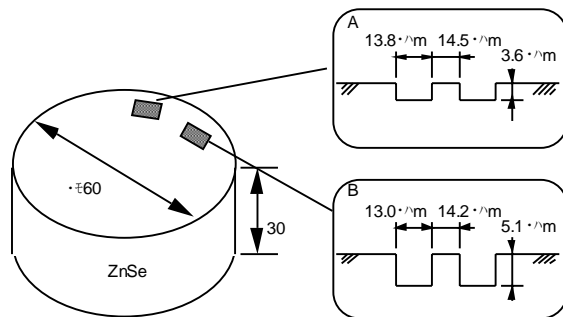


Fig.4 Geometry of grooves engraved on a ZnSe mold wall surface

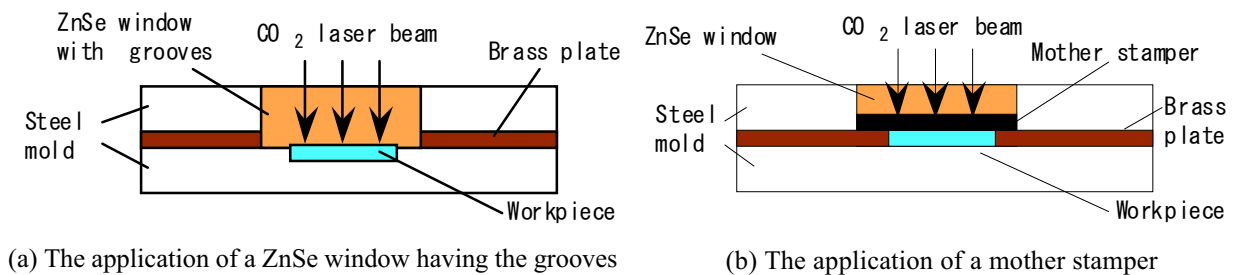


Fig.3 Details of precise mold system used in the second-stage

to a radiation source was painted black to improve absorption of radiation. When the second mold is employed, the metallic stamper is heated by radiation, and then, the resin of polystyrene is heated by heat conduction from the heated stamper. A little longer time is, therefore, necessary for the latter to achieve a sufficient transcription.

**3. Improvement of Transcribability in a Two-Stage Molding Process**

First, experiment was conducted with the mold with no metallic stamper shown in fig.3 (a) to examine the feasibility of the proposed transcription molding process assisted by infrared irradiation. The effectiveness of replication of the grooves on the surface of ZnSe mold wall was defined as the ratio of height of protrusion on the workpiece to the depth of groove. Figure 5 shows the effect of the duration of irradiation on replication. It is seen that preferable transcription was achieved by direct irradiation for an appropriate duration despite of the depth of grooves.

Second, in the case using a mother metallic stamper, the depth of a sub-micron pit on the surface is measured by an atomic force microscope (AFM). The AFM photographs for both the surfaces of a mother stamper and a transcribed polymer processed with irradiation are shown in Figs. 6(a) and 6(b), respectively. Further, the influence of mold wall temperature measured by thermocouples mounted on the surface of a

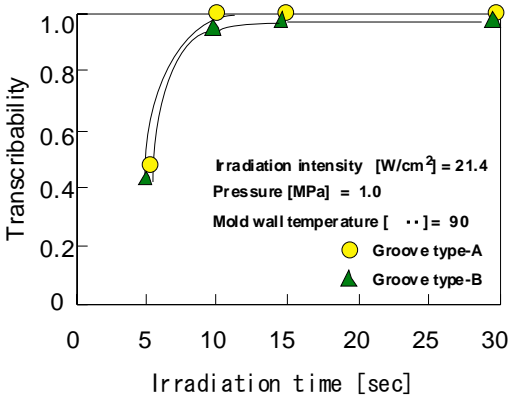


Fig.5 Influence of radiation on transcribability for the grooves on ZnSe mold surface

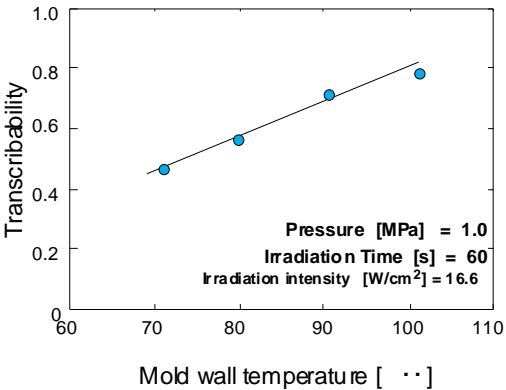
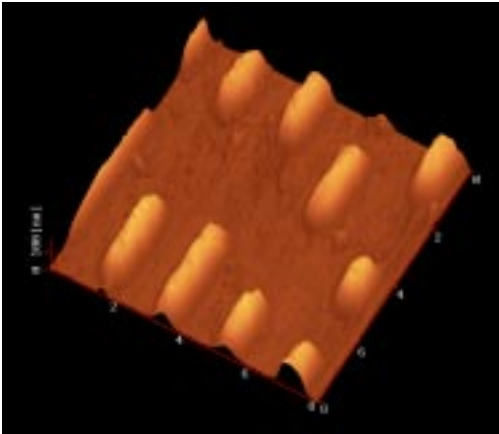
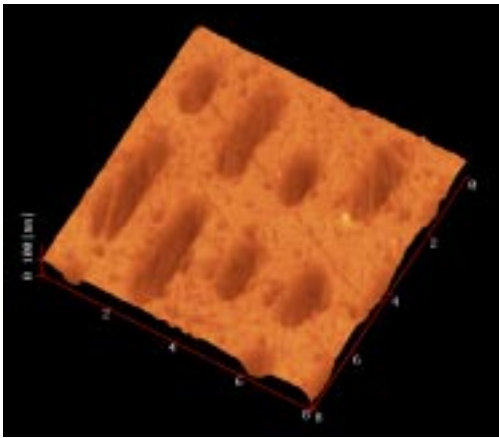


Fig.7 Influence of mold wall temperature on transcribability using the mother stamper



(a) Surface of a mother stamper



(b) Surface of a replicated workpiece

Fig.6 AFM images of stamper and workpiece

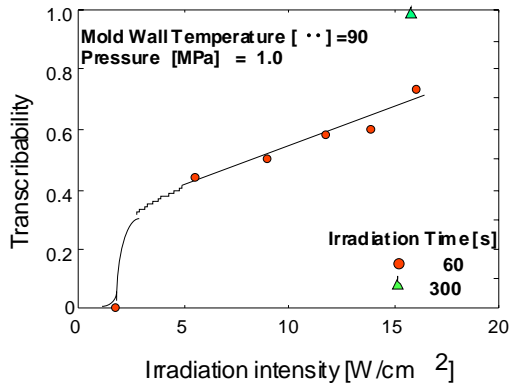


Fig.8 Influence of irradiation intensity on transcribability in the secondary transcription process

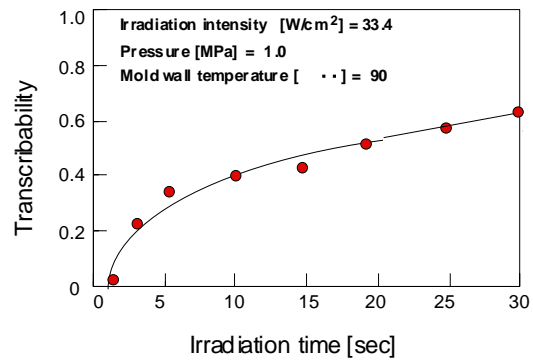


Fig.9 Influence of irradiation time on transcribability in the secondary transcription process

stamper on the transcription is shown in Fig. 7. From this figure, satisfactory feasibility is not obtained without irradiation in case of the mold wall temperature lower than a glass transition one of polymer. Figure 8 shows the influence of irradiation intensity on the transcription. Application of high radiation intensity results in favorable transcription in this process. The effect of time duration of irradiation on transcription in case of a CD stamper adopted is shown in Fig. 9. The temperature of resin surface contacted with a metallic stamper is raised promptly after radiation is supplied on the other surface of stamper; therefore, the sub-micron transcription is able to be completed in a few tens second processing.

#### 4. Conclusion

The feasibility of this proposed procedure was experimentally examined using the system with a CO<sub>2</sub> laser beam as a radiation source and the ZnSe window transparent the beam. The transcription of a micro-scale information on the mold surface to the one of molded plastics was greatly improved by direct irradiation onto the polymer. Further, the sub-micron scale transcription such as pits of compact disks was experimentally confirmed by the two-stage transcription process. The proposed system has a feature: a conventional injection molding process is able to be employed in the first stage, and a molding system in the second stage is not necessary to bear high pressure and to be sophisticated. This system is feasible for processing high quality components such as optical or electrical devices, micro-scale devices and MEMS components.

#### References

1. M. J. Liou, N. P. Suh, "Reducing Residual Stresses in Molded Parts" Polymer Engineering and Science, Vol. 29, No. 7, (1989).
2. E. Brinksmeier, W. Preuss, "Basics of Precision Replication Techniques" Proceeding of the ASPE Spring Topical Meeting on Precision fabrication and Replication", Vol.19, pp.23-28 (1999).
3. Y. Kurosaki, I. Satoh, "A Precision Polymer Injection Molding Process Assisted by Infrared Radiation to Upgrade both Optical Quality and Transcribability" Proceeding of the ASPE Spring Topical Meeting on Precision fabrication and Replication, Vol.19, pp.46-49 (1999).
4. Y. Kurosaki, I. Satoh, T. Saito, "Heat Transfer Aspect to Upgrade the Quality of Plastics" Proceeding of the Symposium of Energy Engineering in the 21 Century, pp.84-95. (2000).