Heat Conduction and Polymer Flow in Microstructured Mold for Laser-Assisted Imprinting

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Laser-assisted imprinting is expected to be a high-speed direct fabrication method for nanostructured substrates among nanoimprint lithography technologies.[1] It was demonstrated that a method in which only the surfaces of the substrate and mold are heated leads to not only a short cycle time but also low energy consumption in the imprinting process.[2] Our group proposed a laser-assisted roller imprinting (LARI, inset in Fig. 1) and demonstrated to replicate nano and microstructures.[3] However, mechanism in heat conduction and polymer flow in microstructured mold in LARI. The process parameters such as pressing pressure, laser power, diameter, and irradiation time corresponding to scan speed are depended by the pattern size and materials. In this study, we designed a model experiment to define the time schedule of heat conduction in the polymer and the flow of the polymer.

Figure 1 shows the schematic of the process in a microscale during laser-assisted imprinting. Immediately after the laser is irradiated on the mold (a), the mold surface is heated and the polymer is heated by a heat transfer and the flow is started (b). Even after the laser irradiation is stopped (c), the flow continues due to residual heat in the polymer and filling is finished (d). When the polymer is cooled under the temperature at which its viscosity is transited, the filled polymer is solidified (e). Qualitatively, when the structure is smaller, the flow speed is high and the heat transfer is more dominant. This is because the replication speed of submicron structure could be fit with a heat-transfer simulation in our previous study.[2,3] As shown in this figure, the time difference between the time of filling (t_{fill}) and that of solidifying (t_{solid}) is fruitless for high-speed replication. Note that this schematic is one dimensional model, and actual phenomena have three dimensions and the heat transfer in plane direction should be considered.

Figure 2 shows the schematic of model experiment with spot irradiation and consideration of two dimensions. The Ni mold has line-and-spaces with 15 μm height, 15 μm width, and 15 μm interval and the polymer used was a polymethyl methacrylate (PMMA) film. The laser power, diameter, and pressing pressure were varied 70, 100 W, 500, 650 μm, 10, 25, 40 MPa, respectively. The width of filled area was plotted as a function of irradiation time. The heat transfer was numerically simulated and the time for polymer flow was defined individually.

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[1] S. Y. Chou, C. Keimel, and J. Gu, *Nature*, 417 (2002) 835.

[2] K. Nagato, K. Takahashi, T. Sato, J. Choi, T. Hamaguchi, M. Nakao, *J. Mater. Proc. Technol.* 214 (2014) 2444-2449.

[3] K. Takahashi, K. Nagato, J. Wang, T. Hamaguchi, M. Nakao, *Dig. EIPBN*, 2014

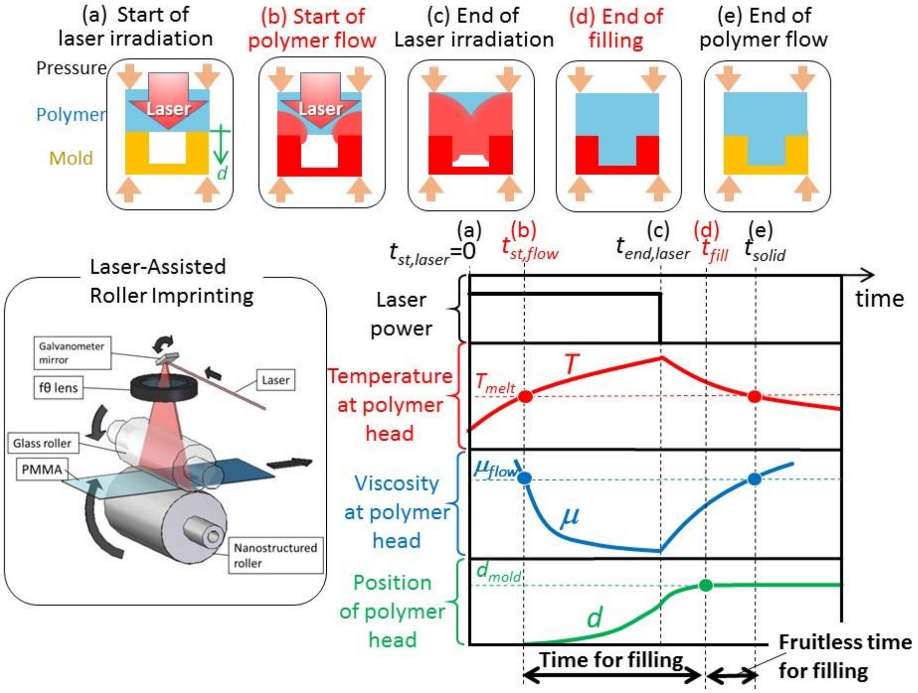

Figure1 Schematic of micromechanism of heat conduction and polymer flow in Laser-Assisted Roller Imprinting.

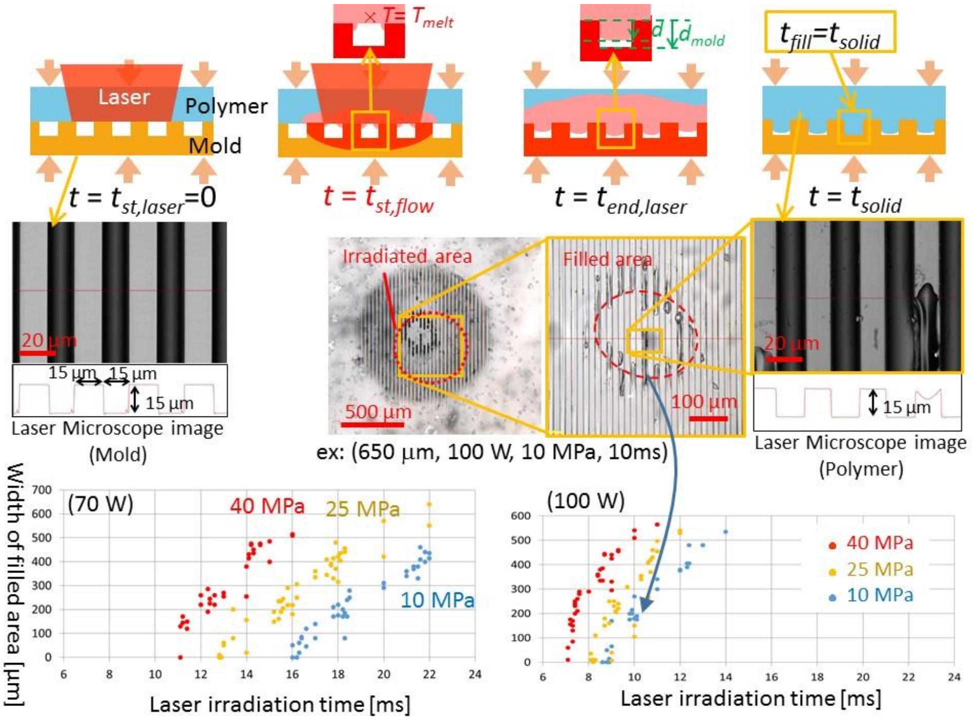

Figure2 Procedure of model experiment with spot irradiation and results of width of filled area with different powers and pressures.