ABSTRACT
Simulations and experiments were performed to assess the predictability of dimensional and locational tolerances of passive alignment structures on injection molded microfluidic components. A center-gated disk with square microscale assembly features, to aid metrology, was made using injection molding. The features have depths and lengths of 100, 200, 300, 400 micrometers, respectively. Dimensions and locations of the features were measured using SEM and optical microscopy.

INTRODUCTION
Assembly of microfluidic modules with different functions to obtain more capable instruments may significantly expand the available options in the detection and diagnosis of disease through DNA analysis and proteomics. Polymer modules may lead to less expensive production and wider adoption, but the technology for precise assembly must be developed so that repeatable, reliable assays can be performed. Polymers have a wide range of mechanical, thermal, and chemical properties that are suitable for realization of modular microfluidic systems [1].

Screw theory [2] was applied for the design of assembly features which align polymeric modular microfluidic devices in microassembly. The designed assembly features prevent infinitesimal motions between modular polymeric microfluidic devices so that misalignment of the devices is minimized. Computer-aided engineering models were constructed to predict the flow behavior of the polymer melt during the filling of micro injection molds. The constructed CAE models were verified through injection molding experiments.

BACKGROUND
Passive kinematic constraints are widely used in precision assembly and were used to assemble silicon wafers with submicrometer accuracy by Slocum and Weber [3]. Screw theory has been used to analyze the state of constraint of assembly features [2]. Injection molding is one of the most promising methods for replicating polymeric modular microfluidic systems since it is cost-effective and has high replication accuracy for the features of the microstructures [2]. Replication quality depends on various process parameters, including mold temperature, flow rate, and melt temperature. For successful replication of features, numerical and experimental analysis has been used for the design of micro injection molding processes [4, 5]. Despa and Kelly showed proper combinations of mold cavity temperature and injection flow rate enabled manufacture of high aspect ratio microstructures (HARMS) and the mold cavity temperature was a dominant parameter for complete filling of the mold cavity [6].

METHODS
For the design of assembly features for modular polymeric microfluidic devices, screw theory [4], based on using twists and wrenches to represent constraining forces/moments and motions, was used to analyze the state of constraint of modules with assembly features. It was shown that a set of three V-groove and sphere joints in Figure 1 constrain all of the degrees of freedom of two microfluidic devices without over-constraint, so that the precise, passive alignment between the devices was achievable.

Polymer modules with square microscale assembly features, to aid metrology, were made using injection molding. The features have depths and lengths of 100, 200, 300, 400 micrometers, respectively. There were 10 millimeter gaps between features. In injection molding, several process parameters including injection pressure, mold temperature, and injection velocity can influence the flow behavior of the polymer melt in filling the mold cavity, and the deflection of assembly features after cooling. CAE models, using Moldflow Plastics Insight® 5.1 (Moldflow, Framingham, MA), were constructed for the simulation of mold filling as shown in Figure 2. The model consisted of a molded circular disk with the features and a sprue.
Experiments were performed with mold surface temperatures 100, 125, and 150˚C to verify simulation results. Dimensional and locational tolerances of microstructures were measured using a scanning electron microscope and a Measurescope (Nikon, MM-22) and verified for the design of passive alignment features.

RESULTS AND DISCUSSION

Simulations showed the complete filling of micro scale assembly features with polycarbonate at mold surface temperatures of 150˚C as shown in Figure 3. Figure 4 is SEM pictures of molding results. From comparison of simulation and experimental results, it was known that simulation overestimated replication quality.

CONCLUSIONS

The results of this research will contribute to replication of microstructures and precise, passive alignment of modular polymer microdevices without additional optical alignment processes enabling cost-effective mass microfabrication.

Figure 1. Multiple v-groove and sphere combination assembly.

Figure 2. CAE model for the filling analysis

Figure 3. Filling analysis a mold surface temperature 150˚C.

(a) 10mm (b) 20mm (c) 30mm

Figure 4. SEM pictures of molding results 100 um cubes along the radial direction away from the center gate.

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