# Study on Micro Transportation Systems Based on Electrostatic Actuators Utilizing Micro Electro Mechanical Systems (MEMS) Technology

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This dissertation has presented the design, fabrication, and evaluation of silicon Micro Transportation Systems (MTS) for transporting micro containers based on electrostatic actuators and ratchet mechanism. Aiming at the industrial applications, a basic research on hot embossing process for fabrication of polymer micro structures of electrostatic actuator was also carried out.

The new micro transportation systems presented in this dissertation can be used for transporting and classifying micro and nano samples during examination and analysis under microscopes in medical, biochemical, and nano-technology areas. In this research, micro containers with dimensions of $450\times210\times30\mu m^3$ (length×width×thickness) were driven by electrostatic comb-drive actuators and ratchet mechanism to move in straight and curve paths with different velocities. In this dissertation, two kinds of driving mode were presented. One is parallel driving mode, in which the micro containers are moved in parallel with the driving direction of the actuator, and the other is orthogonal driving mode, where the micro containers are moved perpendicularly with the driving direction of the actuator. One unit module of the MTS has dimensions of $6\times6\ mm^2$. Different MTS with complicated trajectory paths can be created by combining straight module, turning module, and separation module. Design and evaluation results of the two kinds of the driving mode have been demonstrated.

The MTS have been fabricated from SOI (Silicon on Insulator) wafer based on MEMS (Micro Electro Mechanical Systems) technology, such as photo lithography, D-RIE (Deep Reactive Ion Etching) and vapor HF etching technique using only one mask. Transportation velocity of the MTS is proportional to the frequency of the driving voltage. In this study, the straight transportation velocity from 0.01mm/s to 0.71mm/s was obtained by applying voltage of 190 (Vpp) with driving frequency ranges from 1Hz to 40Hz. Furthermore, 90degree turning module and two directions switching module have been realized.

In this research, in order to spreading and introducing the MTS for industrial applications, hot embossing process of polymer material, whose cost is more than one order lower than that of silicon technology, is proposed. Basic research on hot embossing, including development of a hot embossing system, fabrication of smooth silicon mold, and molding/de-molding techniques, has been performed. PMMA micro structure with line and space of 2μm, height of 30μm, i.e. aspect ratio of 15, has been achieved. Prospect for batch production of polymer structures by hot embossing technique has been realized.

The dissertation consists of 8 chapters as follows:
Chapter 1 gives an introduction and overview of the prior art micro conveyance systems.
Chapter 2 presents the fundamentals of the electrostatic theory and electrostatic comb-drive actuator.
Chapter 3 introduces the design, working principle, simulation of the first type, i.e. the parallel driving mode, of the silicon micro transportation system.
Chapter 4 introduces the design, working principle, simulation of the second type, i.e. the orthogonal driving mode, of the silicon micro transportation system.
Chapter 5 describes the complete fabrication process of the silicon MTS based on MEMS technology.

Chapter 6 presents the evaluation and characterization of the two types of silicon MTS.
Chapter 7 describes the development of a hot embossing system, fabrication of smooth silicon molds, and hot embossing technique to fabricate polymer micro structures.
Finally, chapter 8 summarizes and concludes the research, and discusses about the future work.