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RESEARCH PAPER

A microfluidic-based dynamic microarray system with single-layer pneumatic valves for immobilization and selective retrieval of single microbeads

Hojin Kim · Joonwon Kim

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Abstract A simple yet effective dynamic bead-based microarray is necessary for multiplexed high-throughput screening applications in the fields of biology and chemistry. This paper introduces a microfluidic-based dynamic microbead array system using pneumatically driven elastomeric valves integrated with a microchannel in a single polydimethylsiloxane (PDMS) layer that performs the following functions: single-microbead arraying with loading and trapping efficiencies of 100 %, sequential microbead release for selective retrieval of microbeads of interest, and rapid microarray resettability (<1 s). The key feature is the utilization of an elastomeric membrane as a valve for trapping and releasing single microbeads; this membrane is deformable depending on the applied pneumatic pressure, thereby simply providing a dual trap-and-release function. We propose an effective single-microbead-trapping mechanism based on a dynamic flow-change network and a mathematical model as the design criterion of a trapping site. A sequential microbead release technique via a multistep "release-retrap-and-repeat" method was developed for the selective retrieval of trapped microbeads with a simple configuration consisting of a single PDMS layer and a simple macro-to-micro connection. The proposed dynamic microbead array could be a powerful tool for high-throughput multiplex bead-based drug screening or disease diagnosis.

Keywords Microfluidics · Single-microbead array · Single-layer pneumatic valve · Sequential release · Device resettability

1 Introduction

Microarray-based techniques have been developed to meet the demand for multiplexed high-throughput screening for the investigation of numerous biomolecules, chemicals, and the interactions among them. Depending on the sample arraying method, microarrays can be categorized into two types: static and dynamic. With advancements in particle synthesis technology, the dynamic microarray composed of heterogeneous microcarriers such as microbeads with surfaces that are coated with various molecules or their compounds (e.g., amino acids, peptide) is emerging as a powerful tool for biomedical applications such as drug screening and disease diagnosis (Nolan and Mandy 2006; Skelley et al. 2009); in contrast, static microarrays consist of samples patterned on a static solid support (Robinson et al. 2002; Steinert et al. 2009; Malainou et al. 2012). Because of their large surface-to-volume ratio, microbeads have a higher capacity to bind molecules, thereby improving the detection limit and reaction time compared to static arrays with planar surfaces (Verpoorte 2003). In addition, they can easily be transported, mixed, and separated for various purposes (e.g., multiplexed assays).

However, to fully exploit its advantages, a dynamic microarray system should offer the following essential functions: (1) high trapping efficiency of single microbeads as well as high loading efficiency to observe the binding specificity of surface molecules of each microbead in real time and over the long term under continuous flow conditions; (2) selective retrieval to identify molecules of

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H. Kim · J. Kim (✉)
Department of Mechanical Engineering, Pohang University of Science and Technology (POSTECH), San 31, Pohang, Kyungbuk 790-784, Republic of Korea
e-mail: Joonwon@postech.ac.kr

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