A METHODOLOGY FOR RAPID PROTOTYPING MICROFLUIDIC DEVICES WITH SOPHISTICATED FUNCTIONALITY

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ABSTRACT
Microfluidic laboratory-on-a-chip (LOC) systems based on a modular architecture are presented. A multi-layer approach segregates components belonging to two fundamental categories: passive fluidic components (channels and reaction chambers) and active electromechanical control structures (sensors and actuators). Components belonging to these two categories are built separately on different physical layers and can communicate fluidically via cross-layer interconnects. We demonstrated the utility of this architecture by developing systems for two separate biochemical applications: one for detection of protein markers of cancer and another for detection of metal ions.

Keywords: biochemical analysis, modular system, microfluidic breadboard, reconfigurable

1. INTRODUCTION
Microfluidic technology is attracting significant interest from the life science and materials communities. Unfortunately, many of these potential end-users do not have access to sophisticated microfluidic chips and microfabrication facilities. Their ability to explore the technology and contribute to the growth of the microfluidic field is therefore limited. We present a new methodology that allows researchers to build highly functional, custom microfluidic systems that integrate valves, mixers, sensors, and other elements without the need for a cleanroom.

2. ARCHITECTURE
The methodology is conceptualized on two levels: a single chip level and a multiple chip module (MCM) system level. At the individual chip level, a multi-layer approach segregates components belonging to two fundamental categories: passive fluidic components (channels and reaction chambers) and active electromechanical control structures (sensors and actuators). This distinction is explicitly made in order to simplify the development process and minimize cost. Components belonging to these two categories are built separately on different physical layers, may employ different materials, and can be manufactured at different locations. The chip that hosts the electromechanical control structures is called the microfluidic breadboard (FBB). Whereas the FBB chip would be built by foundries using sophisticated microfabrication processes, the passive chips could be made by researchers in a few days without the use of a cleanroom.

Microfluidic chips with modular and nonplanar (three-dimensional) designs have been investigated in the past [1-4]. Previously demonstrated methods require complex designs due to nonstandard segregation of passive and active components [1-3], have limited reconfigurability [2], and call for intricate fabrication and assembly of many small parts [1-
Users of these systems must conform to the designers’ channel layout, and are unable to efficiently tailor a system to fit their own specifications without major expense. Our design provides a viable solution for realizing custom, highly functional, and low cost LOC systems.

Figure 1. (A) Schematic diagram of a representative FBB. (B) A complete LOC can be built by bonding a passive fluidic chip with an FBB. (C) Different functions may be realized by deploying different passive chips on the same FBB. Multiple chips can be interconnected to form a larger system.

3. IMPLEMENTATION

The FBB (Figure 1A) generally contains valves, pumps, mixers and other active elements and constitutes the foundation on which a second chip with passive components (routing channels and reaction chambers) is mated to complete the LOC (Figure 1B). Fluid communication between these two layers is achieved via through-wafer ports in the FBB. Many different LOC functions can be achieved using different passive chips on an FBB with a standard resource configuration. Multiple modules can be interconnected to form a larger LOC system (MCM level).

Figure 2. First generation FBB implementation. The active chip contains pneumatically actuated valves and reaction chambers. The passive chip consists of a microfluidic channel network. Both the active and passive PDMS chips are reversibly bonded to the silicon breadboard.

Figure 3. Fabricated device and testing results for the detection of free prostate-specific antigen (PSA). (A) The system is capable of concurrently performing eight different bio-bar-code tests by connecting four identical chips to a centralized detection chip. (B) Each chip can run two simultaneous tests. (C) Free PSA was detected at concentrations ranging from 50 fM down to 500 aM based on the intensity of light scattered off the silver-stained gold nanoparticles.
The first generation FBB presented here consists of an oxidized silicon chip with low dead volume through-wafer holes (50 µm diameter) reversibly bonded to a PDMS active chip with valves formed by the multilayer soft lithography technique developed by the Quake group (Figure 2). Passive chips are made of PDMS using soft lithography. Realizing a new functionality only requires a new passive chip. It is feasible for researchers to customize the system since PDMS molding can be adapted to non-cleanroom environments. Thus, researchers have access to the rich features of the FBB while at the same time having the flexibility to determine how these features are used.

4. APPLICATIONS

The utility of this architecture was demonstrated by designing passive chips to realize two entirely different functions using identical FBBs. All the PDMS passive chips were designed and fabricated in two days. The first system implemented the bio-bar-code protein identification protocol [5]. In particular, free prostate-specific antigen (PSA) was detected with a sensitivity of 500 atto-molar concentration in a 1 µl buffer solution. Figure 3 shows the fabricated system that can concurrently run eight different tests. The second system used a DNAZyme-based biosensor [6] to detect low levels of Pb²⁺ (lead) down to 500 nM concentration. Four samples with varying concentrations were tested in four parallel 1 nl reactors (Figure 4).

Figure 4. (A) Schematic and (B) picture of the fabricated device used to detect lead. Four reactors on the FBB were used in parallel to run four separate tests. (C) The results were visualized with a fluorescence stereomicroscope.

REFERENCES


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