Available online at www.sciencedirect.com
ScienceDirect
Sensors and Actuators B 132 (2008) 614–622
SENSORS AND ACTUATORS B CHEMICAL
www.elsevier.com/locate/snb

Microanalysis system with automatic valve operation, pH regulation, and detection functions

Hiroki Hosono, Wataru Satoh, Mariko Toya, Katsuya Morimoto, Junji Fukuda, Hiroaki Suzuki *

Graduate School of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan

Available online 3 January 2008

Abstract

A microanalysis system with functions including automatic valve operation for mixing solutions, pH regulation, and detection based on electrochemiluminescence (ECL) was fabricated. Automatic valve operation was achieved by means of direct electrowetting using one of two solutions as a part of an electronic circuit. A valve formed with a gold electrode was opened when the second solution was filled in a compartment, causing the mixing of the two solutions. The pH regulation was achieved by using a nonstandard three-electrode system. The pH of the solution could be changed as desired by changing the working electrode potential, and the negative feedback function maintained the pH at a constant level. The ECL was generated on a platinum working electrode. Amino acids were detected as model analytes. A reagent solution containing tris(2,2′-bipyridyl)ruthenium(II) ($Ru(bpy)_3^{2+}$) and a sample solution containing an amino acid were mixed, and the pH was adjusted using the pH regulator. When +1.1 V (vs. Ag/AgCl) was applied to the electrode, red luminescence was observed. An increase in the ECL intensity was observed with an increase in the concentration. Amino acids of concentrations ranging from sub nM to 1 mM could be determined on the integrated device.

Keywords: Mixing of solutions; Valve; Electrowetting; pH regulation; Electrochemiluminescence; Amino acid

1. Introduction

With the advance of microfluidic technology, integrated bio/chemical microsystems with high functionalities have started to be reported [1–5]. Most of the present microsystems, however, consist of a chip with only microflow channels and have too much reliance on external instruments, such as microsyringe pumps. We believe that the current style of microsystem construction is transitioning into the development of ultimate microsystems of high functionalities. To achieve systems comparable to conventional macroscopic instruments, components such as pumps, a temperature control unit, a pH regulator, and sensors need to be integrated. In addition, a challenging issue for next-generation microsystems is the achievement of automatic control without an external signal input using software. The electrochemical principles of operation will provide a way to achieve these components and functions.

Microfluidic transport is the most critical function in microanalysis systems. To develop a microfluidic system that can be integrated on a chip, electrowetting provides a realistic methodology. Electrowetting permits implementing a change in the wettability of a metal electrode [6–8]. Previous studies have already demonstrated its potential for the construction of microsystems with high functionalities [9–14]. In this study, we used this technique to form a mixing valve. Many previous devices that rely on electrowetting have been based on the so-called electrowetting on dielectric (EWOD), which focuses primarily on the transport of droplets [15–17]. The use of an insulating layer is to suppress the electrolysis of water and to achieve reproducible changes in wettability. On the other hand, direct electrowetting, in which liquid makes direct contact with the electrode, features extremely low driving voltage and power consumption. In previous studies, we have demonstrated that the technique can be used to mobilize a continuous fluid in a network of flow channels [12–14]. The advantage of direct electrowetting is not limited to them. We will demonstrate that the valve function using direct electrowetting can be directly coupled with an external electronic circuit for switching. In this system, the solutions could be mixed with a fixed mixing ratio immediately

* Corresponding author. Tel.: +81 29 853 5598; fax: +81 29 853 4490.
E-mail address: hsuzuki@ims.tsukuba.ac.jp (H. Suzuki).

0925-4005/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.snb.2007.12.054

after the solutions were transported and filled two compartments in the reaction chamber.

When conducting analyses on microsystems, the adjustment of the pH of a solution is often a critical requirement to take full advantage of the properties of biomolecules, such as enzymes. We demonstrate in this study that on-chip pH regulation with an automatic feedback function can be achieved by using an electrochemical three-electrode system in a nonstandard manner. Although current approaches for pH adjustment include solution mixing in a microflow channel or the use of buffering components, additional procedures are not required when using a pH regulator. The pH of a solution can be set to desired values, and the pH is maintained by the feedback function of the device.

To show the applicability of our integrated device, an ECL sensing system with a photodiode was also integrated, and amino acids were detected. The detection required procedures such as the mixing of solutions and the adjustment of pH and was a good model reaction for the evaluation of the performance. The device functioned as expected, and amino acids could be determined reproducibly on the chip down to the pM order.

2. Experimental

2.1. Reagents and materials

The reagents and materials used for the fabrication and characterization of the device were purchased from the following commercial sources: a thick-film photoresist, SU-8 2100, from Micro Chem (Newton, MA, USA); a negative photoresist, OMR-83, from Tokyo Ohka Kogyo (Kawasaki, Japan); a precursor solution of polydimethylsiloxane (PDMS), KE-1300T, from Shin-Etsu Chemical (Tokyo, Japan); tris(2,2′-bipyridyl)dichlororuthenium(II) hexahydrate, from Sigma–Aldrich Japan (Tokyo, Japan). The other reagents used were of analytical reagent grade and were obtained from Wako Pure Chemical Industries (Osaka, Japan). Standard solutions and reagent solutions were prepared with solutions containing 0.1 M KCl. To check the performance of the pH regulator, the detection of the ECL was also carried out using the following buffer solutions: 0.1 M KH_2PO_4–NaOH (pHs 7.0 and 8.0), 0.1 M H_3BO_3–NaOH (pHs 9.0 and 10.0), and 0.1 M K_2HPO_4–NaOH (pHs 11.0 and 12.0). All solutions were prepared with distilled deionized water.

2.2. Structure of the microsystem

The fabricated microsystem is illustrated in Fig. 1. Electrodes were formed on a glass substrate for the automatic valve operation, the pH regulation, and the generation of the ECL. To use the limited chip area effectively, different combinations of electrodes were used for different purposes (Fig. 2). Platinum, iridium, iridium oxide, and Ag/AgCl were used as the electrode materials. The electrodes had unique shapes and areas depending on their role. Details will be explained in the following sections. Compartments including a reaction chamber were formed with PDMS. First, a template was formed with a thick-film photoresist (SU-8). Then, a replica was formed by pouring a precursor solution and removing the cured PDMS. The volume of the reaction chamber was 0.7 μl. After the patterns

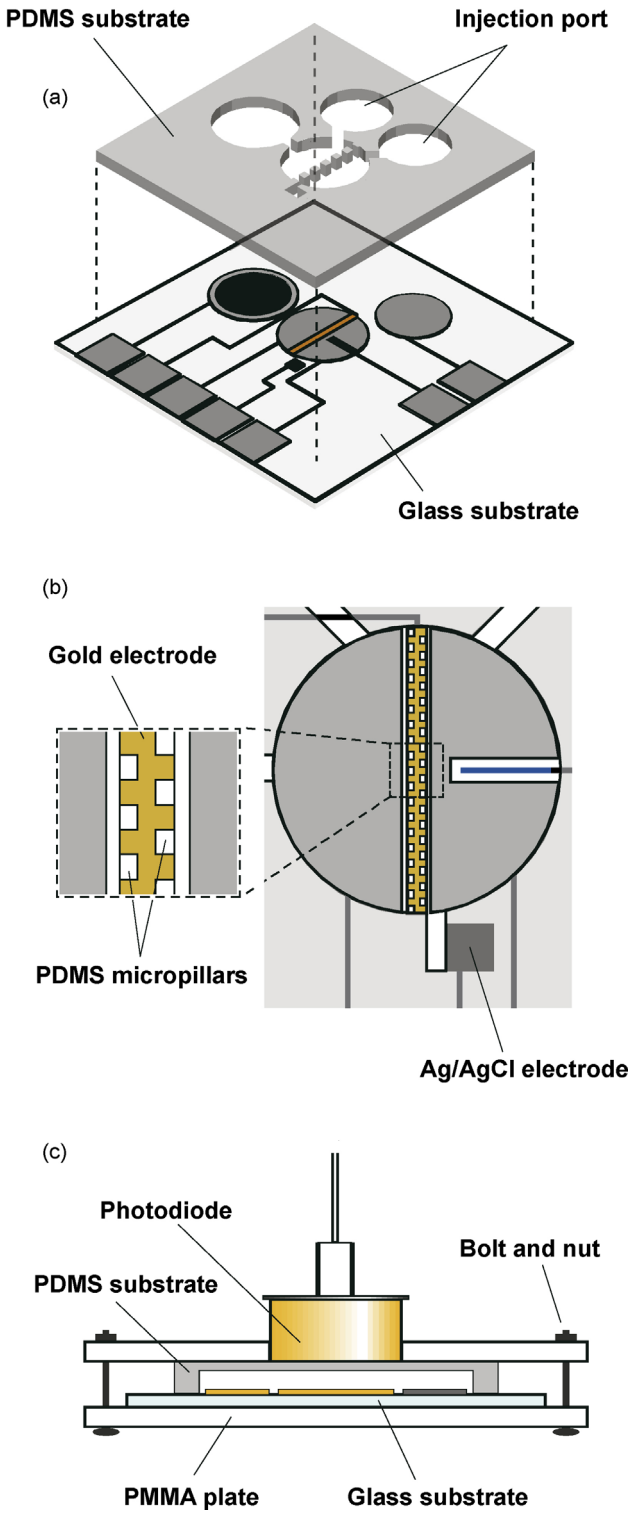

Fig. 1. Microsystem with automatic valve operation, pH regulation, ECL generation, and detection functions. (a) Decomposed structure. (b) Magnified view of the reaction chamber. (c) Cross section of the completed system showing the position of the photodiode.