DIGITAL IONIC CIRCUITS ON A MICROFLUIDIC CHIP

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ABSTRACT

A sophisticatedly designed polyelectrolyte diode was fabricated on a microchip and exhibited well-defined nonlinear rectifying behavior. Multiple polyelectrolyte diodes were integrated on a microchip to produce a variety of logic gates based on ionic circuits. By employing a fluorescent dye, the polyelectrolyte micro plugs also acted as optical indicators displaying the input signals applied to individual diodes in the ionic circuit on a microchip. Also, this system visualized the dynamic distribution of ions in a charged polymer phase under an electric field on a real time basis through fluorescence images.

KEYWORDS: Polyelectrolyte diode, Rectification, Logic gate, Ionic circuit

INTRODUCTION

A polyelectrolyte diode is a device based on strong Donnan exclusion in the electrostatic junction between two oppositely charged polyelectrolytes[1]. This junction system acts as a rectifier similar to a silicon-based electronic p-n junction. A forward bias makes the counter ions migrates toward the junction area of the plugs, while a reverse bias drives them from the polyelectrolyte phases to bulk solutions. Due to a difference between the resistances under forward and reverse bias across the junction, this electrical circuit exhibits nonlinear characteristics.

Since polyelectrolyte diode was first proposed by Bockris et al. in 1959[2], a few reports have been published on the nonlinear behavior, theoretical modeling, experiment results. However, polyelectrolyte systems have witnessed only minor advancement in terms of both fundamental understanding and useful applications. In the previously reported systems[3], the current versus voltage behavior (i-v curve) was significantly affected by the electrochemical reactions at the electrode interface because the resistance of electrode interface was not negligible compared with that at the polyelectrolyte junction. More importantly, no miniaturized network system, which is essential not only to quick response to an external electric input but also to logically integrating many polyelectrolyte junctions for further application has been reported. Here, we show well defined rectification at the microchip-based polyelectrolyte diode and a prototype of the integrated system, ‘ionic circuit’.

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EXPERIMENTAL

The components and the structure of the proposed system are shown in Figure 1. A pair of positively charged poly diallyldimethylammonium chloride (pDADMAC) and negatively charged 2-acrylamido-2-methyl-1-propanesulfonic acid (pAMPSA) were photopolymerized at the narrowest region by sequential UV exposure through a pre-patterned mask to the corresponding monomers in the channel. An anionic fluorescent dye, fluorescein, was utilized to display the dynamic distribution of ions across a pair of oppositely charged polyelectrolyte plugs.

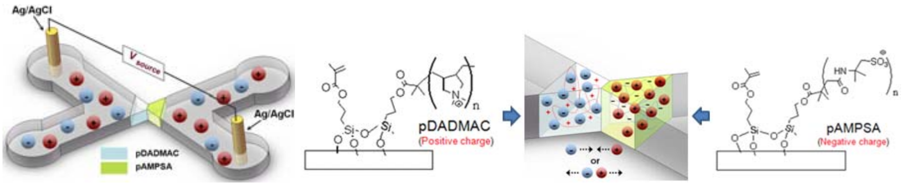

Figure 1. Schematics of microchip based polyelectrolyte diode.

RESULTS AND DISCUSSION

Our microchip system having narrow neck-like channel can show clear rectified curve purely governed by ionic conductance variation (Figure 2A and 2B) and visualize the dynamic distribution of ions on a real time basis by employing fluorescent dyes as shown in Figure 2C.

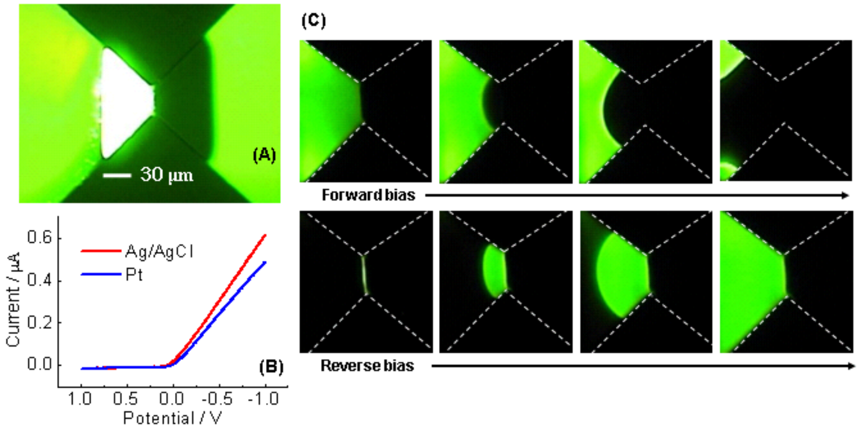

Figure 2. (A) A polyelectrolyte diode comprising pDADMAC (left) and pAMPSA (right) on a microchip. A 10 mM NaCl solution containing 1 μM fluorescein sodium salt was used. No electric field is applied. (B) i–v curves in 10 mM NaCl aqueous solution using Ag/AgCl or Pt electrodes. (C) Fluorescence images of a pDADMAC region (left) captured every 20 s (forward bias) and 10 s (reverse bias) in a 10 mM NaCl solution containing 1 μM fluorescein under an electric field.

More interestingly, the microchip-based polyelectrolyte ionic system can be patterned and integrated to operate as an “ionic circuit”. Figure 3 illustrates the microchip patterns and equivalent circuits for AND gate and NAND gate, which comprise two and three pairs of polyelectrolyte plugs, respectively. In addition to the electrical signals, the fluorescent emission at the polyelectrolyte plugs allows us to optically read the input signals that are applied to the individual polyelectrolyte ionic units in the logic gates. As an example, Figure 4A(d) shows that the on and off states of each polyelectrolyte diode are displayed via light emission, indicating input signals.

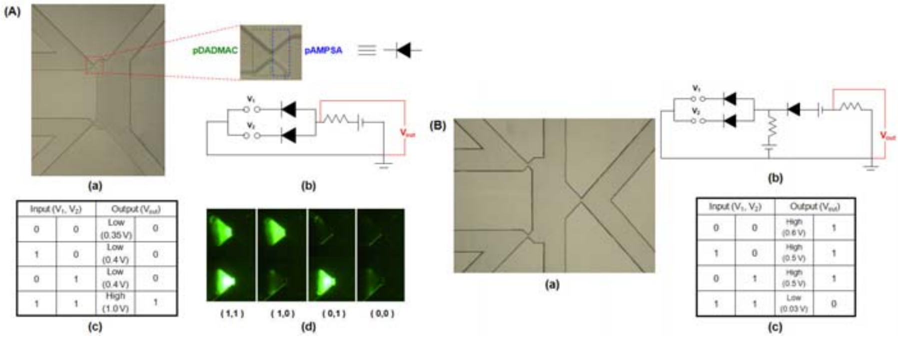

Figure 3. (A) AND logic circuit. A microchip pattern (a), the equivalent circuit (b), the truth table (c), and the fluorescent output images (d) for the microchip-based AND logic gate. (B) NAND logic circuit. A microchip pattern (a), the equivalent circuit (b), the truth table (c) for the microchip-based NAND logic gate. The input voltages were 4 V and 0 V.

CONCLUSIONS

The proposed microchip-based polyelectrolyte system may open new avenues of research, and suggest novel applications such as monitoring the dynamic distribution of specific ions at interfaces in a layer-by-layer membrane system, developing more advanced “iontronics”, e.g. junction gate field-effect transistor (JFET) and amplifier, and producing intelligent chip devices that can mimic the nonlinear functions of biological systems, e.g. asymmetric neuronal signaling across cell membranes.

REFERENCES

[1] L. Krasemann and B. Tieke, Selective Ion Transport across Self-Assembled Alternating Multilayers of Cationic and Anionic Polyelectrolytes, Langmuir, 16, 287-290 (2000)

[2] B. Lovrecek, A. Despic and J. O. Bockris, Electrolytic junctions with rectifying properties., Journal of Physical Chemistry, 63, 750-751 (1959)

[3] O. J. Cayre, S. T. Chang and O. D. Velev, Polyelectrolyte Diode: Nonlinear Current Response of a Junction between aqueous ionic gels, Journal of the American Chemical Society, 129, 10801-10806 (2007)