

# Gate Controlled Ionic Transport Nanofluidic Channel Fabricated by Silicon Planer Process

Kazuhiro Takahashi<sup>1,2</sup>, Junpei Nishimoto<sup>1</sup>, Yoshinaga Uemura<sup>1</sup>, Kazuya Atsumi<sup>1</sup>, Toshiaki Hattori<sup>1</sup>,  
Masato Futagawa<sup>1</sup>, Koichi Okumura<sup>1</sup>, Makoto Ishida<sup>1</sup>, and Kazuaki Sawada<sup>1,2</sup>

<sup>1</sup> Toyohashi University of Technology  
1-1 Hibarigaoka, Tempakucho, Toyohashi, Aichi 441-8580, Japan  
Phone: +81-532-44-6746 E-mail: takahashi@ee.tut.ac.jp  
<sup>2</sup> JST CREST

## 1. Introduction

Control of ionic transport through nanofluidic devices has attractive features for ability to create new functional devices and chemical bio-machine interface. In particular, local ionic stimulation to cells is a key technology for exploring the cellular function. There were some literature about fabrication and characterization about nanofluidic channel with gate electrodes to control an electrical double layer (EDL) which is modified the surface charge [1-3]. The previously reported nanofluidic channels were measured conductance change by using drain-source bias. However, the proton is transported by the drain-source bias as well as other cations. Therefore, the change of the pH level at the outlet would cause a harmful effect to cells.

In this paper, we have developed a gate controlled ionic transport nanofluidic channel fabricated by silicon planer process for highly integration of nanofluidic channels. With the measurement of gate controlled ionic current attributed by diffusion efficiency of K<sup>+</sup> ion we present the feasibility of selective passage of K<sup>+</sup> ion for cell stimulation.

## 2. Design

Fig. 1 schematically illustrates a concept of local ionic stimulation to cells using a multidimensional nanofluidic channel array. We designed 40-nm-deep nanofluidic channel which controls selective passage for ions by electrical double layer (EDL). Aluminum gate electrodes are prepared above the nanochannel in order to control the length of EDL. Silicon nitride based nanochannels have a negative charge on the sidewall. From the requirement of

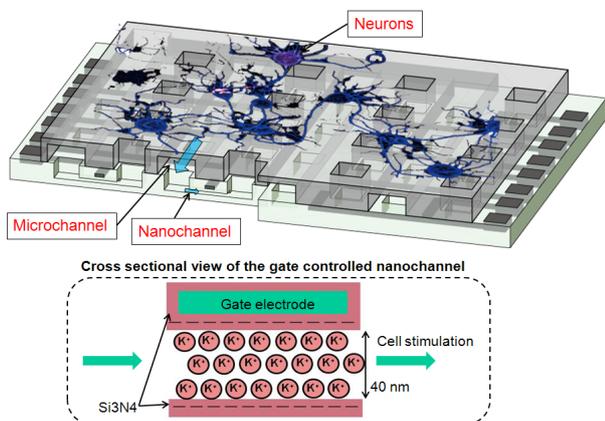


Fig. 1 Schematic image of local ionic stimulation to cells using a multidimensional nanofluidic channel array.

electroneutrality, the EDL formed by cations is filled in the overall 40-nm-channel.

## 3. Fabrication

Fabrication procedures are shown in Fig. 2; (a) a silicon substrate is thermal oxidation (100 nm), and Si<sub>3</sub>N<sub>4</sub> film was deposited by thermal CVD. (b) Poly crystalline Si, which is act sacrificial layer for nanofluidic channel, is deposited 40 nm by thermal CVD, and patterned. It is 50 μm long, 10 μm width and 40 nm depth. (c) After Si<sub>3</sub>N<sub>4</sub> film is deposited by plasma CVD, Al gate electrodes are placed on the nanofluidic channel, and the surface of this device is covered SiO<sub>2</sub>/Si<sub>3</sub>N<sub>4</sub> film for water proofing. (d) Ion inlet and outlet node are opened by RIE until poly-Si film is existed. The substrate is treated XeF<sub>2</sub> gas, and poly-Si sacrificial layer is removed. (e) Dry film resist is used to make microchannel network for long and multi transportation.

The thickness of nanofluidic channel is restricted by the poly-Si thickness and its accuracy is very high. Fig. 3 shows an optical micrograph of the nanofluidic channel with gate electrodes. Nanochannel is placed in center with connected filmresist microchannel. Al gate electrodes are allocated vertically with the nanochannel. Fig. 3(b) shows a cross sectional view of the nanochannel by TEM microscope, and 40 nm channel was confirmed clearly.

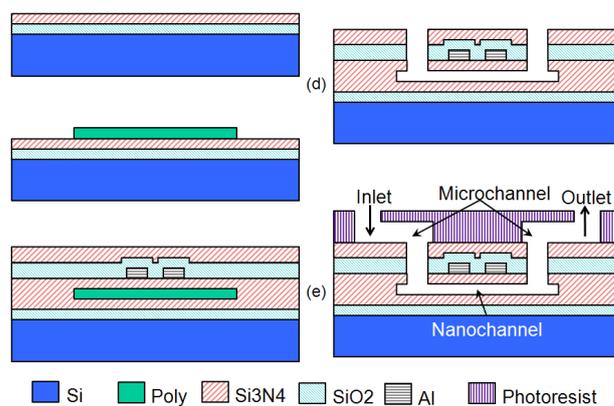


Fig. 2 Fabrication procedures

## 4. Experimental

The control of ionic transport current is possible if the depth of the channel is comparable to the thickness of the EDL. As Si<sub>3</sub>N<sub>4</sub> have negative surface charge, positive ions

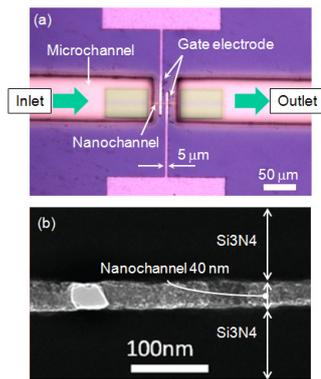


Fig. 3 (a) Optical micrograph of the nanofluidic channel with gate electrodes. (b) Cross sectional view of 40-nm-depth nanofluidic channel.

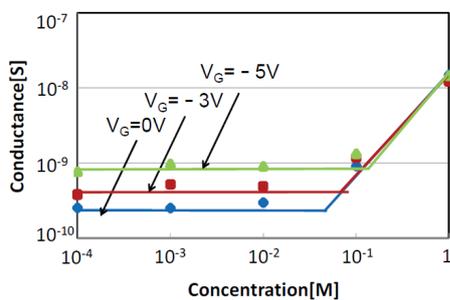


Fig. 4 Ionic electrical conductivity in KCl solution was controlled by the gate voltage in low concentration region. In linear region, both  $K^+$  and  $Cl^-$  ions are transported in nanofluidic channel. As negative voltage increase, saturation points move to high concentration.

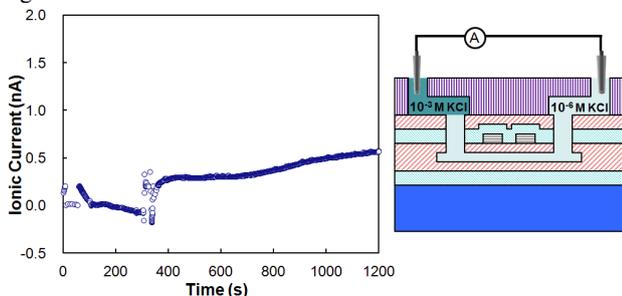


Fig. 5 Ionic current change by diffusion efficiency of  $K^+$ .

(anions) fill in the fabricated nanofluidic channel and the ions conduct in one direction. When a voltage is applied across the nanochannel, the thickness of EDL can be controlled. Fig. 4 shows a typical result in KCl solution. Ionic electrical conductivity was controlled by the gate voltage. Only  $K^+$  ions contribute ion conduct in saturation region. In linear region, both  $K^+$  and  $Cl^-$  ions transducer in nanofluidic channel. As negative voltage increase, saturation points move to high concentration. It means that  $Cl^-$  ions transport disable through nanofluidic channel.

We measured ionic current change by concentration gradient of KCl, as shown in Fig. 5. When the 1 mM KCl solution was added to the inlet, we observed ionic current change of 300 pA. The  $K^+$  concentration at the outlet was also measured by an atomic absorption spectrometer, and

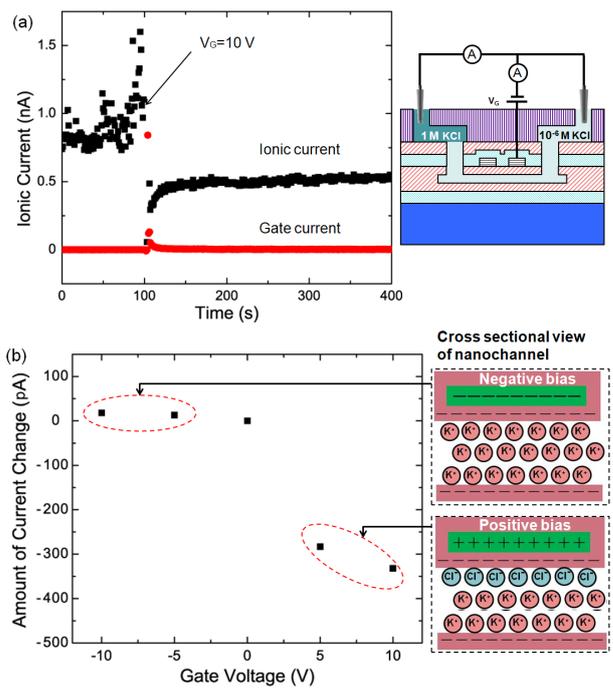


Fig. 6 (a) Measured ionic current through the nanochannel with gate voltage of 10 V. KCl solutions were supplied 1 M and  $10^{-6}$  M to inlet and outlet, respectively. (b) The ionic current as a function of gate voltage.

the concentration was increased to  $2.5 \mu M$ .

Fig. 6(a) shows measured ionic current through the nanochannel. We observed initial current of 820 pA which is only contributed by  $K^+$  ions moved by concentration difference between inlet and outlet of KCl solution. The ionic current was decreased to 490 pA when gate voltage of 10 V was applied, which means both ions flow in the nanochannel. The ionic current as a function of gate voltage is plotted in Fig. 6(b). The ionic current was drastically changed due to increasing  $Cl^-$  ions in the nanochannel by applied positive gate bias while no current change was observed with negative gate bias.

## 5. Conclusions

This paper presents a nanofluidic channel with Al gate electrodes developed by conventional silicon planar process, which can control ionic current through the nanochannel by the gate electrode voltages. The ionic current change of 330 pA due to increasing  $Cl^-$  ions in the nanochannel was successfully demonstrated by applied positive gate bias while no current change was observed with negative gate bias. The gate controlled ionchannel device would be expected for local ionic stimulation to cells.

## References

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