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BIOMIMETIC MICROFLUIDIC NEURONS FOR HYBRID EXPERIMENTS

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ABSTRACT

This paper reports a new way to explore in the neuromorphic engineering, the biomimetic artificial neuron using microfluidic techniques. This device is able to mimic the electrical activity of one biological neuron. Usually these artificial neurons are made in Silicon but this device could replace the electronic one and solve most of the issues of biocompatibility. This PDMS device is composed of two chambers for intra and extra-cellular modelling, different PDMS channels, selective permeable membrane for positive ionic exchange, quake valves and electrodes for recording the membrane potential. We obtain an electrical membrane potential similar to the biological neuron.

KEYWORDS: Neuromorphic engineering, Neuron, Biomimetic

INTRODUCTION

The neuromorphic engineering is the design of biomimetic artificial neural systems. Mostly of these systems are silicon-based [1], [2]. The main goal of those systems is the design of tools for biomedical applications like neuroprosthesis [3] and for the understanding of the human nervous system [4]. Nevertheless using silicon neurons bring some bio-compatibility issues (reject, power consumption). That's why a new way of neuromorphic engineering should be explored: the artificial neural systems based on microfluidic techniques (Figure 1). This new research does not exist yet in the state of the art.

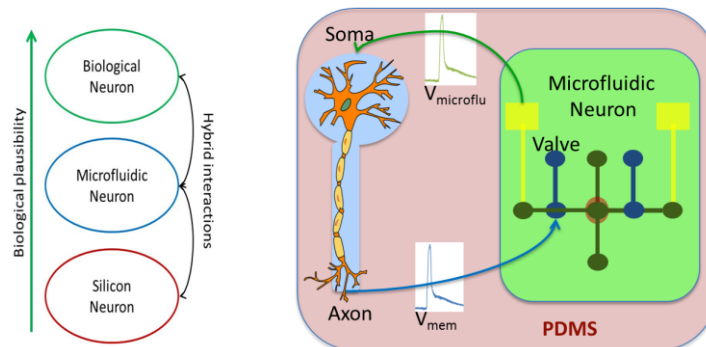


Figure 1: Microfluidic neuron position and future hybrid experiments between real neurons and microfluidic neurons.

THEORY

The main goal of this artificial neuron is to simplify the interactions with biological neurons and to reduce the bio-compatibility issues keeping the same ionic currents (K^+ , etc.) than in biology and using biocompatible material like PDMS. The biological neuron transmits electrical signals based on ion flow through their plasma membrane. Action potentials are propagated along axons and represent the fundamental electrical signals by which information are transmitted from one place to another in the nervous system.

EXPERIMENTAL

Based on this physiological behavior and Hodgkin-Huxley formalism [5], we propose a microfluidic structure composed of chambers representing the intra and extracellular environments, connected by channels actuated by Quake valves [6]. The Quake valve are activated for closing the channel and then to

put the membrane potential to 0V. The activation of these valves is done thank to air pressure injection (Figure 2).

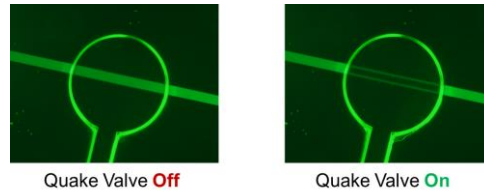


Figure 2: On the left picture, the Quake valve is not activated, on the right one, it is activated by air pressure.

These channels are equipped with selective permeable membranes (Nafion) to mimic the exchange of species found in the biological neuron. Thick PDMS membrane is used to create the Quake valve membrane. Integrated gold microelectrodes are used to measure the potential difference between the intracellular and extracellular environments: the membrane potential (Figure 3).

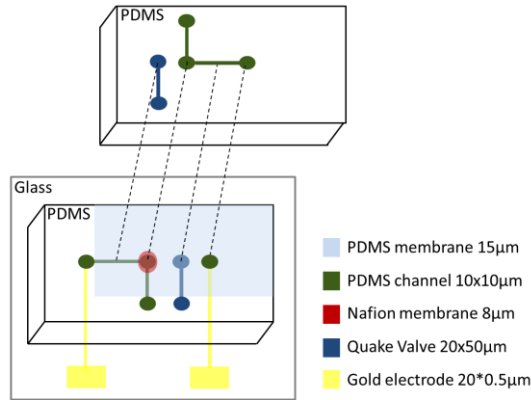


Figure 3: Description of the different layers of the microfluidic neuron. In the bottom left PDMS channel, we use a 1mmol.L^{-1} KCL and in the upper right PDMS channel, a $10\mu\text{mol.L}^{-1}$.

RESULTS AND DISCUSSION

We obtain an electrical behavior similar to the biological neuron (Figure 4). The two action potentials are created by two air pulses of 100ms which close the Quake valve (one at 5.2s and one at 6.3s). The repolarizing phase has slower velocity than the rising phase like we observe in biology. The main parameter for controlling the shape of the action potential is the difference of ion concentration between the two chambers. In our case, we use different concentrations of KCl (1mmol.L^{-1} and $10\mu\text{mol.L}^{-1}$), which involve a 120mV of difference of potential (Nernst equation). We could also control the spike frequency with the programmed time sequence of the quake valve controller.

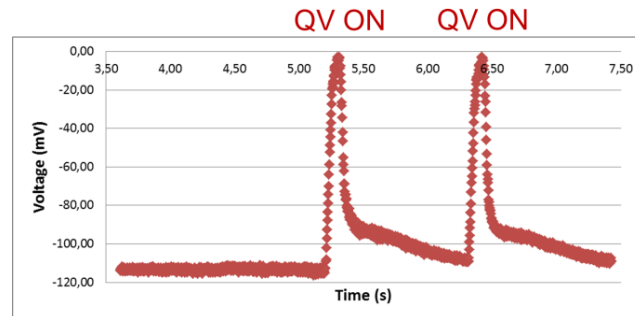


Figure 4: Membrane potential of the microfluidic neuron depending of the activation of Quake valve.

CONCLUSION

The preliminary results of this microfluidic device demonstrate that it is able to mimic the electrical activity of one biological neuron, in terms of amplitude, shape and frequency.

The next step of our work is to make hybrid experiments in the same chip: neuron culture in one part of the PDMS device and the artificial neurons in the other part. Figure 5 describes this PDMS device. In the left part, gold microelectrode arrays is used for stimulation or recording of biological cells like neurons or muscle cells. In the right part, the microfluidic neuron is used for stimulating the biological part.

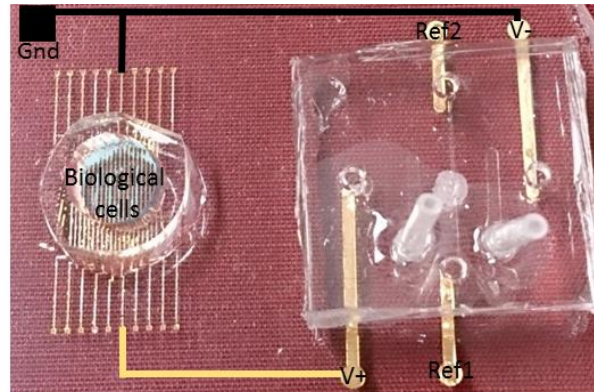


Figure 5: PDMS platform for hybrid experiments with gold electrode array for cell culture (left) and microfluidic neuron (right).

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