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Abstract

A Low-Cost Testbed for Neural Microelectrodes †

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Abstract: The performances of microelectrode arrays for neural interfaces strongly depend on electrode design. Due to a lack of simulation tools, electrode engineers often have to refine new designs empirically. This process requires setups of electrical and electrophysiological hardware that are not specific to electrode testing and unnecessarily costly. We propose a low-cost testbed for specifically targeting metrics relevant to electrode performance and functions, which relies on an off-the-shelf measurement tool and only on components necessary for such testing. We experimentally demonstrate the platform by characterizing microelectrodes by means of impedance spectroscopy and recording the extracellular action potentials from in vitro primary rat neurons.

Keywords: microelectrode array; neural interface; electrode characterization; microfabrication

1. Introduction

Electrode design is crucial for the performance of microelectrode arrays (MEAs) used for neural interfaces and cellular electrophysiology [1]. New electrode developments often involve iterative experimentation using certain sets of performance metrics [1,2]. Setups assembled using standard instruments and MEA recording systems are, however, neither cost-optimized nor readily configurable for electrode characterizations. Therefore, we propose a testbed that provides performance and functional testing for electrode development featuring low costs of ~EUR 500, ease of assembly, and compactness. The proposed testbed includes two important tests for electrodes, namely, electrochemical impedance spectroscopy (EIS) and the capability to record action potentials (APs) of electrogenic cells. We experimentally demonstrate the testbed on in-house made MEAs.

2. Materials and Methods

The testbed was built using an off-the-shelf system-on-chip (STEMLab 125-10, Red Pitaya, Solkan, Slovenia) and a custom-printed circuit board featuring a set of multiplexers (MUX) and two amplifiers. MEAs were fabricated on glass wafers (150 nm Pt metal and 1-µm SiO_2 passivation layer), featuring 60 working electrodes (WEs) and a reference electrode (RE). Chips were packaged to form a bath chamber. Pt-black was electro-deposited on the WEs in selected chips. The testbed was operated in two modes: (1) EIS and (2) electrophysiological recording (Figure 1a).

For EIS, the MEA bath was filled with phosphate-buffered saline. A sinusoidal voltage excitation signal was swept from 10 Hz to 10 kHz, and the current was recorded from each WE. The impedances were calculated by a digital demodulation technique. For electrophysiological recordings, E18 rat cortical neurons were plated on the arrays. On 31 days in vitro (DIV), the voltage at each WE was amplified (gain = 430), recorded at 15.26 kS/s, and filtered (300 Hz–5 kHz). Continuous recordings of 1.07 s duration were performed repeatedly.

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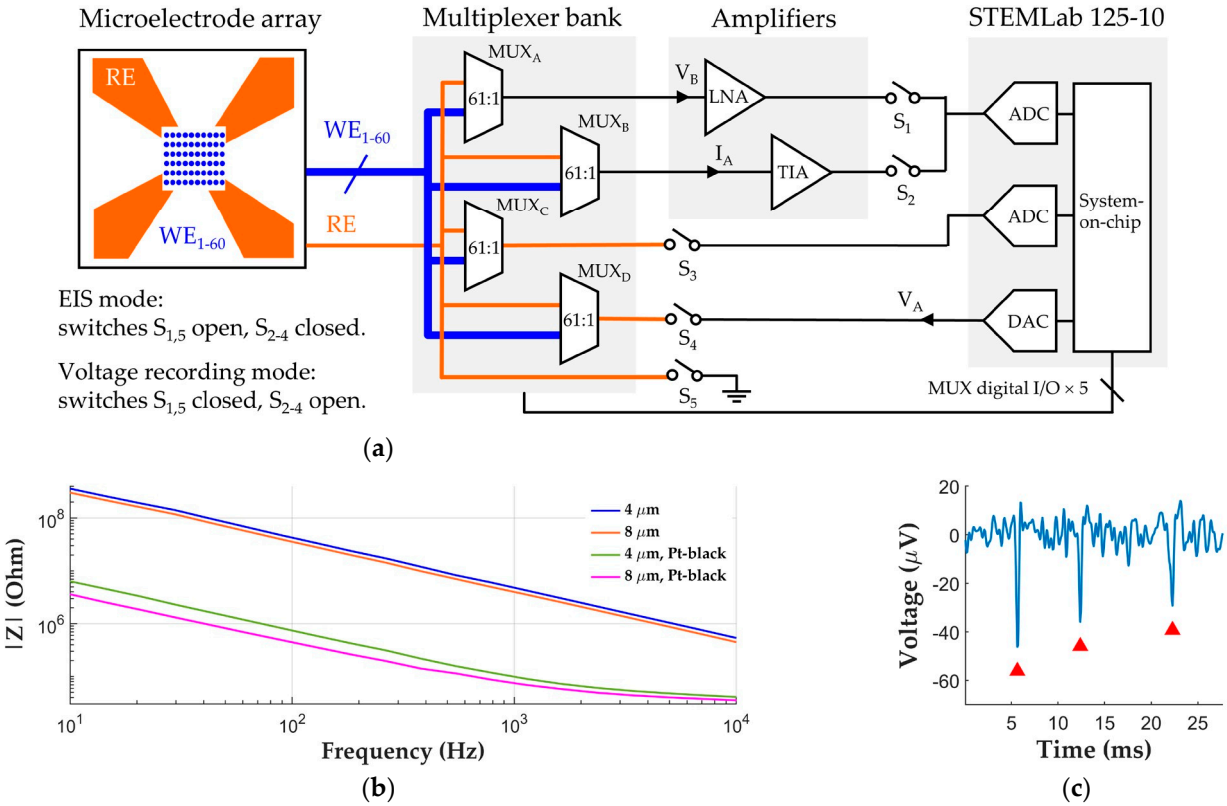

Figure 1. Testbed schematic and results. (**a**) An MEA was connected to a 61:4 MUX bank. Two of the outputs were connected to a low-noise amplifier (LNA) and a transimpedance amplifier (TIA). The STEMLab 125-10 hosts a system-on-chip, analog–digital and digital–analog converters (ADC/DAC), and digital outputs (I/Os) to operate the MUXs. Switches $S_{1–5}$ set up either EIS or recording mode. For EIS, a frequency-swept voltage signal (V_A) is applied to the RE, and the current through the WE (I_A) is measured by the TIA. For electrophysiological recordings, the RE is grounded, and the voltage (V_B) is recorded from a WE after amplification by the LNA. (**b**) Spectra of mean impedance magnitudes ($|Z|$) of electrodes of 4 and 8 µm diameter, with and without Pt-black (n = 15 each). (**c**) Representative voltage recording of extracellular APs (marked with red triangles) from 31 DIV rat neurons.

3. Discussion

We used the testbed to obtain impedance spectra for electrodes of 4 and 8 µm diameter, with and without Pt-black (Figure 1b), showing the effects of size and Pt-black on impedance reduction.

We tested 8 µm Pt-black electrodes for the AP recording of rat cortical neurons. Figure 1c shows a representative voltage recording, where extracellular APs are clearly visible.

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