EFFECTS OF SUB-10µm ELECTRODE SIZES ON EXTRACELLULAR RECORDING OF NEURONAL CELLS

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ABSTRACT

In this paper, we present a study of the electrophysiological recording characteristics of metal electrodes of dimensions below 10 x 10 µm^2. Electrodes with different sizes were fabricated in microelectrode arrays and characterized with respect to both noise and neuronal recording properties in order to estimate optimal electrode sizes.

KEYWORDS: Micro Electrode Array, Metal Electrodes, Neuronal cells, *in-vitro*, Extracellular recording

INTRODUCTION

Recently developed *in vitro* High-Density Micro Electrode Array (HD-MEA) systems offer up to several thousand electrodes in very dense arrangements on a single chip (electrode center-to-center pitch below 17µm) [1]. A low electrode pitch is favorable, since it allows for sub-cellular spatial sampling and selective recordings. Reducing the pitch further will make it necessary to use smaller electrodes. However, decreasing the size of the electrodes commonly causes a reduction in signal-to-noise ratio (SNR) due to an increase in thermal noise and higher electrode sensitivity to background perturbations [2]. It is unknown, how far one can go towards smaller electrodes while keeping good SNR.

EXPERIMENTAL

Electrodes of four different sizes were fabricated on a CMOS based HD- MEA [1], as shown in Fig 1. The electrodes were fabricated from Pt-metal layers, and, on some of the devices, Pt-black was electrochemically deposited. The HD-MEA features on-chip recording channels, which were used to acquire the extracellular signals from the electrodes and to assess the electrode noise characteristics.

RESULTS AND DISCUSSION

We first used the CMOS chip to measure the noise characteristics of each electrode with and without Pt-black deposition. Noise Power Spectral Density (PSD) was calculated between 1 Hz and 10 kHz, and

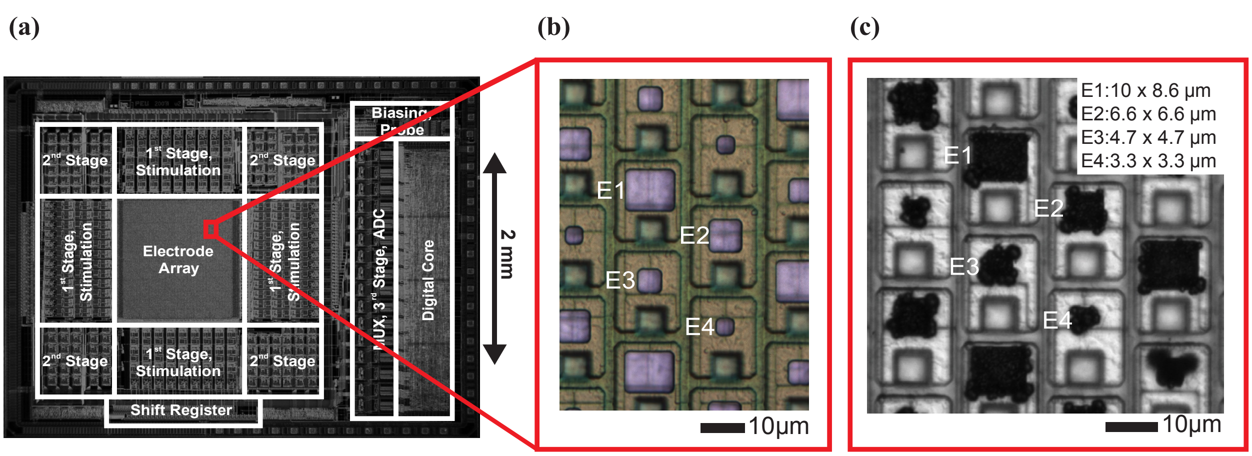

Figure 1: (a) Die micrograph of the CMOS microelectrode array (MEA) (b) Electrodes without Pt-black deposition (c) Electrodes with Pt-black deposition.

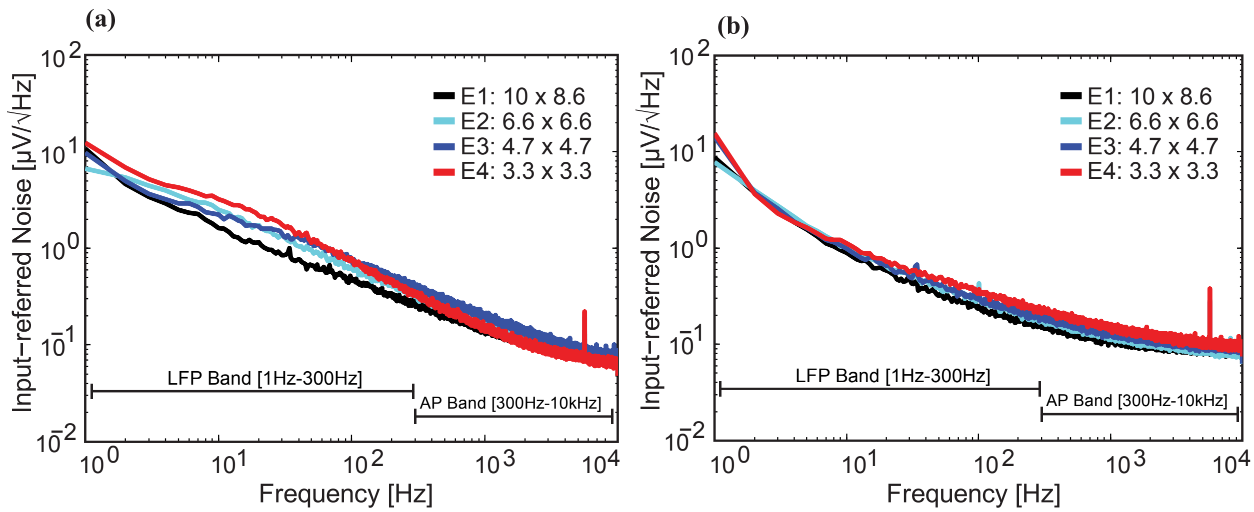

Figure 2: Noise analysis of electrodes of variable size; PSD of electrodes without (a) and with (b) Pt-black deposition

we quantified the influence of the electrode size on noise levels (Fig 2). As expected, smaller electrodes showed higher thermal noise. From the noise PSD we calculated the integrated noise in 2 different spectral regions of interest: the Local Field Potential (LFP) band (1Hz - 300Hz) and the Action Potential (AP) band (300Hz - 10 kHz). The electrode-size dependence of the noise was not very pronounced in the AP band for electrodes without Pt-black deposition. Noise levels for Pt-black electrodes in both bands were comparably low.

Next, we were interested in how the electrode size affects the effective signal amplitude. For this purpose an artificial signal, an alternating voltage of 1mV peak-to-peak at 1 kHz, was applied to the solution, and the signal was acquired from each type of electrode. As expected, the absolute impedance of the electrodes played an important role for the recording of signals. We saw significant attenuation (44%) in the measured signals (Fig 3), which is due to the fact that the electrode impedance is comparable to the input impedance of the voltage recording amplifiers [3]. By reducing the absolute electrode impedance through Pt-black deposition, we were able to decrease the effect of signal attenuation to around only 5% (Fig 3).

We also measured biological signals from retinal ganglion cells of an acute retina placed on the array [4]. With Pt-black electrodes, there was no significant influence of the electrode size on the average action potential negative peak amplitudes (Fig 4).

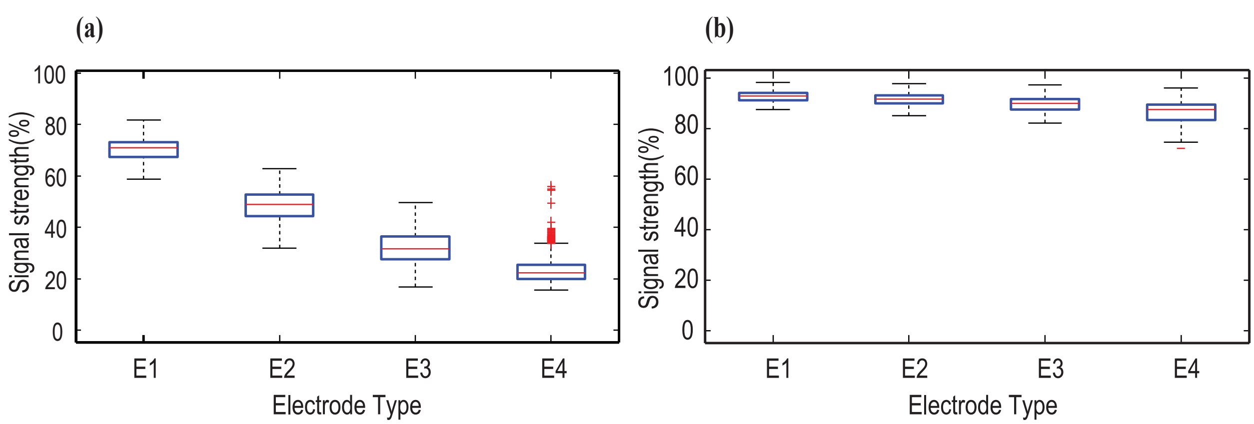

Figure 3. Effect of electrode size on signal amplitude; (a) without Pt-black, signal peak amplitudes decrease with smaller electrode size; (b) with Pt-black, the influence of the electrode size is significantly reduced.

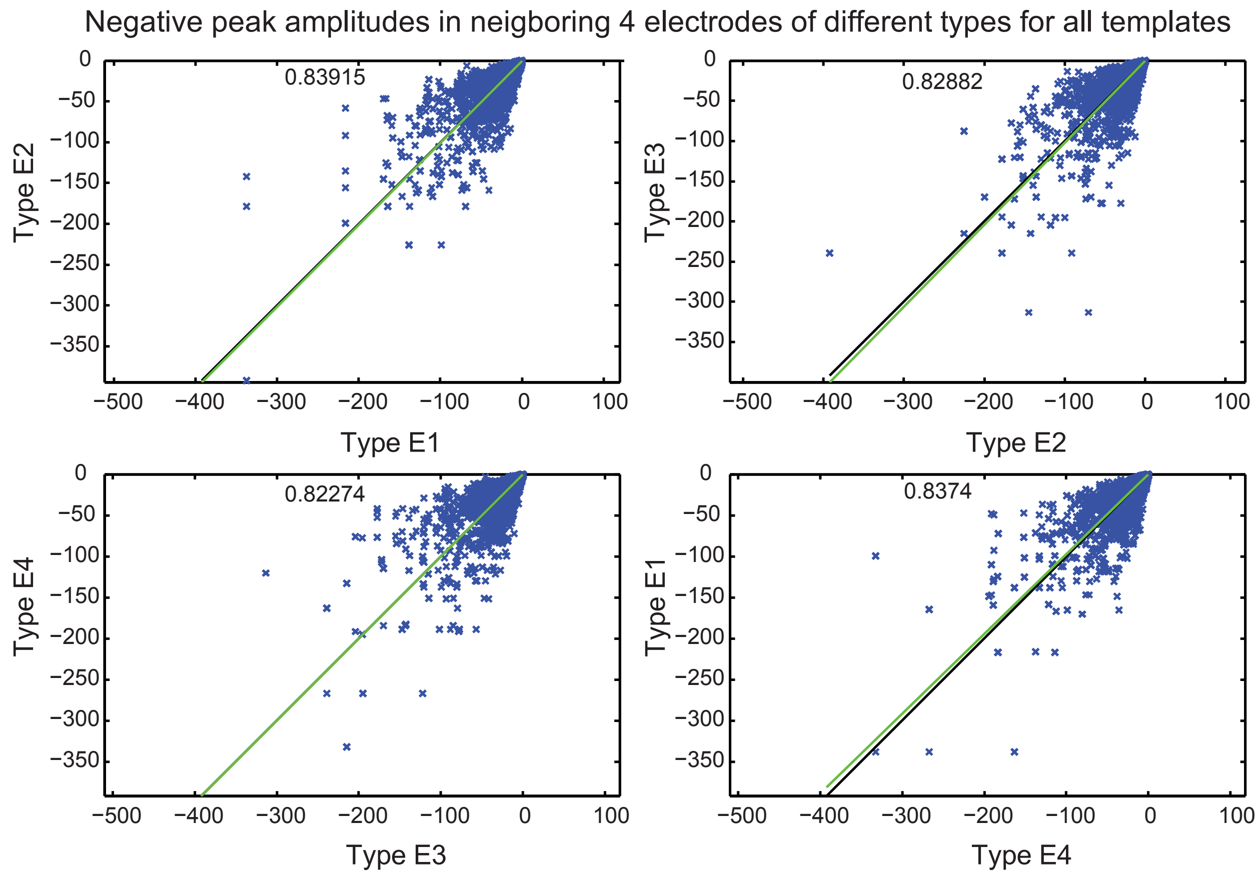

Figure 4: Biological signals from retinal ganglion cells recorded on Pt-black electrodes. Plots of the negative peak amplitudes of 154 spikes on electrodes of one distinct type (x-axis) versus those of the closest electrode of a different type (y-axis). The black line marks identity, the green line marks the first principal component of the data set.

CONCLUSION

We have demonstrated that it is possible to reduce the electrode size for extracellular neuronal recordings down to 3.3 x 3.3µm^2 without significantly degrading SNR performance for cases in which the overall electrode impedance can be reduced, e.g., by Pt-black deposition.

ACKNOWLEDGEMENTS

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