

Ferroelectric Microelectrode Array with System-Integrated Direct-Digitization ASIC for Neural Recording

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Summary:

We present a bioelectronic interface platform comprising a passive ferroelectric microelectrode array (FeMEA) biochip directly connected to DC-coupled sigma-delta analog-to-digital converters (ADCs) with a power consumption of less than 10 μ W per channel. The FeMEA biochip platform is validated with pre-recorded neuronal signals in the action potential band (0.3 – 10 kHz) and in the local field potential band (1 – 300 Hz), thereby demonstrating utility for *in-vitro* neurophysiology applications and future *in-vivo* neural probes with ferroelectric electrodes.

Keywords: Ferroelectric microelectrode arrays (FeMEAs), analog-to-digital converters (ADCs), neural recording, low-power consumption

Background, Motivation and Objective

Bioelectronic devices for targeted neural stimulation and recording of bioelectric signals, e.g., in implant systems or wearables, offers enormous opportunities for the treatment, prevention and rehabilitation of neurodegenerative disorders and chronic diseases [1,2]. Key prerequisites for the successful use of future bioelectronic devices are their long-term stability, sensitivity and safety, which are all largely determined by the properties of the bioelectronic interface.

The traditional approach to bioelectronic interfacing is based on metallic electrodes in contact with electrogenic cells or tissue [1,2]. However, when using metallic electrodes (e.g. Pt) for neural stimulation, it is difficult to avoid electrochemical degradation processes at the interface which can lead to corrosion and to cell and tissue damage [3]. One possible solution to avoid electrochemical degradation processes in bioelectronic applications are ferroelectric electrodes [4]. There, a metallic electrode is coated with a ferroelectric insulator, whereby electrochemical degradation processes are suppressed and the stimulation current corresponds to a displacement current induced by ferroelectric polarization reversal.

The read-out electronics require low-power consumption. Recently, the concept of in-situ digitization of neuronal signal utilizing DC-coupled sigma delta analog-to-digital converters (ADCs)

has been introduced and validated with generic electrode materials including Pt and IrOx [5,6]. However, the combination of ferroelectric electrodes connected to low-power recording frontends formed by an application-specific integrated circuit (ASIC) has not been tested yet.

Description of the System

In this work, we introduce a bioelectronic interface platform comprising a passive ferroelectric microelectrode array (FeMEA) biochip directly connected to DC-coupled sigma-delta ADCs with a power consumption of less than 10 μ W per channel [6]. An overview of the complete system is shown in Fig. 1(a). The FeMEA biochip is depicted in Fig. 1(b) and has 60 circular TiW electrodes (30 μ m in diameter) which are coated with 8-nm ZrO₂ with field-induced ferroelectric properties [7]. The electrode pitch is 200 μ m and the FeMEA biochip is also compatible with commercial MEA readout systems. The experimental configurations for testing the functionality of the recording ASIC and for measuring pre-recorded neural signals with the FeMEA connected to the recording ASIC are shown in Fig 1(c,d) respectively. It should be noted, that the first stage of the ADC is formed by a dedicated input transistor T_{IN} and hence, the ferroelectric electrode connected to the gate of T_{IN} corresponds to an extended-gate field-effect transistor (EGFET) sensor [8].

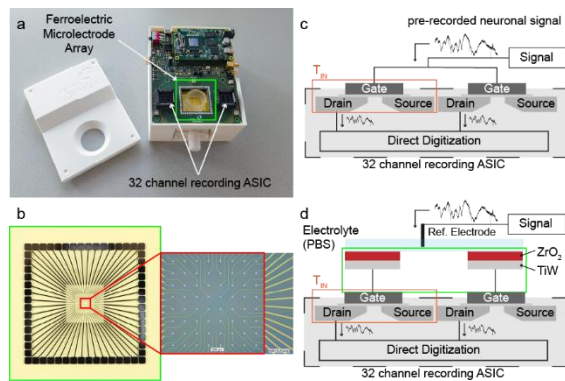


Fig. 1. (a) Overview of the prototype system. (b) FeMEA biochip. (c) Experimental set-up for ASIC testing. (d) Experimental set-up for measuring pre-recorded and pre-processed neural signals with FeMEA connected to the recording ASIC.

Results

We developed and designed a system for evaluating the capabilities of recording neuronal signals with ferroelectric coated MEAs in combination with a direct-digitization frontend. Fig. 2a shows the recording of a pre-recorded and pre-processed neural signal applied directly to the designed neurorecording ASIC. In comparison, Fig. 2b contains the signal measured by the combination of ASIC and FeMEA biochip immersed in electrolyte. The artificial neural signals contain spikes induced by action potentials (APs, frequency band 0.3 – 10 kHz) and slower oscillations due to local field potentials (LFPs, frequency band 1 – 300 Hz). The measured signals with a FeMEA electrode connected to the ADC is shown in Fig. 2(b). AP spikes and LFPs are clearly visible, which demonstrates full functionality of the system. Moreover, our results demonstrate the possibility to utilize ferroelectric electrodes in EGFET sensors, which are so far operated solely with conductive (i.e., uncoated) electrodes [8].

The presented work serves as a basis for future highly-integrated in-vitro and in-vivo bioelectronic devices, including EGFET-based sensors, that combine ferroelectric electrodes with low-power readout electronics on a single chip.

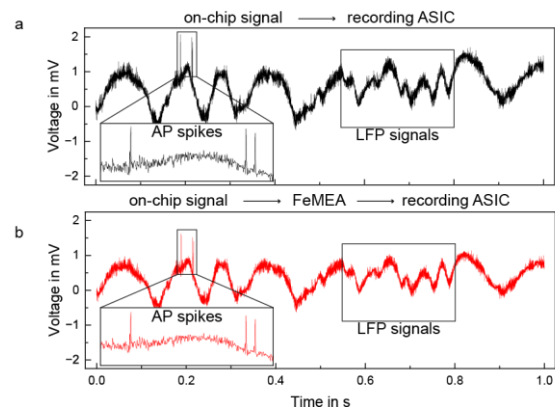


Fig. 2. Validation of the entire systems with pre-recorded neural signals. (a) Input Signal directly connected to recording ASIC. (b) Input signal applied to reference electrode in electrolyte and recorded with FeMEA electrode connected to recording ASIC.

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