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High channel count electrode system to investigate thalamocortical interactions

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Abstract

A novel silicon-based microelectrode array with one- and two-dimensional variants was developed in the framework of the EU-funded research project NeuroProbes. The electrode array comprises complementary-metal-oxide-semiconductor based integrated circuitry to implement the concept of electronic depth control which is used to select up to 32 recording sites from more than 1000 possible electrode channels integrated on four slender probe shafts. The electrode array was tested in acute experiments performed simultaneously in cortex and thalamus of the rat brain. In both brain regions good quality local field potential and multiunit activity was recorded during the tests.

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Keywords: Silicon-based neural probe array; electronic depth control; CMOS integrated circuit; thalamocortical interaction

1. Introduction

Electrophysiology research of brain function is based on the analysis of electrical signals recorded from single neurons or populations of neurons simultaneously. Microelectrode arrays containing multiple recording sites, i.e. tens [1], hundreds [2] or even over thousand [4], implemented on the same probe are used to obtain a large amount of information from a single recording session. According to the concept of electronic depth control (EDC) successfully demonstrated in [2,4], thousands of biopotential recording sites are placed on the penetrating shafts of the device in combination with switching electronics. With the aid of this approach, it is possible to adjust recording site positions independently inside the brain tissue without any movement of the probe. The concept was implemented in the form of one- and two-dimensional probes, tested successfully under in vivo conditions in the rat thalamocortical system.

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2. Probe design, realization and in vivo tests

The probe shanks containing the switching electronics are realized using commercial 0.5 μm and 0.6 μm CMOS (complementary-metal-oxide-semiconductor) technologies combined with post-CMOS processing to realize the recording sites and define the probe shape [2]. The on-shaft electronics consists of a switching matrix built from a daisy chain of D-type flip-flops that drive simple transmission gates. The recording electrode sites can be electronically switched onto eight output lines using these transmission gates. Each recording site can only be switched onto two [2] or four [4] of the possible eight output lines. However, the flexibility of usage is not shortened since any combination of two so called tetrodes (a group of four recording electrodes, placed most proximally to each other) can be selected at the same time. In addition to the switching electronics, the CMOS wafer also contains an amplifier circuit for pre-amplification as well as signal multiplexing [4]. Two variants of EDC probes were implemented. Variant 1 comprises a 4 mm-long single-shaft probe with 188 recording contacts and a recording site pitch of 40 μm. Each Pt recording electrode site has a diameter of 20 μm [4]. Variant 2 has a comb-like probe structure with four shafts 8 mm in length comprising 257 IrOx recording sites on each shaft with a diameter of 50 μm and a recording site pitch of 60 μm. Both the single-shaft and the four-shaft comb-like probes are connected to a printed circuit board (PCB) using wire bonding. The PCB of variant 2 contains in addition a CMOS-based front-end electronics. This front-end electronics comprises a preamplifier, a channel buffer, a multiplexer and an output buffer. In case of the comb-like device, an interface box was designed to control the probe, provide second stage amplification, filtering and demultiplexing of the analog signals. The output of either the single shank or the comb-like probe can be connected to any standard recording system or handled by the custom developed NeuroSelect software [3]. The software enables the user to select the probe channels either manually or use the built-in function to automatically scan through the whole probe to find the channels with the best signal-to-noise ratio.

The probes were tested in acute experiments using adult rats under ketamine-xylazine anesthesia. The probes were inserted into the primary somatosensory cortex and the underlying thalamic nuclei. We were able to record good quality local field potential, multiunit activity and single unit activity with both probe variants simultaneously from cortex and thalamus. This recording capability may give us a powerful tool to reveal more information about the intricate relationship of cortical and thalamic activity.

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