in press with "Biomedizinische Technik", Proceedings of the AnnualConference of the German Biomedical Engineering Society, 2002, Karlsruhe

A 64(128)-CHANNEL MULTISITE NEURONAL RECORDING SYSTEM

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Abstract — ***We used a recently described all-dry silicon etch process for SOI wafers to fabricate 64-site electrode arrays in stereotrode arrangement for acute cortical recordings. The fork-like probes are connected to pre-amplification units by flexible, Y-shaped interconnects. This facilitates maximal experimental flexibility for simultaneously recording from all available channels from the cortex of anaesthetised rats. Preconditioned signals are amplified by a novel modular main amp, which may be software or dial controlled. Signals are 16bit digitized, recorded, analyzed, stored and processed on a DSP-based modular data acquisition system. Digital data is processed, filtered and denoised on all up to (4*32) 128 channels based on an extremely fast wavelet transformation framework.***

Keywords— ***multisite neuronal recording, silicon probes, real time, wavelet, lifting scheme***

Introduction

The current understanding of how the nervous system functions is based on numerous observations of the behavior of single units or a small ensemble of units correlated to some external stimulation or behavioral event [8]. However, the processing power of the nervous system lies in its network and interconnections [5, 10, 13]. Thus the key to understanding the nervous system is to make observations of the activity of numerous cells at the same instant [6]. Our objective is to develop a complete system, which enables acute, neurophysiologic and simultaneous recordings from up to 128 micro-electrodes with minimal tissue traumatization and perfect control of recording site position. Obviously, this objective can only be achieved by integrating micromachining techniques with sophisticated signal conditioning and advanced signal processing. In the following we report the development of silicon batch-fabricated, 64-site microelectrodes, which may be used in groups of two with a 128 channel amplifier system and a (n*32) channel data acqusition device based on off-the-shelve DSP-boards..

Silicon Probes with 64 Recording Sites

Our results presenting fork-like silicon probes with 32 recording sites (Figure 1), as well as details to our micromachining process based on an all-dry etch process with a Silicon-on-Insulator (SOI) wafer as substrate are described in detail elsewhere [11]. Six photolithography masks permit an advanced multilayer process. The conductor traces (Figure 1c) in Ti/Au and the Ti/Pt recording sites (Figure 1b) are defined by evaporation and lift off, permitting conductor line widths down to 1 µm. Three dielectric and insulating layers are deposited using either a dual frequency stress free PECVD process or different stress compensating materials, in order to achieve low total intrincic stress in the probe shafts. Trenches around each base plate and the shafts are defined by a front side deep reactive ion etch (DRIE) [12]. The base plate (Figure 1e) of the probe has the full SOI wafer thickness, whereas the free standing structures, the shafts (Figure 1a), are DRIE-etched from the backside down to approx. 25 µm thickness, using the buried oxide layer of the SOI wafer as etch stop.

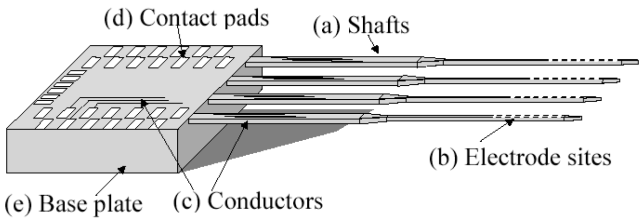

Fig. 1: Schematic drawing of a fork-like silicon multisite microelectrode

The main difference between the 32 and the 64 site probes consists of the bigger base plate to house 64 bond pads, an increase in resolution, new experimentally motivated array arrangements and a doubling of recording sites by introducing a second site, i.e. a stereotrode, 30µm apart from the original site or by increasing the number of shafts. The stereotrode arrangement facilitates selectivity for subsequent sorting and classification of spikes [7].

It was shown earlier, that two closely neighbouring sites may record neural signals from the same cell, but with differing amplitudes. This additional information supports each following analysis step significantly.

Figure 2 shows a scanning electron micro-graph of one of our new probes in comparison to a human hair. Figure 3 gives an overview over a complete, unmounted probe.

Preliminary electrical characterization show evidence for recording site impedance in the order of 2.5 MΩ at a driving frequency of 1kHz. Thus, these probes are suited for intracortical acute recordings from a brain, as well as for a galvanic platinum black deposition.

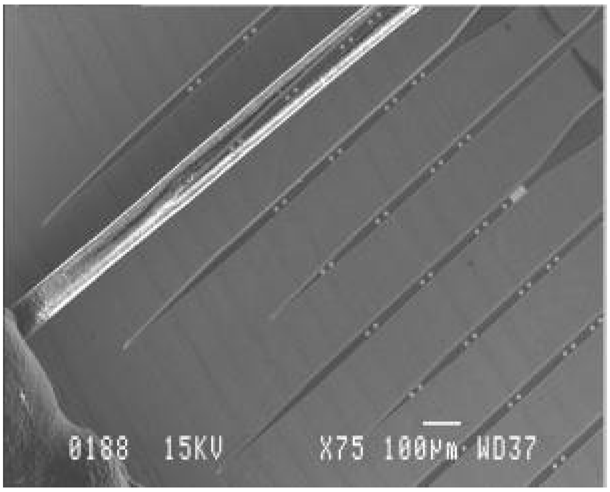

Fig. 2: SEM picture of the shafts of a 64 site, 8 shaft micro probe compared to a human hair. Clearly visible is a bigger site on the 4th shaft from the bottom: This is a site dedicated to electrolytic lesioning for histology.

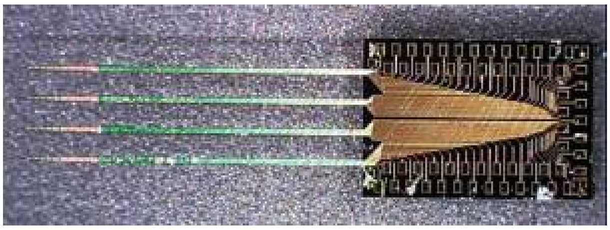

Fig. 3: Overview of a 64 site, 4 shaft probe. Clearly visible are the comparably huge bond pads on the base plate to the right.

Interconnect and Packaging

Ready processed probes are glued to flexible PC-boards and wired-bonded to the appropriate contacts. The wire bonded base plate is covered with an epoxy glob top. The flex board is a custom made (HP-Etch, Järfälla, Sweden, www.hpetch.se) Y-shaped product fitting to two 32-channel Molex 52559 ZIF connectors (www.molex.com). The Y-shape enables the user to adjust his experimental setup in a way as the restricted area around a craniotomy permits. He can either plug the probe in one 64 -or two 32-channel preamps. Obviously, two preamp boxes may be placed at opposing sides of the surgical area, which we account for by the bending capabilities of the flex board (Figure 4).

Data Conditioning

Above mentioned flexible connectors are plugged into the front end of our low-noise 32 channel miniaturized preamplifier, which in turn amplifies the signal by a factor of 16 and is accumulator operated.

A long SCSI cable carries all preamplified signals to the programmable gain main amplifier PGMA-64. The PGMA-64 has 64 differential input amplifier channels with high common mode rejection ratio (100dB). Each channel is software controlled. The gain on each channel can be selected via a front-panel interface unit, see Figure 6, and also via DAQ software. The whole setup for a 64 channel recording system is shown in Figure 7.

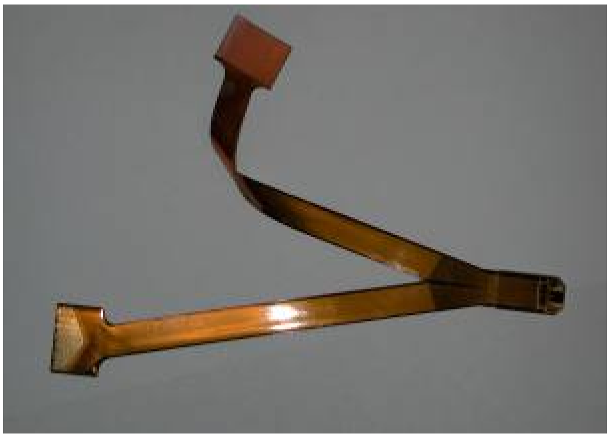

Fig. 4: Y-shaped flexible connector between microprobes (to be connected at the right side) and Molex ZIF connectors (to be connected left and top).

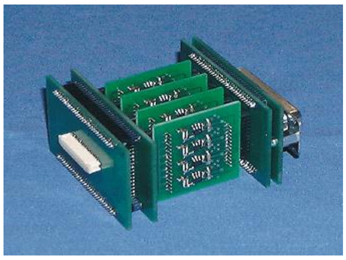

Fig. 5: 32 channel Preamplifier without aluminum casing. Clearly visible are the four SMD-amplifiers boards, each dedicated to 8 channels.

Fig. 6: Front panel user interface of PGMA-64. This interface allows gain settings of each of the 64 channels: either singly, in groups of 8, or all at once.

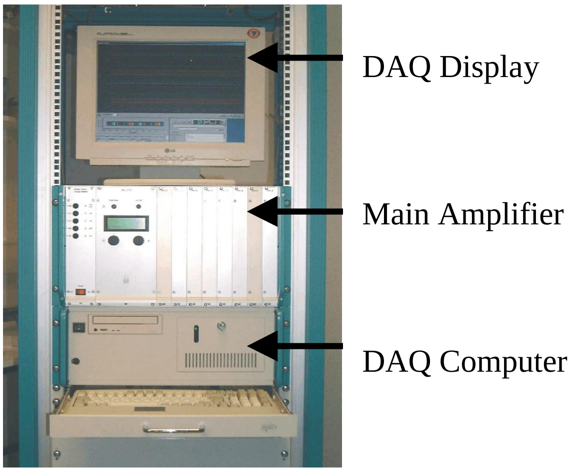

Fig. 7: 64 channel recording setup mounted in a rack. From top: the DAQ Display, 64 channel main amplifier, industrial PC housing two DSP boards.

Based on its low noise characteristics (21nV/sqrtHz) the main amplifier system delivers a very good signal to noise ratio of the recorded neural signals. The PGMA-64 is a broadband amplifier (0.04Hz...16kHz) that can be extended to up to 128 channels.

The amplifier system is now commercially available at Thomas RECORDING GmbH. Further technical details on this may be found under www.ThomasRecording.com.

Synchronous Multichannel Data Acquisition in Steps of 32

The data acquisition system is based on off-the-shelve DSP boards (M67, Innovative Integration, California, USA) residing in a modern personal computer running Windows NT/2000. Each DSP board can be extendend with analog digital conversion (ADC) modules, based on the OMNI-BUS specification. We are using two AD16 modules per board, which together provide the abilility to record from 32 channels simultaneously without mulitplexing [4].

One AD16 module provides the M67 board with 16 channels of high speed (up to 195 kHz), 16-bit resolution analog input to digital output conversion (A/D) per module site. There are 16 A/D converters for simultaneous conversion on all channels. Each of the 16 input channel consists of a high precision, DC accurate sigma-delta A/D converter (AD7722, Analog Devices, Norwood, MA, USA) with front end conditioning circuitry. The A/D converters are clocked either using a DDS timer of the M67 board or an external clock. Conversion results are transferred into a FIFO which can store up to 512 16-bit samples. The AD16 triggers an interrupt, which is serviced by a routine running on the DSP and fetches the data from the FIFO to store it into the onchip memory using a DMA transfer. The DSP boards are connected with the host system via the PCI bus (see Figure 8). Our current host system consists of a 1GHz Pentium III with 256 MB SDRAM (Synchronous DRAM) on a DSM (Munich, Germany) Slot CPU.

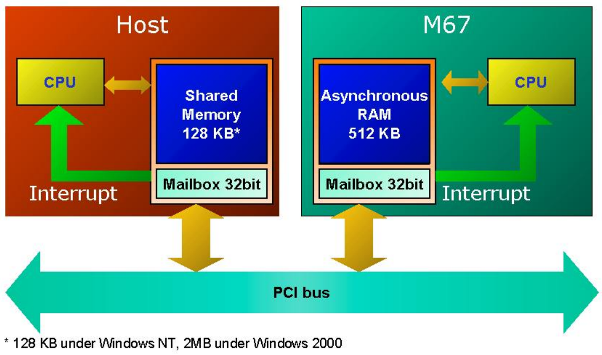

Fig. 8: Illustration of the PCI and memory connection from the M67 target card to the PC Host.

The data acqusition system for (2*32=) 64 channels is built from two M67 boards both equipped with two AD16 modules. The data acquisition on these boards is synchronized by two different means.

First, there is the so called SyncLink which provides the clock signals of one board to the other board. We call the board which provides the clock signals master and the other is called slave. When synchronized, the master boards DDS timer signal is also used by the slave board, which then ignores its own DDS timer.

Second, the single AD converters on the AD16 modules need to be synchronized with each other as well in a row using their Sync pins. Again the first AD16 in the rows functions as master which triggers the synchronization to all others. All four AD16 boards are therefore using the same clock. Figure 9 shows a picture of two M67 boards synchronized on one PCI backplane.

In principle it is possible to synchronize as many M67/AD16 groups in one PC as there are PCI-slots, however, due to the high data load in our application, we restrict ourselves to maximal 4 M67/AD16 groups leading to 128 recordable channels.

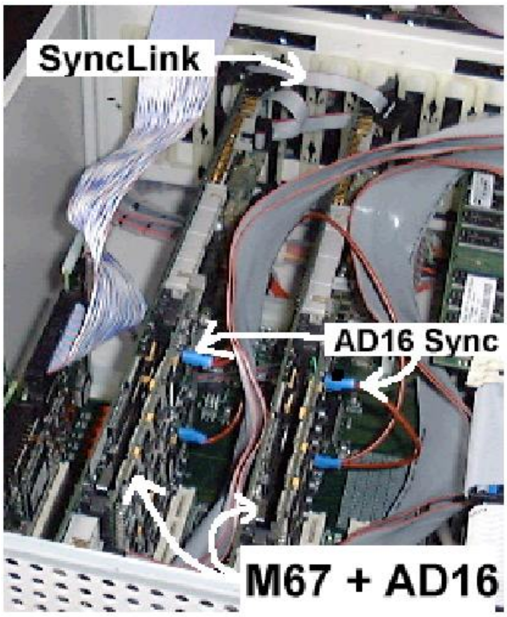

Fig. 9: Picture of two M67 boards synchronized via the timer SyncLink and the AD16 Sync on one PCI backplane.

Due to the high sampling rate of up to 50kHz per channel, incoming data have to be processed in an efficient and fast way. We solved this requirement by utilizing a framework for online wavelet transformation with the Fast Lifting Scheme Wavelet transform. Basics of this methods may be found at [14] and are described for our application elsewhere [4].

In brief, we do not perform filtering steps followed by a subsequent downsampling, but instead split the data stream in odd and even coefficients, which are then influencing their respective processing. This in place method reduces the calculation complexity compared to standard Discrete Wavelet Transform for another factor of 2 and enables nearly real time calculation on the DSP.

The resulting wavelet coefficients are then used for further noise reduction, filtering and compression as shown in Figure 10 and 11 and described in [9,15].

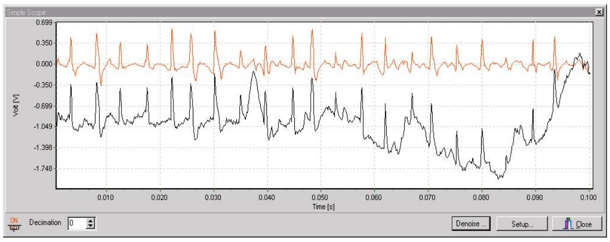

Fig. 10: Display of an unprocessed neural record (dark, lower trace) and a Daubechies 2-wavelet filtered trace of the same signal.

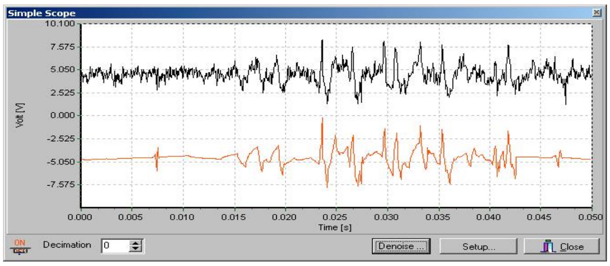

Fig. 11: Unfiltered (upper trace) and wavelet denoised signal (lower trace). The user can choose which type of denoising strategy and which wavelet he wishes to use. Here: Daubechies 2 and VisuShrink denoising.

Experimental Applications

Our silicon probes, together with our new multisite setup recorded successfully field potentials in the piriform cortex of an in vitro guinea pig preparation [1, 2], but was even able to record to our knowledge for the first time ever with silicon probes from the cerebellum of an anaesthetized rat [3]. Some sample recordings are shown in Figure 12.

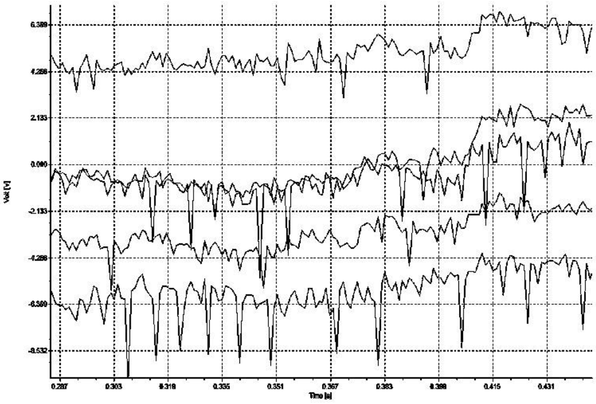

Fig. 12: Evoked spikes recorded in cerebellum.

It proved thereby quite stable against mechanical and electrical interference, thus facilitating the widespread use of Multisite Neuronal Recording with silicon probes.

Acknowledgements

We are deeply indebted to the members of the VSAMUEL consortium for fruitful cooperation. In particular we thank the group of E. De Schutter who provided the recordings from cerebellum.

This work was in part supported by the EU under contract IST-1999-10073 and the German Ministry of Research contract 16SV1433.

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