Array of individually addressable microelectrodes

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Abstract

The realization and preliminary testing of two types of ultramicroelectrode arrays consisting of 100 square-shaped Pt electrodes (5×5 μm, 25×25 μm) is described. In order to limit the number of external connections, the 'on chip' multiplexing approach is chosen. The matrix of 100 elements is addressed by 22 connections, using a basic NMOS analog multiplex. Tests on the electronics show good performances for switching times, background current and signal-to-noise ratio. Electrochemical measurements in 1 M H_2SO_4 illustrate switching and multiplexing. Comparisons of voltammograms of the Pt electrodes with those of bulk material reveal a good surface quality.

Introduction

Planar microelectrode arrays are currently developed for a number of applications in various fields of (bio)electrochemistry, ranging from mapping (i.e., 'real time' imaging) of electroactive species [1–3], through multisensors [4] to cell electrical activity monitoring [5, 6] and stimulation [7].

One of the problems encountered when having a large number of individually addressable electrodes is the correspondingly large number of external connections. This problem can be circumvented, as described in this paper, using an 'on chip' multiplexing approach. Short switching times are to be achieved so that the array can also be used for fast kinetic investigations.

Experimental

Circuit description

The circuit is an array of 100 square platinum electrodes, of 5 or 25 μm sides, arranged in a 2.1 mm^2 matrix, separated by 145 μm. The analog multiplex is obtained by assigning two switches to each electrode, one of them corresponding to the 'line' address of the electrode and the other to its 'column' address. The simultaneous activation of both address lines makes the electrode active by closing the electrical circuit. The signal is then transmitted through two conductive switches to a common 'data line' (Fig. 1). Activating one address line or none of them leaves the electrode at the high impedance of the switch (R_{off}). The switches are realized using the transmission gate principle, one NMOS transistor per switch (Fig. 2(a)). The advantages of such multiplexing are the reduced number of transistors for the assigned function and the bi-directional aspect of the switches. This architecture reduces the number of bonding pads for n^2 elements down to $2n$ for the multiplex plus two additional pads for signal output and bulk bias (i.e., 22 connections).

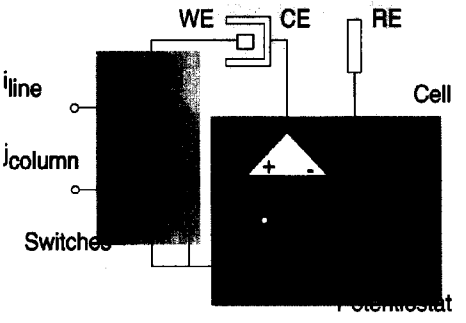

Fig. 1. Schematic of the working principle. WE = working electrode, RE = reference electrode, CE = counter electrode; V_{appl} = applied potential.

It must be pointed out that the chosen approach does not enable the switching of two or more electrodes simultaneously at *different* potentials and the collection of *individual* signals without recourse to time multiplexing.

The counter electrode is designed to cover the logical circuitry, thus also providing light shielding.

Technology

The substrate is a standard p-doped silicon wafer of 5–7 Ω cm. Channel stop, doping of the source and the drain of the transistors is obtained by diffusion from 4000 Å doped CVD oxides. An 800 Å thick gate oxide is thermally grown. Contact holes are wet etched with

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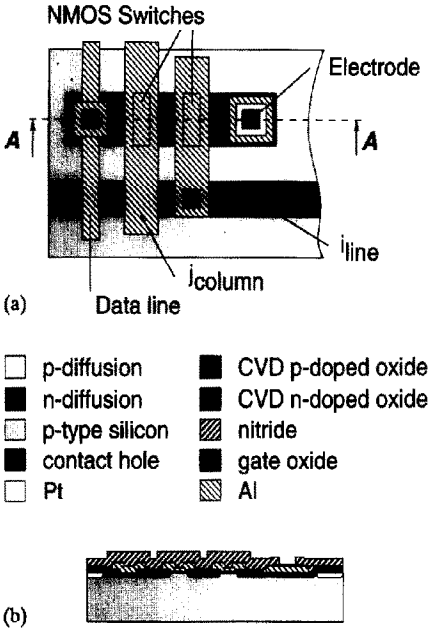

Fig. 2. (a) Schematic of the electrode and its associated switches; top side view. (b) A–A = cross section view of the processed electrode and its associated switches.

BHF solution. Address lines are made of 6000 Å evaporated aluminium and patterned in Alu-etch. Electrodes are realized with 1000 Å e-gun evaporated platinum, patterned by lift-off. A 6000 Å thick CVD SiO_2 or PEVD Si_3N_4 layer is deposited as a passivation layer. Openings for the electrodes are obtained by wet etch or by plasma (Fig. 2(b)).

Each circuit is saw-diced and encapsulated on a 24 DIL. An O-ring seal is made on top of the circuit with standard silicone adhesive.

Instrumentation

Testing of the electronics is performed with a Hewlett Packard 4145B Semiconductor Parameter Analyser.

Electrochemical measurements are performed in an O-ring cell, fixed on top of the circuit, using an electrolyte of 1 M H_2SO_4, with an SCE reference electrode and a Pt counter electrode. The potential is controlled by an EC/225 IBM voltammetric analyzer.

The switching signals for the transistors are obtained externally by an addressing unit developed in-house. Different scan (single or continuous) and operation modes (individual electrode, columns or lines of electrodes) are accessible.

Results and discussion

Initially the multiplexing function was tested. The NMOS switch exhibits the same characteristics as a single transistor with a similar gate. The background current of the switches is considerably lower than 10 pA for the 'off' operating mode, and should not exceed 0.1 nA for the whole matrix. Since the estimated current of a 5 μm side microsquare electrode is several nA, signal-to-noise ratio is acceptable. In the 'on' operating mode (gate voltage: 5 V) the switch impedance (R_{on}) is ≈ 3 kΩ, which corresponds to a potential drop of less than 1 mV for the expected current range. The 'off' state impedance (R_{off}) reaches values of 10^{12} Ω. Rise and fall times of the signal upon switching are respectively ≈ 180 μs and ≈ 30 μs, for 1 kHz commutation frequency, 1 MΩ load resistance and 5 V drain potential. These electronics should enable the observation of the transient behaviour of electrochemical reactions.

The Pt surface of our electrodes was tested through cyclic voltammetry in a solution of 1 M H_2SO_4. The results were related to bulk material and comparison shows the deposited Pt surface to be satisfactory.

Successful switching of the electrodes in solution is illustrated by plotting the background current (mainly charging current) upon switching and for different operating modes. The current magnitude is approximately ten times higher when addressing a full line of electrodes (Fig. 3(a)) than for a single one (Fig. 3(b)).

Evidence of multiplexing was demonstrated by successively adding one electrode at a time to the selected

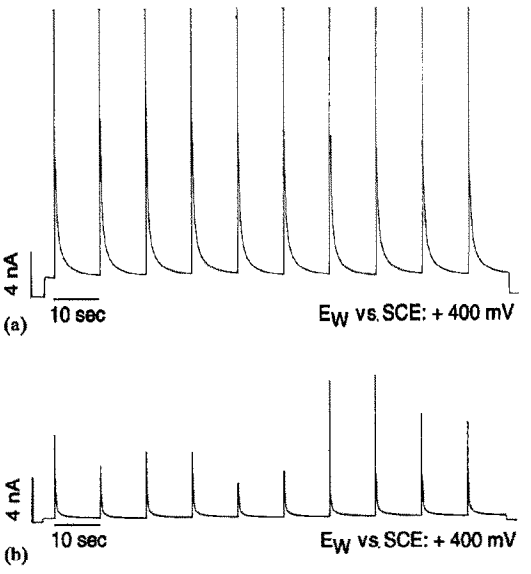

Fig. 3. (a) Background current transient of a line of 10 Pt microelectrodes of 625 μm^2 each, in a solution of 1 M H_2SO_4. E_w = applied potential to the working electrodes. (b) Background current transient of one single Pt microelectrode of 625 μm^2, in a solution of 1 M of H_2SO_4. E_w = applied potential to the working electrode.

ones. The current magnitude increased more or less proportionally to the number of operating electrodes (not shown). These measurements were performed in a solution of 1 M H_2SO_4 and 10 mM ferricyanide.

Further investigations will be performed using the model ferri/ferrocyanide couple and the O_2 reduction reactions.

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