Microelectrode Array for Cardiac Potential Mapping

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Abstract

This work deals with the fabrication of fully IC and biocompatible device composed of an array of microelectrodes assembled into a catheter for cardiac potential mapping. The device is designed to allow the study mechanisms of alterations in cardiac rhythm following Chagas disease in small animals. The array consists of up to 8 silver/silver chloride reference microelectrodes (10 µm x 10 µm). IC compatibility is provided by utilization of doped polysilicon as base material for the electrodes and interconnecting lines. On the other hand, the biocompatibility is due to the silicon nitride coverage. To produce the required silver chloride/silver electrode, electroless nickel was deposited followed by silver and silver chloride formation. Preliminary fabrication results are present and a catheter-based system is outlined.

1. Introduction

Cardiac potential mapping is a method by which potential recorded directly from the heart, against a reference potential, is spatially depicted as a function of time in an integrated manner [1]. The localization of the electrodes, the recording model used as well as the method of display (isopotential or isochronous) provides many important information of the electrophysiological behavior of the heart [2]. One of the applications of such mapping is related to the localization of the area of origin of the arrythmia in the ventricular tachycardia, which may leads to infarction [3].

The heart potential mapping is accomplished by placing an array of spatially defined recording electrodes on the endocardial or epicardial regions and recording the potential waves of polarization and depolarization for each heart beat [1-3]. Differential information from adjacent electrodes is processed and then isopotential and/or isochronous plotting are generate and analyzed. Figure 1 exemplifies the results for two systems developed at facilities of the Heart Institute of University of São Paulo, which consists on 128 silver electrodes (ϕ = 1,5 mm), assembly on a latex mesh sock [4-6].

It has been a trend to perform cardiac mapping by larger arrays (>200) with small dimensions (< 500µm) electrodes [7]. In order to enhance the signal stability reference electrodes, like silver/silver chloride, have been used [7,8]. The fabrication of such structure can be achieved by several ways such as [7,9,10]:

- metal microfibers (Φ=50µm) insulated wires placed into rigid or semi-rigid forms;
- stacked up fine wire ribbon cables and
- silicon based and micromachining technologies.

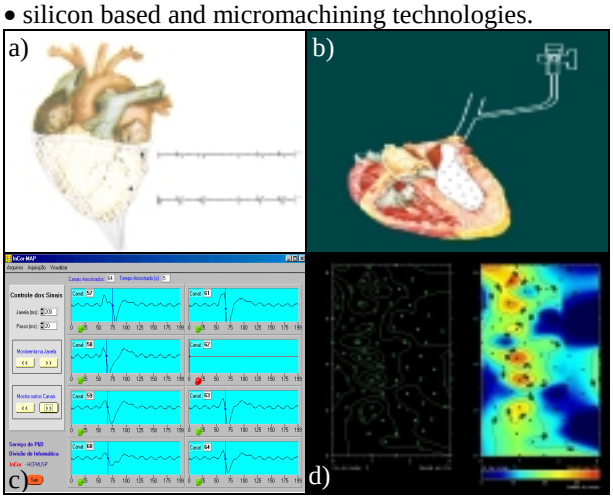

Fig. 1. Array of 128 silver electrodes (ϕ =1,5 mm), assembled on latex mesh sock for (a) epicardial and (b) endocardial potential mapping. Experimental data (from a dog) for (c) isochronous and (d) isopotential, from [4-6].

Although some representative results were reported for 400 microelectrodes (50µm, 100µm apart) ribbon cables [7], individually insulated microwires and commercially available cables hve drawbacks on time demanding and fine alignments required to build up a dense and reliable spatially distributed arrays, where the connections play a key role, as reported for 224 electrodes (Φ=140µm), made by metal wires [9].

On the other hand, silicon based and micromachining techniques meet those requirements with several advantages, listed below, where up to 1024 electrodes were fabricated for mapping chemical activity [12].

- batch fabrication;
- possibility to submicrom dimensions and high density electrode arrays;
- easy shape definition by computer designed photomasks;
- high reproducibility and low cost.

These techniques are particularly useful on the present demand for minimal invasive diagnosis, by placing the electrode array in a catheter with additional advantage to possible ablation *in situ* of the heart tissue that causes arrhythmia[13,14].
In this work we modified the fabrication of an array of microelectrodes to provide fully IC and biocompatible device towards the development of a catheter mapping system.

2. Array fabrication

The array consists of up to 8 silver/silver chloride reference microelectrodes (10 µm x 10 µm), and it is a new version of one previously reported [15-17]. On this new approach we kept the same design, but the fabrication steps were changed to provide fully integrated circuits and biological compatibility. Doped polysilicon was used as the conducting lines; at the detection region, nickel was electroless deposited, followed by electrodeposition of silver. Finally the silver chloride was formed, as describe in the figure 2. There is also one medium (~$70x10^{-3}$ mm^2) and another large (1 mm^2) silver chloride electrodes, to be used as a potential reference on the detection. Typical dimensions of the total structure are: a length of 10 mm and a width of 3 mm. Silicon nitride biocompatible film was used as a cover material.

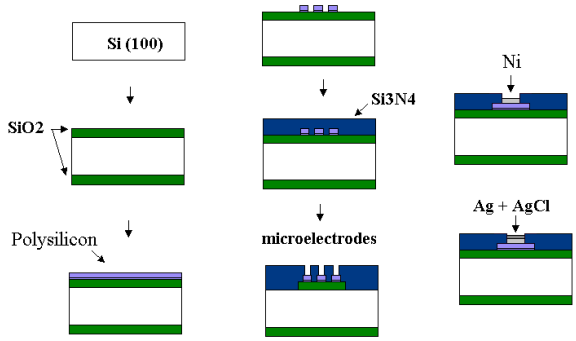

Fig. 2. Microelectrode array fabrication sequence

The array was fabricated using the silicon planar technology through the following sequence:
a)Wet oxidation of 2" silicon wafers (p type, orientation: <100>, resistivity 1 - 10 Ωcm) to obtain at least 1 µm of SiO_2;
b)Polysilicon LPCVD deposition (500 nm), 630^0C, P=500mTorr, SiH_4 (49.5 sccm) and N_2 (280sccm);
c)Phosphorus SOG spinning deposition;
d)Diffusion (Rs= 20Ω/sq.);
e)Electrode lines (20 µm wide), contact pads (500 µm x 500 µm), reference (68,800 μm^2) and counter (2,000 µm x 500 µm) electrode areas, patterning with mask 1;
e)Si_3N_4 deposition by LPCVD (~500 nm);
f)Si_3N_4 plasma etching (CF_4+O_2) over contacts, detection, counter and reference areas, defined by mask 2;
g)Nickel electroless deposition;
h)Scribing to individuals sensors;
i)Wiring bonding to a carrier;
j)Covering of the bonding pads and the gold wires with a silicone resin;
j)Selective silver electrodeposition and silver chloride formation by chemical reaction.

2.1 Electroless and electrodepositions

In order to obtain the required silver chloride/silver electrode, we electroless deposited nickel over doped polysilicon. For this purpose we used a solution with a classical electroless reaction that occurs on catalytic surfaces, in the presence of hipofosphite ions that acts as reductor agents. This reaction occurs only in alkaline environment and the main reaction is described below. The solution composition was 15 g/l $NiCl_2$, 10 g/l $Na_2H_2PO_2$, 30 g/l NH_4Cl_2, 35 g/l $(NH_4)_2C_6H_6O_7$, 10 ml/l NH_4OH , 85 ^oC and pH = 7.8. The deposition rate was 1000Å/min. [18]

$$Ni_2^{++} H_2PO_2^- + H_2O \rightarrow H_2PO_3^- + 2H^+ + Ni^0$$

The next step was silver electrodeposition in solution of 0.1 M AgNO3 + 10% vol.NH4OH and its oxidation in chloride solution of 3M NaCl, as described in previous work [19]. The experimental setup, figure 3, provides real time and *in situ* observation in both silver deposition and silver chloride formation. We used solutions "in flow" (33ml/min.) to assured good plating.

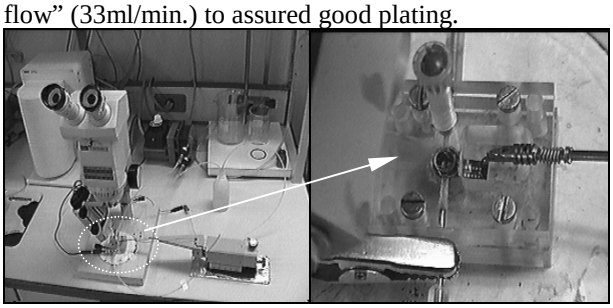

Fig. 3. Experimental setup for fabrication of Ag/AgCl reference electrode.

Several applied potentials were explored to verify its influence on the deposition uniformity. We obtained a value of –200 mV for the silver deposition (j=0.5 A/cm^2) and +200mV for silver chloride formation. A stainless steel probe was used as a second electrode. The potential difference between the fabricated reference electrode and a commercial one was measured in a solution of 3 molar of NaCl. We observed values lower than 30 mV in the best case. Figure 4 presents results for silver and silver chloride formation. These preliminary experiments were performed at medium size electrode ($69x10^{-3}$ mm^2) The next step will apply this process for the microelectrodes.

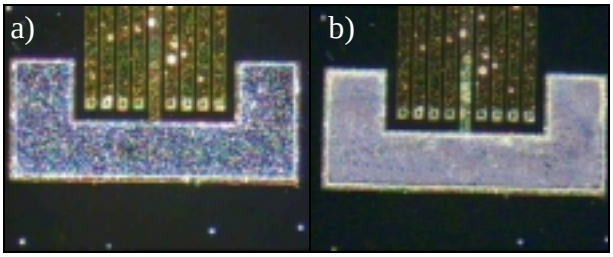

Fig. 4. Dark filed optical images of silver deposition (a) and silver chloride formation (b) for the $69x10^{-3}mm^2$ electrode.

Figure 5 presents a preliminary sketch of the device, were up to 2000 (10 µm x 10 µm) microelectrodes could be placed in the 1mm catheter internal diameter. Multiplexing chip is required to decrease the connecting wires.

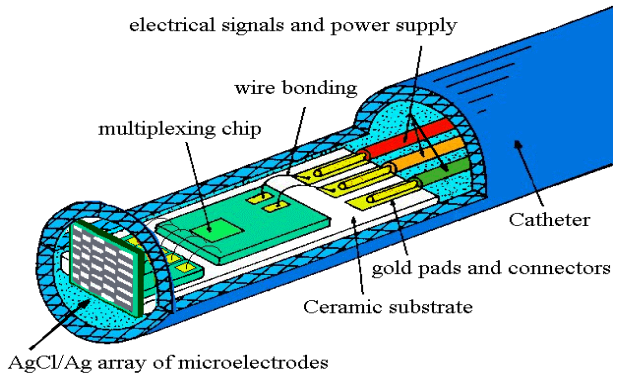

Fig. 5. Sketch of up to 2000 (10 µm x 10 µm) microelectrodes array for catheter (ϕ = 1 mm) based cardiac potential mapping.

Conclusions

Fully IC and biocompatible array of microelectrodes - up to 8 (10 µm x 10 µm) - was fabricated towards the development a catheter based cardiac potential mapping system. One of the applications of the electrodes mapping is the study mechanisms of alterations in cardiac rhythm following Chagas disease in small animals. We used polysilicon as base material and silicon nitride as protection layer. The required silver chloride microelectrodes were obtained by electroless nickel, followed by silver and silver chloride formation. For a medium size electrode ($69x10^{-3}$ mm^2) good deposition uniformity was obtained using -200mV ($j=0.5$ A/cm^2) and +200mV for silver chloride formation. Comparison with commercial reference electrode results in potential difference around 30 mV, in the best case.

A preliminary sketch of the device was also presented. Much work is under development on this initial stage of the project and updated results will be presented in the near future.

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