CHARACTERIZATION OF A CATHETER FOR INTRACAVITARY CARDIAC POTENTIAL DETECTION

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ABSTRACT

This paper presents in vitro characterization of a catheter for intracavitary cardiac potential detection. The detection is made by silicon technology microelectrodes using phosphorus-doped polysilicon for interconnections and silicon nitride for passivation. Microelectrode areas of 10μm^2 where obtained built over a 430μm high, 385μm wide and 8mm long silicon structure placed into a catheter tubing with 0.5mm internal diameter. The results obtained in vitro suggest that the catheter can be used to detect intracavitary cardiac potentials in rats.

INTRODUCTION

The detection of cardiac potential by using array of microelectrodes inside of a catheter represents the actual demand for minimal invasive diagnosis, with additional advantage to localize areas in the heart, through potential mapping, that presents anomalous electrophysiological behavior. Furthermore, those regions may be *in situ* ablated without an open-heart surgery (1,2).

The heart potential mapping is accomplished by placing an array of spatially defined electrodes on the endocardial or epicardial regions and recording the potential waves of polarization and depolarization for each heart beat (3-6). Differential information from adjacent electrodes is processed and then isopotential and/or isochronous plotting are generate and analyzed (7,8). Although this represents a standard procedure, non-contact methods based on potential reconstruction (9) and voltage-sensitive fluorescent dyes (10) are also been explored.

In this work we modified the fabrication of an array of microelectrodes to provide fully IC and biocompatible catheter mapping system.

DEVICE FABRICATION AND ASSEMBLYING

The array consists of up to 8 silver/silver chloride reference microelectrodes (10 μm^2), fabricated by using silicon planar technology and it was previously reported (11,12). Phosphorous doped polysilicon was used as conducting lines and silicon nitride biocompatible film was used as passivation material. In order to assemble those electrodes inside a catheter with internal diameter of 0.5 mm, we cut precisely the device using dicing saw equipment. The final silicon structure, with the microelectrodes defined at cross section of the interconnection lines, has 430µm high, 385µm wide and 8mm long. Results of the device fabrication and its assemble is displayed in the figure 1, using scanning electron microscopy (SEM).

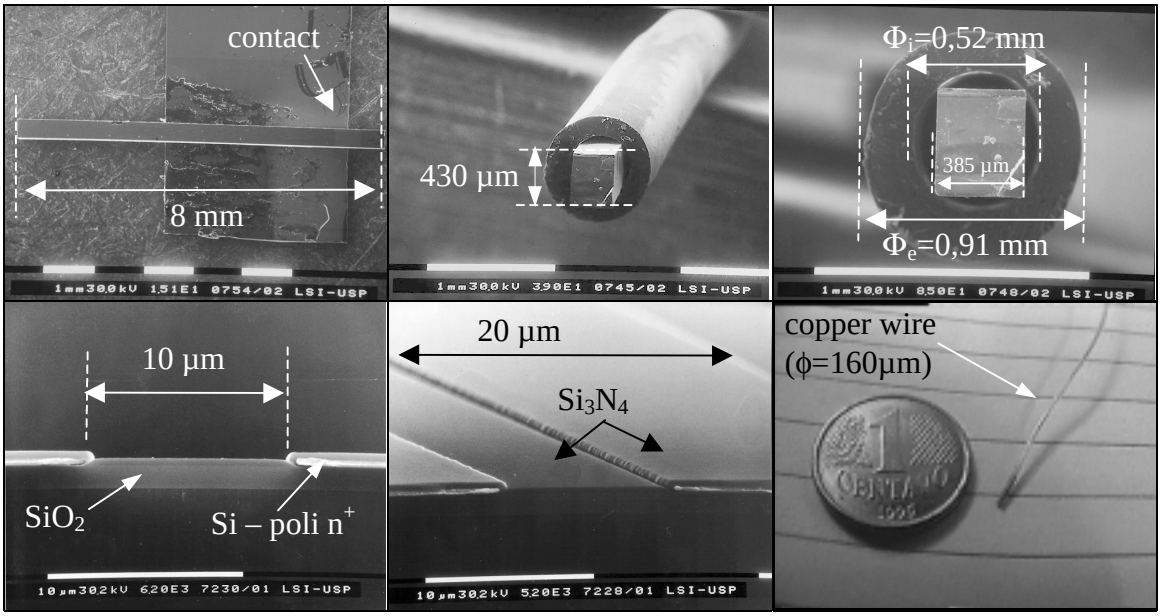

Figure 1. SEM sequence of images of the device assembling, microelectrode details and dimensions. Final picture shows the final catheter compared with a one cent of Brazilian real.

As expected, the assemblig was a critical step since we had to deal with small dimension wires. To avoid breaking the 25 µm gold ultrasonic bonded wires, special care was taken at introduction of the device inside the tubing, since it went through tightly. We used silver epoxy (Epo-Tek H20E – Epoxy Technology Inc.) to connect electrically the gold wire with a varnished copper wire (ϕ=160 µm). Epoxy curing was carry out under a 60W lamp (90^{o}C, 2 hours). We did not observed any damage on the catheter tubing caused by this heating process. One could try to access the microelectrode contact directly by using silver epoxy, e.g., without the gold wire, but as we observed, this decreases reproducibility.

In the next item, the electrochemical characterization of the catheter is described

CATHETER CHARACTERIZATION

In the catheter characterization we mainly determine the microelectrode interconnection resistance, the detection electrodes area, and its *in vitro* response.

Microelectrode Characterization

Since we are dealing with long and small cross section polysilicon lines, their electric resistance may be detrimental in the detection. The measure sheet resistance (R_{sh}) for the phosphorous doped polysilicon was about 20 Ω/ (four point probe method). Therefore for a typical microelectrode interconnection line of 20μm wide and 8 mm long, the calculated resistance is up to R= 8KΩ.

In order to evaluate the influence of the interconnection line resistance and the microelectrode area, we set-up a cyclic voltammetry (CV) electrochemical experiment using a standard solution of potassium ferricyanide - $K_3[Fe(CN)]_6$ (10 mM in 0,1 M KCl). All experiments were performed with a fully computer controlled potentiostatic system (BAS - Bioanalytical System CV 50W) as partially described in a previous work (13).

In order to explore the influence of the interconnection resistance we replaced the actual polysilicon lines by a potentiometer (50 KΩ) in series with a gold microelectrode (ϕ=10μm) used as a detection electrode; silver/silver chloride and platinum commercial electrodes were also used as reference and auxiliary electrodes. The applied potential swept from +500 mV to –500mV at 100mV/s and the redox process was analyzed for different series resistance, figure 2(a).

It can be observed from the results, a slightly variation on the oxidation and reduction currents with increasing series resistance from 0 Ω to 50 kΩ (6 times higher than calculated for the polysilicon lines). This influence is more neglected if we considered that the potential detection is obtained by high input impedance amplifier, which drain less current than shown in this experiment. So we concluded that series resistance presents in the doped polysilicon shall not interfere in the detected potential.

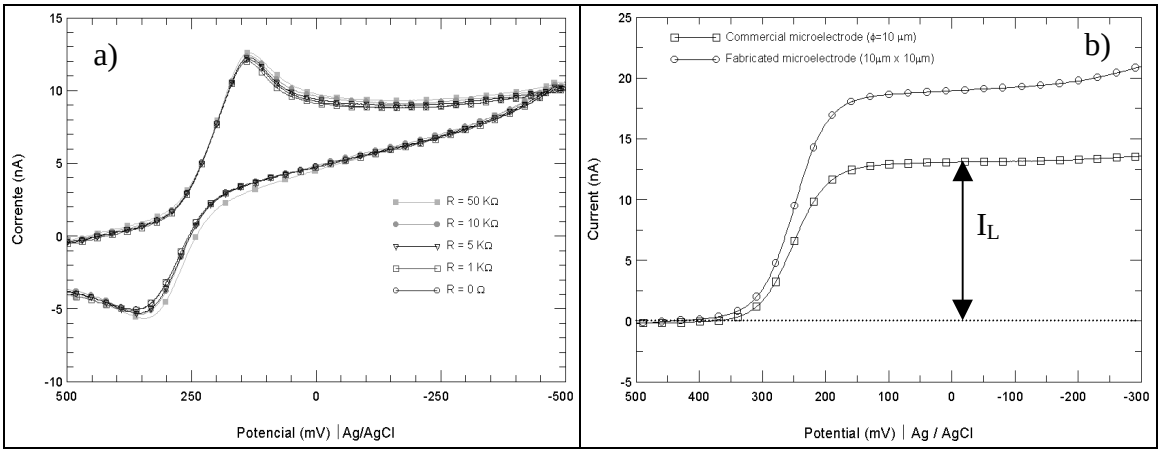

Figure 2. a) redox curves of potassium ferricyanide for several resistances in series with a gold microelectrode (ϕ=10μm) and b) diffusion limited curves used to determine the microelectrode area.

The microelectrode area (A) was also obtained electrochemically, through the diffusion-limited (I_L) reduction current relationship given below:

$$A = \frac{\pi}{(4nFD_0C)} x I_L \qquad [1]$$

where n is the electron transference in the reaction (n =1 in this case), F represents the Faraday constant (F=9,6485x10^4 C/mol), D_o is the ferricyanide diffusivity (D_o=7,6x10^{-6} $cm^2.s^{-1}$), C is its concentration (10 mM/dm^3) and r is the electrode radius.

Figure 2(b), shows a typical reduction curve for a (10x10)μm fabricated microelectrode, before the silver/ silver chloride formation, compared with a commercial (ϕ=10μm) gold electrode.

In Vitro Experiments

The assembled catheter were tested *in vitro* in the Department of Physiology at USP. The experimental set-up consists in a signal stimulator Grass S8800 (Grass Instruments Co.), figure 3(a) which supplied potential pulses of 50V high, 2ms of duration and 1 second of period. For safety reasons, the applied signal passed through an isolation unit (Grass SIU8T), not shown and then stimulated a pair of stainless steel electrodes (E1 and E2) placed 5 mm apart, figure 3(b). The electrodes were placed in an electrolyte solution (seawater). The detected signal was picked up at silver chloride electrodes (G1 and G2), figure 3(b), and differentially amplified (10x) and filtered (10 Hz < f < 1KHz) in a pre-amplifier unit Grass P55AC, figure 3(c). Finally the signal is digitized and processed.

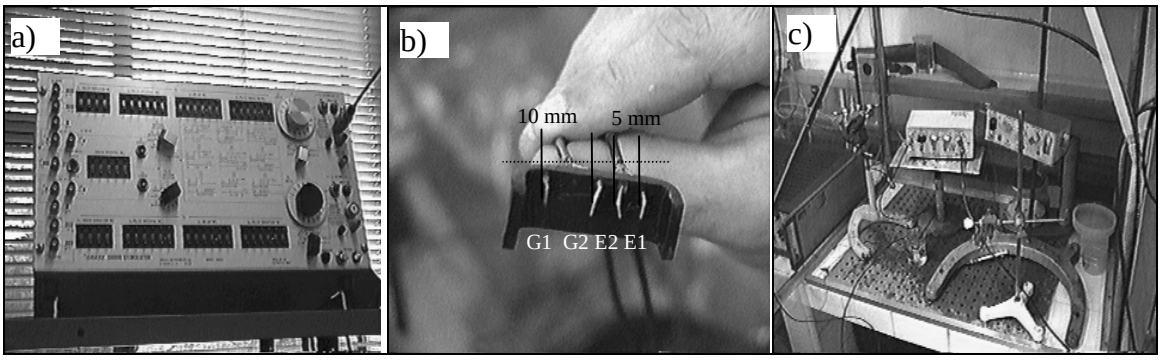

Figure 3. Experimental set-up for *in vitro* cateter characterization: a) signal stimulator unit, b) electrode arrangement and c) pre-amplification and filtering unit.

The electrode form the catheter were tested replacing G1 in the arrangement. We also compared its response with two different electrodes as described in table 1. All experiments were made under the same conditions and 30 consecutive stimulation were performed the check the reproducibility. The results are shown in figure 4.

Table 1 – Electrodes used in the *in vitro* experiments.

Electrode	**Material**
A	Ag/AgCl from the original set-up -fig.3(b)
B	Commercial Ag/AgCl
C	Microelectrode Ag/AgCl from the catheter

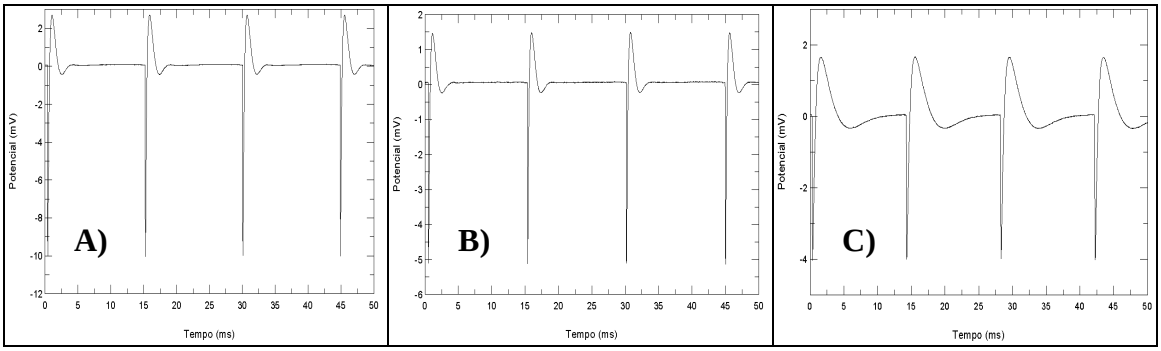

Fig.4. Preliminary in vitro results for three different electrodes A) silver chloride from the set-up, B) commercial Ag/AgCl and C) microelectrode Ag/AgCl from the catheter.

It was observed a slightly variation in the signal amplitude which could be associated to a difference in the spatial localization of the electrodes in the set-up. Nevertheless this preliminary *in vitro* results suggest the applicability of the catheter made with silicon planar microelectrodes in the detection of intracavitary cardiac potentials in rats.

CONCLUSION

Characterization of a catheter for intracavitary cardiac potential detection is presented. The detection was made by a modified fabrication of an IC and biocompatible array of microelectrodes, using phosphorus-doped polysilicon for interconnections and silicon nitride for passivation. Microelectrode areas of $10\mu m^2$ where obtained built over a 430µm high, 385µm wide and 8mm long silicon structure placed into a catheter tubing with 0.5mm internal diameter. Catheter characterization was made focusing in the microelectrode interconnection resistance and determination of its area. *In vitro* experiments suggested that the catheter can be used to detect intracavitary cardiac potentials in rats.

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