Life time assessment of microelectrodes for neural stimulation applications

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***Abstract*—As the ultimate goal of neural prosthetic devices is the chronic stimulation in disabled patients, a challenging and important work concerns lifetime assessment of the electrode materials. Therefore the stability of the electrode materials in a stimulation configuration must be studied and evaluated, and we propose a new dedicated characterization platform adapted to our microfabricated electrodes.**

Keywords—microelectrode; aging; neural stimulation; PEDOT; Black-Pt; Diamond

I. Introduction

Electrical stimulation of neural tissue has been demonstrated for many different applications in the recent times. One of the most established and well known application is the cochlear implant [1] that is able to restore the hearing capacity on deaf people. Electrical stimulation is also used in the motor restoration in patients with spinal cord injuries [2] or in applications for the treatment of neurological disorders such as Parkinson or epilepsy. These latter rely in Deep Brain Stimulation which uses electrodes that penetrate into the brain to electrically stimulate specific regions [3, 2]. In the field of the sensory restoration, concurrently to cochlear implants, several teams are working on sight restoration either by the stimulation of the brain cortex associated to the vision or by the direct stimulation of the retina [4, 5].

Such new applications, especially the sight restoration ones, demand small electrode sizes down to microelectrodes to be more specific and to stimulate precisely a small group of target neurons. This size reduction creates new constraints in terms of electrical performances. Therefore, new electrode materials are being investigated as, for example, conductive polymers or carbon-based materials that can replace traditional materials such as the platinum or gold.

The recent studies on these materials have been focused mostly on their electrical performance, biocompatibility and in vivo stability [3, 6, 7, 8]. However, the goal of these prosthetic devices is the chronic stimulation in disabled patients which induces long lifetime implantation. For that purpose, the stability of the electrode materials in a stimulation configuration must be studied and evaluated in the long term.

II. Methods

As implanted electrodes show a limited functional lifespan, the goal of our study is to reproduce the conditions that the electrode should face in a real in vivo application in terms of temperature (T), pH, and stimulation current levels, and study the changing of its characteristics along the time by implementing an in vitro methodology.

For this purpose, we have developed a characterization platform to study some of the materials used nowadays in neural electrical stimulation in a comparative way, to evaluate the implant stability. This test bench has the capacity to stimulate the electrodes, to measure their characteristic and to control the solution parameters in an automatized way. It refers as a rapid accelerated aging protocol.

We have decided to study 5 different types of materials. Two of them are noble metals which are widely used in electrical stimulation applications: gold and platinum, one is nanostructured (black platinum), one is a conductive material, PEDOT, because it is a widely in vitro an in vivo tested material, and the last is carbon-based diamond due to its excellent electrochemical properties.

For the stimulation of the electrodes we have chosen a biphasic charge balanced stimulation which amplitude can be modified independently for every electrode. This current stimulation is generated by a Howland current pump driven by a function generator that allows creating arbitrary functions. This configuration has been chosen due to the low cost of implementation of this circuit since one circuit is needed for each stimulated electrode.

In order to accelerate the ageing process of the electrodes the temperature is set to 77 ºC. This temperature as well as the pH is controlled by two commercial sensors (Atlas Scientific ENV-40-pH and PT-1000) connected to the system by an I2C bus. Based on body temperature (37°C), the accelerated aging factors were chosen from literature [9, 10], as shown on Table I.

TABLE I. EQUIVALENT TIME FOR ACCELERATED AGING FACTOR ESTIMATION

Temperature (ºC)	**Ageing Factor**	**Real experiment time (days)**	**Equivalent time (days)**
37	1	260	260
67	8	260	2080
80	20	180	3600

The characterization of the electrode is done by means of Electrochemical Impedance Spectroscopy (EIS) in an automatic and configurable way using a BioLogic SP200 potentiostat.

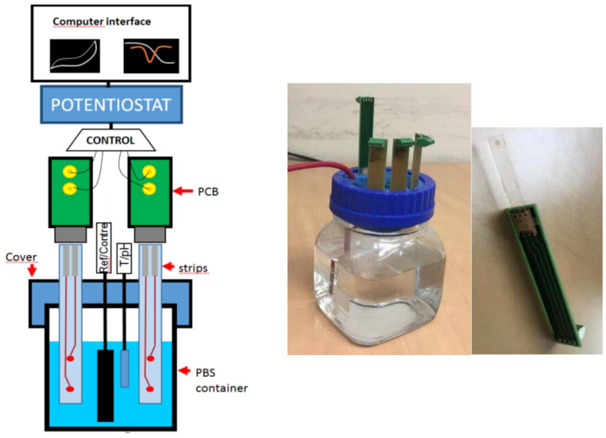
In order to study different materials in the same conditions, our system is modular and for every material we have fabricated strips that contain three electrodes of same diameter. This configuration allows us to use two electrodes of the strip for stimulation and one for controlling its electrical state. Due to this configuration we have fabricated one printed circuit board for every strip that contains two stimulation circuits and the switching elements needed to commutate between the stimulation mode and a measuring mode.

A LabView interface has been also developed in order to control the switching of the system and store the acquired data. This interface allows us also to set the timetable for the measurements and observe the last measurements as well as the evolution of the solution parameters.

Finally the EIS data measured can be fitted to the appropriate model using MATLAB. This fitting allows us to extract some information about the degradation of the electrodes by analyzing the evolution of the different parameters of the model such as the transfer resistance or the capacitance. In addition, scanning electron microscopy can be used to control the aspect of the electrodes at the end of the ageing protocol.

III. RESULTS AND DISCUSSION

We first describe the electrode fabrication process. The two noble metals (Fig 1.A) are sputtered on a glass wafer using a thin layer of TiW to improve the adhesion. Although they are very stable materials, their electrical characteristics are not enough in case of microelectrodes with reduced size (< 100µm in diameter) because of high impedance values. For that reason, we also used black platinum which is a Nano porous platinum that is electroplated on the surface of the



(A) (B)

Fig. 2. Configuration of the ageing modular system (A) and example of strips used (B)

metallic electrodes (Fig 1.B) and their developed effective surfaces improve their electrical characteristics. PEDOT was electro polymerized on the surface of the metallic electrodes using a potentiodynamic cyclic voltammetry

and an EDOT-NaPSS solution. Diamond was selectively growth on fused silica substrates and metallic contact and paths were patterned afterwards to reduce the serial impedance (Fig 1.C).

Second, our rapid accelerated aging protocol is based on the different elements described: the strips supporting 3 microelectrodes, connected to a dedicated PCB, and to the stimulation circuits and interfaces, Figures 2.A and 2.B. The bottle will be filled with phosphate buffered saline (PBS) solution composed of 0.0027 M KCl and 0.0137 M NaCl with pH of 7.4. It will be changed or refilled regularly to avoid sodium concentration variation due to water evaporation with temperature.

Third, the electrode impedance data collected with the system is fitted with a model consisting on three elements: one resistor in series with the parallel of a constant phase angle (CPA) element and a resistor (Fig.3). This model, which considers the resistance of the electrolyte (R_s), the double layer capacitance (CPA) and the charge transfer resistance (R_{ct}), is described by the equation Eq 1. The impedance of the CPA is

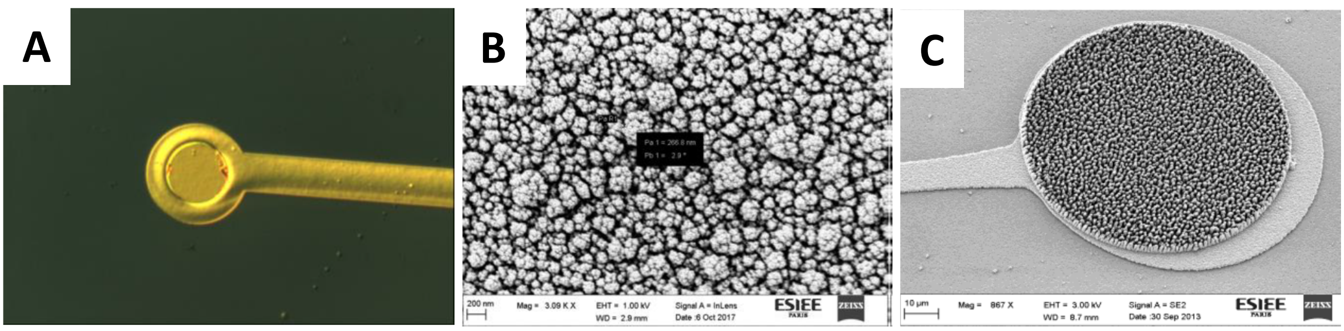


Fig. 1. Optical and SEM images of fabricated microelectrodes: gold (a), black platinum (b) and diamond (c)

$Z_{CPA} = 1/(j \cdot w \cdot Q)^n$ where Q is a measure of the magnitude and n represents the inhomogeneities of the surface [11].

$$Z = R_s + \frac{R_{ct}}{1 + R_{ct}/Z_{CPA}} \quad (1)$$

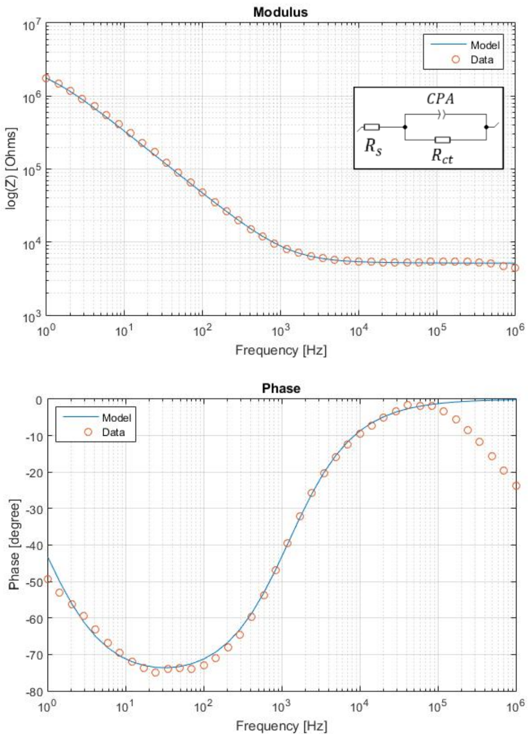


Fig. 3. Fitting of the EIS measured data from a 60 um diameter black platinum electrode to the described model

Test done over three 60 um diamond microelectrodes show the evolution of the 1 kHz frequency module of the impedance in Fig 4. Electrode A and B are stimulated with balanced biphasic current pulses of 10 uA amplitude and 200 us per phase while the electrode C is not stimulated to use it as control. As the graph shows the control electrode stays constant while the stimulated ones suffer a frequency shift after a certain stimulation time.

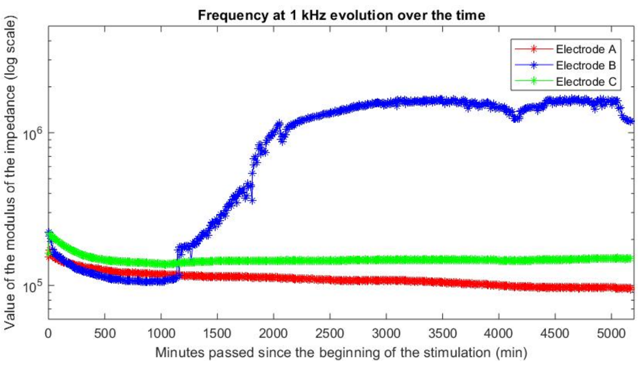


Fig. 4. Evolution of the impedance module at 1 kHz for a strip of 60 um diamond microelectrodes.

IV. Conclusion

We developed a specific accelerated ageing platform for microelectrode characterisation to evaluate the lifespan of different materials in the perspective of chronic implants for neural rehabilitation.

We can fabricate metal, conductive polymer or carbon-based electrodes depending on the selected microfabrication process, and we created a test bench for automatic broad spectrum electrochemical impedance spectroscopy (1 Hz–1 MHz) under controlled conditions (temperature, pH). We intend to correlate the physical changes with impedance data to identify possible degradation or failure causes. Measurements are still on-going and the final objective is to compare the different materials used for neural stimulation applications in terms of life time performance.

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